A Nonconventional CO_2-EOR Target in the Illinois Basin: Oil Reservoirs of the Thick Cypress Sandstone

Project Number DE-FE0024431

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U.S. Department of Energy
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Presentation Outline

- Background
- Methodology
- Accomplishments to Date
- Summary
- Future Plans
- Acknowledgements
- Appendices

Background: Thick Cypress Ss

- nCO_2-EOR and storage opportunity
  - NE-SW trending thick sandstone fairway though central Illinois Basin

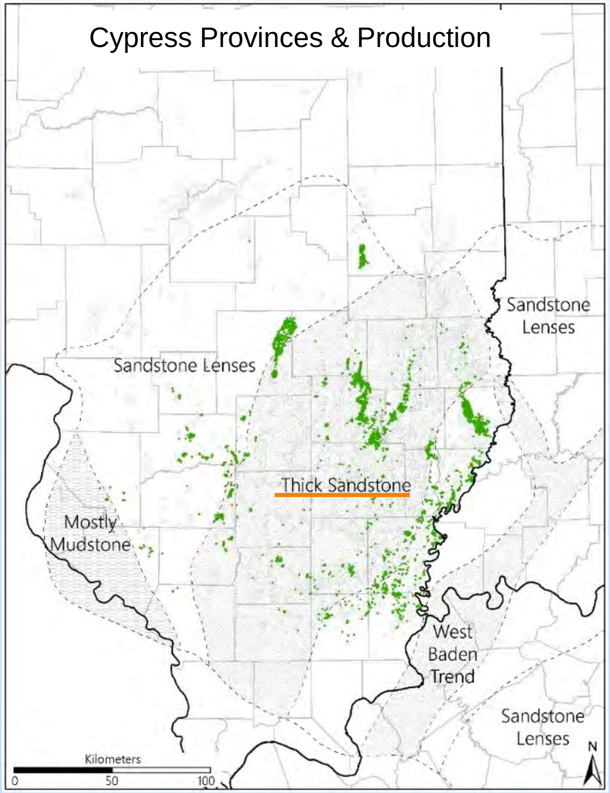
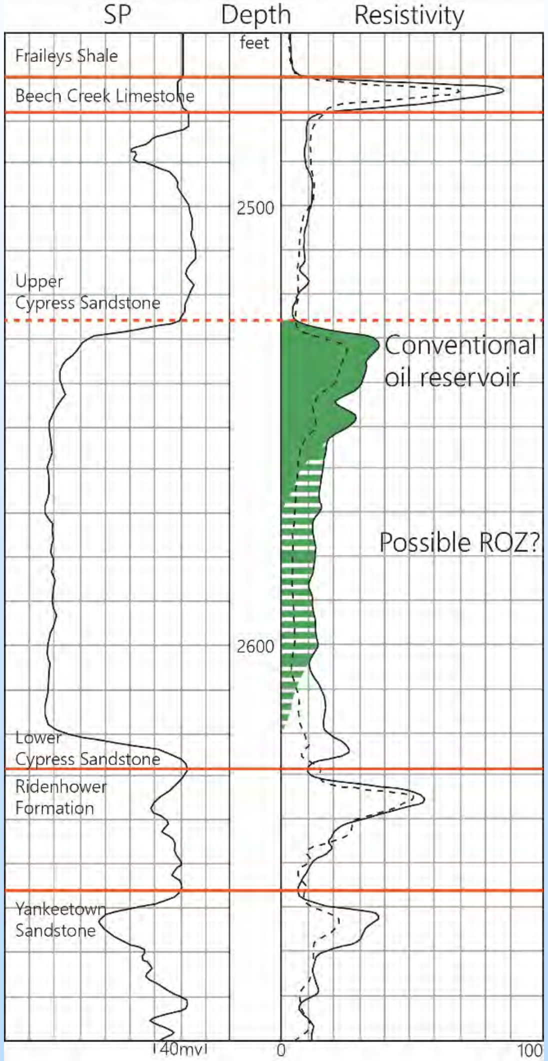
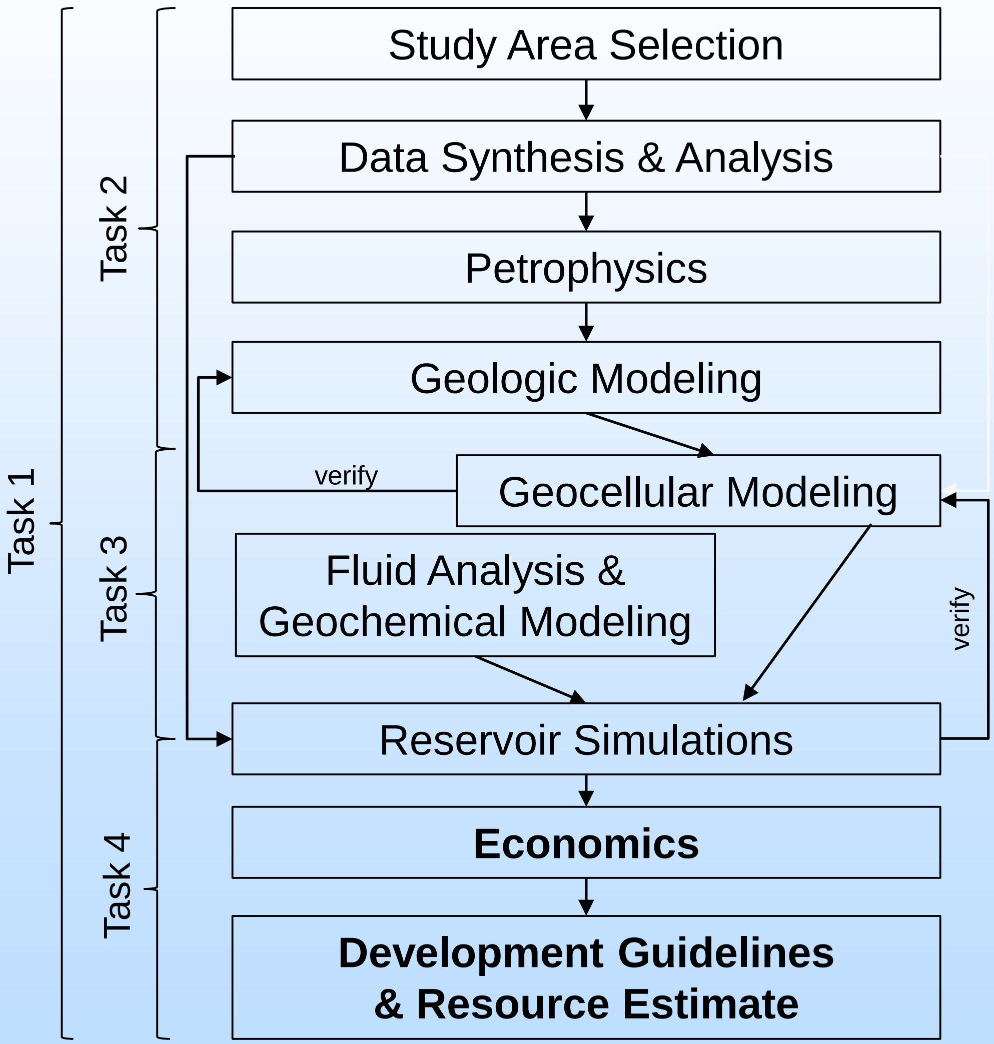


Figure modified from Nelson et al. 2002

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



Methodology



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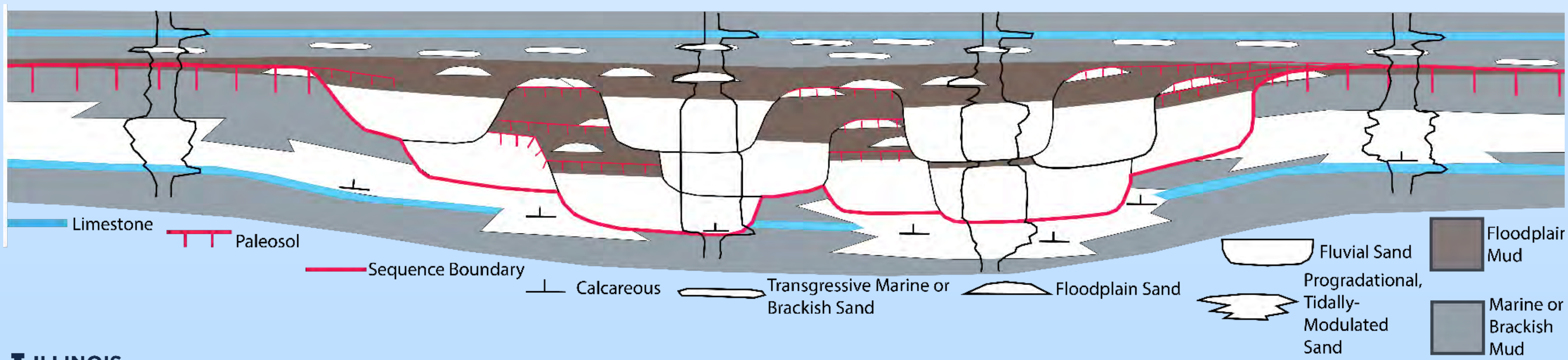
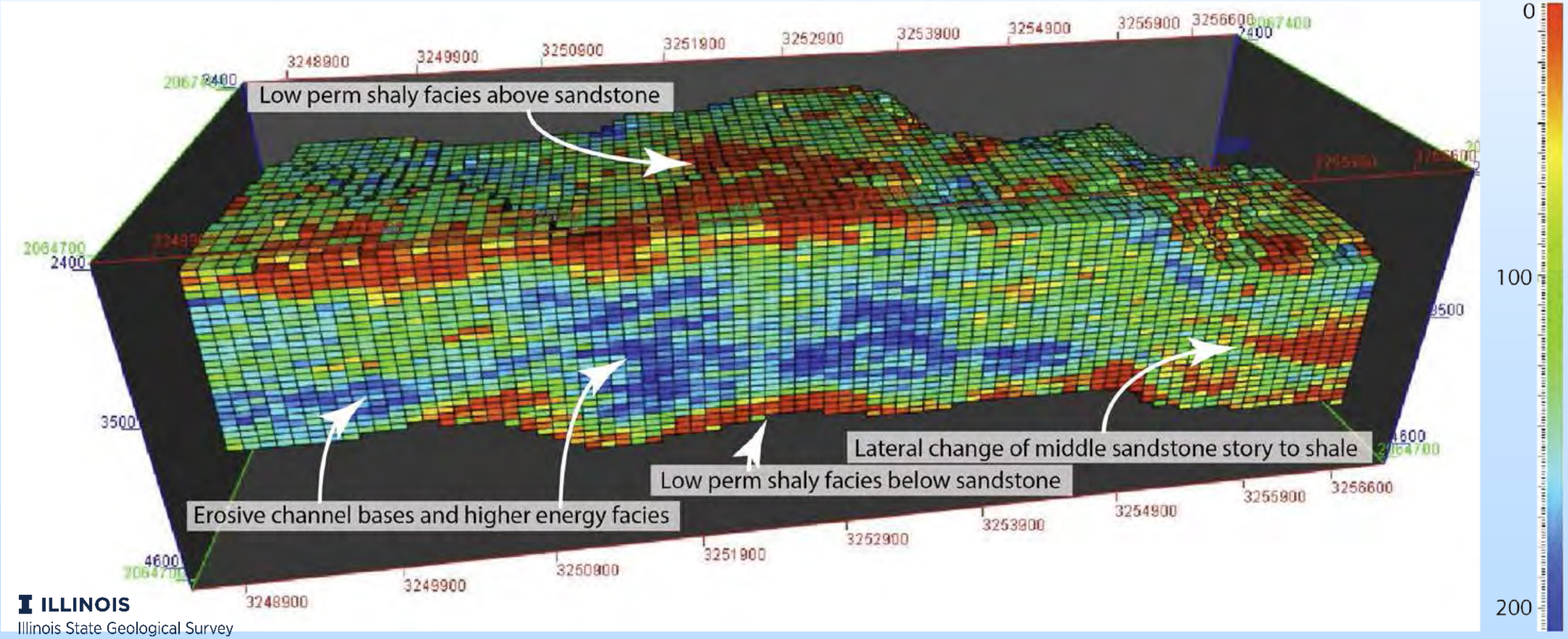
Geological Modeling

- Developed a geologic model of the Cypress Sandstone
  - Multistorey fluvial sandstones within a ~ 25 km wide belt
  - High lateral continuity near the base of the formation (sheet sandstones); decreases upward (isolated arcuate sandstones)
  - Limited range of grain size (vf-f) but intraformational channel boundaries have grain size and mineralogical contrasts that result in streaks of high permeability
    - Heterogeneity impact reservoir and well log analysis



Geocellular Modeling

- Constructed model to incorporate observed geologic heterogeneity across scales
  - Sandstone/shale facies relationships
  - Permeability variations within stacked sandstones



Reservoir Simulation

- **Developing strategies to maximize oil recovery and CO_2 storage based on pattern simulation:**
  - Simultaneous flooding of the MPZ and ROZ (Case 1-10)
  - Sequential flooding: 1. flood ROZ after CO_2 breakthrough in MPZ (Case 11, 12), and 2. flood ROZ and produce from both MPZ and ROZ after CO_2 breakthrough in MPZ (Case 13)
- Applying best strategies to field scale simulations for Noble Field

Case	Injector	Producer	EOR (Mstb)		Net Utilization (Mscf/stb)		Storage ratio		EOR %		CO_2 storage efficiency	
			ROZ	MPZ	ROZ	MPZ	ROZ	MPZ	ROZ	MPZ	ROZ	MPZ
1	Entire MPZ and ROZ	Entire MPZ and ROZ	86	319	18	9	36.5%	63.5%	11.2%	17.8%	10.5%	23.4%
2	Entire MPZ only	Entire MPZ only	46	260	27	10	32.1%	67.9%	6.0%	14.6%	8.4%	22.8%
3	Entire ROZ only	Entire ROZ only	39	227	30	11	31.5%	68.5%	5.1%	12.7%	7.9%	22.0%
5	Lower 20% ROZ	Upper 20% ROZ	28	180	35	14	27.0%	73.0%	3.6%	10.1%	6.4%	22.2%
6	Lower 20% ROZ	Upper 20% MPZ	28	191	32	14	25.3%	74.7%	3.7%	10.7%	6.0%	22.8%
7	Lower 20% ROZ	Upper 10% MPZ	24	203	27	14	19.3%	80.7%	3.2%	11.4%	4.4%	23.6%
8	Lower 20% ROZ	Lower 20% MPZ	26	188	38	14	27.5%	72.5%	3.4%	10.5%	6.7%	22.6%
9	Lower 20% ROZ	Lower 10% MPZ	47	180	0.19	0.37	12.1%	87.9%	6.2%	10.1%	0.1%	0.6%
10	Upper 20% MPZ	Lower 10% MPZ	23	191	25	15	16.8%	83.2%	3.0%	10.7%	3.8%	24.1%
11	Entire MPZ then ROZ after CO2 breakthrough	Entire MPZ then ROZ after CO2 breakthrough	46	260	27	10	32.1%	67.9%	6.0%	14.6%	8.4%	22.8%
12	Entire MPZ then ROZ after CO2 breakthrough	Entire MPZ then ROZ + MPZ after CO2 breakthrough	46	260	27	10	32.1%	67.9%	6.0%	14.6%	8.4%	22.8%
13	Entire MPZ and ROZ. Then Entire ROZ after 1-2 years	Entire MPZ and ROZ. Then entire MPZ after 1-2 years	58	280	23	9	34%	66%	8%	16%	9%	22%
13a	Entire MPZ and ROZ. Then Entire ROZ after 1 year	Entire MPZ and ROZ.	83	315	19	9	36%	64%	11%	18%	10%	23%
1b	Case 1 with injection BHP = 1571 (DP = 0.6 psi/ft)	Entire MPZ and ROZ	28	184	20	14	18%	82%	4%	10%	4%	22%

Comparison of results for each case at 1.0 PV CO_2 injected

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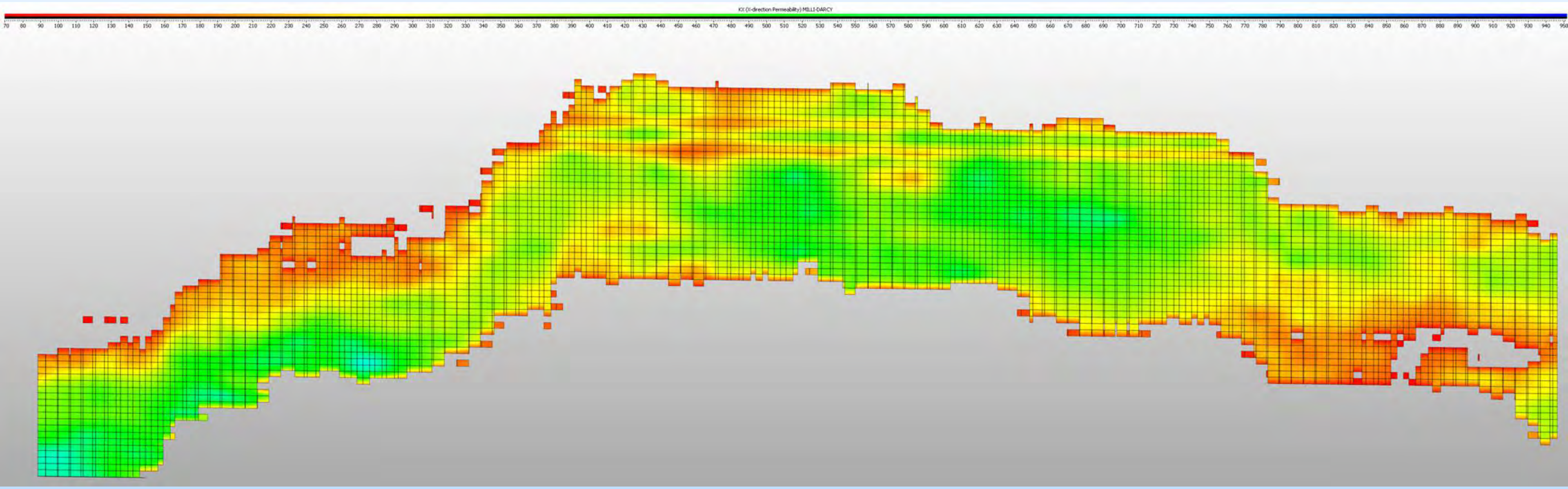
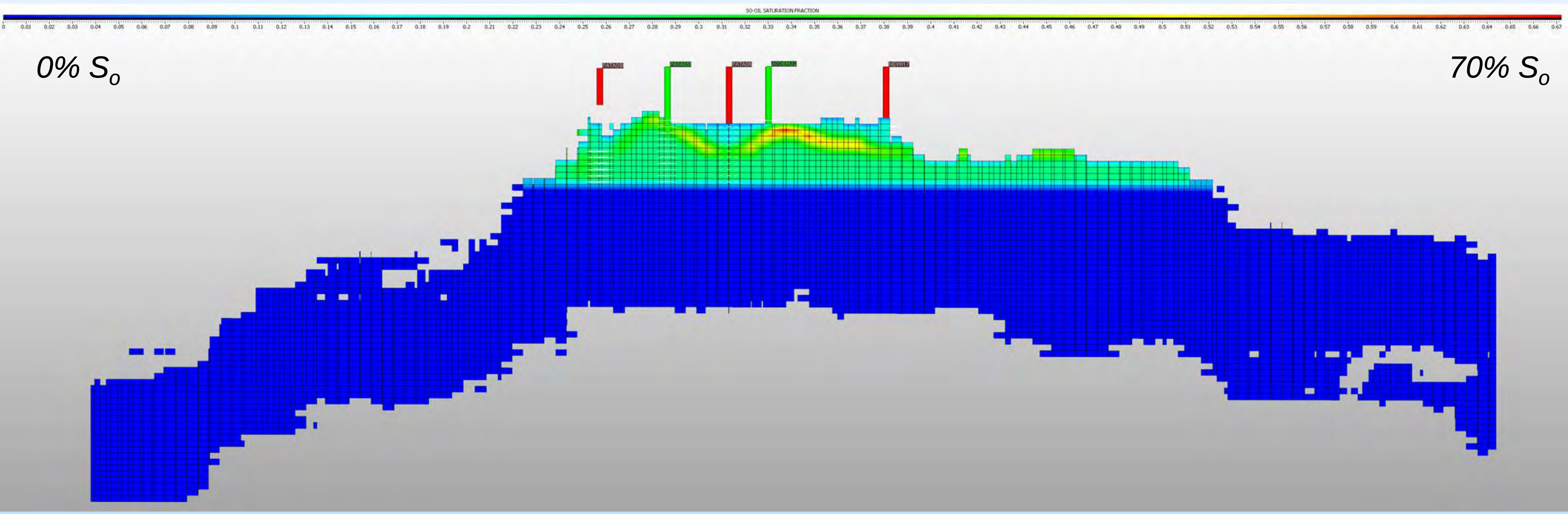


Perm distribution. Range: 70 – 950 md. Warmer colors indicate lower permeability

Reservoir Simulation

- Fluid displacement mechanisms similar to that in homogeneous pattern floods were observed in full field 80-acre 5-spot simulation
- The presence of underlying aquifer in heterogeneous model delays:
  - **Sinking of oil from MPZ into ROZ**
  - Downwards movement of CO_2 plume



Oil saturation at CO_2 breakthrough. Green wells are producers, red are injectors.

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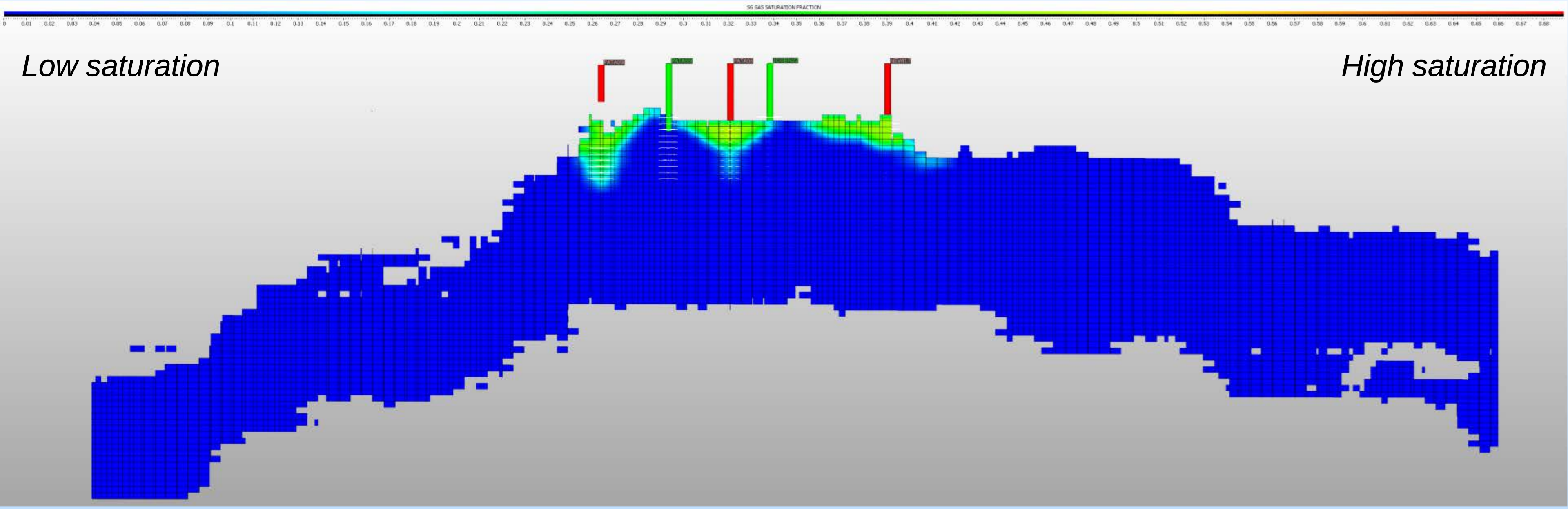

Gas saturation at CO_2 breakthrough. Green wells are producers, red are injectors.

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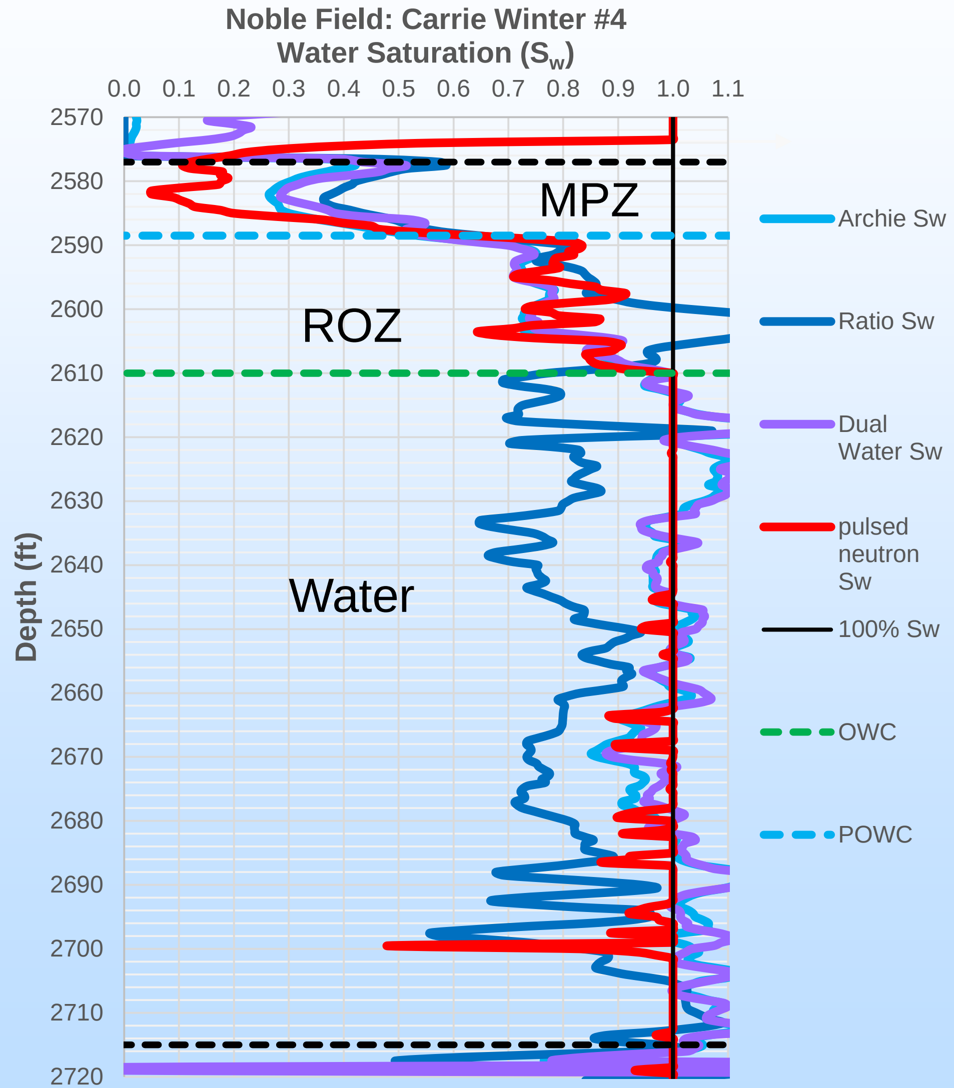
Petrophysics

- **Calculated water saturation (S_w) profiles from existing logs:**
  - **Archie, Ratio, Dual Water Methods**
- **Calibrated to pulsed neutron logs in existing wells in Noble Field**
- Developed fluid contact curves to define the Producing OWC and Ultimate OWC



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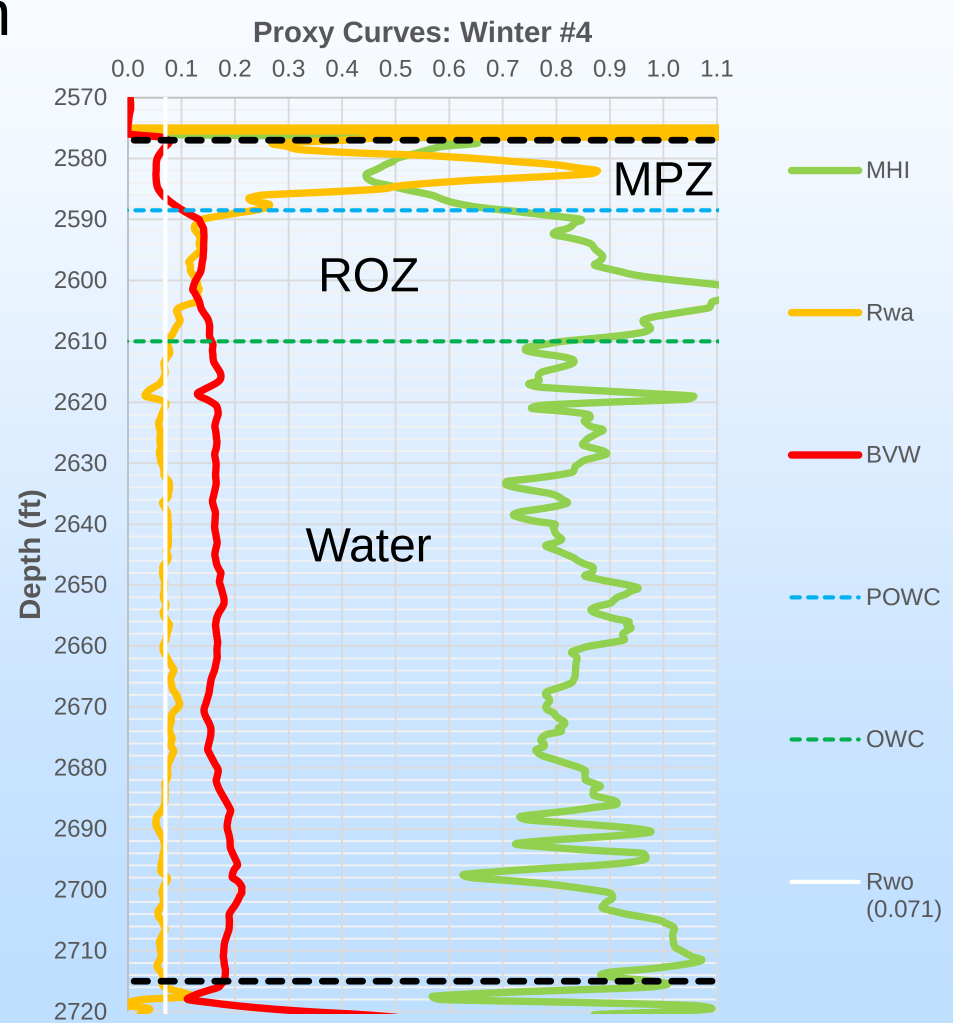

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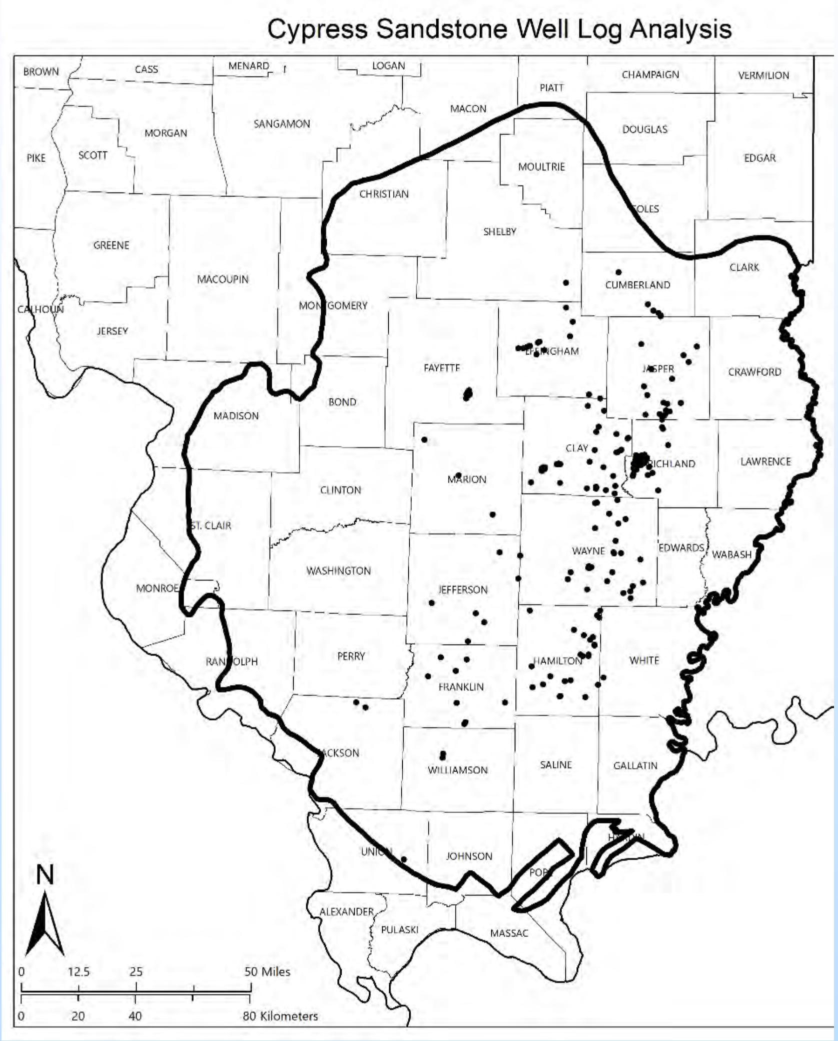
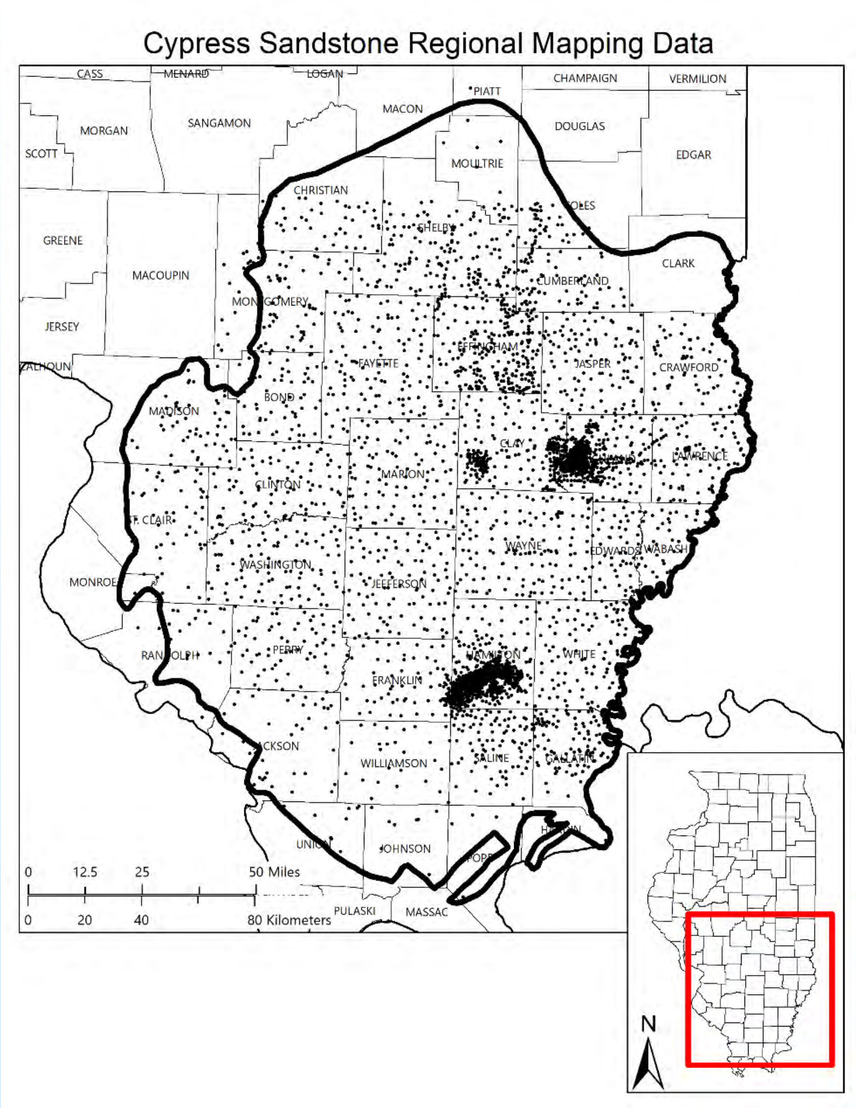
Petrophysics

- Applied log analysis to ~300 wells through thick Cypress Sandstone fairway
- Observed regional variability in:
  - Formation water resistivity
  - Reservoir quality
    - V_{shale}
    - Cementation exponent (m)
  - Oil column thickness
- Detected oil in 191 wells
  - 123 MPZ+ROZ, 68 ROZ only
- Observed consistent ROZ oil saturation of 20 to 30%



Resource Assessment

- **Refined regional isopach and facies maps using data from ~4,500 wells**
- Determined regional Phi-h using core and porosity log data from ~1,700 wells
- Mapped ~17,500 wells with Cypress oil indicators (perfs, shows, core analysis, DSTs) and analyzed well logs from 260 wells to delineate ROZ fairways



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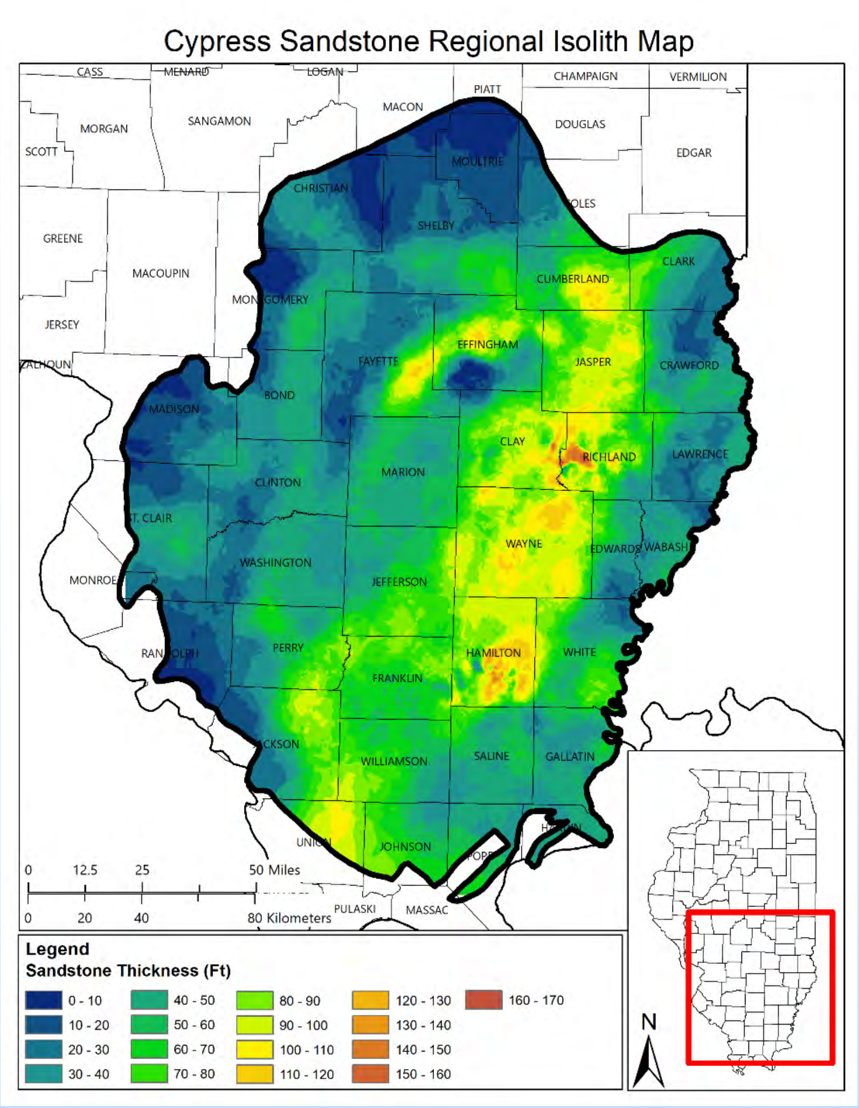

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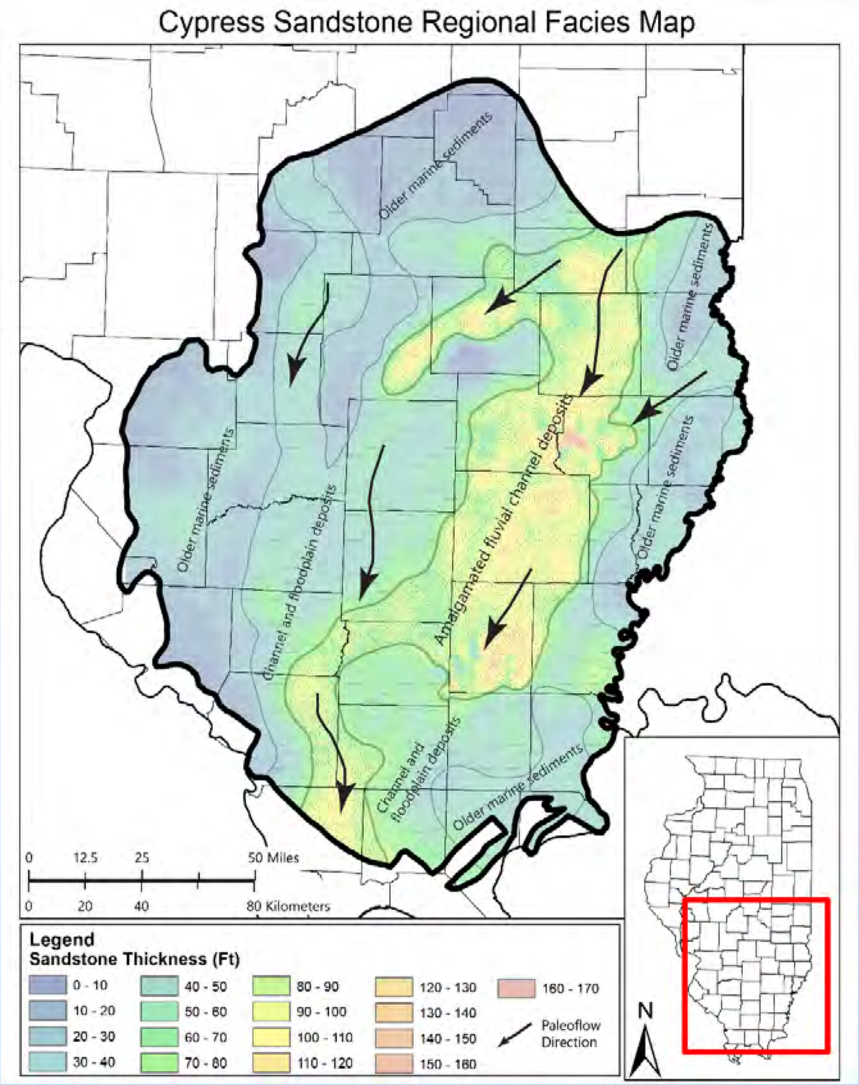

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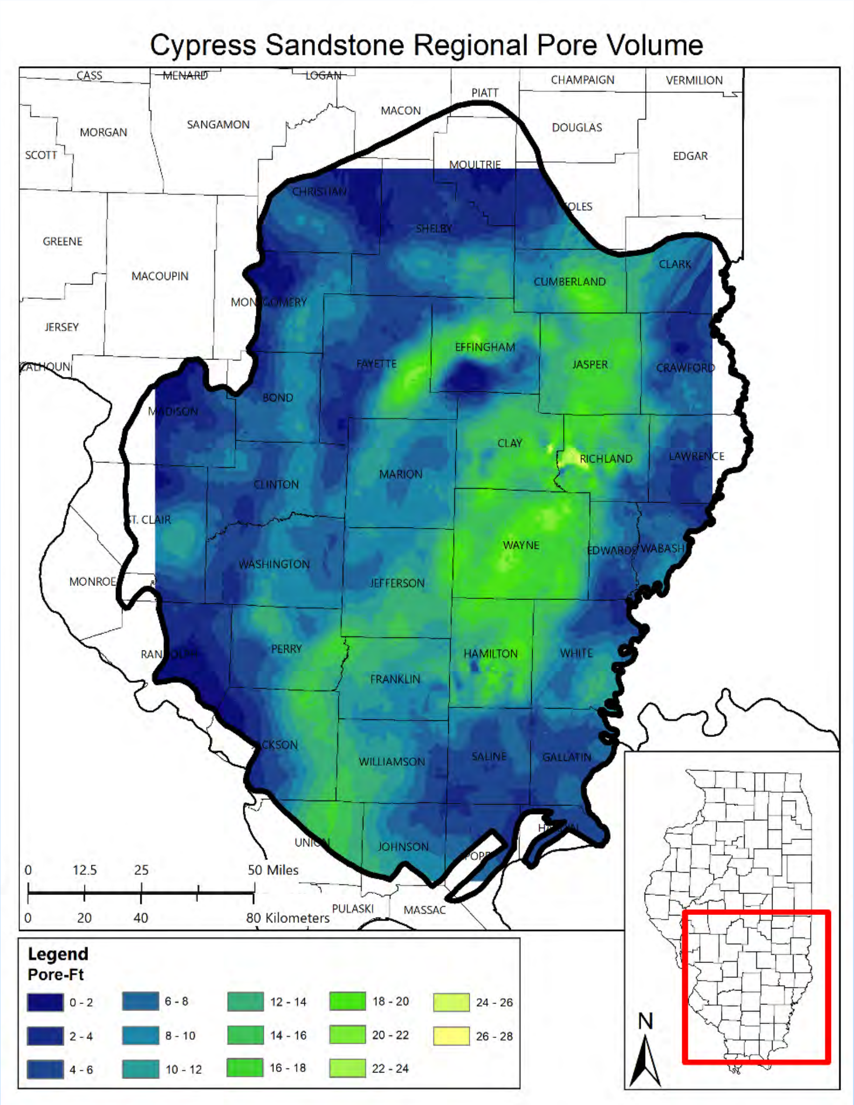

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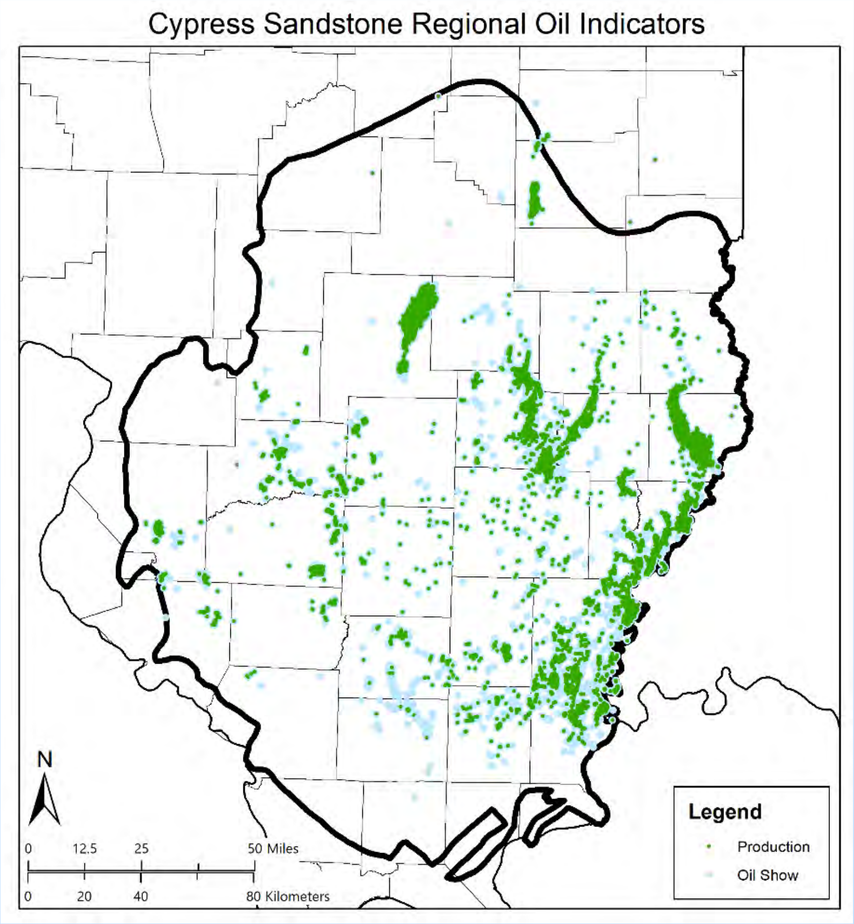

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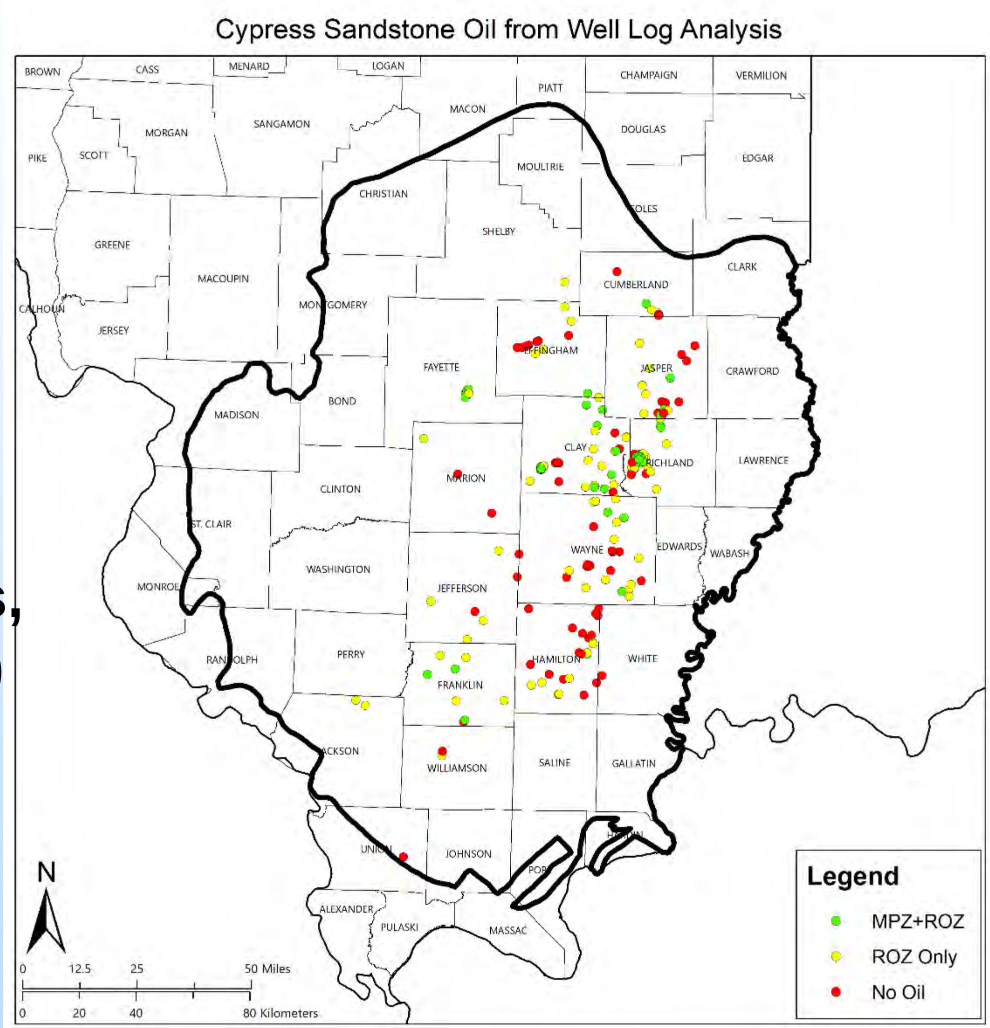

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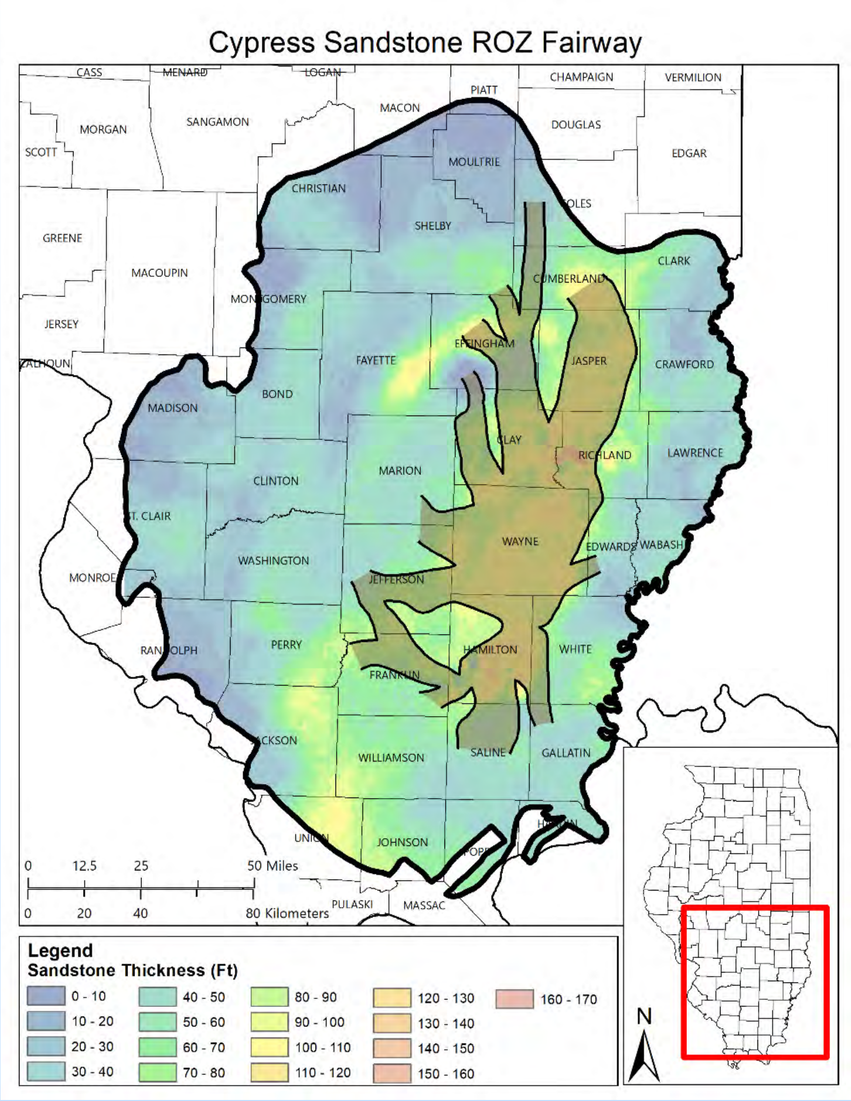
Resource Assessment

- **Mapped extent of ROZ fairway based on production, oil shows, and well log analysis**
  - **Pathways guided by Cypress sandstone isopach, oil indicators, and basin structure**
- Defining potential ROZ prospects within the fairway
  - Areas with overlapping data indicating residual oil – especially with no associated production



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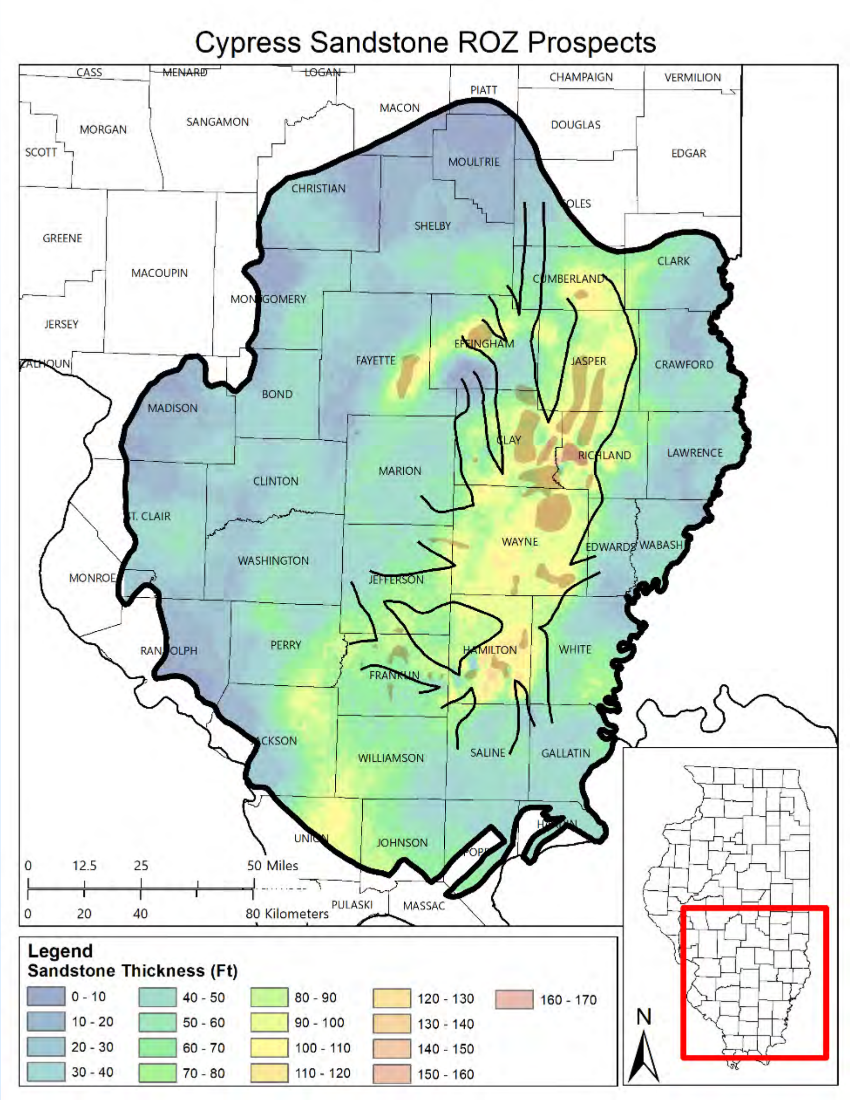


Lessons Learned

- The thick Cypress Sandstone is likely to contain an ROZ fairway
- Properties of a siliciclastic ROZ are different than those observed in the Permian Basin
  - Regional geologic characterization is key to understanding the distribution (or occurrence) of ROZs at the basin scale
    - Necessary for better constraining brownfields and identifying greenfields
- Care must be taken in incorporating old/existing data into ROZ exploration and assessment
  - Identifying and quantifying low saturations requires reliable data

Synergy Opportunities

- Algorithm for finding siliciclastic ROZs developed as part of this study has applications in mature/well developed basins including the Williston and Powder River Basins
- Findings from this study will advance knowledge and awareness of the thick Cypress Sandstone as an ncCO_2-EOR resource and should provide the framework for an eventual field demonstration
  - This study may demonstrate that the resource exists in other analogous formations in the Illinois Basin providing greater opportunities for resource development

Summary

- Cypress Sandstone is composed of multistory fluvial/estuarine sandstone bodies
  - High reservoir quality throughout the vertical succession of stacked sandstone bodies with implications for ROZ formation and nCO_2-EOR
  - Despite heterogeneity, the thick, clean nature of the sandstone lends itself to ROZ exploration by reducing uncertainty in analysis
- Well log analysis requires detailed characterization for absolute values of saturation
  - Areas with less robust datasets allow for analysis to indicate relative positive/negative indication of oil saturation

Summary

- Pattern model simulations allow selection of most promising ROZ development scenarios that can be scaled up for full-field simulation
- Multiple indications of Cypress ROZs
  - Noble Field - Tilted OWC and a paleo-OWC related calcite cement; well log analysis validated extent and saturation
  - Regional – Oil shows/oil saturation data with no production or attempted production that failed because of too much water
    - Well log analysis methods developed at Noble Field also predicts ROZs around the basin

Future Plans

- Continue integration of regional geologic characterization with regional well log analysis and results of field-scale reservoir simulation to develop regional resource estimate for economic nonconventional CO_2-EOR and storage in the Cypress Sandstone
  - Highlight ROZ prospects and quantify ROZ resource
- Conclude in-progress manuscripts and shift focus to final report

Acknowledgments

- Research herein was supported by US Department of Energy contract number DE-FE0024431
- Through a university grant program, IHS Petra, Geovariences Isatis, and Landmark Software were 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

Appendix: Benefit to DOE Program Goal and Area of Interest

- Goal: Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness
- FOA Area of Interest: 1A - Opportunities, Knowledge Advancements, and Technology Improvements for CO_2 Storage in Non-Conventional CO_2-EOR Targets – Residual Oil Zones (ROZs)

Appendix: Benefit to DOE Program Benefits Statement

- Field development guidelines for CO_2-EOR (e.g., well patterns, spacing, and orientations as well as CO_2 injection profiles) will be constructed to maximize economic oil recovery and CO_2 storage efficiency.
- It is projected that CO_2-EOR is an effective means of recovering additional oil from a formation that has historically low primary production and no waterflooding or EOR attempts. The formation is expected to have a high CO_2 storage (i.e. net utilization) compared to conventional CO_2-EOR.

Appendix: Program and Project Overview Goals

DOE Program

- Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness
- Develop and advance technologies to significantly improve the effectiveness and reduce the cost of implementing carbon storage
- Adapt and apply existing technologies that can be utilized in the next five years while developing innovative and advanced technologies that will be deployed in the next decade and beyond

ncCO_2-EOR TC ILB

- Identify and quantify nonconventional CO_2 storage and EOR opportunities in the thick Cypress Sandstone in the Illinois Basin
  - Economics/NCNO
  - Field development strategies
  - Near term deployment

Appendix: Program and Project Overview Objectives

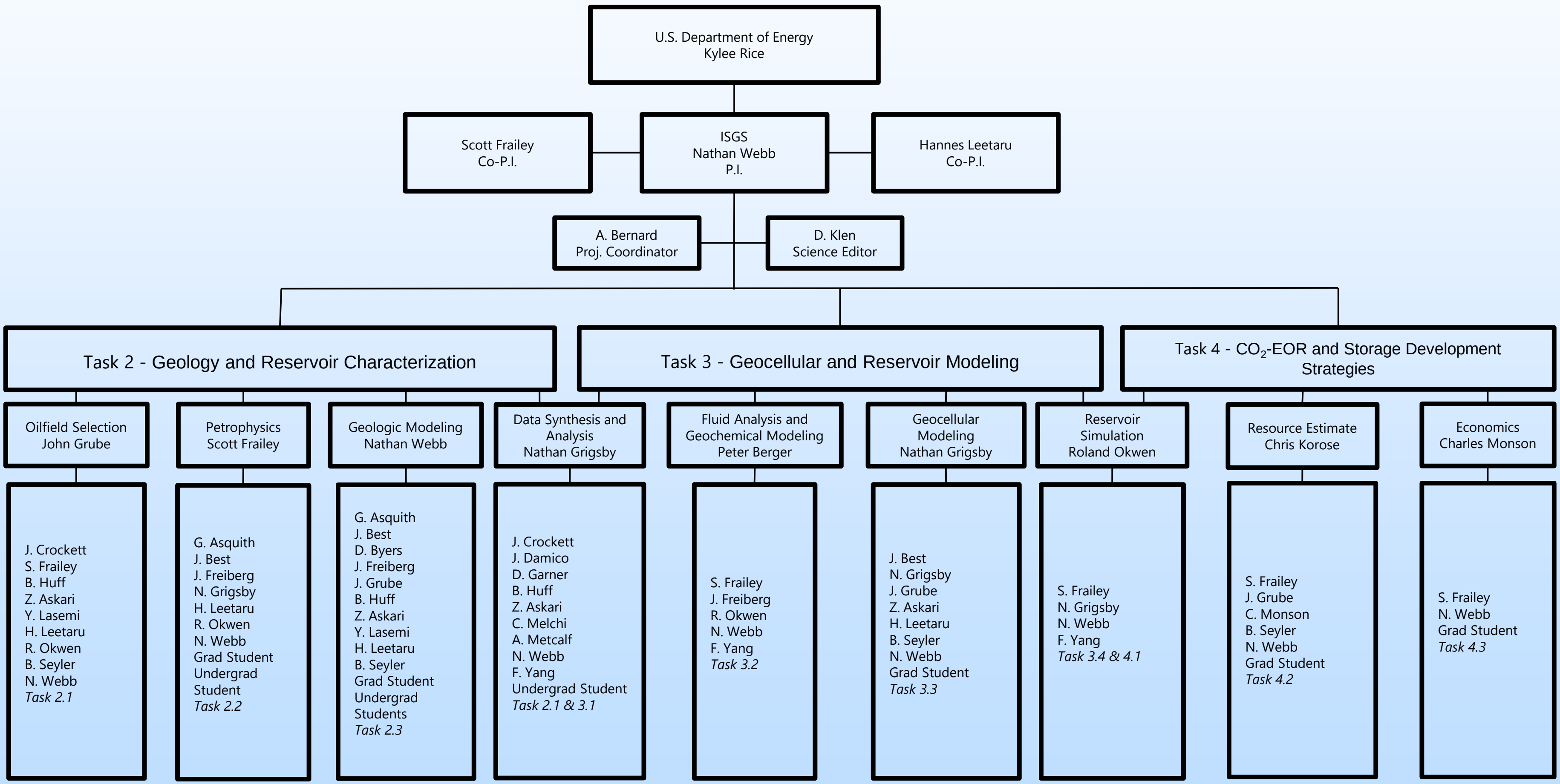
DOE Program

- Detailed characterization
- ROZ fairway locations; CO_2 storage and EOR resource
- Field and lab tests
- Development methods for increasing CO_2 storage and improving oil recovery

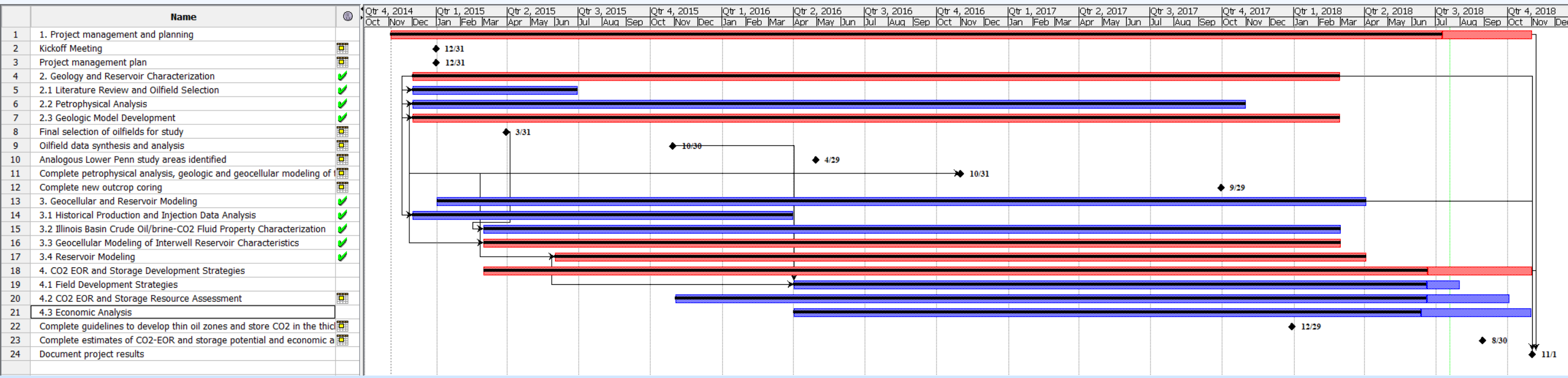
ncCO_2-EOR TC ILB

- Correlate oil production to geologic/reservoir properties
- Map CO_2 storage and EOR resource fairway (e.g. oil recovery)
- Obtain and analyze new core, logs, and fluid samples
- Develop screening and selection criteria; full field development strategies; economics and NCNO

Appendix: Organization Chart



Appendix: Gantt Chart



Appendix: Bibliography

- Publications:

  - Giannetta, L.G., Webb, N.D., Grigsby, N.P., Butler, S.K., *in review*, The Role of Clay Microporosity in Identifying ROZs in the Cypress Sandstone of the Illinois Basin
  - Grigsby, N.P, and S.M Frailey, *in prep*, Methodology for using well logs to identify residual oil zones: An example from Noble Field, Illinois.
  - Grigsby, N.P., and N.D. Webb, *in prep*, A method for developing the production history of Illinois Basin geologic formations.
  - Grigsby, N.P., and N.D. Webb, *in press*, Using detailed geologic characterization to construct a representative geocellular model of the thick Cypress Sandstone in Noble Oil Field, Illinois, for CO2-EOR and storage
  - Howell, K.J., *2017*, Sedimentology of Multistory Fluvial Sandstones of the Mississippian Cypress Formation, Illinois, USA. MS Thesis
  - Webb, N.D. and Grigsby, N.P., *in press*, Geologic Characterization of Noble Oil Field, Western Richland County, Illinois
  - Webb, N.D., and N.P. Grigsby, *in prep*, Geologic characterization of the Cypress Sandstone in the Kenner West Oil Field, Western Richland County, Illinois, for nonconventional CO_2-enhanced oil recovery and storage

Appendix: Bibliography

- Abstracts and Presentations:

  - Arneson, J.J., Grigsby, N.P., Frailey, S.M., and Webb, N.D., 2016, Using petrophysics to determine the presence of residual oil zones in the thick IVF Cypress Sandstone at Noble Field, southeastern Illinois: NCGSA 2016, 50th Annual Meeting, Urbana-Champaign, IL, USA.
  - Daum, J.M., Howell, K.J., and Webb, N.D., 2016, Petrography of the Chesterian (Upper Mississippian) Cypress Sandstone in the Illinois Basin: NCGSA 2016, 50th Annual Meeting, Urbana-Champaign, USA.
  - Giannetta, L.G., Butler, S.K., and Webb, N.D., 2016, Identification of clay microporosity in the reservoir characterization of the Cypress Sandstone: Implications for petrophysical analysis, reservoir quality, and depositional environment: NCGSA 2016, 50th Annual Meeting, Urbana-Champaign, IL, USA.
  - Grigsby, N.P., 2016, Leveraging spontaneous potential and neutron density porosity logs to construct a geocellular model: an example from the thick Cypress Sandstone at Noble Field, Illinois: NCGSA 2016, 50th Annual Meeting, Urbana-Champaign, IL, USA.
  - Webb, N.D., 2016, The Mississippian thick Cypress Sandstone: A nonconventional CO2-EOR target in the Illinois Basin: AAPG Annual Convention and Exhibition, Calgary, Alberta, Canada. *Awarded Best Poster
  - Webb, N.D., and Grigsby, N.P., 2016, Reservoir characterization of the thick IVF Cypress Sandstone in Noble Field, Illinois, for nonconventional CO2 –EOR: NCGSA 2016, 50th Annual Meeting, Urbana-Champaign, IL, USA.

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  - Giannetta, L.G., Webb, N.D., Butler, S.K., and Grigsby, N.P., 2016, Using clay microporosity to improve formation evaluation in potential ROZs: Cypress Sandstone, Illinois Basin: ESAAPG Annual Meeting, Lexington, KY, USA
  - Askari, Z., Lasemi, Y., and Webb, N.D., 2016, Cypress Sandstone reservoir characterization across the Clay City Anticline, Richland and Clay Counties, Illinois: ESAAPG Annual Meeting, Lexington, KY, USA
  - Webb, N.D., Grigsby, N.P., Arneson, J.J., Giannetta, L.G., and Frailey, S.M., 2016 An integrated approach to identifying residual oil zones in the Cypress Sandstone in the Illinois Basin for nonconventional CO2-EOR and storage: ESAAPG Annual Meeting, Lexington, KY, USA
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  - Webb, N.D., 2017, Improved oil recovery in the Cypress using an unconventional approach: Illinois Oil and Gas Association Annual Meeting, Evansville, IN, USA