Multidisciplinary Characterization and Modeling of Mississippian Carbonate and Silica-Rich Reservoirs, Northern Oklahoma*

Matthew Pranter¹, Anna Turnini², Kurt Marfurt², and Deepak Devegowda²

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Abstract

Mississippian carbonate and silica-rich deposits of the mid-continent formed on a regionally extensive carbonate ramp and form shoaling-upward lithofacies successions that stack into high-frequency cycles. The cycles form several prograding depositional packages that downlap to the south. Lithologies include tripolitic chert and limestones that vary from mud- to grain-dominated fabrics. Tripolitic chert, the primary reservoir, most likely formed during periods of exposure; however, hydrothermal processes are also a possible cause. While the chert is most common at the top of the Mississippian, other cycles are capped by high-porosity, low resistivity chert. Lithofacies from core are calibrated to well logs using various methods and tied to seismic attributes to predict and map their spatial distribution. Support Vector Machines (SVM), a supervised-learning method in data mining, learns and recognizes the patterns that exist between the core and log datasets. SVM analyzes lithofacies (from core) and logging response and produces a model for lithofacies that is used to predict lithofacies in non-cored wells. The lithofacies logs are used to establish the stratigraphic framework and are integrated with seismic data (attributes) to condition 3-D reservoir models of lithofacies and petrophysical properties. The models are important to show depositional, diagenetic, and structural trends, analyze reservoir connectivity, and relate production to these characteristics.

References Cited

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¹University of Oklahoma, Norman, OK (matthew.pranter@ou.edu)

²University of Oklahoma, Norman, OK

Dowdell, B.L., H. White, and K.J. Marfurt, 2013, Poststack Acoustic Impedance Characterization of a Mississippian Tripolitic Chert Reservoir, Osage County, Oklahoma: The Shale Shaker, v. 63/5, p. 364-375.

Gutschick, R., and C. Sandberg, 1983, Mississippian Continental Margins on the Conterminous United States, *in* D.J. Stanley and G.T. Moore (eds.), The Shelf Break: Critical Interface on Continental Margins: Soc. Econ. Paleontologist Mineralogists Special Publication 33, p.79-96.

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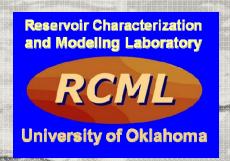
*Professor and Lew & Myra Ward Chair in Reservoir Characterization

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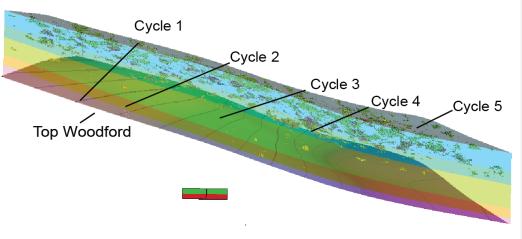
Research Questions

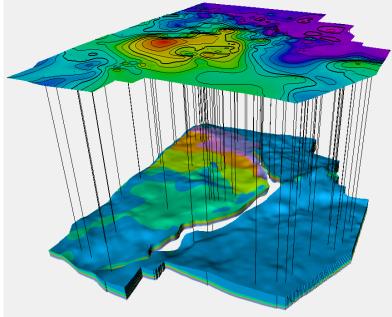


- 1. What are the stratigraphic and structural controls on reservoir quality and productivity?
- 2. What are the dominant lithologies / lithofacies and their well-log signatures?

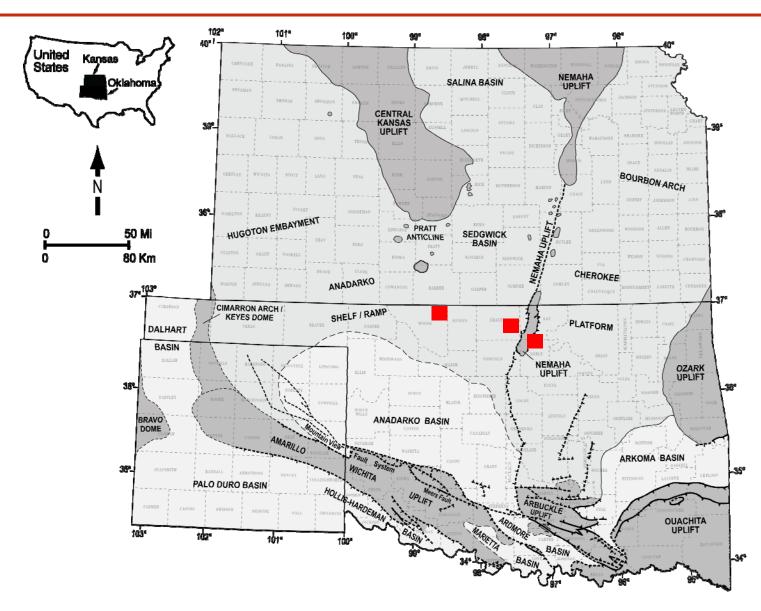
3. How do the lithologies / lithofacies and petrophysical

properties vary spatially?

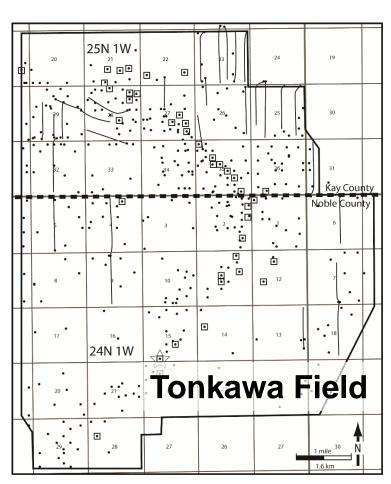










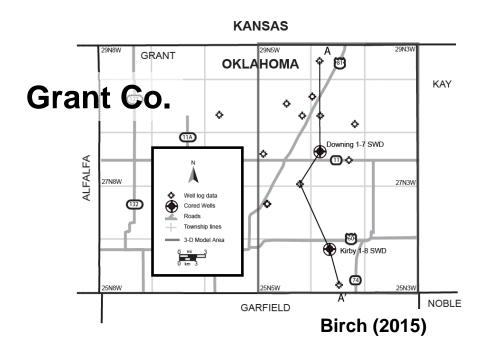


Turnini (2015)



1 Core
290 vertical wells
31 horizontal wells
42 mi² (108 km²) seismic survey
Production data





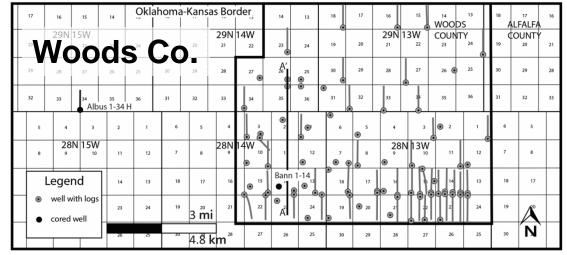


3 cores (> 1600 ft)
Digital log data for 14 wells
Numerous wells with raster data
>150 core plugs (10 ft-increment)
Thin sections





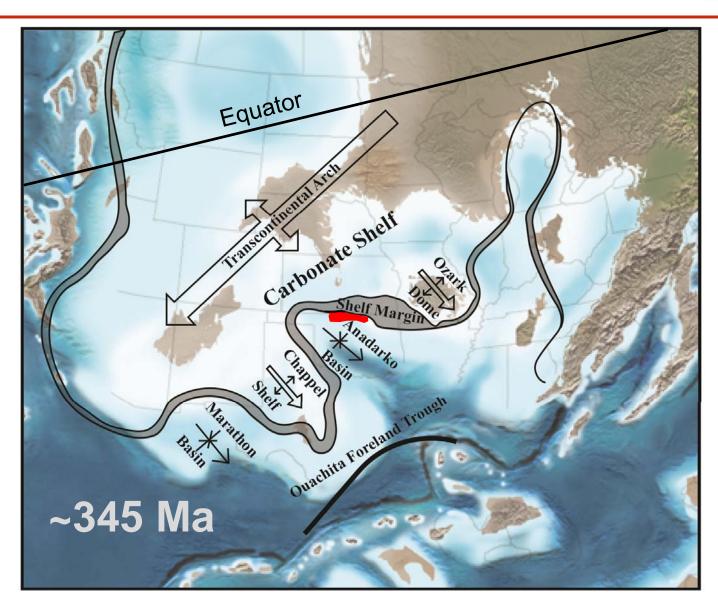
2 cores
Digital log data - 32 vert. wells
GR MWD for 50 horizontal wells
70 mi² (181 km²) seismic survey
111 thin sections and
petrophysical measurements
from core plugs
Production data



Lindzey (2015)

Early Mississippian Paleogeography

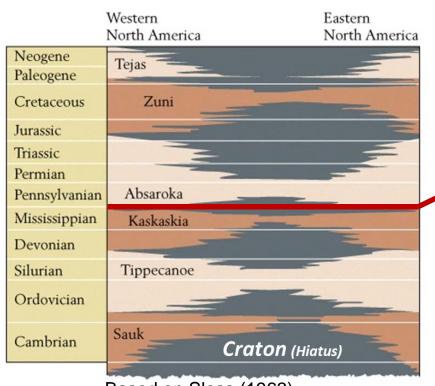




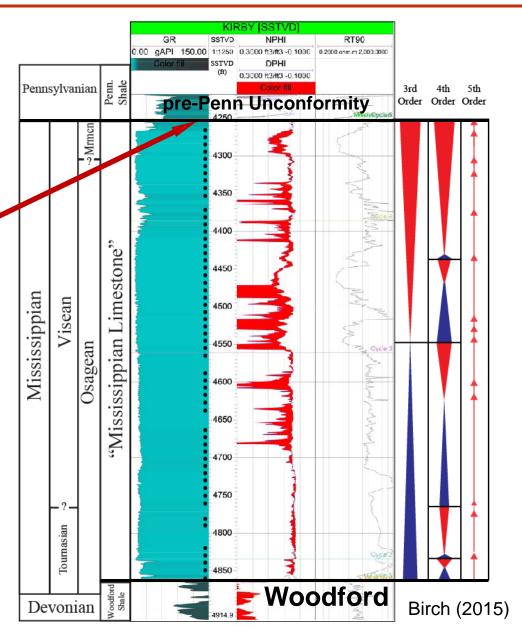
Adapted from Blakey (2014) and Gutschick and Sandberg (1983)

Mississippian Stratigraphy



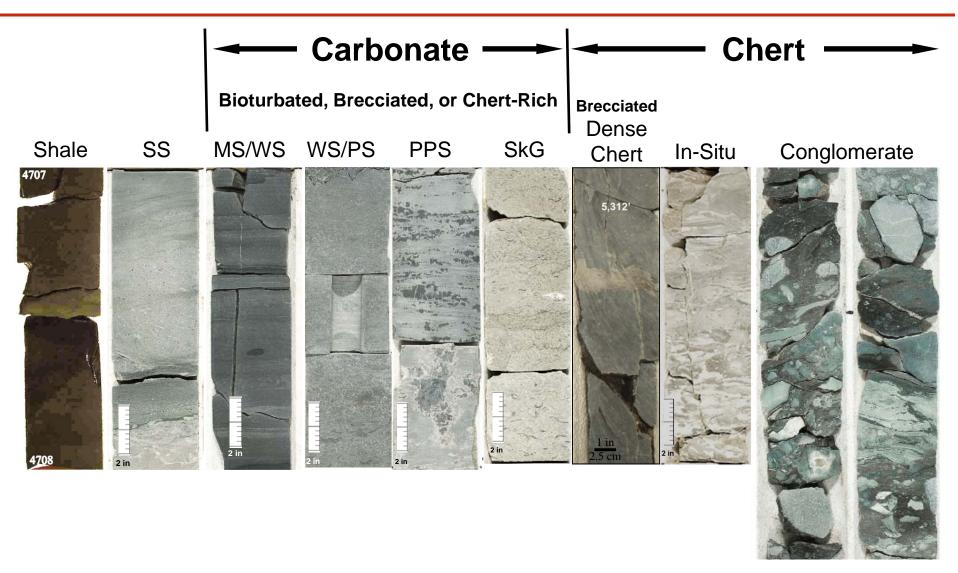


Based on Sloss (1963)



Mississippian Lithologies / Lithofacies

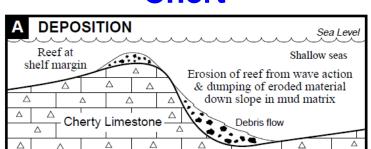




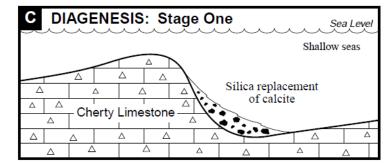
Tripolitic Chert Development

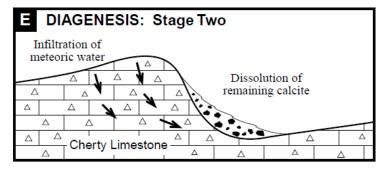


Detrital Conglomeratic Chert

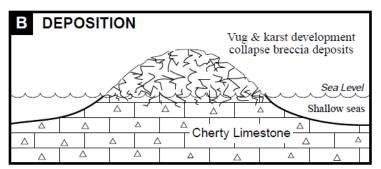


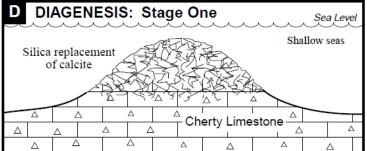
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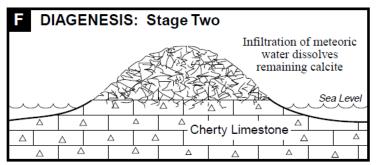




In-Situ, Weathered Chert

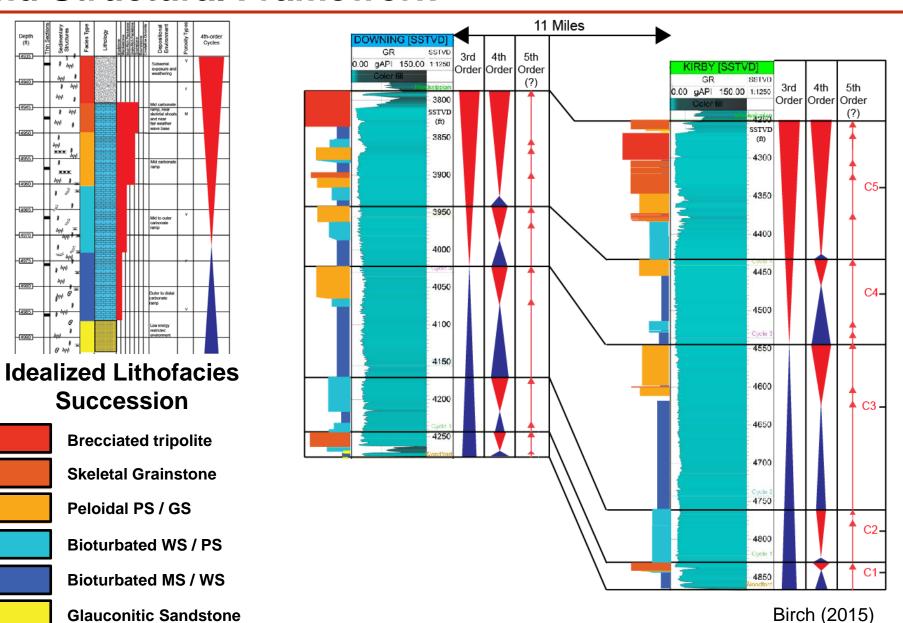






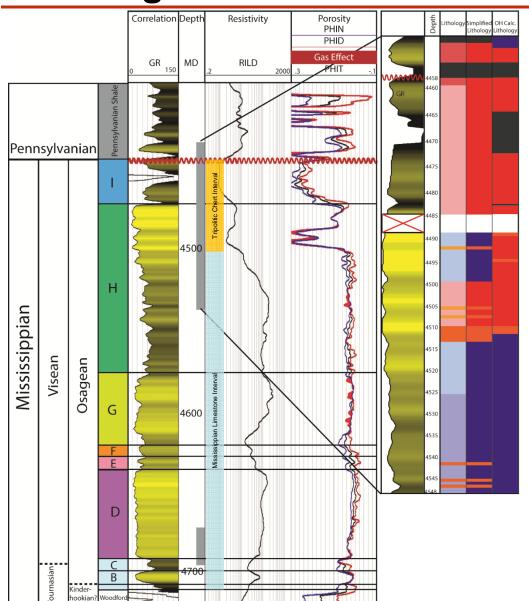
Mississippian Stratigraphic and Structural Framework





Mississippian Lithology Estimation – Well-log cut-offs



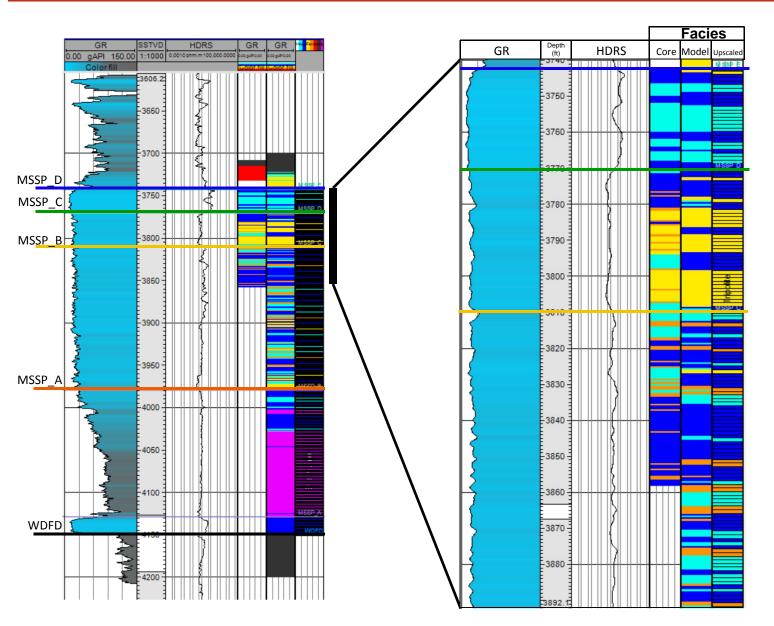


7 main lithologies 4 lithologies for log estimation and modeling 80% accuracy (log cut-offs: GR, RHOB, and RILD)

Key Lithologies Identified in the Core		Simplified Lithologies for OH log calculations	
Conglomeratic Tripolitic chert			Tripolitic Chert
In-situ Tripolitic chert			
Brecciated Limestone			Limestone
Bioturbated Limestone			
Dense chert band			Dense Chert
Brecciated Dense Chert			
Carbonaceous Shale			Shale

Mississippian Lithology Estimation – Artificial Neural Network





Artificial Neural Network (ANN)

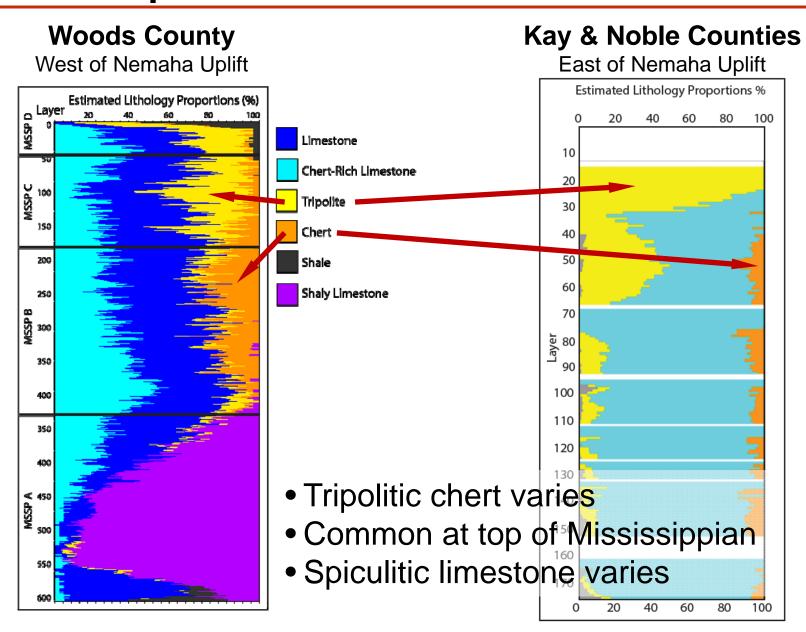
- RhoB
- PE
- ResD
- Nphi

Vshale cutoff 0.7

Accuracy = 65%

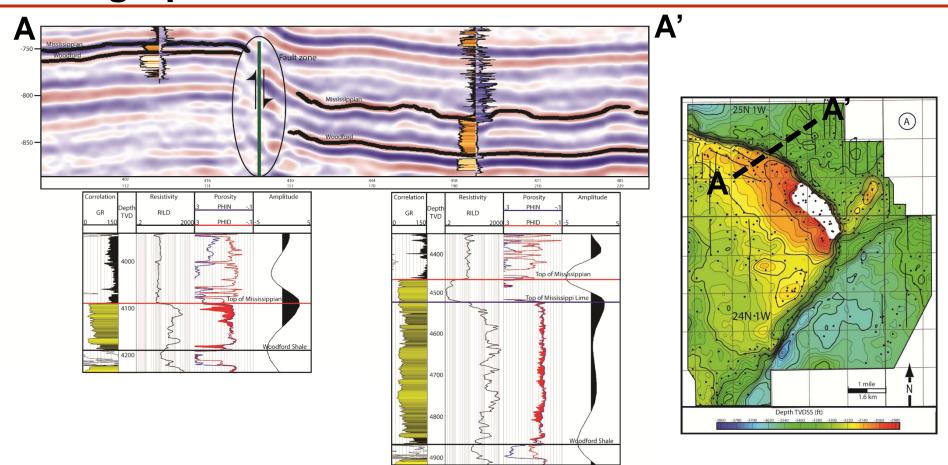
Mississippian Lithology Vertical Proportion Curves





Tonkawa Field Area: Mississippian Stratigraphic and Structural Framework

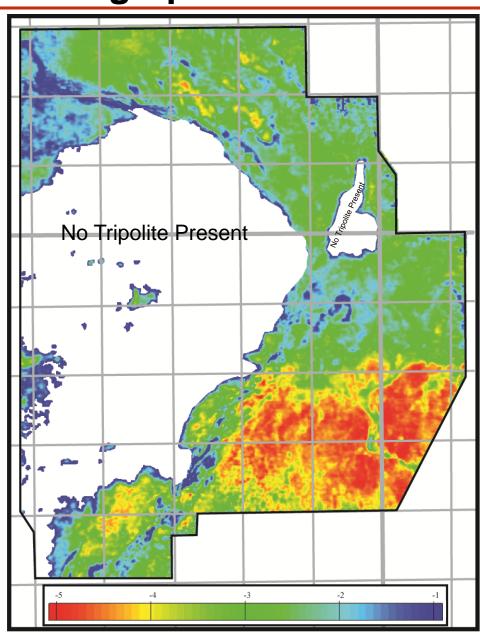




- If tripolite is present at the top of the Mississippian = trough
- If limestone is present at the top of the Mississippian = peak
- 3 horizons are resolvable on seismic:
 - Top Mississippian, Top Mississippian Limestone, and Woodford Shale

Tonkawa Field Area: Mississippian Stratigraphic and Structural Framework



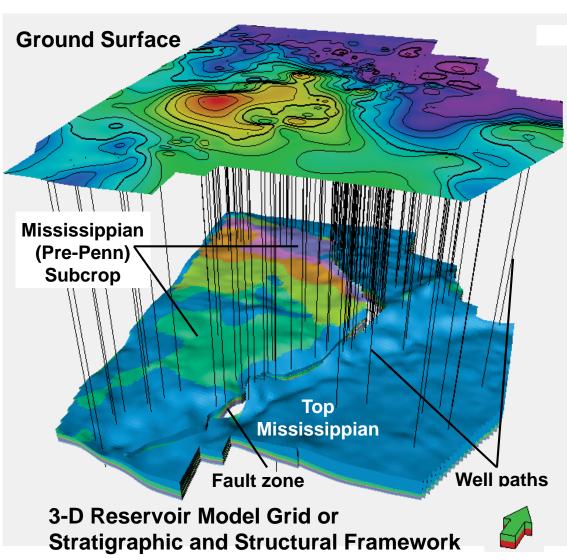


Top Mississippian Amplitude Map

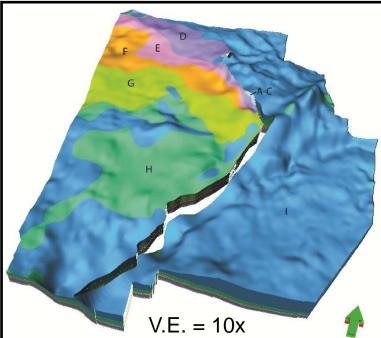
- Where the amplitude is negative (and shown in the figure) it is interpreted to be where tripolitic chert is present
- Positive amplitudes (removed) – tripolite is not present

Tonkawa Field Area: Mississippian Stratigraphic and Structural Framework



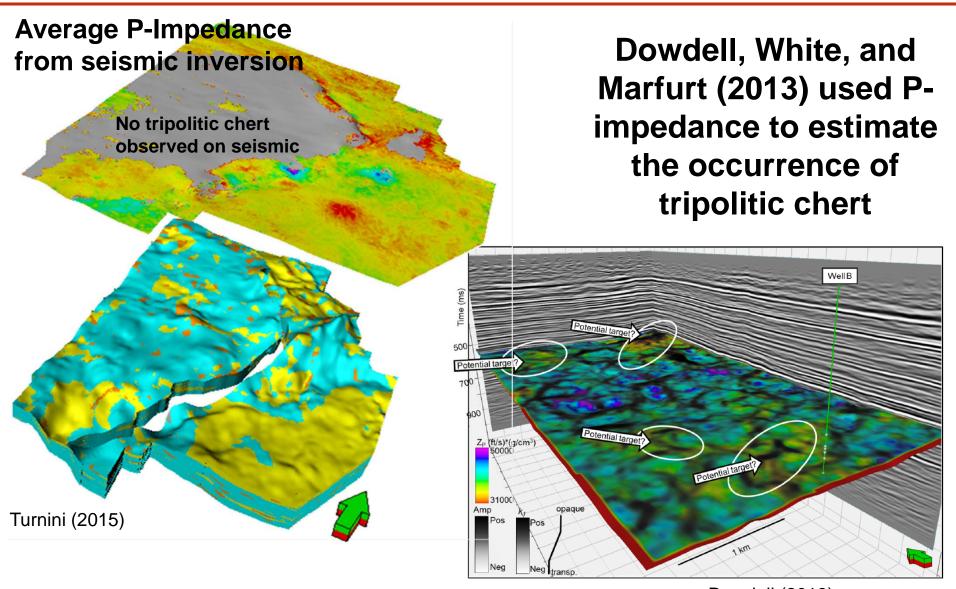


1 Core
290 vertical wells
31 horizontal Mississippian wells
42 mi² (108 km²) seismic survey



How does tripolitic chert vary between wells?

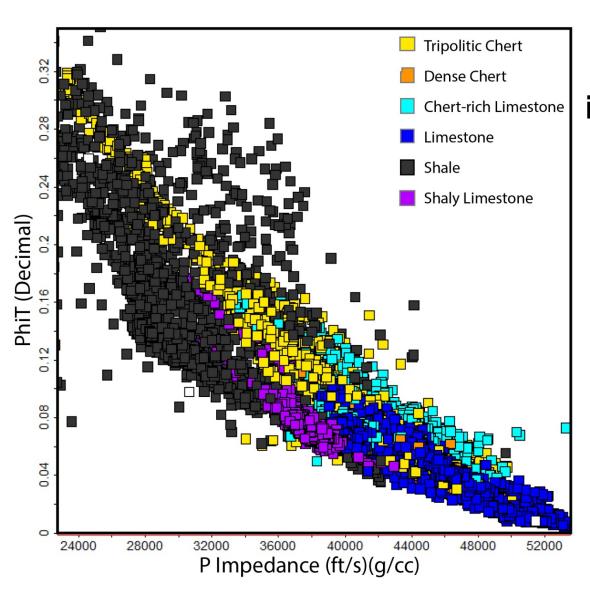




Dowdell (2013)

P-impedance to estimate Mississippian lithology





Dowdell, White, and Marfurt (2013) used P-impedance to estimate the occurrence of tripolitic chert

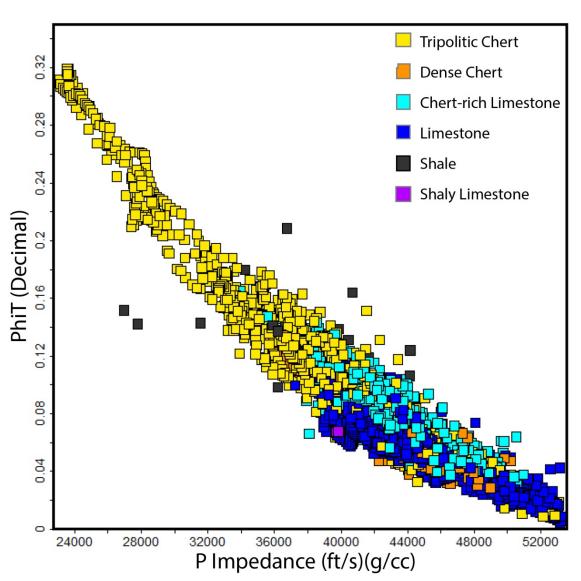
Zp < 34,000, P(tripolite) = 0.9

Zp > 46,000, P(tripolite) = 0

Valid for trend mapping

P-impedance to estimate Mississippian lithology





Dowdell, White, and Marfurt (2013) used P-impedance to estimate the occurrence of tripolitic chert

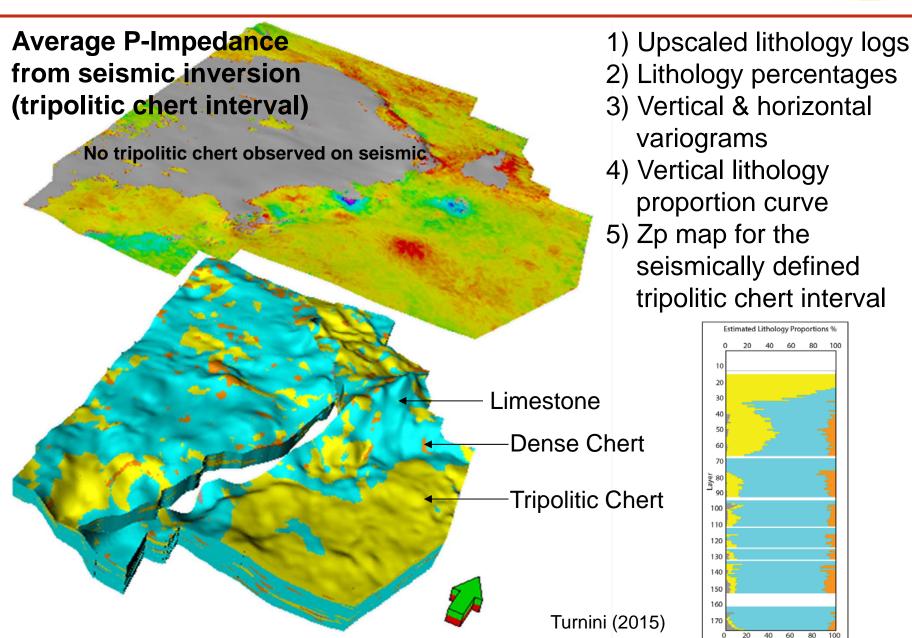
Zp < 34,000, P(tripolite) = 0.9

Zp > 46,000, P(tripolite) = 0

Valid for trend mapping

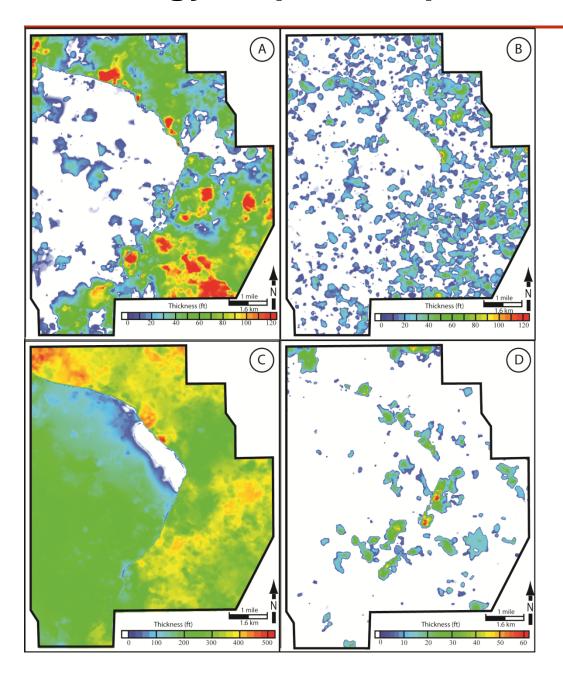
Mississippian 3-D Lithology Model





Lithology Isopach Maps

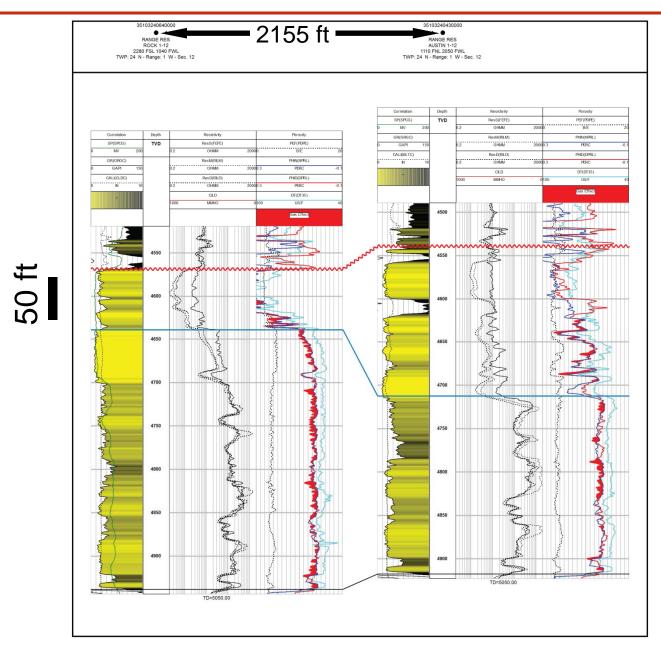




- A. Tripolitic Chert
- **B. Dense Chert**
- C. Limestone
- D. Shale

Thickness Anomalies – Karst Features?

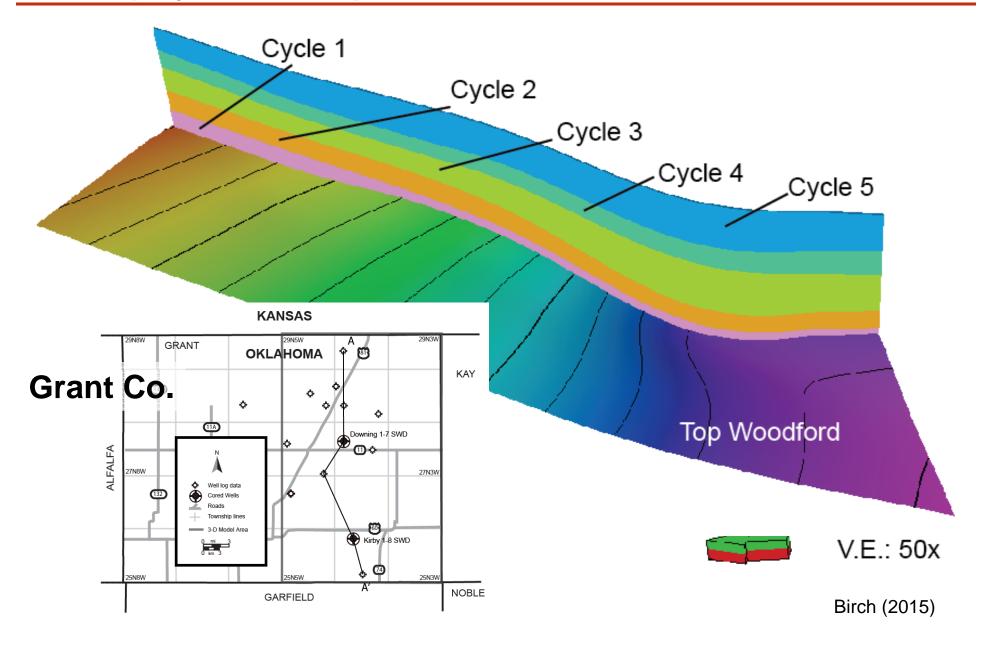




Turnini (2015)

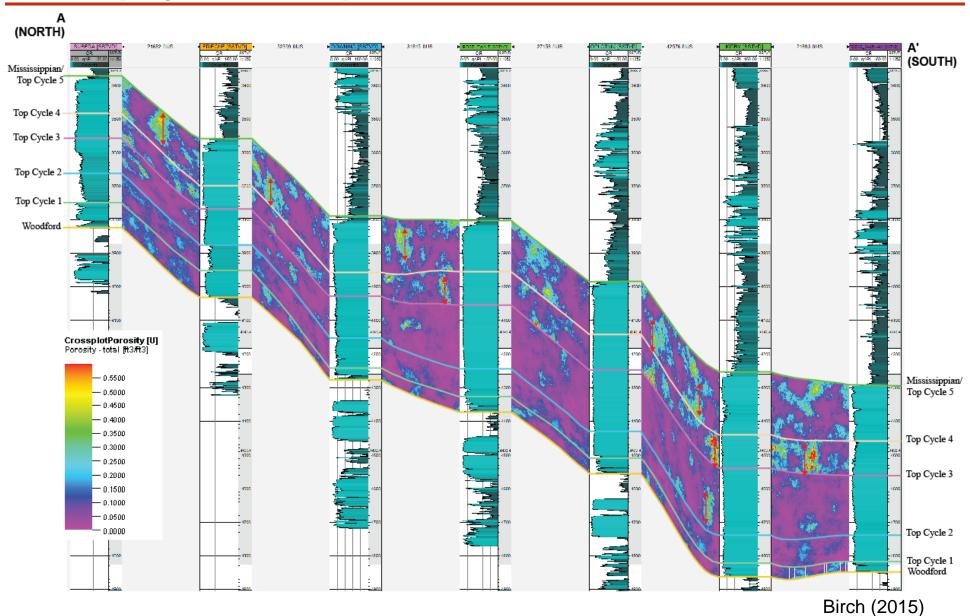
Stratigraphic Controls on Petrophysical Properties





Stratigraphic Controls on Petrophysical Properties

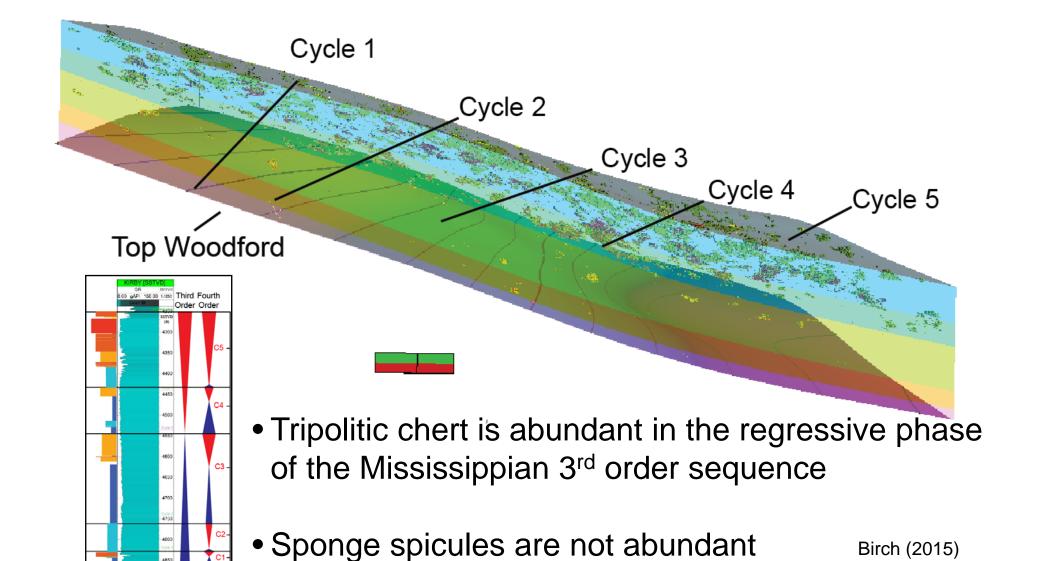




Stratigraphic Controls on Petrophysical Properties

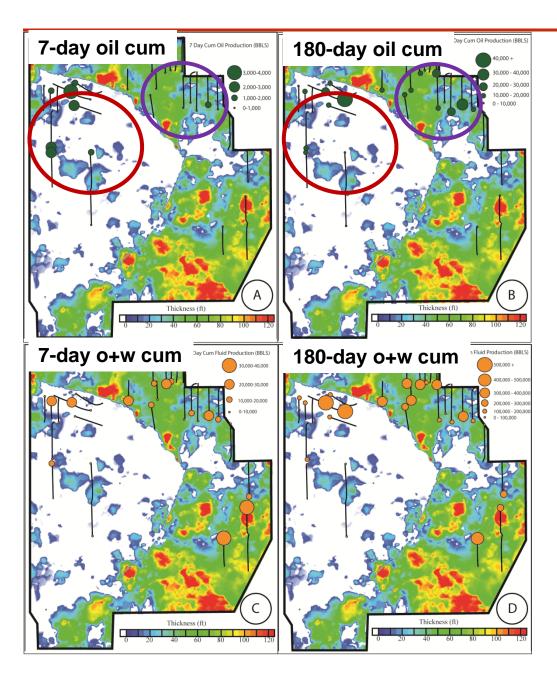


Birch (2015)



Controls on Production



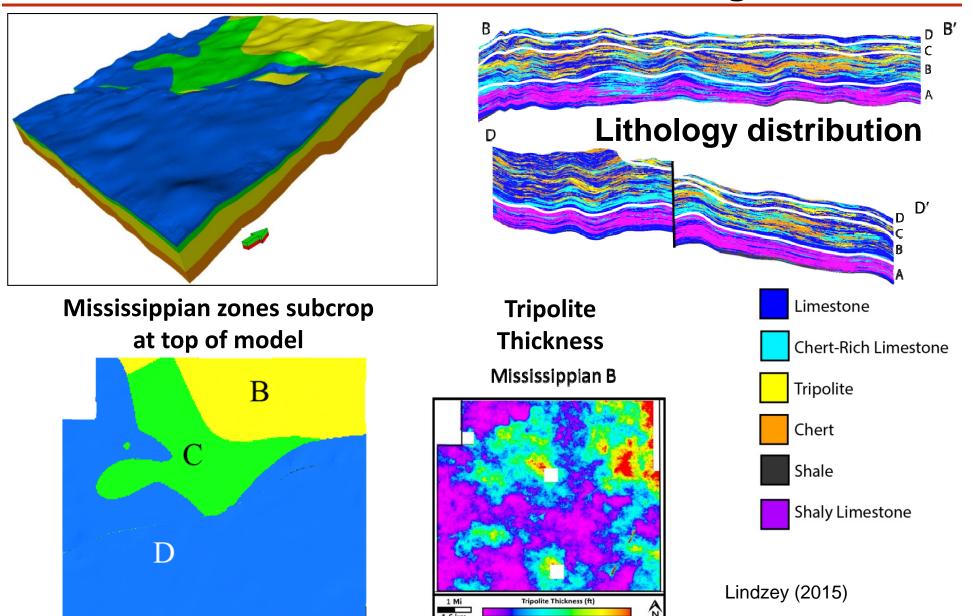


In general, areas of thin tripolitic chert reach peak oil production early, but decline rapidly because of limited reservoir volume

Areas with thicker tripolitic chert can take longer to reach peak oil production but produce at higher rates for longer periods and have higher long-term cumulative production; however, this production is variable...

Woods County Seismic-Constrained Reservoir Modeling

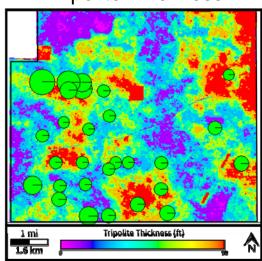




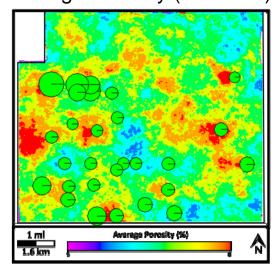
Production from Vertical Wells Tripolite Thickness is Important!



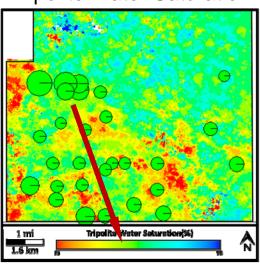
Tripolite Thickness



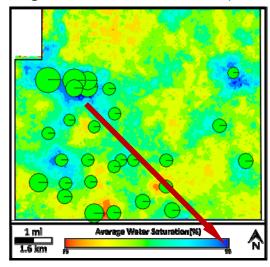
Average Porosity (all zones)



Tripolite Water Saturation

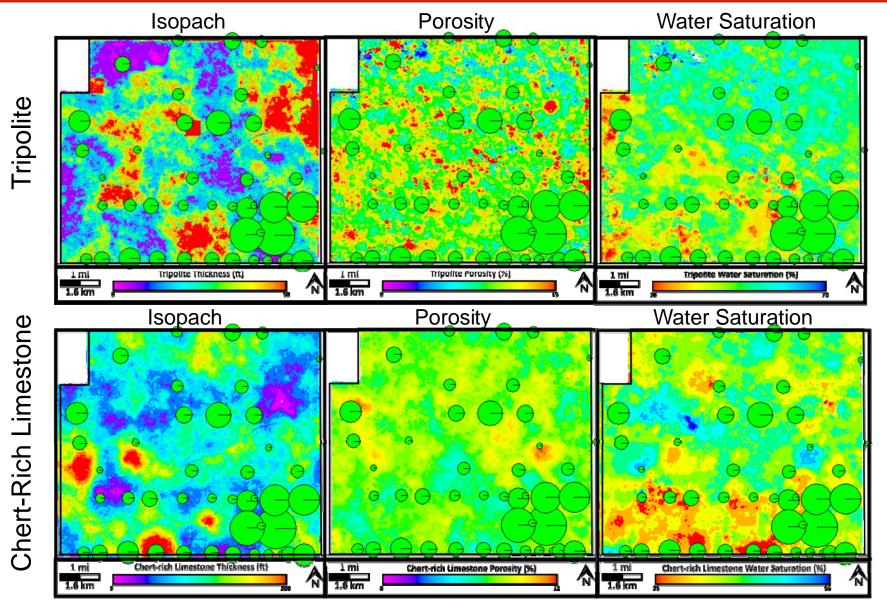


Average Water Saturation (all zones)



Production from Horizontal Wells Fractured Limestone is Important too!

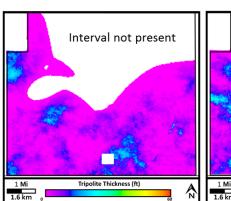


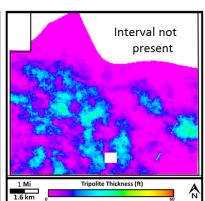


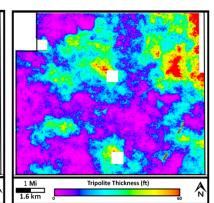
Future Directions...

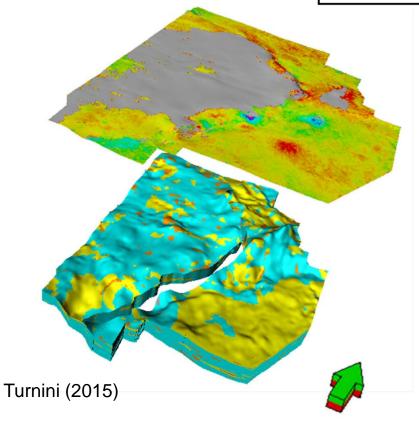


- Lateral variability
- Petrophysics
- Fracture analysis& modeling

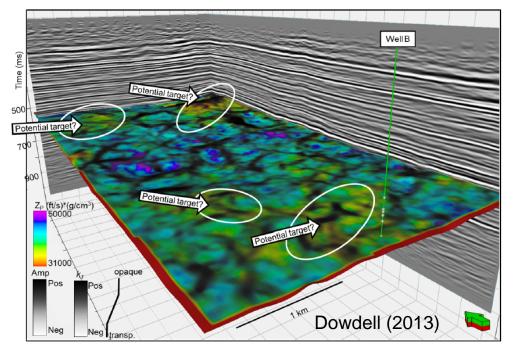












Conclusions



- Reservoir lithologies are tripolitic chert and chert-rich limestone
- Higher reservoir quality is most commonly associated with the regressive phase of the third-order Mississippian sequence
- The degree and areas of diagenetic alteration and the sequencestratigraphic framework provide the main controls on reservoir quality
- Production from tripolitic chert is sensitive to thickness, porosity, and water saturation
- Production from chert-rich limestone is most likely fracture controlled
- Oil production and total fluid production are not necessarily related, and the differences between the two should be further explored