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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Illinois State Geological Survey

U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology, Innovation and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

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Presentation Outline

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

Background: Thick Cypress Ss

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

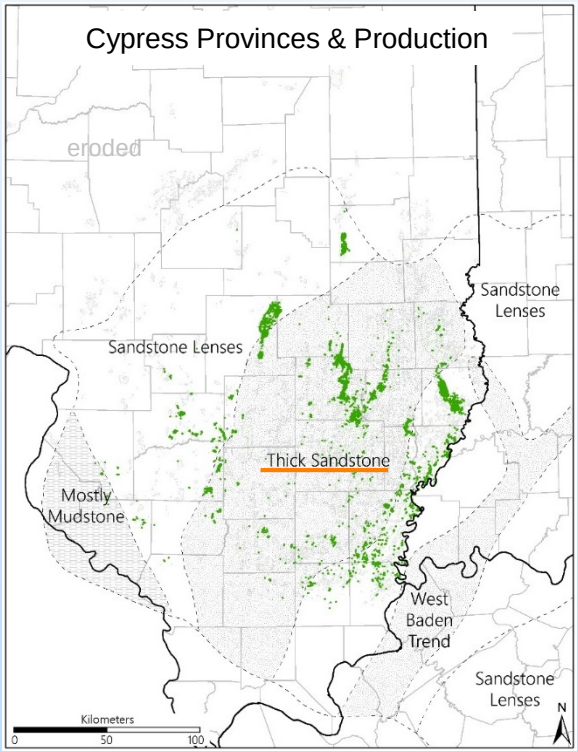
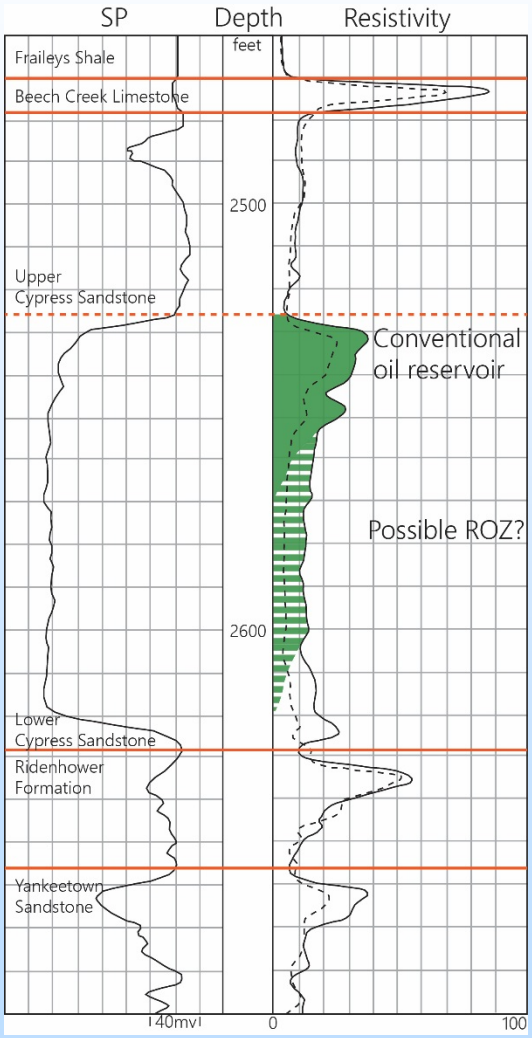
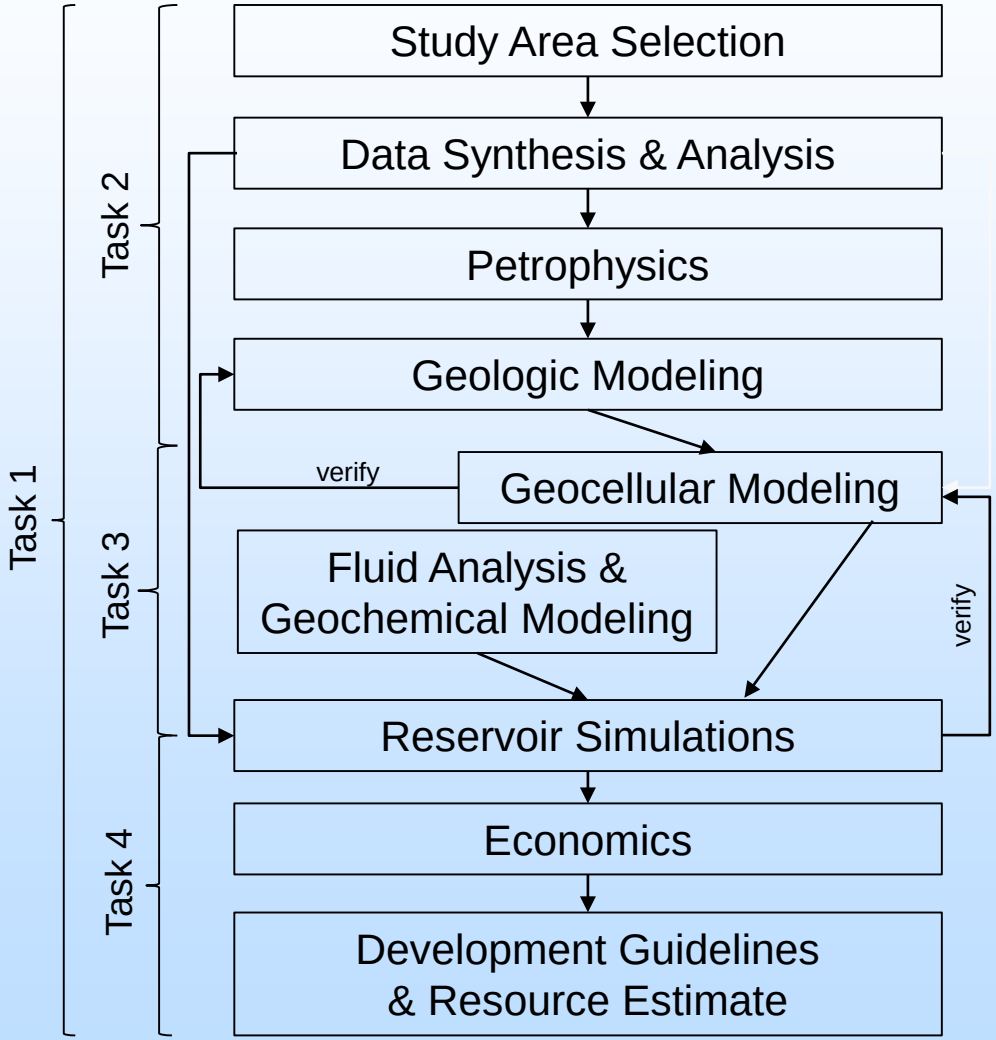


Figure modified from Nelson et al. 2002

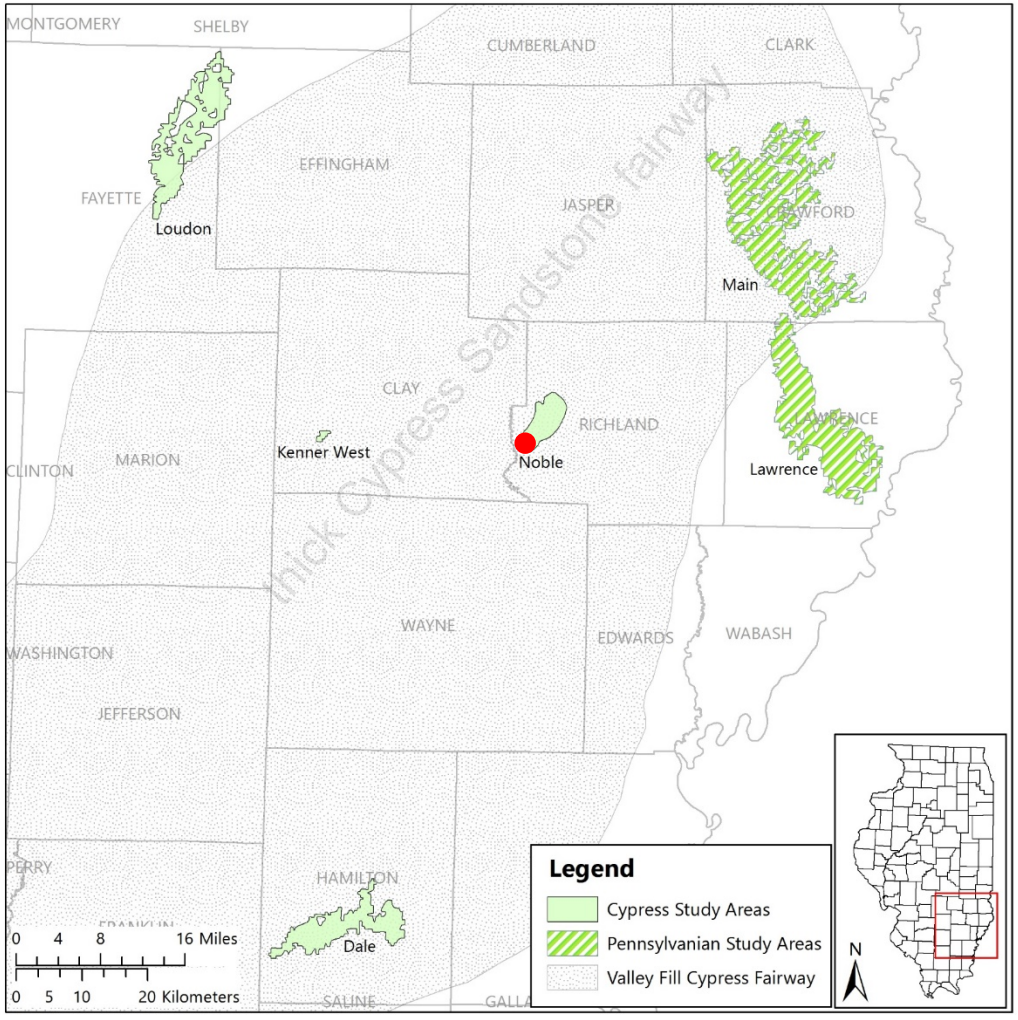
- Thin Oil Zones in Thick Sandstones
  - Residual and mobile oil above brine
  - Fining upward (grain size) sequence / increasing permeability with depth
  - Difficult to produce economically due to water coning and management
- Nonconventional CO_2-EOR
  - Potential ROZ
  - High net CO_2 utilization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



Methodology



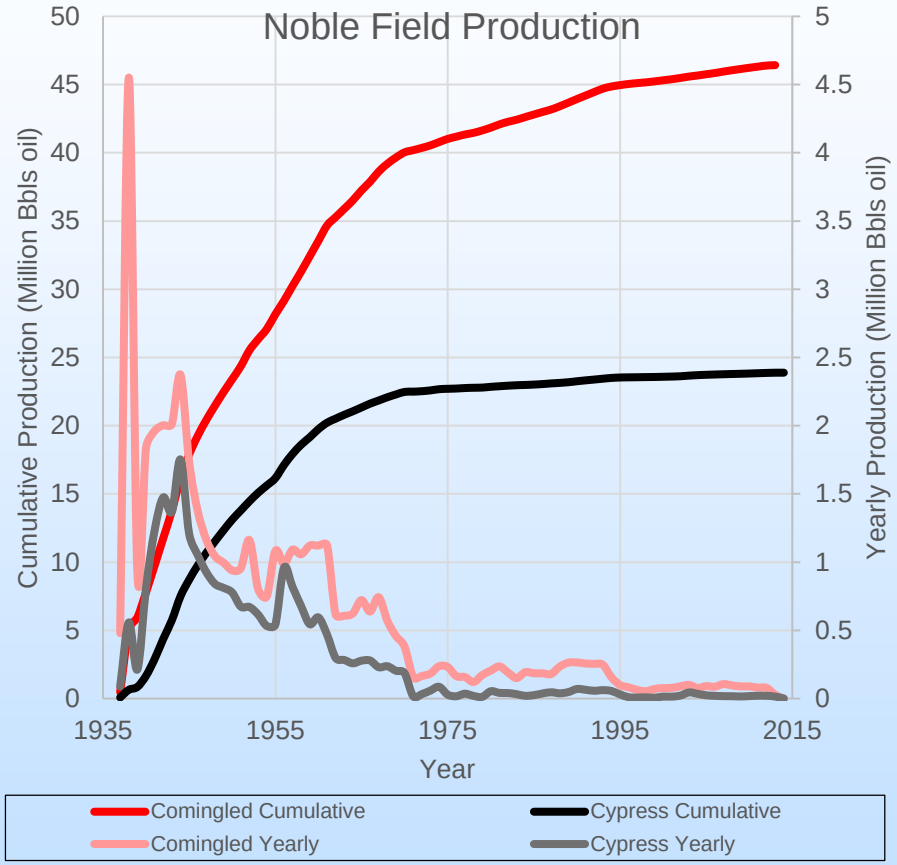
Study Area Selection

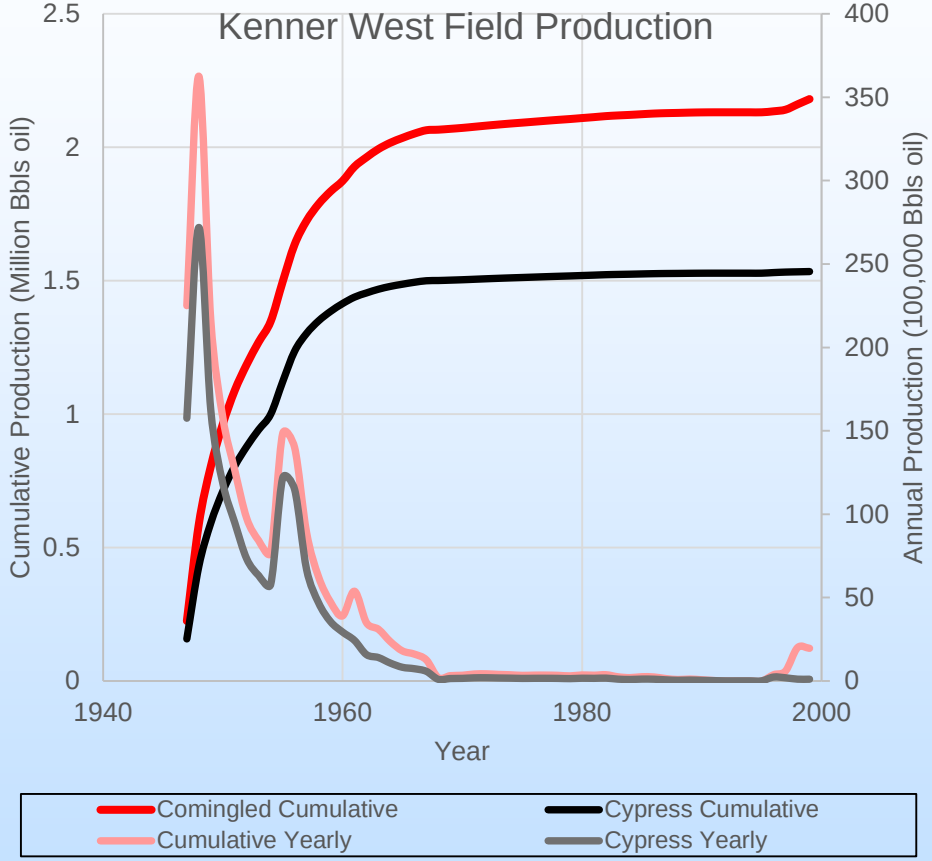


Oil fields (green) being studied and planned core locations (red dots) within the thick Cypress Sandstone fairway

- Selected four Cypress and two Pennsylvanian oilfields for detailed study
  - Cypress: Noble, Kenner West, Loudon, Dale
  - Pennsylvanian: Main, Lawrence
- Assessed type and quality of data in each field

Data Synthesis and Analysis

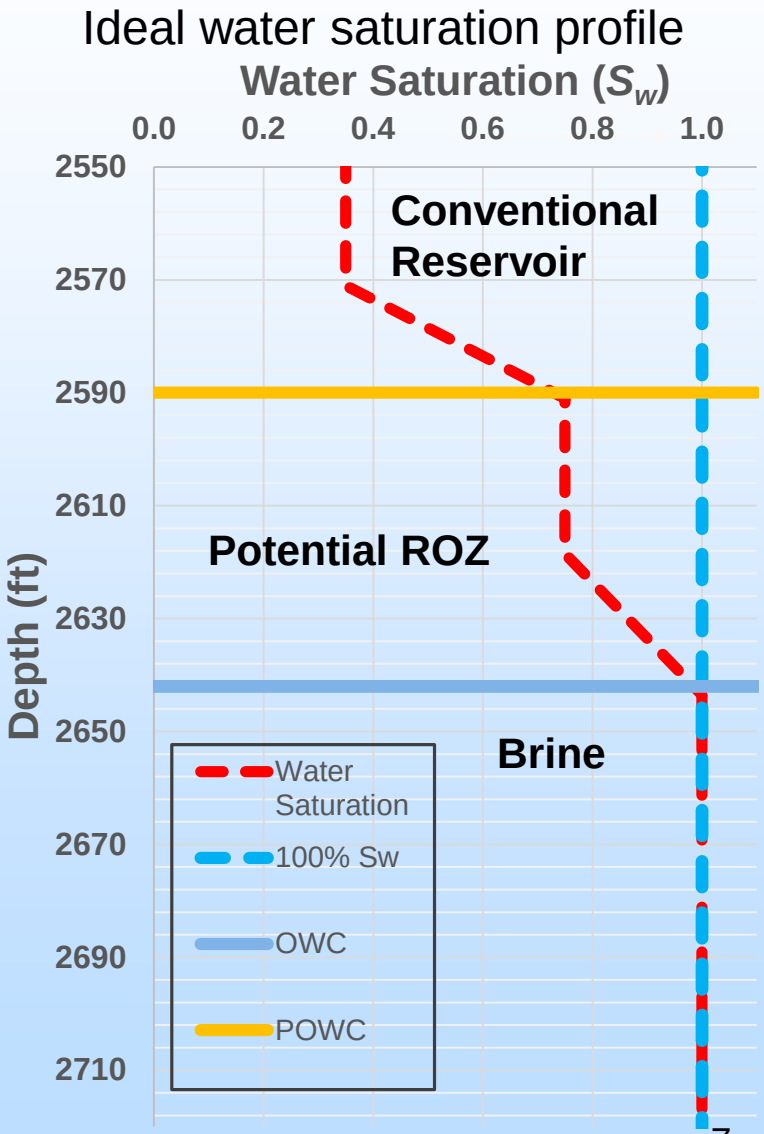




- Analyzed data from each oilfield study area
  - Focused on Noble and Kenner West Fields for modeling and simulation
  - Primary/secondary oil recovery efficiency 15 to 25%

Petrophysics

- Calculated water saturation (S_w) profiles from logs using three methods:
  - Archie (Resistivity + Porosity logs)
  - Ratio (Resistivity logs only)
  - Dual water (Resistivity + Porosity logs + core analysis data)
    - Removes the influence of dispersed clay that produces anomalously high S_w values
- Collected pulsed neutron logs in existing wells in Noble Field to compare with log analysis methods



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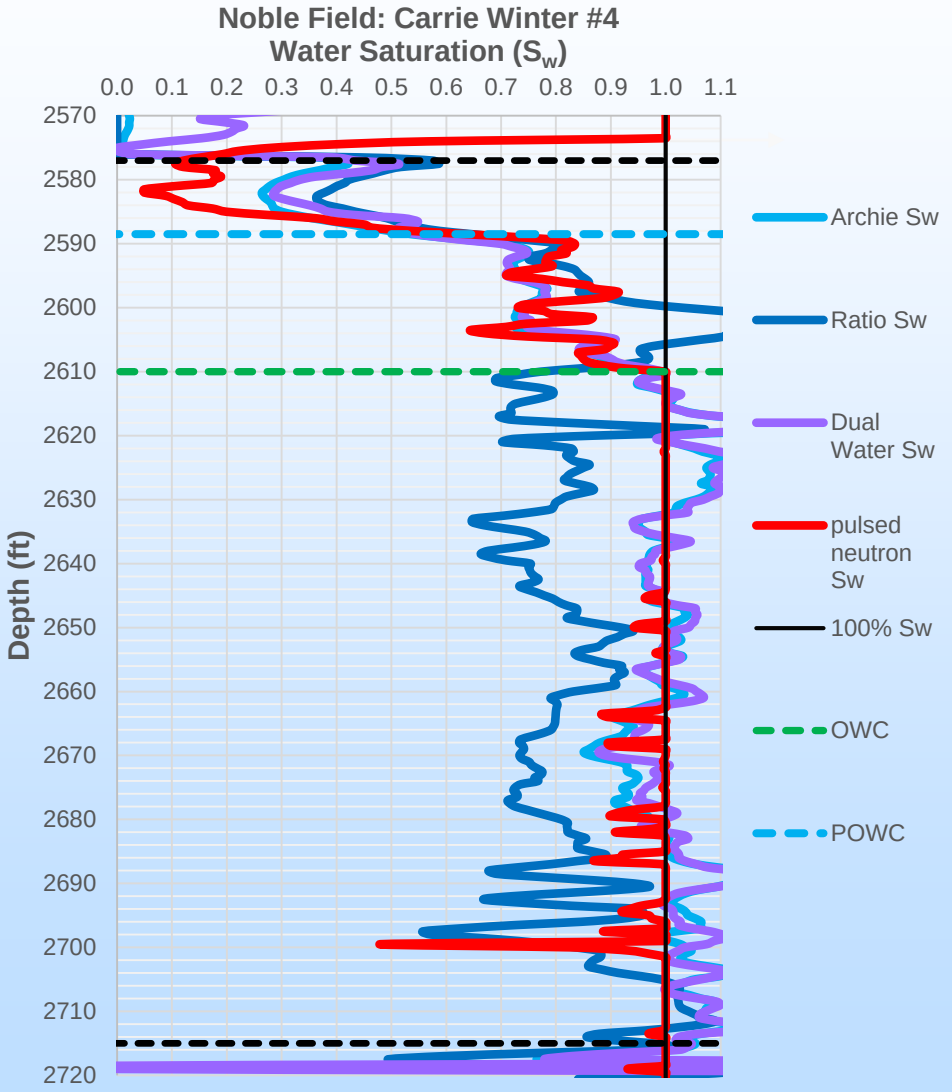
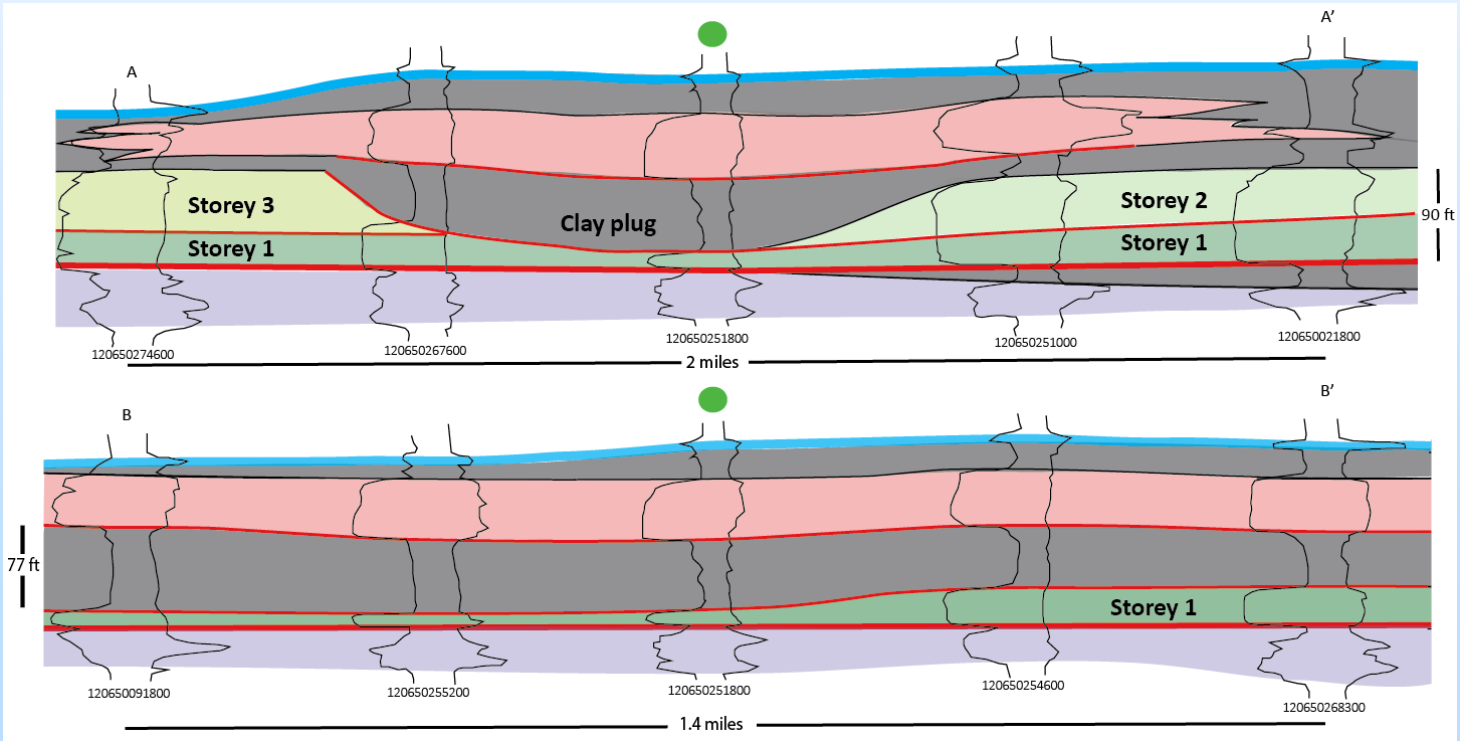


Geological Modeling

- Expanded from field-scale studies to regional research and mapping
  - Assessed heterogeneity across scales
- Collected two new Cypress cores
  - One near outcrop - geology
  - One in Noble Field – geology and oil saturation
- Conducted outcrop study to better understand architecture of facies observed in core

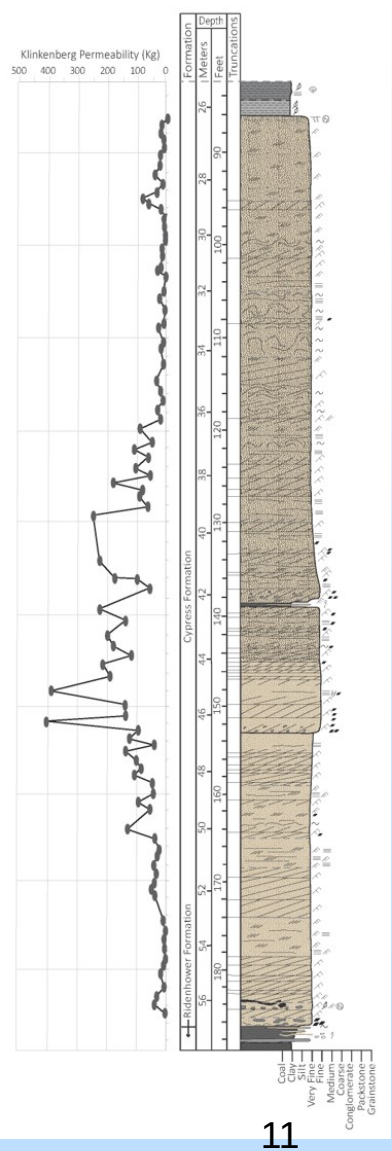
Geological Modeling

- Defined architectural elements of the Cypress Sandstone that contribute to reservoir heterogeneity
  - Arcuate sandstone active channel fills
  - Abandoned channel clay plugs
  - Sheet-like sandstone bodies



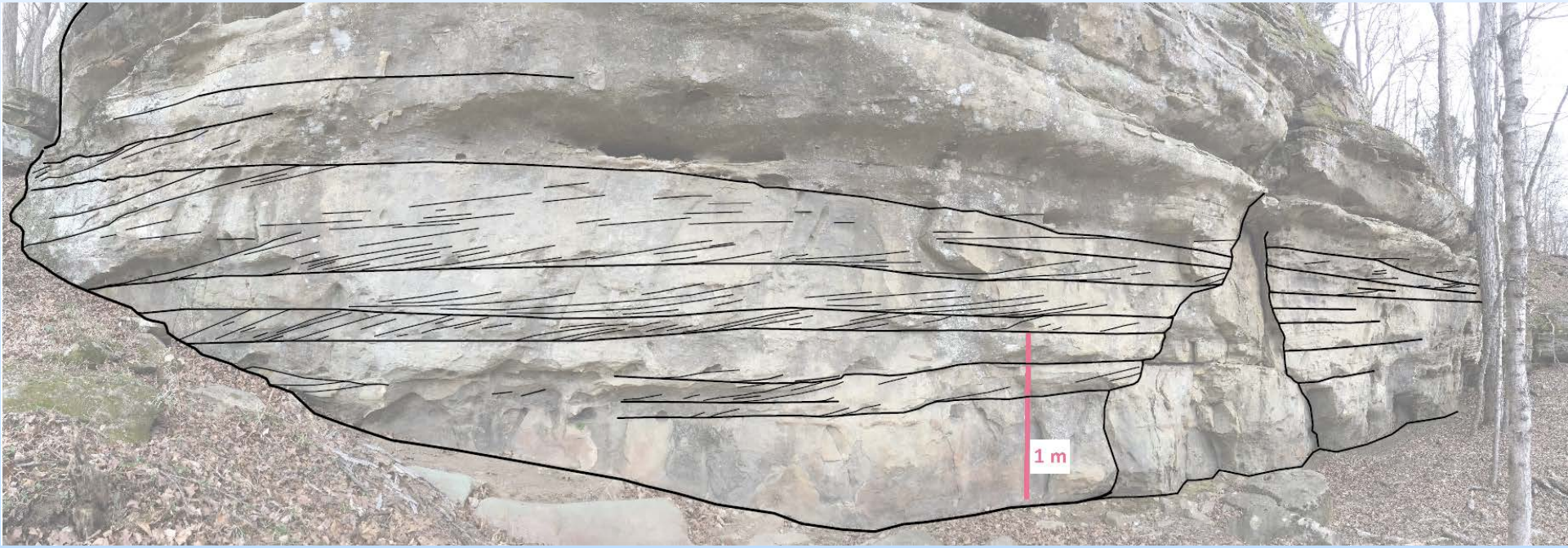
Geological Modeling

- Related architecture and facies scale features to reservoir heterogeneity
  - Mean x-set thickness = 0.29 m
  - Evidence for point bars 16-20 m thick
    - Subtle basal lags, abrupt grain size increase
    - Dominantly fine grained; fining up
    - Decrease in bedform size upwards
- Correlating textural properties of the sandstone (in this case, grain size) to permeability
  - Demonstrates the link between genetic geologic units and reservoir properties.



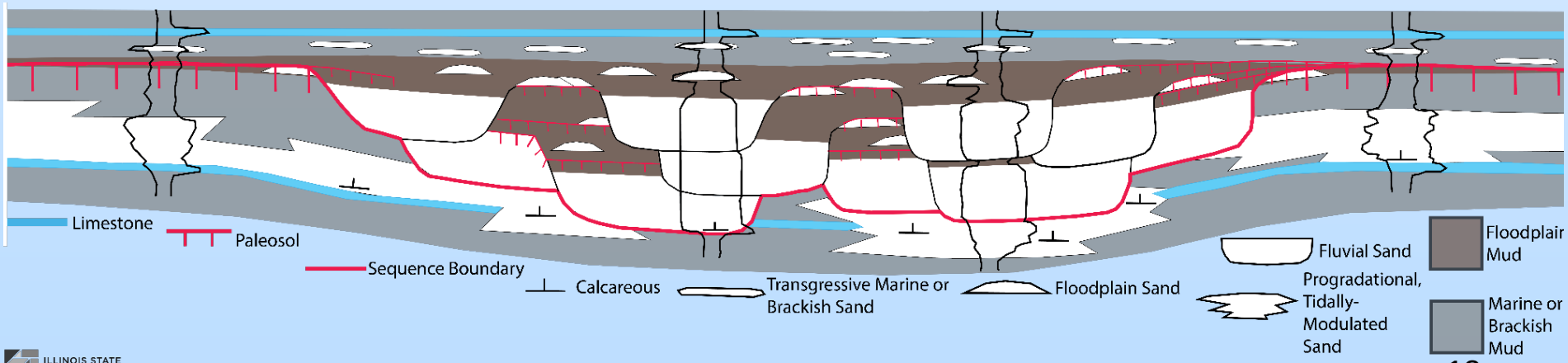
Geological Modeling

- Confirmed the scale of features observed in core through outcrop study
  - Small cross-sets: mean thickness = 0.27 m
  - Low angle cross-sets common: angle of ~15° or less
- Gained a better understanding of lateral and vertical change that can be expected in the subsurface through outcrop study



Geological Modeling

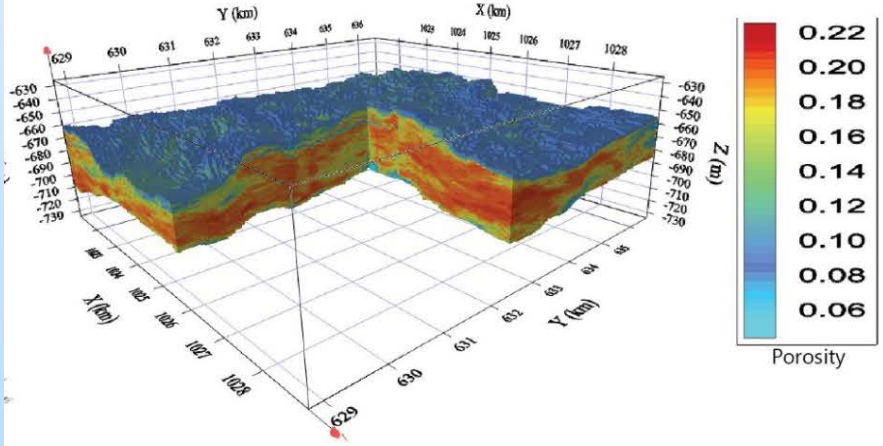
- Developed a conceptual geologic model of the Cypress Sandstone
  - Multistorey sandstones within a ~ 25 km wide fluvial belt
  - High lateral continuity near the base of the formation (sheet sandstones); decreases upward (isolated arcuate sandstones)
  - Reservoir quality remains high throughout the vertical succession where sandstone elements are stacked
    - Relatively few widespread baffles within genetic units
    - High permeability conduit for hydrodynamically controlled ROZ formation



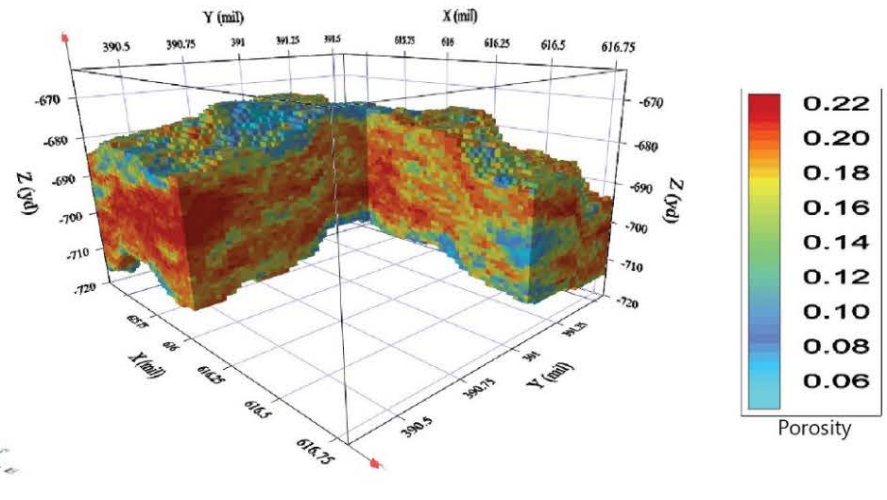
Geocellular Modeling

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

Noble Porosity Model

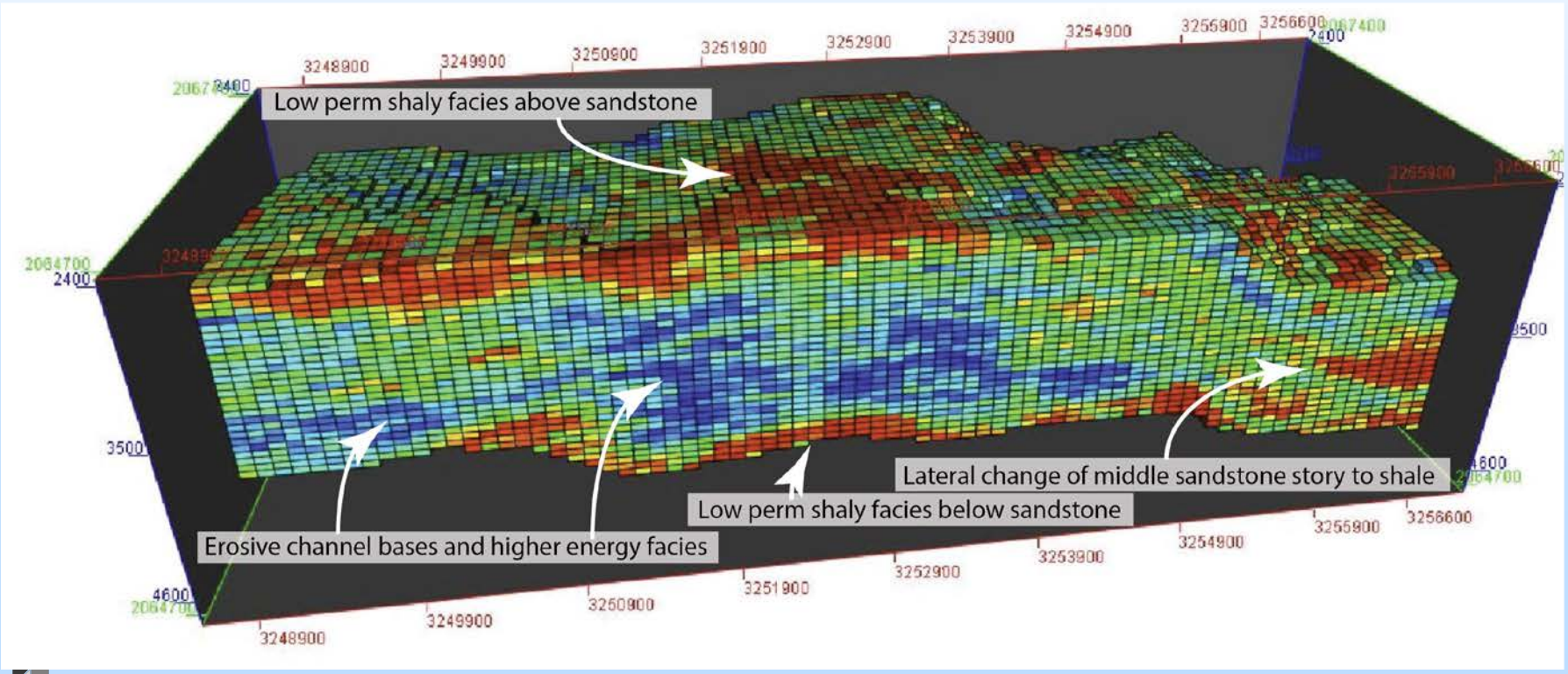


Kenner West Porosity Model



Geocellular Modeling

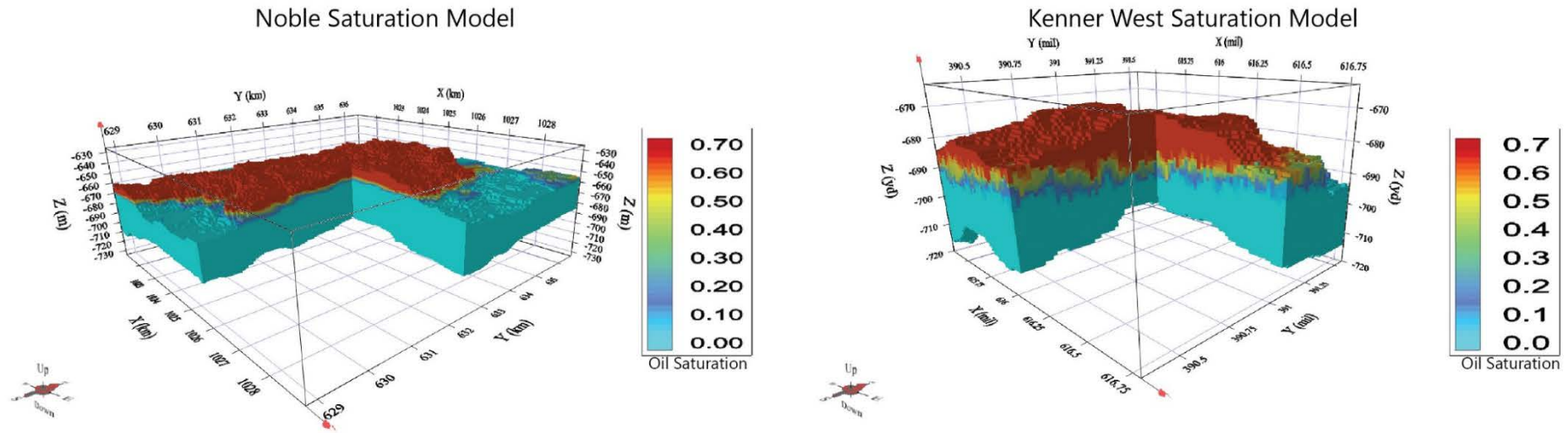
- Ensured models incorporated observed geologic heterogeneity across scales
  - Sandstone/shale facies relationships
  - Permeability variations within stacked sandstones



Geocellular Modeling

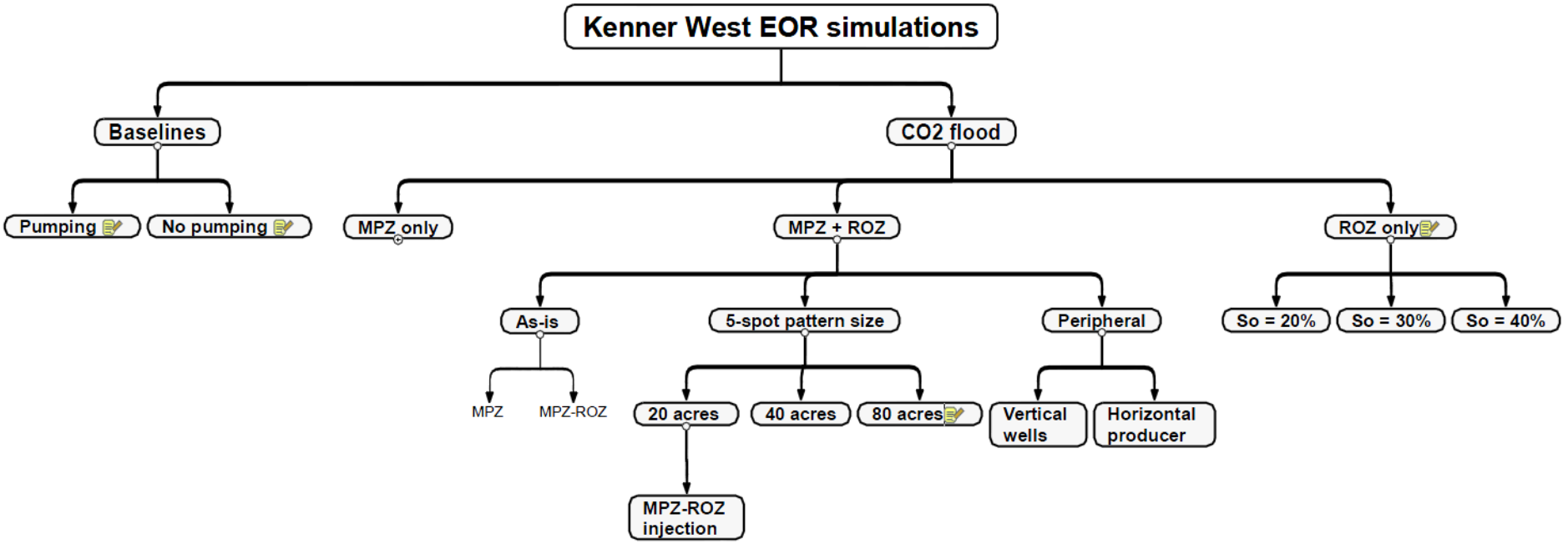
- Developed water saturation models for use as initial conditions in reservoir simulations based on well log analysis

	Noble	Kenner West
Area (acres)	15,280	1,150
MPZ OOIP (MMBO)	108	11
ROZ OOIP (MMBO)	80	19



Reservoir Simulation

- Simulated field development strategies in the Kenner West Field including different well patterns, spacings (including a horizontal well), and conformance scenarios



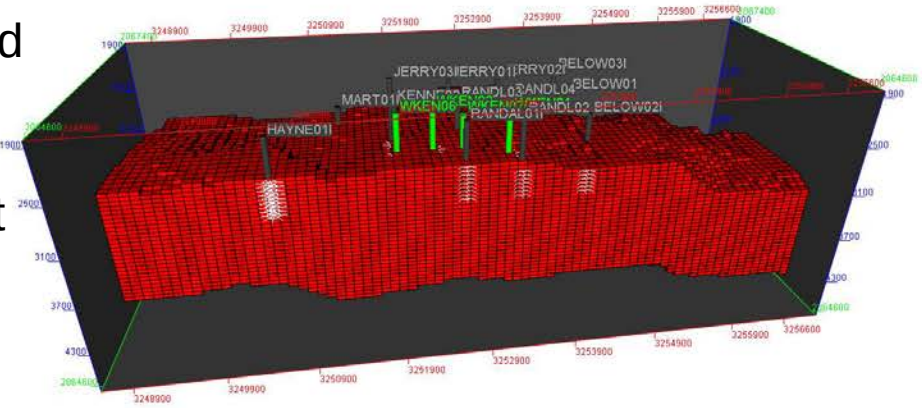
Reservoir Simulation

Time 1: Before EOR Starts

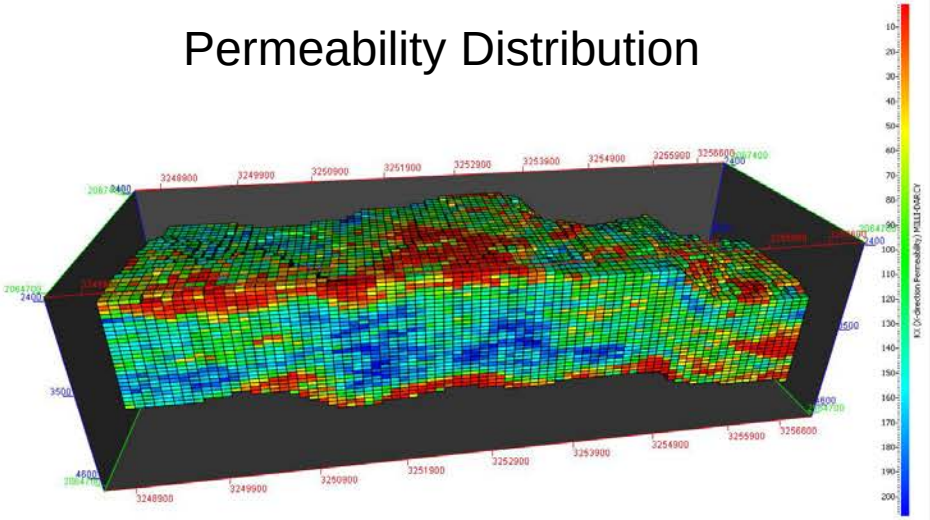
After Primary/waterflood

Water coning/inefficient recovery of MPZ

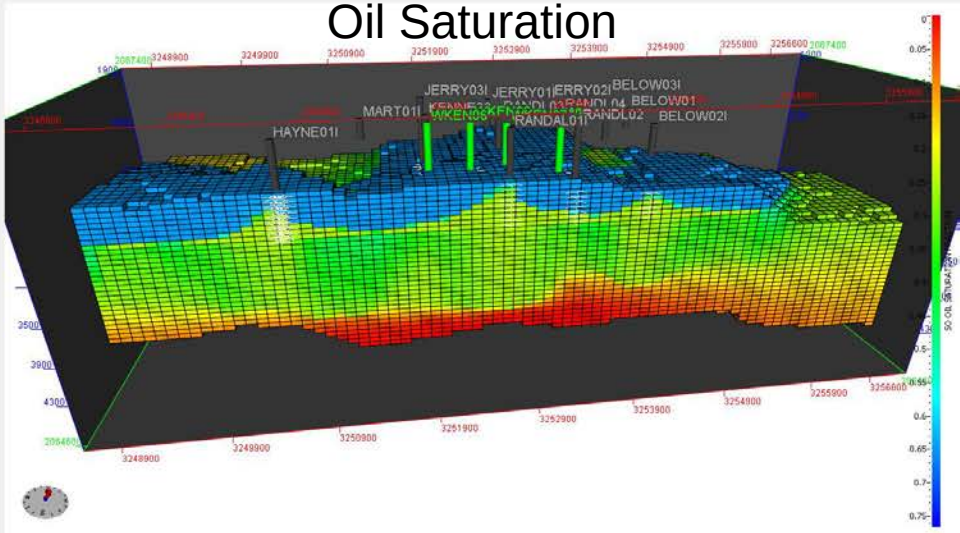
CO_2 Saturation



Permeability Distribution



Oil Saturation

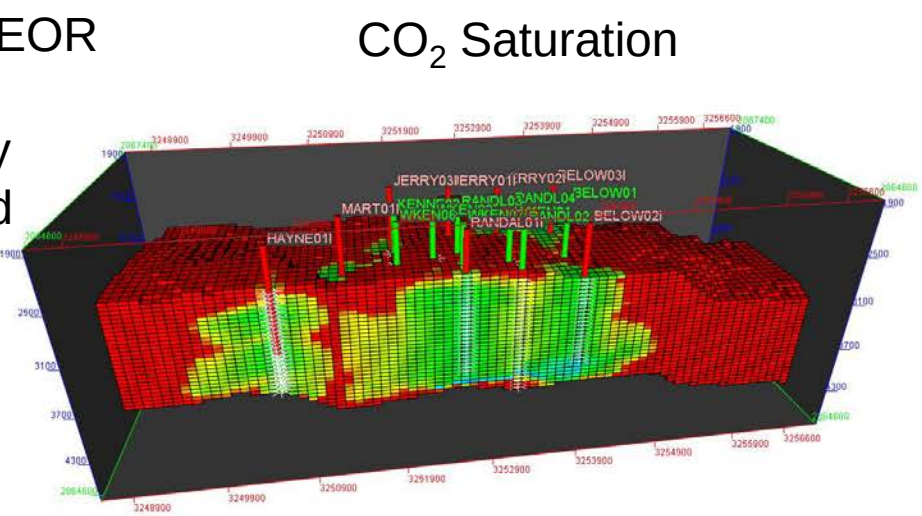


Reservoir Simulation

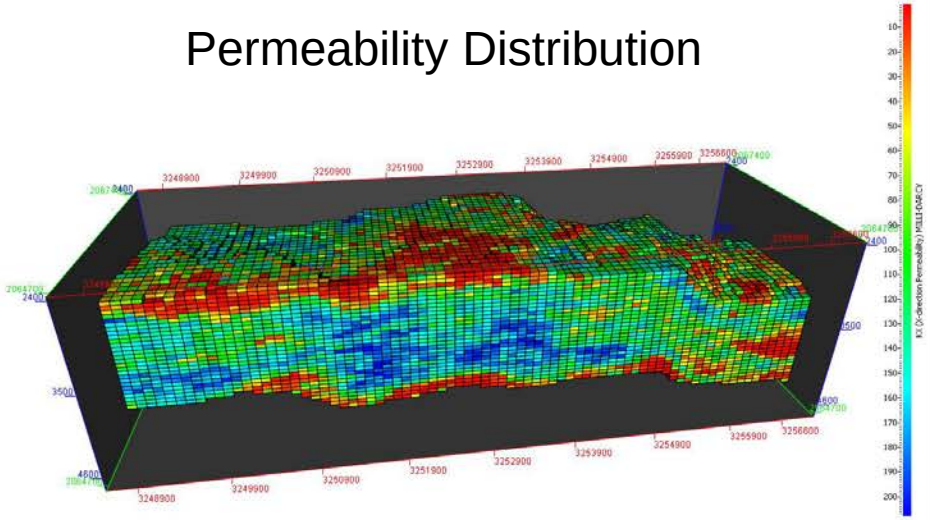
Time 2: A few years of EOR

Buoyancy and solubility of CO_2 sweep ROZ and MPZ

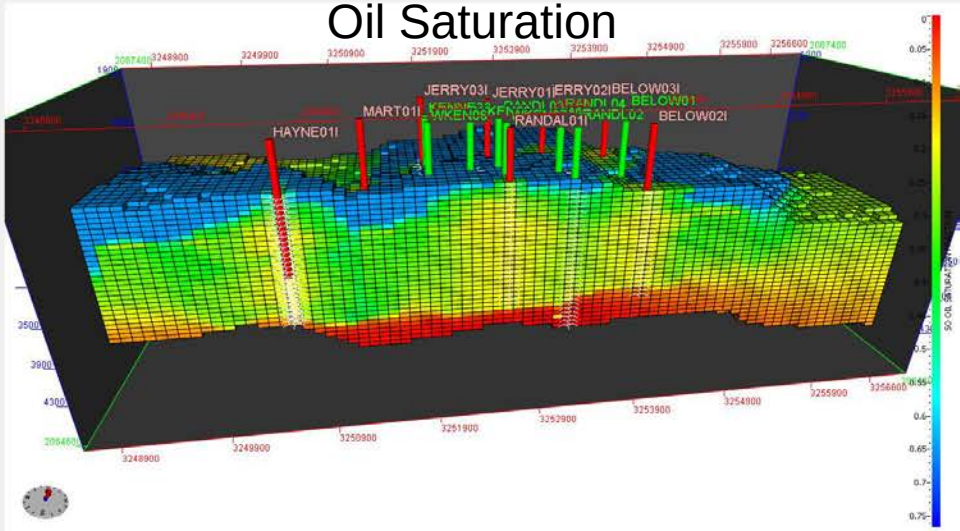
CO_2 Saturation



Permeability Distribution



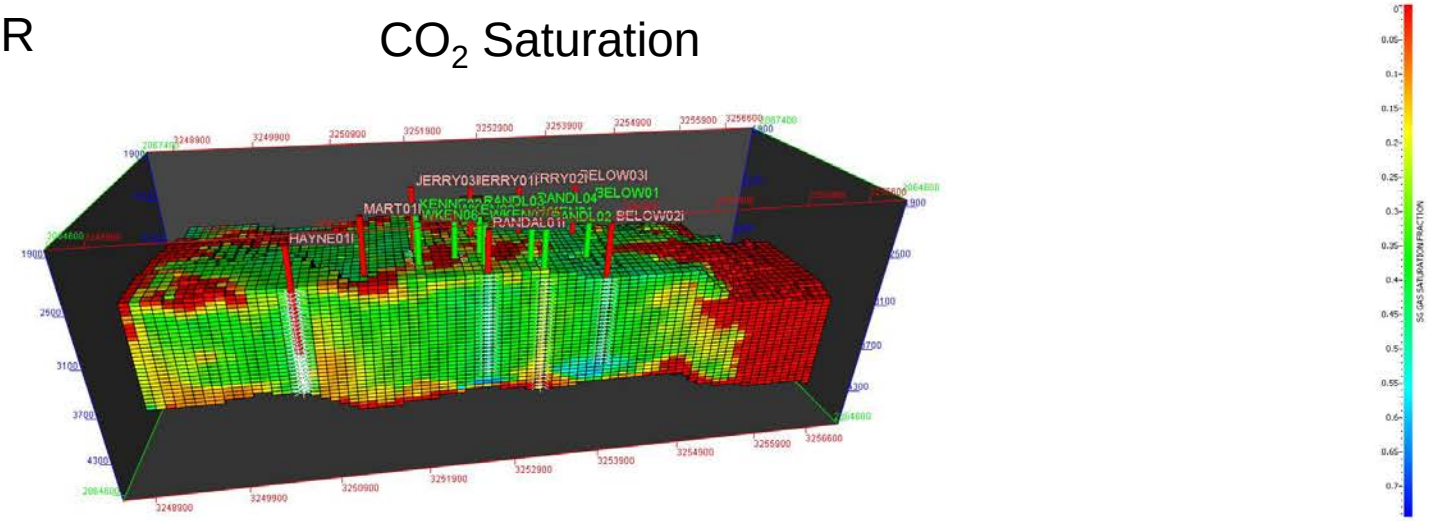
Oil Saturation



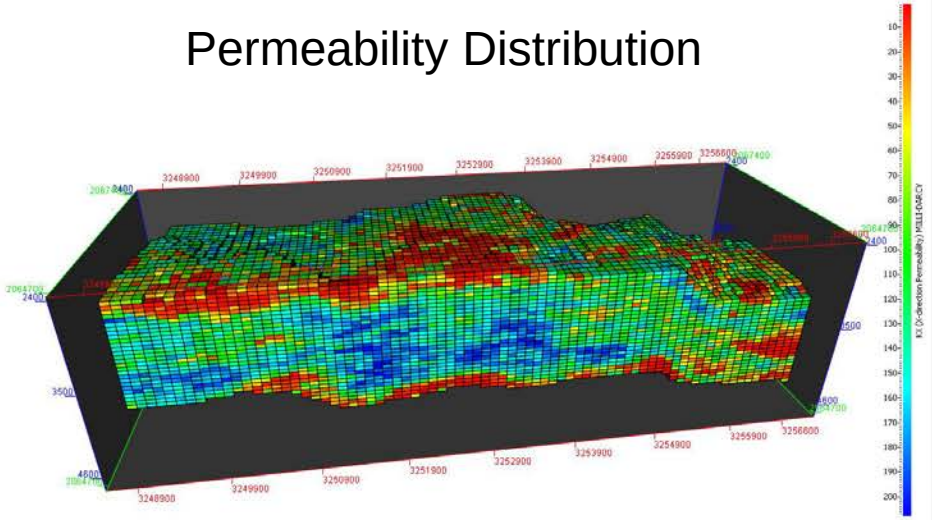
Reservoir Simulation

Time 2: 8 Years of EOR

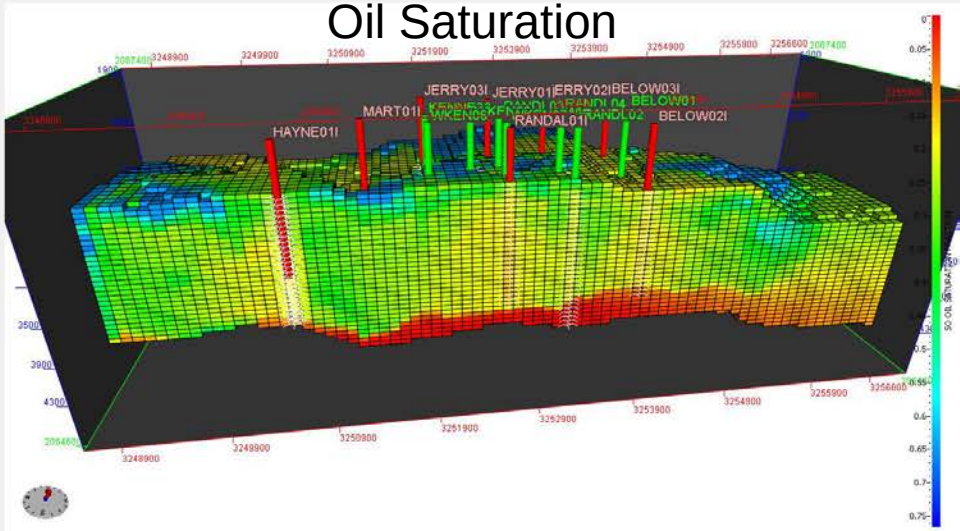
CO_2 Saturation



Permeability Distribution

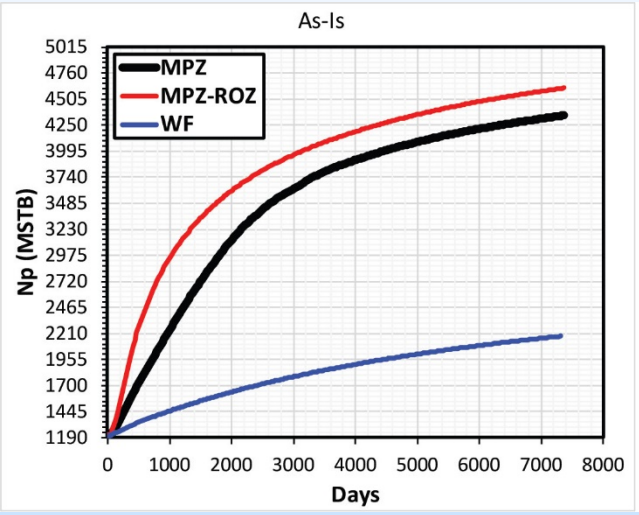


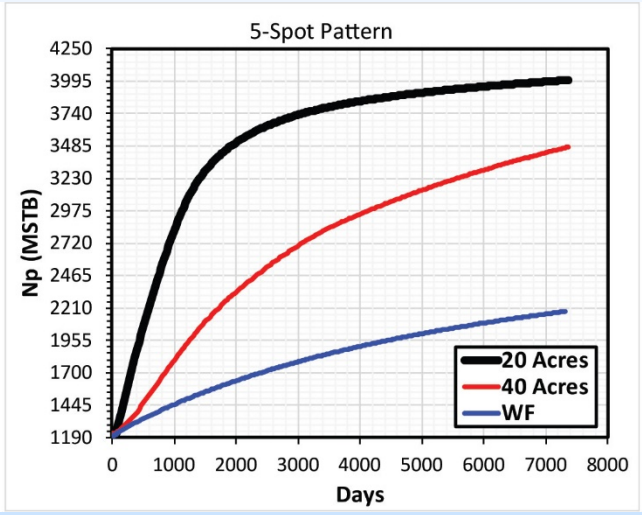
Oil Saturation

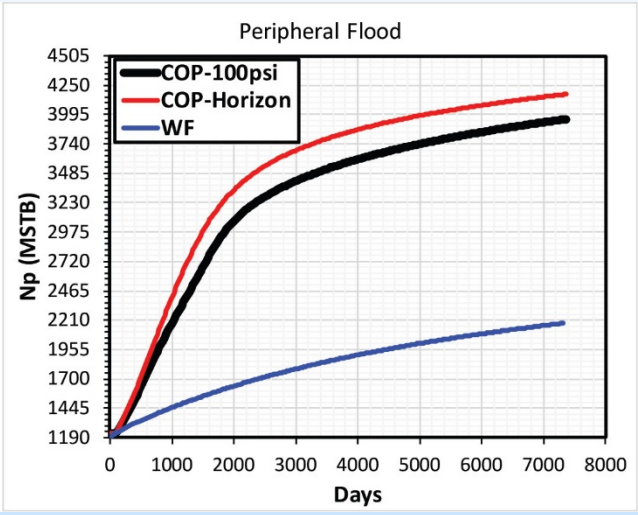


Reservoir Simulation

- Preliminary results show improvement in oil production with CO_2-EOR of MPZ + ROZ



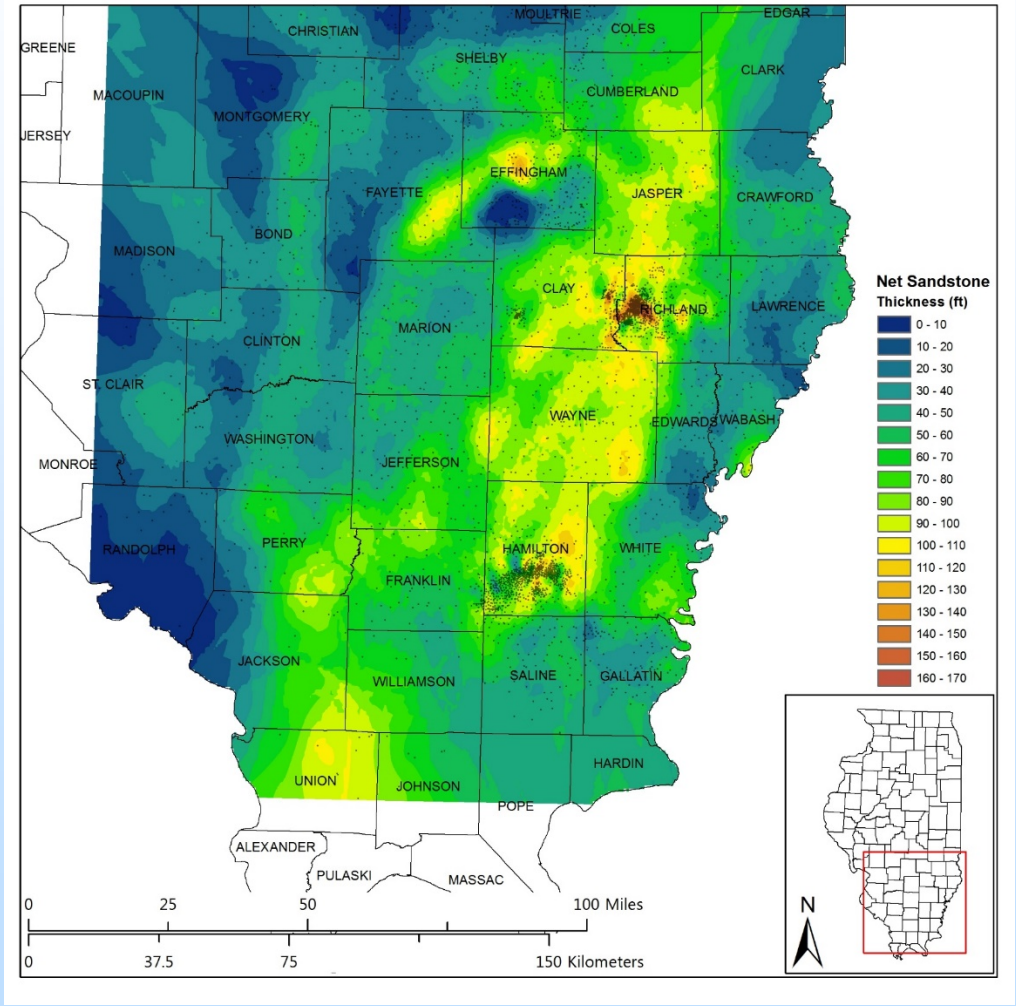




- Next Steps:
  - Run analogous simulations in the larger Noble Field model
  - Normalize all results to OOIP, economics, and CO_2 storage/efficiency so they can be directly compared
    - Allows recommendations for field development strategies

Economics and Resource Estimate

- Reviewed parameters for economic analysis
- Correlated 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



Lessons Learned

- Geocellular models and well log methods to define fluid saturations require a robust geologic interpretation and core for calibration
  - Multiple scales of heterogeneity within the sandstone must be represented in models to ensure representative simulations
  - Expected low residual oil saturations makes understanding of clays within the sandstone critical for accurate petrophysical analysis results
- Obtaining core samples from the ROZ has been more difficult than anticipated
  - Designing core flood experiments to simulate ROZ formation in Cypress Sandstone core plugs
    - Allows improved accuracy of well log analysis because residual oil saturation and resistivity can be directly measured

Synergy Opportunities

- After algorithm for finding ROZs in mature/well developed basins is validated as part of this study, we look forward to comparing the results with findings from 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
  - Geocellular models reflect the observed heterogeneity
- Reservoir simulations have been history matched and are running hypothetical scenarios
- Multiple indications of an ROZ within the Cypress
  - Tilted OWC and a paleo-OWC related calcite cement are a key indicators of possible ROZ in Noble Field
  - Petrophysical analysis indicates possible ROZs in Noble and Kenner West Fields
    - Results from new core could confirm

Future Plans

- Analyze new cores and cased hole logs to better tie geologic properties to petrophysical characteristics and make analysis of fluid saturations more robust
  - Determine if new core from Noble Field confirms an ROZ
- Integrate regional geologic characterization with regional well log analysis to develop regional resource estimate for nonconventional CO_2-EOR in the Cypress Sandstone
  - Apply lessons learned from reservoir simulation to better understand economic feasibility in the Illinois Basin
- Relate detailed characterization results to regional scale geology to better understand the Cypress Sandstone petroleum system
  - Propose conceptual framework for ROZ formation within the Cypress

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 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

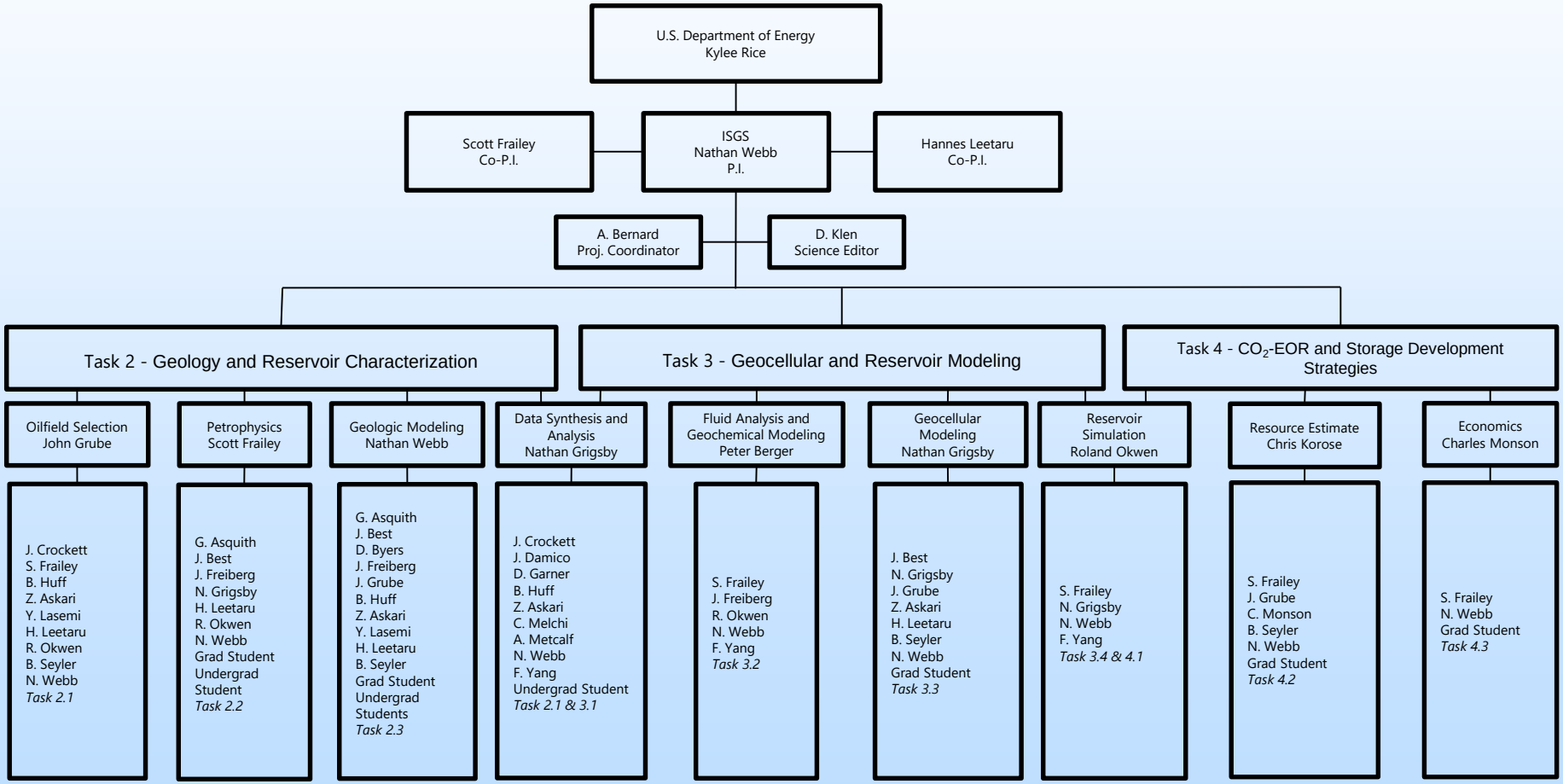
DOE Program

- 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

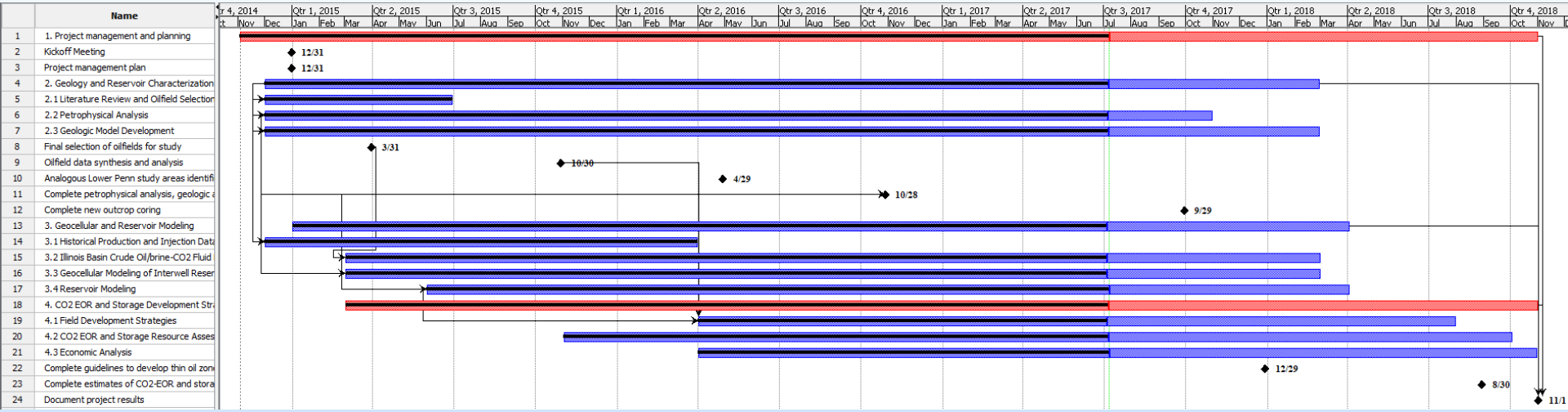
$ncCO_2$-EOR TC ILB

- 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 internal 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 prep*, 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 internal review*, 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.
  - 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
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