

A Nonconventional CO₂-EOR Target in the Illinois Basin: Oil Reservoirs of the Thick Cypress Sandstone

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Presentation Outline

- Benefit to DOE Program
- Program and Project Overview
- Methodology
- Outcomes
- Accomplishments to Date
- Summary
- Bibliography

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 CO₂ Storage in Non-Conventional CO₂-EOR Targets – Residual Oil Zones (ROZs)

Benefit to DOE Program: Benefits Statement

- Field development guidelines will be developed to maximize economic oil recovery and CO₂ storage efficiency.
- It is projected that CO₂-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 CO₂ storage (i.e. net utilization) compared to conventional CO₂-EOR.
- Through the application of these techniques, guidelines can be recommended for CO₂-EOR development (e.g., well patterns, spacing, and orientations as well as CO₂ injection profiles) of the thick Cypress (and similar formations) with the end result of maximized incremental recovery and CO₂ storage.

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

ncCO₂-EOR TC ILB

- Identify and quantify nonconventional CO₂ 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; CO₂ storage and EOR resource
- Field and lab tests
- Development methods for increasing CO₂ storage and improving oil recovery

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- Correlate oil production to key geologic/reservoir properties
- Map CO₂ 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

- Thick Cypress Sandstone presents an opportunity for ncCO_2 -EOR and storage
 - Large NE-SW trending fairway though the center of the Illinois Basin

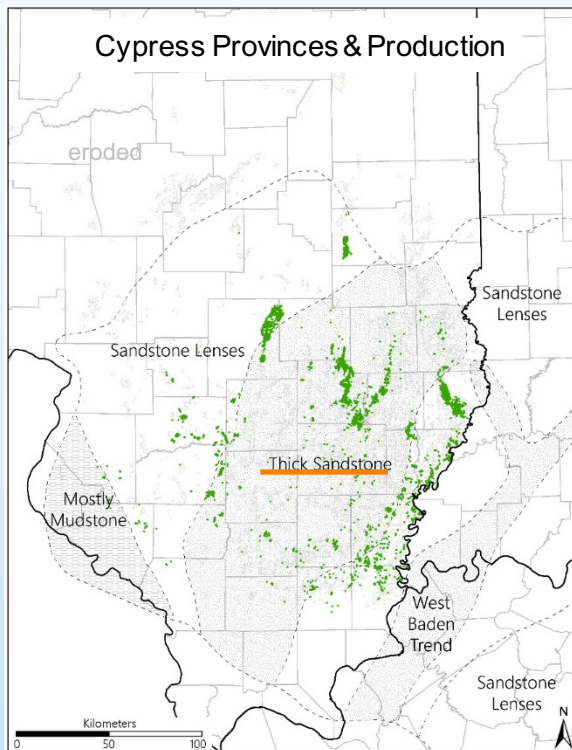


Figure modified from Nelson et al. 2002

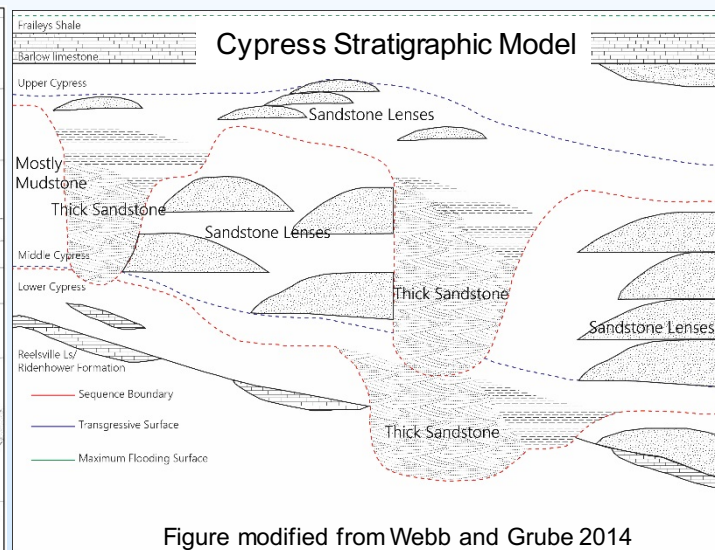


Figure modified from Webb and Grube 2014

**Thick Cypress Sandstone
thought to consist of incised
valley deposits**

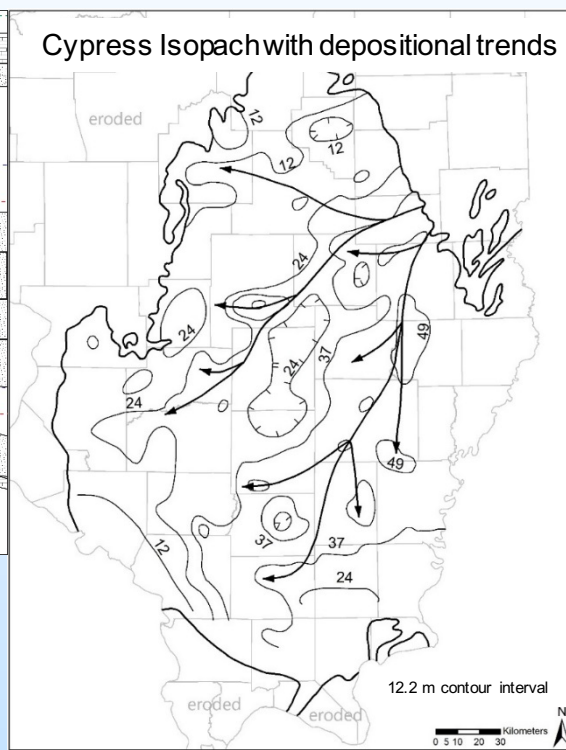
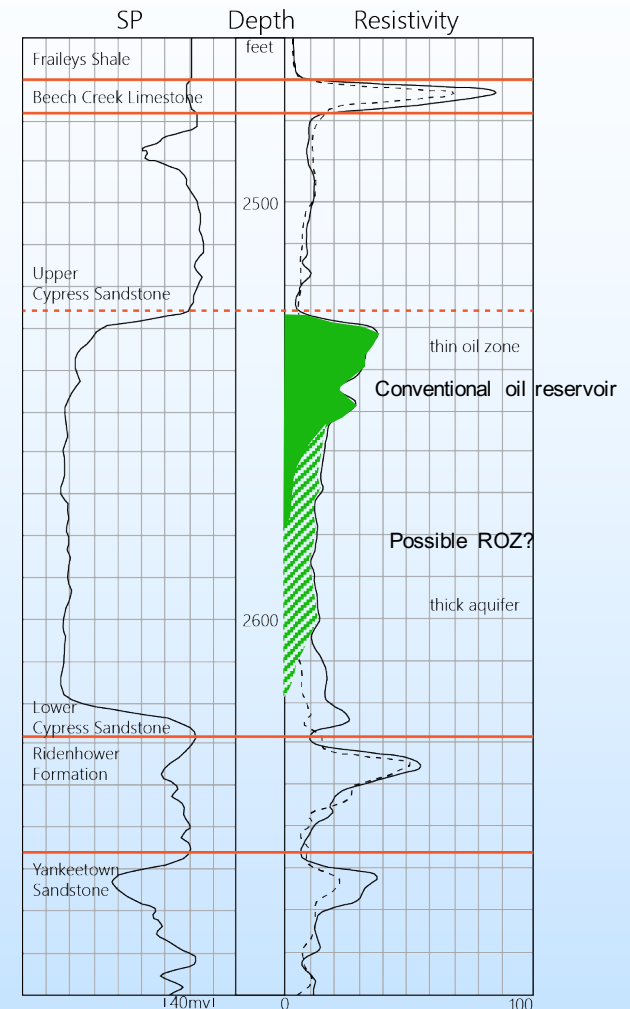


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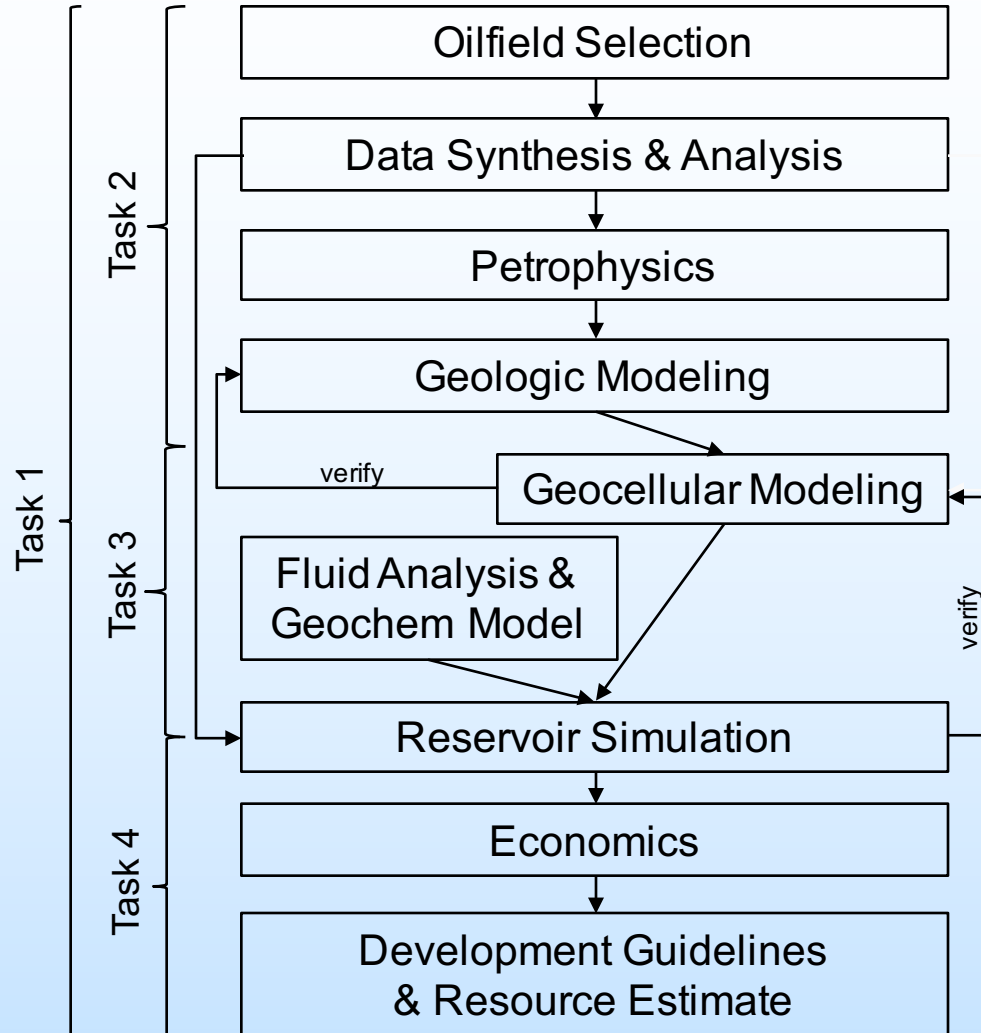
Methodology

Background: Thick Cypress Ss

- Thin Oil Zones in Thick Aquifer Sandstones
 - Residual and mobile oil above thick saline aquifer
 - Fining upward (grain size) sequence / increasing permeability with depth
 - Difficult to produce economically due to water coning and water management
- Nonconventional CO₂-EOR
 - Largely bypassed resource due to historical production difficulty
 - Sandstones 30+ meters thick and mostly saline aquifer
 - Saline storage potential of 0.2 to 2.3 Gt of CO₂ (DOE/MGSC, 2012)

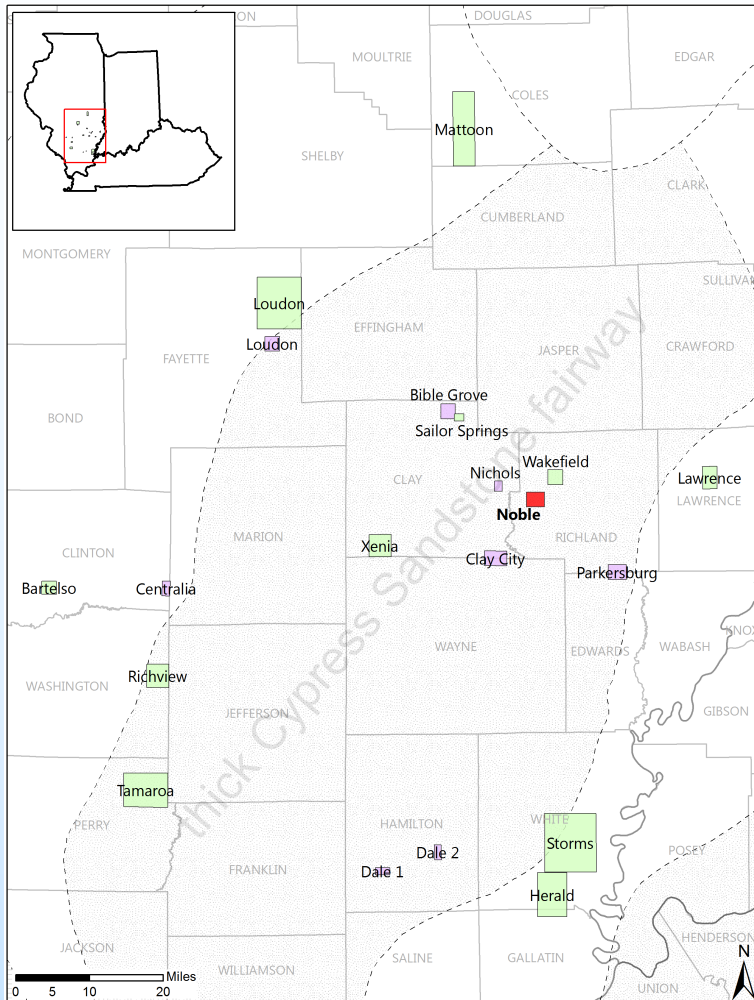


Methodology



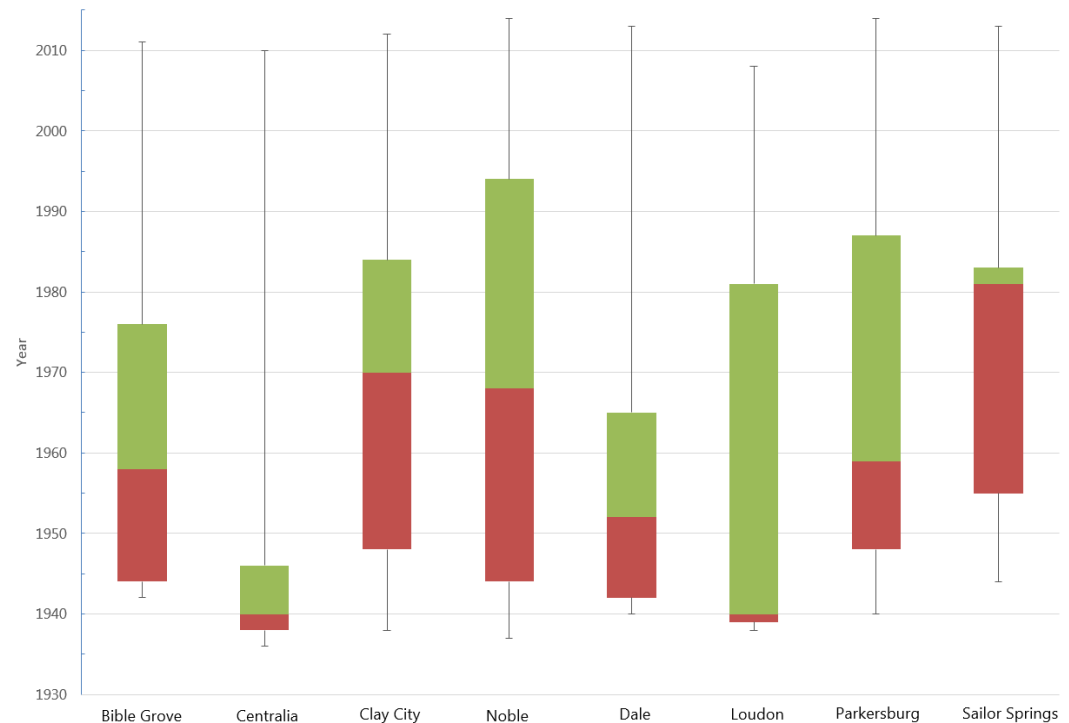
Oilfield Selection

- Chose eight oilfields to investigate
- Assessed the type and quality of data for each oilfield



Candidate oilfields in purple, past studies in green
 Noble Field, in red, was selected for study

Drilling history: Discovery to present



Each line segment and colored box represents 25% of the total drilling activity for the history of each field
 Contact between red and green boxes marks 50% of total drilling activity in each field

Oilfield Selection

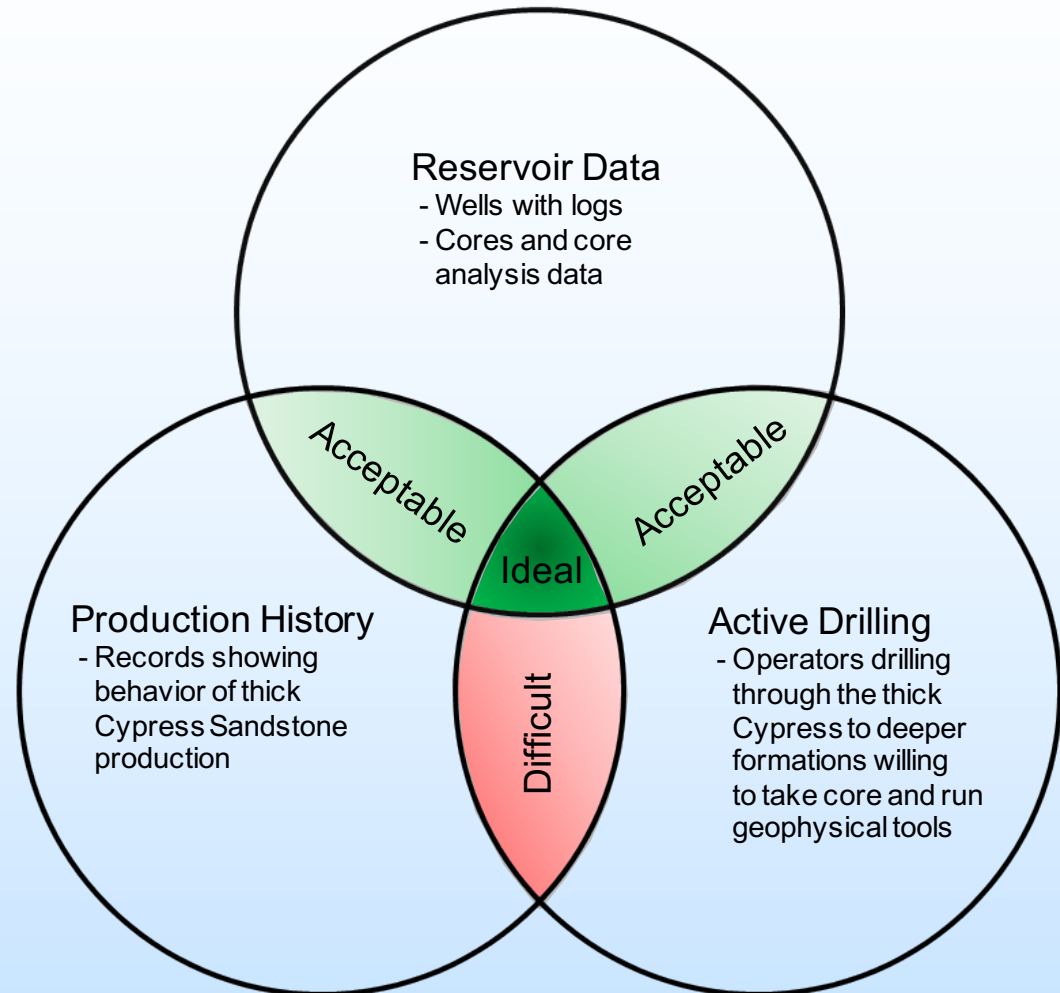
- Compared geologic and reservoir data attributes of oilfields to identify favorable conditions for study

Oilfield Name	Location	Average Depth to Cypress (ft)	Average Cypress Thickness (ft)	Oil zone present? (thickness, ft)	Reservoir Data	Production History	Active Drilling (2014)
Loudon	Fayette Co., T7N, R3E	1500	70	Yes >10	Many electric logs and porosity logs, several cores, some core analysis data	Yes	Yes
Bible Grove	Clay Co., T5N, R7E	2500	100	Yes >10	Many electric logs, a few cores nearby, little core analysis data	Yes	No
Nichols	Clay Co., T4N, R8E	2700	150	Yes >10	Many electric logs, no cores, little core analysis data	Yes	Yes
Noble	Richland Co., T3N, R9E	2600	150	Yes >10	Many electric logs and porosity logs, a few cores, abundant core analysis data	Yes	Yes
Clay City	Clay and Wayne Co., T2N, R8E	2700	90	Yes <10	Many electric logs and porosity logs, no cores, some core analysis data	Yes	No
Parkersburg	Richland/Edwards Co., T2N, R14W	2800	Transitioning to thinner stacked sandstones	No*	Many electric logs and porosity logs, no cores, some core analysis data	No	Yes
Centralia	Clinton Co., T1N, R1W	1200	Transitioning to thinner stacked sandstones	No*	Many old electric logs with many that do not penetrate the entire Cypress, a few cores, some core analysis data	No	No
Dale 1 & 2	Hamilton Co., T6S, R5E & T6S R7E	2700–2900	70–90	Yes <10	Many electric logs, A few cores, no core analysis data	No	No

*The oil zone may be very thin, if present, and is difficult to detect because of the transitional nature of the Cypress Sandstone in the Centralia and Parkersburg areas.

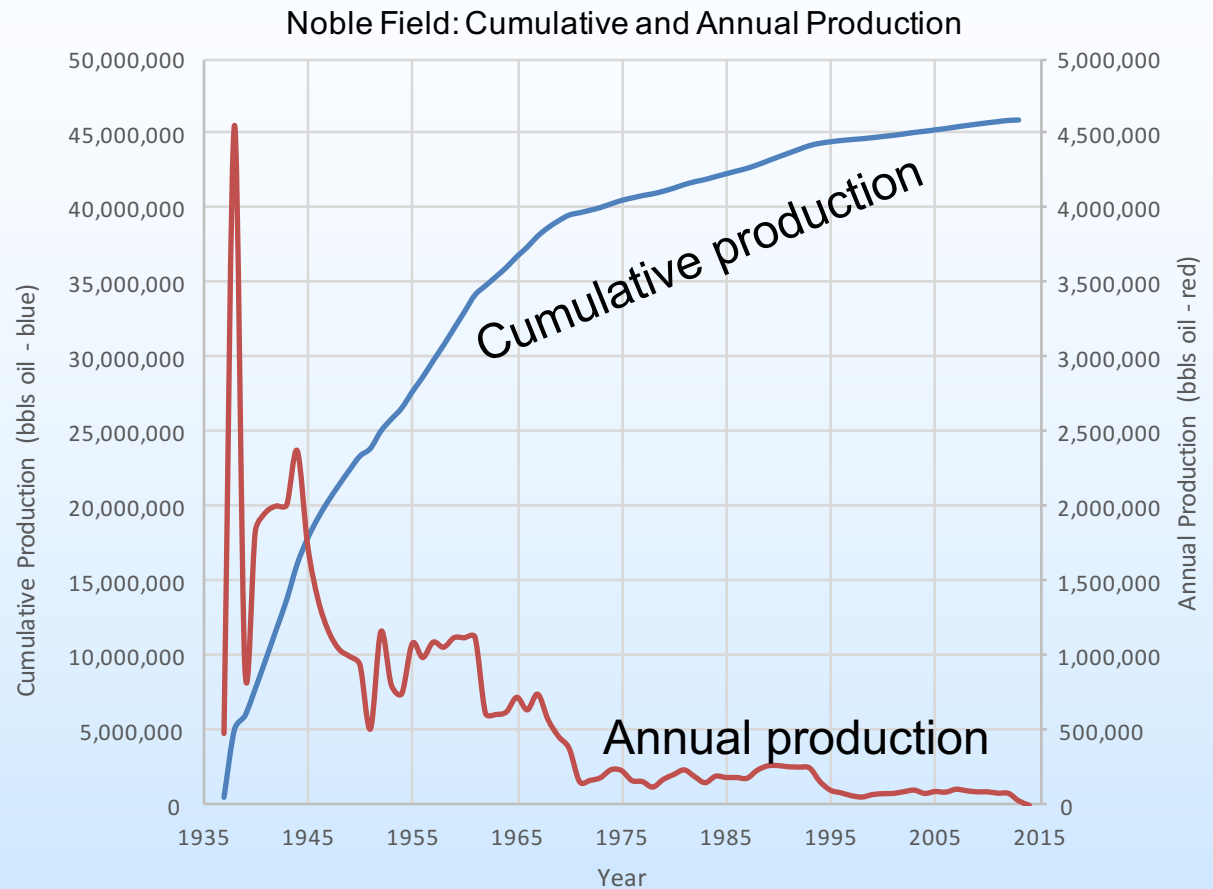
Oilfield Selection

- Inventoried all available data
- Assessed the relative importance of data types
- Reviewed all existing Cypress Sandstone studies
- Selected Noble Field for study



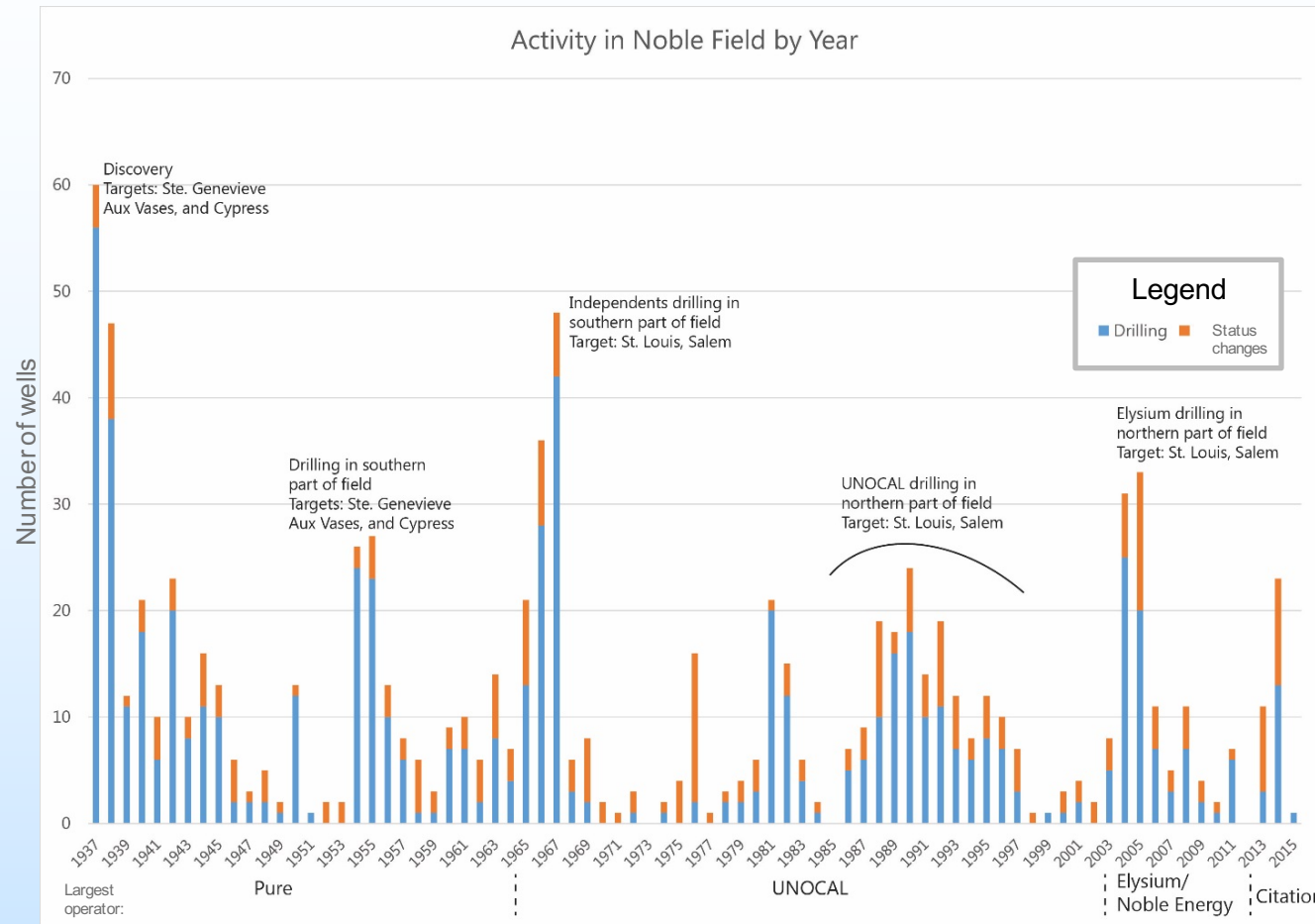
Data Synthesis and Analysis

- Derived Noble Field production history from pipeline reports
- Assigned production history to each well
- Constructed annual and cumulative production curves for Noble Field for all producing formations



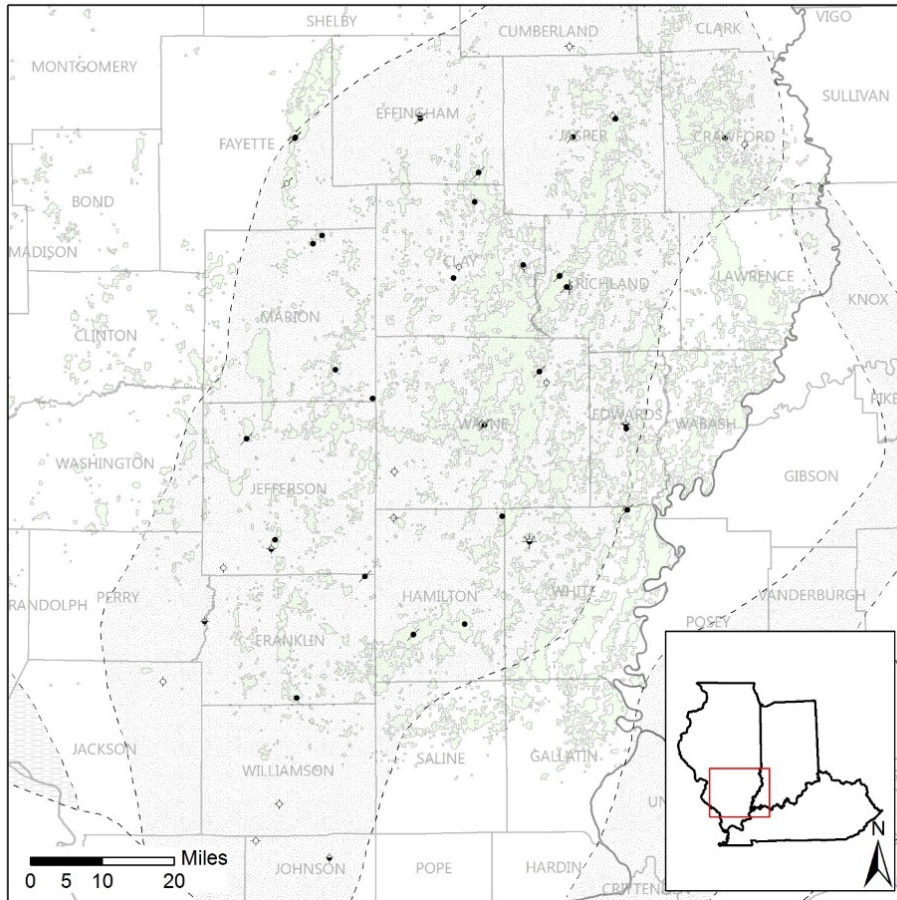
Data Synthesis and Analysis

Activity in Noble Field by Year



- Studied Noble Field historical drilling activity to understand relative productivity of all formations
 - Next Step: Assign proportion of thick Cypress production to each well

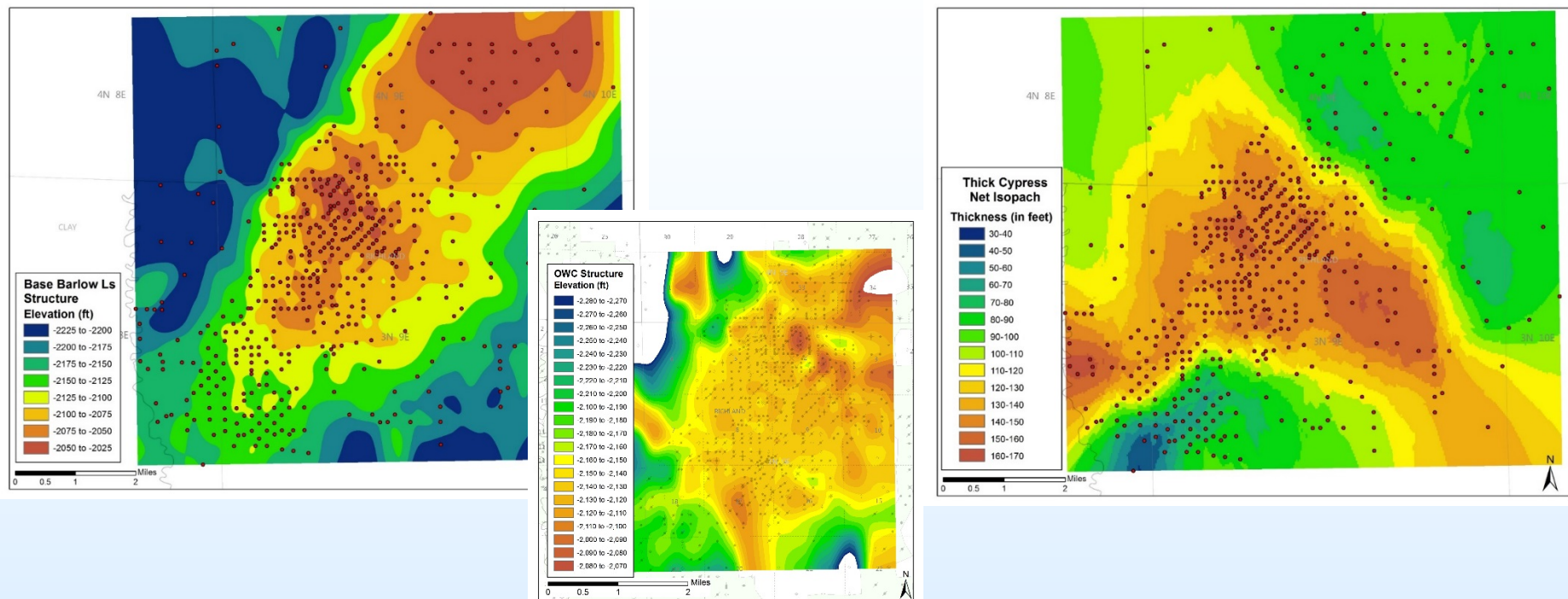
Petrophysics



Wells with geophysical logs selected for petrophysical analysis
Thick Cypress Sandstone fairway is stippled, oilfields in green

- Selected wells within thick Cypress Sandstone fairway
 - Wells represent a range of geologic and reservoir characteristics both within and outside of oilfields
- Testing methods to assess the oil/water contact (OWC) and the presence of ROZ
 - The apparent water resistivity and resistivity-derived porosity methods are being attempted
- Next step: Develop algorithm based on petrophysical analysis to identify ROZs

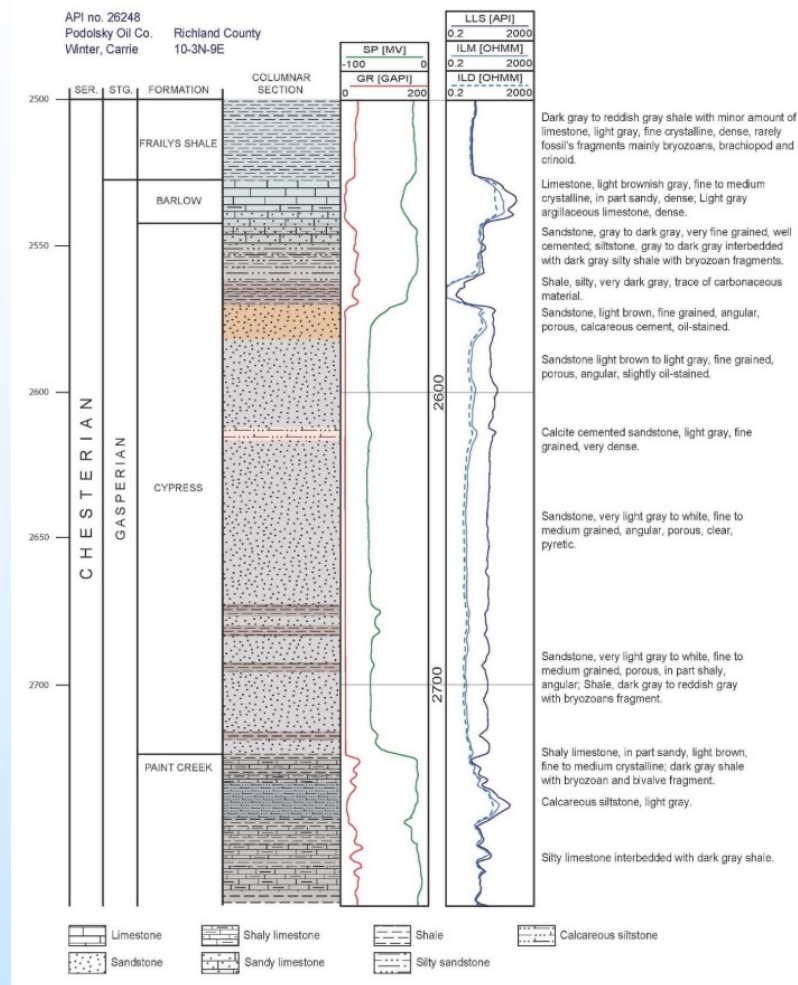
Geological Modeling



- Mapping log and core indicated features of the thick Cypress Sandstone at Noble Field
 - Upper/lower formation contacts, baffles (shaly zones, cemented zones), OWC
 - Defining volumetric parameters of reservoir and nature of OWC
 - OWC is tilted implying current hydrodynamic forces indicating possible ROZ

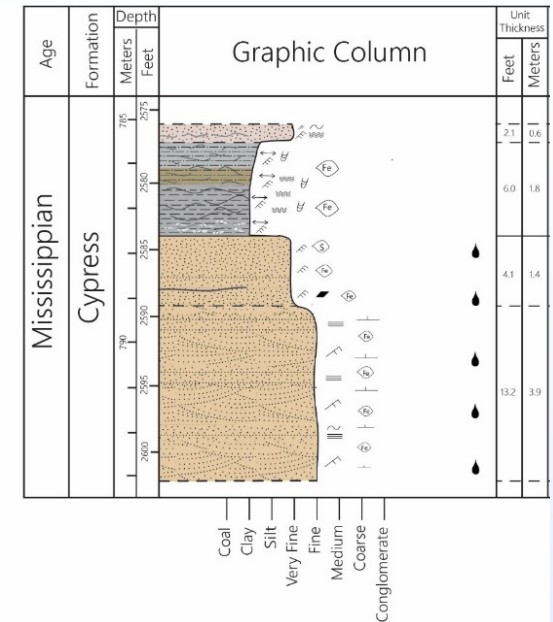
Geological Modeling

- Examining thick Cypress Sandstone sample sets in and near Noble Field
 - Documenting trends
 - Lithology, texture, oil saturation
 - Identifying potential baffles to fluid movement



Geological Modeling

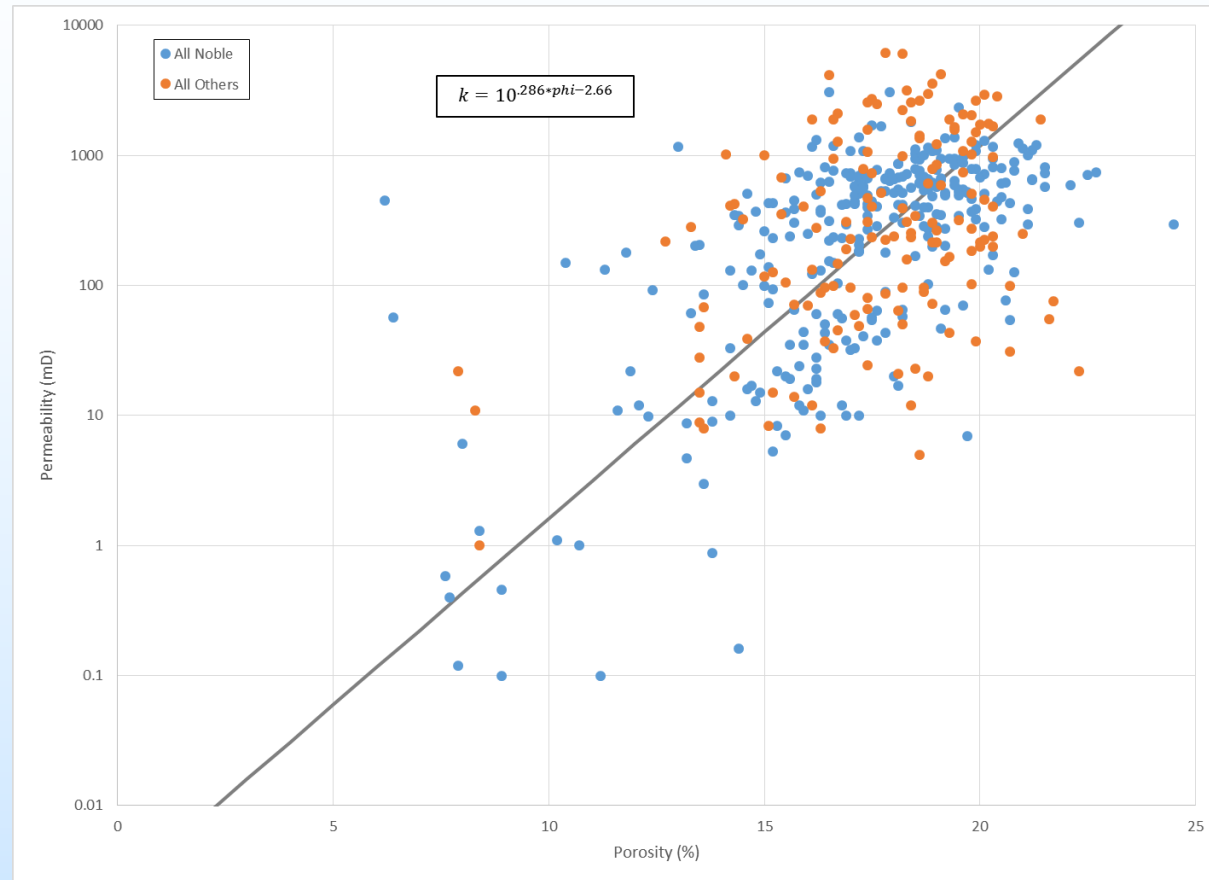
- Describing available cores and sampling for porosity, permeability, mineralogy, trace elements, SEM, and thin sections
 - Defining sedimentary facies and developing an interpretation of depositional environment
 - Investigating scales of and controls on reservoir heterogeneity
- Next Step: Integrate core and log data to map individual reservoir facies



LEGEND	
≡	PLANAR BEDDING
~	SOFT SEDIMENT DEFORMATION
■	SHALE RIP UP CLASTS
~	UNIDIRECTIONAL WAVY BEDDING
~	BIOTURBATION
~	BURROWS
●	OIL STAINED
≡	LOW ANGLE BEDDING
◇	PYRITE
◇	SIDERITE
+	CALCITE CEMENTED
≡	UNIDIRECTIONAL TROUGH CROSS-BEDDING
≡	CARBONACEOUS DEBRIS
≡	BIDIRECTIONAL RIPPLE CROSS LAMINATIONS

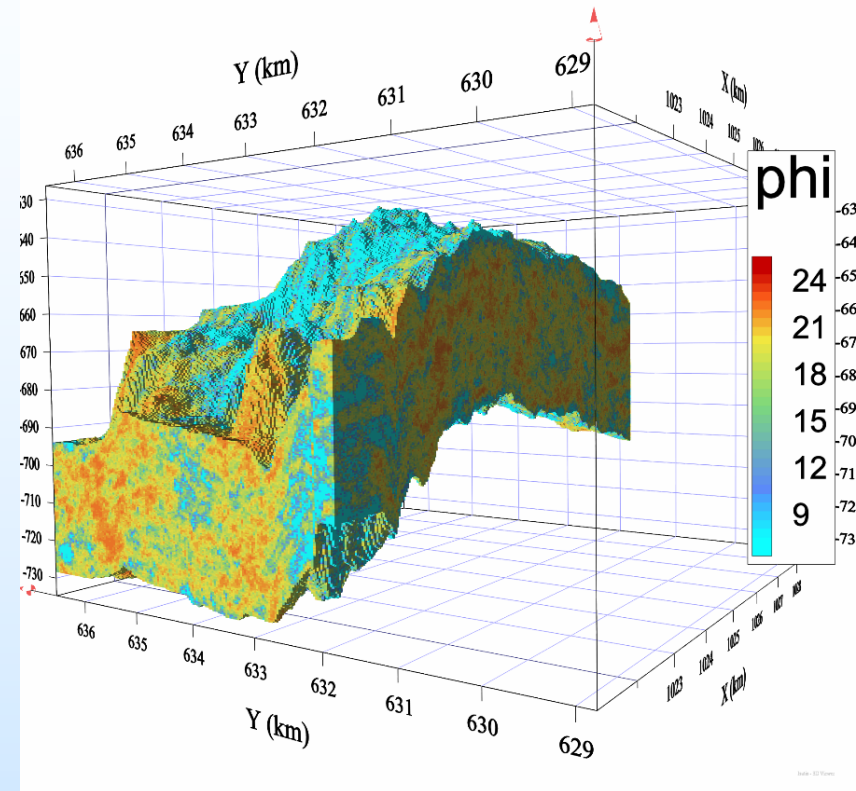
Geocellular Modeling

- Developed a porosity-permeability transform from core data for Noble Field and vicinity
- Digitizing and collecting additional core analysis data to include in the database to refine the porosity-permeability transform



Geocellular Modeling

- Developed a geocellular model based on well locations and the preliminary isopach map of the thick Cypress Sandstone in Noble Field
 - Simplified representation of reservoir geology used to approximate the depth and dimensions for reservoir simulations
- Next Step: Integrate log and core data into rigorous Noble Field thick Cypress Sandstone geocellular model to represent reservoir heterogeneity



Porosity model. Roughly 0.5 x 0.5 mi.
50x vertical exaggeration

Fluid Analysis and Geochemical Modeling

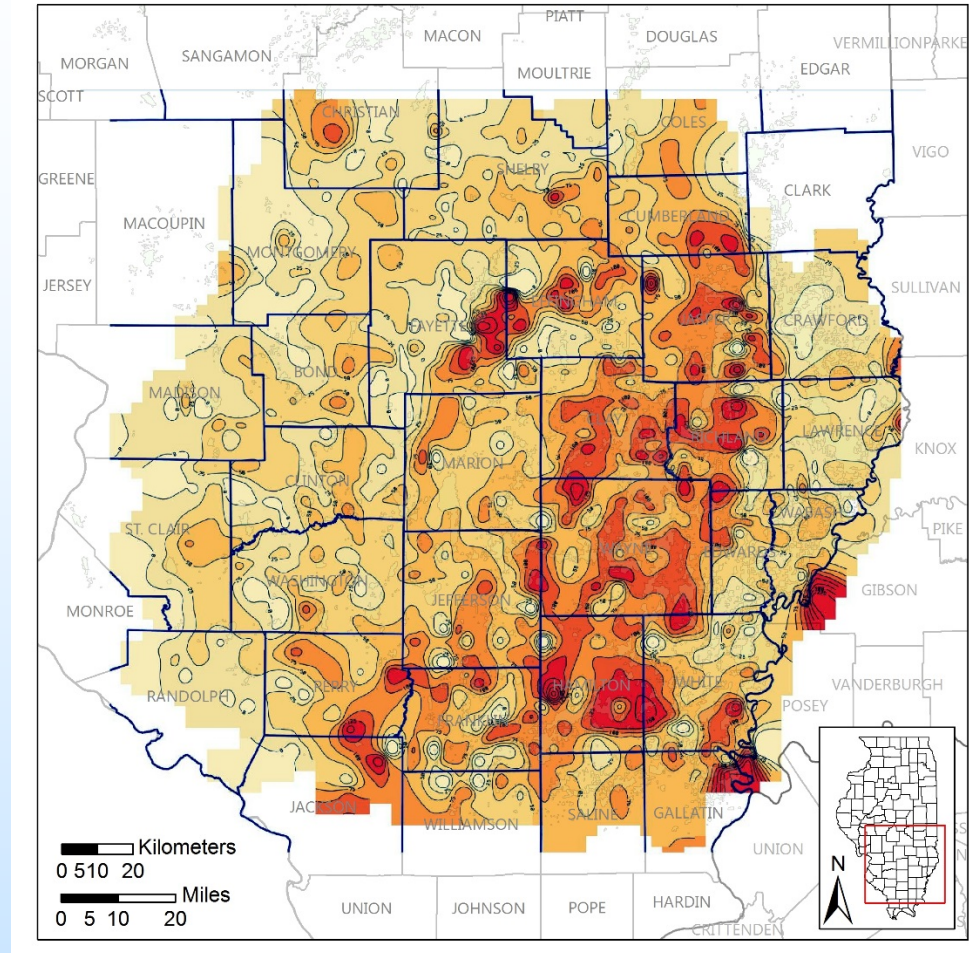
- Constructed a database of current known reservoir fluid properties from Cypress Sandstone samples
- Collected oil and brine samples from Noble Field with the assistance of Citation Oil and Gas
- Next Step: Conduct laboratory experiments to assess properties of oil and brine samples
 - Oil: MMP
 - Brine: Composition

Reservoir Simulation

- Conducting sensitivity analyses of oil saturation distribution within the transition zone and ROZs
- Simulating reservoir conditions using the simple geocellular model to identify and test methods for representing initial oil saturation in a ROZ
- Generating simulation input files that closely replicate production and injection history at Noble Field
- Reviewing literature of EOR techniques in nonconventional ROZs
- Next Step: Conduct simulations to match production history to the rigorous Noble Field thick Cypress Sandstone geocellular model

Resource Estimate

- Refining regional isopach map
- Classifying regional isopach map by facies to define CO₂ storage resource in the thick Cypress Sandstone
- Next Step: Integrate mapping, geology, petrophysics, and reservoir simulation to identify areas with nonconventional CO₂-EOR potential



Synergy Opportunities

- All projects focusing on CO₂-EOR would benefit from including NCNO as screening criteria
- Once an algorithm for finding ROZs in mature/well developed basins 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 ncCO₂-EOR resource and should provide the framework for an eventual field demonstration

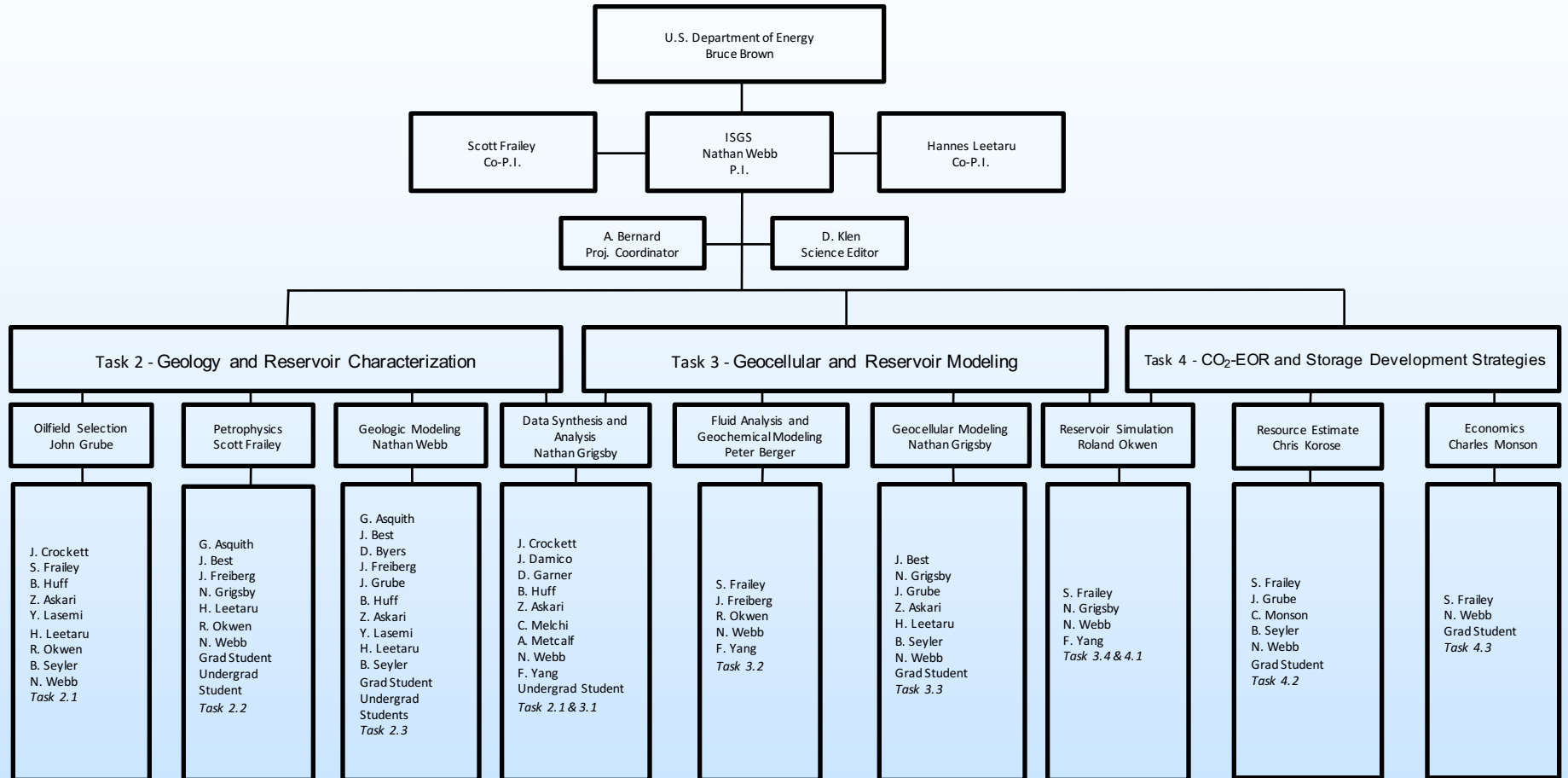
Summary

- Key Findings
 - Tilted OWC in Noble Field implies current hydrodynamic forces and is a key indicator of possible ROZ
- Lessons Learned
 - Difficulty in obtaining new data due to economics of oil industry – new drilling in the basin has decreased
- Future Plans
 - Continue geologic characterization of the thick Cypress Sandstone at Noble Field and elsewhere to understand the range or reservoir conditions in the basin where ROZs may exist

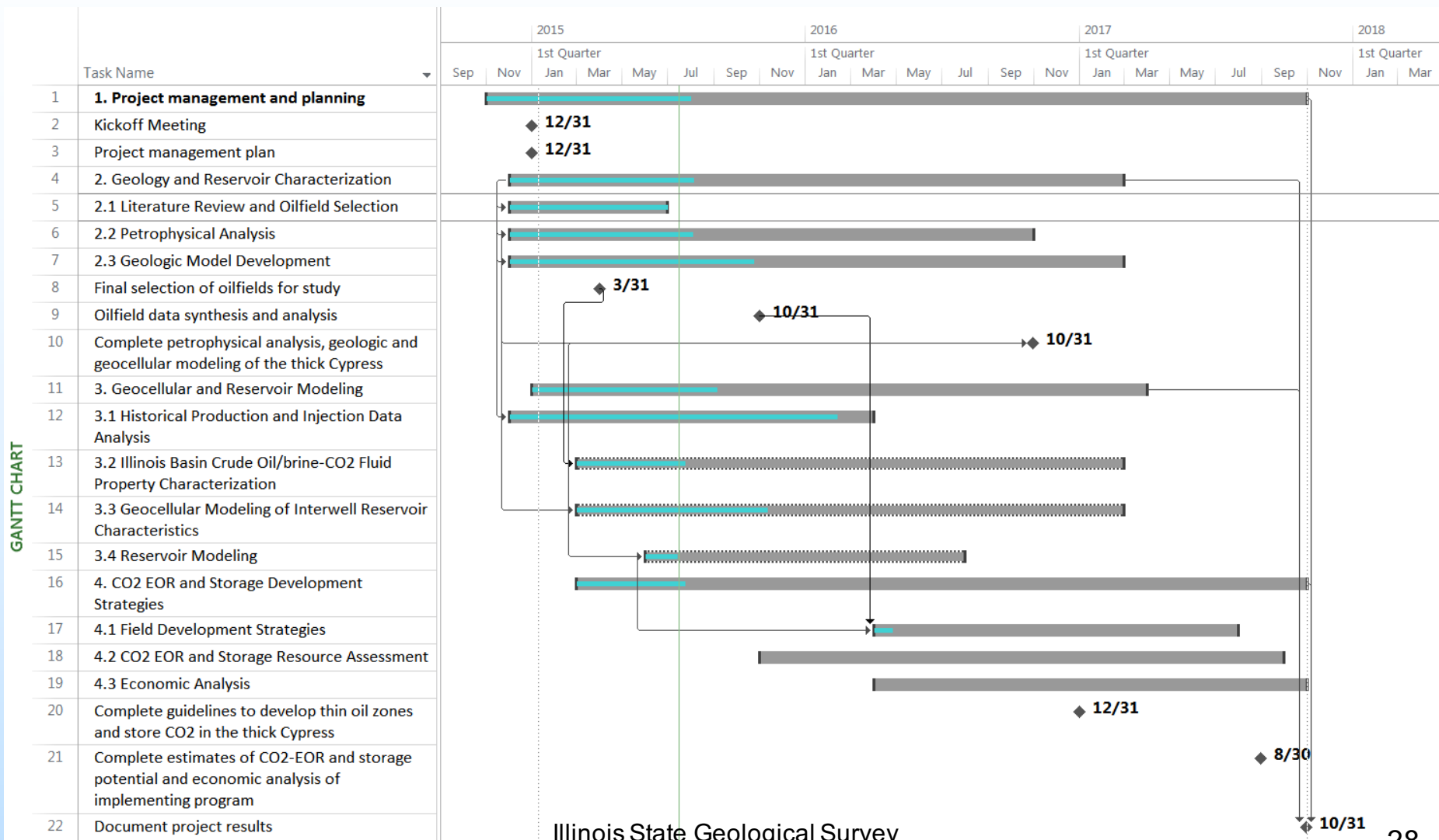
Acknowledgments

- Through a university grant program, IHS Petra and Landmark Software was used for the geologic and reservoir modeling

Appendix: Organization Chart



Appendix: Gantt Chart



Appendix: Bibliography

- Webb, Nathan D. and Grigsby, Nathan P., accepted, Geological characterization and modeling of the Cypress Sandstone at Noble Field, southeastern Illinois, Eastern Section AAPG Meeting, September 21, 2015