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

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Outline

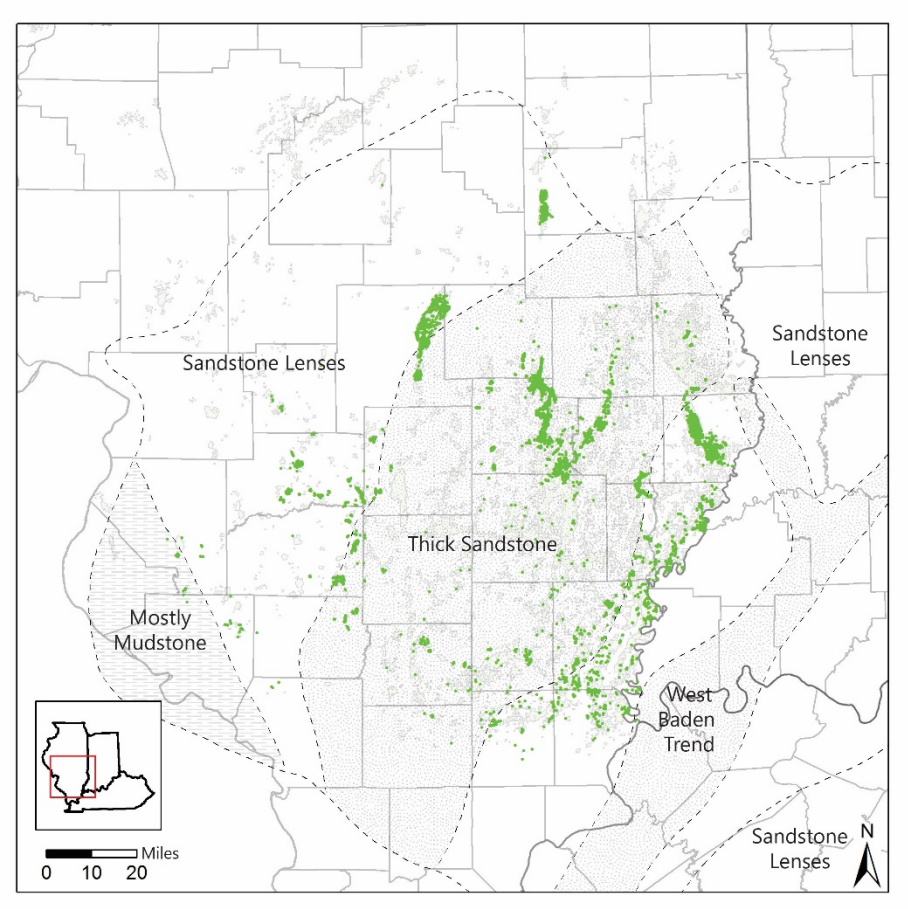
- Background
- Noble Field
  - Building the Database
  - Production History
  - Geology
  - Geocellular Modeling
  - Preliminary Findings
- Implications and Future Work

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

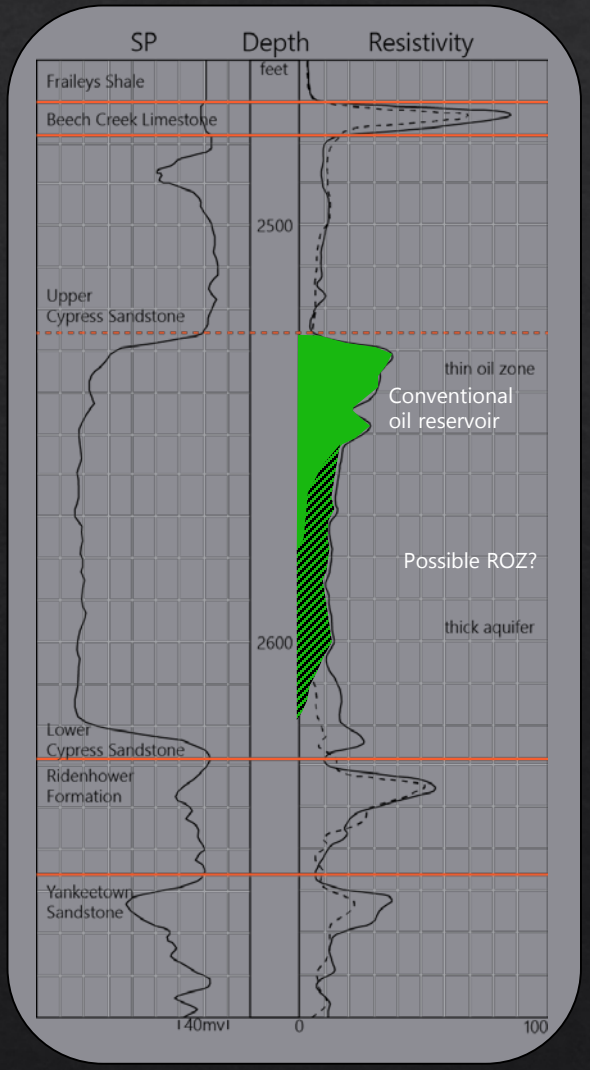
- Multiple Cypress Sandstone provinces in the Illinois Basin
- Production commonly from sandstone lenses
- Oil zones in thick Cypress Ss
  - Mobile oil above thick (100+ feet) saline aquifer
  - Fining upward / increasing permeability with depth
- Potential residual oil zones
  - Naturally waterflooded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



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

Background: Thick Cypress Reservoirs

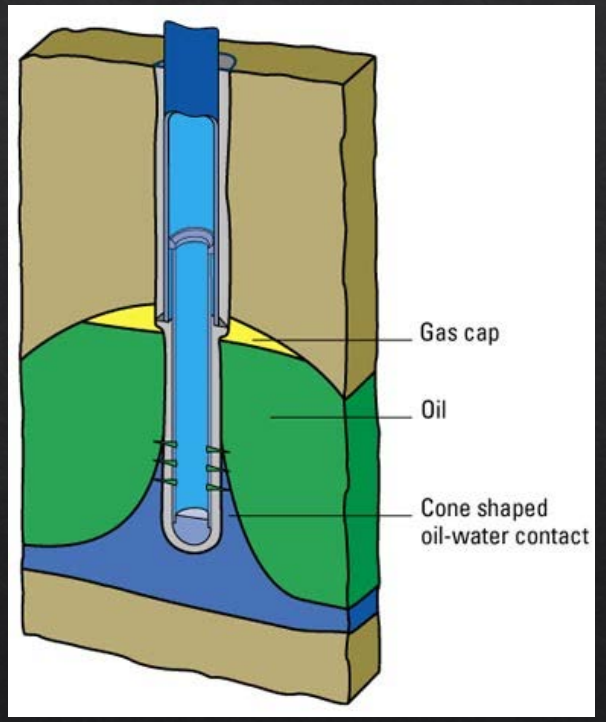
- Nonconventional CO_2-EOR
  - Bypassed resource due to production difficulty
  - Potential ROZ and high net CO_2 utilization
  - Saline storage potential of 3.5 to 40.2 Tcf (0.2 to 2.3 Gt)* of CO_2 in the Illinois Basin (DOE/MGSC, 2012)



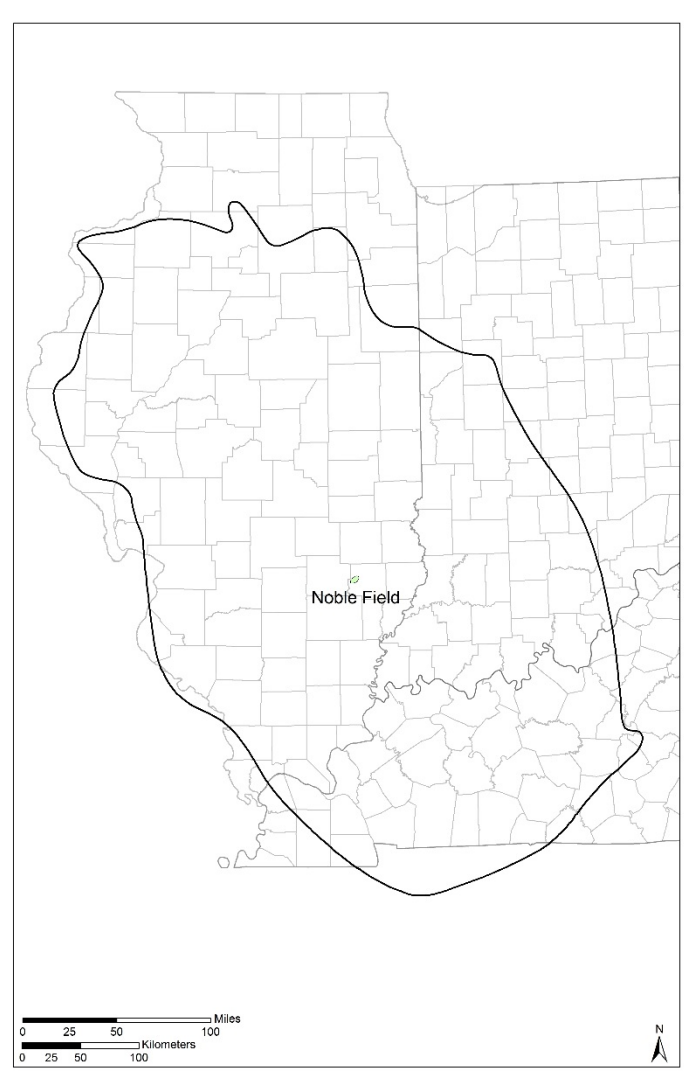
*Using storage efficiency (E) factors of 0.4% and 5.5%, respectively, which represent the P_{10} and P_{90} estimates.

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



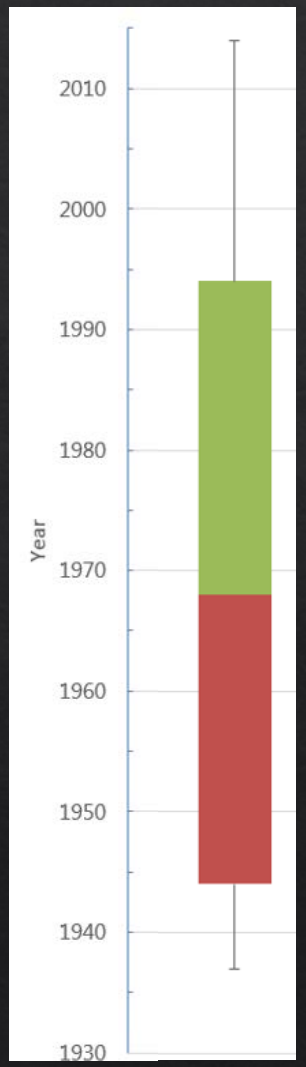
Noble Field Location



- 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

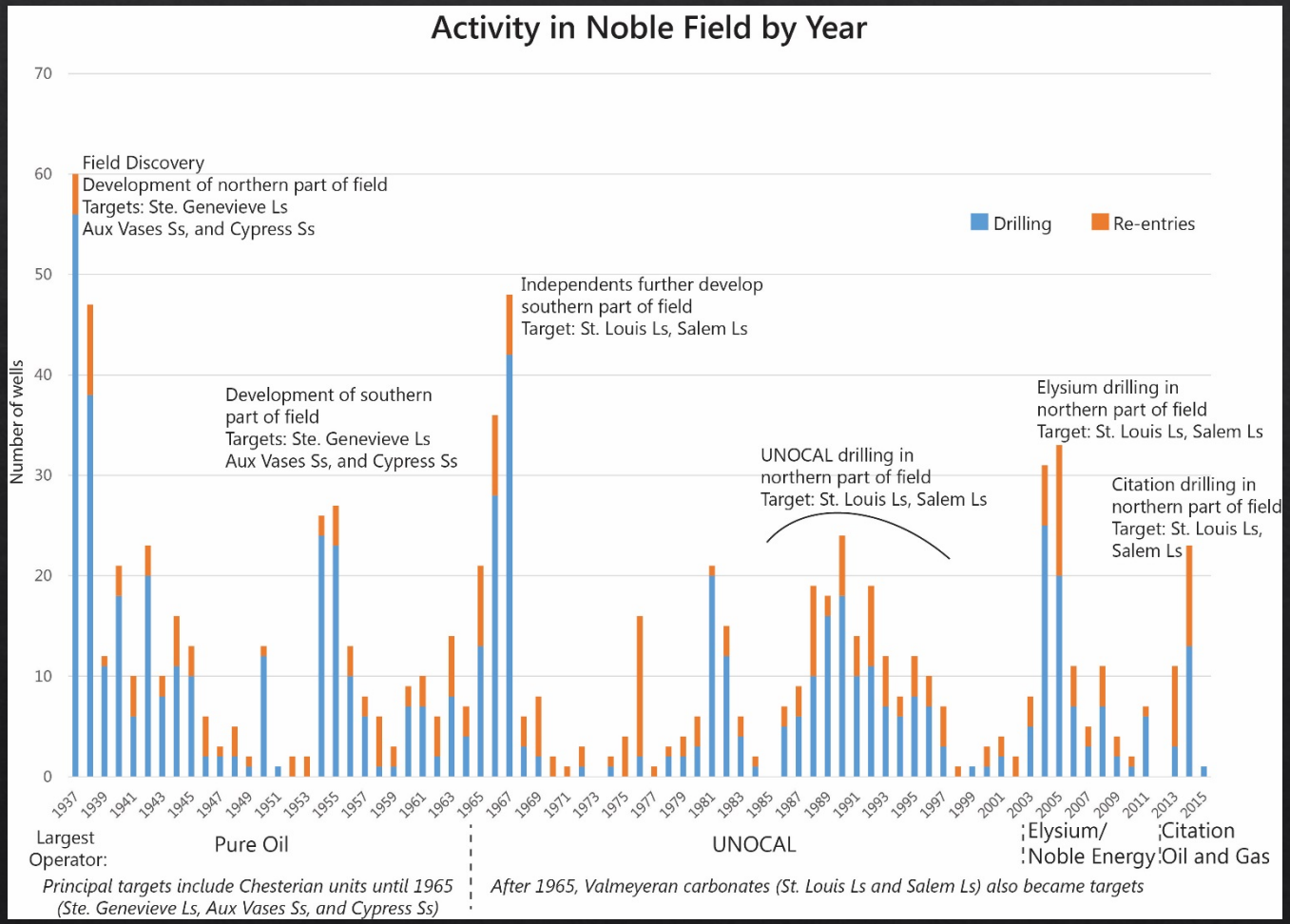
Building the Database

- 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



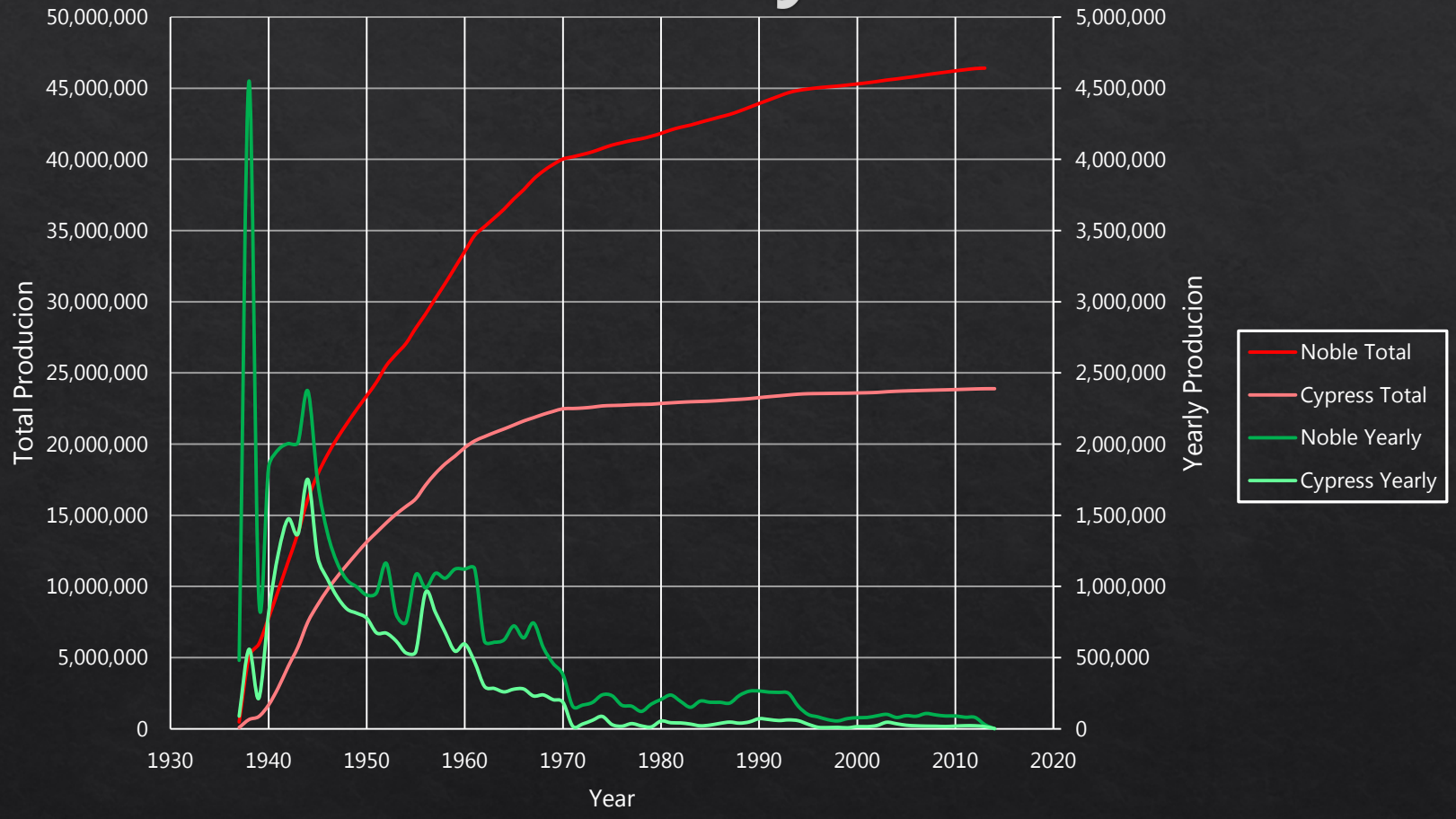
Drilling History:
Each segment represents 25% of total drilling

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

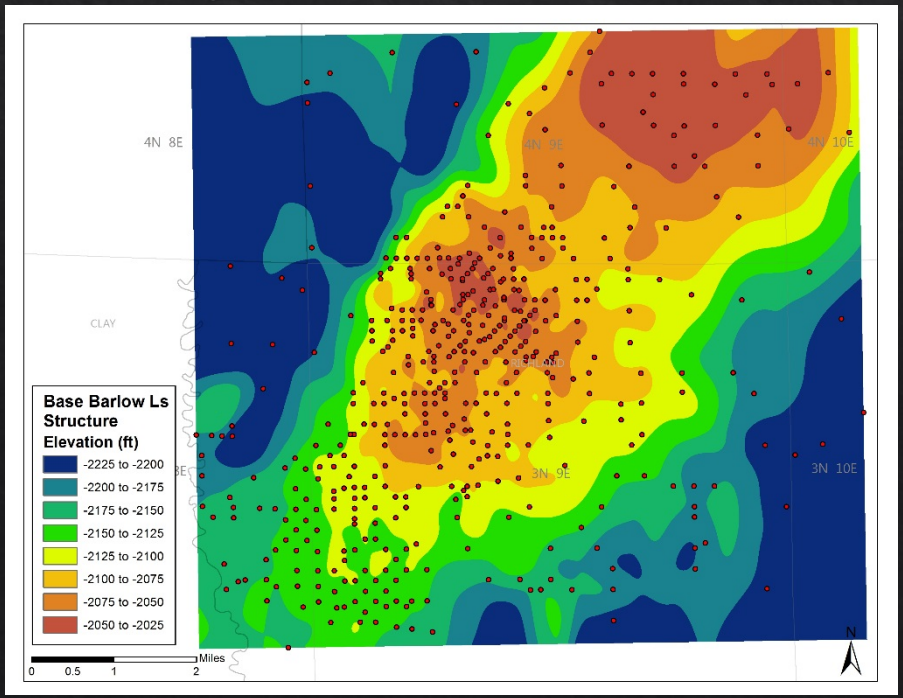
Production History

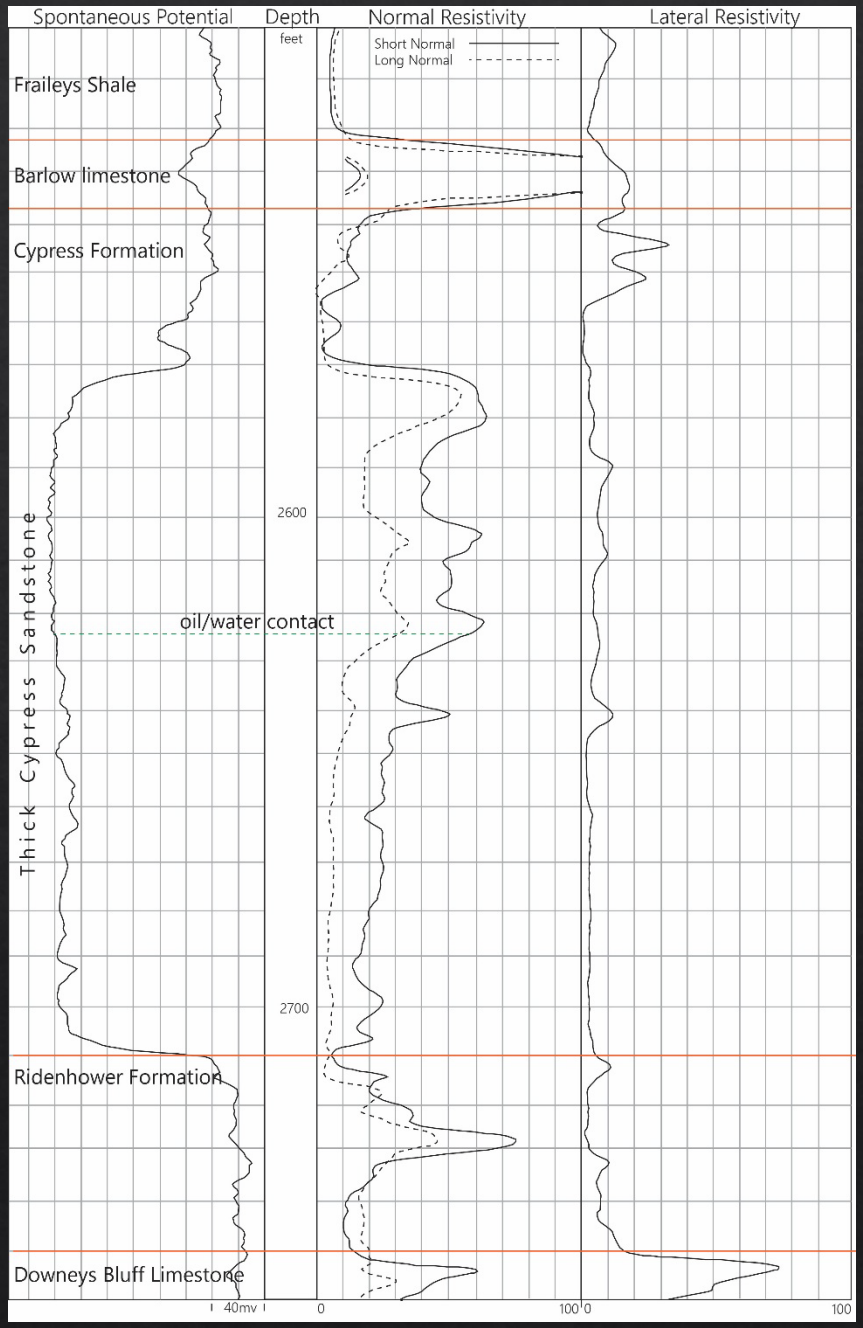


- Cumulative production (all formations) of 46 MMBO at Noble Field
- Up to 50% of this production (23.9 MMBO) from the Cypress Sandstone

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

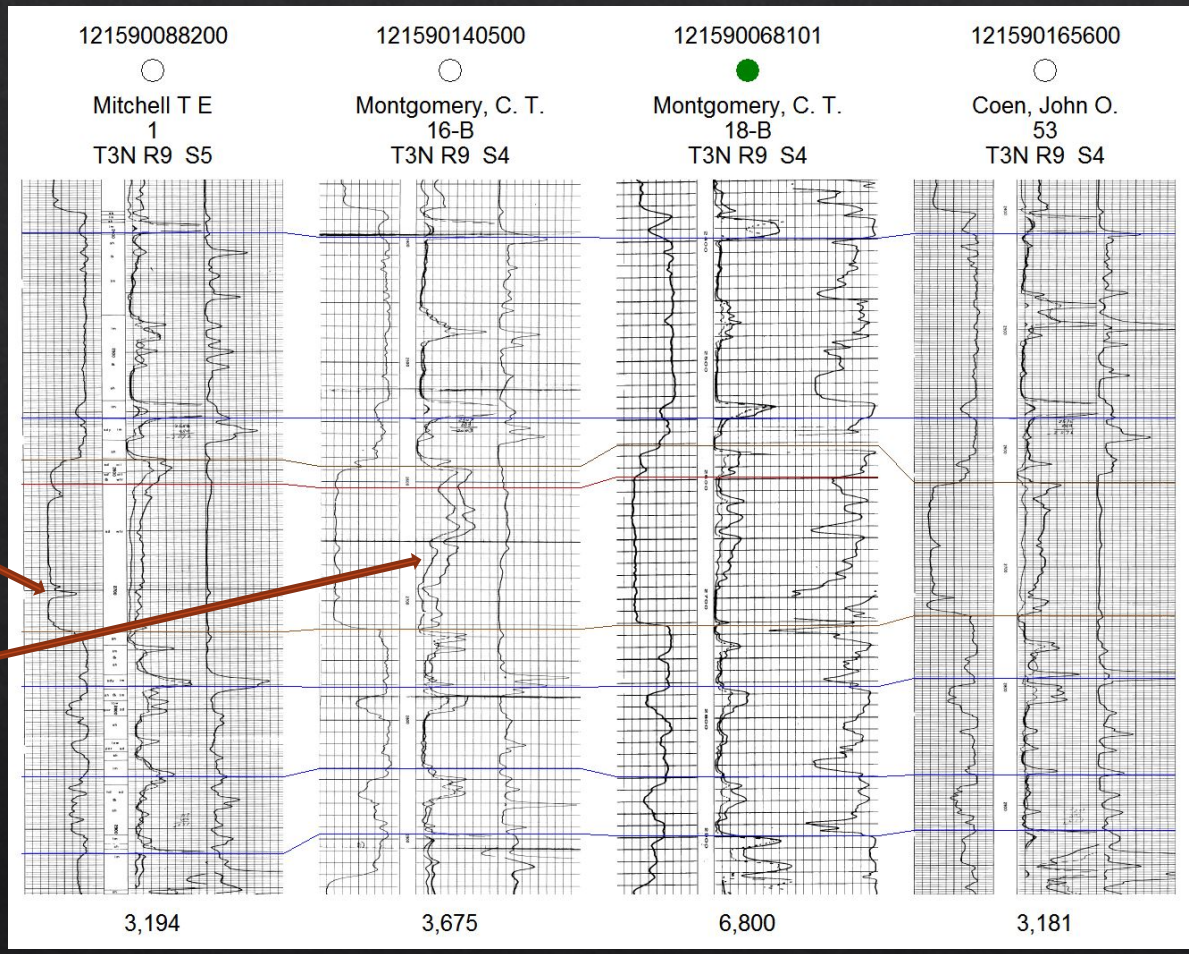




Type log: C.T. Montgomery B-15, API 121590140400

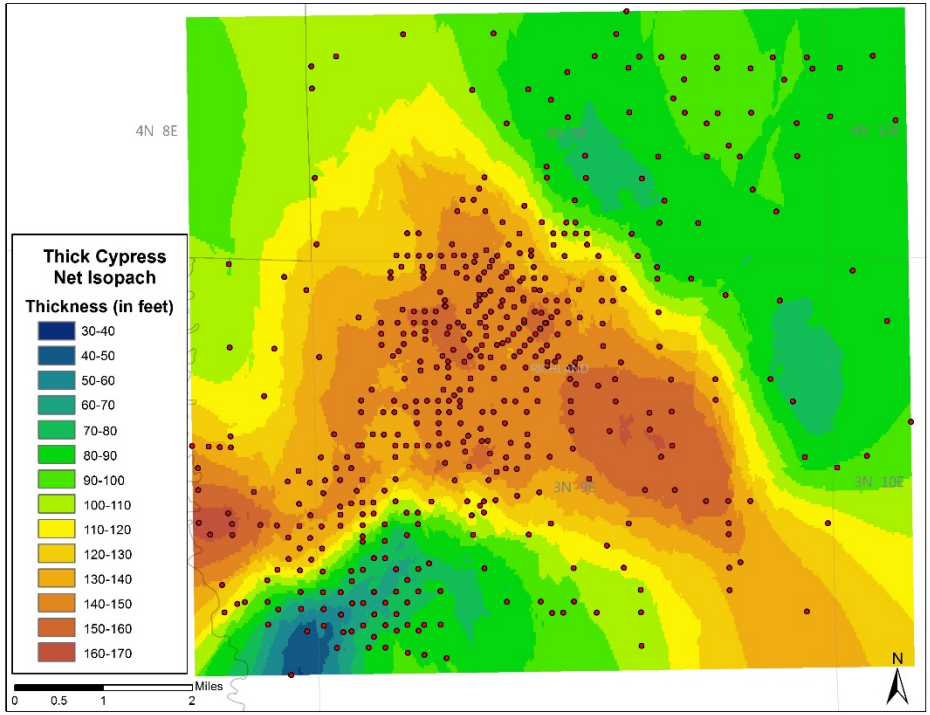
Cross Section Correlations

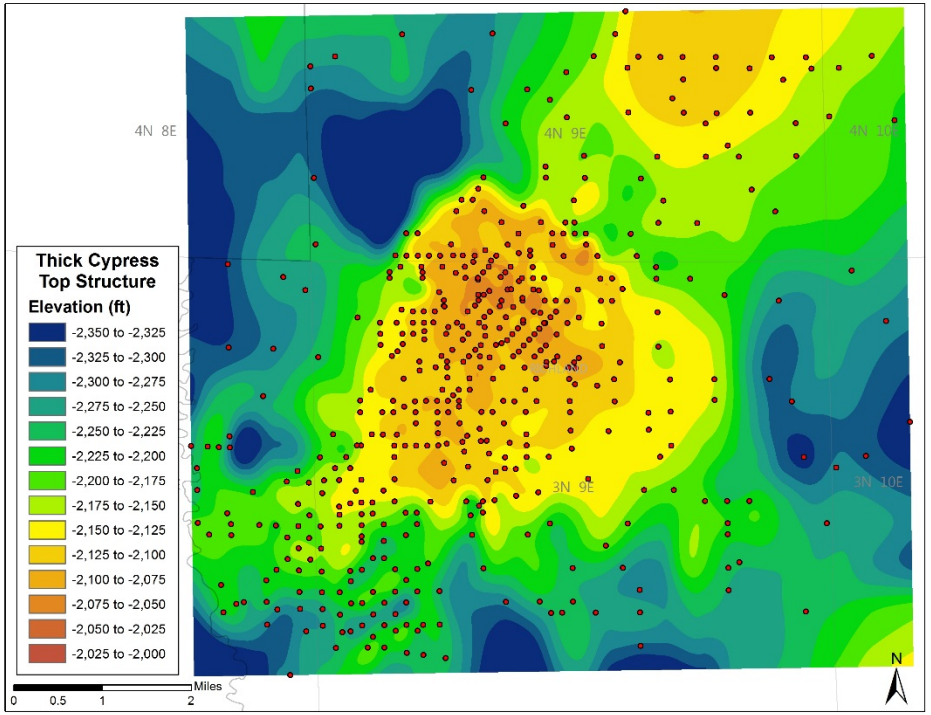
- Well defined, blocky appearance on SP logs
  - Laterally continuous – easy correlation
  - Few internal baffles
    - Some continuous shale breaks
    - Persistent calcite cemented zones
  - Base of sandstone can truncate underlying units



East - West log cross section

Cypress Sandstone Geometry

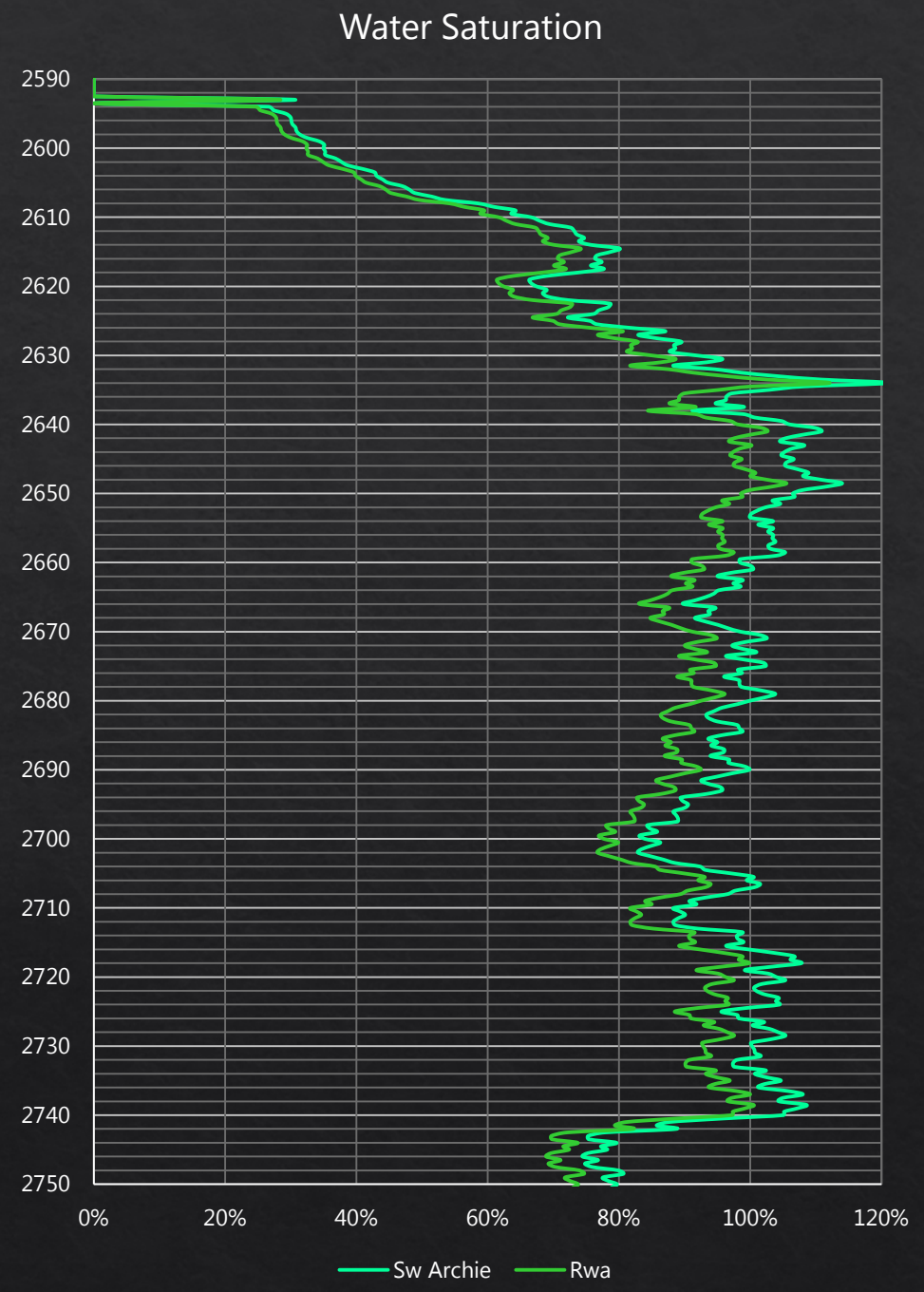




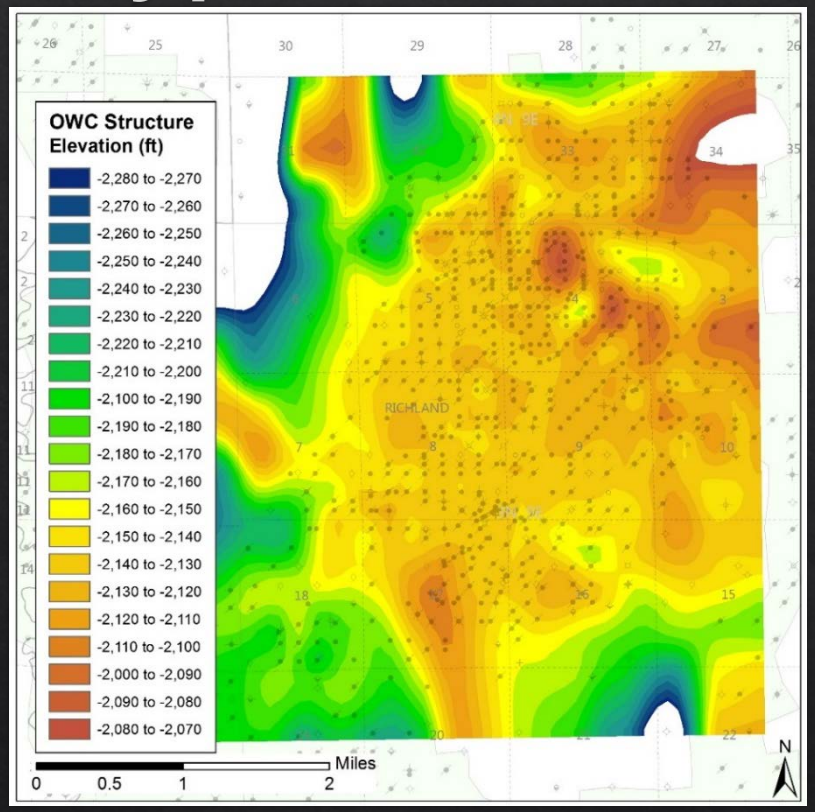
- Isopach map shows generally E-W trending sandstone body
  - Thickest sandstone occurs on flanks of the Clay City Anticline
- Structure on top of sandstone shows effects of differential compaction

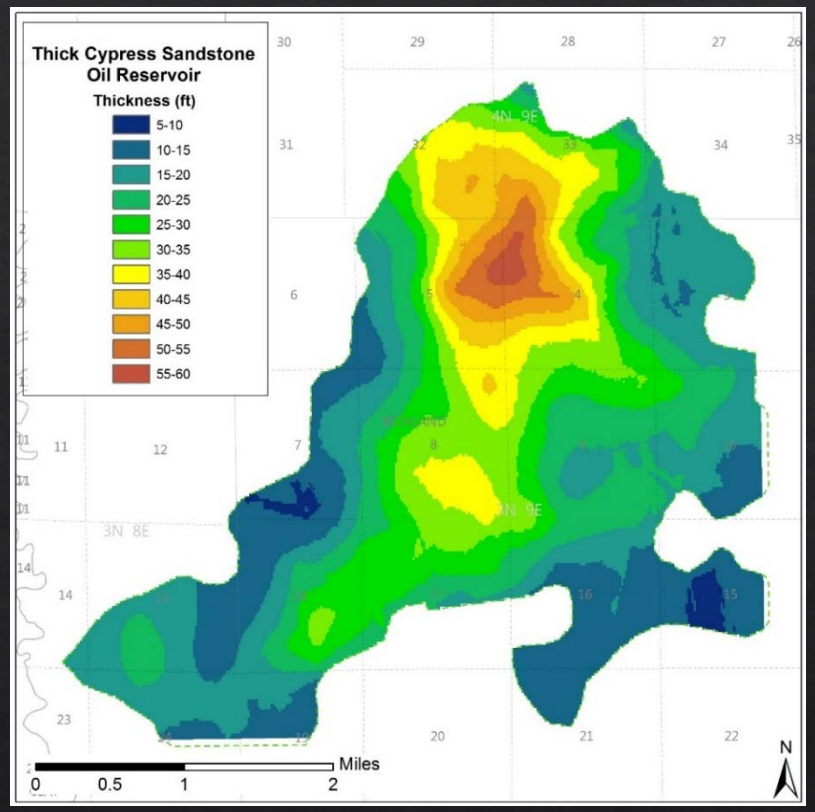
Petrophysics

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



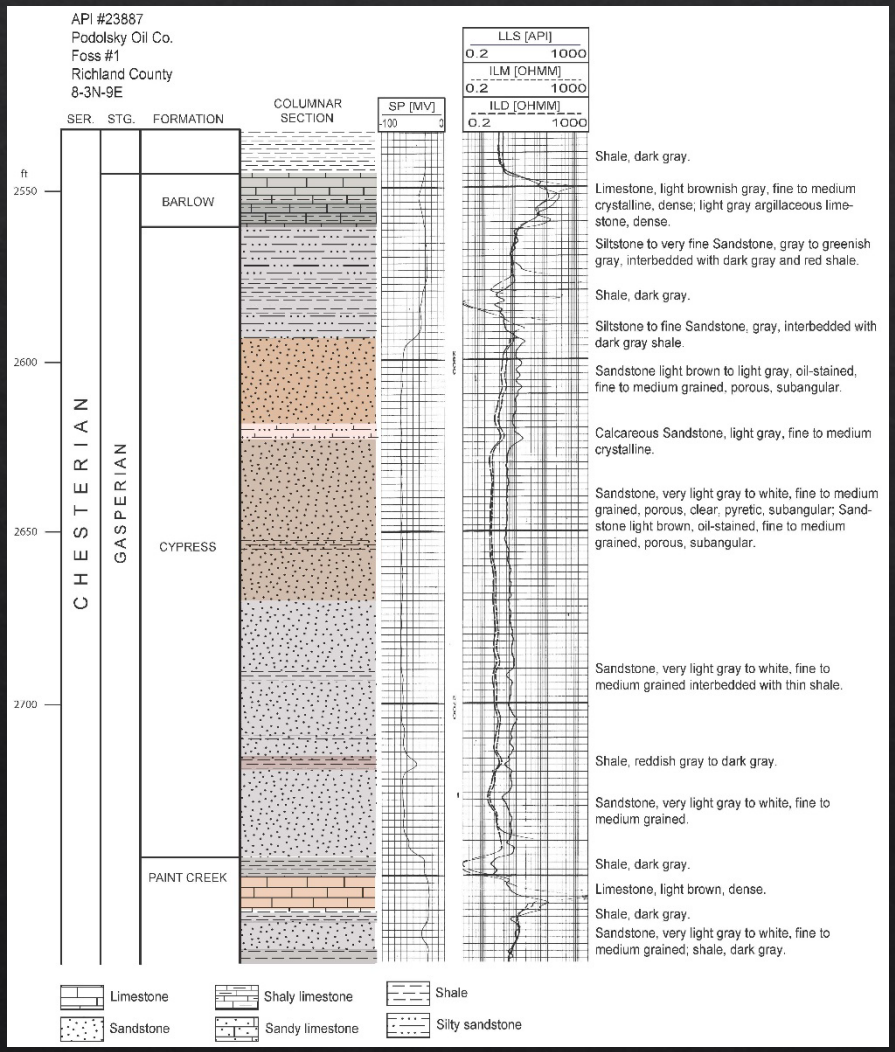
Cypress Sandstone Oil Reservoir





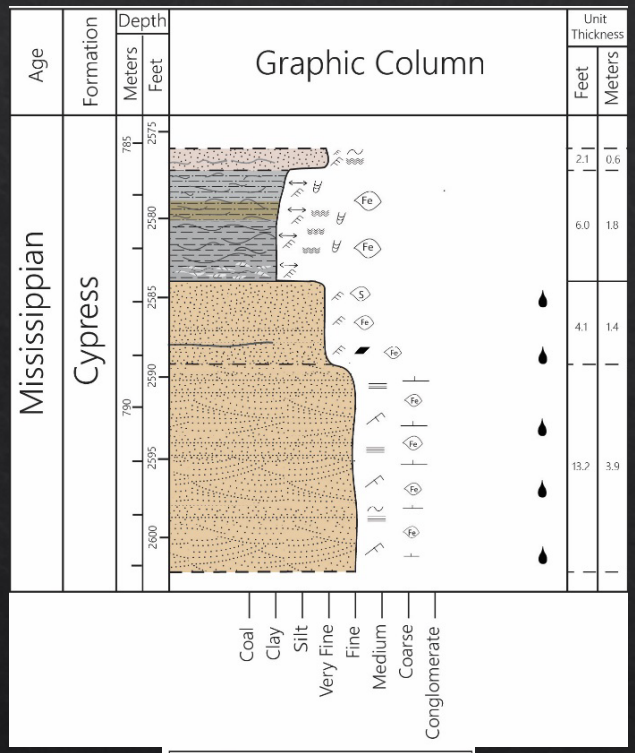
- Tilted oil/water contact (OWC) indicates possible ROZ
- Isopach of reservoir above OWC shows off-structure oil
- Preliminary OOIP of Cypress Ss ~100 MMBO without ROZ
  - Recovery efficiency of ~24%

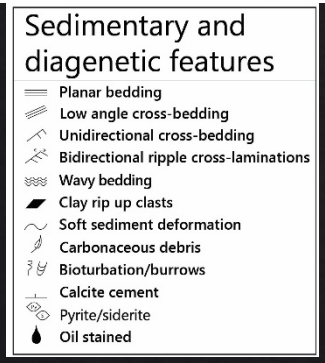
Sedimentology



- 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

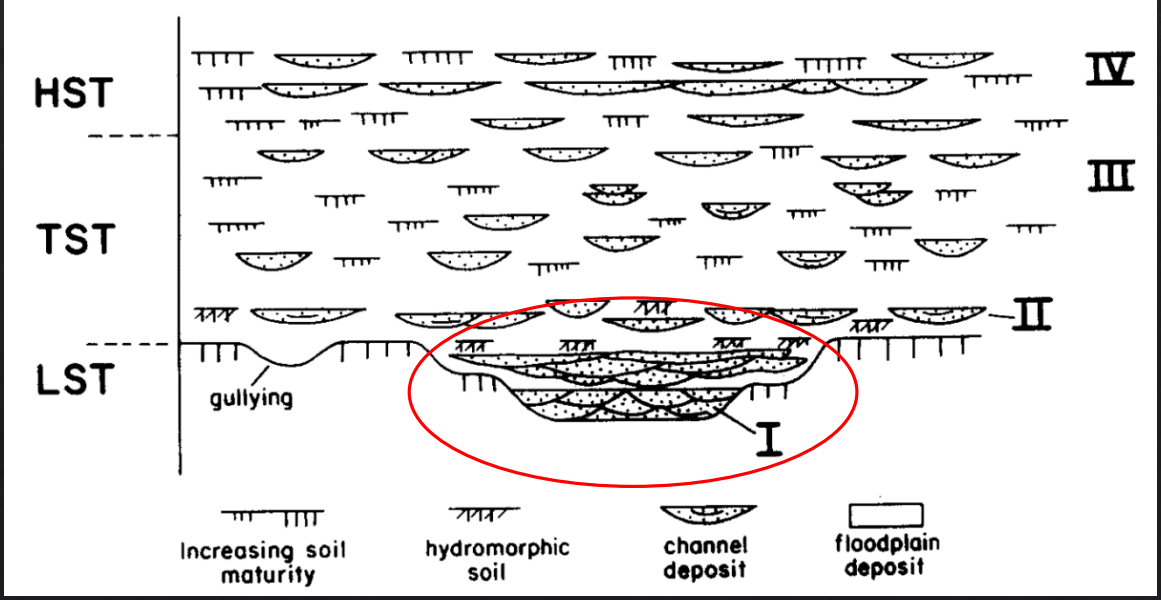




- Describing available cores and conducting facies analysis
  - Fluvial cross-bedded sandstones grade upward into heterolithic, estuarine deposits
- Sampling cores for porosity, permeability, mineralogy, trace elements, SEM, and thin sections
  - Developing diagenetic history
  - Determining effects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

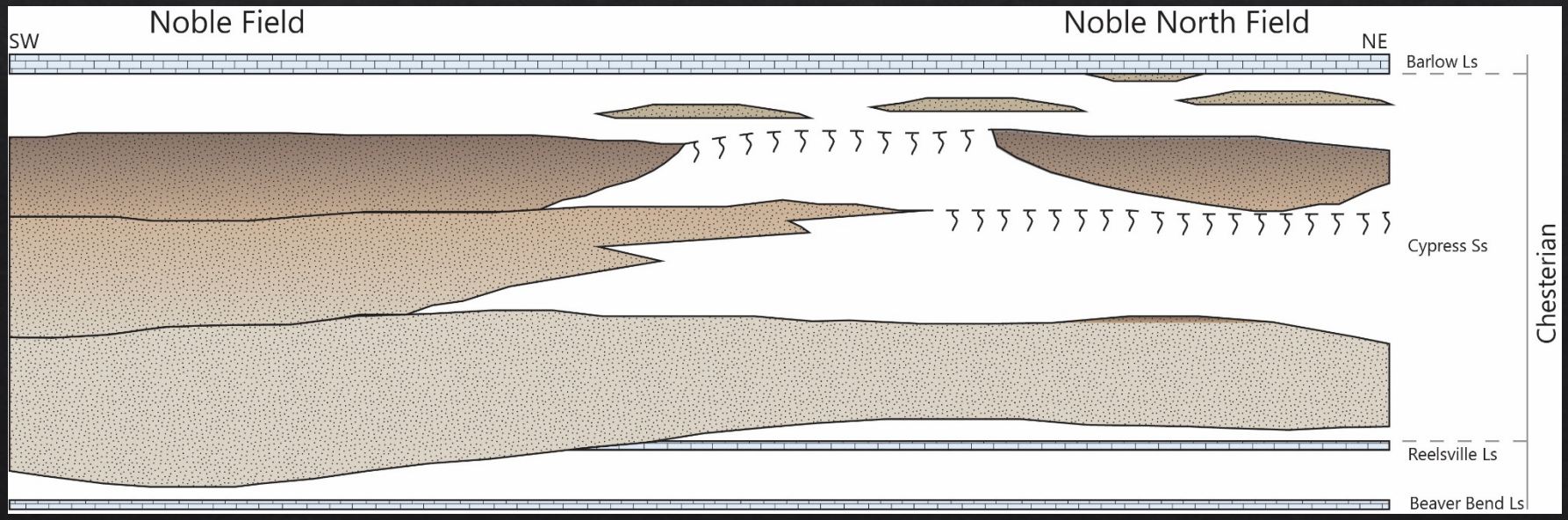
Depositional Environment

- 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



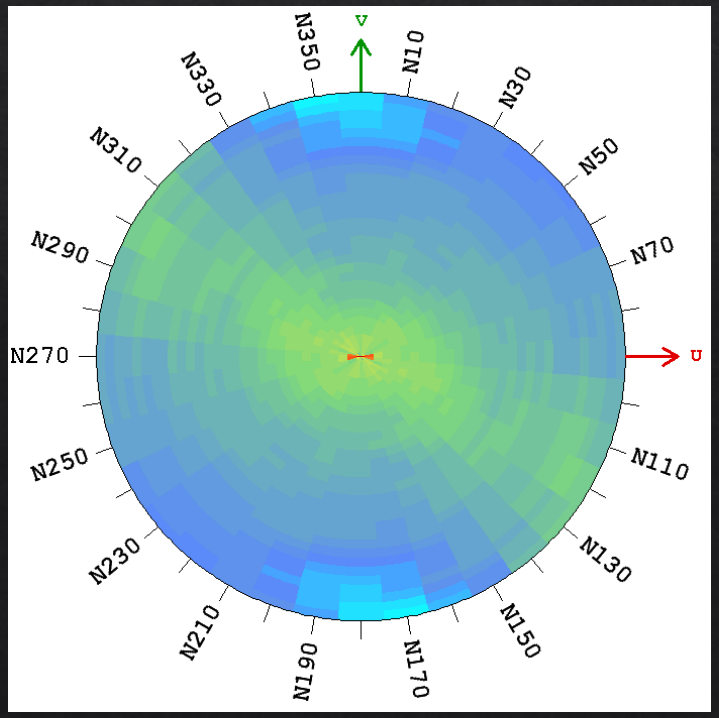
Geological Model

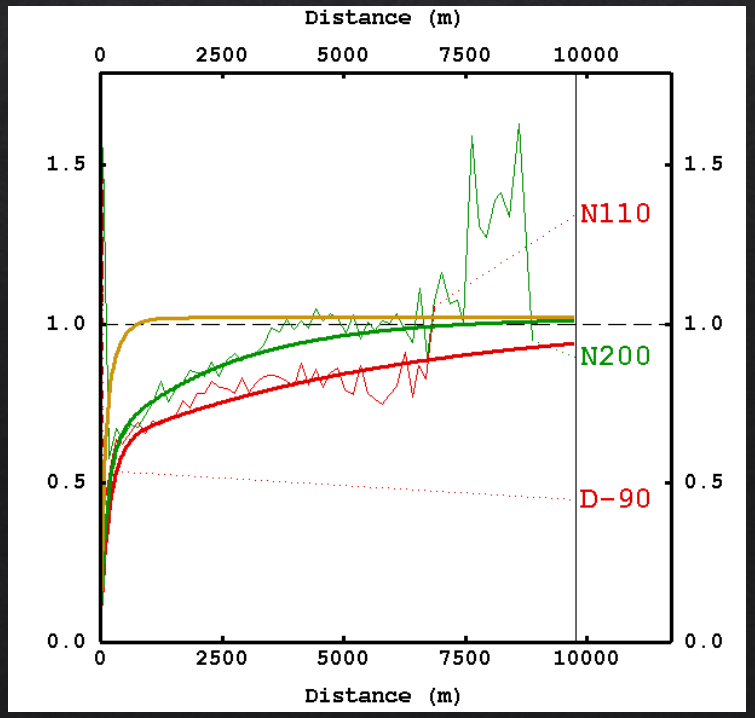
- Basal sandstone story blankets entire field and reportedly covers much of the nearby counties; indicates low accommodation
- Middle and upper sandstone stories amalgamate at Noble Field but are less persistent elsewhere
  - Top of thick Cypress Ss is convex upward where sandstones stack
  - Differential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



Variogram Development

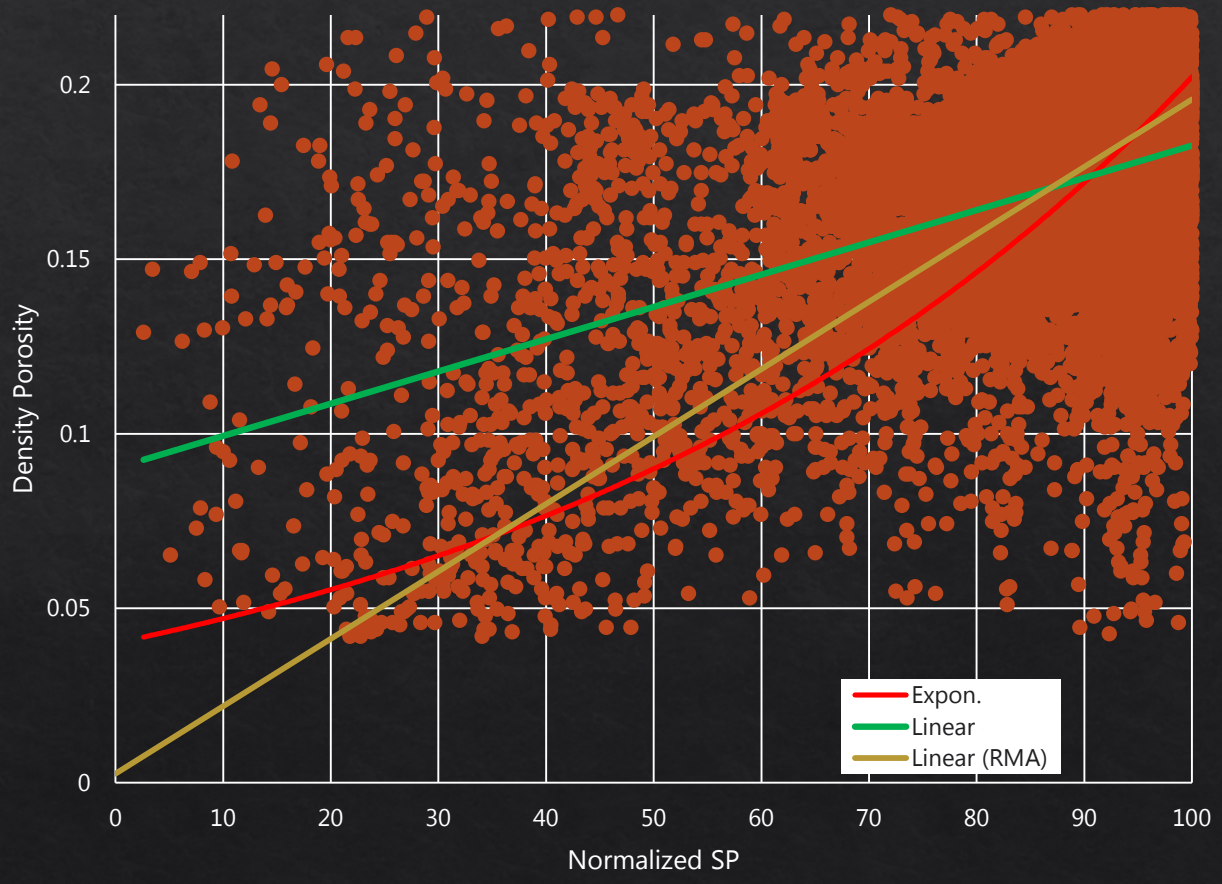
- 385 SP logs and 129 neutron-density porosity logs used to develop geocellular model that closely reflects geologic observations
  - Normalized SP logs used in variogram model to detect reservoir anisotropy and quantify spatial autocorrelation
  - Variogram reflects E-W trend of Cypress Sandstone body





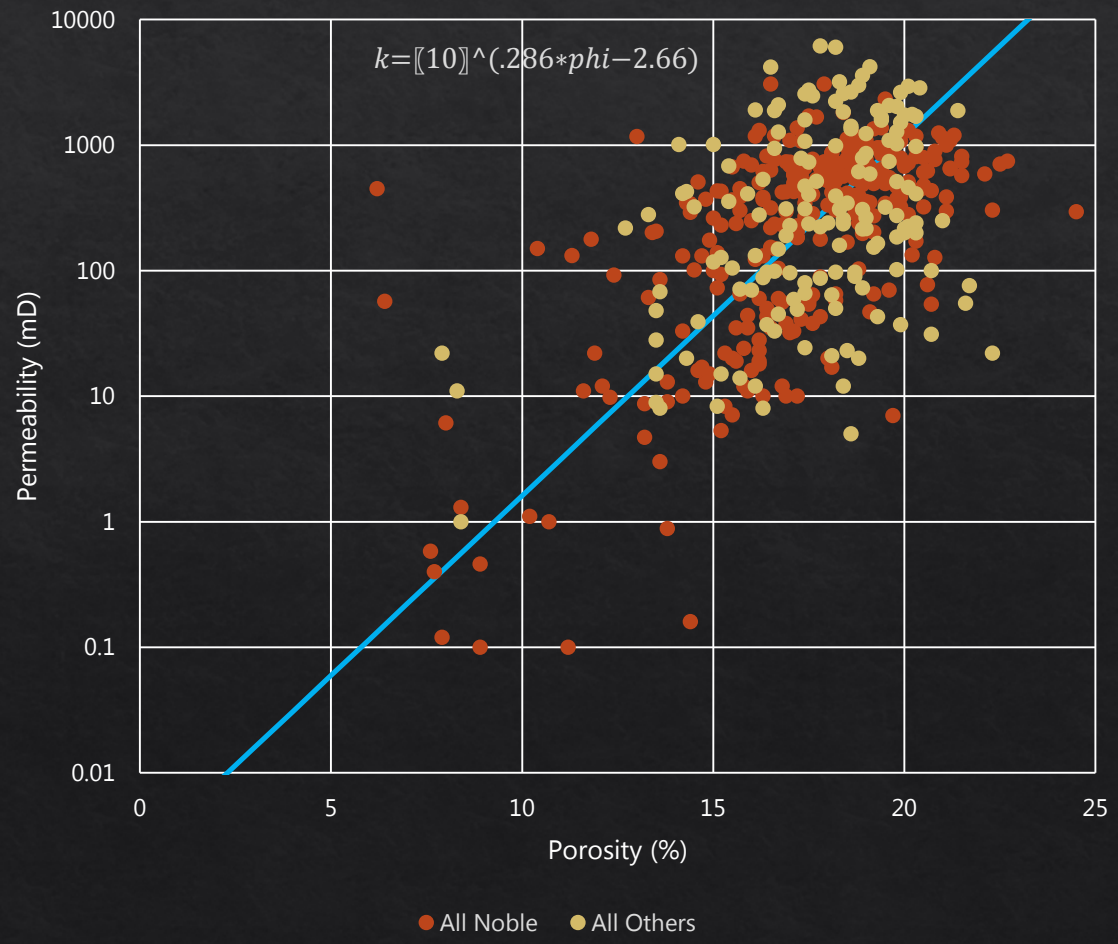
SP Log/Porosity Transform

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



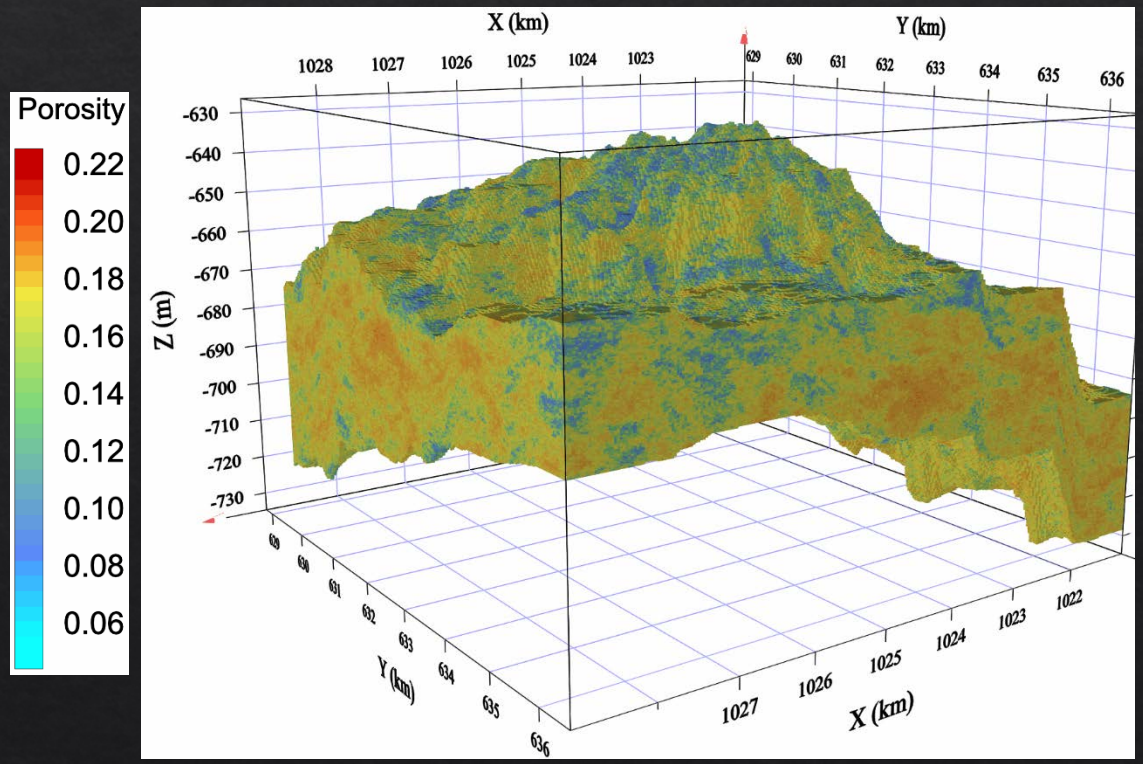
Porosity/Permeability Transform

- 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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