

# **PS CO<sub>2</sub> Storage and EOR Resource Assessment of the Cypress Sandstone Residual Oil Zone Play in the Illinois Basin\***

**Nathan Webb<sup>1</sup>, Nate Grigsby<sup>1</sup>, and Scott Frailey<sup>1</sup>**

Search and Discovery Article #11263 (2019)\*\*

Posted October 21, 2019

\*Adapted from poster presentation given at 2019 AAPG Annual Convention and Exhibition, San Antonio, Texas, May 19-22, 2019. Update of article, "[The Mississippian Thick Cypress Sandstone: A Nonconventional CO<sub>2</sub>-EOR Target in the Illinois Basin](#)", [Search and Discovery Article #10859 \(2016\)](#).

\*\*Datapages © 2019 Serial rights given by author. For all other rights contact author directly. DOI:10.1306/11263Webb2019

<sup>1</sup>Illinois State Geological Survey, Prairie Research Institute, University of Illinois at Urbana-Champaign, Urbana-Champaign, Illinois (ndwebb2@illinois.edu,)

## **Abstract**

Residual Oil Zones (ROZs) are volumes of rock in which oil accumulated and was later naturally displaced by encroaching water, leaving residual oil saturation in the range of 20% to 40%. Carbon dioxide enhanced oil recovery (CO<sub>2</sub>-EOR) is used to recover oil from known thick carbonate ROZs in the Permian Basin. In other basins, ROZs are not recognized or are ill-defined. Due to the technical and economic limitations of recovering oil at residual saturation to water, there have been few attempts at ROZ production. Therefore, a challenge in ROZ resource assessment is identifying ROZs and quantifying the oil in place. In addition to the economic benefit of oil production via CO<sub>2</sub>-EOR, ROZs have the potential for associated CO<sub>2</sub> storage. In the Illinois Basin, an ROZ play has been identified in the Mississippian Cypress Sandstone. The results of the resource assessment of the Cypress ROZ play is presented.

The Cypress Sandstone includes a fairway of thick (up to 175 ft (53 m)) multistory fluvial sandstones that are laterally continuous and vertically amalgamated with high porosity and permeability. Regional correlation and mapping using log data from 4,500 wells provided the basis for a net-sandstone isopach map. Conventional core analysis and porosity log data from ~2,000 wells were combined with the isopach map to generate an isoporosity map. Based on these maps, the thick Cypress fairway covers ~1.9 million acres and contains ~1 million acre-ft (1 billion m<sup>3</sup>) of pore volume.

To identify the oil saturation distribution in the fairway, the Illinois State Geological Survey oil field database was searched for ROZ indicators (e.g. oil shows, core saturation). The Cypress ROZ play was delineated by 18,000 wells with ROZ indicators. To quantify the oil in place, 200 well logs were analyzed, providing thickness and saturation data to constrain the locations of ROZs prospects within the play. Using the median residual oil saturation from well log analysis of 23%, an estimated 1.7 billion barrels of oil in place is contained within the prospects, of which up to 168 million barrels is estimated to be recoverable using a continuous CO<sub>2</sub> flood EOR factor of 9.9% assuming miscible conditions. Associated CO<sub>2</sub> storage in the ROZs, not accounting for main pay zones or underlying brine aquifers, is estimated to be 7.6 billion tonnes,

assuming 45 tonnes/1000 barrels. This resource assessment demonstrates the potential of the Cypress ROZ play for CO<sub>2</sub>-EOR and associated storage.

Abstract

Residual Oil Zones (ROZs) are volumes of rock in which oil accumulated and was later naturally displaced by encroaching water, leaving residual oil saturation in the range of 20 to 40%. Carbon dioxide enhanced oil recovery (CO<sub>2</sub>-EOR) is used to recover oil from known thick carbonate ROZs in the Permian Basin. In other basins, ROZs are not recognized or are ill-defined. Due to the technical and economic limitations of recovering oil at residual saturation to water, there have been few attempts at ROZ production. Therefore, a challenge in ROZ resource assessment is identifying ROZs and quantifying the oil in place. In addition to the economic benefit of oil production via CO<sub>2</sub>-EOR, ROZs have the potential for associated CO<sub>2</sub> storage. In the Illinois Basin, an ROZ play has been identified in the Mississippian Cypress Sandstone. The results of the resource assessment of the Cypress ROZ play will be presented.

The Cypress Sandstone includes a fairway of thick (up to 175 ft [53m]) multistory fluvial sandstones that are laterally continuous and vertically amalgamated with high porosity and permeability. Regional correlation and mapping using log data from 4,500 wells provided the basis for a net-sandstone isopach map. Conventional core analysis and porosity log data from ~2,000 wells were combined with the isopach map to generate an isoporosity map. Based on these maps, the thick Cypress fairway covers ~1.9 million acres (0.8 million hectare) and contains ~1 million acre-ft (1 billion m<sup>3</sup>) of pore volume.

To identify the oil saturation distribution in the fairway, the Illinois State Geological Survey oil field database was searched for ROZ indicators (e.g. oil shows, core saturation). The Cypress ROZ play was delineated by 18,000 wells with ROZ indicators. To quantify the oil in place, 200 well logs were analyzed, providing thickness and saturation data to constrain the locations of ROZs prospects within the play. Using the median residual oil saturation from well log analysis of 23%, an estimated 1.8 billion barrels of oil in place is contained within the prospects, of which up to 196 million barrels is estimated to be recoverable using an 80-acre blanket WAG CO<sub>2</sub> flood EOR factor of 11.4% assuming miscible conditions. Associated CO<sub>2</sub> storage in the ROZs, not accounting for main pay zones or underlying brine aquifers, is estimated to be 10.4 billion tonnes. This resource assessment demonstrates the potential of the Cypress ROZ play for CO<sub>2</sub>-EOR and associated storage.

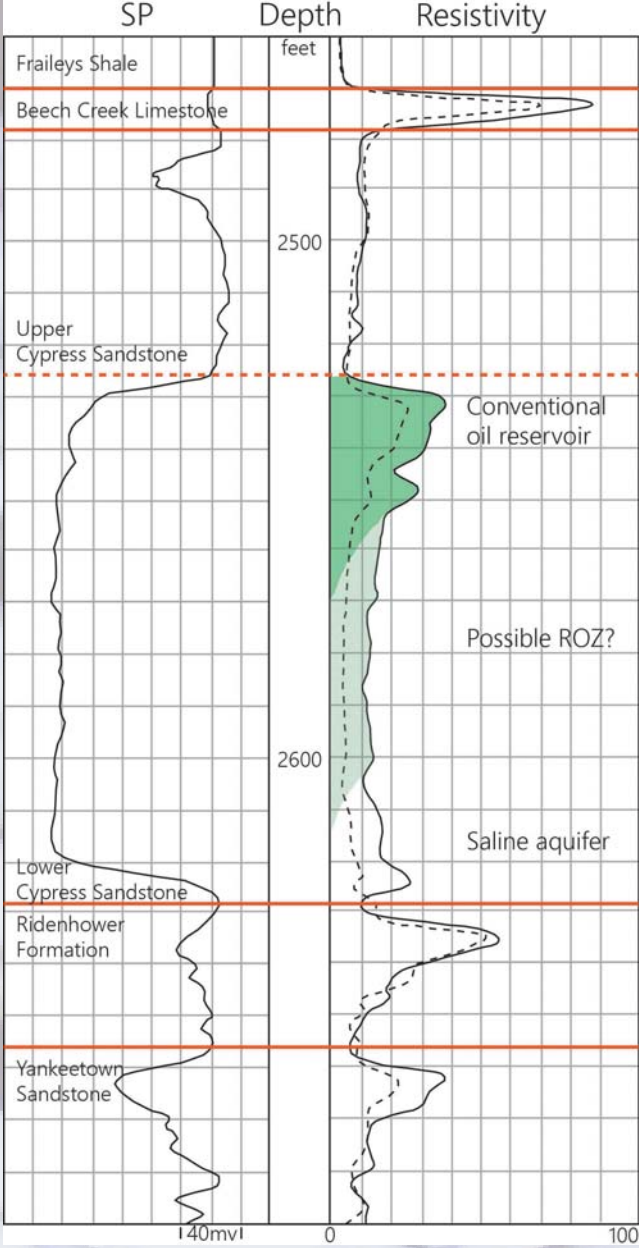
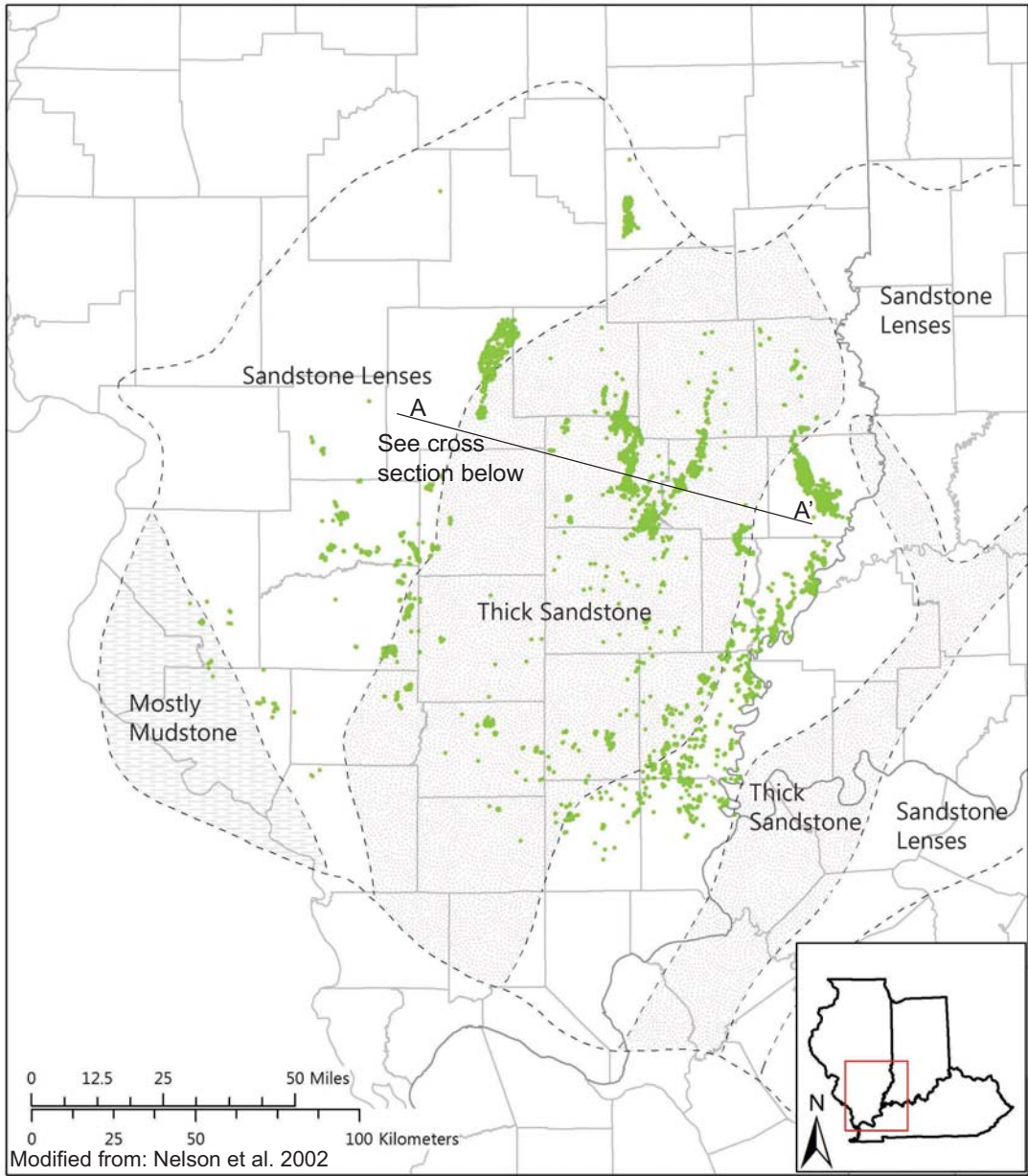
Motivation

- Determine the potential resource for net carbon negative oil production via CO<sub>2</sub>-EOR and geologic storage in a siliciclastic ROZ
- Objectives of this four-year study include:
    - Characterizing geology of CO<sub>2</sub>-EOR target Cypress Sandstone
    - Identifying ROZs via direct and indirect oil indicators
    - Developing a CO<sub>2</sub>-EOR and storage strategy for the regional resource based on detailed case studies

Background and Study Area

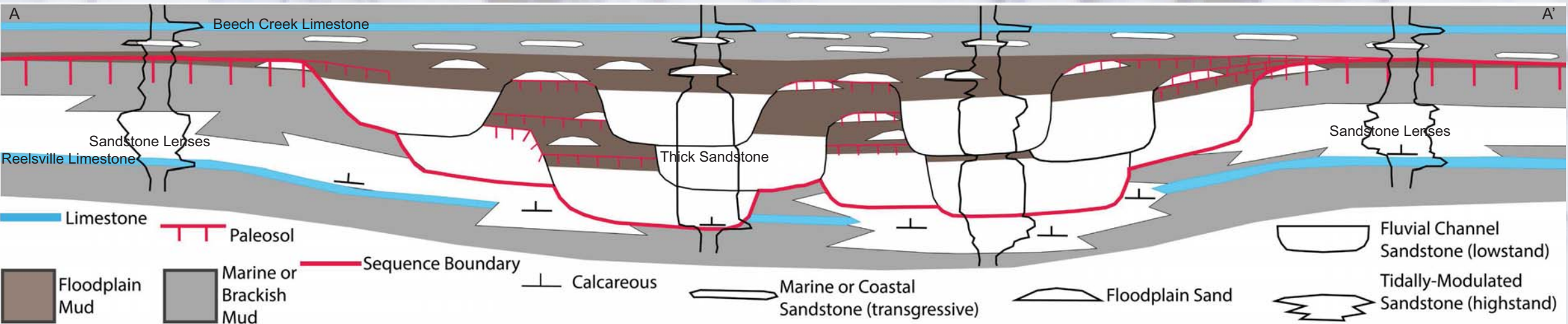
Cypress Sandstone (Upper Mississippian) of the Illinois Basin

- Multiple depositional facies (Below)
- Oil production (green dots) dominantly from sandstone lenses
- Thin Cypress Sandstone reservoirs are an under-produced resource
  - Thin main pay zones (MPZs) above thick (100+ feet) brine aquifers
  - Water coning issues hamper oil production attempts
- Thin MPZs have potential underlying residual oil zones (ROZs)
  - Porous and permeable fairway may have been naturally waterflooded
- EOR potential in MPZ + ROZ with high net CO<sub>2</sub> utilization
- Saline storage potential of 3.5 to 40.2 Tcf (0.2 to 2.3 Gt) of CO<sub>2</sub> in the Illinois Basin (DOE/NETL, 2012)



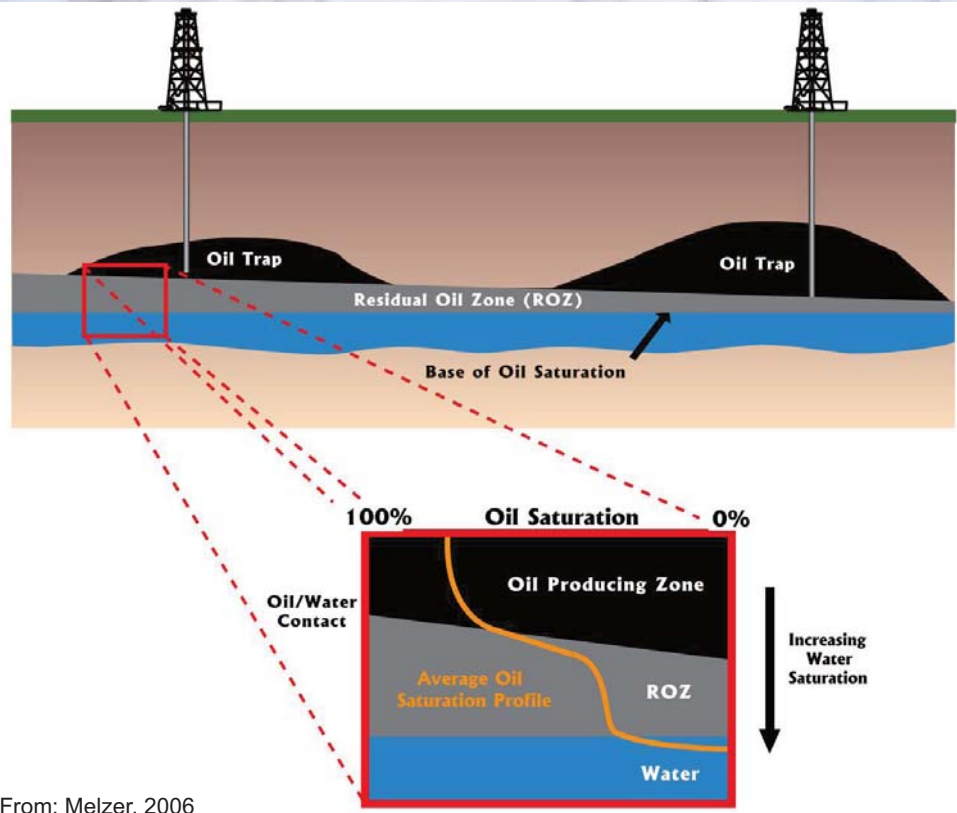
SYSTEM	SERIES	FORMATION	GRAPHIC
PENNSYLVANIAN	MORROWAN	Atokan	Tradewater Fm
		Caseyville Fm	
MISSISSIPPIAN	CHESTERIAN	Lower Kinkaid Ls	
		Degonia Ss	
		Clore Fm	
		Palestine Ss	
		Menard Ls	
		Waltersburg Ss	
		Vienna Ls	
		Tar Springs Ss	
		Glen Dean Ls	
		Hardinsburg Ss	
		Haney Ls	
		Fraileys Shale	
		Beech Creek Ls	
		Cypress Ss	
		Paint Creek Fm	
		Reelsville Ls	
VALMEYERAN		Beaver Bend Ls	
		Bethel Sandstone	
		Downeys Bluff Ls	
		Yankeetown Ss	

Above - Stratigraphic column showing Upper Mississippian stratigraphy of Illinois Basin  
Below - Interpretive framework for deposition of thick Cypress Sandstone within incised valleys in the central Illinois Basin

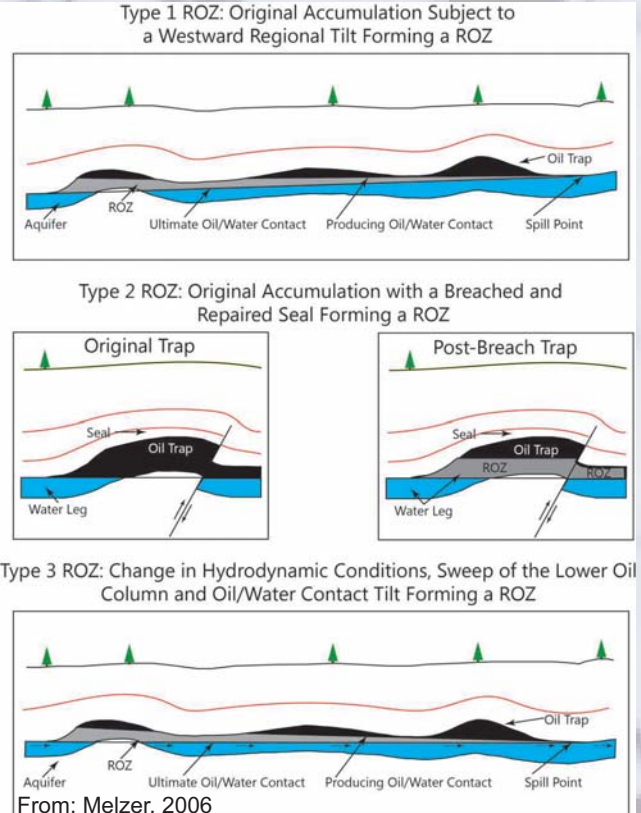


Residual Oil Zones (ROZs)

- Formed as a result of natural waterflooding over geologic time
  - Brownfield: Has MPZ
  - Greenfield: No MPZ
- Same characteristics as swept portions of a mature waterflood
- Permian Basin examples
  - 15% to 35% So
  - 10% to 20% can be recovered by CO<sub>2</sub>-EOR
  - Scale and saturations could be different in the Cypress Sandstone of the Illinois Basin



From: Melzer, 2006



From: Melzer, 2006

# CO<sub>2</sub> Storage and EOR Resource Assessment of the Cypress Sandstone Residual Oil Zone Play in the Illinois Basin

**ILLINOIS**  
Illinois State Geological Survey  
PRAIRIE RESEARCH INSTITUTE

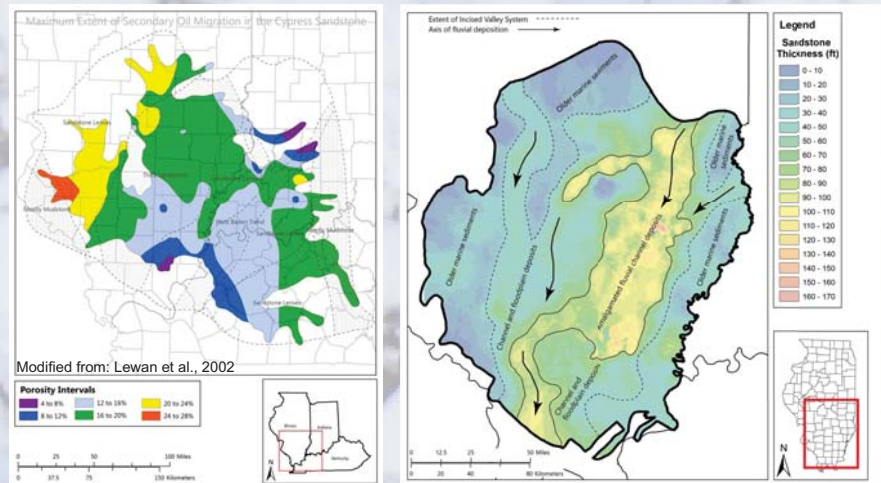
Nathan D. Webb, Nathan P. Grigsby, and Scott M. Frailey

ndwebb2@illinois.edu, Illinois State Geological Survey, Prairie Research Institute, University of Illinois at Urbana-Champaign

**NEL** NATIONAL  
ENERGY  
TECHNOLOGY  
LABORATORY

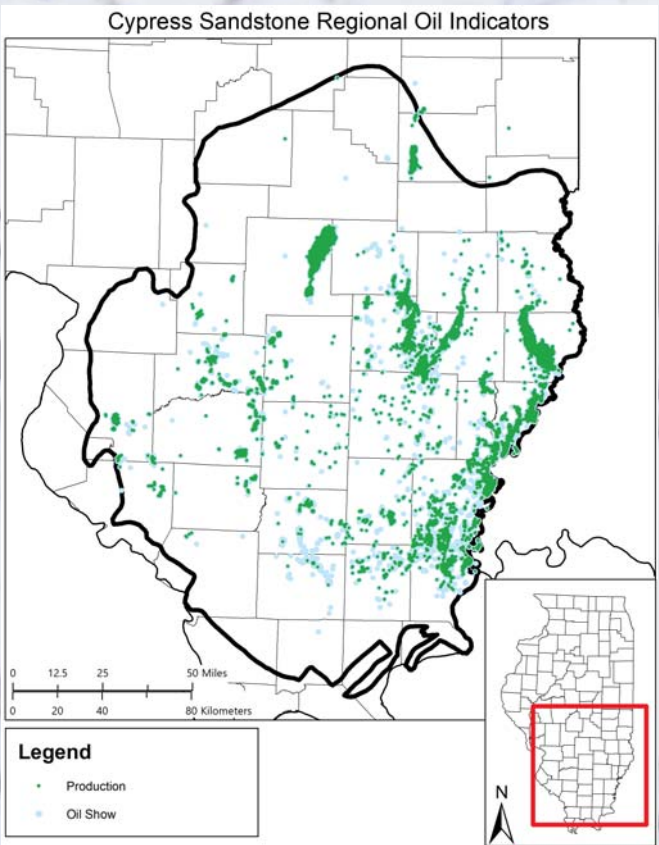
## Methodology: ROZ Identification and Mapping

Understanding petroleum migration into (e.g. Lewan et al., 2002) and reservoir characteristics of the Cypress Sandstone in the Illinois Basin (e.g. Webb et al., 2016) provide the framework for identifying potential ROZs.



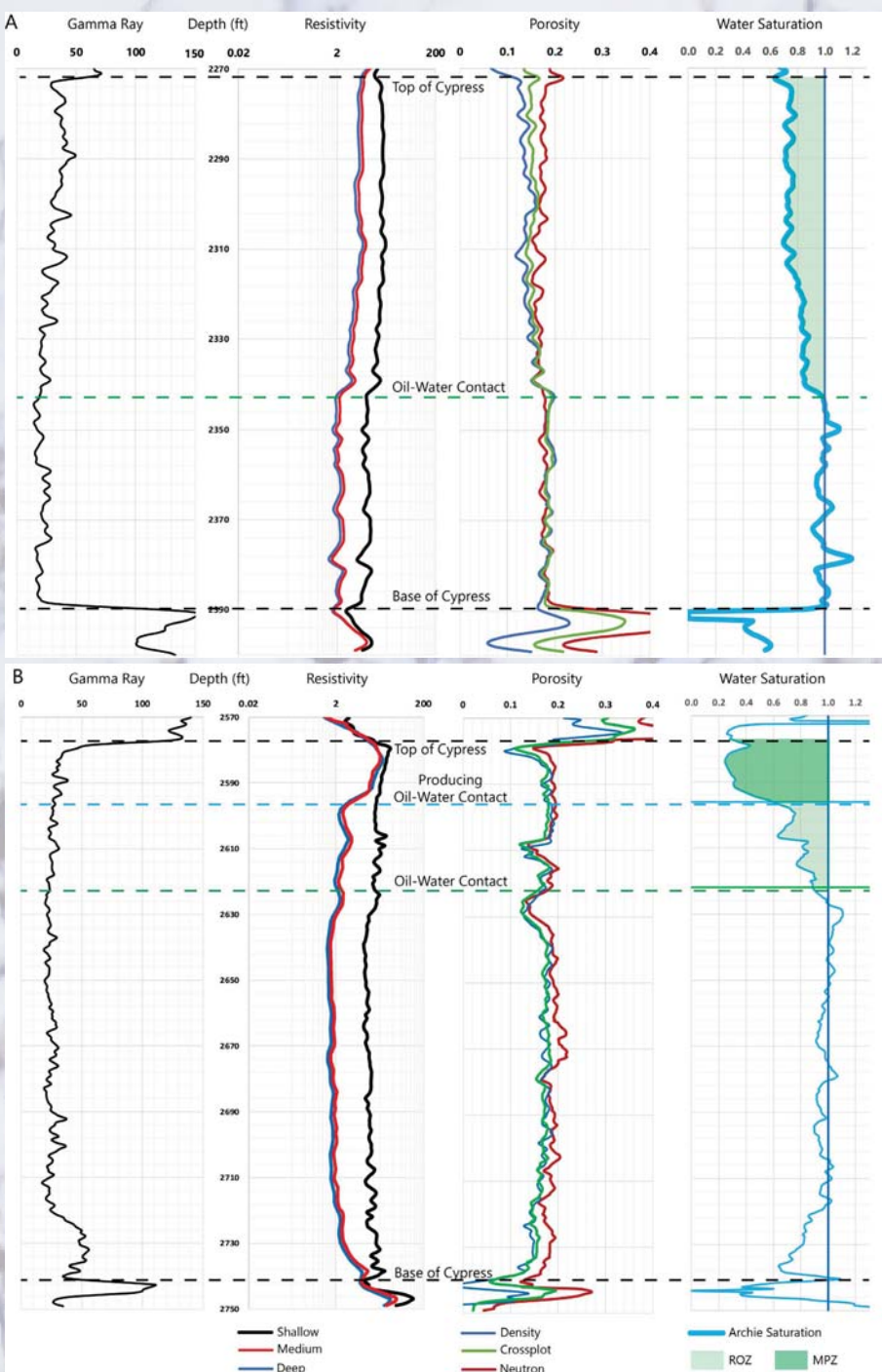
Followed Trentham and Melzer's (2016) "cookbook" approach to document and reinterpret existing data to identify oil indicators used to explore for ROZs:

- Production or perforations
- Oil shows
- Core oil saturation
- Drill stem tests



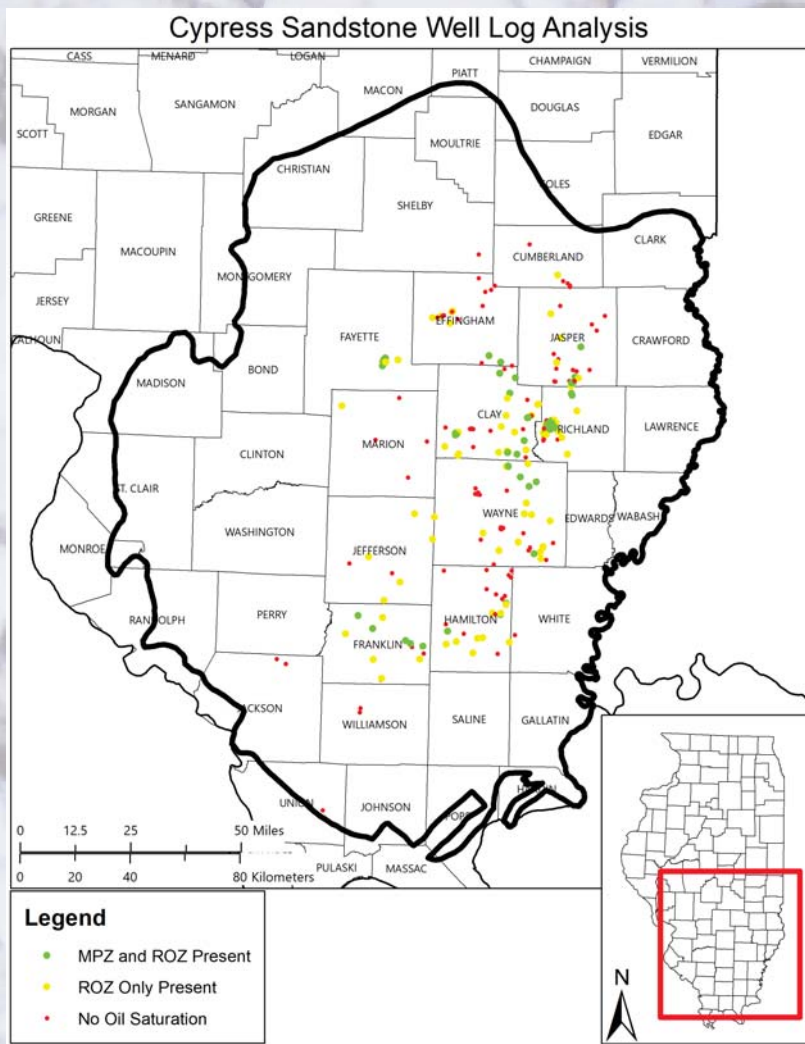
Identification of oil indicators, especially in areas with no associated production and within the thick sandstone fairway, guided the selection of wells for further analyses.

Applied well log analysis to quantitatively determine the thickness and saturation values of residual oil.

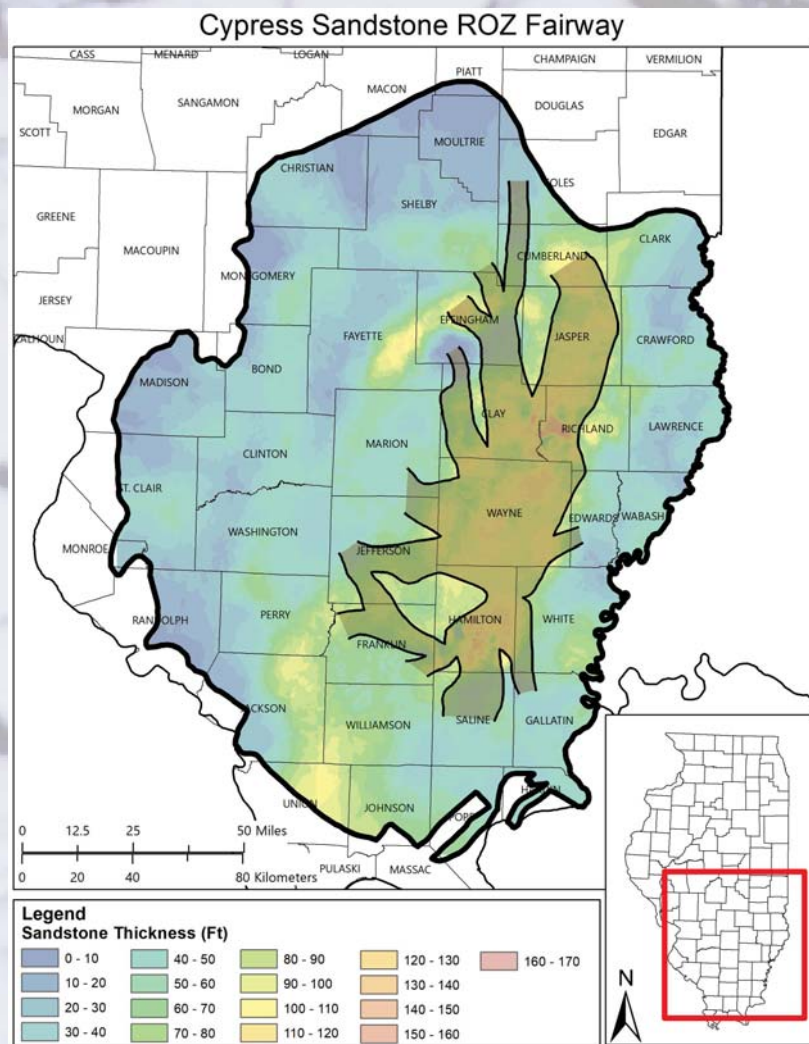
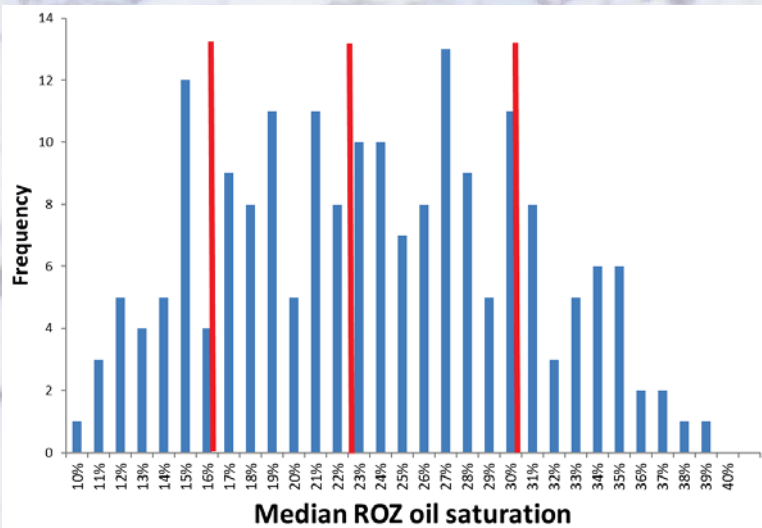


Example well log analyses showing both greenfield (A) and brownfield (B) ROZ development in the Cypress Sandstone. Gamma-ray log shown in left track, resistivity log shown in left-center track, neutron-density porosity log shown in right-center track, and calculated water saturation shown in right track. A) Water saturation stabilizes at around 75% (25% oil saturation) for the upper 70 feet of the reservoir, indicating a thick greenfield ROZ. B) Water saturation is low (~25%) in the top ~20 feet of the reservoir (the main pay zone), and stabilizes at around 75% (25% oil saturation) for ~20 feet below the MPZ, indicating a brownfield ROZ.

## Results: ROZ Fairway and Prospects

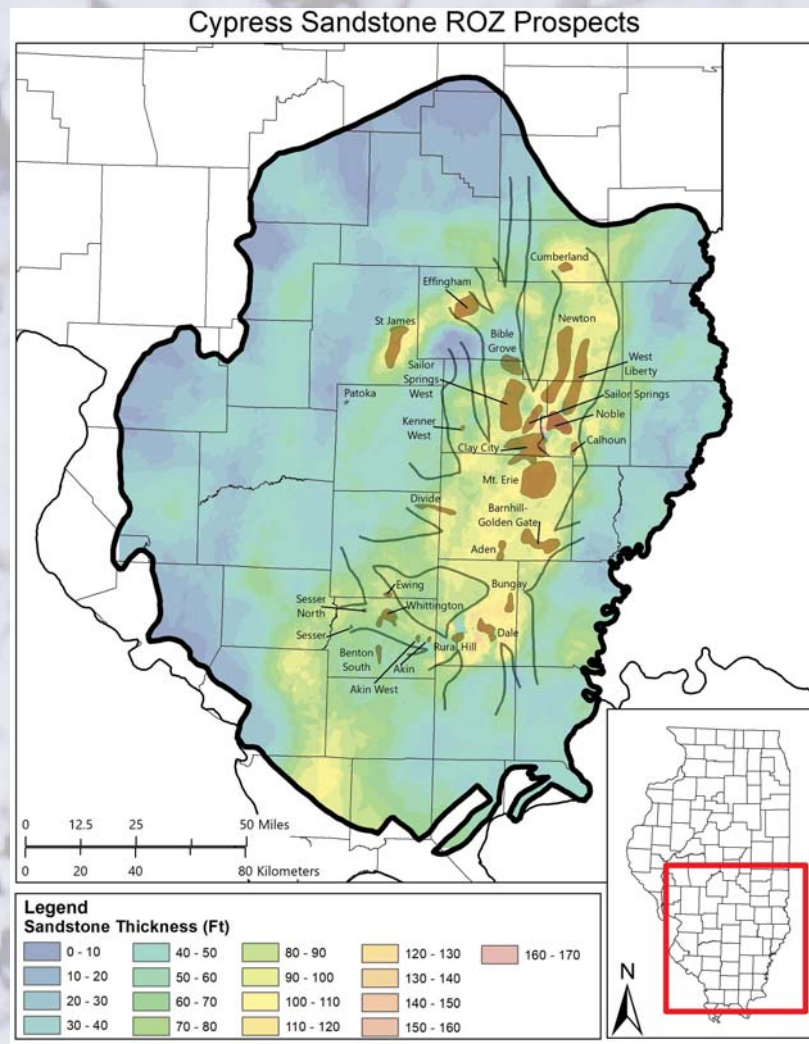


Above - Map showing results of well log analysis. Wells with both MPZ and ROZ are shown in green dots, wells with only ROZ are shown with yellow dots, and wells with no indications of oil saturation are shown with red dots. Below - Probability distribution function of median residual oil saturation for 194 wells across the Basin that contained a ROZ. Median (23%) and standard deviations (16% and 30%) are shown with red lines.



Above - The Cypress Sandstone ROZ fairway (shaded in brown) is defined as the area of the Basin that, based on regional mapping and data analysis, has potential to contain ROZ prospects. Map developed based on:

- Isopach map to define porous and permeable facies
- Isopach and structure maps guided spider map of potential oil migration pathways
- Occurrence of oil indicators from well data (~18,000 wells with oil indicators) and well log analysis
- Within the ROZ fairway, discreet ROZ prospects were defined (Above Right)
- Prospects were delineated by grouping wells with Cypress oil indicators with wells in which well log analysis indicated a ROZ
- Structure and thickness maps were used to delineate the boundaries of each potential prospect, where appropriate; some prospects lack clearly defined structural closure
- Regional isopach map was used for volumetric calculations within each defined prospect (Right)



Above - Map of Cypress ROZ prospects, shown in brown. ROZ fairway boundaries are outlined in black. Below - CO<sub>2</sub>-EOR, Net Utilization, and Storage for ROZ prospects. An asterisk (\*) next to the prospect name denotes prospects with ROZs that were shallower than the 2,100 ft depth cutoff where the immiscible factors were applied.

Prospect Name	Oil in place (million bbl; S <sub>oi</sub> = 23%)	CO <sub>2</sub> -EOR (million bbl)	CO <sub>2</sub> Storage (million tonnes)	Oil in place (million bbl)	CO <sub>2</sub> -EOR (million bbl)	CO <sub>2</sub> Storage (million tonnes)
Aden	34.8	4.0	11,058	3.3	2.9	7,954
Akin	2.1	0.2	4,928	0.1	0.2	3,545
Akin West	3.8	0.4	5,896	0.1	0.3	4,241
Barnhill-Golden Gate	104.1	1.9	8,850	3.8	8.5	6,366
Benton South	6.4	0.7	3,301	0.2	0.5	2,374
Bible Grove	46.9	5.1	5,415	1.7	3.8	3,895
Bungay	26.4	3.0	8,411	1.0	2.2	6,050
Calhoun	52.0	5.9	25,501	1.9	4.3	18,343
Clay City	120.8	3.8	4,935	4.4	9.9	3,549
Cumberland	56.4	6.4	21,134	2.0	4.6	15,455
Dale	24.4	2.8	4,381	0.9	2.0	3,151
Divide	31.6	3.6	7,162	1.1	2.6	5,152
Effingham*	49.9	2.7	2,124	0.4	2.7	171
Ewing	8.7	1.0	9,010	0.3	0.7	6,481
Kenners West	6.4	0.7	11,546	0.2	0.5	8,505
Mt. Erie	299.6	4.2	10,143	10.9	24.6	7,295
Newton	240.6	6.4	8,961	8.7	19.7	6,846
Noble	56.6	6.5	5,391	2.1	4.6	3,878
Patoka*	2.0	0.1	3,490	0.0	0.1	3,490
Rural Hill	29.2	3.3	12,226	1.1	2.4	8,794
Sailor Springs	20.2	2.3	2,909	0.7	1.7	2,093
W	219.2	15.0	8,182	8.0	18.0	5,885
Sesser	3.3	0.4	16,808	0.1	0.3	10,652
Sesser North	8.5	1.0	21,433	0.3	0.7	15,417
St. James*	169.1	6.4	8,693	1.3	8.6	486
West Liberty	169.2	19.3	7,178	6.1	13.9	5,163
Whittington	46.9	5.4	8,074	1.7	3.8	5,807
Totals	1,828.7	195.8	60.4	144.1	10,406.1	

Conclusions:

Cypress Sandstone Resource Assessment

- Preliminary estimate of oil in place for all ROZ prospects
  - ◊ Oil in place may or may not be technically recoverable
  - ◊ ROZ fairway likely contains oil beyond the boundaries of the prospects defined here

ROZ S <sub>OR</sub> = 16%	R <sub>OZ</sub> SOR = 23%	R <sub>OZ</sub> SOR = 30%
1.3 billion bbl	1.8 billion bbl	2.4 billion bbl

- Based on well log analysis, the median S<sub>o</sub> within Cypress ROZs is 23%, with +/- one standard deviation of 16% and 30%
- MGSC (2005) estimated the total original oil in place for Cypress Sandstone main pay zones in the Illinois Basin to be 2.65 billion barrels
  - ◊ Identified ROZ prospects may contribute an additional 49% to 91% to oil in place values for the Cypress Sandstone



References

Lewan, M.D., M.E. Henry, D.K. Higley, & J.K. Pitman, 2002, Material-balance assessment of the New Albany-Chesterian petroleum system of the Illinois Basin. AAPG Bulletin, v.86, no.5, p. 745–777.

Melzer, L.S., 2006, Stranded Oil in the Residual Oil Zone. Contract Report for Advanced Resources International and US Department of Energy, 35 p.

Midwest Geological Sequestration Consortium (MGSC), 2005, An assessment of geological carbon sequestration options in the Illinois Basin. US DOE Contract Report: DE-FC26-03NT41994, 477 p.

Nelson, W.J., L.B. Smith, J.D. Treworgy, L.C. Furer, & B.D. Keith, 2002, Sequence Stratigraphy of the Lower Chesterian (Mississippian) Strata of the Illinois Basin. Illinois State Geological Survey, Bulletin 107, 70 p.

Trentham, R., & L.S. Melzer, 2016, A Cookbook Approach to Exploring for, and Evaluating, Residual Oil Zones in the San Andres Formation of the Permian Basin. Southwest Section AAPG Annual Convention, Abilene, TX, April 11, 2016.

U.S. Department of Energy/National Energy Technology Laboratory (DOE/NETL), 2012, United States 2012 Carbon Utilization and Storage Atlas, Fourth Edition, 129 p.

Webb, N.D., N.P. Grigsby, J.J. Arneson, L.G. Giannetta, & S.M. Frailey, 2016, An Integrated Approach to Identifying Residual Oil Zones in the Cypress Sandstone in the Illinois Basin for Nonconventional CO<sub>2</sub>-EOR and Storage, Eastern Section American Association of Petroleum Geologists Meeting, Lexington, KY, September 27, 2016.

Future Work: Continued Research on Illinois Basin ROZs

ROZ validation and screening for other ROZ and stacked CO<sub>2</sub>-EOR and associated storage opportunities

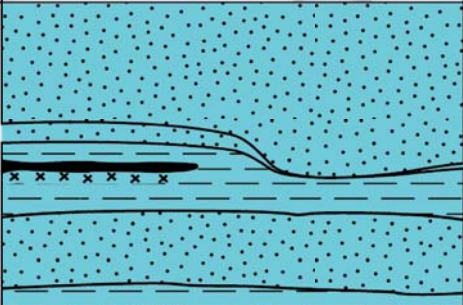
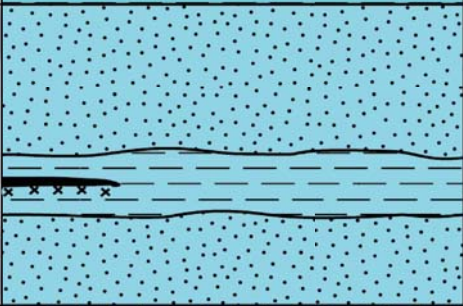
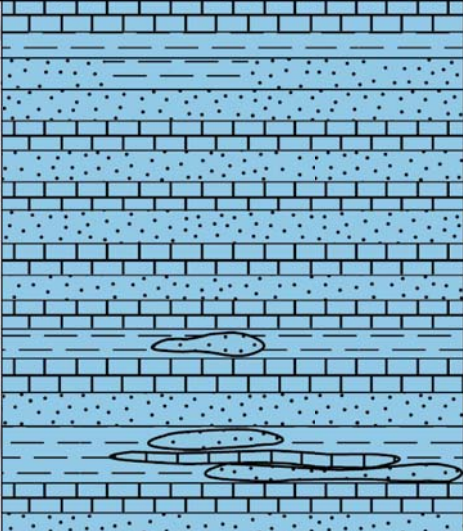
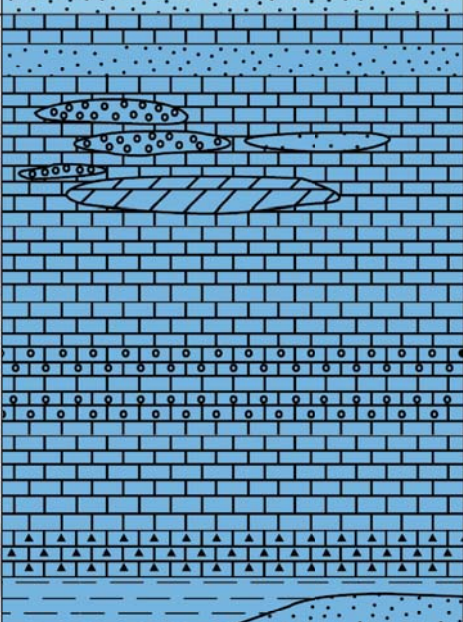
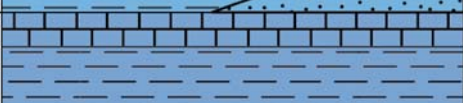
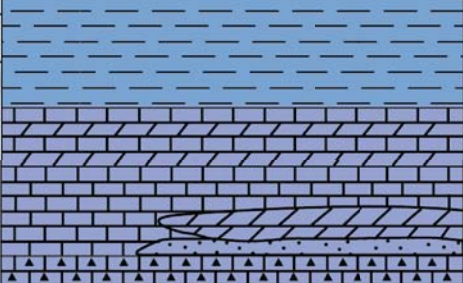
- Conduct additional well log analyses to improve confidence in:
  - ◊ Spatial distribution of Cypress ROZ fairway and prospects
  - ◊ ROZ thickness, porosity, and saturation
  - ◊ Volumetric estimates of oil in place
- Apply CO<sub>2</sub>-EOR and storage factors based on reservoir simulations and published results to determine economic viability of the ROZ play
- Drill a new well and collect fresh core through the Cypress in the Noble ROZ Prospect to validate thickness and saturation estimations
- Expand analyses to include other Illinois Basin formations with potential to host ROZs (Right)

Acknowledgements

- US Department of Energy contract numbers DE-FE0024431 and DE-FE0031700
- Through a university grant program, IHS Petra software was used for the geologic modeling, Geovariances Isatis software was used for geocellular modeling, and Landmark Nexus software was used for the reservoir simulation
- For project information, including reports and presentations, please visit:

[www.isgs.illinois.edu/research/erd/nco2eor](http://www.isgs.illinois.edu/research/erd/nco2eor)

Illinois Basin Stratigraphy

System	Series	Lithology	Oil Reservoirs	ROZ Potential
Pennsylvanian	Atokan		Lower Pennsylvanian Sandstones	✓
	Morrowan			
Mississippian	Chesterian		Kinkaid Limestone	
		Degonia Sandstone	✓	
		Clore Formation	✓	
		Palestine Sandstone		
		Menard Limestone		
		Waltersburg Sandstone		
		Vienna Limestone		
		Tar Springs Sandstone	✓	
		Glen Dean Limestone		
		Hardinsburg Sandstone	✓	
		Haney Limestone		
		Big Clifty Sandstone		
	Beech Creek Limestone			
	Cypress Sandstone	✓		
	Valmyeran		Ridenhower Formation	
		Downeys Bluff Limestone		
		Yankeetown Sandstone	✓	
		Renault Limestone		
Aux Vases Sandstone				
Ste. Genevieve Limestone				
Spar Mountain Sandstone	✓			
Devonian	Kinderhookian		St. Louis Limestone	
		Salem Limestone		
	Upper		Ullin Limestone	✓
		Fort Payne Limestone	✓	
		Carper Sandstone	✓	
		Chouteau Limestone		
		New Albany (Group)		
		Lingle Limestone		
		Geneva Dolomite	✓	
		Clear Creek Chert		

Contributors

The four year study of the Cypress Sandstone involved contributions from a number of ISGS staff:

- Project leadership – Nathan Webb, Scott Frailey, Nathan Grigsby
- Geologic Characterization – Nathan Webb, Kalin Howell, Mingyue Yu, Leo Giannetta, Jared Freiburg, Shane Butler, Yaghoob Lasemi, Zohreh Askari
- Geocellular Modeling and Production History – Nathan Grigsby
- Well log Analyses – Nathan Grigsby and Scott Frailey
- Reservoir Simulation – Roland Okwen, Fang Yang, Scott Frailey
- Feedback/Discussion – John Grube and Bev Seyler