Using Well Log Analysis to Identify Residual Oil Zones at Noble and Kenner West Oil Fields, Illinois*

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Abstract

Carbon dioxide enhanced oil recovery (CO_2-EOR) has been used to produce oil from thick, naturally occurring intervals of low oil saturation, or residual oil zones (ROZs), in the Permian Basin. Residual oil zones are widespread within the Permian, Big Horn, and Williston Basins that, in addition to CO_2-EOR, have potential for significant storage of CO_2. Traditionally, open-hole well log analyses focus on higher oil saturations with specific analyses focused on irreducible saturation and movable hydrocarbons. Identifying ROZs in other basins requires methods to find lower oil saturations resulting from the natural waterflooding processes that form ROZs. This study presents a procedure that uses a combination of established well log analyses to identify ROZs. This study uses conventional and shaly-sand well log analyses to identify and characterize the thickness and residual oil saturation of suspected ROZs beneath the main pay zones in the Cypress Sandstone at Noble and Kenner West Oil Fields, Illinois. Archie, ratio, and dual-water methods were used to calculate oil saturation, and a combination of the moveable hydrocarbon index, bulk volume water, and apparent water resistivity were used to aid in picking the top and base of the main pay and ROZs. The oil saturations estimated for four wells at Noble Field were validated with pulsed-neutron logs, and the depths of the ROZ for 20 wells at Kenner West were validated with oil saturations from core analysis reports. The ROZ well log analyses procedure has been effective for both fields. Preliminary results indicate a ROZ approximately 25-30 ft (~8-9 m) thick at Noble and 30-50 ft (~9-15 m) thick at Kenner West. Residual oil saturation at both fields is around 20% - 30%. Core flood studies are planned to estimate actual residual oil saturation to water; additionally, new core will be cut to measure residual oil saturation directly. Planned work includes analyzing wells on the basin scale to identify areas that have a high potential to contain a ROZ and mapping the lateral distribution of ROZs within the Illinois Basin.

Reference Cited

Kuuskraa, V.A., M.L. Godec, and P. Dipeietro, 2013, CO_2 Utilization from "Next Generation" CO_2 Enhanced Oil Recovery Technology: Energy Procedia, v. 37, p. 6854-6866.

Using well log analysis to identify residual oil zones at Noble and Kenner West Oil Fields, Illinois

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GEOLOGICAL SURVEY
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Outline

- Motivation
- Ideal Saturation Curve
- Method
- Noble Field
- Kenner Field
- Conclusions

Motivation: ROZs+CO_2EOR

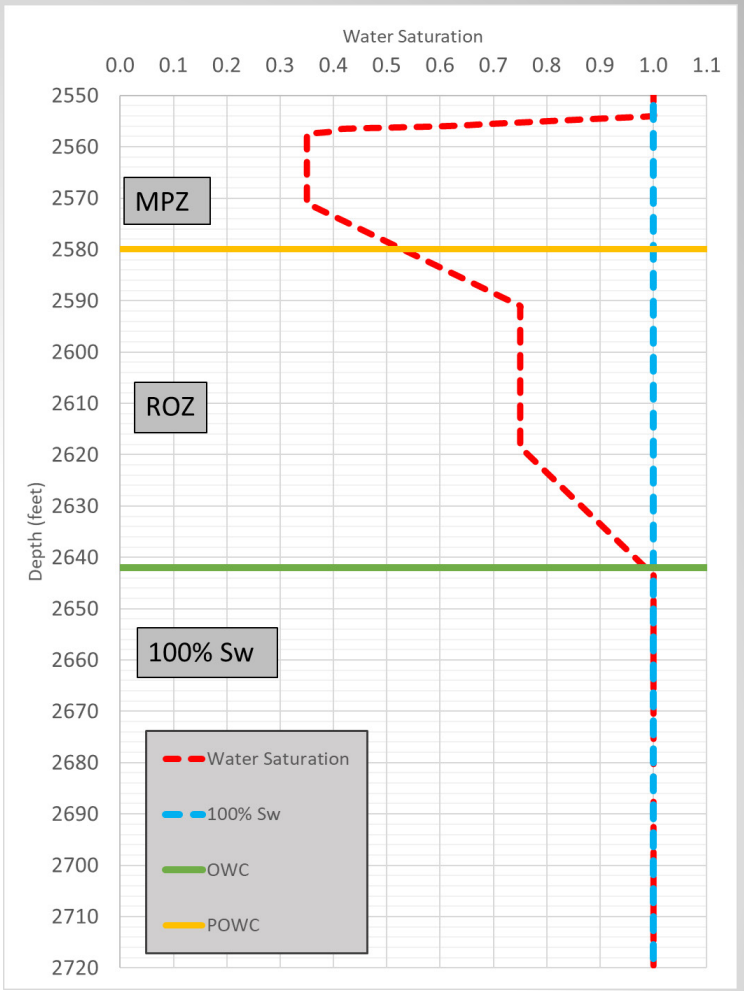
- Thick naturally occurring ROZs in Permian, Big Horn, Powder River, Williston Basins
- > 140 Billion bbls oil within ROZs in Permian Basin (Kuuskraa et al., 2013)
  - 27 billion economically recoverable via CO_2EOR
  - Success at Wasson, Seminole, Salt Creek, Goldsmith, Tall Cotton Fields (and others)
  - Net carbon negative oil
    - Large storage capacity

Motivation: ILB

- Are there ROZs within the ILB that have been historically overlooked?
- Can we use existing well logs to locate/characterize them?
  - Quick, cheap preliminary screening tool
  - Validate with more established methods
  - Are neutron density logs necessary?
- Test in study areas > extend to rest of basin

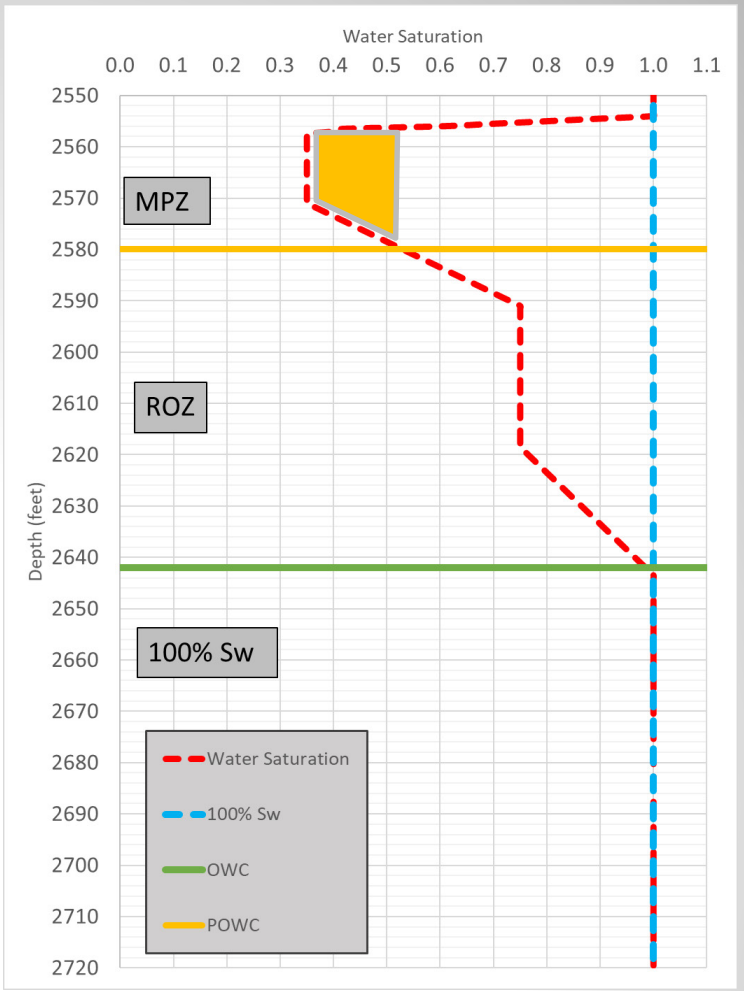
Ideal Saturation Curve

- 3 intervals
  - Separated by 2 depths
  - POWC
    - Mobile oil saturation
  - OWC
    - Water saturation reaches 100%



Ideal Saturation Curve

- Irreducible water saturation is 35%
- So at POWC is 50%
  - Primary Recovery



Ideal Saturation Curve

- Irreducible water saturation is 35%
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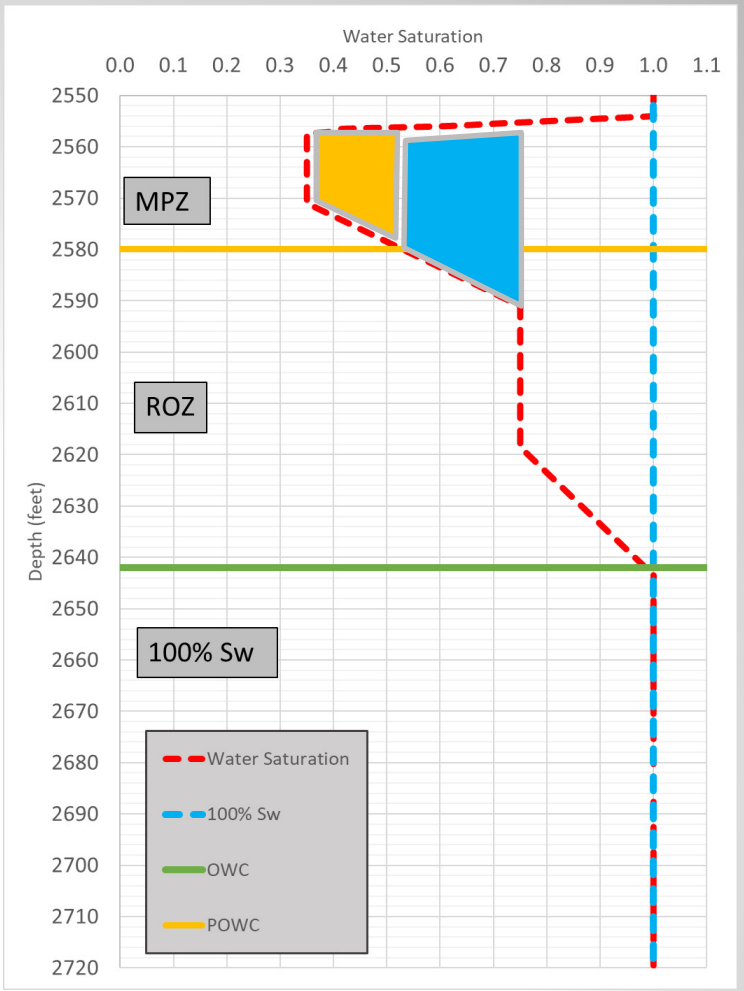
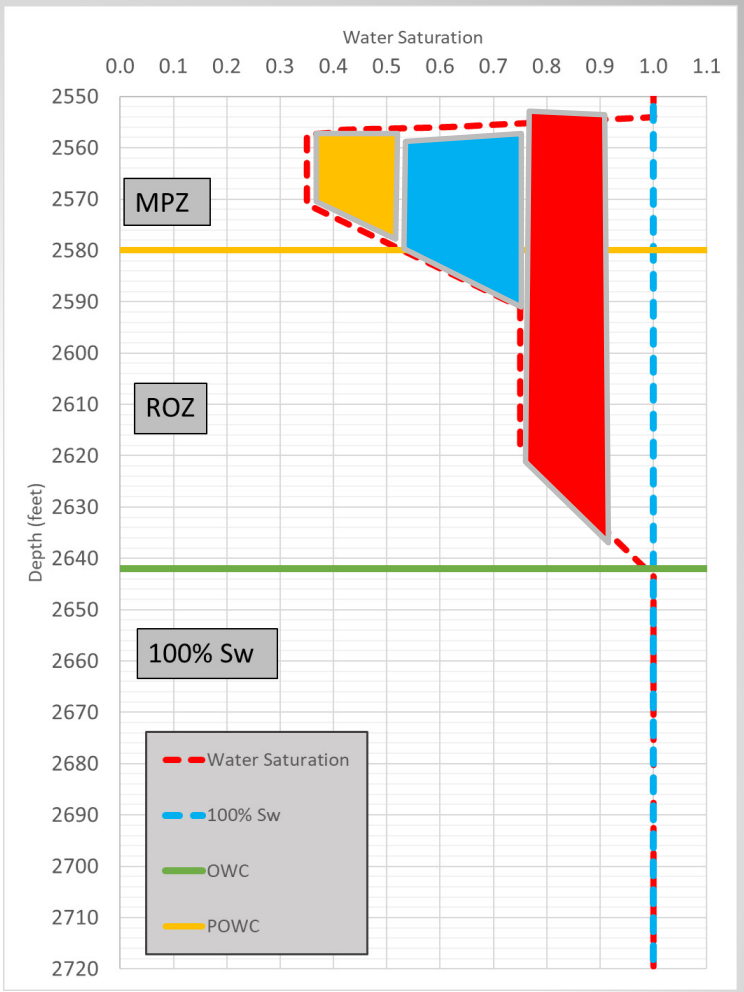
  - Primary Recovery
- Residual oil saturation is 25%
  - Secondary recovery
  - (waterflood)



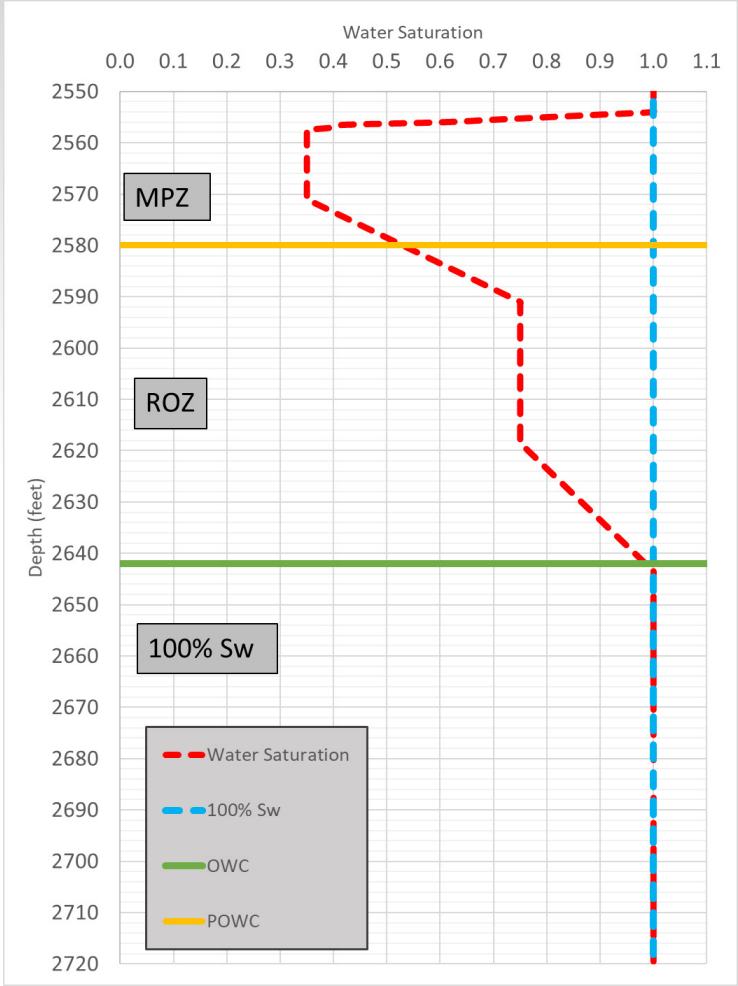
Ideal Saturation Curve

- Irreducible water saturation is 35%
- So at POWC is 50%
  - Primary Recovery
- Residual oil saturation is 25%
  - Secondary recovery
  - (waterflood)
- CO_2EOR



Ideal Saturation Curve

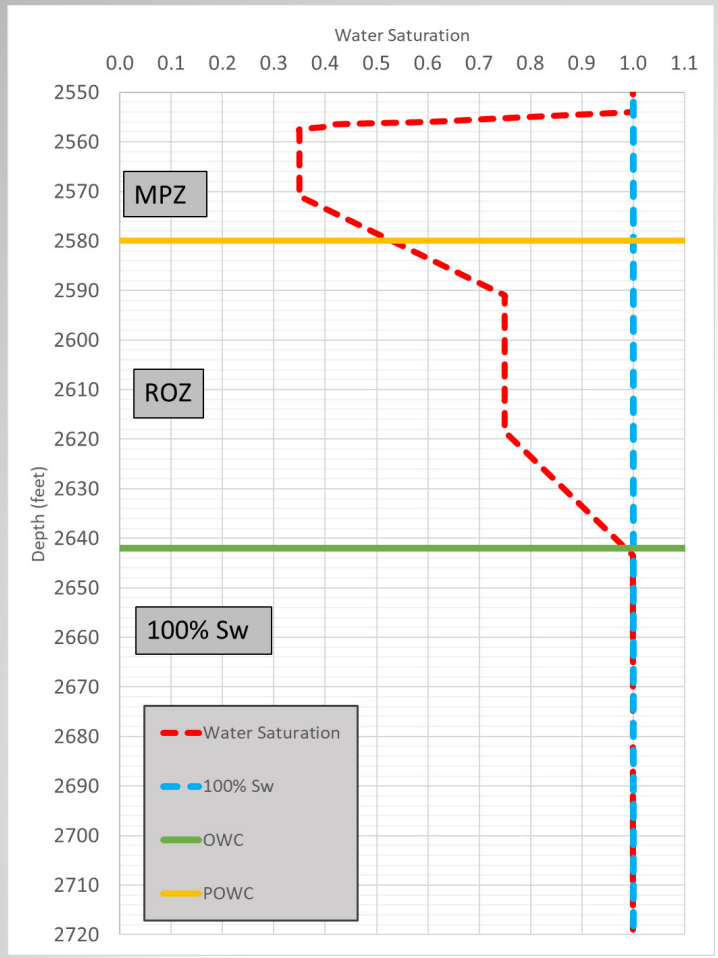
- Characterize profile by:
  - Thickness of MPZ, ROZ, oil column
  - Median oil saturation within MPZ and ROZ
  - Oil saturation at POWC

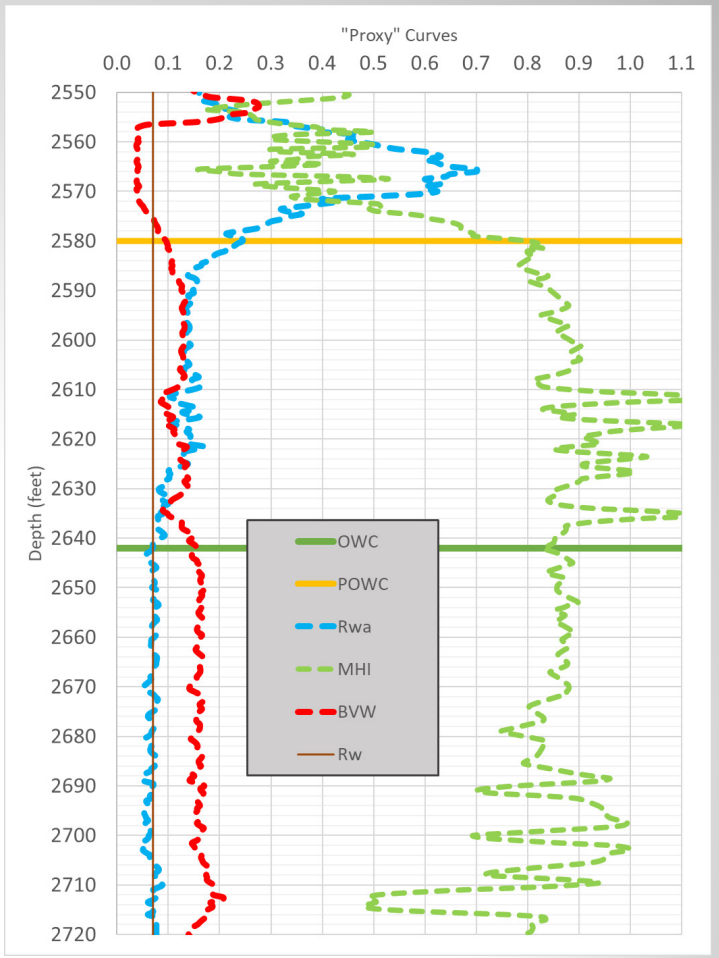


Method

- Water Saturation
  - Archie
  - Ratio
  - Dual Water
- “Proxy” curves
  - Moveable Hydrocarbon Index
  - Bulk Volume Water
  - Apparent Water Resistivity

Method


Water Saturation
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1
Depth (feet)
2550 2560 2570 2580 2590 2600 2610 2620 2630 2640 2650 2660 2670 2680 2690 2700 2710 2720
MPZ
ROZ
100% Sw
Water Saturation
100% Sw
OWC
POWC


"Proxy" Curves
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1
Depth (feet)
2550 2560 2570 2580 2590 2600 2610 2620 2630 2640 2650 2660 2670 2680 2690 2700 2710 2720
OWC
POWC
Rwa
MHI
BVW
Rw

Noble Field

- Calculate and analyze curves for 94 wells
- Create maps and statistically analyze results to identify trends/outliers
- Validate with 4 pulsed neutron logs
- Use historical data to validate POWC/OWC
  - Producing perforations
  - Shows of oil on drilling records
  - Core reports

Thick Cypress Sandstone

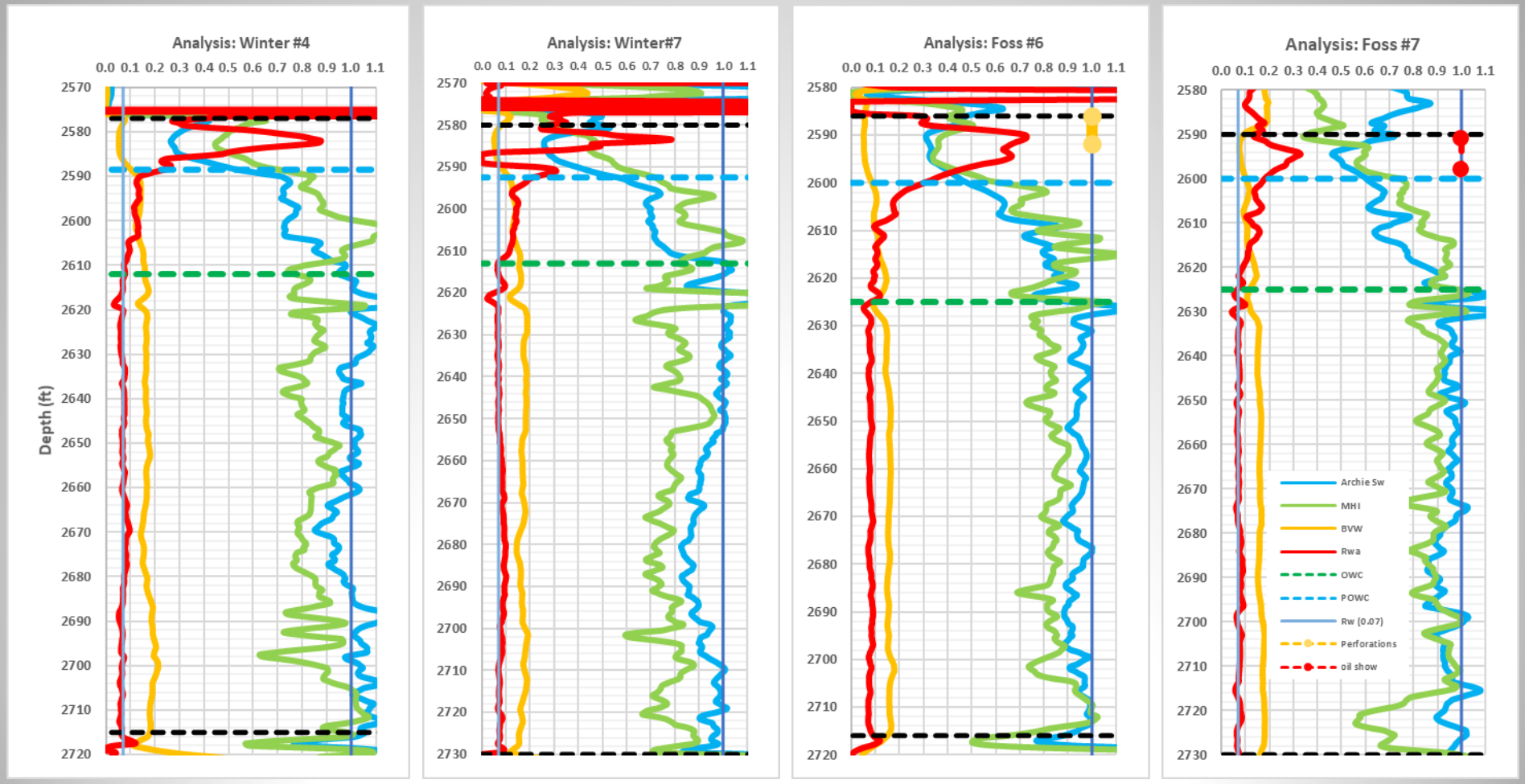
- Detailed geologic characterization
- Thick, fairly homogenous clean sandstone
  - Good porosity and high permeability
  - Few shale breaks throughout
  - Calcite cement layers near oil water contact(s)
- Production from several formations including a thin MPZ above thick aquifer in thick Cypress

4 Example Wells

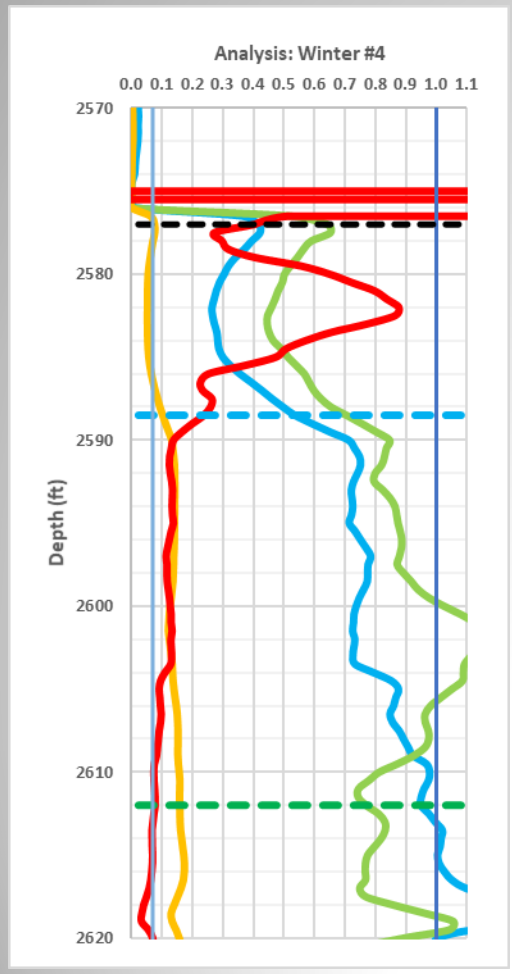
- Pulsed neutron logs on 4 previously drilled and logged wells taken in 2017

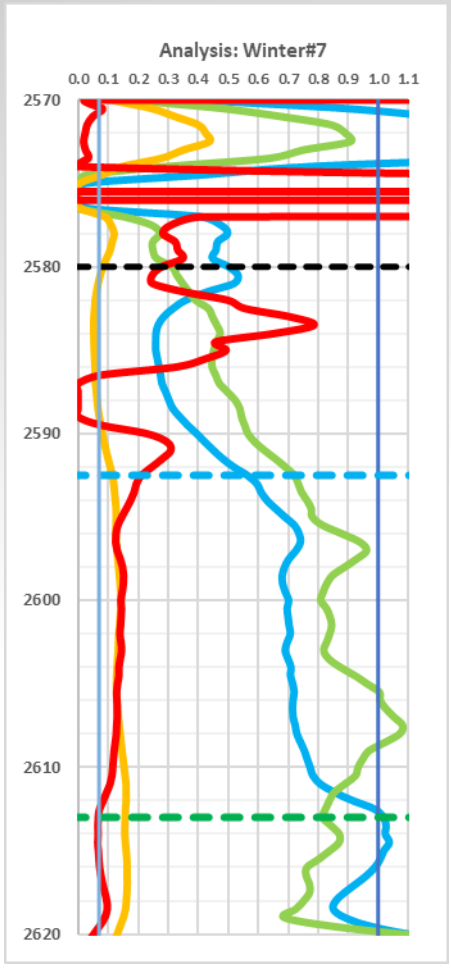
Well Name	Year Drilled	Notes
Winter #4	2007	Good behind pipe oil saturation
Winter #7	2011	
Foss #6	1994	Cypress Producer
Foss #7	2006	

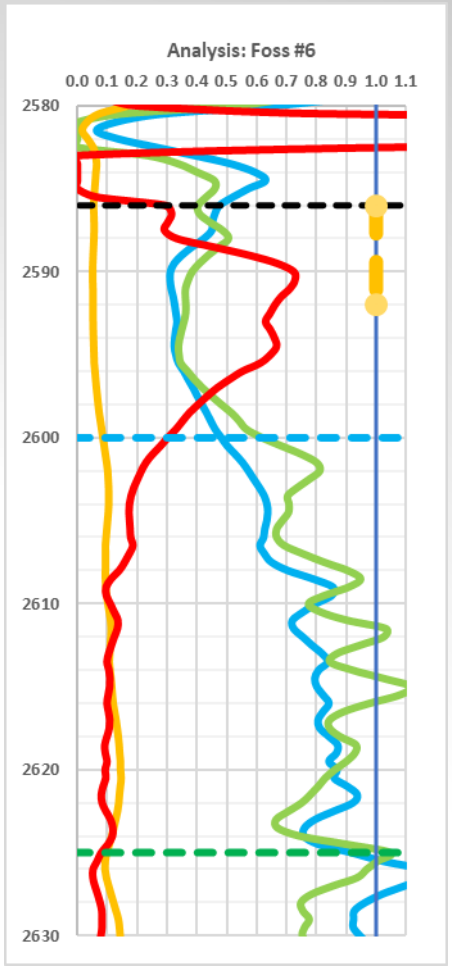
Example Well Log Analysis

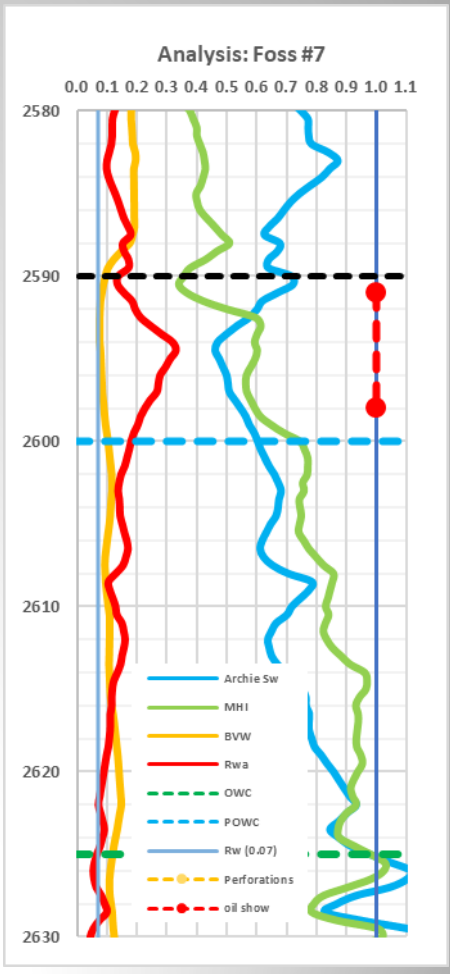


Example Well Log Analysis (zoomed in)









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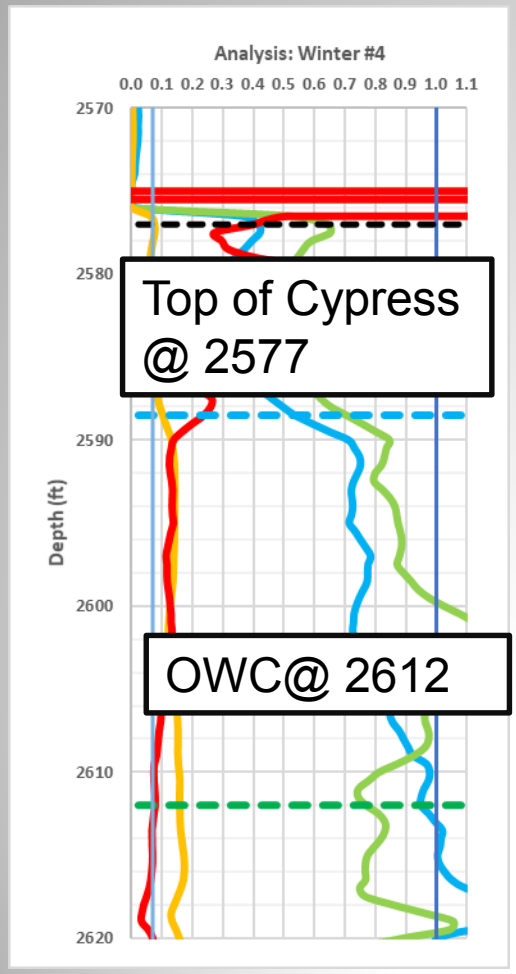
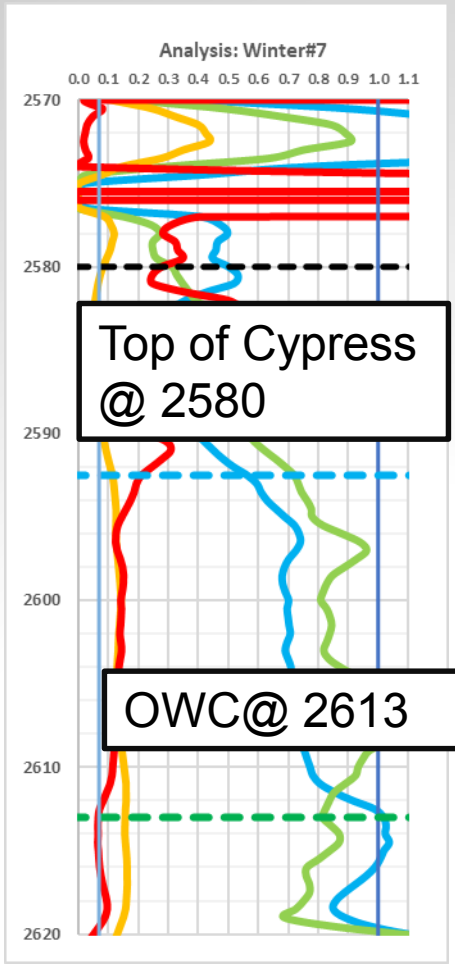
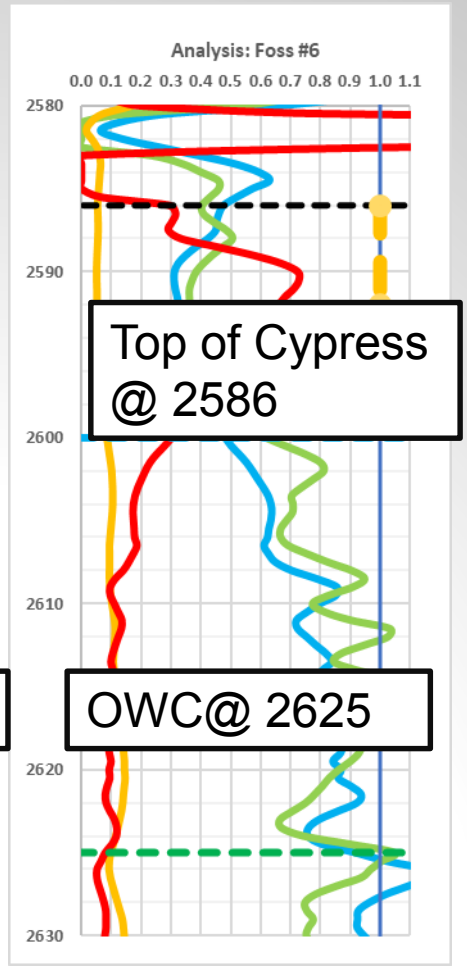
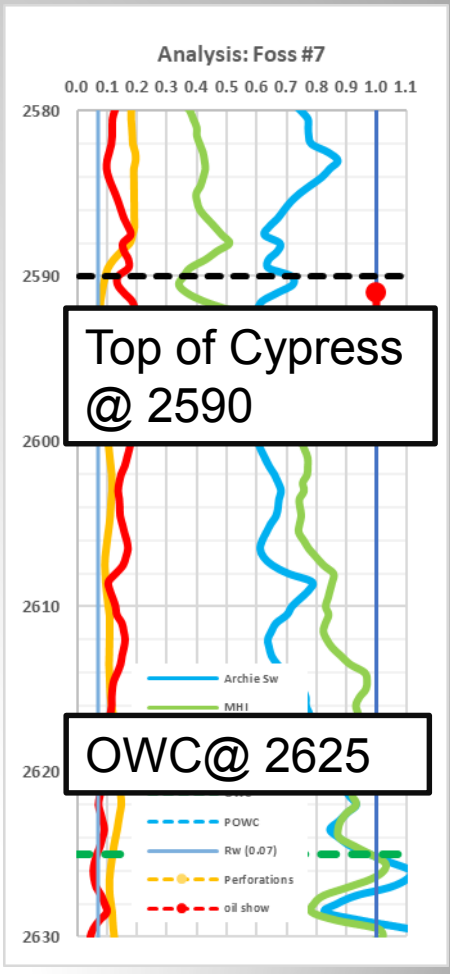
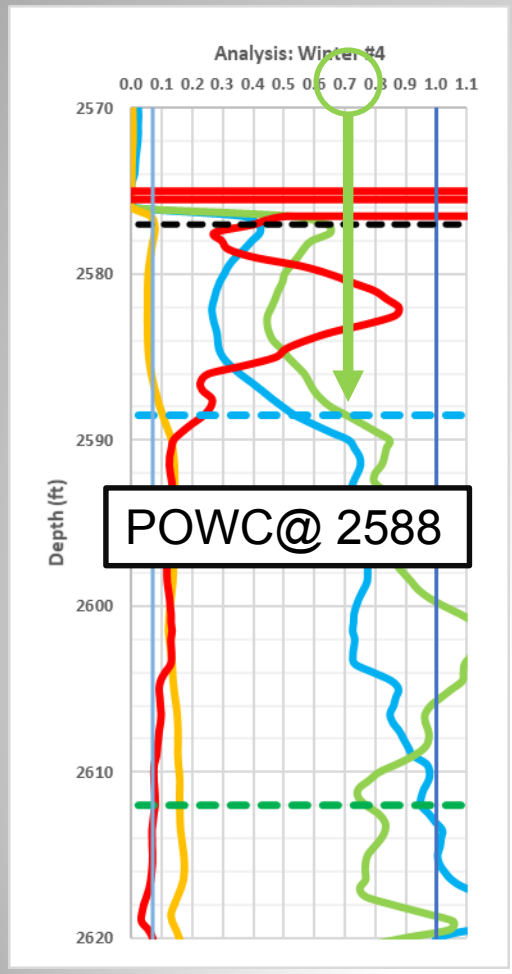


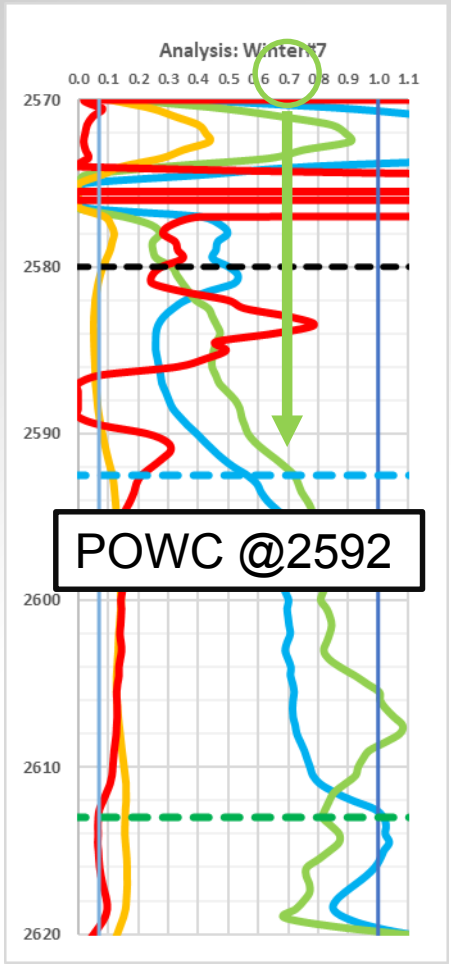


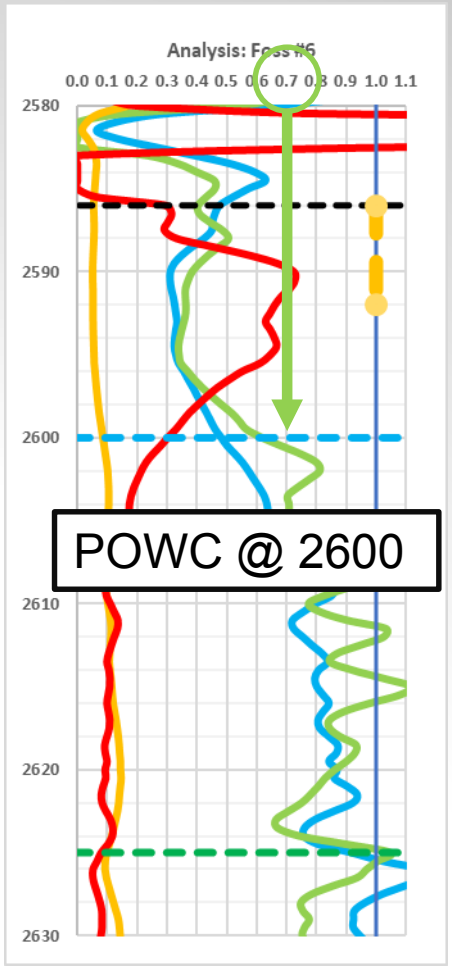


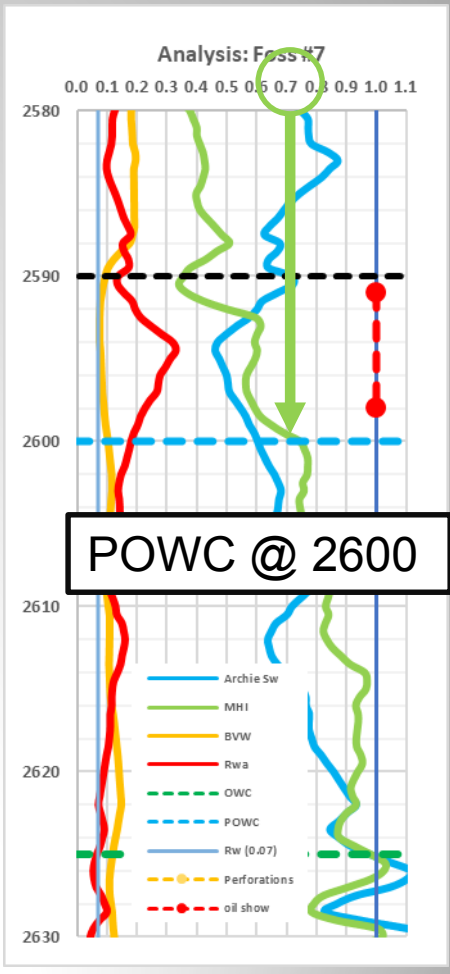


Example Well Log Analysis (zoomed in)

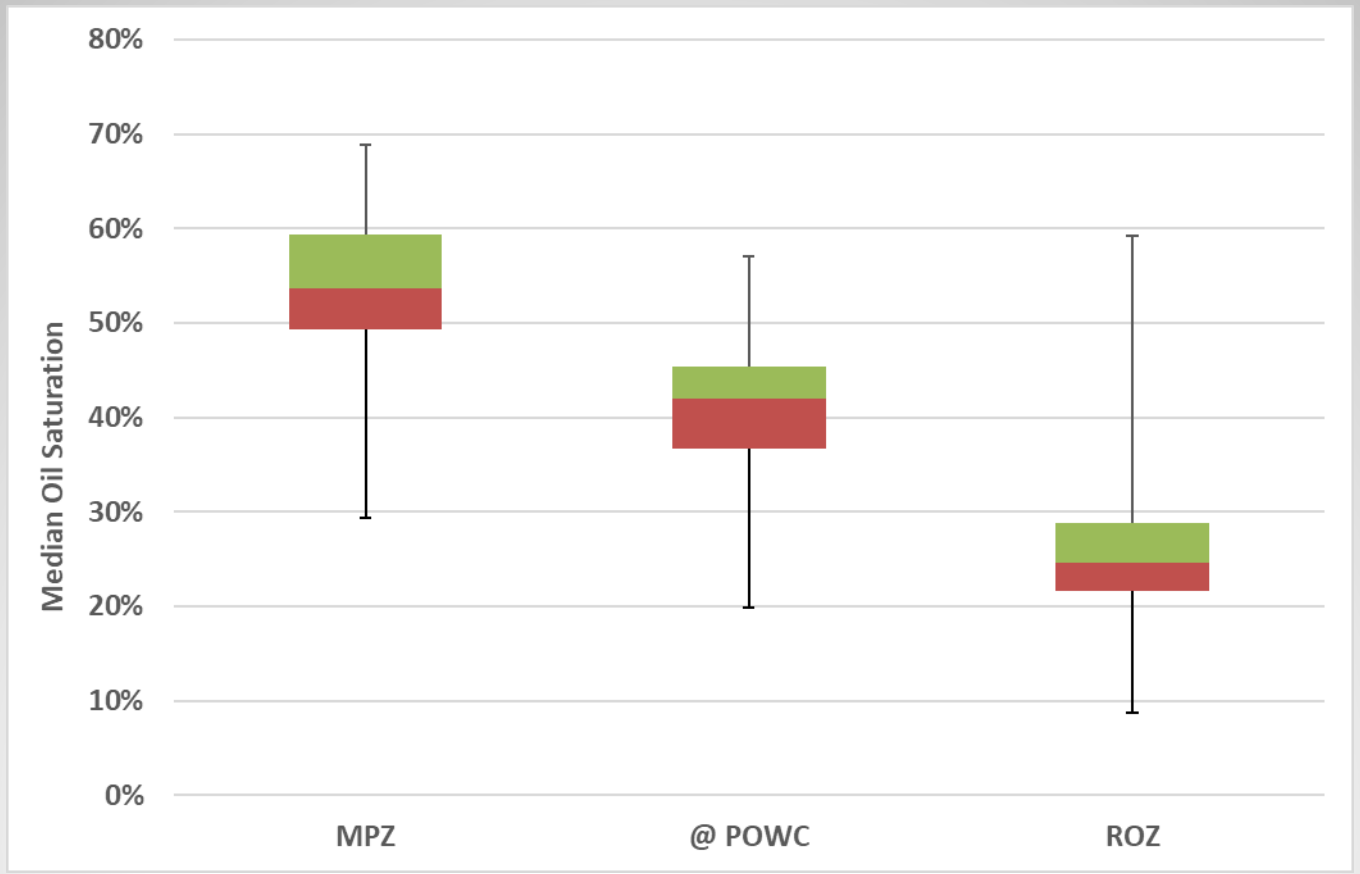




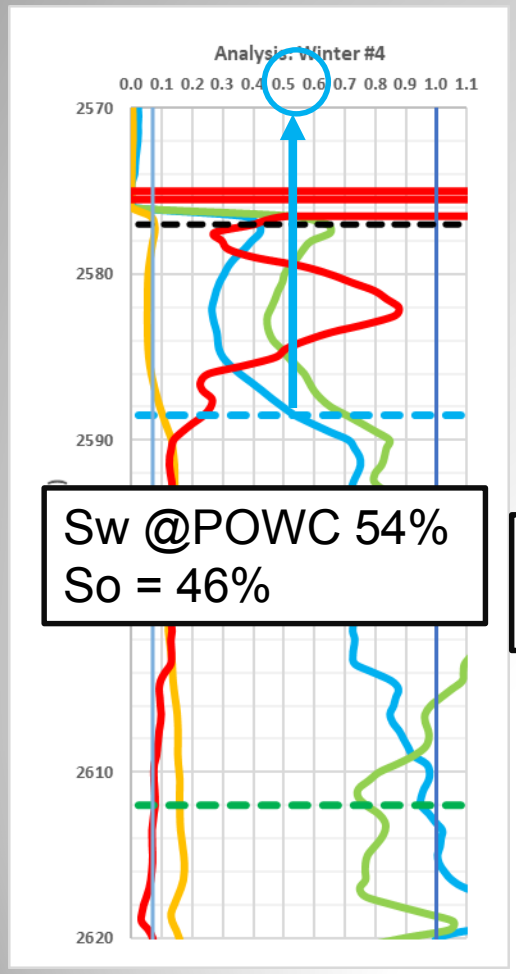


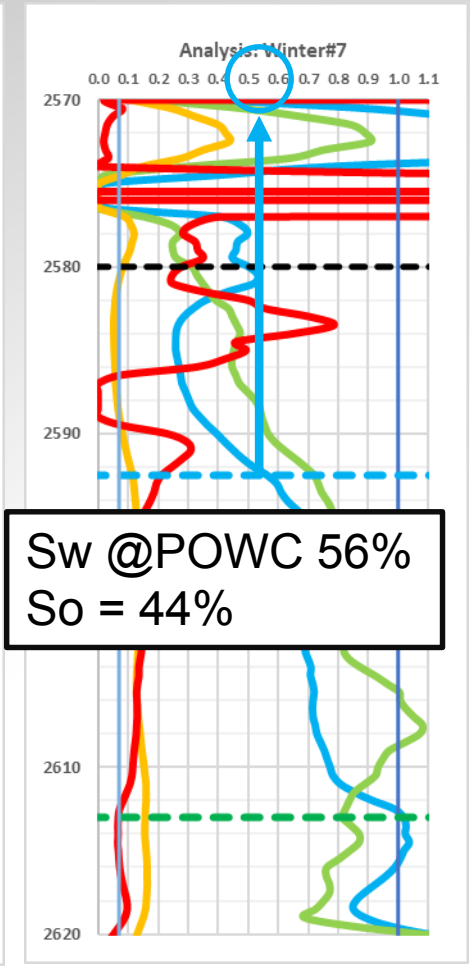


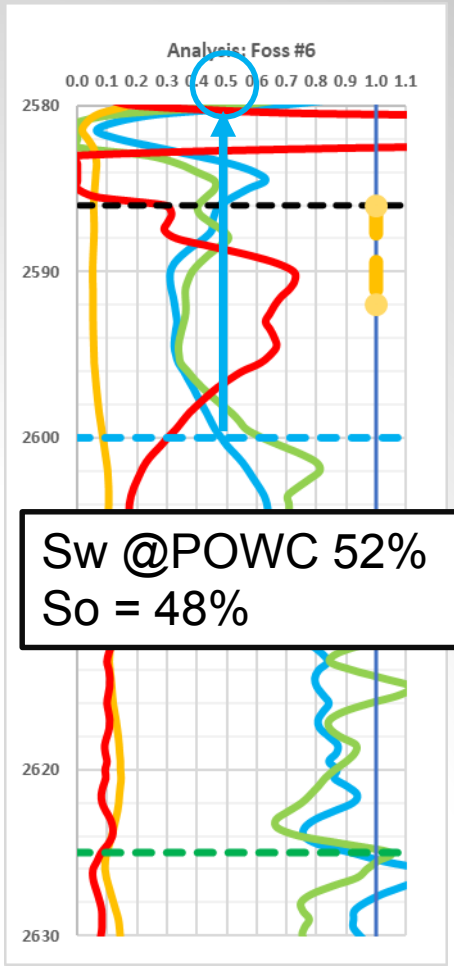
Archie Oil Saturation by Interval (96 wells)

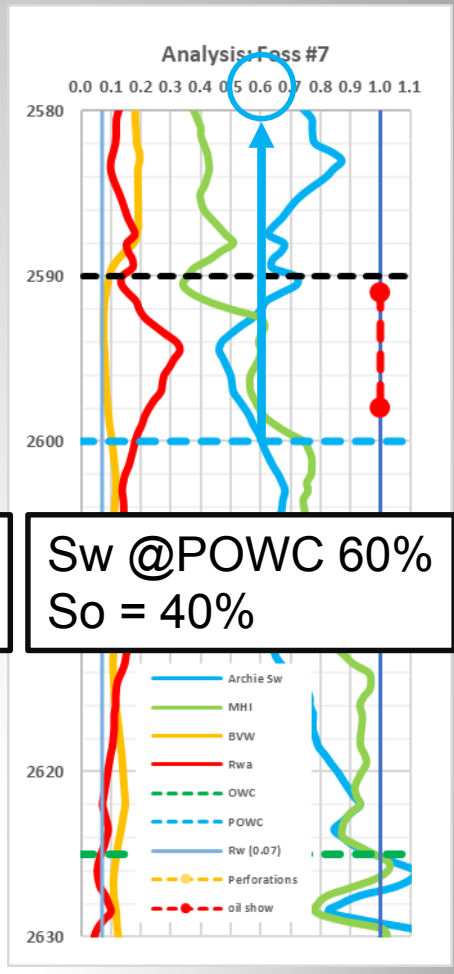


Example Well Log Analysis (zoomed in)

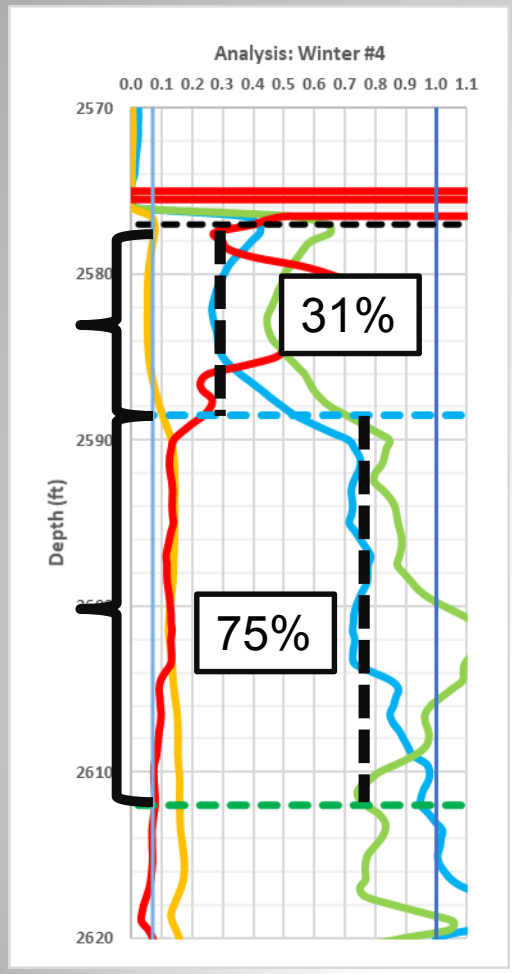


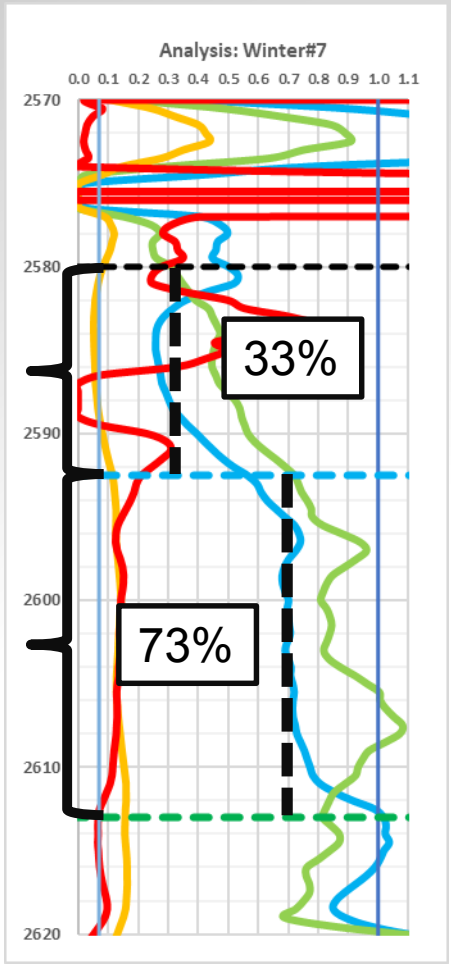


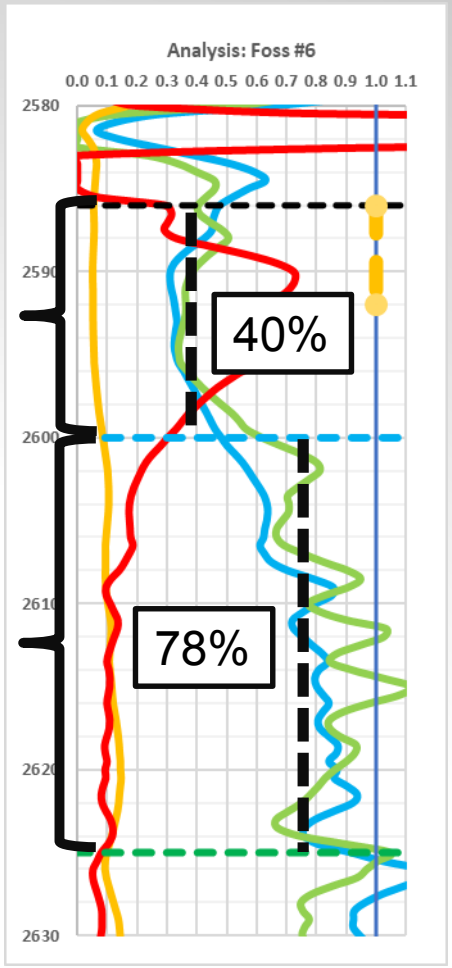


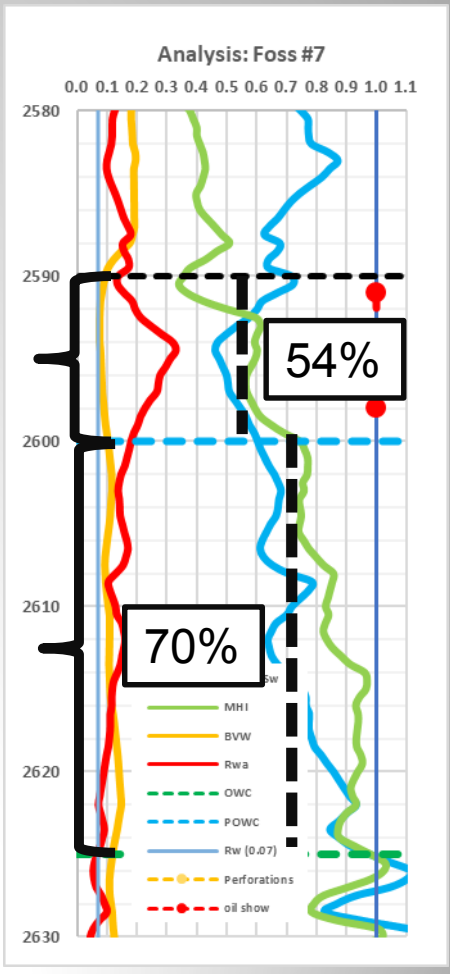


Example Well Log Analysis (zoomed in)

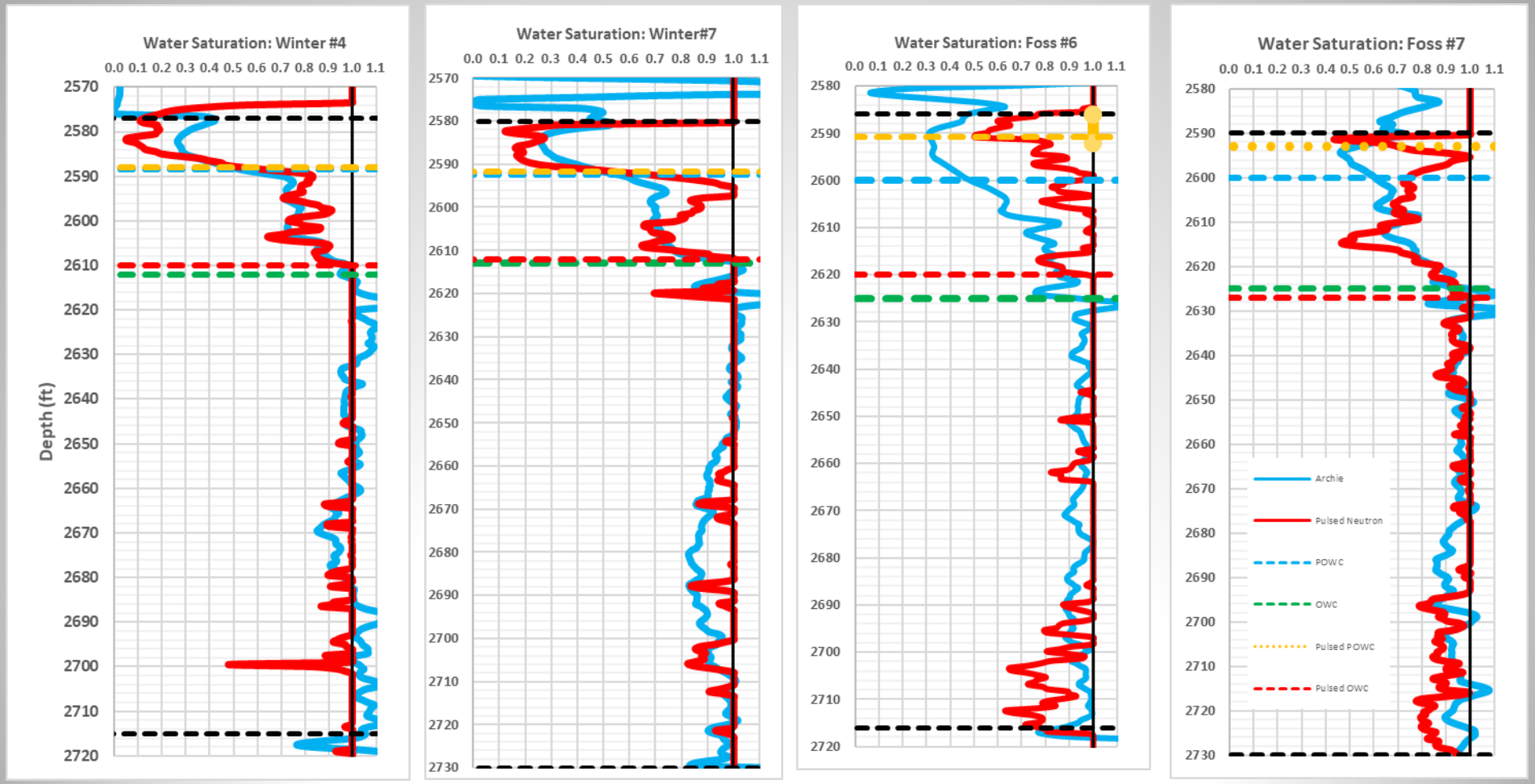




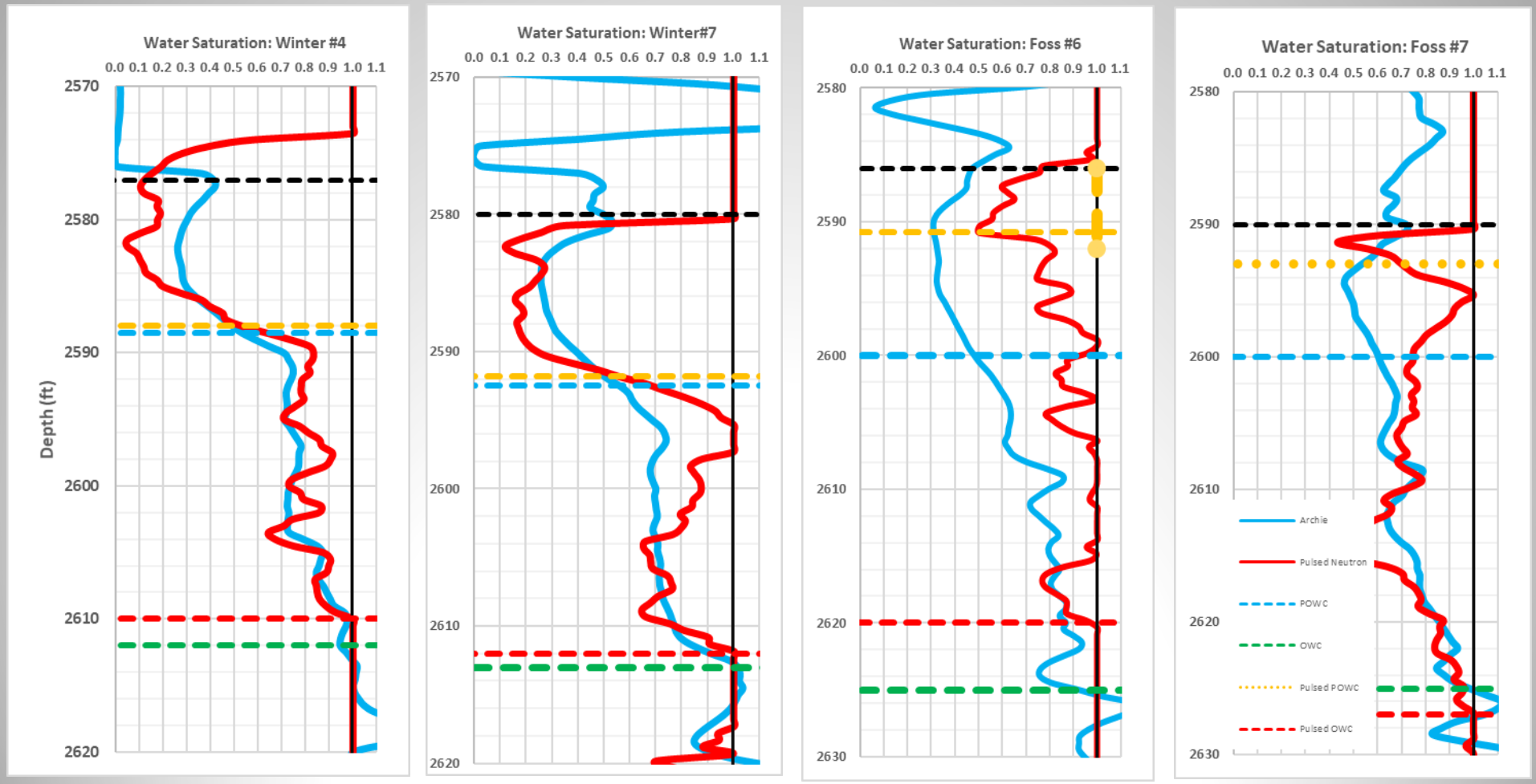




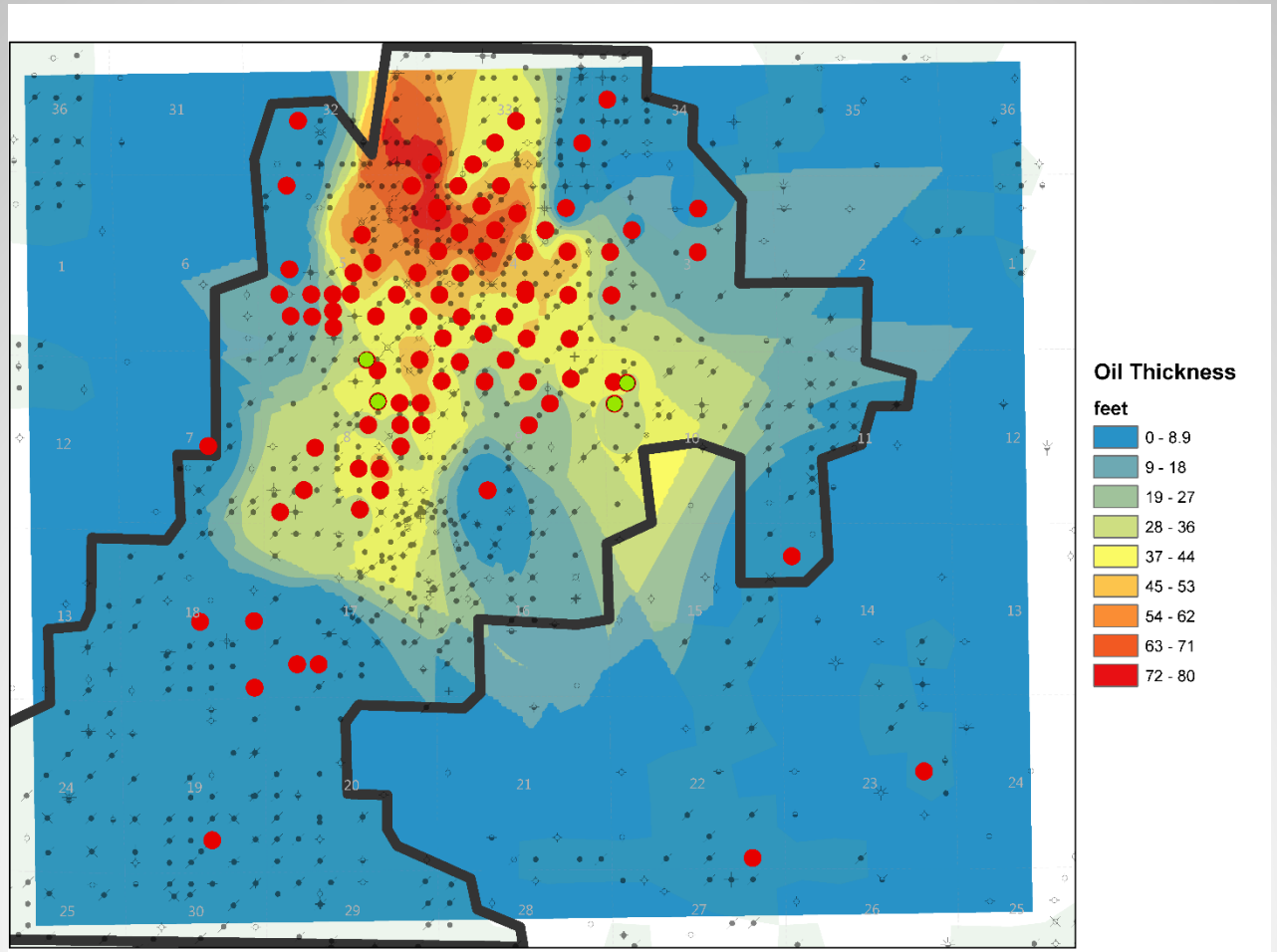
Pulsed Neutron Saturation



Pulsed Neutron Saturation (zoomed in)



Noble Oil Isopach

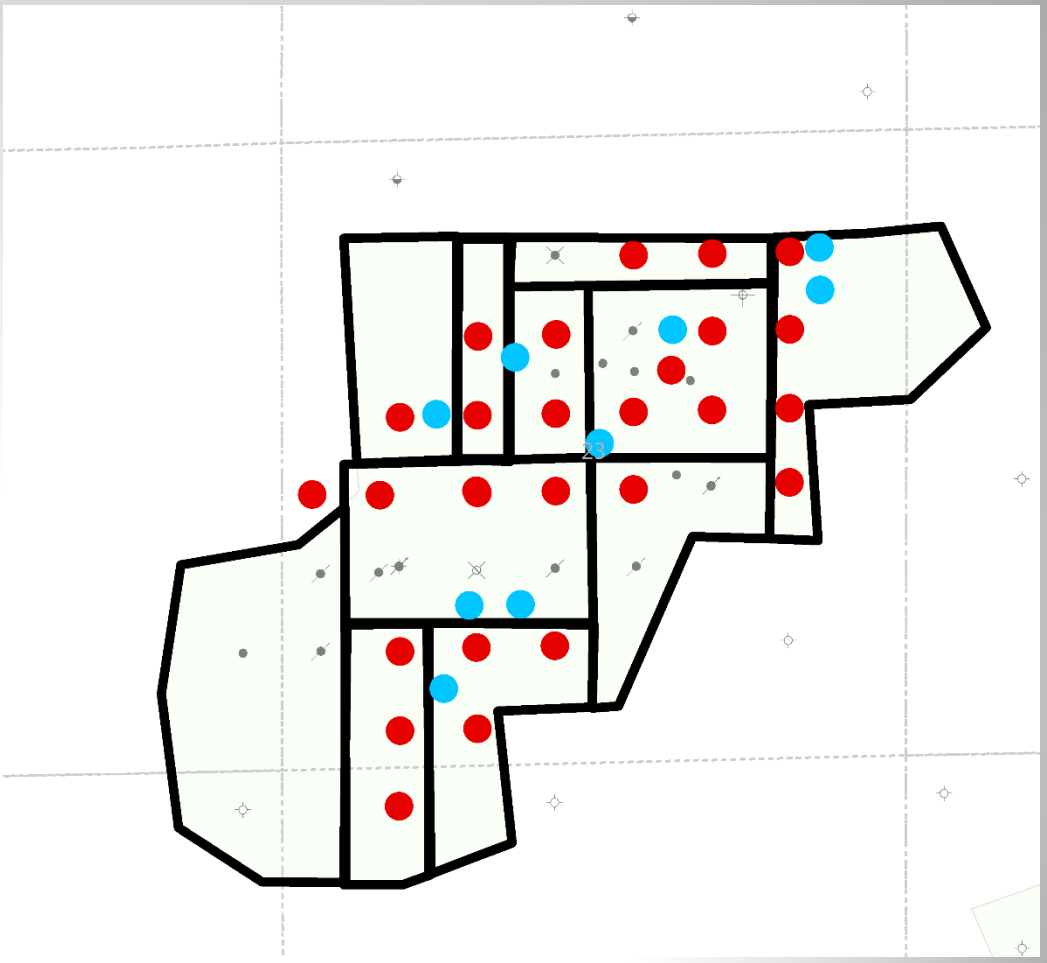


Noble Results Overview

- Consistent results
  - Oil saturation at POWC ~40 - 45%
  - Residual oil saturation ~20 - 25%
- Reasonable trends
- Results match pulsed neutron logs
  - Same OWC, residual oil saturation
- Results match historical records
- Ratio Sw too low
  - Fails at high water saturation?

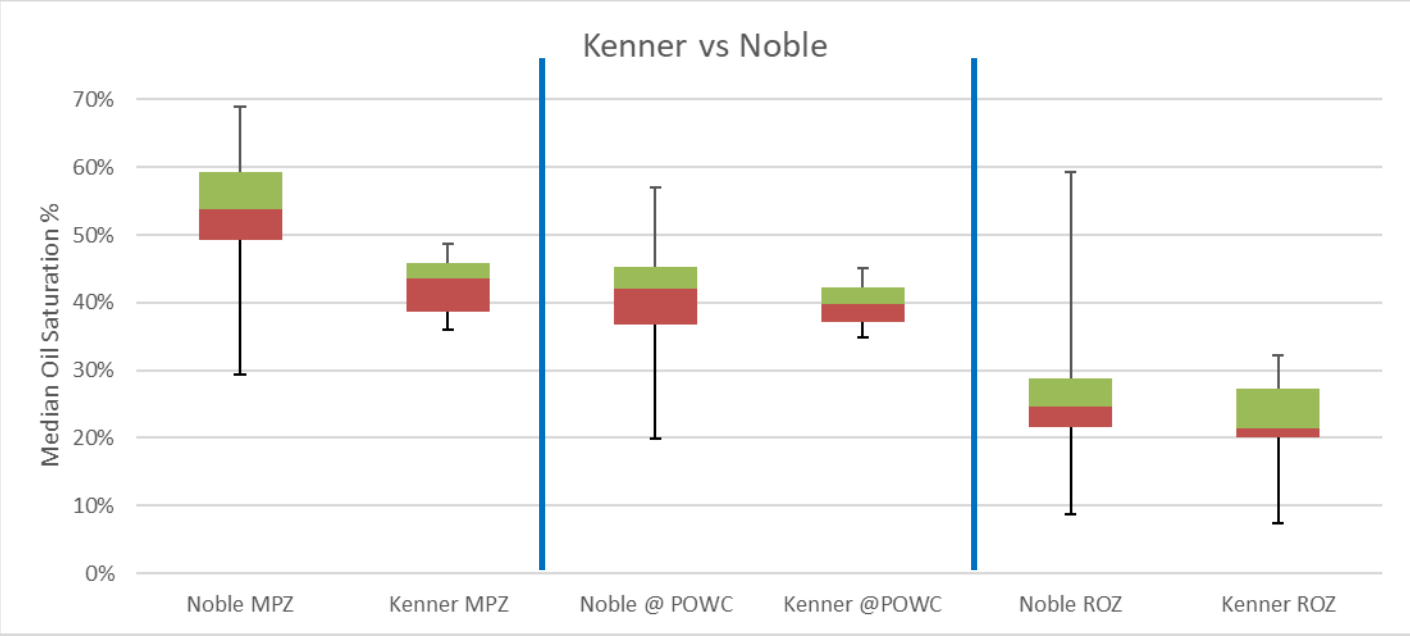
Kenner West

- “mini” Noble
  - ~20 miles west
  - Similar rock and fluid properties
- 26 40s wells
  - SP + resistivity logs
- 9 90s wells
  - N/D porosity logs



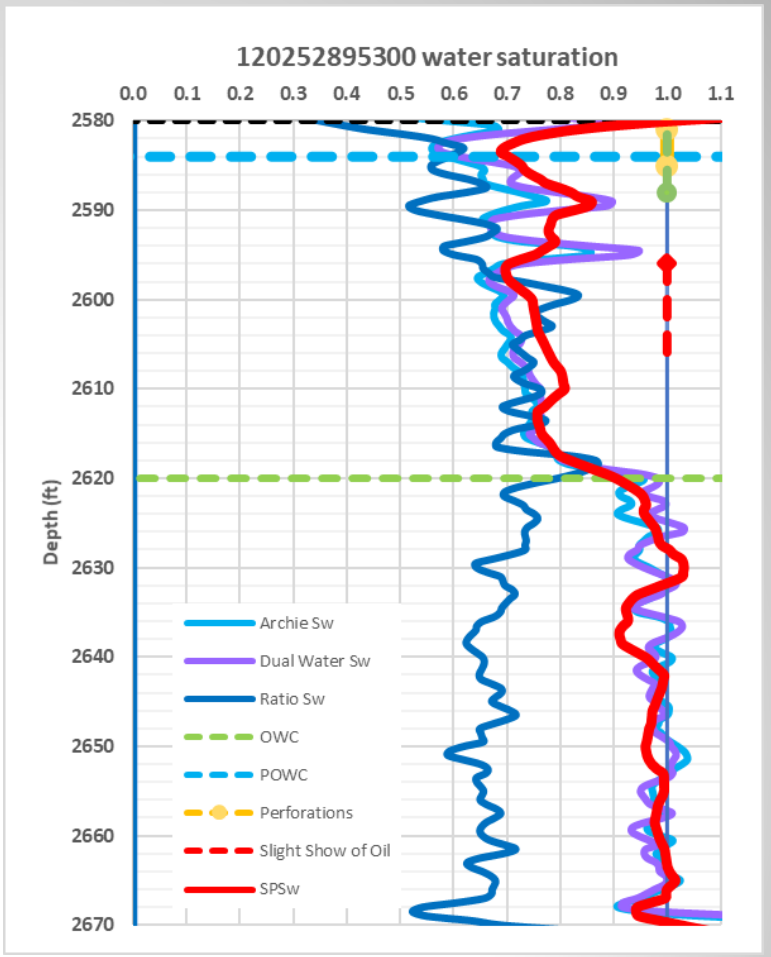
Kenner Neutron Density logs

	Noble	Kenner 90s
MPZ So	55%	45%
So at POWC	45%	40%
Residual So	25%	25%
Count	94	9



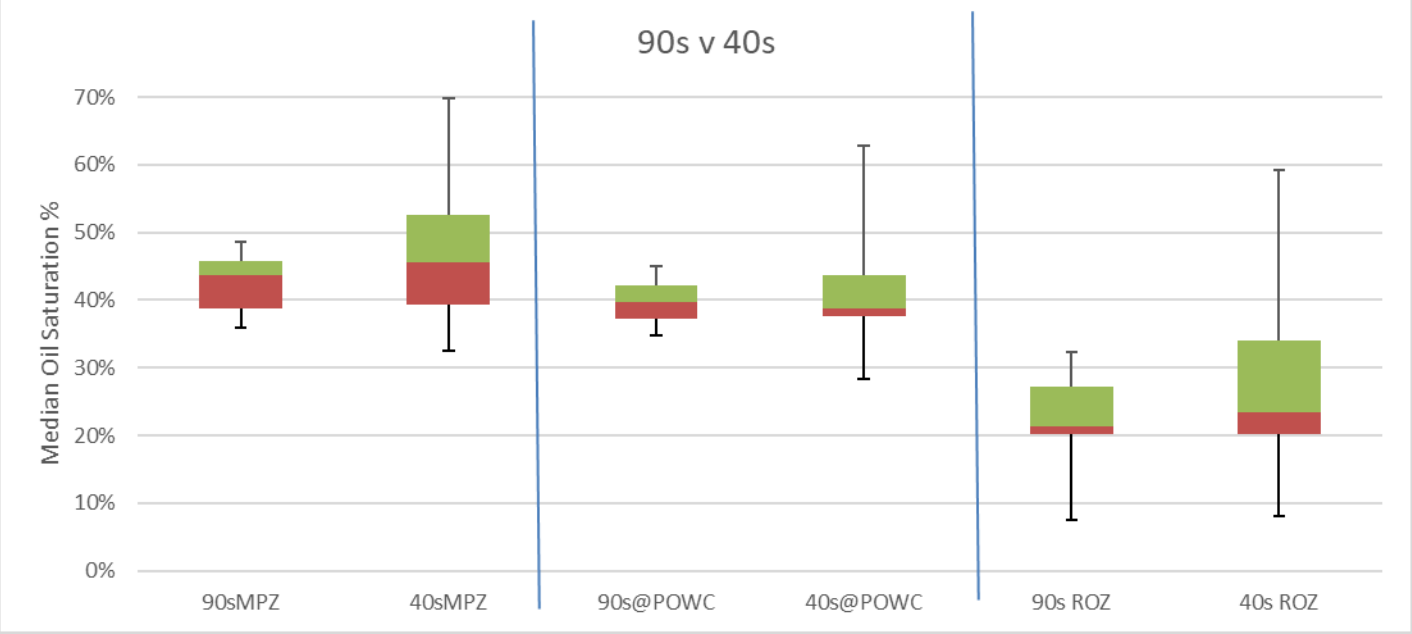
Kenner e-logs

- Can we use elogs to identify and characterize ROZ?
  - Ratio saturation failed
  - SP or SN derived porosity can be used in Archie
- IP: 4 bbls oil, 233 bbls water per day

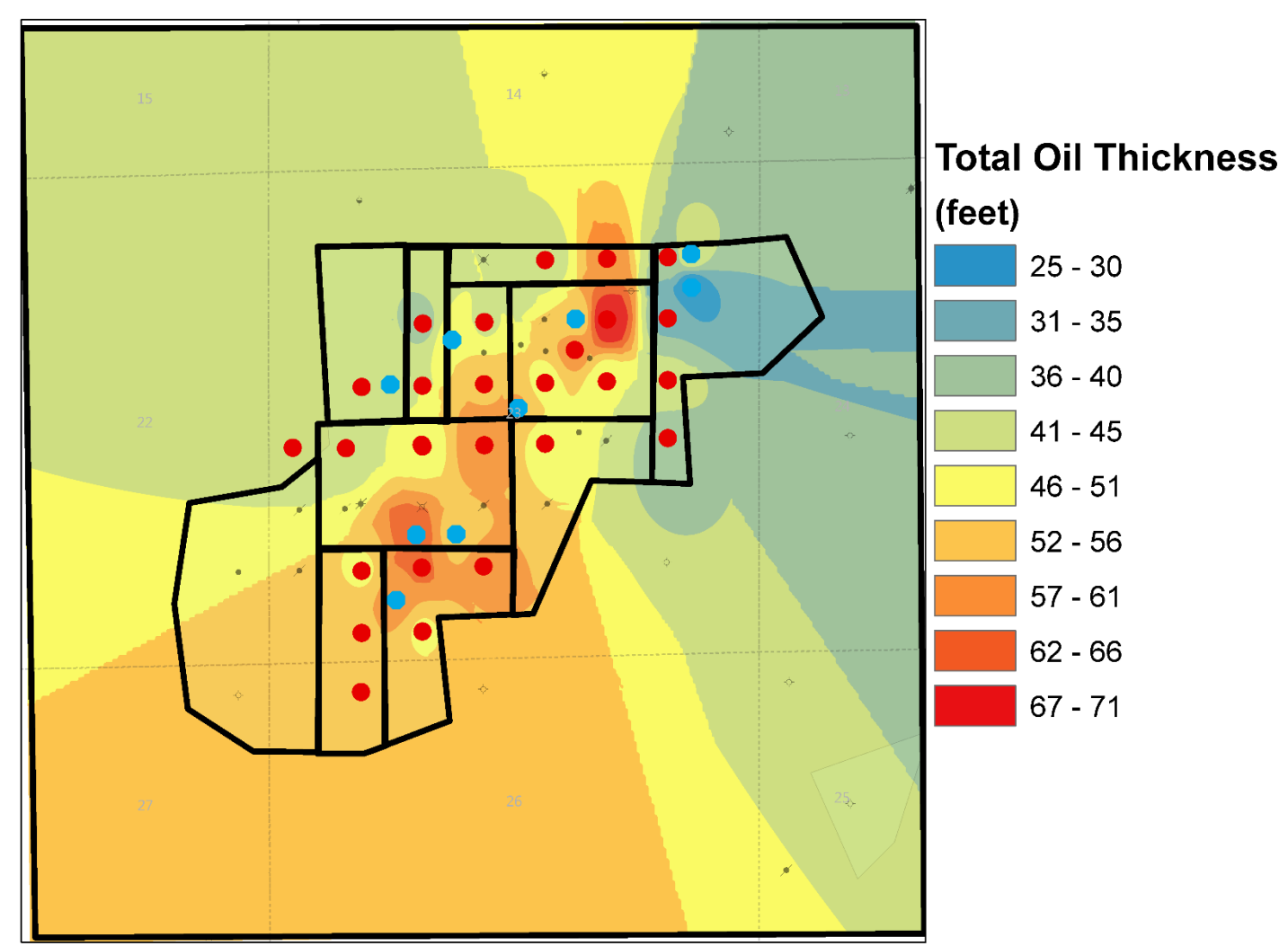


Kenner e-logs

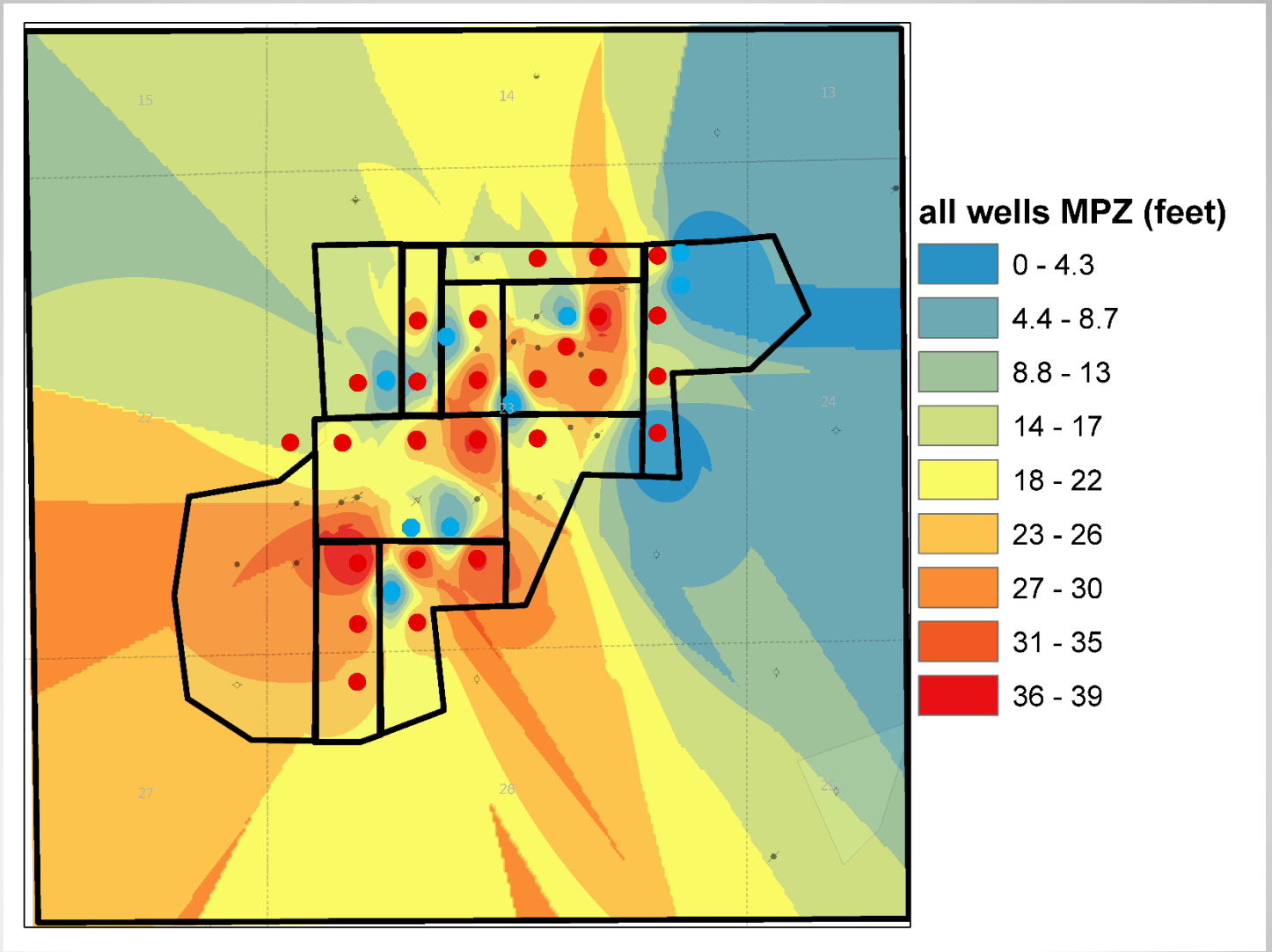
	Noble	Kenner 90s	Kenner 40s
MPZ So	55%	45%	45%
So at POWC	45%	40%	40%
Residual So	25%	25%	25%
Count	94	9	26



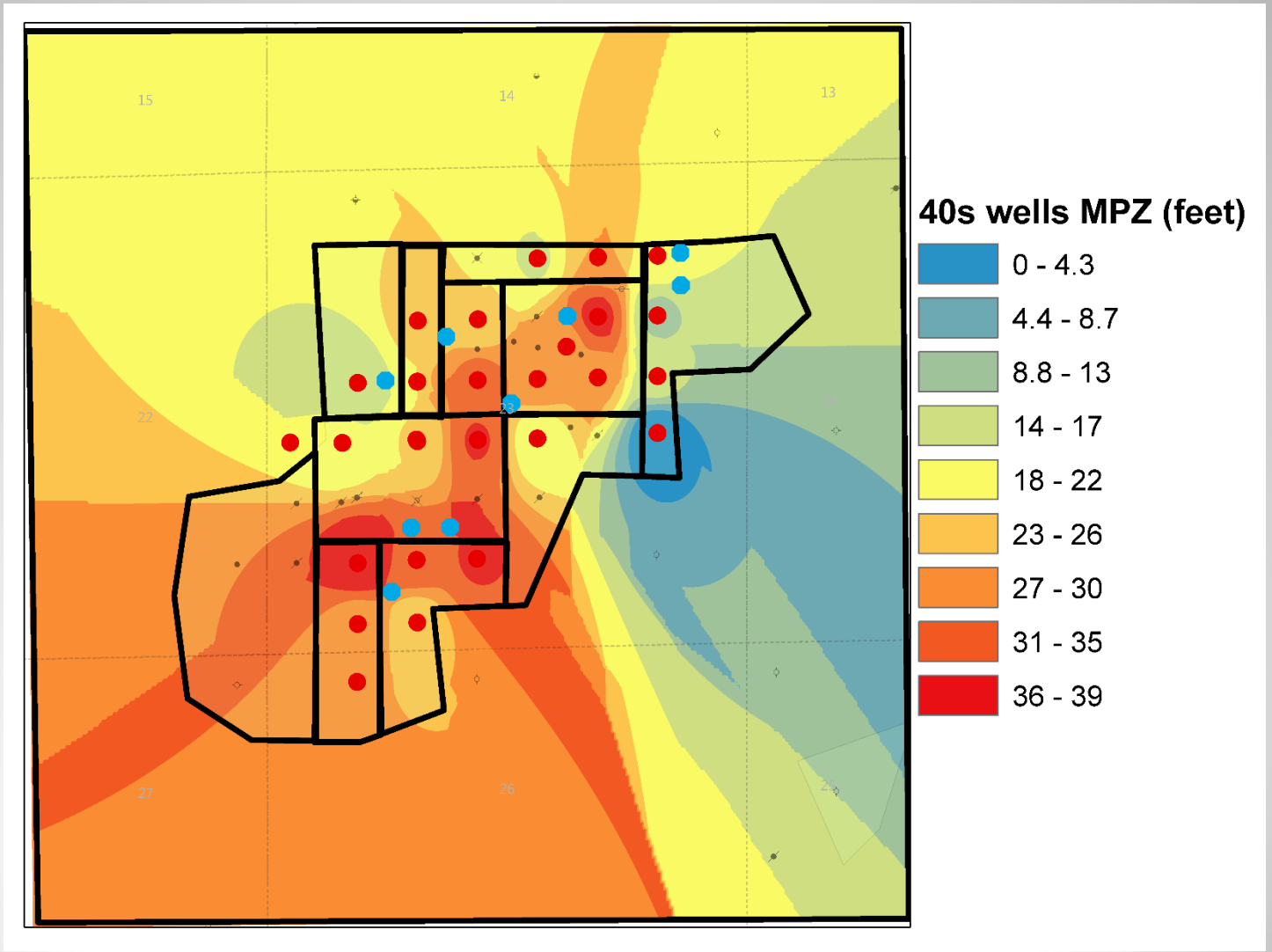
Kenner Oil Isopach



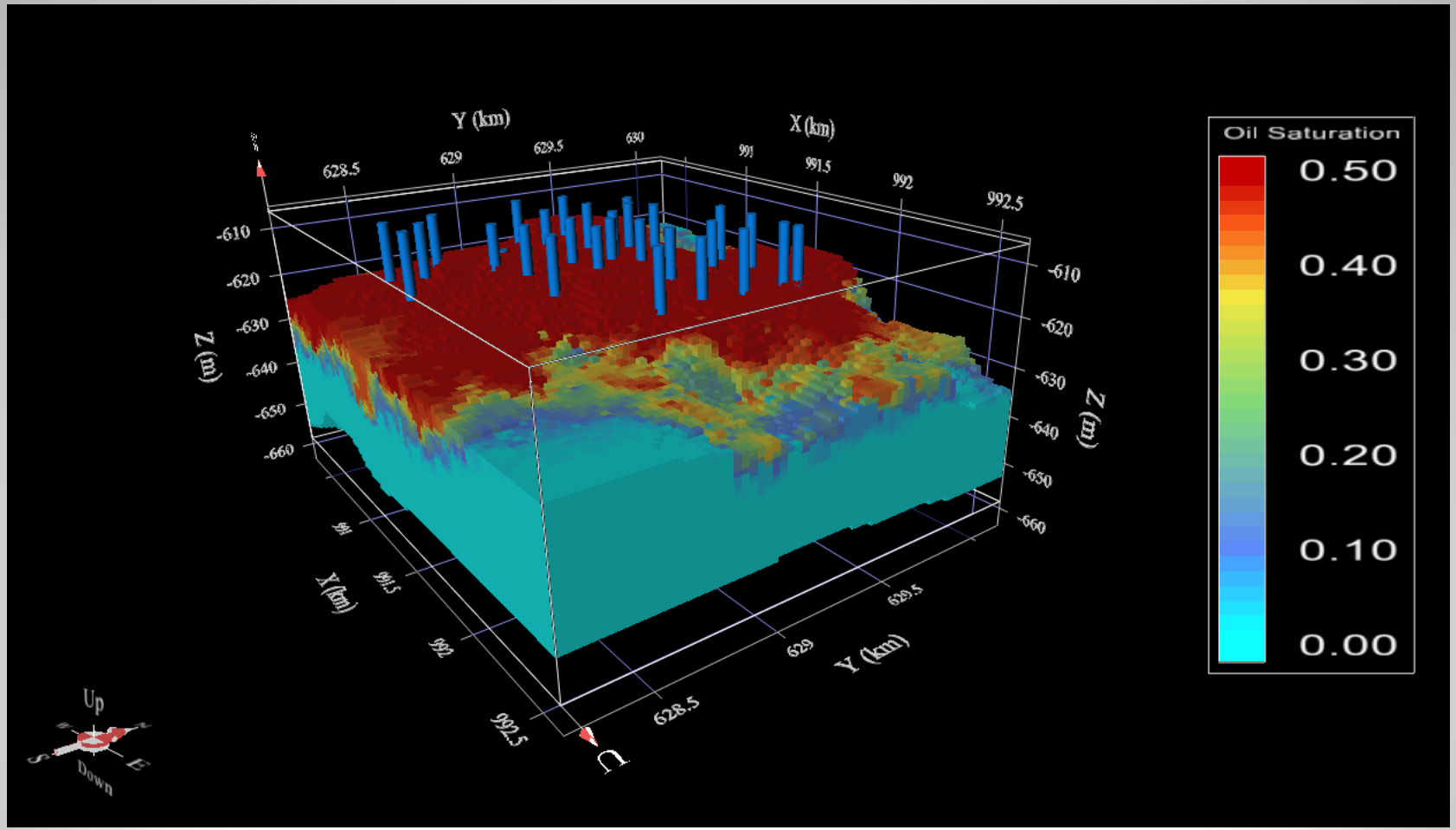
Kenner Map all MPZ



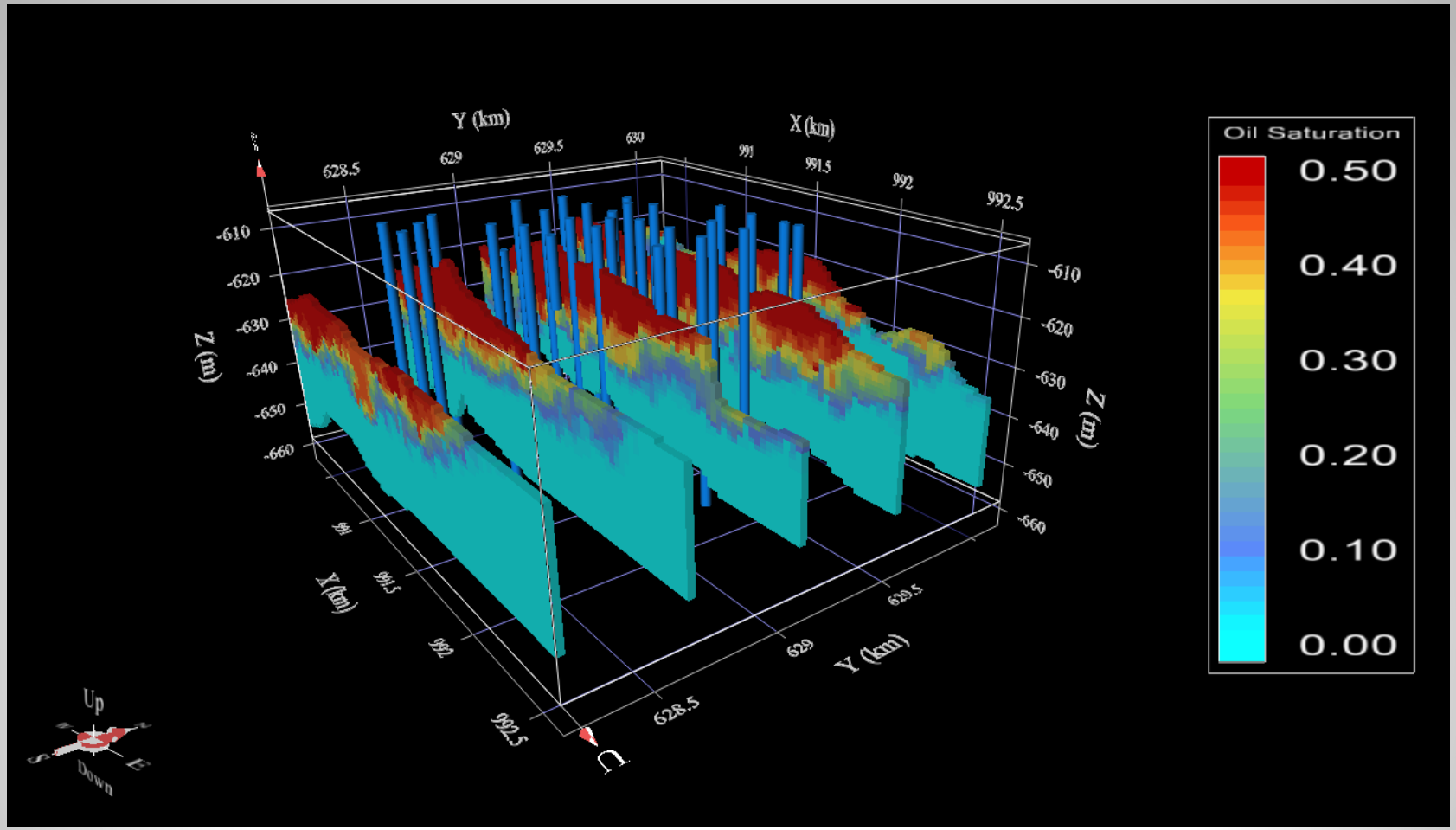
Kenner Map 40s MPZ



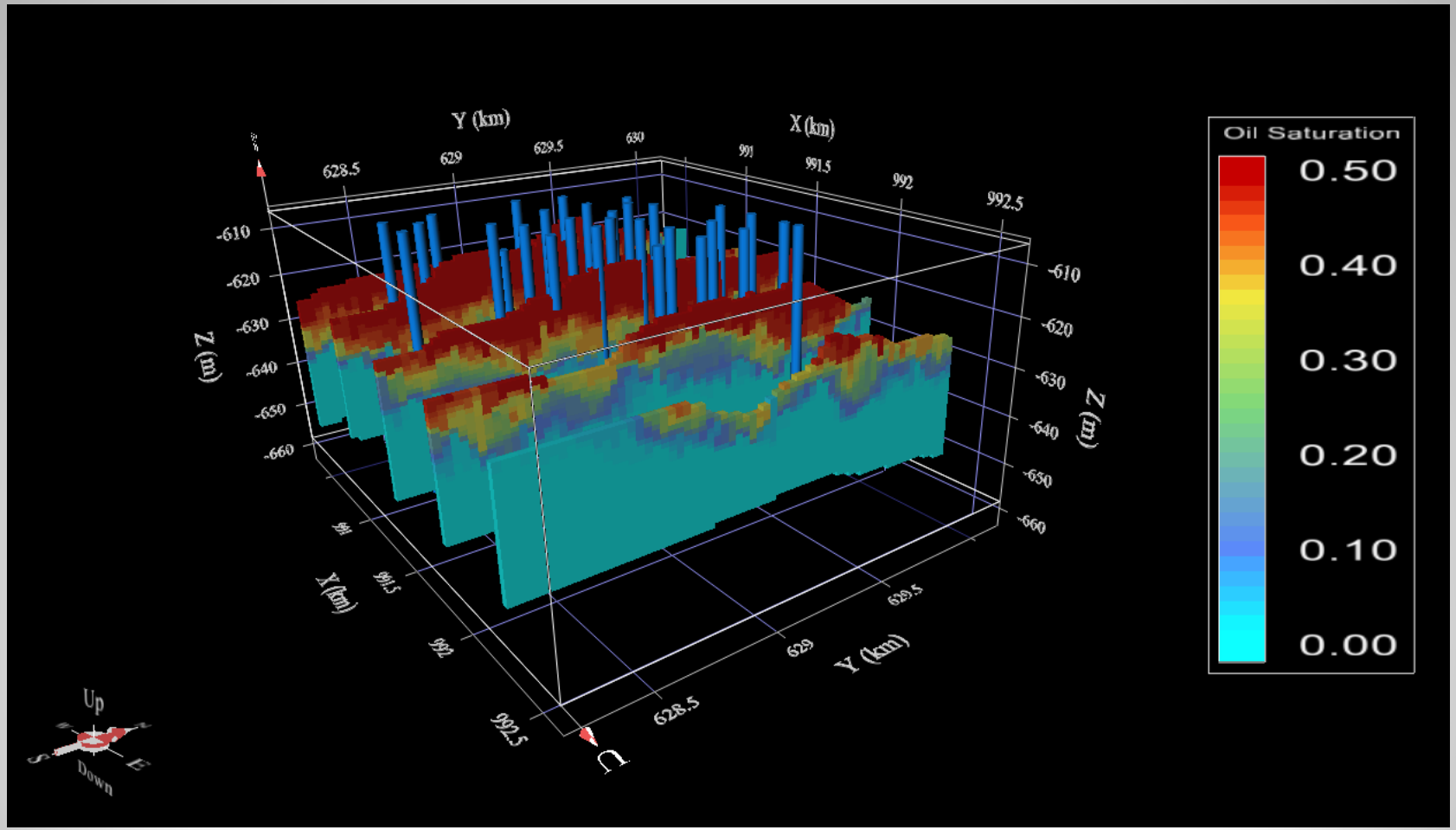
Kenner Initial Condition Model



Kenner Initial Condition Model



Kenner Initial Condition Model



Conclusions

- Evidence of ROZs in the ILB
  - Within thick Cypress Sandstone at both Noble and Kenner West Fields
- Well logs can be used to find/characterize them
- Worked in this case but…
  - Important to validate with other methods
  - Because formation is homogenous and well understood?

Thank You

- Questions?

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

Reference

- (Kuuskraa, V.A., M.L. Godec, and P. Dipeietro, 2013, CO2 Utilization from “Next Generation” CO2 Enhanced Oil Recovery Technology: Energy Procedia, v. 37, 2013, p. 6854—6866.

Pulsed Neutron Comparison

- From other wells:
- So at POWC ~45%
- ROS ~25%

	ND+Resistivity				Pulsed Neutron			
	POWC	OWC	@POWC	ROS	POWC	OWC	@POWC	ROS
Winter #4	2588	2612	46	25	2588	2610	46	18
Winter #7	2593	2613	44	28	2592	2612	44	17
Foss #6	2603	2625	49	22	2591	2620	50	1
Foss #7	2600	2625	40	28	2593	2627	23	26

Method

- Water Saturation
  - Archie: $\sqrt[n]{\frac{a*R_w}{\emptyset^m*R_t}}$
  - Ratio: $\left[\frac{R_{xo}/R_t}{R_{mf}/R_w}\right]^{\frac{5}{8}}$
  - Dual Water

Method

- "Proxy" curves
  - MHI $\frac{S_w}{S_{xo}} = \sqrt{\frac{R_{xo}/R_t}{R_{mf}/R_w}}$
  - BVW $S_w * \emptyset$
  - Rwa $\frac{\phi^m * R_t}{a}$