A Nonconventional CO$_2$-EOR Target in the Illinois Basin: Oil Reservoirs of the Thick Cypress Sandstone

Project Number DE-FE0024431

Nathan Webb, Scott Frailey, and Hannes Leetaru

Illinois State Geological Survey

Presentation Outline

- Benefit to DOE Program

- Program and Project Overview

- Methodology

- Accomplishments to Date

- Summary

- Acknowledgements

- Appendices

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)

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.

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

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

Methodology
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
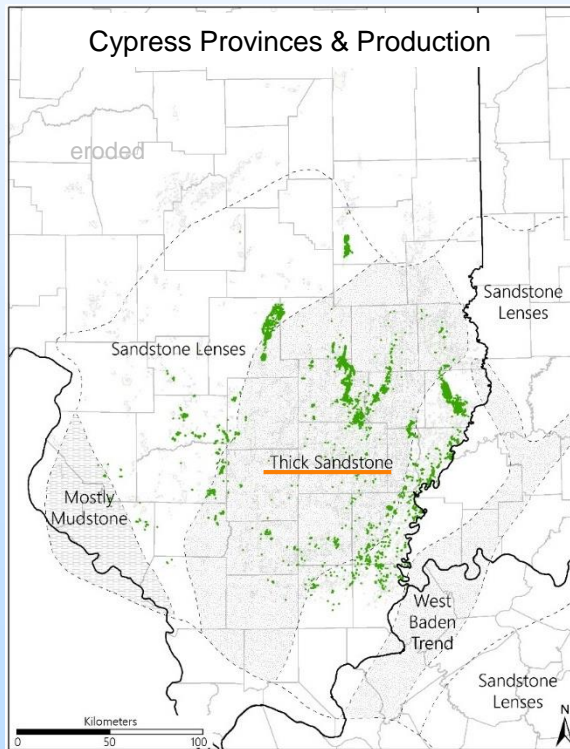

Cypress Provinces & Production

Figure modified from Nelson et al. 2002

Cypress Stratigraphic Model

Sequence Boundary
Transgressive Surface
Maximum Flooding Surface

thick sandstone fairway
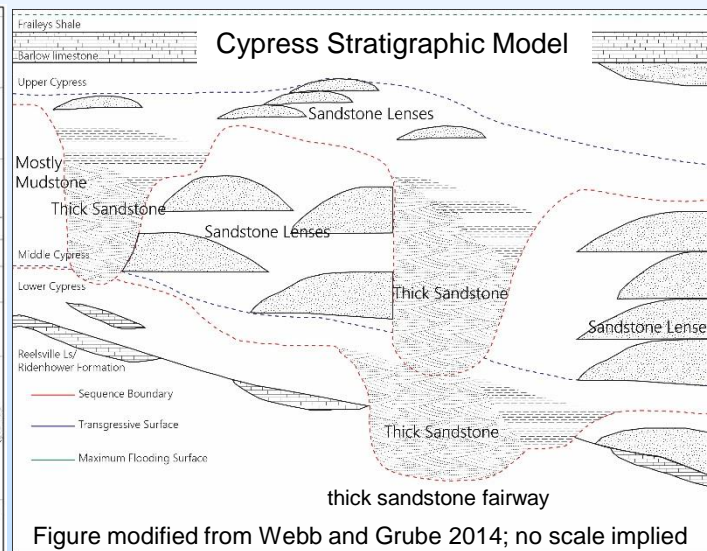
Figure modified from Webb and Grube 2014; no scale implied

Thick Cypress Sandstone consists of incised valley deposits

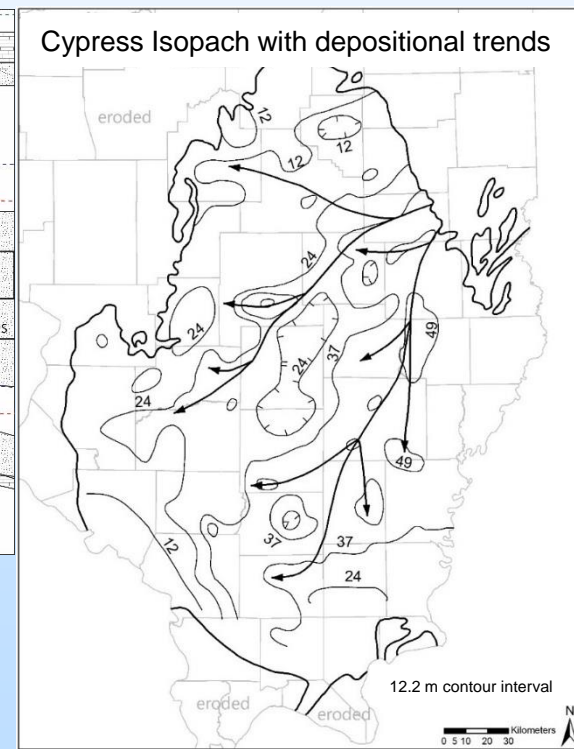Cypress Isopach with depositional trends

12.2 m contour interval

Figure modified from Seyler et al. 2000

Methodology
Background: Thick Cypress Ss

- 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)
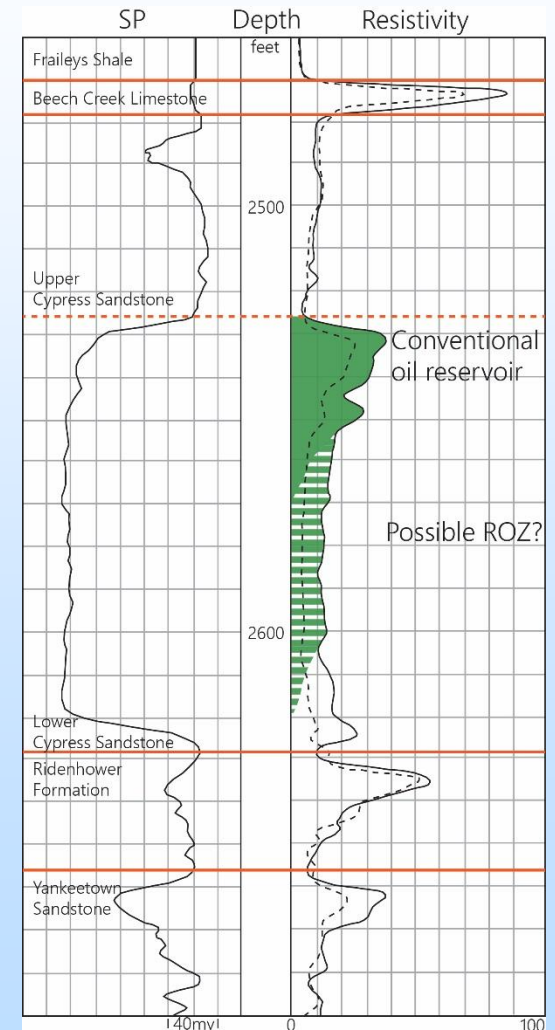
Methodology
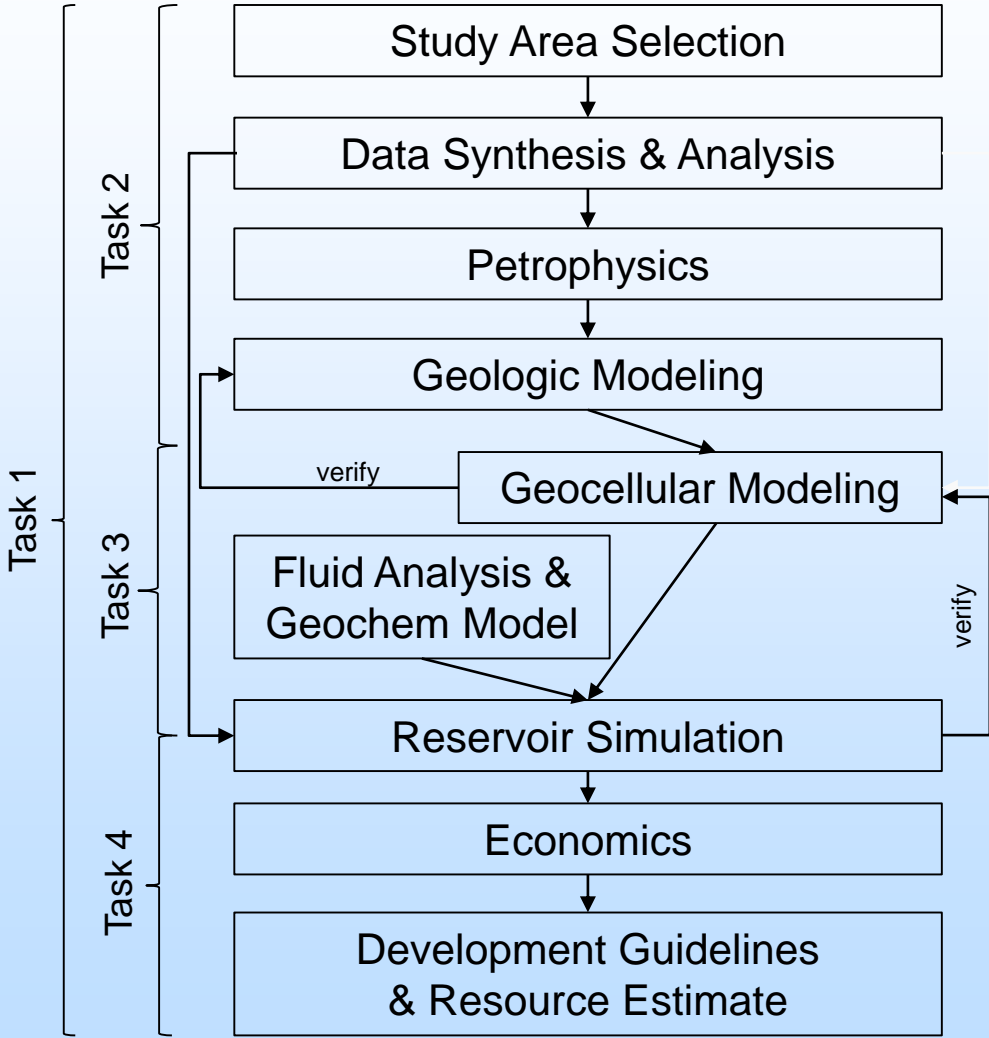
Study Area Selection
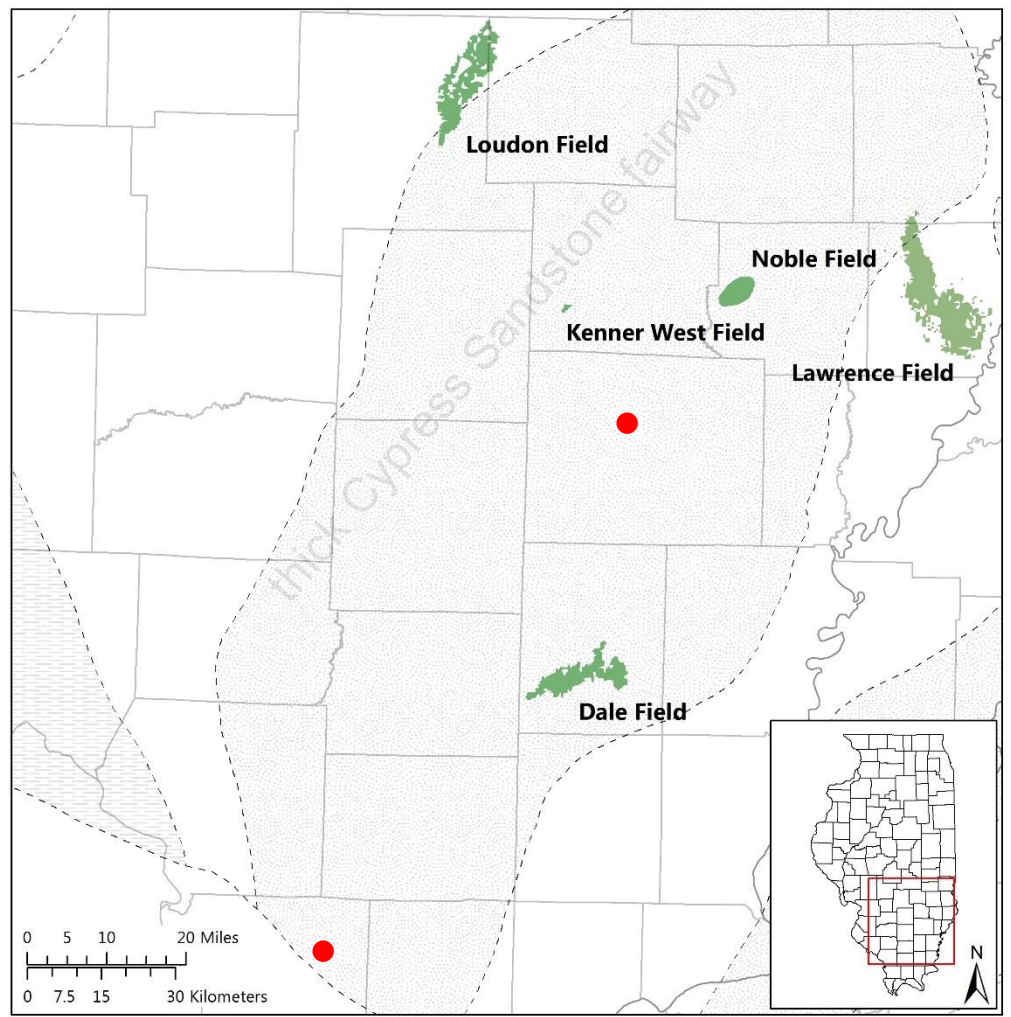
Oil fields (green) being studied and planned core locations (red dots) within the thick Cypress Sandstone fairway

- Chose four Cypress and one Pennsylvanian oilfield for detailed study
  - Cypress: Noble, Kenner West, Loudon, Dale
  - Pennsylvanian: Lawrence
- Assessed type and quality of data in each field
- Chose sites for Cypress Ss core and logs
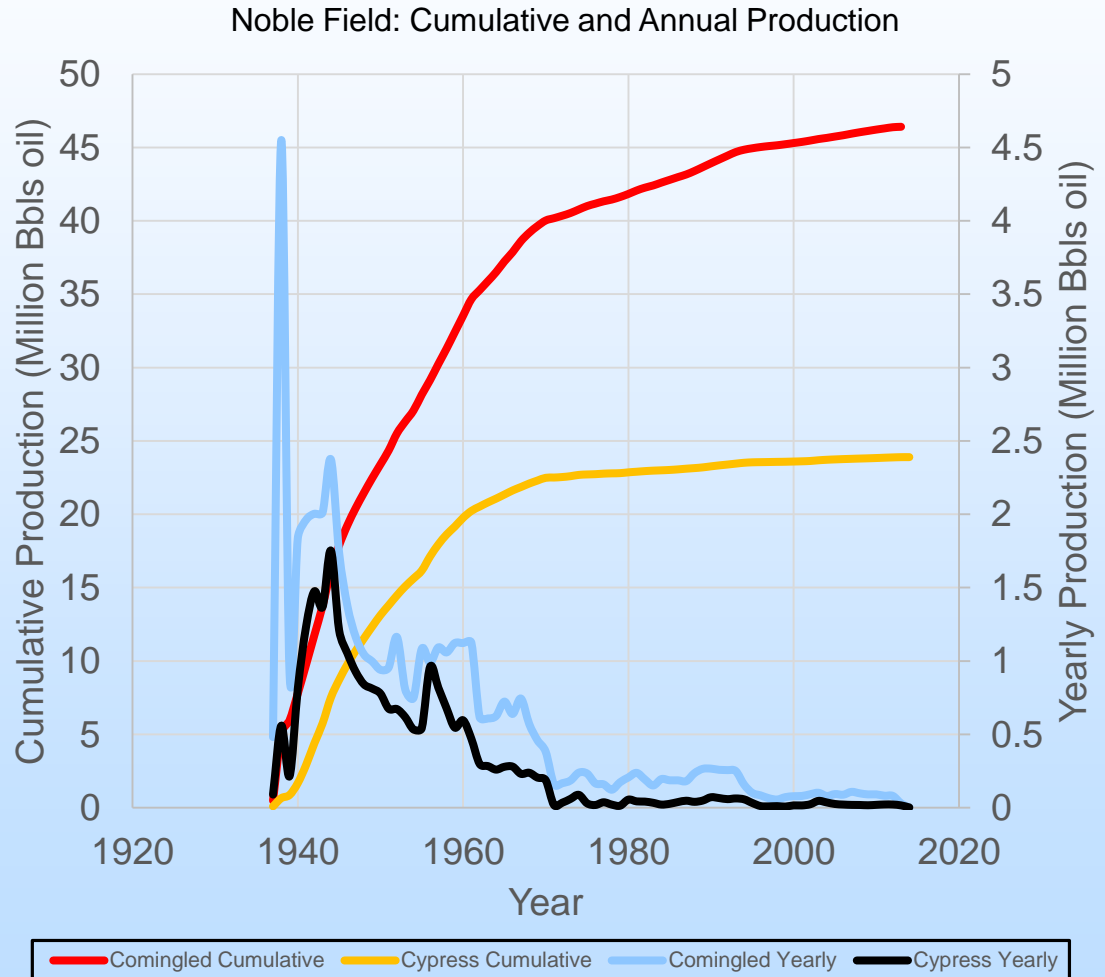 - Characterizing geology and determining fluid saturations

Study Area Selection

- Compared geologic and reservoir data attributes of oilfields to determine objectives for study

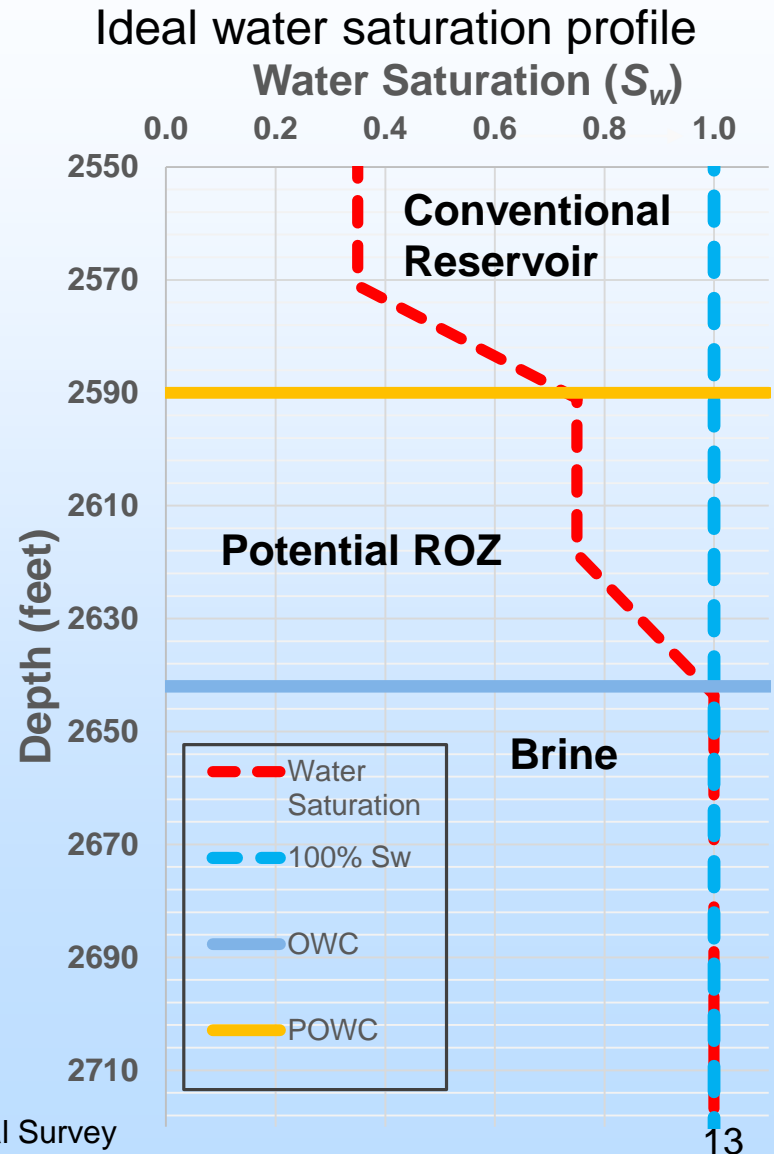| Oilfield	Main Objective	Strengths	Limitations
Noble	Characterization for history matching and forward simulation, identifying ROZs	Dense log coverage, production data, active area for fluid sampling and cased hole logging	Few cores
Kenner West	Characterization for history matching and forward simulation, identifying ROZs	Core porosity/permeability data, similarities to Noble Field give confidence in geologic model	No available core
Dale	Stratigraphy, identifying ROZs	Dense well log coverage, large size, core, microcosm for regional resource study	Few porosity logs
Loudon	Stratigraphy, identifying ROZs	Facies relationships at edge of thick Cypress Ss fairway	Few cores
Lawrence (Analogous Pennsylvanian Ss)	Sedimentology, identifying ROZs	Dense log coverage, core for sedimentological study	No production data for early field history

Data Synthesis and Analysis

- Analyzed data from each study area
  - Determined number of wells, log types for mapping, petrophysical analysis and modeling
- Related analytical data to core facies
  - Developed production history for Noble and Kenner West Fields
- Assembled inputs for reservoir simulation

Noble Field: Cumulative and Annual Production

Legend: Comingled Cumulative, Cypress Cumulative, Comingled Yearly, Cypress Yearly

Petrophysics

- Calculated water saturation (S_w) profiles from logs in Noble Field 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

Ideal water saturation profile

Water Saturation (S_w)

Depth (feet)

Conventional Reservoir

Potential ROZ

Brine

Legend:
- Water Saturation
- 100% Sw
- OWC
- POWC

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 in Noble Field
  - Conducted visible cut tests to confirm oil saturation
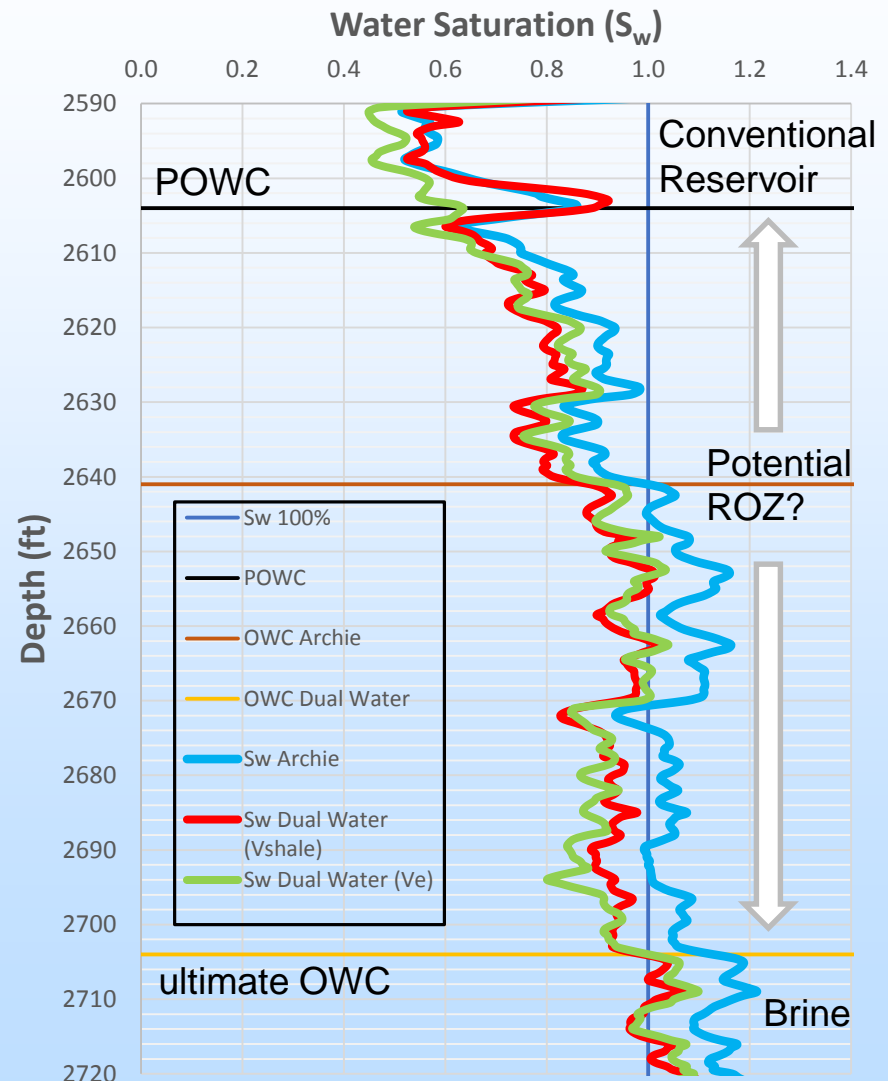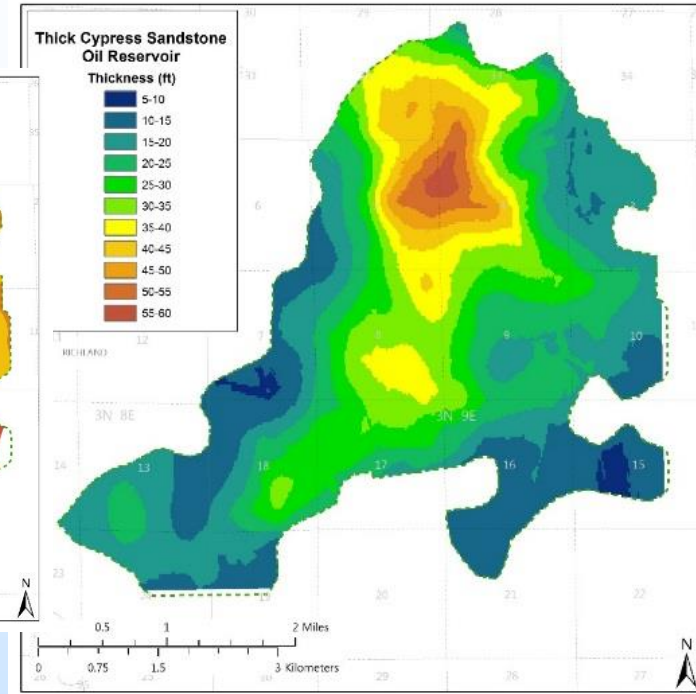
Geological Modeling
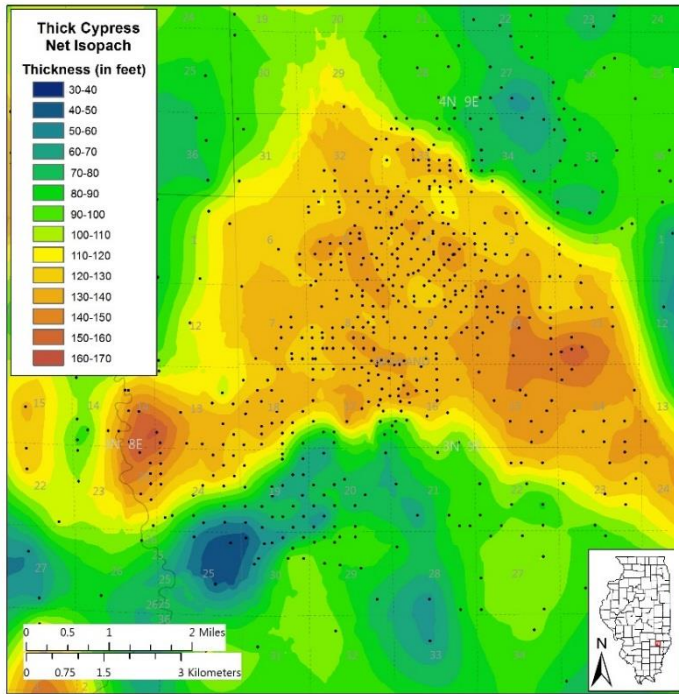
Cypress net sandstone isopach map
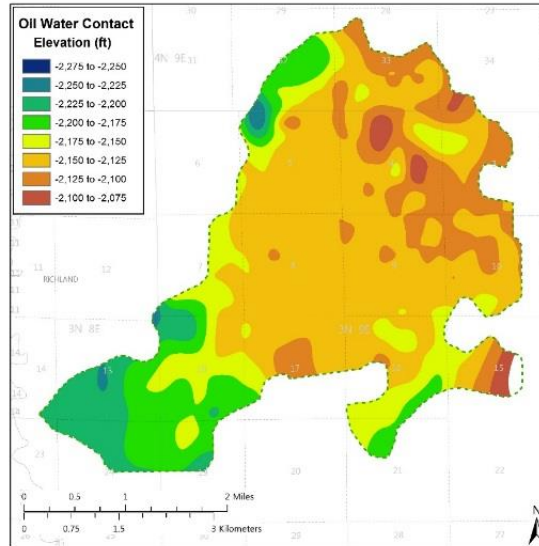
OWC structure map

Oil reservoir isopach map

- Mapped log and core indicated features of the thick Cypress Sandstone at Noble (shown) and Kenner West Fields
  - Picked upper/lower contacts, baffles (shaly and cemented zones), OWC
  - Noted a tilted OWC, and paleo-OWC related calcite cements indicative of ROZ
 - Determined volumetric parameters of reservoir and nature of OWC

Geological Modeling

- Interpreted the Cypress Sandstone at Noble Field as part of a lowstand (LST) incised valley fill environment

  - 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
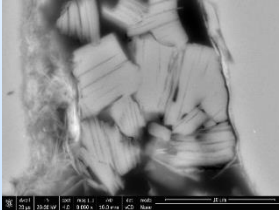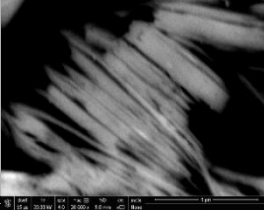

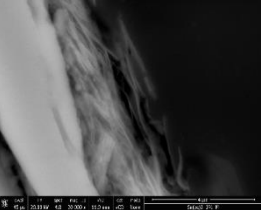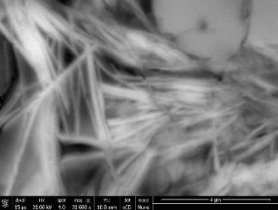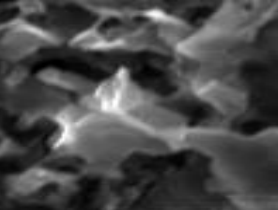*Wright and Marriott, 1993*
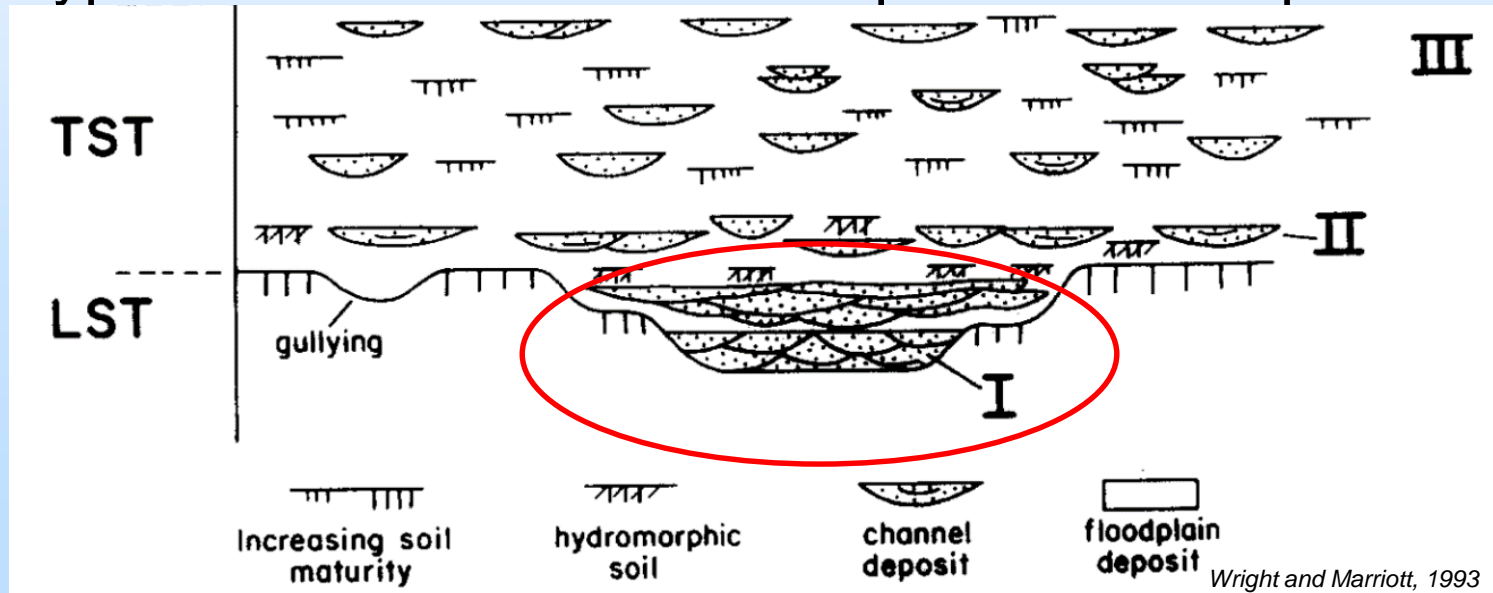
Geological Modeling

Clay mineralogy – Montgomery B-34
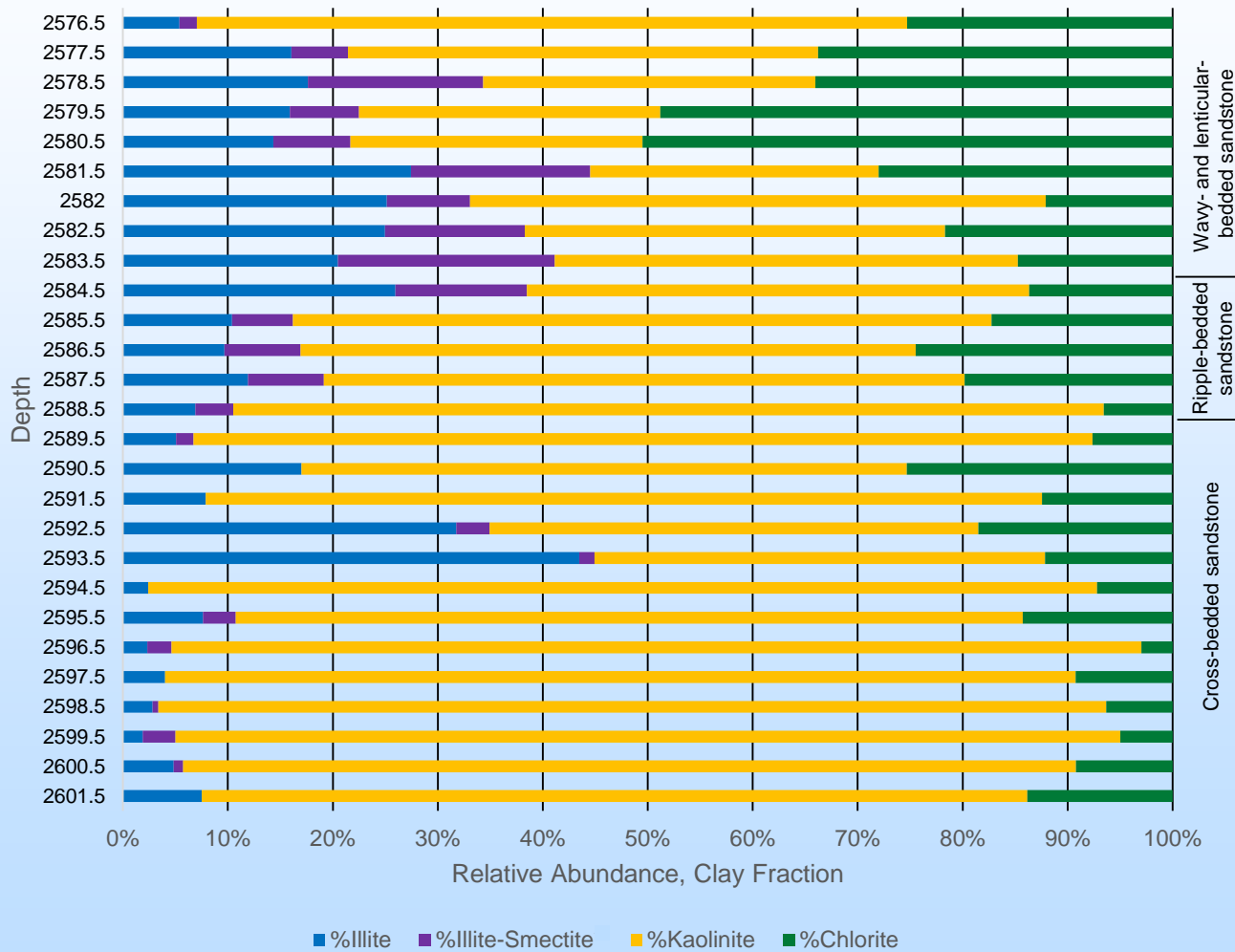
- Analyzed XRD results and related mineralogy to facies and porosity / permeability

  - Understanding depositional and diagenetic controls on reservoir quality

Geological Modeling

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

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
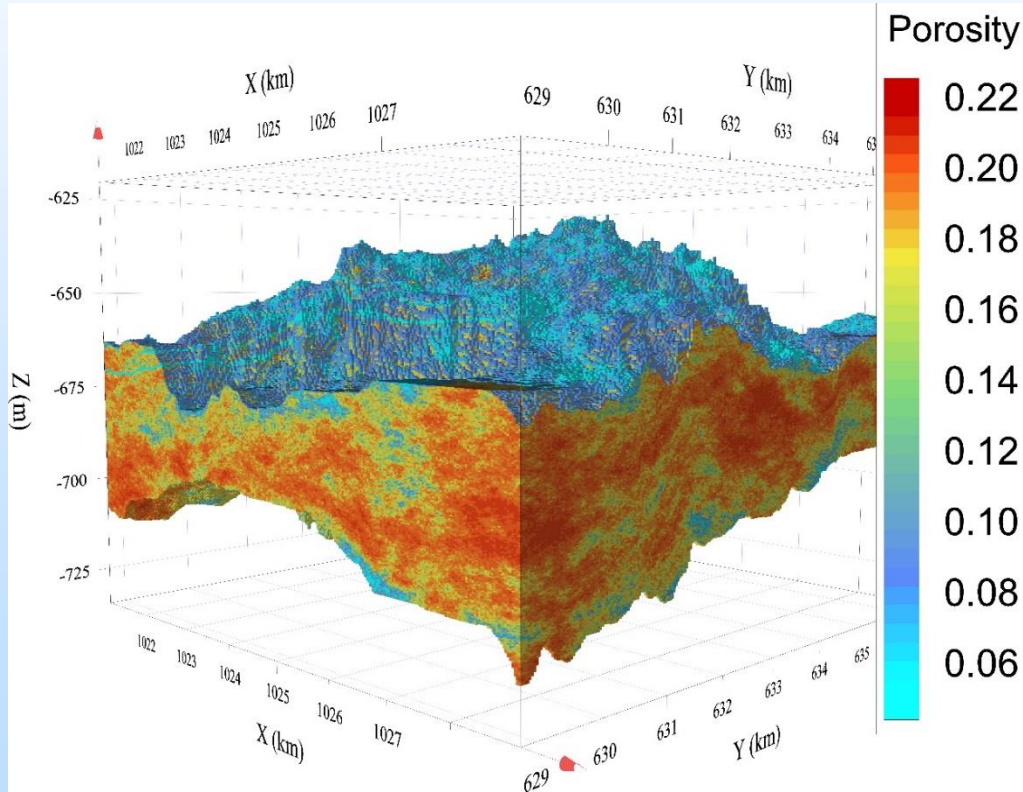
- Low porosity calcite-cemented sandstone zones
- Excluding microporosity from total porosity for accurate resource assessment
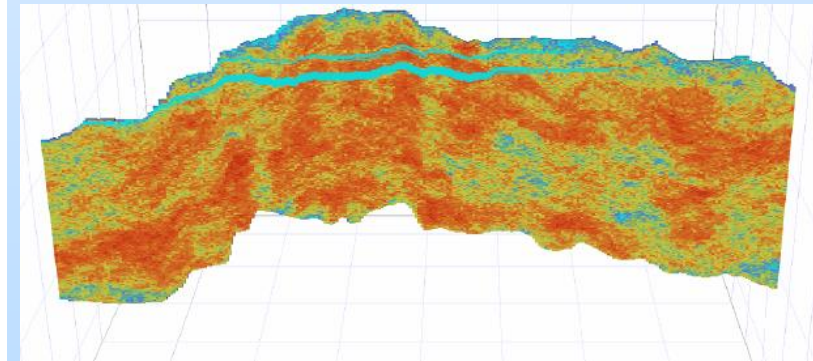
Fluid Analysis and Geochemical Modeling

- Constructed a database of current known reservoir fluid properties from Cypress Sandstone samples

- Collected oil and brine samples from Noble Field with the assistance of Citation Oil and Gas

- Conducted laboratory experiments to assess properties of oil and brine samples
  - Oil: MMP, API Gravity, Density, Viscosity
  - Brine: Composition

- Sampling and analyzing source rocks to fingerprint oil to understand migration into the reservoir
  - Understanding the mechanism for ROZ formation

Reservoir Simulation

- Determined method for representing initial oil saturation

- Performing equation of state simulation for Noble and Kenner West crude oils

- Calibrating (history-match) of Noble and Kenner West Field reservoir models
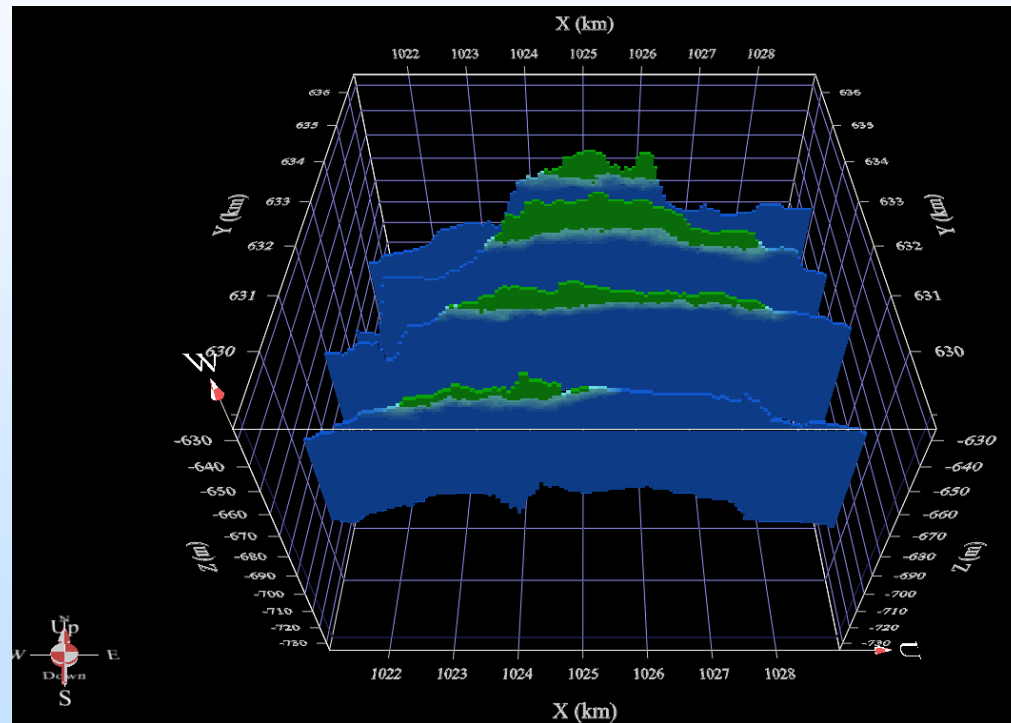
Economics and Resource Estimate

- 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

Cypress Sandstone thickness (feet)

0–25	75–100
25–50	100–125
50–75	>125

structure contour on the base of the Barlow limestone (elevation relative to sea level in feet)

oil fields
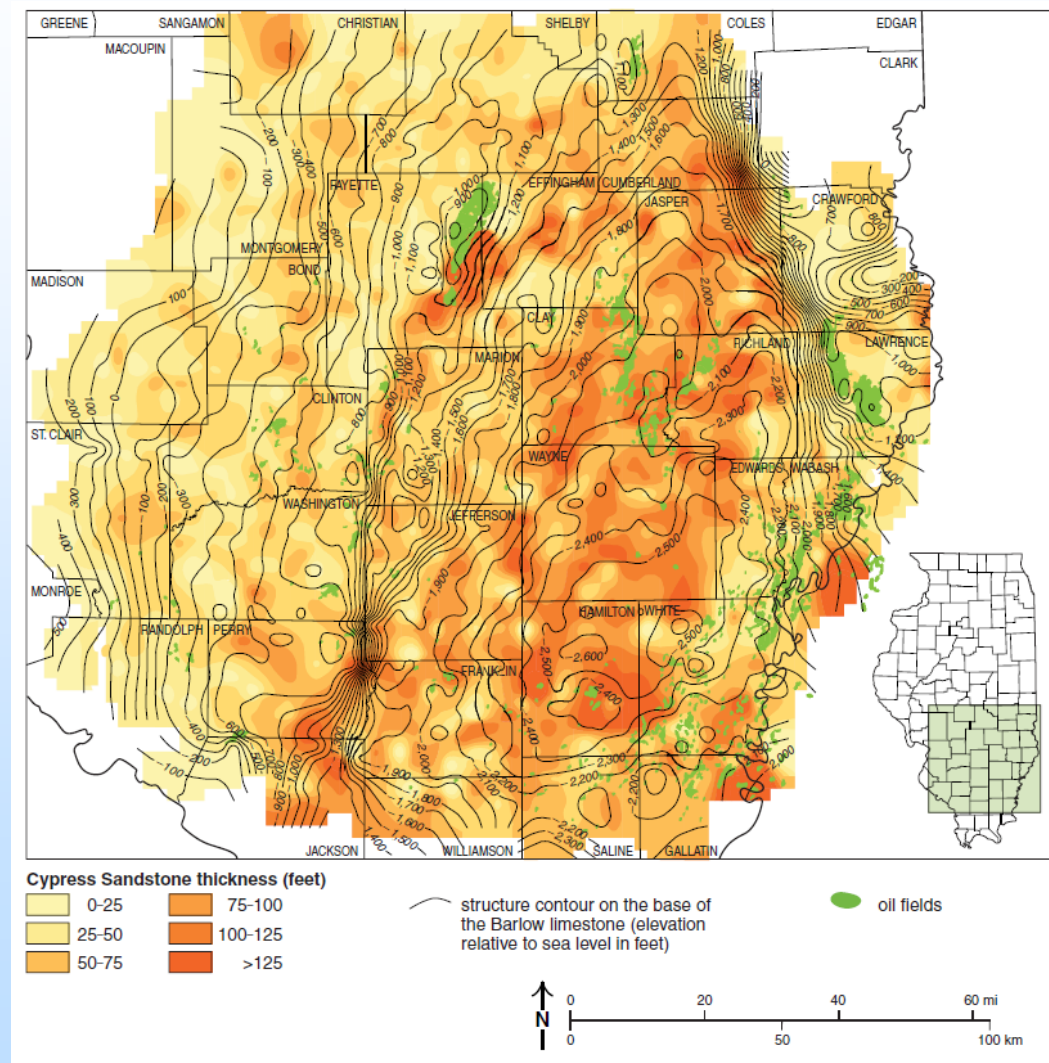
Synergy Opportunities

- 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

- Key Findings at Noble and Kenner West Fields
  - Multiple indications of an ROZ within the Cypress Ss
    - Tilted OWC and a paleo-OWC related calcite cement are a key indicators of possible ROZ
  - Combination of structural/stratigraphic controls on oil trapping
  - Cypress Sandstone is composed of multistory fluvial/estuarine sandstone bodies
  - Petrophysical analysis indicates possible ROZ but needs to account for dispersed clay in sandstone
    - Significant microporosity affects conductivity of the formation and thus estimates of fluid saturation

Summary

- **Lessons Learned**
  - Geocellular models and petrophysical methods to define fluid saturations require a robust geologic interpretation and core for calibration
    - Expected low residual oil saturations makes understanding of clays within the sandstone critical for accurate petrophysical analysis results

- **Future Plans**
  - Characterize geology of the thick Cypress and analogous Pennsylvanian sandstones across the basin to understand the range of geologic and reservoir controls on ROZs
    - Relate detailed characterization results to regional scale geology to better understand the Cypress Sandstone petroleum system
  - New coring and cased hole logging to better tie geologic properties to petrophysical characteristics and make analysis of fluid saturations more robust

Acknowledgments
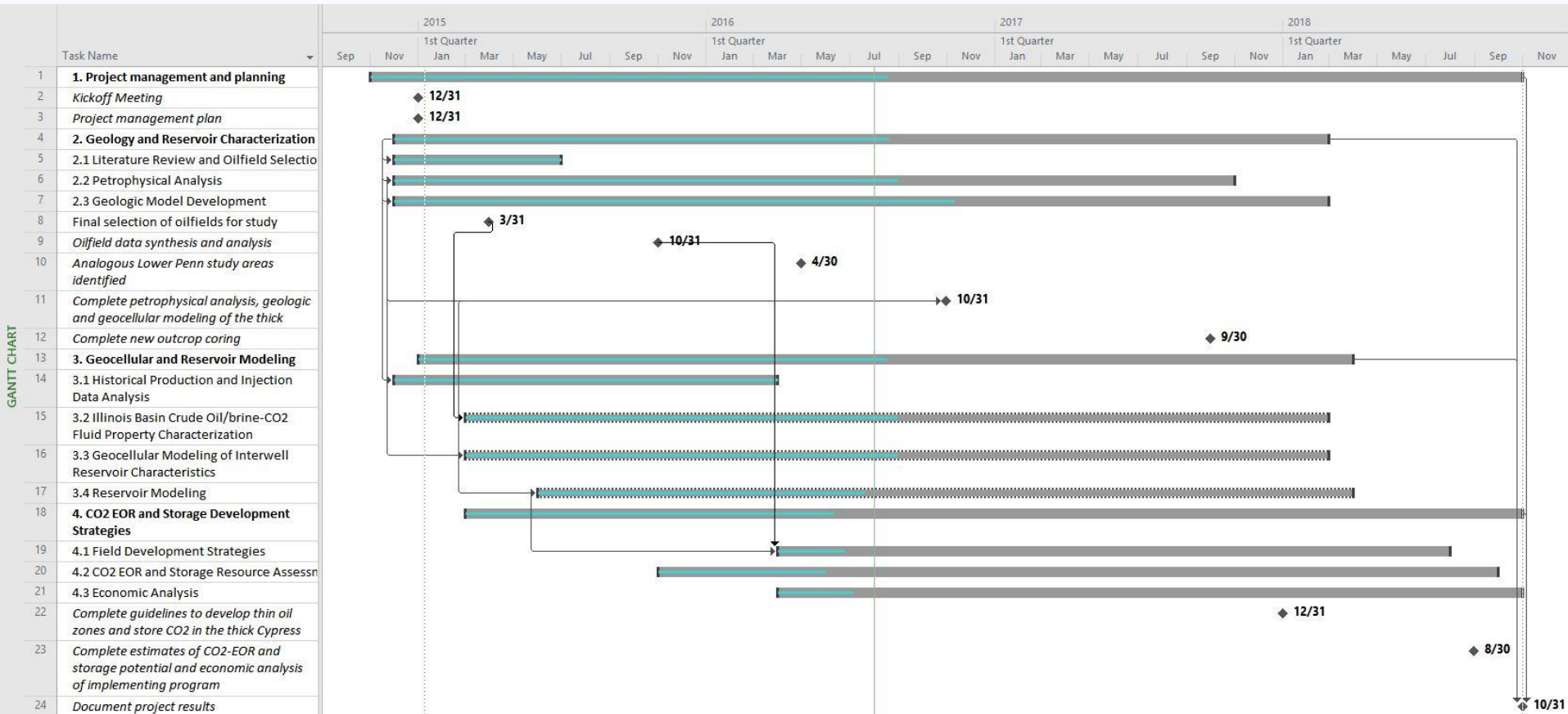
- Research herein was supported by the US Department of Energy contract number DE-FE0024431

- 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

Appendix: Organization Chart

Illinois State Geological Survey
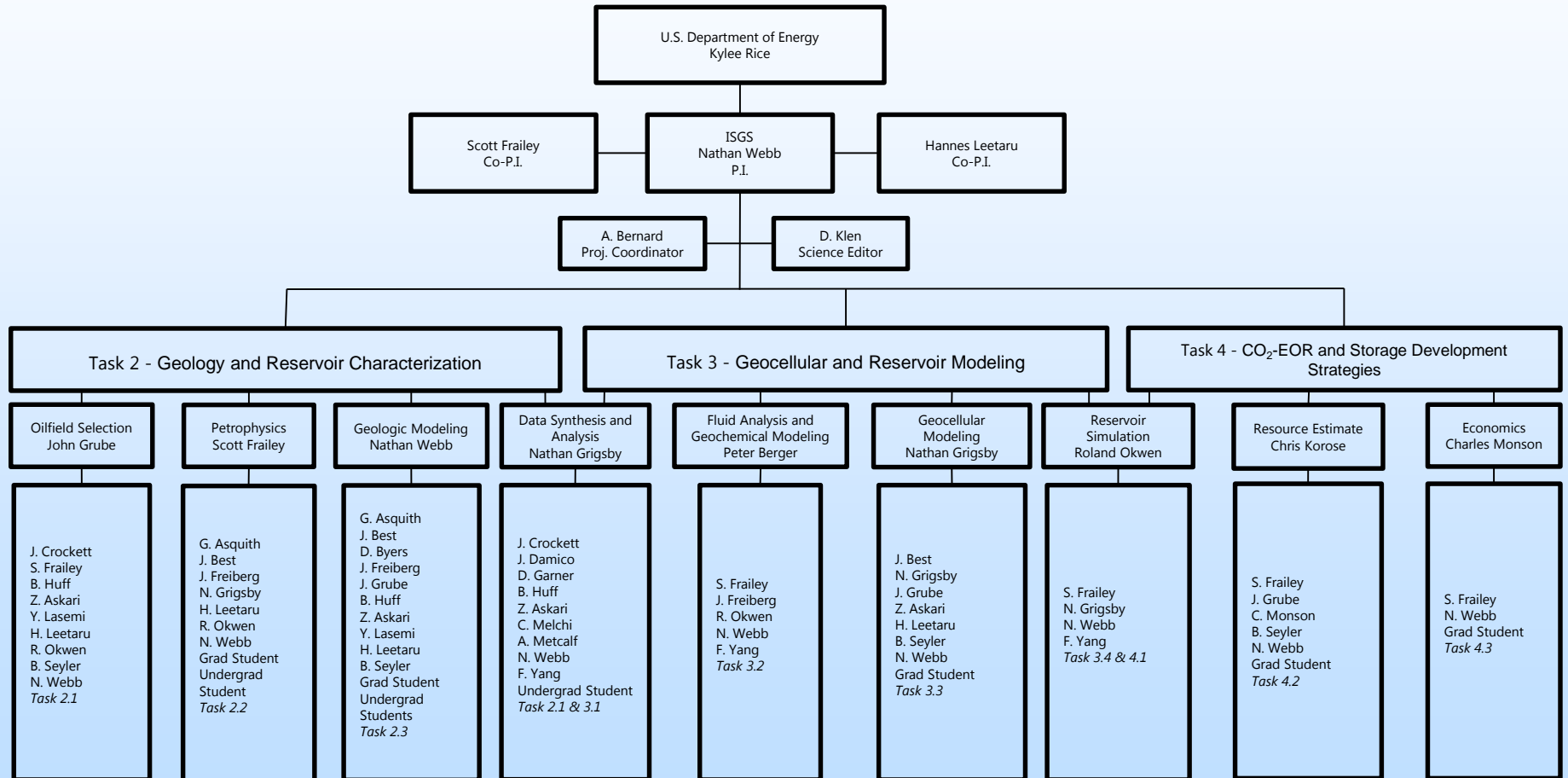
Appendix: Gantt Chart

Appendix: Bibliography

- <u>Journal, one author</u>:
  - N/A

- <u>Journal, multiple authors</u>:
  - Giannetta, Leo G., Webb, Nathan D., Grigsby, Nathan P., Butler, Shane K., *in internal review*, The Role of Clay Microporosity in Identifying ROZs in the Cypress Sandstone of the Illinois Basin

- <u>Publication</u>:
  - Webb, Nathan D. and Grigsby, Nathan P., *in internal review*, Geologic Characterization of Noble Oil Field, Western Richland County, Illinois

Appendix: Bibliography

- <u>Abstracts and Presentations</u>:

  - Arneson, Joshua J., Grigsby, Nathan P., Frailey, Scott M., and Webb, Nathan 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, Jaclyn M., Howell, Kalin J., and Webb, Nathan D., 2016, Petrography of the Chesterian (Upper Mississippian) Cypress Sandstone in the Illinois Basin: NCGSA 2016, 50th Annual Meeting, Urbana-Champaign, USA.

  - Giannetta, Leo G., Butler, Shane K., and Webb, Nathan 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, Nathan 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, Nathan D., 2016, The Mississippian thick Cypress Sandstone: A nonconventional CO_2-EOR target in the Illinois Basin: AAPG Annual Convention and Exhibition, Calgary, Alberta, Canada.

  - Webb, Nathan D., and Grigsby, Nathan P., 2016, Reservoir characterization of the thick IVF Cypress Sandstone in Noble Field, Illinois, for nonconventional CO_2 –EOR: NCGSA 2016, 50th Annual Meeting, Urbana-Champaign, IL, USA.