Geological Characterization and Modeling of the Cypress Sandstone at Noble Field, Southeastern Illinois*

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Abstract

The Mississippian Cypress Sandstone is a prolific oil-producing horizon in the Illinois Basin, with production typically from NE-SW oriented tidal bars. However, a thick Cypress Sandstone fairway, deposited as part of an incised valley fill system that eroded the older Cypress tidal bars, lies in the central part of the Basin. The thick Cypress Sandstone can exceed 46 m and, in places, contains a relatively thin oil reservoir in the top. These oil reservoirs have low primary recovery due to excessive water coning and are an unproduced oil resource in the Basin, but recent horizontal drilling in these zones has had some success. Such reservoirs provide an economic incentive to mitigate greenhouse emissions via nonconventional carbon dioxide (CO_2) enhanced oil recovery (EOR) by storing more CO_2 compared to oil reservoirs conventionally flooded with CO_2.

Noble Field, discovered in 1937 in Richland County, Illinois, includes some of the Basin's most productive thick Cypress Sandstone reservoirs. Geophysical log correlation and mapping over more than 259 km^2 indicates a generally east-west trending sandstone body nearly 4.8 km wide and up to 52 m thick. The thick Cypress Sandstone at Noble Field has 15–19% porosity and permeability values that can exceed 1 Darcy with an oil column that can surpass 6 m. Sedimentary facies analysis of available core is being conducted to better understand the depositional environment and internal heterogeneity of the reservoir.

This presentation focuses on detailed geologic characterization of the Cypress Sandstone at Noble Field, leveraging a large and diverse dataset typical of Illinois Basin oil fields to evaluate potential economic CO_2-EOR and storage with aims to extrapolate findings to other areas of the Basin. Geologic characterization, in conjunction with digital porosity log data from over 130 wells, is being used to create a three-dimensional geocellular model that represents the internal architecture of the reservoir for use in reservoir simulations. Historical records are being used to establish the production history by lease to set the initial conditions of the model for hypothetical CO_2 injection scenarios. Preliminary results of detailed characterization and three-dimensional geocellular modeling at Noble Field will be presented.

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Illinois State Geological Survey

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Outline

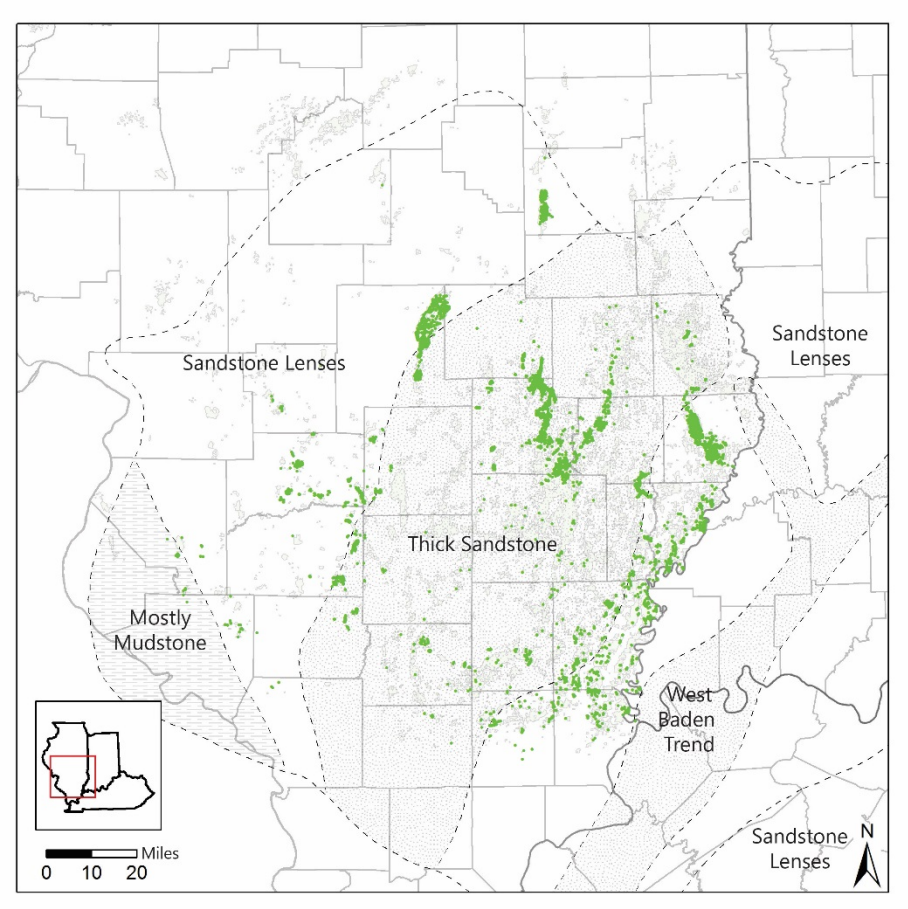
- Background
- Noble Field
  - Building the Database
  - Production History
  - Geology
  - Geocellular Modeling
  - Preliminary Findings
- Implications and Future Work

Background: Motivation for study

- Oil zones in the top of thick sandstones are a target for CO_2-EOR and geologic storage
  - EOR: Conventional reservoir and possible residual oil zone (ROZ)
  - Storage: Vast capacity in aquifer
- Objectives: Four year study to…
  - Develop a method to economically recover incremental oil while storing CO_2 in the underlying aquifer
  - Identify ROZs by looking for direct and indirect indicators
    - Direct: Oil saturation profiles from core or log analysis
    - Indirect: Tilted oil/water contact, relatively fresh water, different oil composition
  - Determine potential for net carbon negative oil production

Background: Cypress Ss Provinces

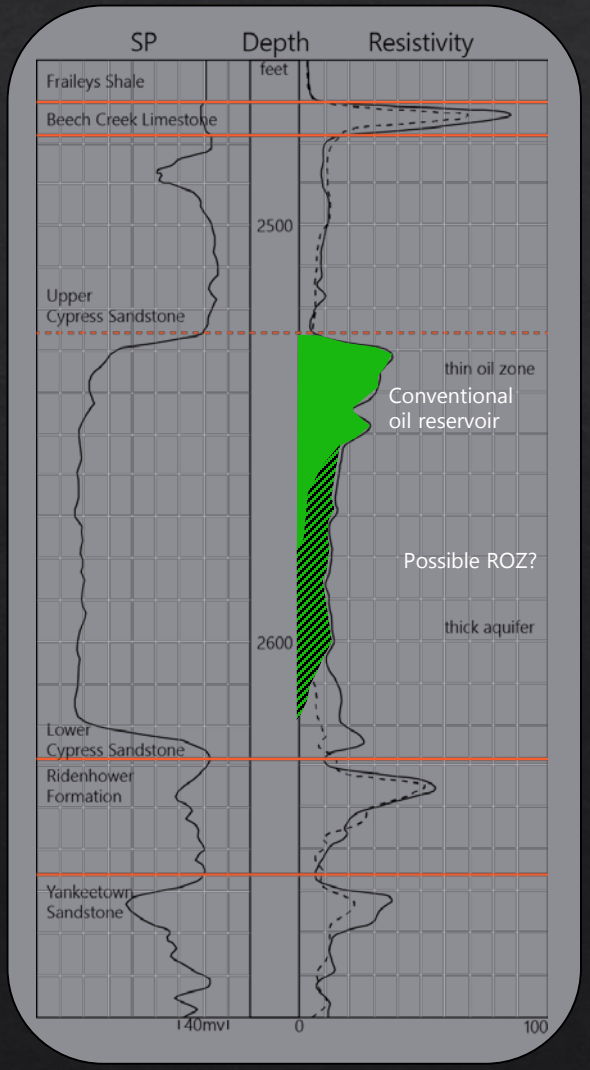
- Multiple Cypress Sandstone provinces in the Illinois Basin
- Production commonly from sandstone lenses
- Oil zones in thick Cypress Ss
  - Mobile oil above thick (100+ feet) saline aquifer
  - Fining upward / increasing permeability with depth
- Potential residual oil zones
  - Naturally waterflooded over geologic time



Cypress Sandstone provinces with Cypress producing wells in Illinois shown in green

Background: Thick Cypress Reservoirs

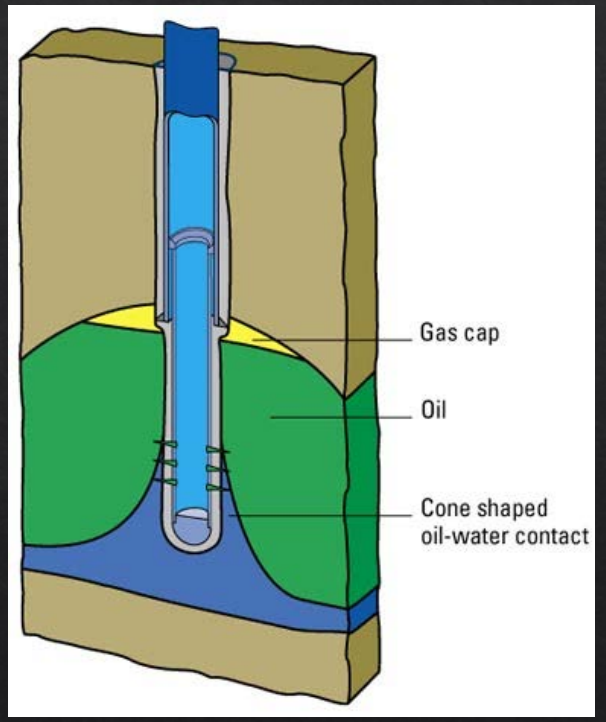
- Nonconventional CO_2-EOR
  - Bypassed resource due to production difficulty
  - Potential ROZ and high net CO_2 utilization
  - Saline storage potential of 3.5 to 40.2 Tcf (0.2 to 2.3 Gt)* of CO_2 in the Illinois Basin (DOE/MGSC, 2012)



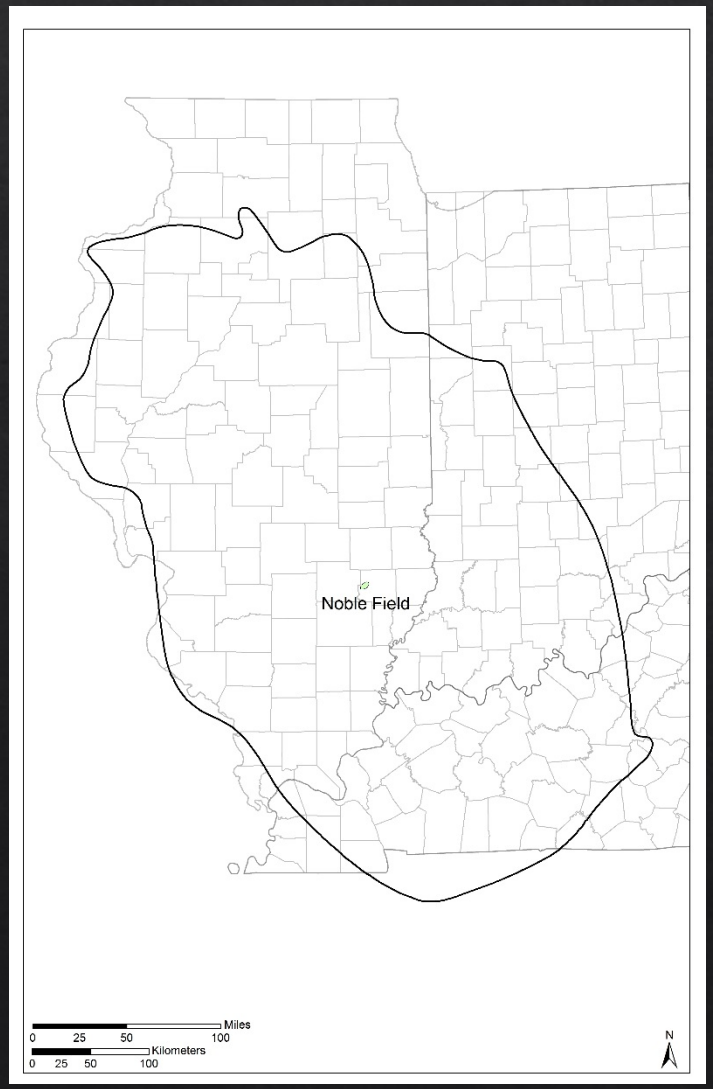
*Using storage efficiency (E) factors of 0.4% and 5.5%, respectively, which represent the P_{10} and P_{90} estimates.

Background: Historical Field Development

- Vertical wells, many bare foot completions
- Reservoirs in thick sandstones had low oil recoveries due to excessive water coning
- Generally primary production only; some "waterflooding" (disposal of produced water)
- Polymer injection to block water (undocumented)
- Horizontal wells drilled in the last few decades
- No substantive long term EOR attempts
- Few areas of the Basin where thick Cypress Sandstone is a prolific producer; Noble Field is the best example



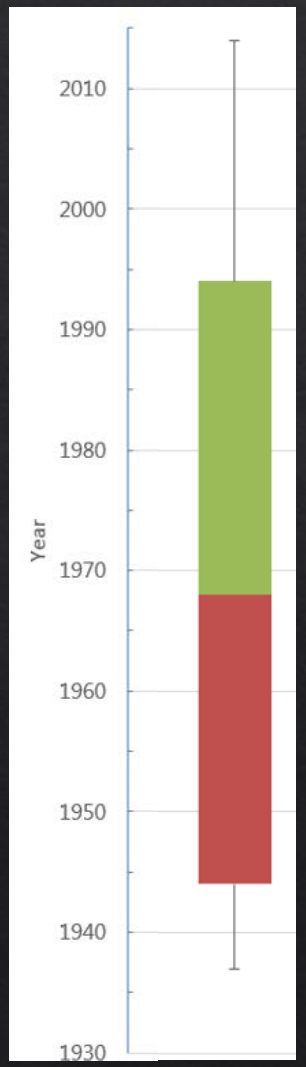
Noble Field Location



- Discovered in 1937 by Pure Oil
- Part of Clay City Consolidated Field
- 5 main producing formations
  - All are Mississippian in age
- Produced >46 MMBO
- Thick Cypress Sandstone is a major producer

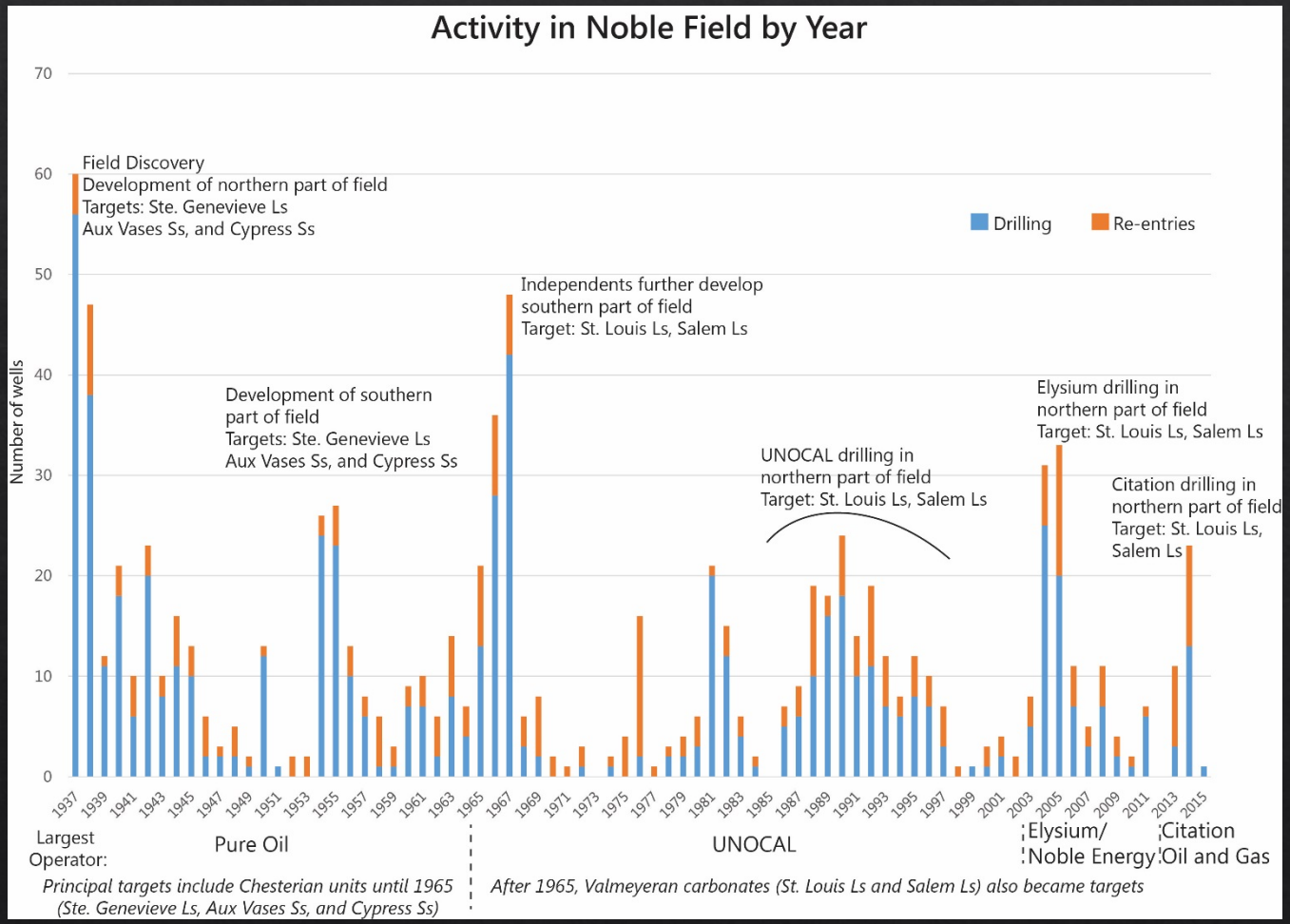
Building the Database

- Pipeline oil production reports
  - Production history assembled
- Geophysical logs of varying types and vintages
  - Log cross sections correlated
  - Scanned logs digitized for geocellular modeling
- Numerous cores taken (few remain intact)
  - Available cores described and sampled
  - Core analysis data digitized and compiled



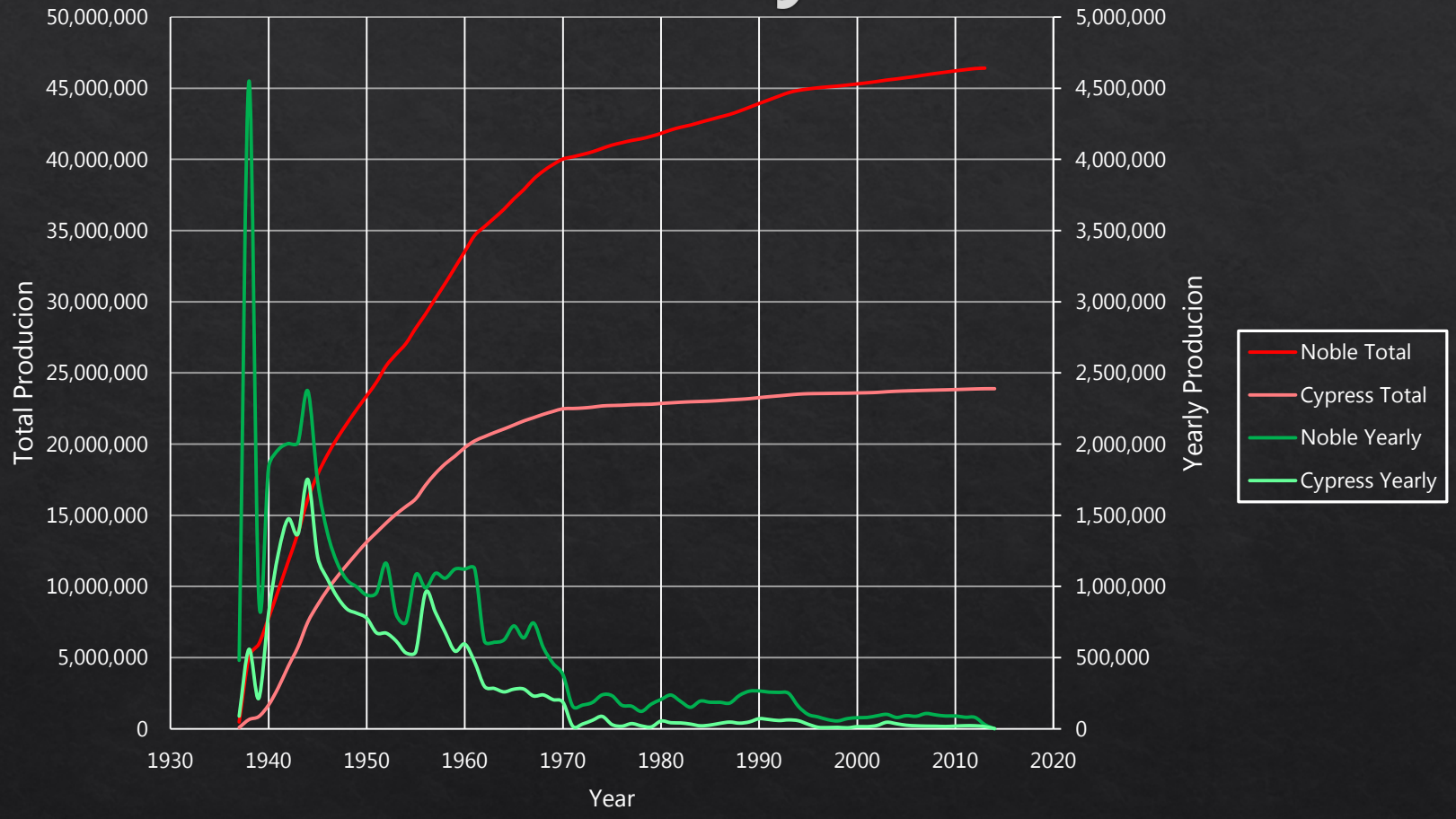
Drilling History:
Each segment represents 25% of total drilling

Drilling History



- Historical drilling activity provides information about timing and targets of drilling
- Helpful in assigning production to target formations
  - Compare to comingled production curve

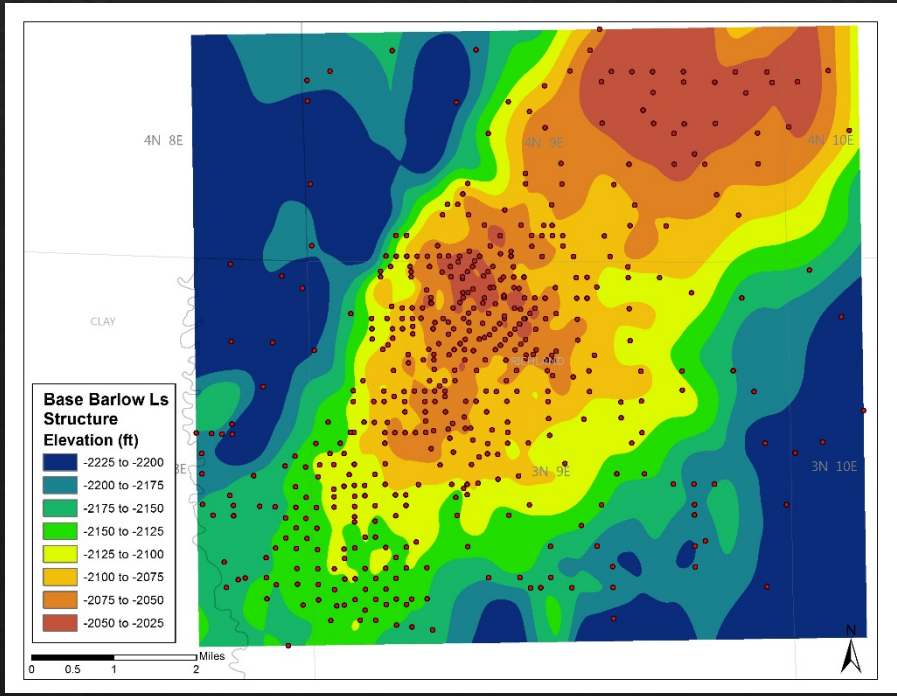
Production History

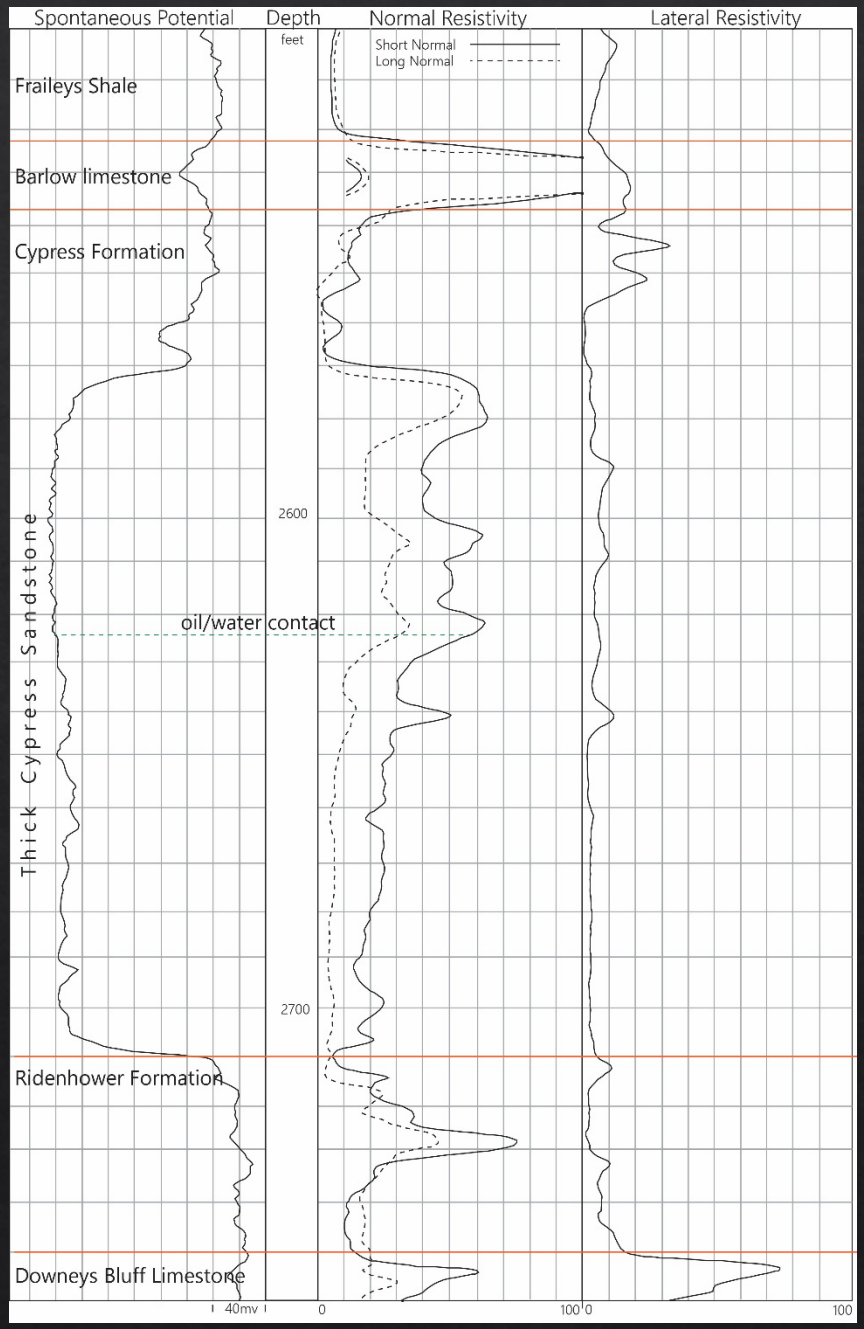


- Cumulative production (all formations) of 46 MMBO at Noble Field
- Up to 50% of this production (23.9 MMBO) from the Cypress Sandstone

Geologic Setting

- Cypress Sandstone is up to ~175 feet thick
- Field is located on SW plunging nose of the 4 mile wide Clay City Anticline

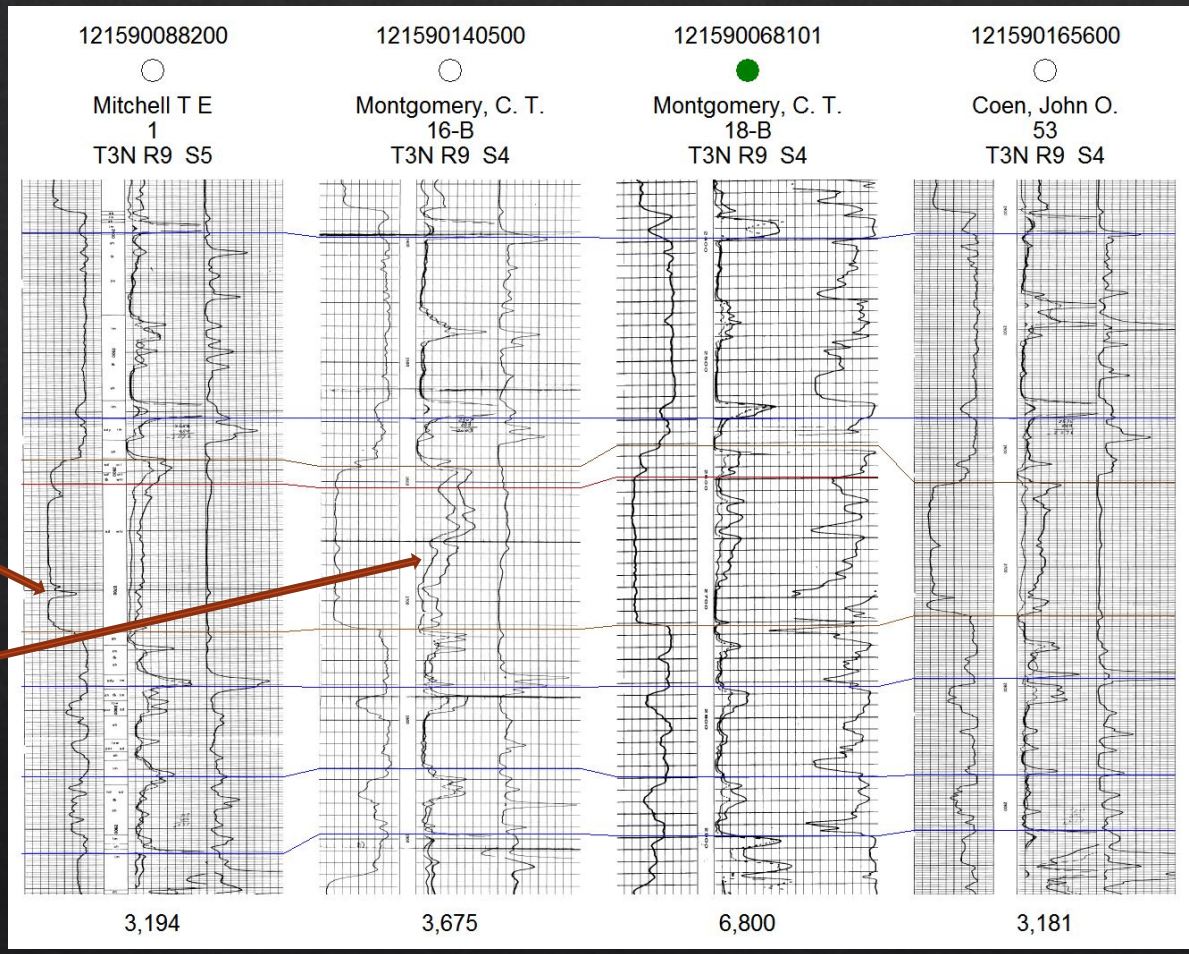




Type log: C.T. Montgomery B-15, API 121590140400

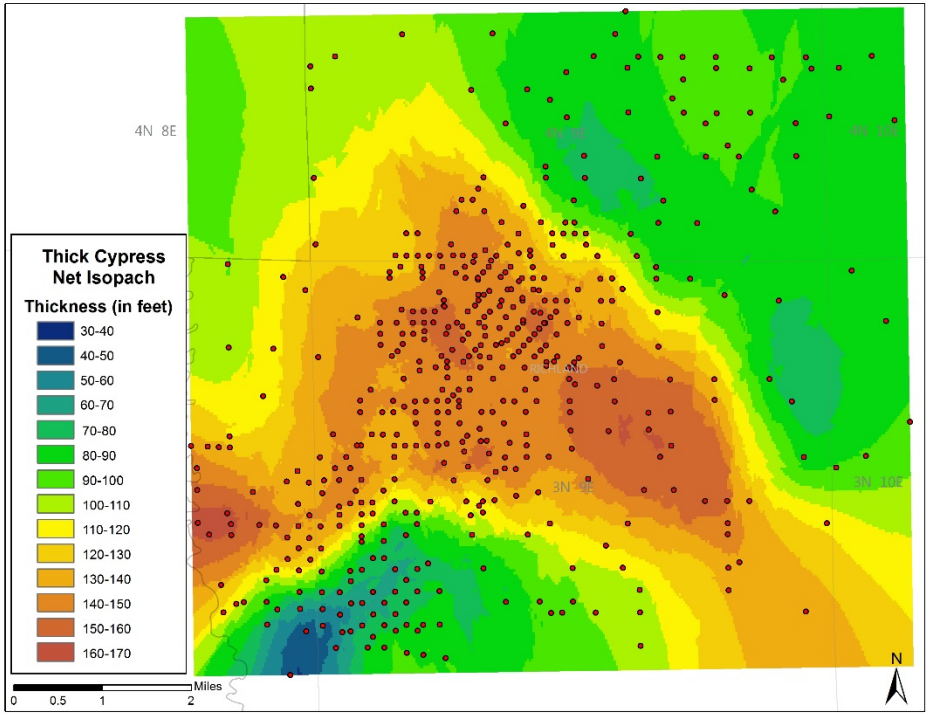
Cross Section Correlations

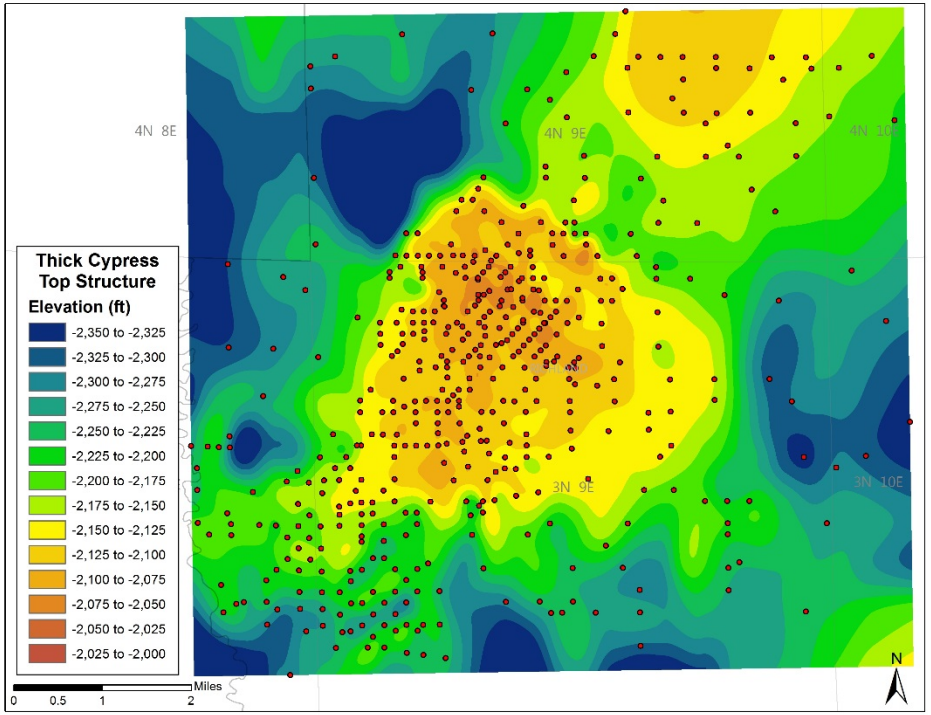
- Well defined, blocky appearance on SP logs
  - Laterally continuous – easy correlation
  - Few internal baffles
    - Some continuous shale breaks
    - Persistent calcite cemented zones
  - Base of sandstone can truncate underlying units



East - West log cross section

Cypress Sandstone Geometry

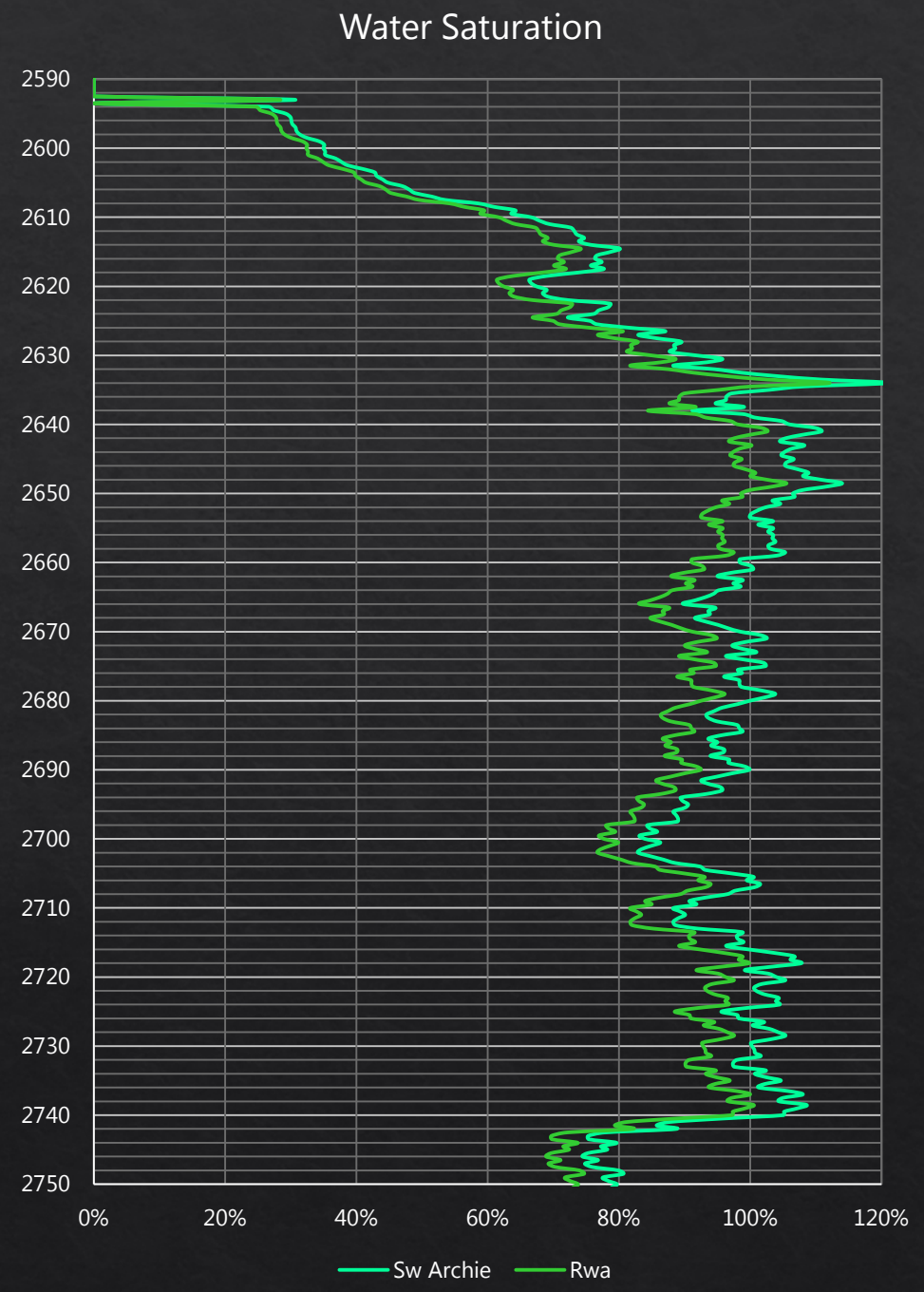




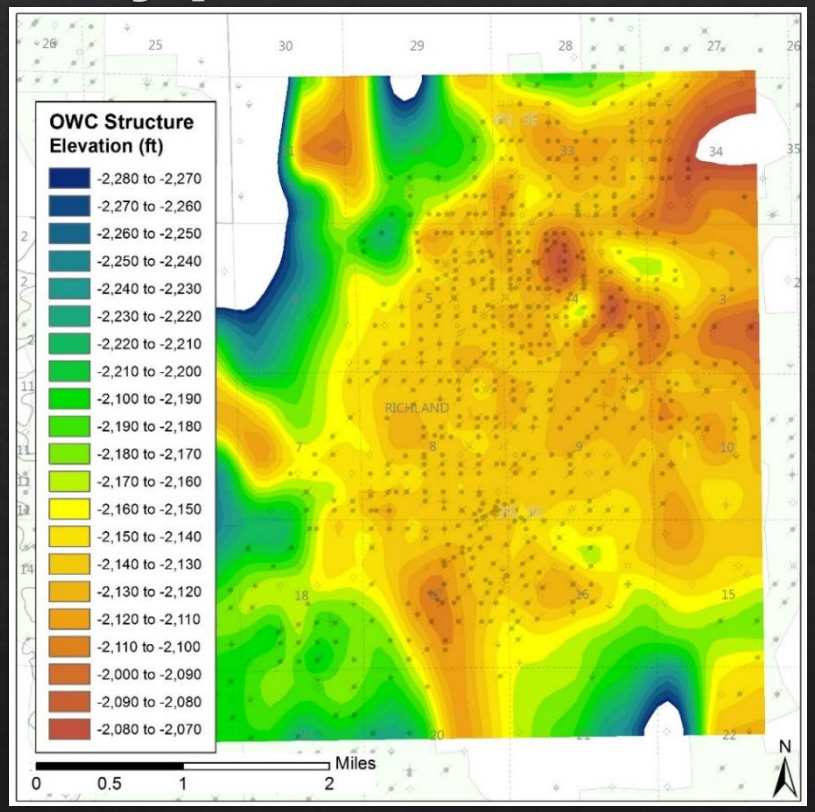
- Isopach map shows generally E-W trending sandstone body
  - Thickest sandstone occurs on flanks of the Clay City Anticline
- Structure on top of sandstone shows effects of differential compaction

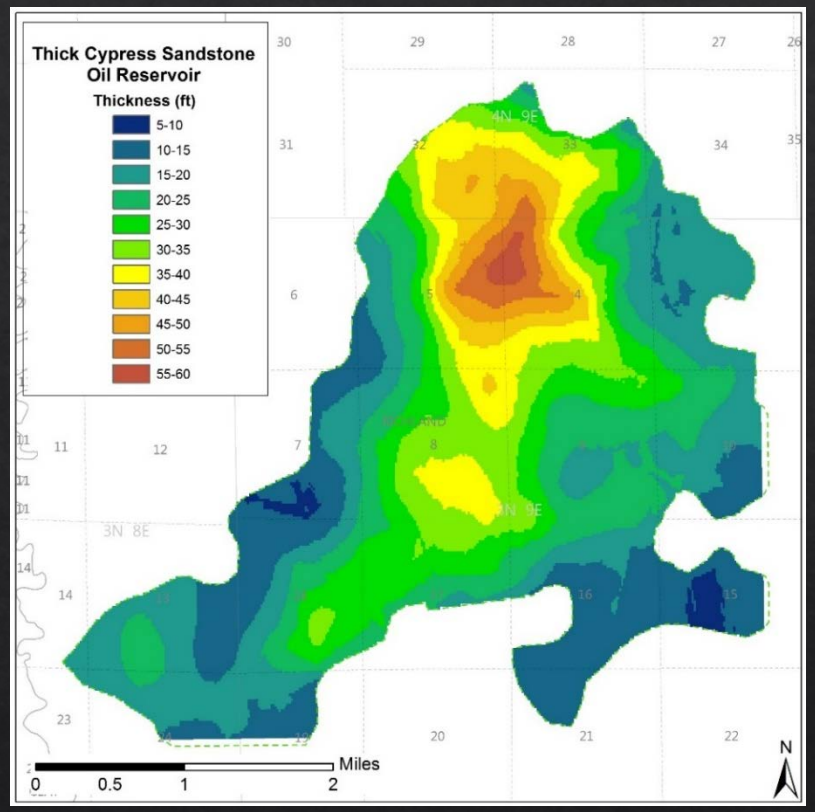
Petrophysics

- Testing various petrophysical methods to identify ROZs
  - Apparent water resistivity
  - Resistivity-derived porosity
  - Ratio water saturation
- Developing methods that can use old e-logs



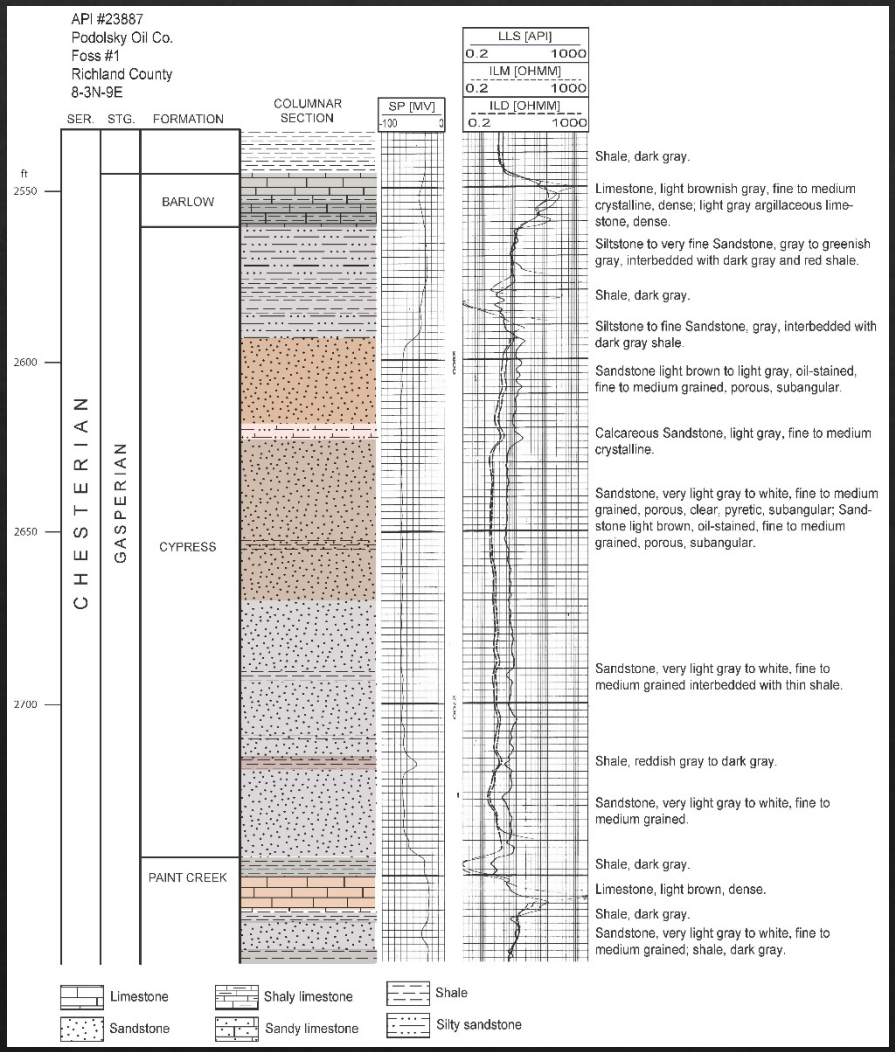
Cypress Sandstone Oil Reservoir





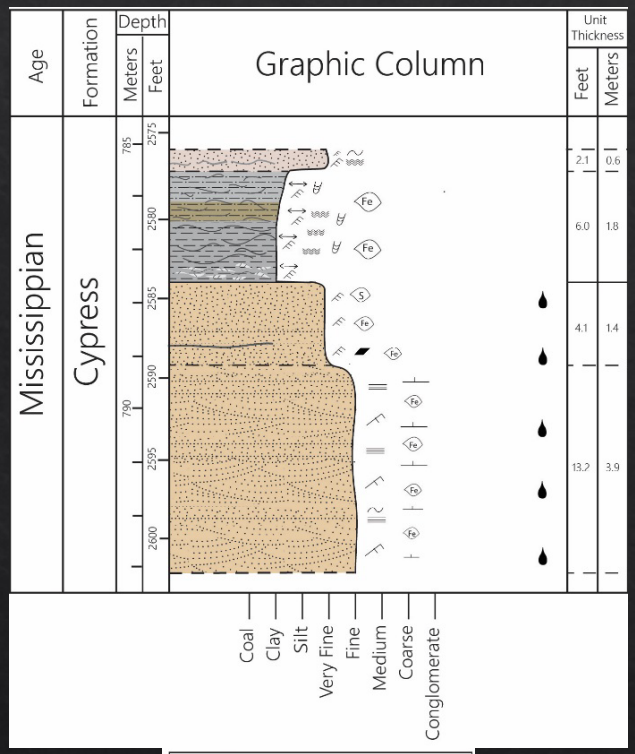
- Tilted oil/water contact (OWC) indicates possible ROZ
- Isopach of reservoir above OWC shows off-structure oil
- Preliminary OOIP of Cypress Ss ~100 MMBO without ROZ
  - Recovery efficiency of ~24%

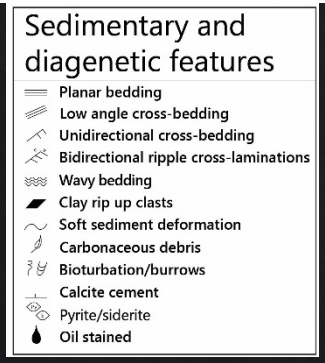
Sedimentology



- Examining sample sets in and near Noble Field
  - Fine to medium grained sandstone; not consistently fining upward
- Describing characteristics of internal baffles
  - Laterally persistent shaly interbeds are fossiliferous
  - Dense, calcite cemented intervals

Sedimentology

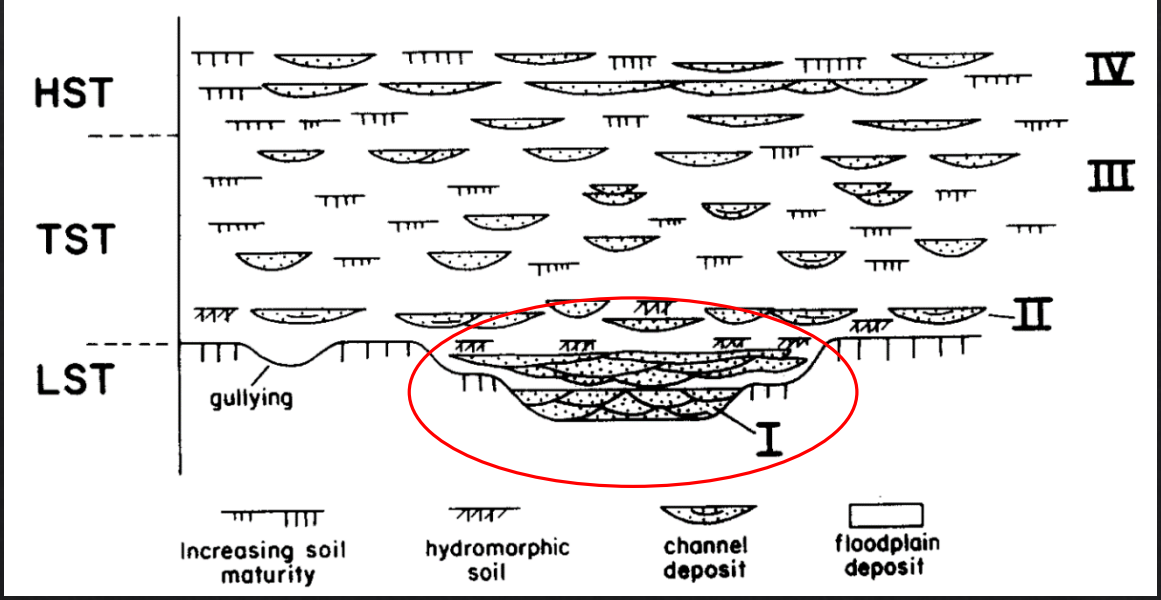




- Describing available cores and conducting facies analysis
  - Fluvial cross-bedded sandstones grade upward into heterolithic, estuarine deposits
- Sampling cores for porosity, permeability, mineralogy, trace elements, SEM, and thin sections
  - Developing diagenetic history
  - Determining effects of diagenesis on reservoir quality

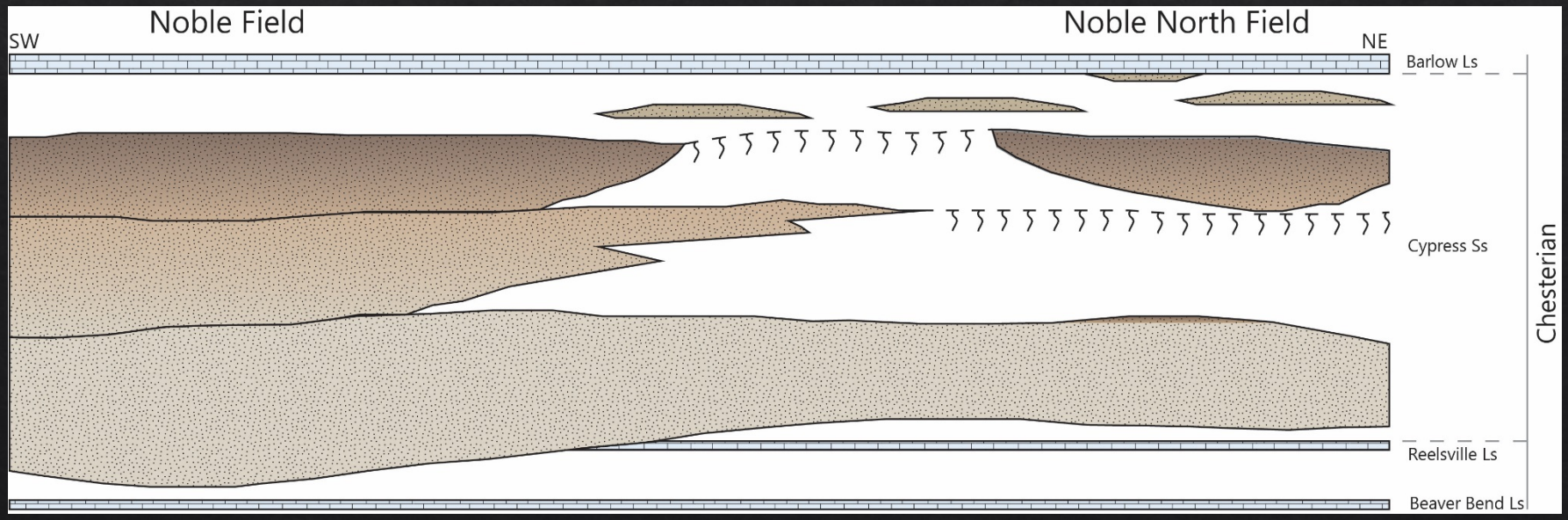
Depositional Environment

- Thick Cypress Sandstone likely part of lowstand (LST) incised valley fill environment
  - Multistory sandstone built through three or more fluvial to estuarine depositional episodes
  - Amalgamated fluvial to estuarine channels are punctuated by marine incursions as indicated by marine fossils



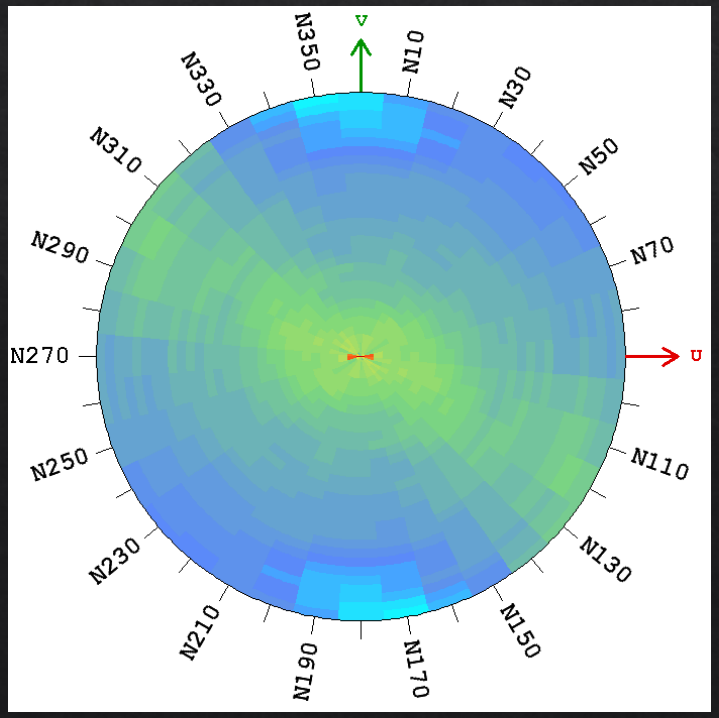
Geological Model

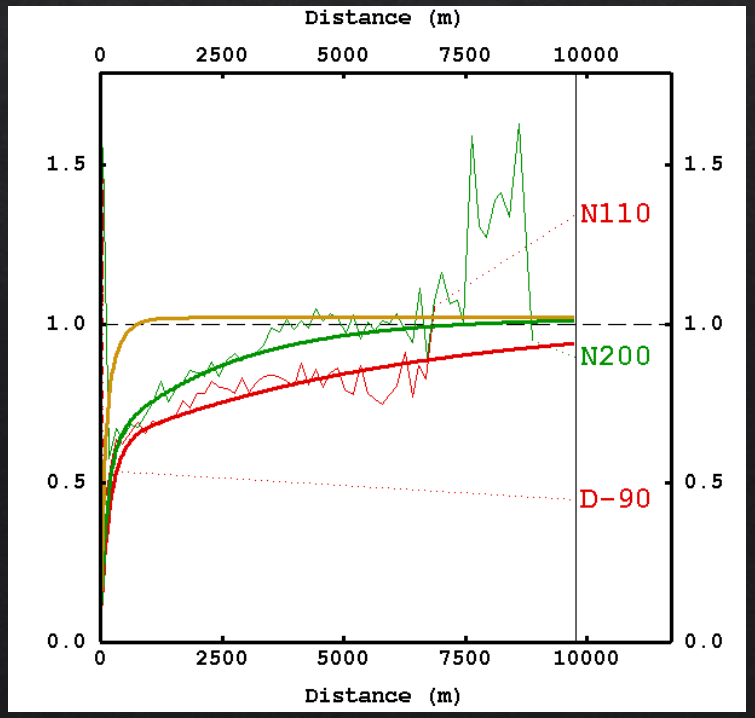
- Basal sandstone story blankets entire field and reportedly covers much of the nearby counties; indicates low accommodation
- Middle and upper sandstone stories amalgamate at Noble Field but are less persistent elsewhere
  - Top of thick Cypress Ss is convex upward where sandstones stack
  - Differential compaction over amalgamated sandstones create stratigraphic traps



Variogram Development

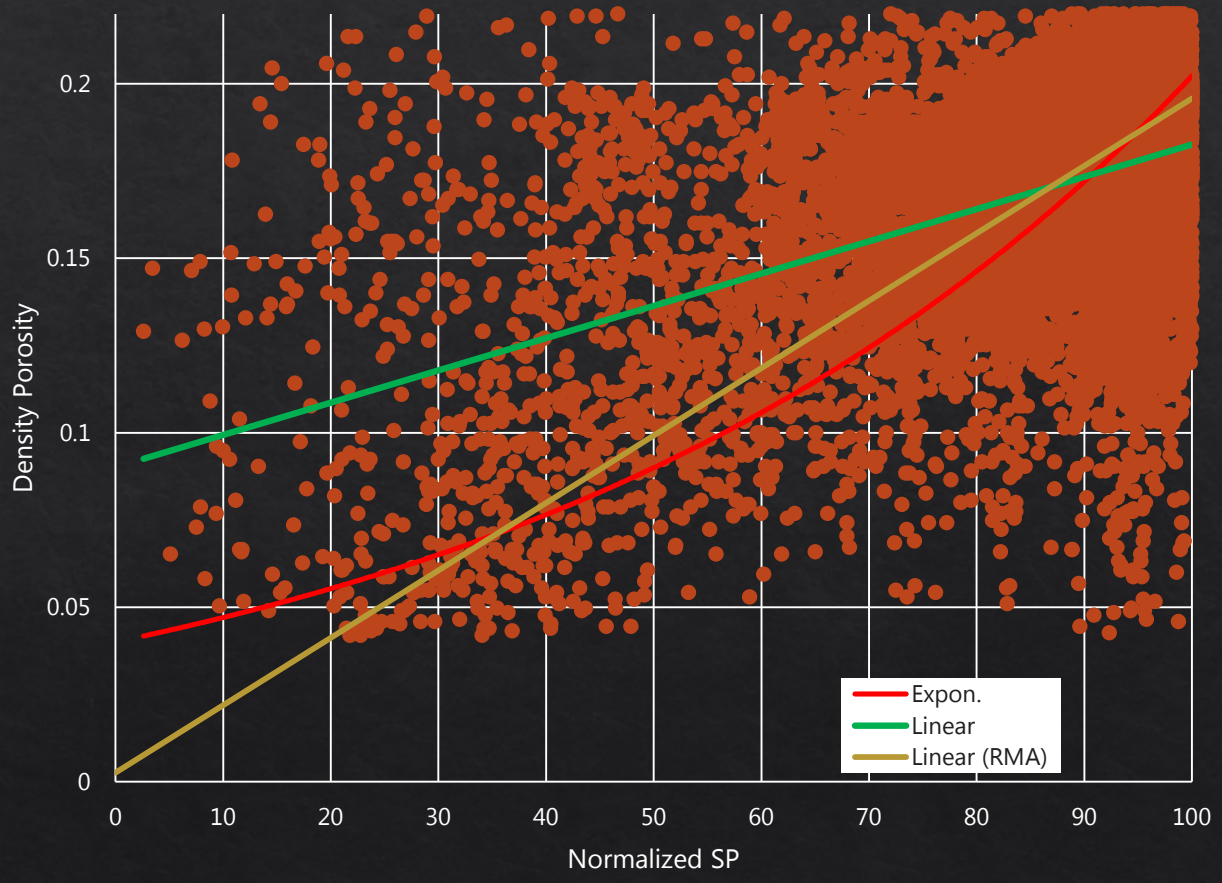
- 385 SP logs and 129 neutron-density porosity logs used to develop geocellular model that closely reflects geologic observations
  - Normalized SP logs used in variogram model to detect reservoir anisotropy and quantify spatial autocorrelation
  - Variogram reflects E-W trend of Cypress Sandstone body





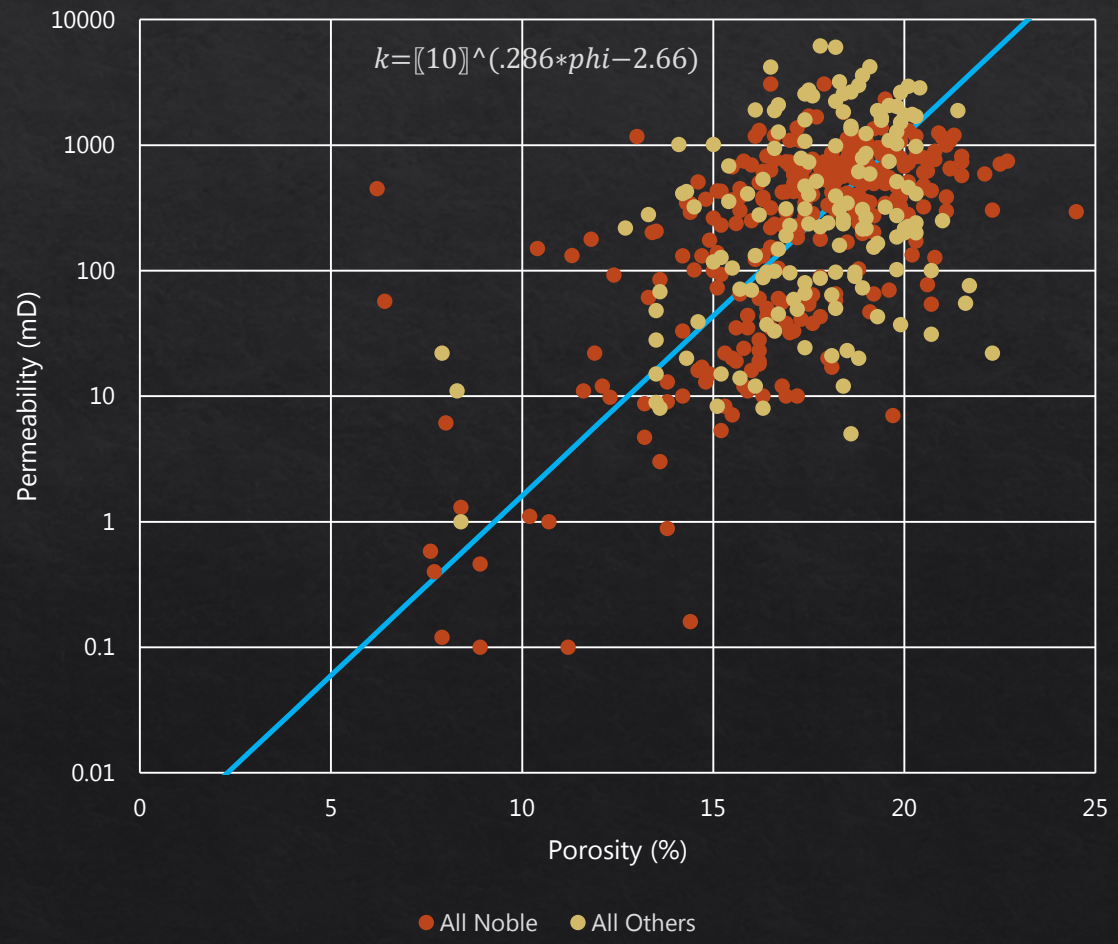
SP Log/Porosity Transform

- Transform created using:
  - Normalized SP curves
  - Core measured porosity and porosity from logs
- Log data is being analyzed to refine the correlation



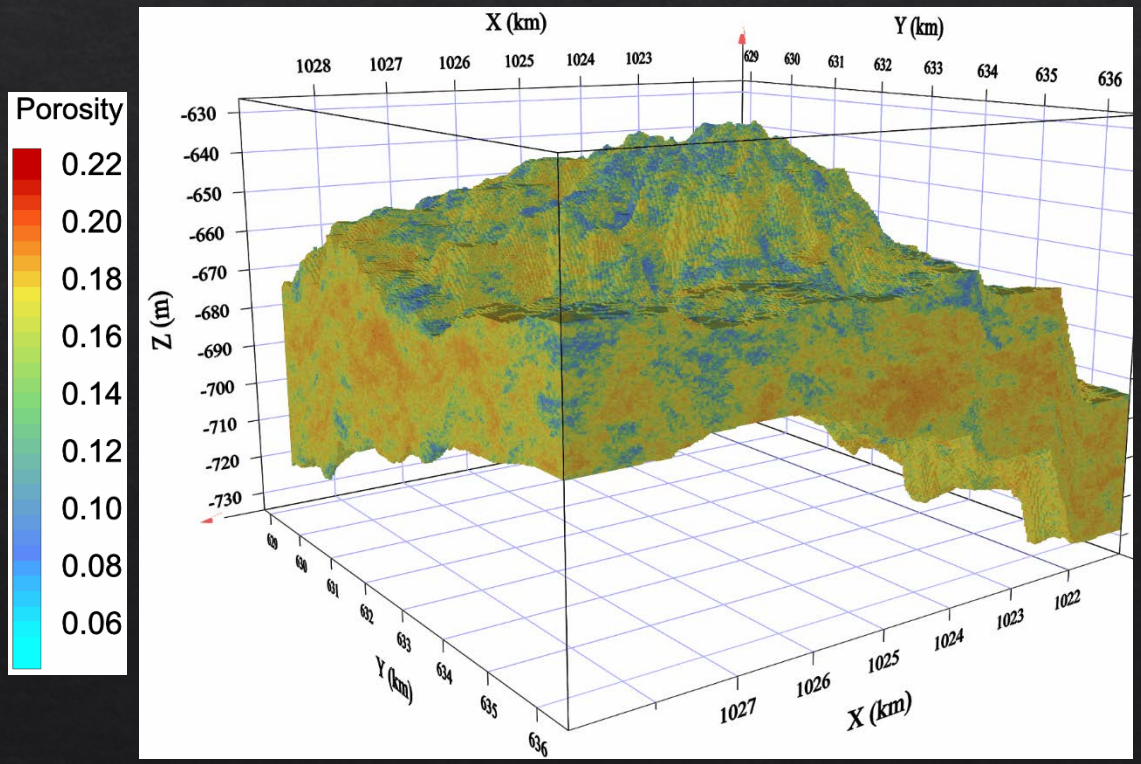
Porosity/Permeability Transform

- Transform created using:
  - Porosity and permeability data from core
  - Most cores only penetrate the upper 50 feet of the thick Cypress Sandstone
- Ongoing work to refine single correlation approaches



Geocellular Model

- Current iteration captures large scale features (sand/shale) but misses thin calcite cemented zones
  - Limitation of SP based model



Noble Field: Preliminary Findings

- Thick Cypress Sandstone contributed ~50% of cumulative production
- Combination of structural and stratigraphic controls on oil trapping
- Oil column up to ~60 feet thick with potential for underlying ROZ
  - Indications from petrophysical analysis
  - Oil/water contact is tilted towards the south
- Multistory fluvial/estuarine sandstone bodies make up the thick Cypress Sandstone
- Geocellular model captures anisotropy and sand/shale heterogeneity but needs further refining to include diagenetic features

Implications and Future Work

- Noble Field has thickest known oil column and <25% recovery efficiency – potential for ROZ and successful CO_2-EOR
- Reservoir simulations to determine most effective CO_2-EOR and storage method
  - Scenarios weighted towards oil production and storage
  - Potential to produce net carbon negative oil (NCNO)
- Regional resource estimate using lessons learned from Noble Field
  - Better understanding of the geology of the thick Cypress Sandstone
- Regional mapping of the thick Cypress Sandstone
  - Identification of locations with oil reservoirs analogous to Noble Field
- Refine algorithm for identifying ROZs
  - Petrophysical methods supported by cased hole pulsed neutron logging, measuring saturation in fresh core, measuring oil and water composition

Acknowledgements

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- 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 reservoir modeling