Geologic Controls on Oil Production from the Niobrara Formation, Silo Field, Laramie County, Wyoming*

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Abstract

The Niobrara Formation, an interbedded source-rock and low-porosity chalk/limestone deposited during the Late Cretaceous in the Western Interior Seaway (WIS), is an important hydrocarbon play throughout the Rocky Mountain region. The interbedded chalks and marls contribute to the petroleum system potential of the Niobrara. Ductile marl units have higher organic carbon content, and act as both a source and seal while most reservoir capacity is in the brittle chalk benches. Silo Field, located in the Denver-Julesburg Basin in Laramie County, Wyoming, has been producing from the Niobrara Formation since 1981. Vertical wells were drilled in the 1980s, followed by horizontal drilling in 1990, and finally, horizontal drilling using modern technology began ~2009. Cumulative production to date is 10.8 MMBO and 9,751 MMCFG. At Silo Field, the Niobrara is ~300 ft. thick, is at depths between 7,500-8,500 ft., and consists of the lower Fort Hayes Limestone and the upper Smoky Hill Member, which contains alternating chalk and marl sections. The middle B chalk bench is the main production target. Despite over thirty years of production history at Silo Field, it is not well understood why only a few wells are top producers while neighboring wells have very poor production rates. Though the Niobrara has been the topic of previous research, little attention has been paid in analyzing relationships between geological trends and production data in a quantitative manner. Our objective is to identify geologic factors that contribute to productive wells or groups of wells ('sweet spots') at Silo Field. We will identify completion practices in order to differentiate whether successful production is due to geological variables like mineralogy, distance from faults, fracture intensity, interval thickness, and porosity; or to how wells were managed. We will present the correlation between production and geologic variables determined from core, well logs, cross-sections and maps, with an emphasis on the B chalk. Our goal is to build a predictive geologic model of spatial and stratigraphic heterogeneity to test whether a relationship exists between geologic variables and production. Results from this study may contribute to understanding other Niobrara plays in the Denver-Julesburg basin like the nearby Wattenberg and Hereford fields in Colorado, and may define what makes the Niobrara Formation unique compared to other source rock reservoirs.

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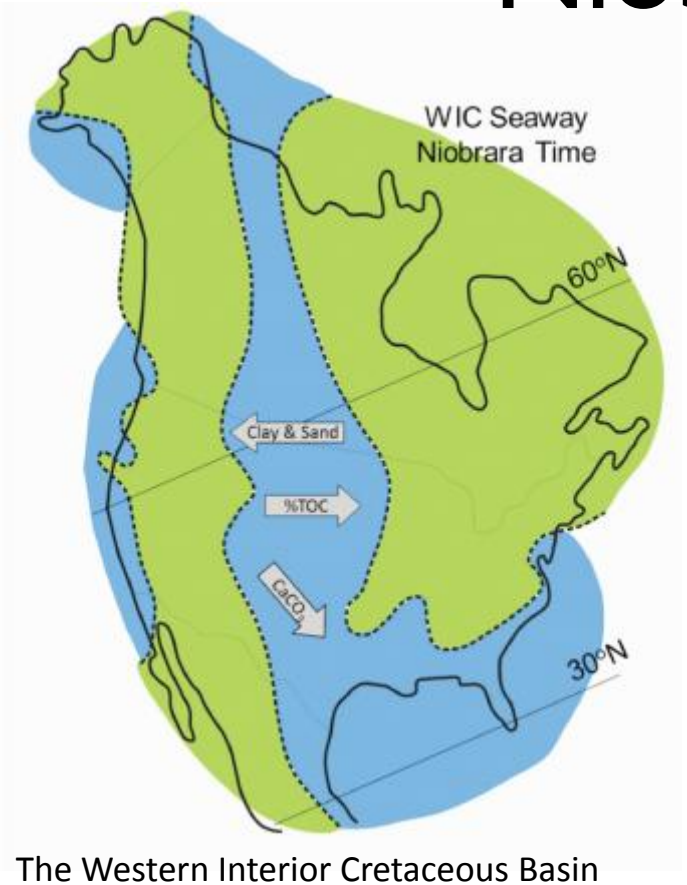
Outline

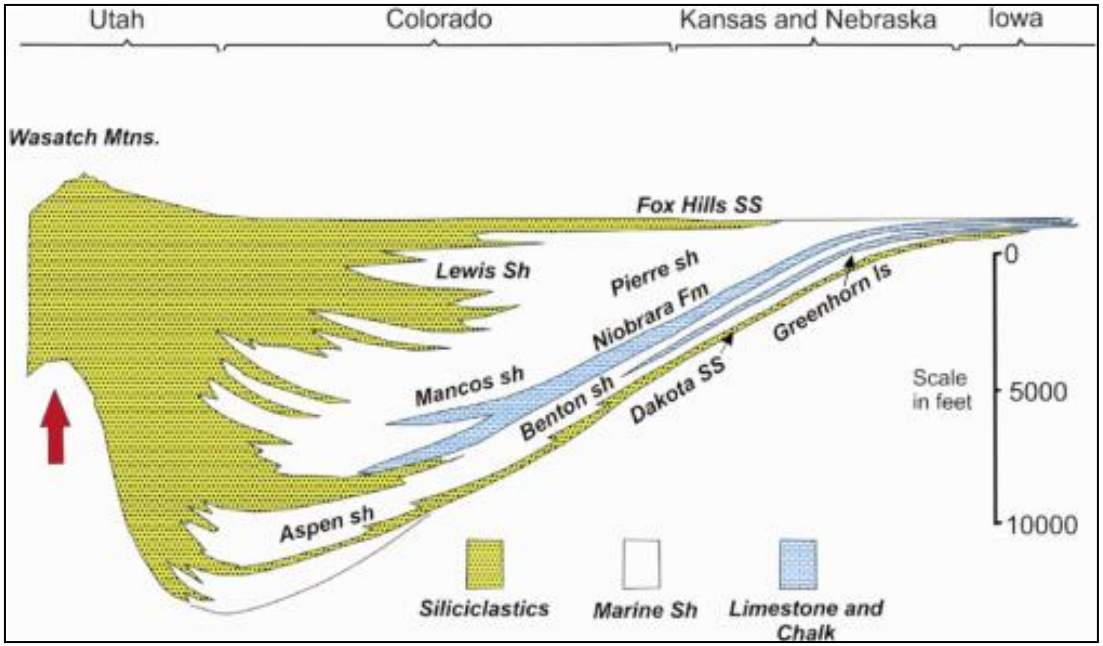
- Niobrara geologic setting and stratigraphy
- Study location
- Previous Silo field studies
- Research questions & methods
- Results
- Conclusions

Niobrara Setting



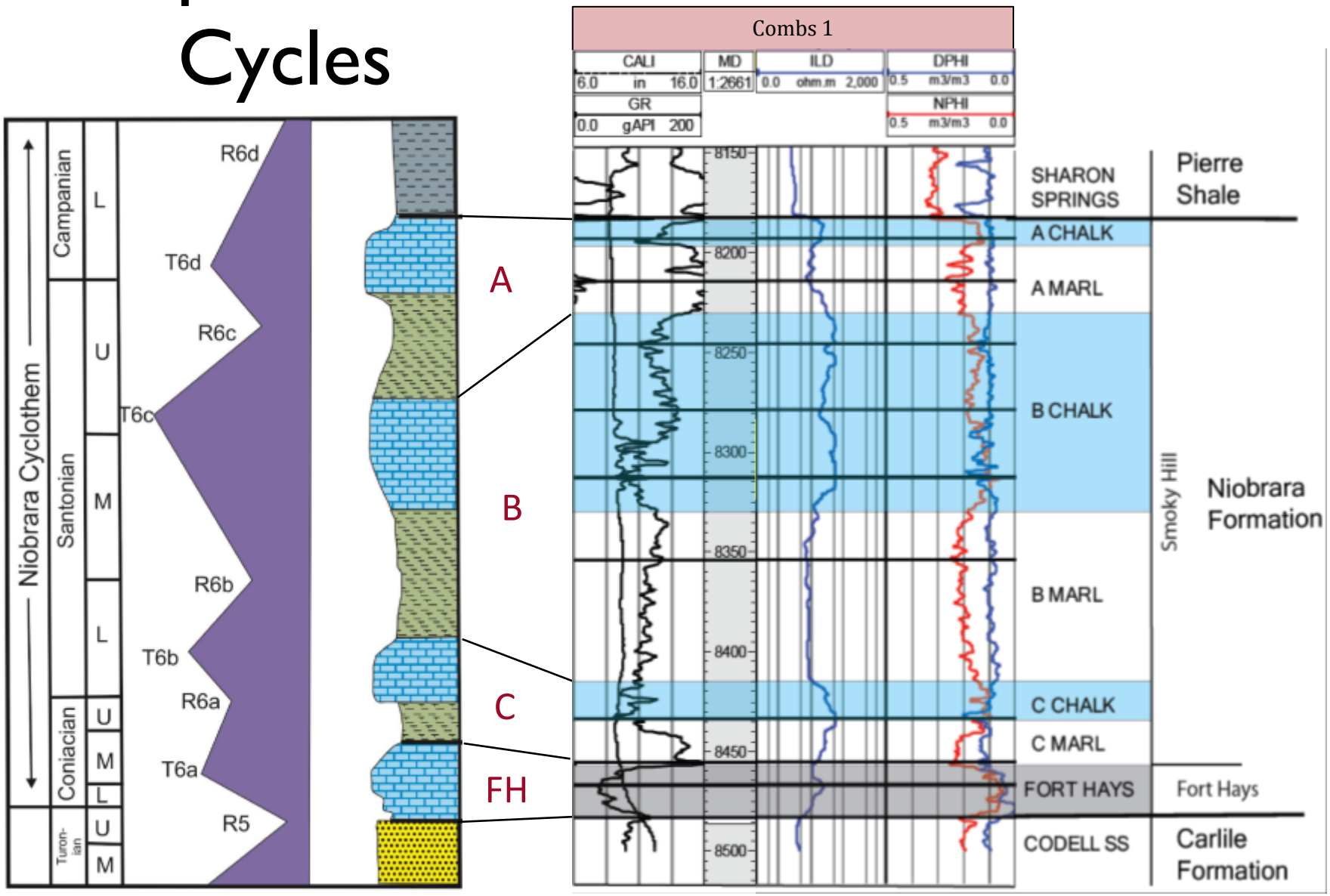
The Western Interior Cretaceous Basin during Niobrara time. Source area for clastics is dominantly to the west, TOC content increases to the east, carbonate content generally increases on the eastern side.

Generalized cross section across the Western Interior Cretaceous Basin. Limestone and chalk beds are present over the eastern two-thirds of the basin.



Sonnenberg (2011), (after Longman, et al, 1998, and Kauffman, 1977)

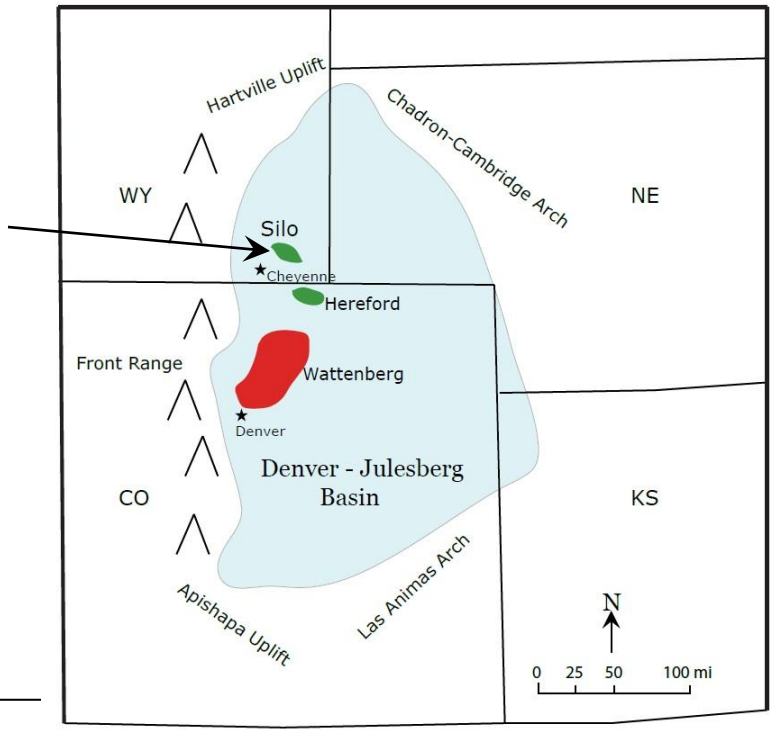
Depositional Cycles



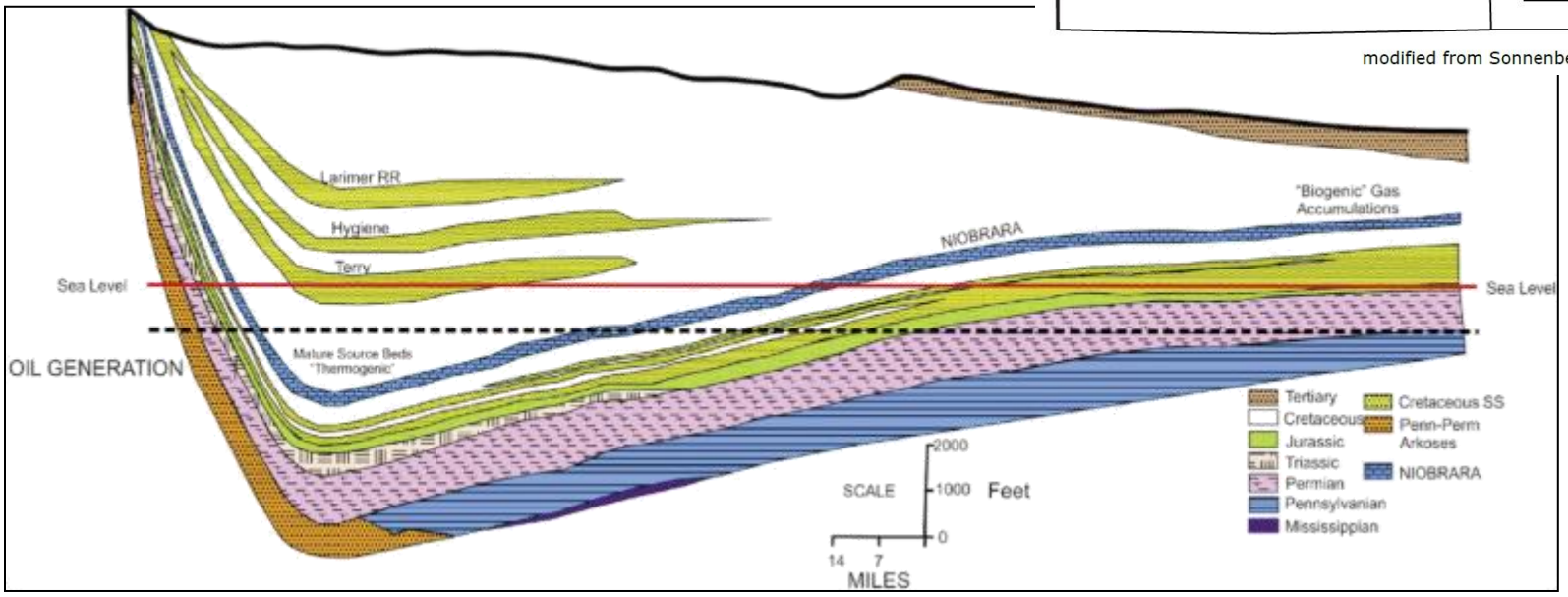
Sonnenberg, 2012, modified from Longman et al., 1998, after Barlow, 1986

Denver Basin

- Asymmetric basin formed by the Laramide orogeny
- Thermally immature in the east (biogenic gas)
- Thermally mature in the west
- Largest producing field is Wattenberg
- Silo is in the northwest part of the Denver basin



modified from Sonnenberg, 2011



West to east diagrammatic cross section for Denver Basin. Shallow biogenic accumulations in the Niobrara are found on the east flank of basin where source beds are thermally immature for petroleum generation.

Sonnenberg, 2011, (after Longman, et al, 1998, and Kauffman, 1977)

Silo Field, WY

Northwest trending zone of flexure

Four township study area

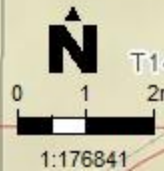
Discovery well in1981

Westward dipping monoclinal fold

1st horizontal well in1990

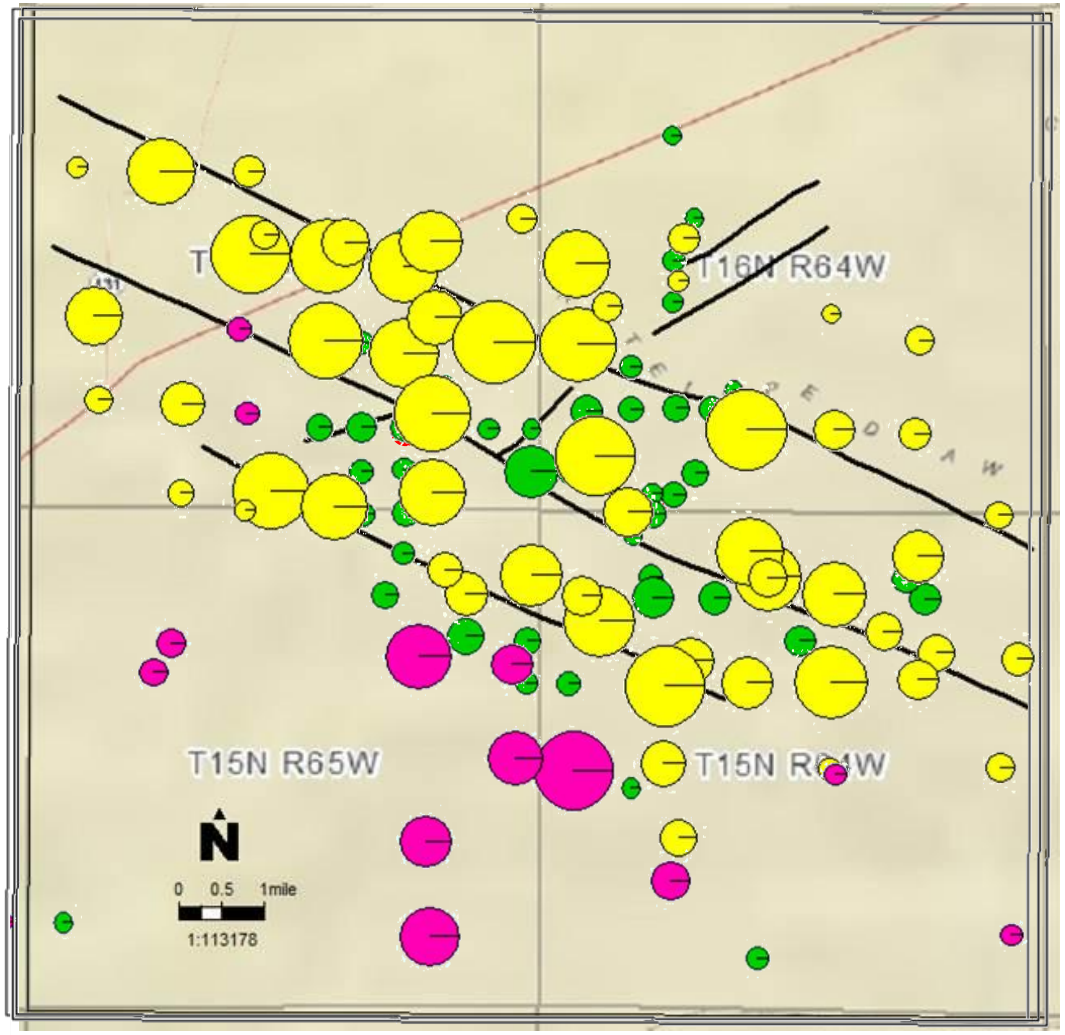
Niobrara oil production since 1983

~30 years of Niobrara production data!



Fault Interpretation from Sonnenberg & Weimer, 1993

Silo Field Drilling History



1st year Cumulative Oil (MBBLS)

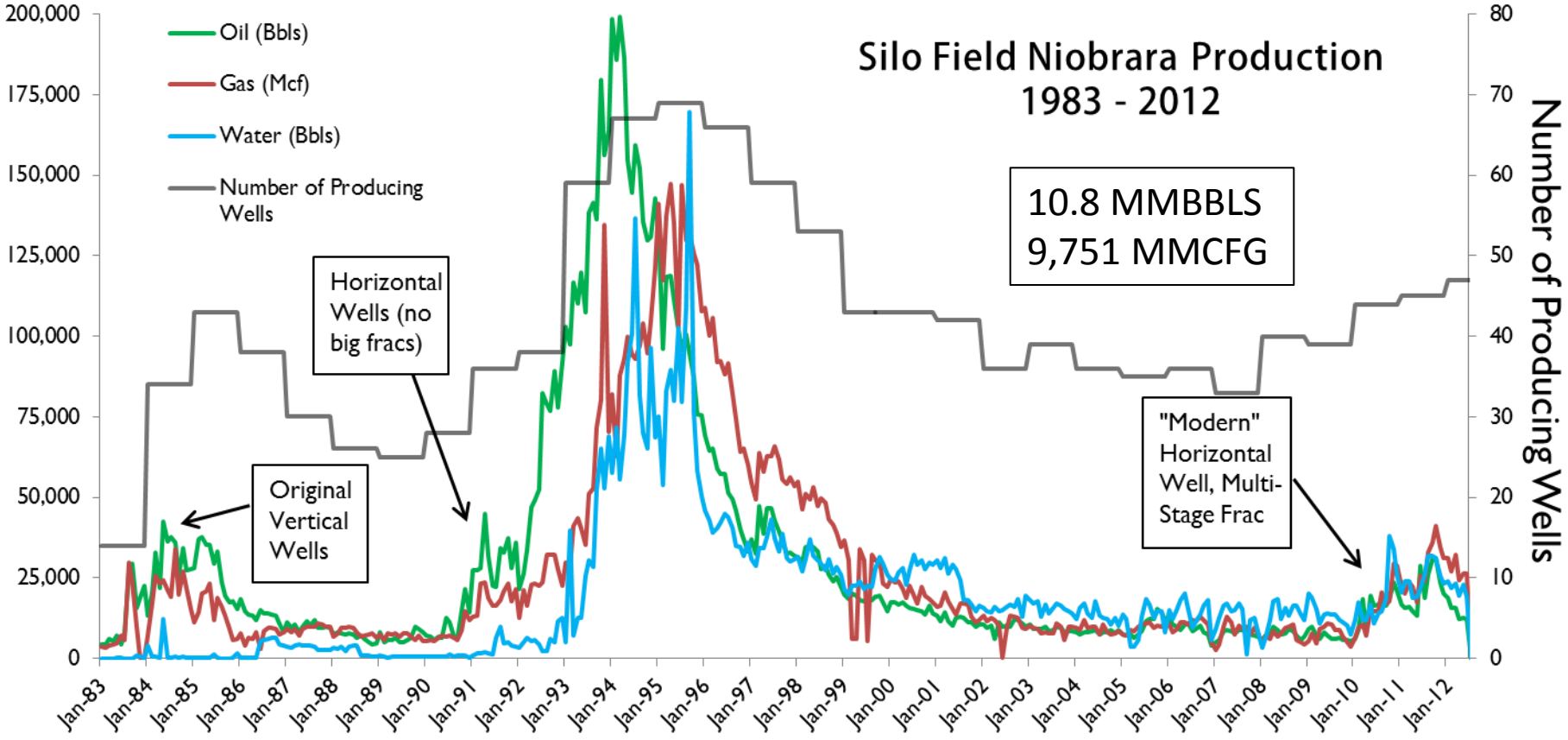
- > 80
- 45 – 80
- 15 – 45
- 5 – 15
- < 5,000

Core

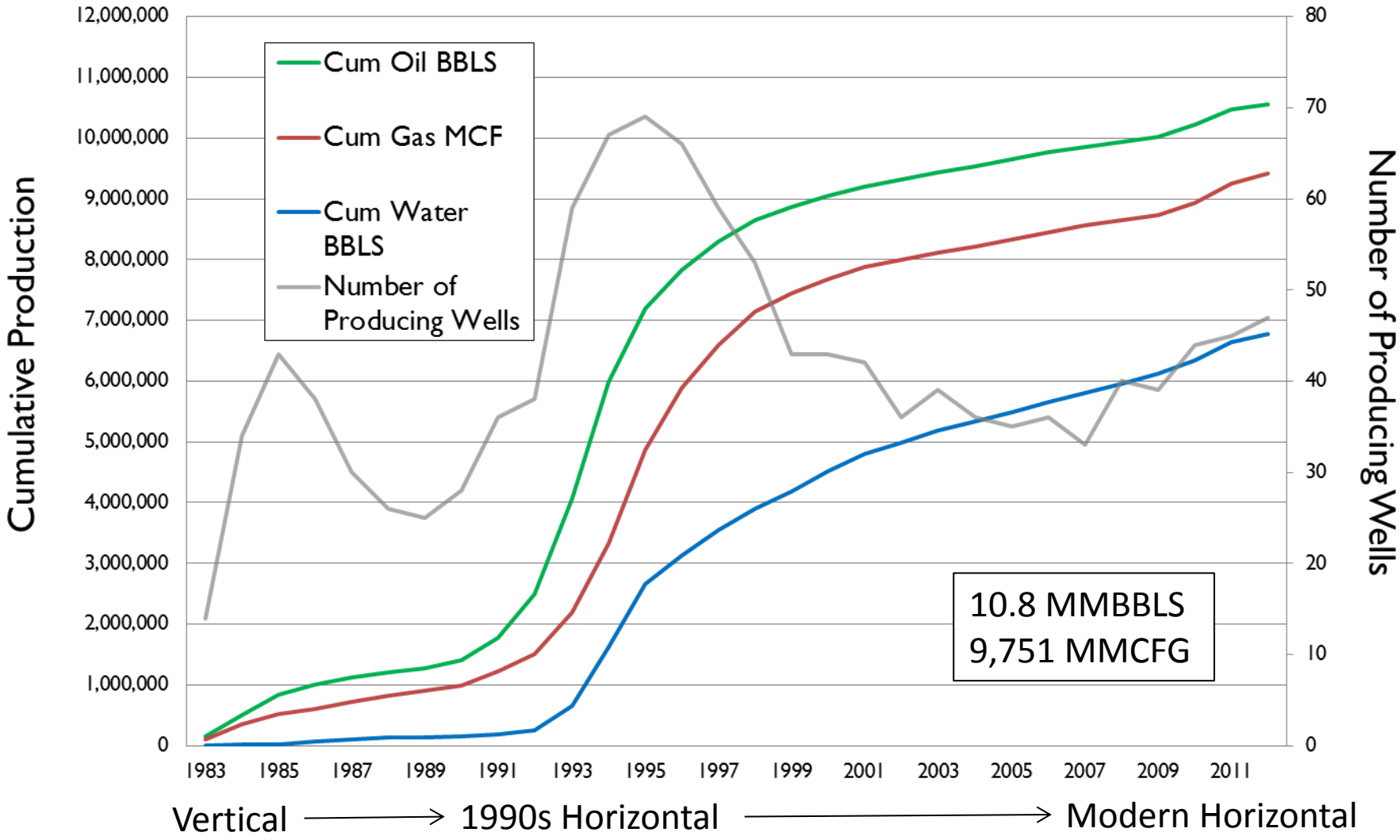
Drilling Era

- 1980s vertical
- 1990 horizontal
- modern horizontal

Silo Field, WY

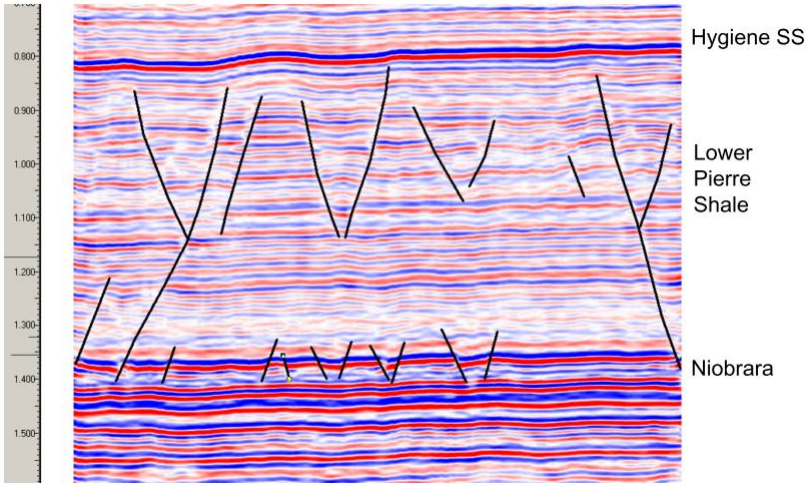


Niobrara cumulative production with number of producing wells through time

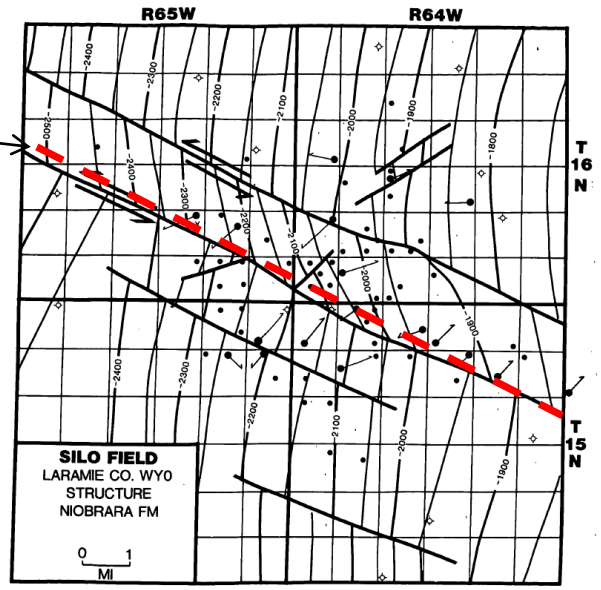


Silo Field Previous Studies

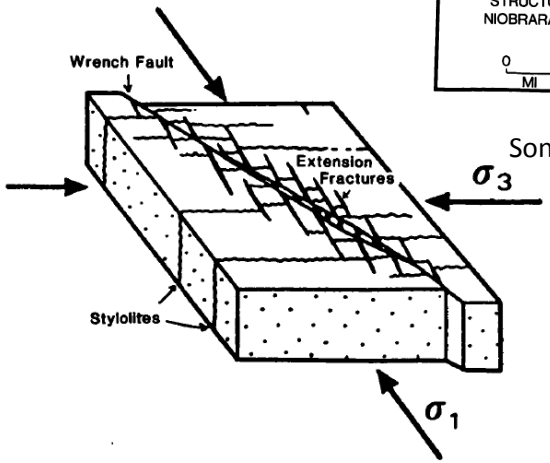
- Natural fractures recognized as important for increased storage and deliverability
  - Increased resistivity indicates presence of oil filled natural fractures
    - Johnson & Bartshe (1991a&b)
    - Sonnenberg & Weimer (1993)
- Origin of fractures
  - Differential Compaction (Thomas, 1992)
  - Wrench fault and fracture model (Sonnenberg & Weimer, 1993)
  - Basement Tectonics (Svoboda, 1995)
  - Permian-aged salt dissolution edge (Oldham, 1996)
  - Polygonal Fault System (Sonnenberg, 2012)



Sonnenberg (2012)



Sonnenberg and Weimer (1993)



Wrench fault model proposed by Sonnenberg and Weimer (1993) is used in this study

Research Questions

- Is there a relationship between geologic variables and successful production?
  - How do geologic variables vary within Silo field?
  - How does production vary within Silo field?
  - What are the most influential geologic variables to production?

thickness, resistivity, mineralogy,
fracture intensity, porosity, TOC

Methods

Collect subsurface data
Core Description
Well Log Analysis

Research previous work

Calibrate core measurements to log data

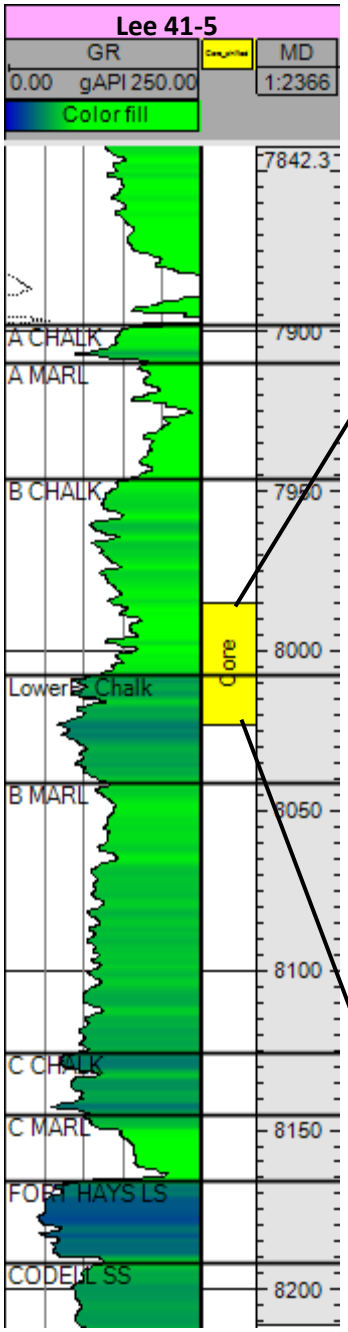
Create cross sections and maps

Collect production and completion data

Analyze relationships between geologic variables and production

All data is publically available from the Wyoming Oil and Gas Conservation Commission and the USGS Core Research Center

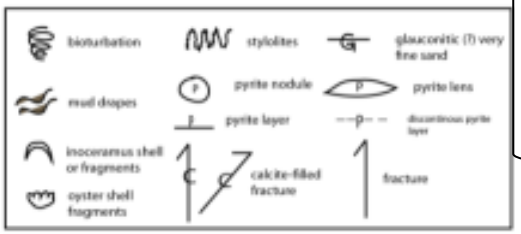
Core Description

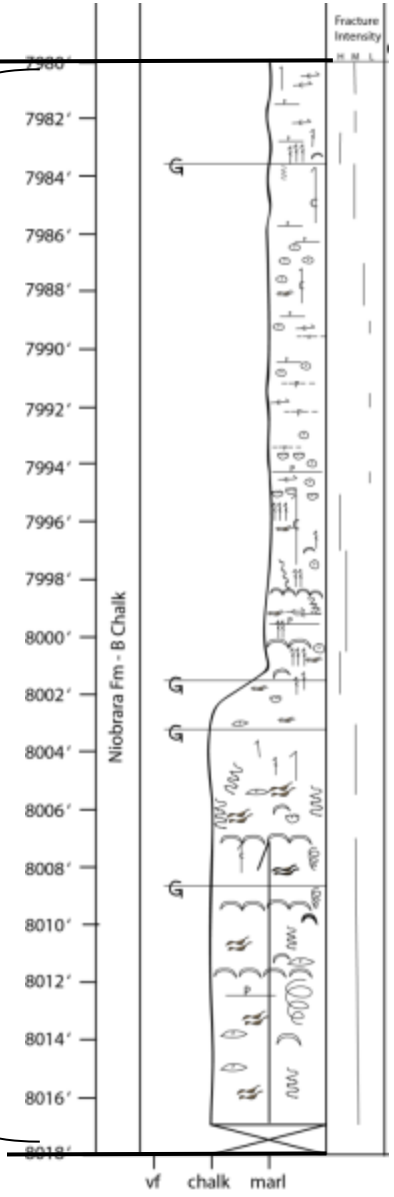


Key Characteristics

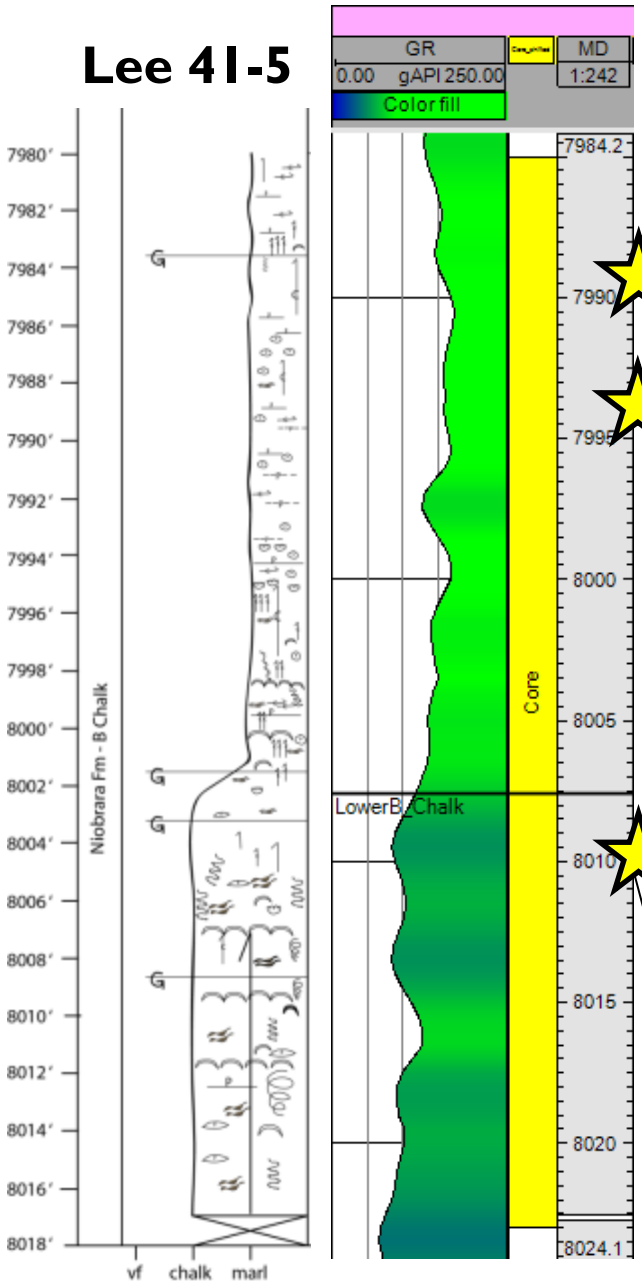
- Gray to dark gray chalk and marl
- Abundant calcite-filled hairline fractures
- Few open fractures
- None to moderate bioturbation
- Stylolites
- Mud laminae
- Inoceramid and oyster shells
- Pyrite laminae, lenses and nodules

37 ft

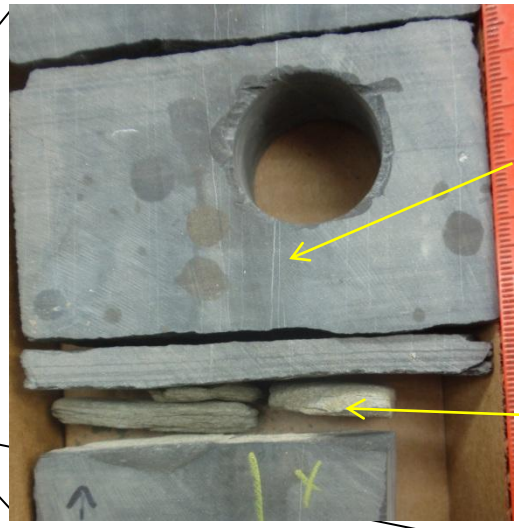




Lee 41-5

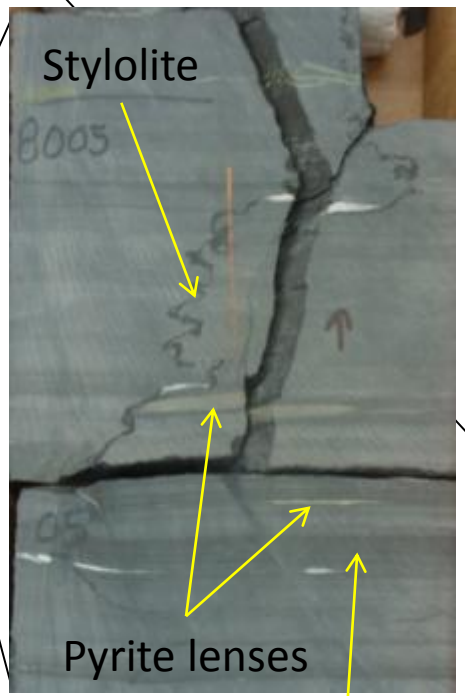


Core shift applied (+5 ft)



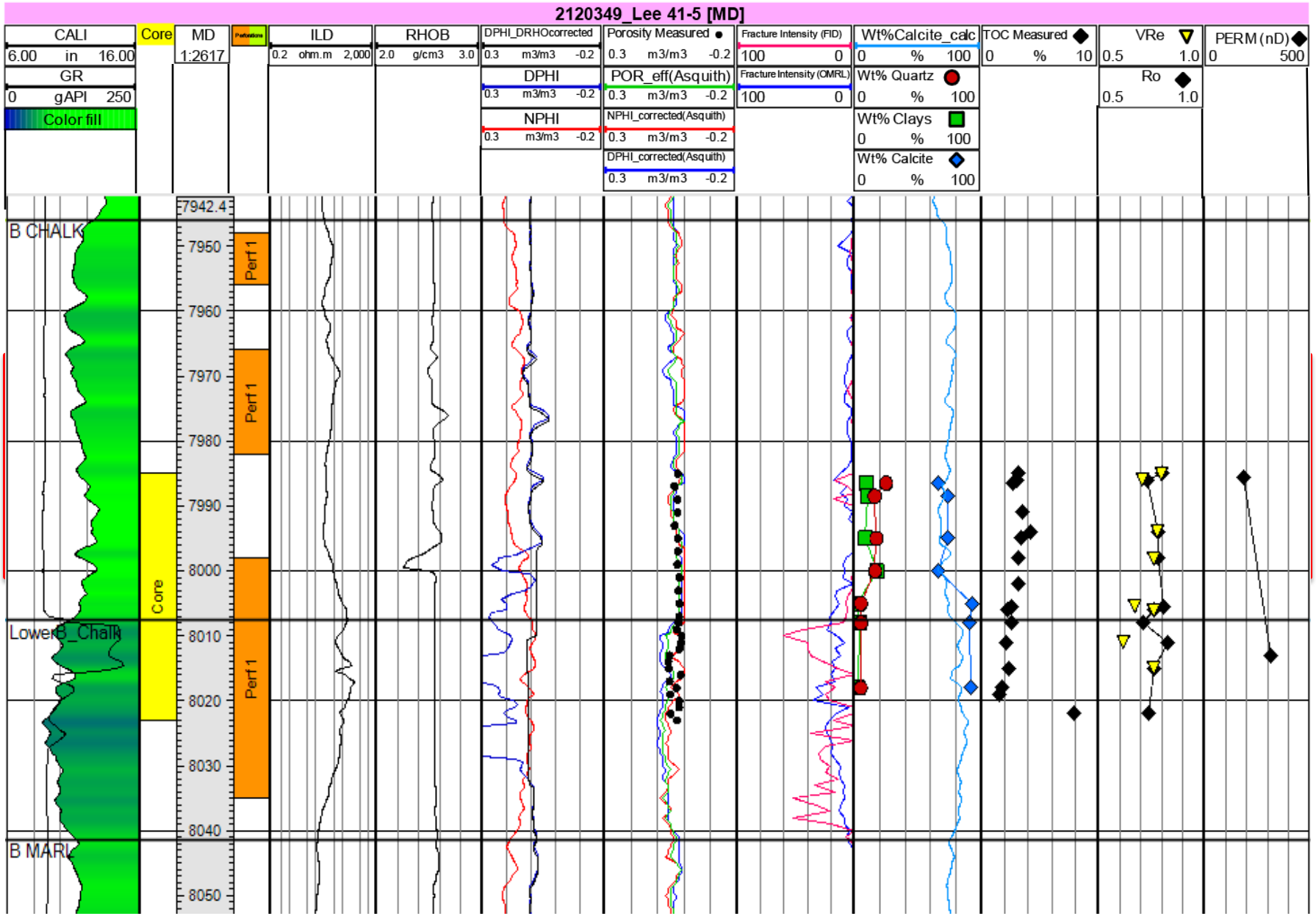
Hairline calcite fractures

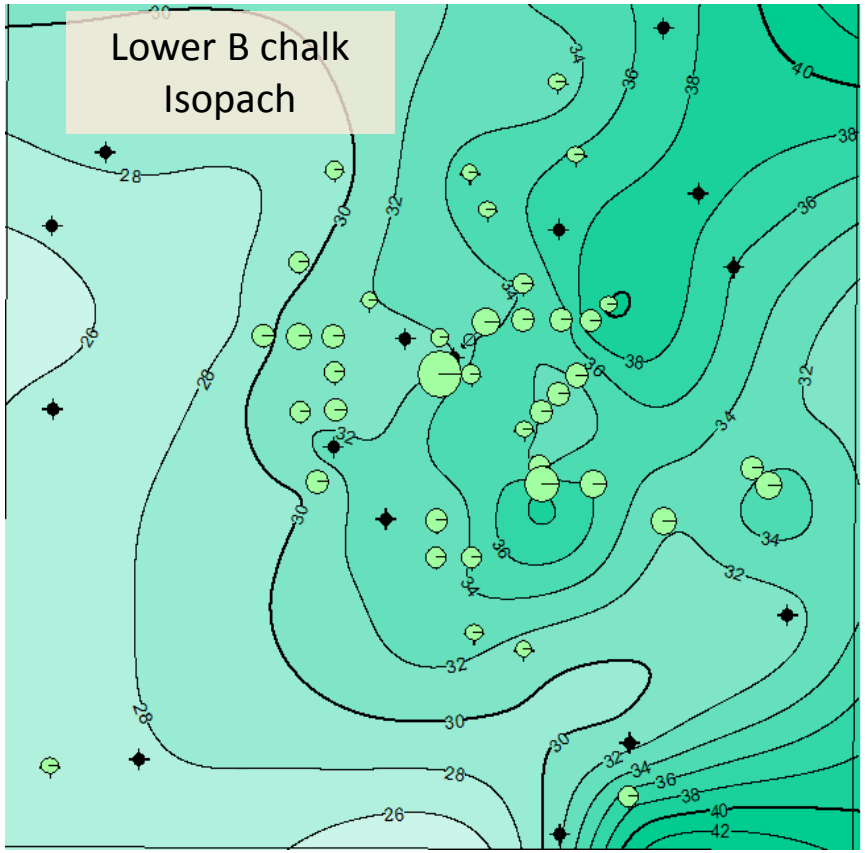
Bentonite layer?

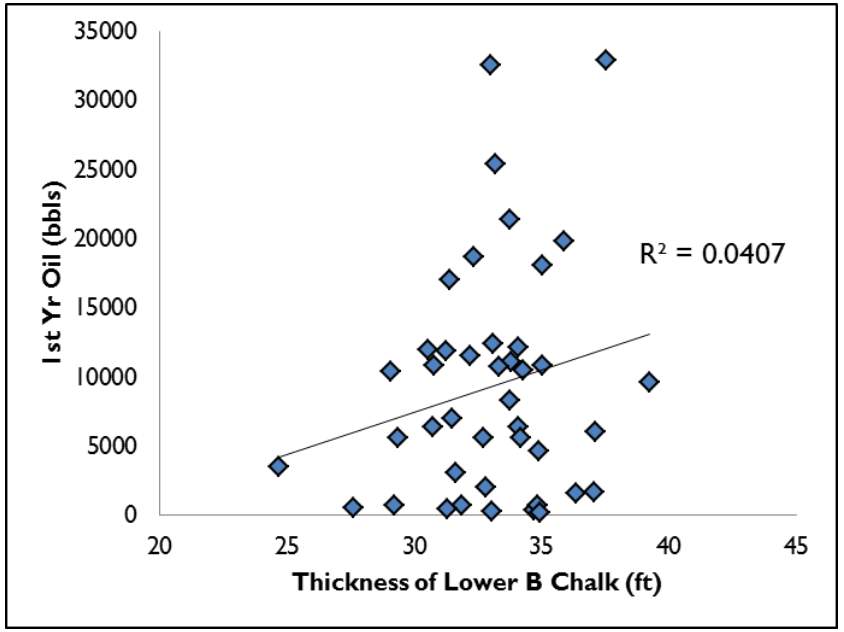


Brown, organic-rich laminations

1 cm

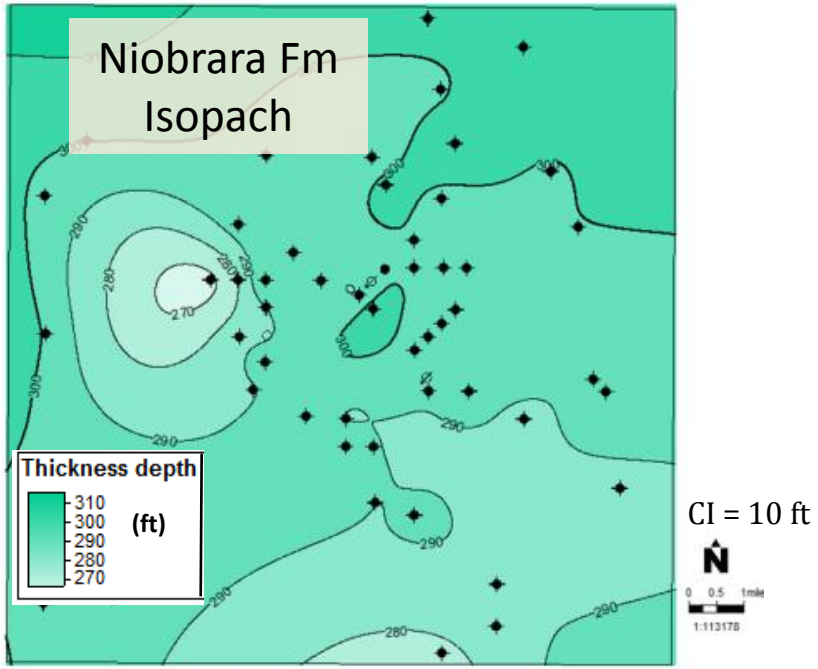

2120349_Lee 41-5 [MD]
CALI
6.00 in 16.00
GR
0 gAPI 250
Color fill
Core
MD
1:2617
Perforations
ILD
0.2 ohm.m 2,000
RHOB
2.0 g/cm3 3.0
DPHI_DRHOcorrected
0.3 m3/m3 -0.2
DPHI
0.3 m3/m3 -0.2
NPHI
0.3 m3/m3 -0.2
Porosity Measured
0.3 m3/m3 -0.2
POR_eff(Asquith)
0.3 m3/m3 -0.2
NPHI_corrected(Asquith)
0.3 m3/m3 -0.2
DPHI_corrected(Asquith)
0.3 m3/m3 -0.2
Fracture Intensity (FID)
100 0
Fracture Intensity (OMRL)
100 0
Wt%Calcite_calc
0 % 100
Wt% Quartz
0 % 100
Wt% Clays
0 % 100
Wt% Calcite
0 % 100
TOC Measured
0 % 10
VRe
0.5 1.0
Ro
0.5 1.0
PERM (nD)
0 500
7942.4
7950
7960
7970
7980
7990
8000
8010
8020
8030
8040
8050
B CHALK
LowerB_Chalk
B MARL
Perf 1
Perf 1
Perf 1
Core

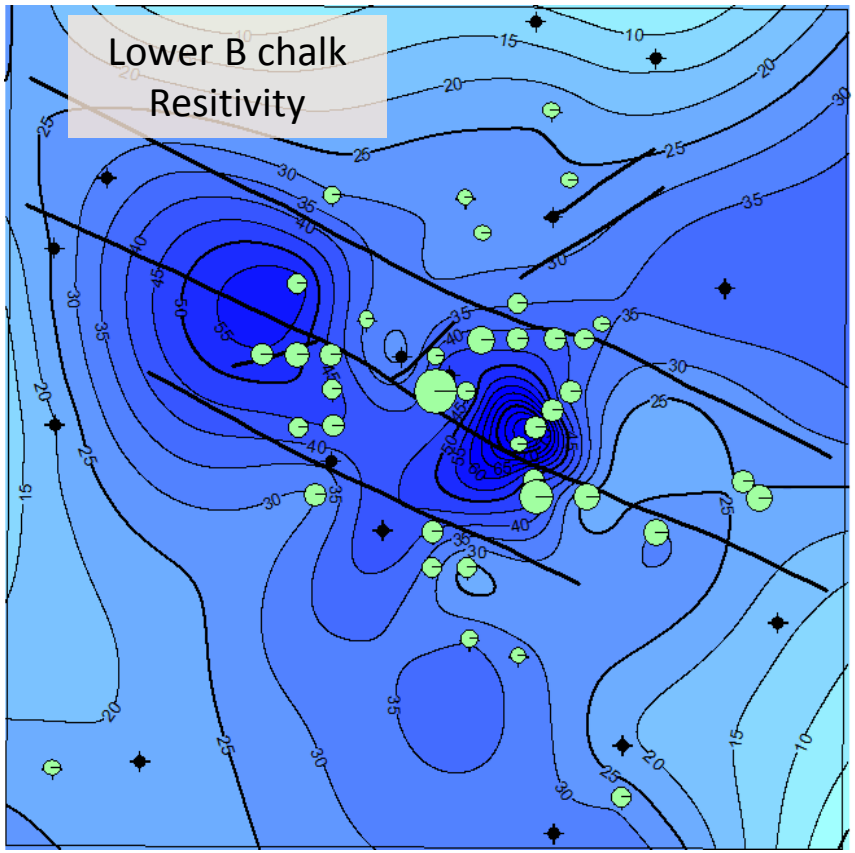


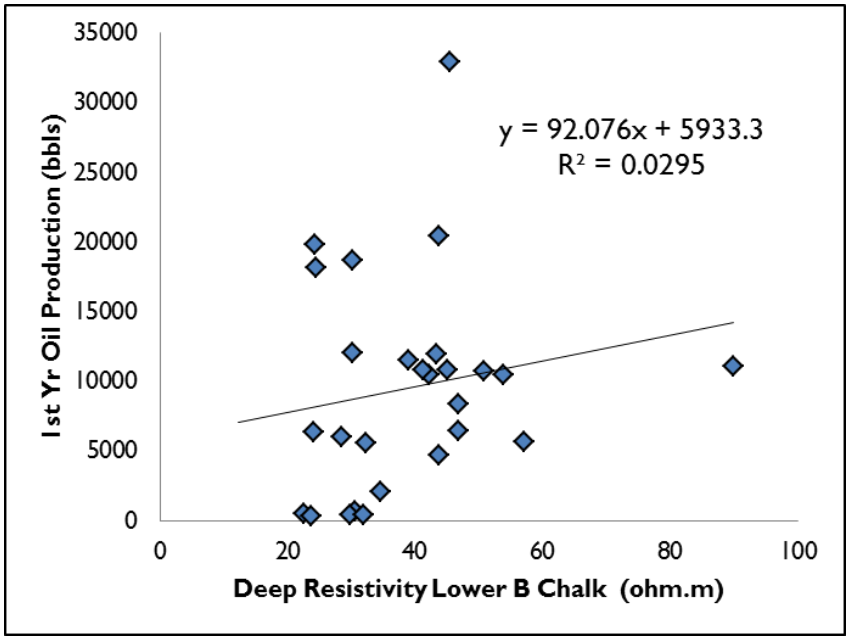


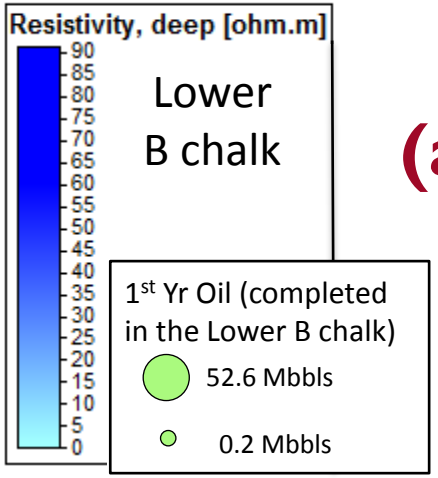
Thickness

Not an influence on first year production









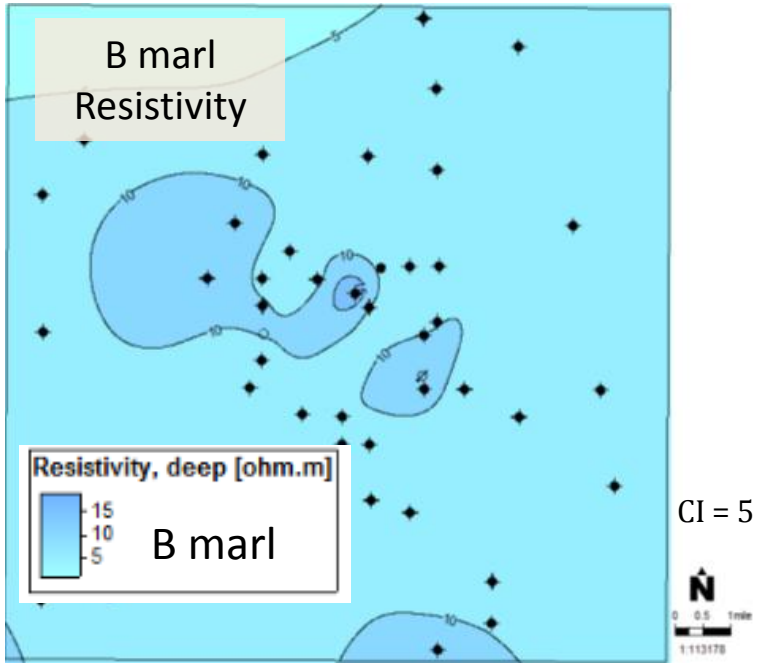
1st Yr Oil (completed in the Lower B chalk)

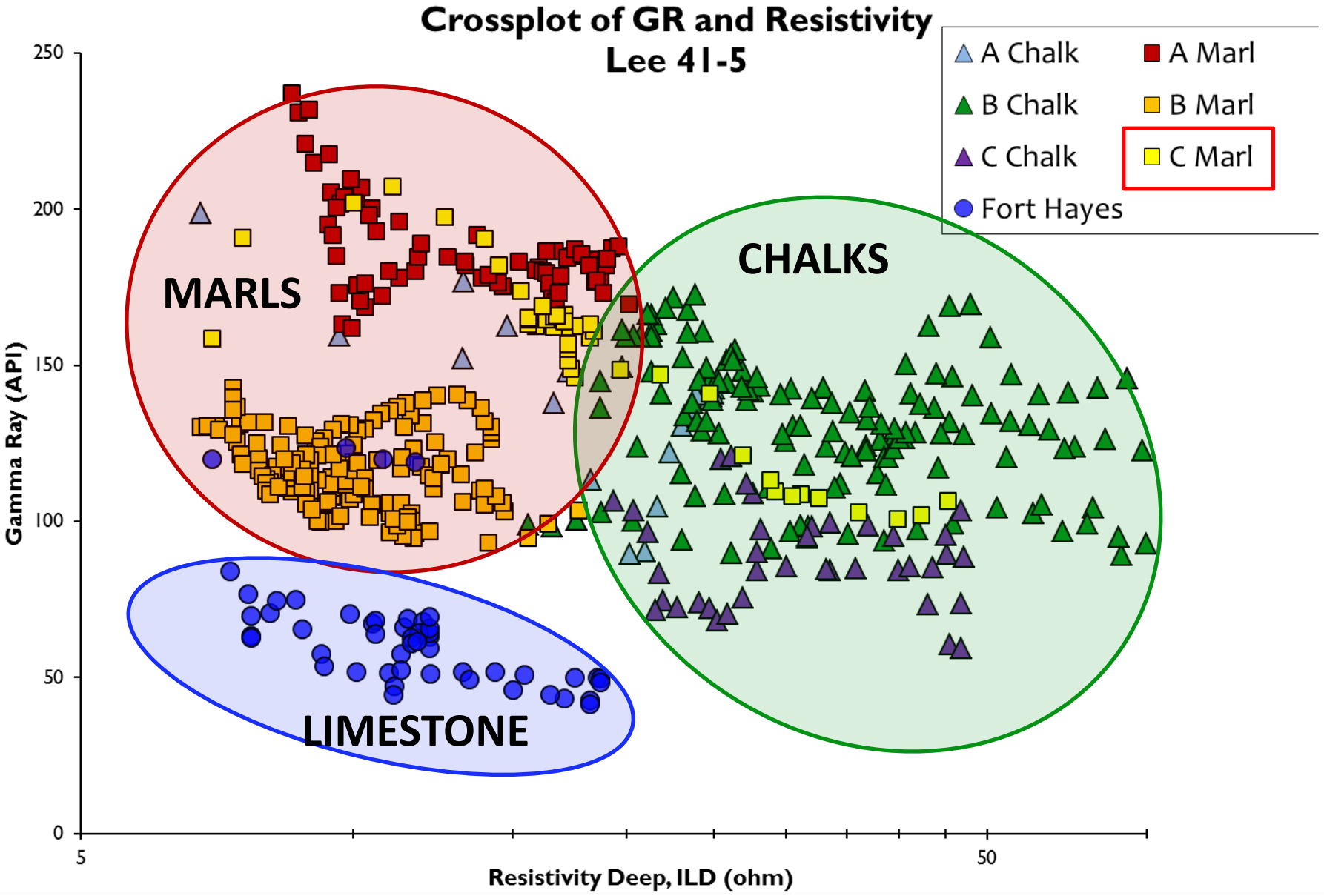
52.6 Mbbls

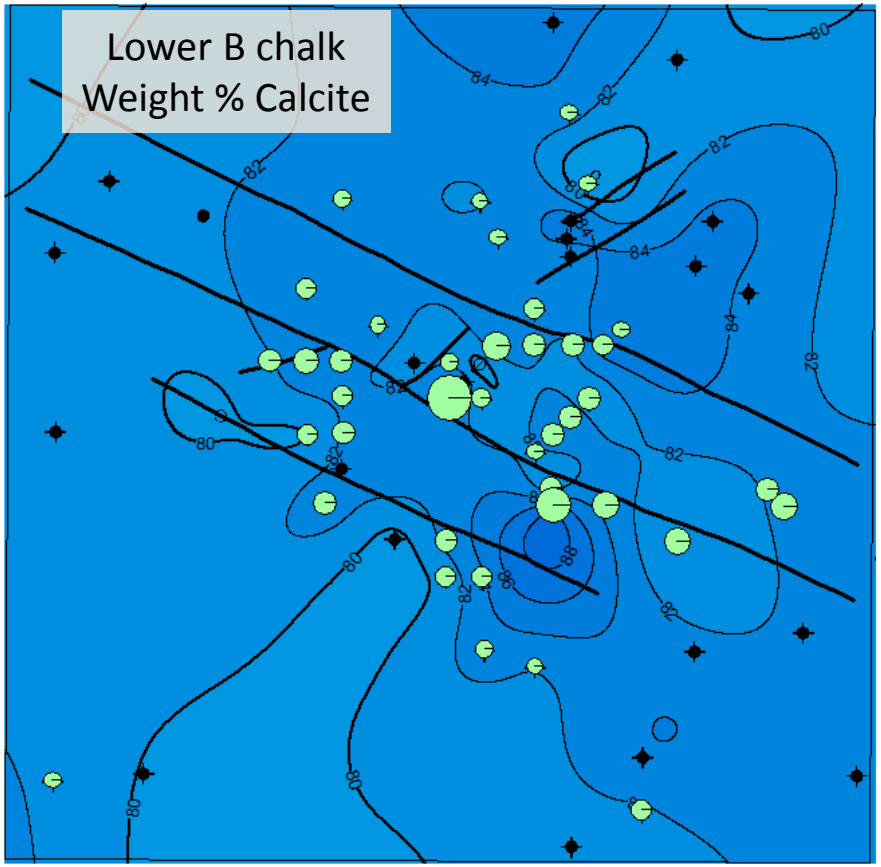
0.2 Mbbls

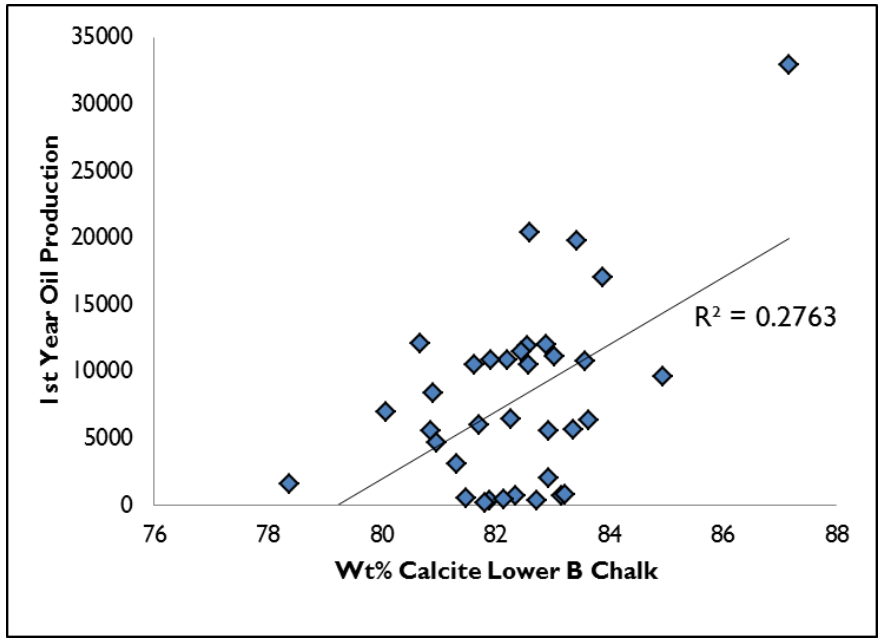
Deep Resistivity (averaged by zone)

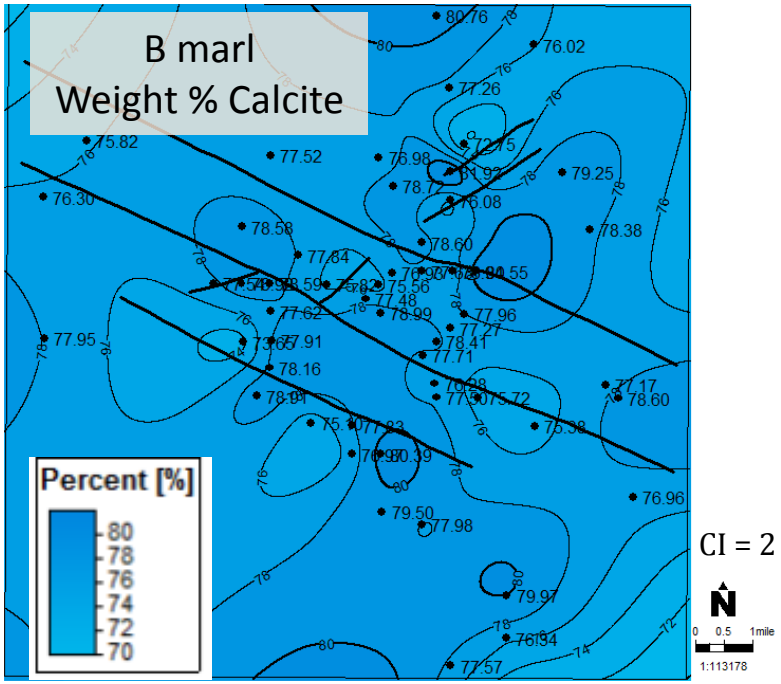
- Not a direct influence on magnitude of first year production
- Indicator of productive intervals




Crossplot of GR and Resistivity
Lee 41-5
A Chalk
A Marl
B Chalk
B Marl
C Chalk
C Marl
Fort Hayes
MARLS
CHALKS
LIMESTONE
Gamma Ray (API)
250
200
150
100
50
0
5
50
Resistivity Deep, ILD (ohm)







Wt % Calcite (averaged by zone)

- Derived by calibrating core XRD measurements to gamma ray log
- Weak correlation with 1st year oil production

1st Yr Oil (completed in the Lower B chalk)

52.6 Mbbls

0.2 Mbbls

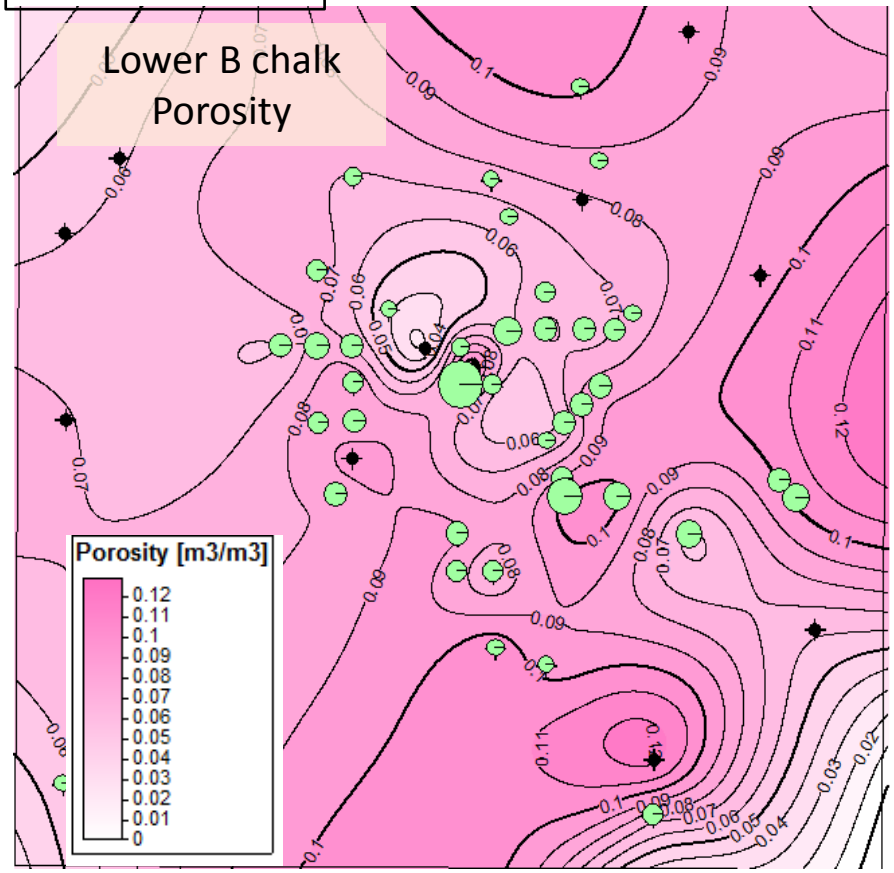
Porosity (averaged by zone)

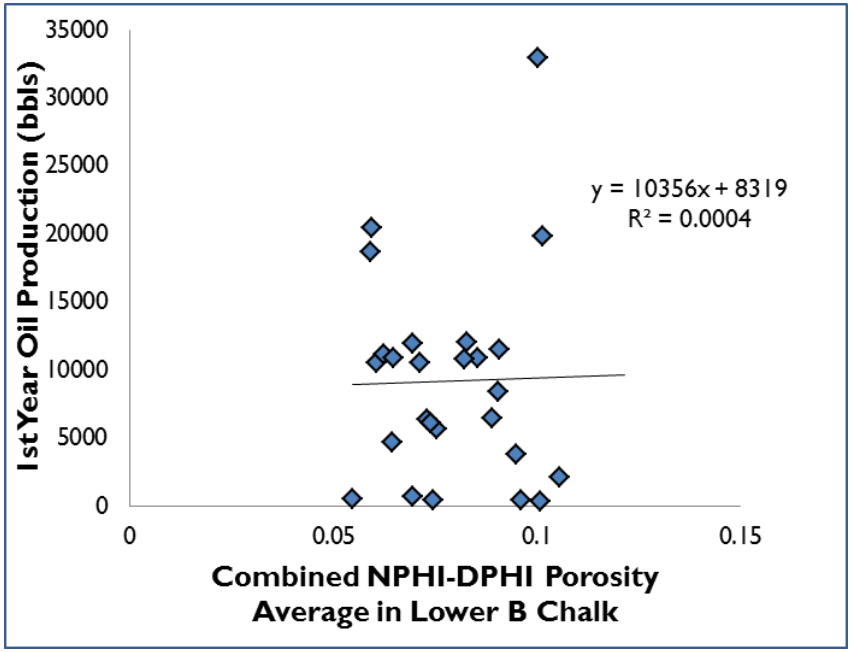
1st Yr Oil (completed in the Lower B chalk)

52.6 Mbbls

0.2 Mbbls

Not an influence on first year production





Porosity Corrections

$$I_{GR} = \frac{(GR - GRclean)}{(GRshale - GRclean)} \quad \text{Equation 1}$$

$$V_{SH} = 0.33[2^{(2 \times I_{GR})} - 1.0] \quad \text{Equation 2}$$

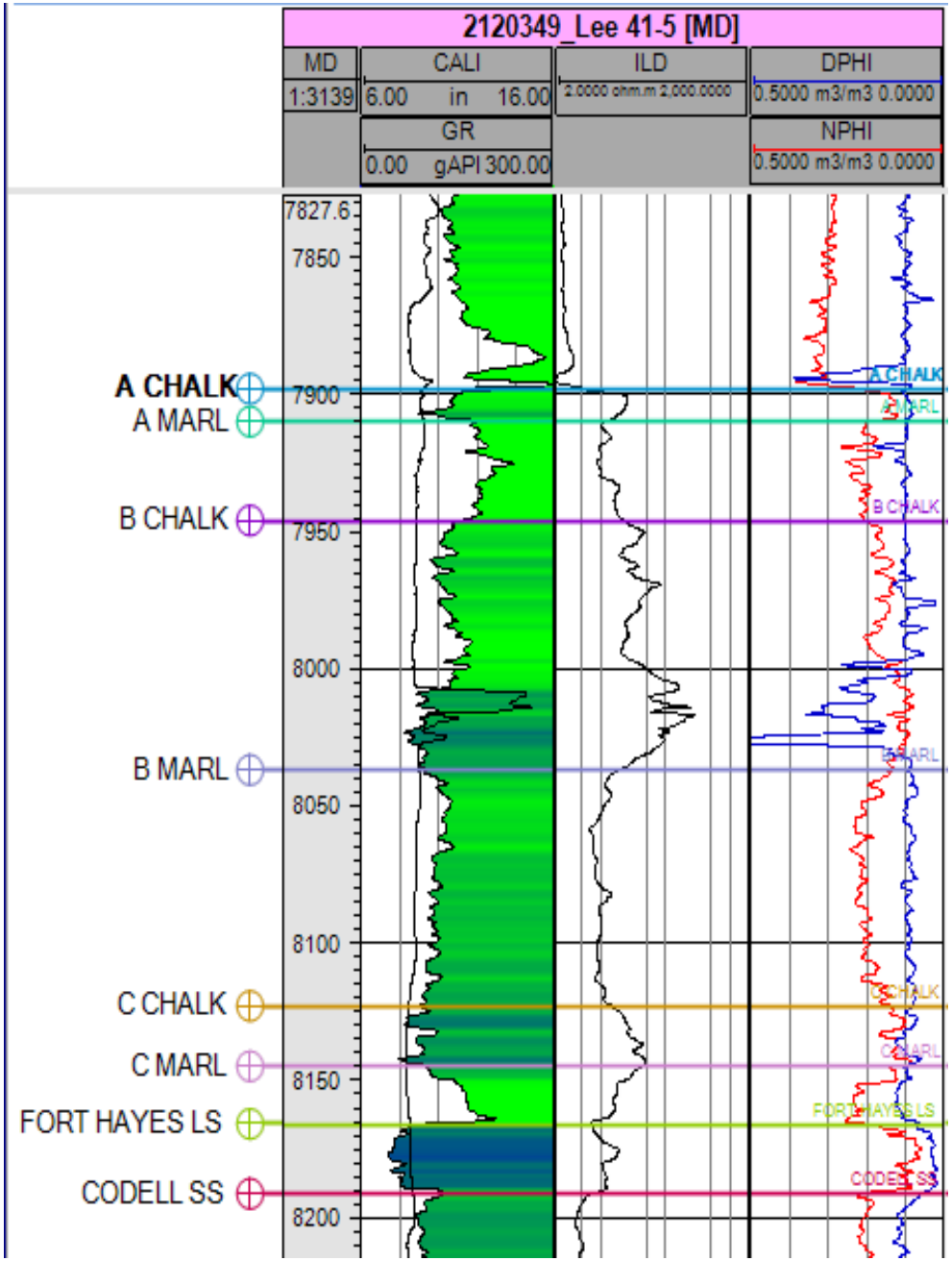
$$\phi_{N\,corr} = \phi_N - \left[\left(\frac{\phi_{N\,clay}}{0.45}\right) \times 0.30 \times V_{SH}\right] \quad \text{Equation 3}$$

$$\phi_{D\,corr} = \phi_D - \left[\left(\frac{\phi_{N\,clay}}{0.45}\right) \times 0.13 \times V_{SH}\right] \quad \text{Equation 4}$$

$$\phi_{N\text{-}D} = \sqrt{\frac{\phi_{N\,corr}^{\,2} + \phi_{D\,corr}^{\,2}}{2}} \quad \text{Equation 5}$$

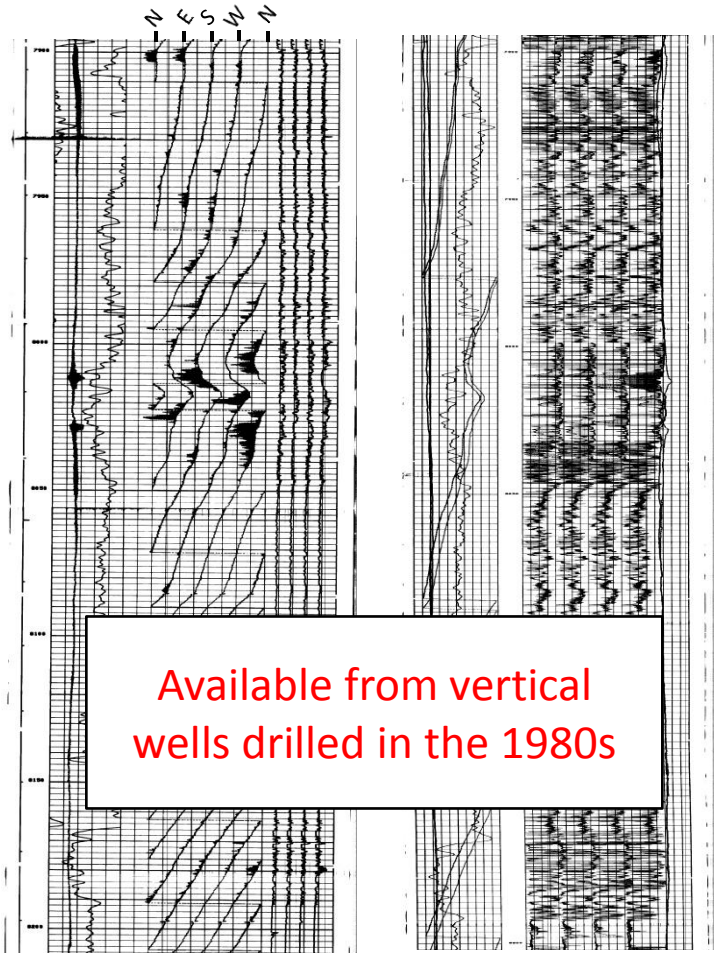
Asquith, 1982

Fracture Identification Logs

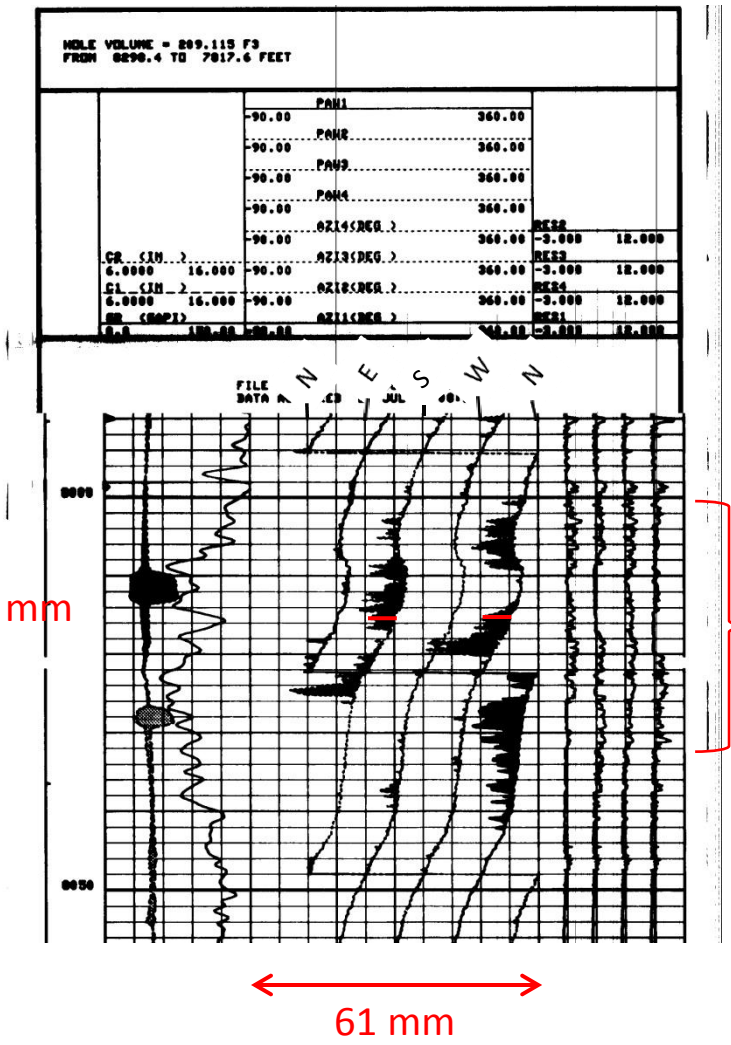


Oriented Micro Resistivity Log (OMRL)

Fracture Identification Log (FID)



Quantifying Fracture Intensity (FI)



Fracture Intensity by foot:

Example:

$$FI = \frac{11\ mm}{61\ mm} \times 100 = \mathbf{18}$$

(Calculated by foot intervals)

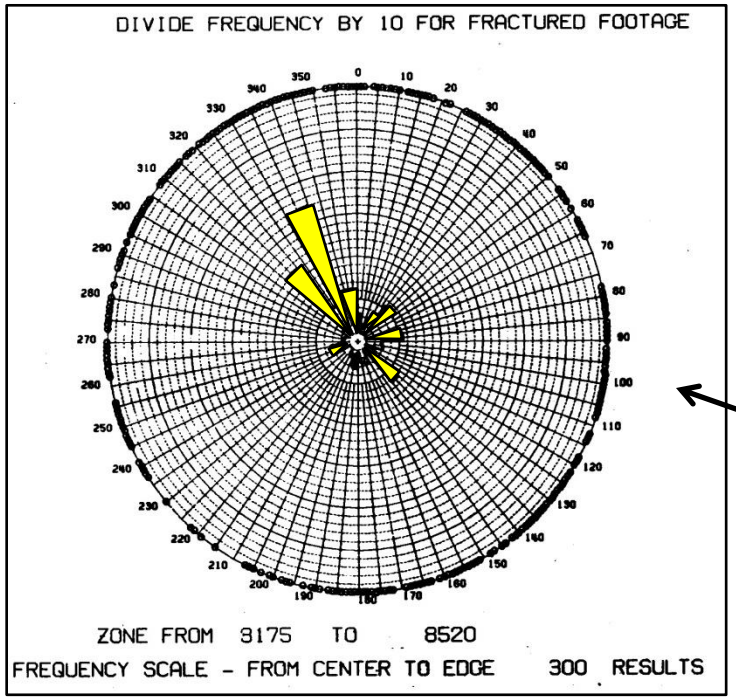
Average FI of Lower B chalk:

Example:

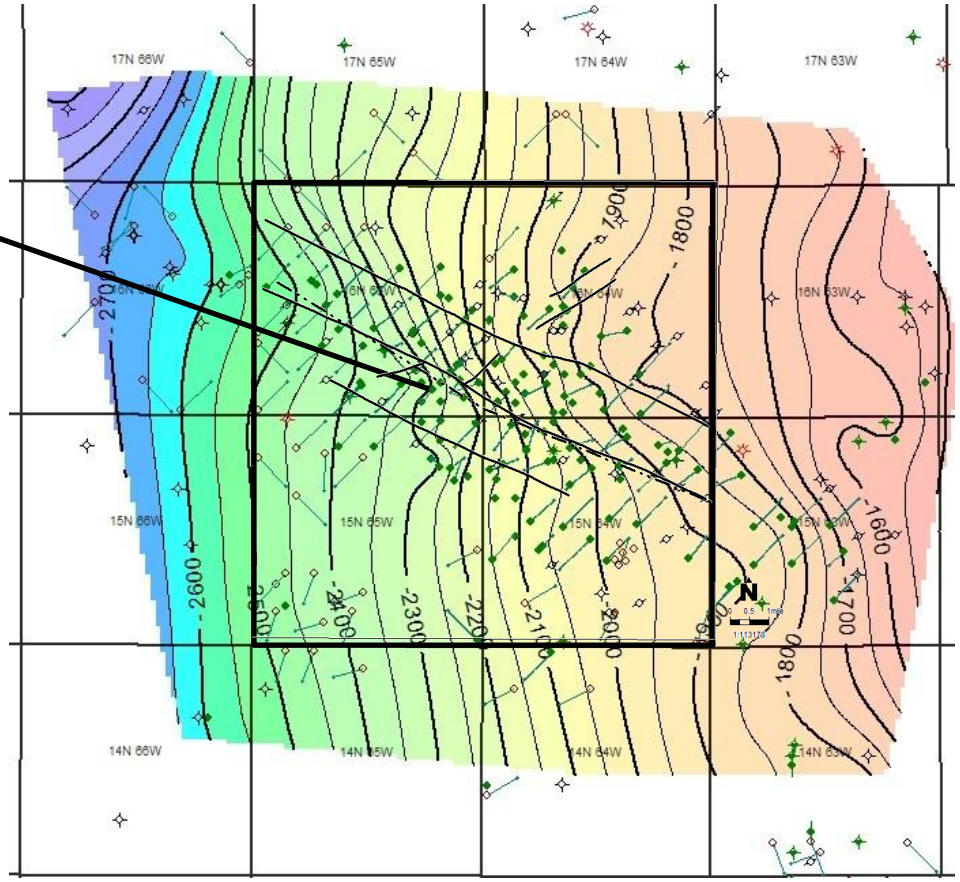
$$= \frac{\sum FI}{Lower\ B\ chalk\ thickness}$$

$$= \frac{560}{32} = \mathbf{17.5}$$

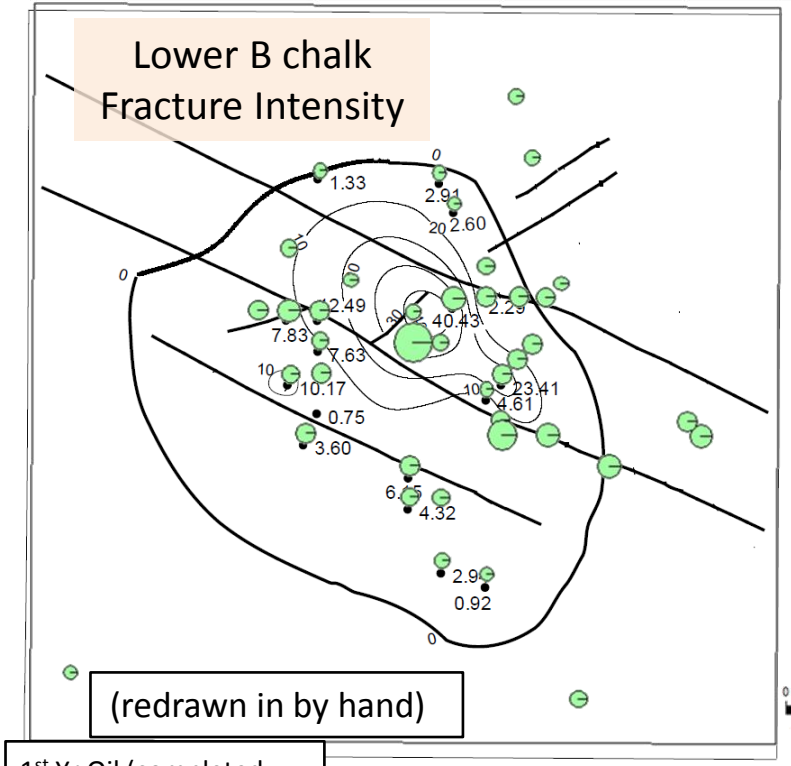
Fracture Orientation and Well Paths



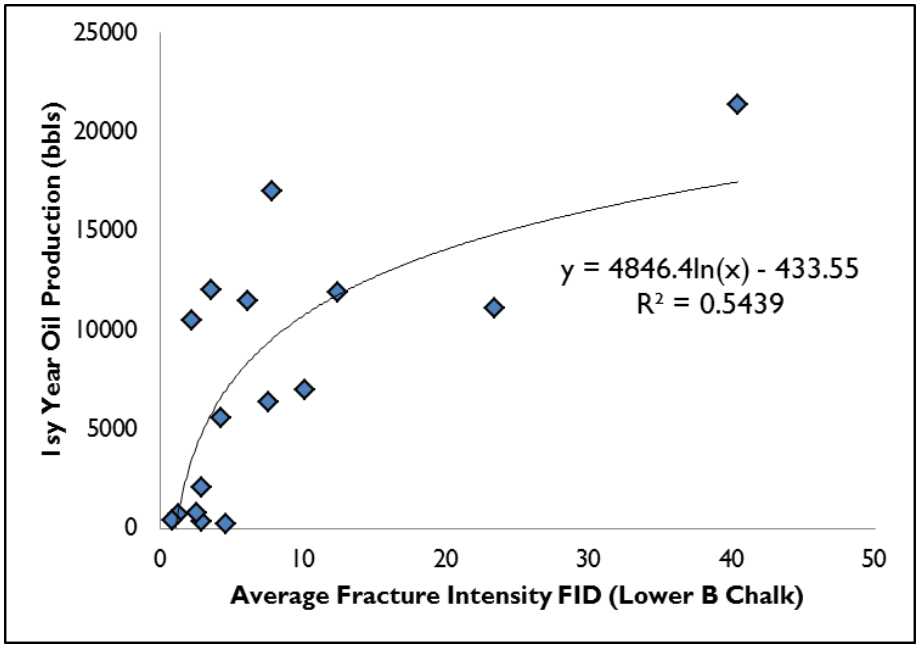
- Majority of 1990 horizontal wells were drilled perpendicular to dominant northwest-southeast fracture network



Sonnenberg, 2011



(redrawn in by hand)

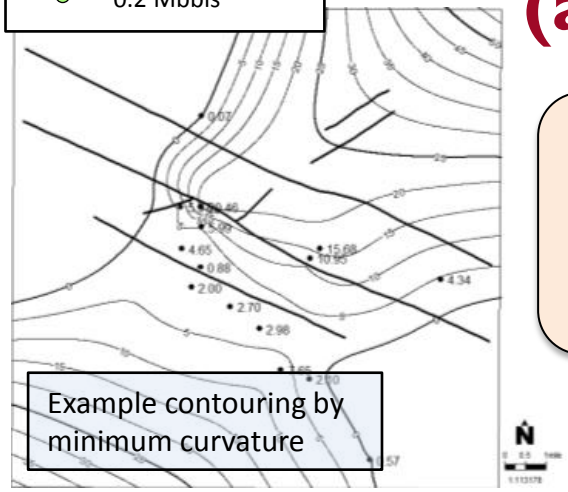


1st Yr Oil (completed in the Lower B chalk)

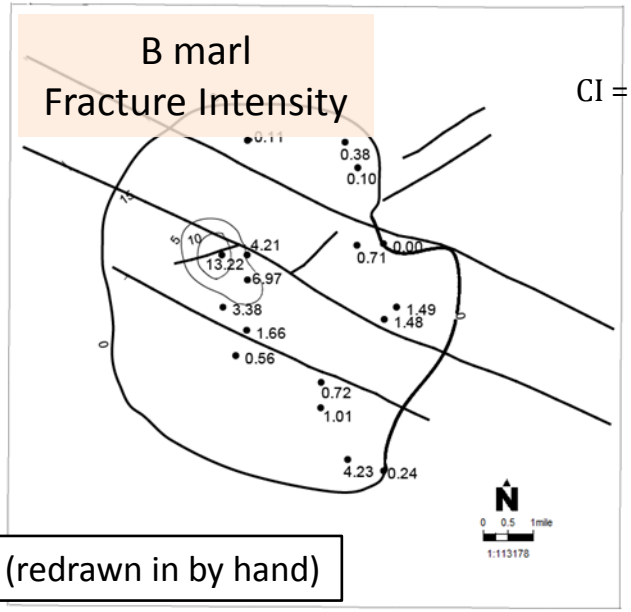
- 52.6 Mbbls
- 0.2 Mbbls

Fracture Intensity (averaged by zone)

- Quantified by measuring fracture identification logs
- Is an influence on 1st year oil production

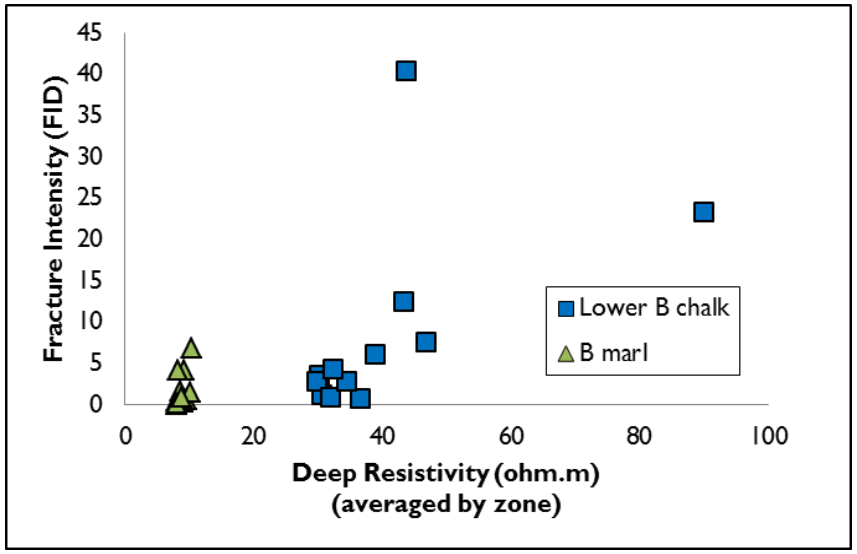


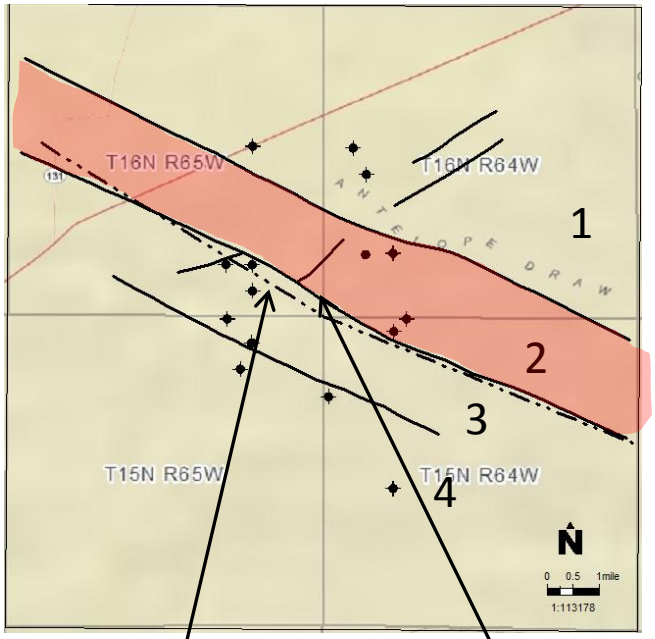
Example contouring by minimum curvature



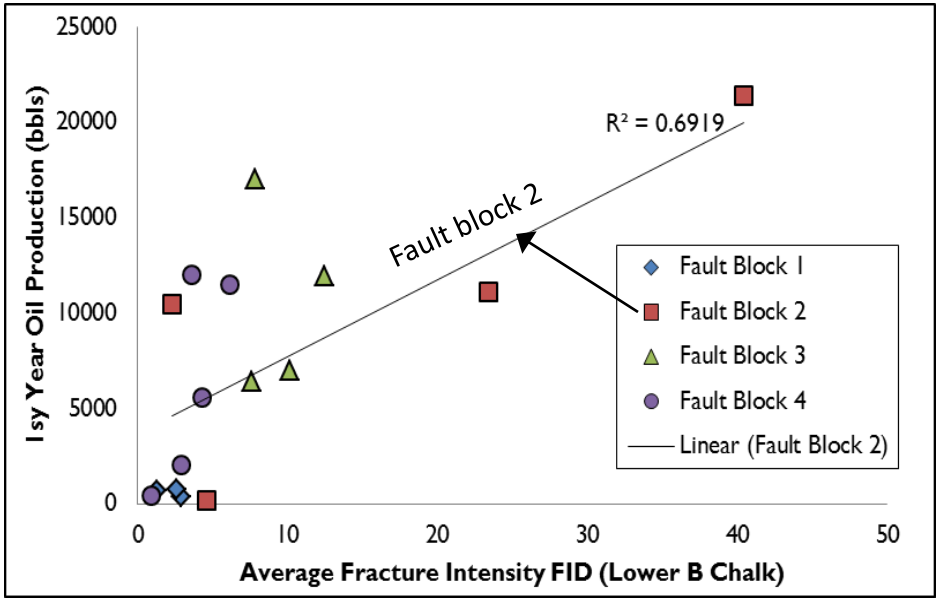
(redrawn in by hand)

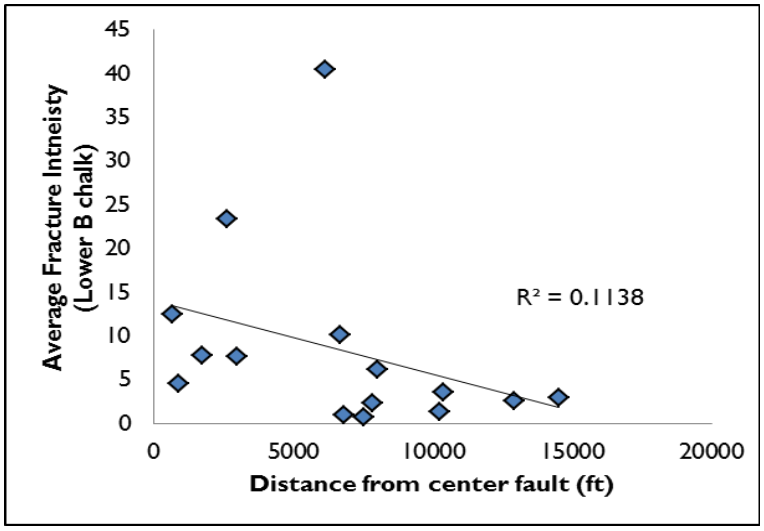
Resistivity as an indicator of natural fractures

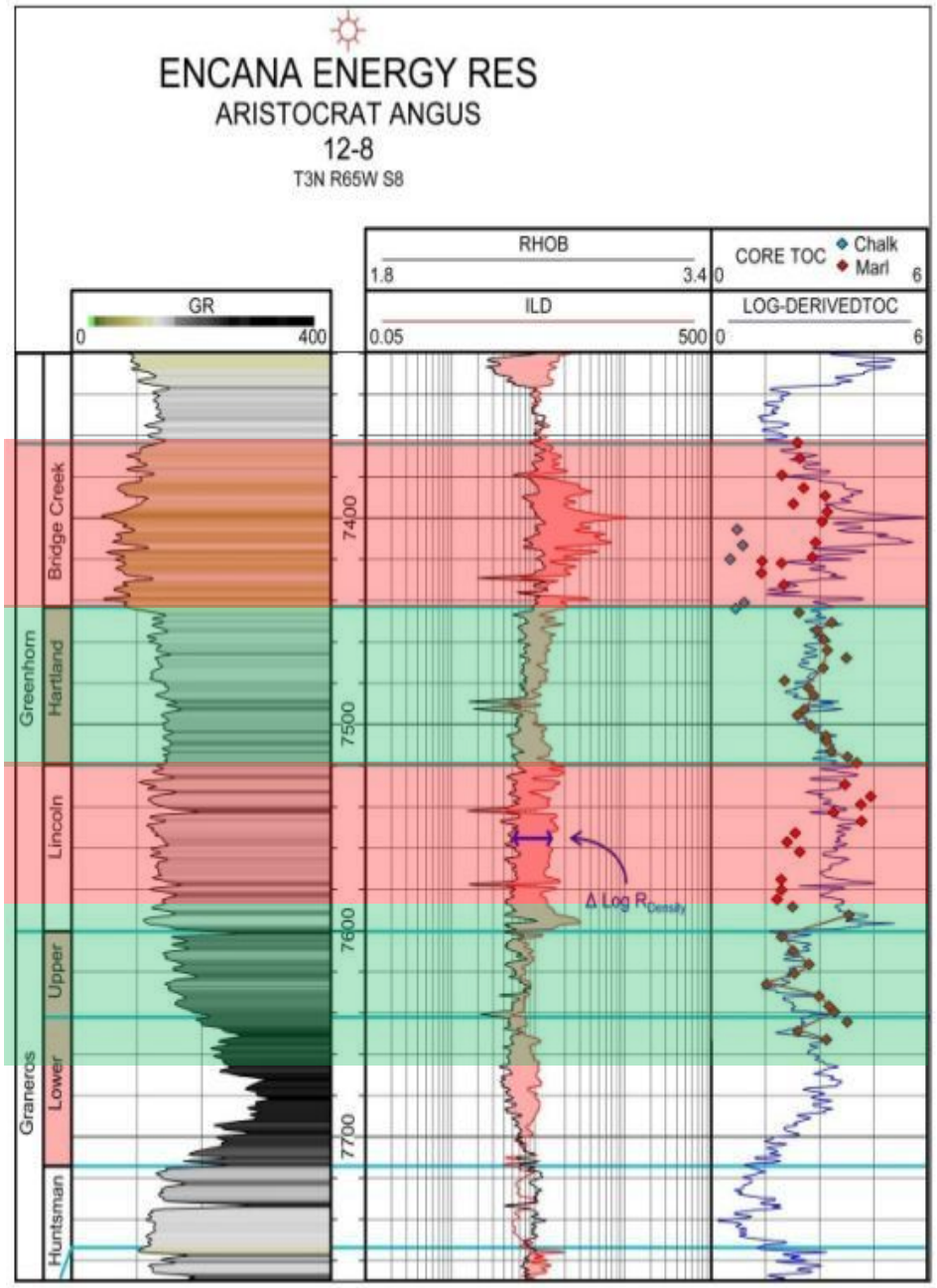




Tectonic control on production/fracture intensity?







DLogR Discussion:

Example from Greenhorn and Graneros Formations

Mismatch in chalky "reservoir" rocks

Good correlation in source rock intervals only!

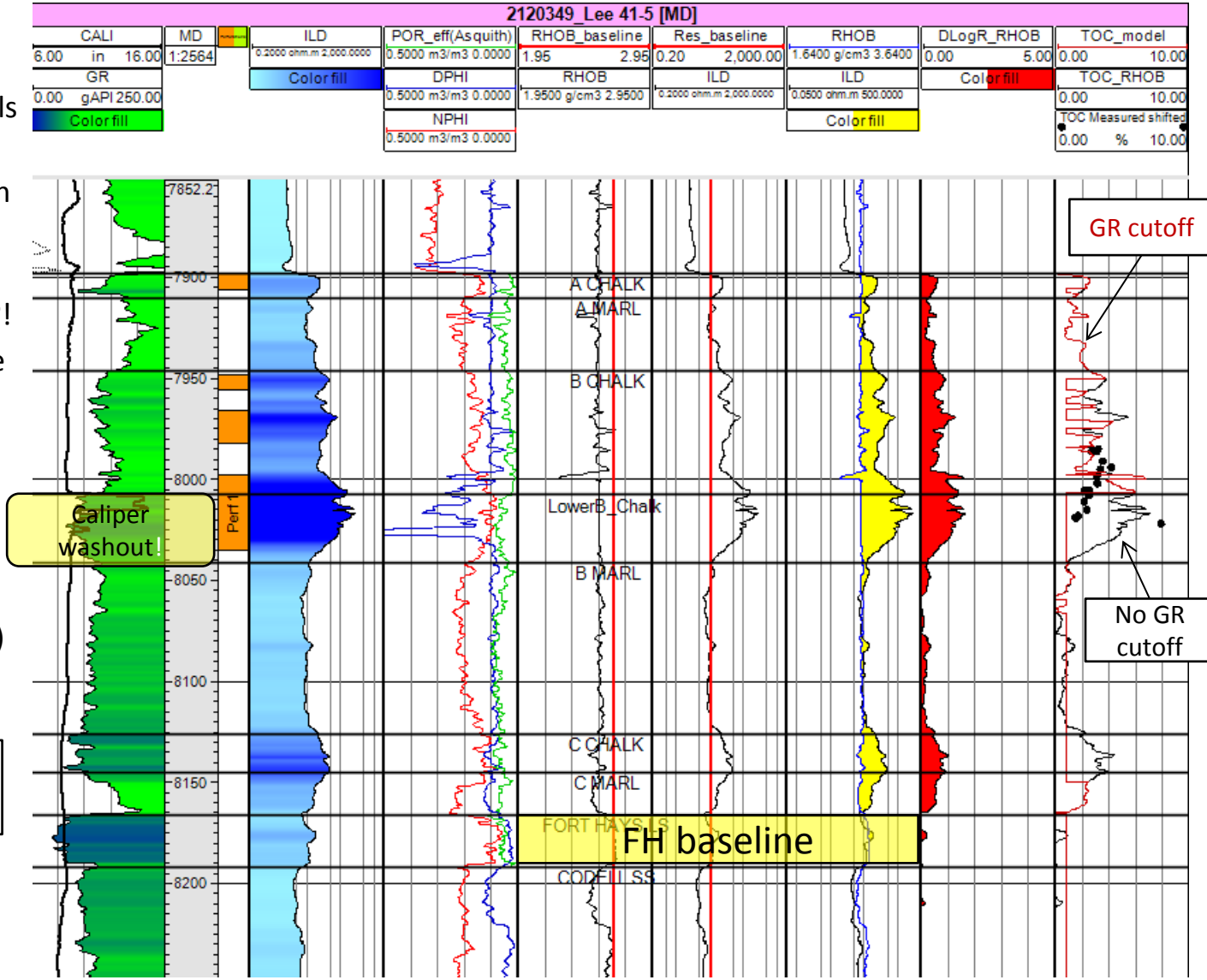
Kaiser, 2012

DLogR method: Application

Passey et al. (1990)

- RHOB-Resistivity overlay (No sonic logs available in wells with core)
- TOC measurements only in cored interval
- Initial results show chalks more organic-rich than marls?!
- Apply GR cutoff to exclude chalks (Resistivity increase is due to migrated oil not presence of OM)
- Generally, no relative decrease in RHOB values in marls (RHOB curve should decrease in organic-rich rocks)

Careful when applying DLogR to estimate TOC



Conclusions

- Yes, natural fracture intensity is important for successful production at Silo field
  - Increased deep resistivity is a good indicator of natural fractures
  - NW-SE trend in production suggests fault proximity and compartmentalization strongly influence production
  - Tectonic control evidenced by increase in fracture intensity with proximity to central fault/salt edge
- Porosity and thickness vary spatially but are not major influences on production in the Lower B chalk

Future Work

- Multivariate analysis
- DLogR method of estimating TOC requires additional work in its application to Silo Field
- Group wells by completion practice to further clarify the role of geologic control on successful production

Thank you!

Questions?

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