COLORADO SCHOOL OF MINES MUDTOC

Chad Taylor, MSc Geology, Summer 2021

RESERVOIR CHARACTERIZATION AND PERFORMANCE ASSESSMENT OF PRIMARY AND SECONDARY UNCONVENTIONAL RESERVOIR TARGETS WITHIN THE HEREFORD FIELD AREA, WELD COUNTY, COLORADO

RCP Phase XVIII: How Did We Get Here?

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Phase XVIII: Key Objectives

- **Objective I:** *Understand drivers and processes of vertical & horizontal connectivity*
- **Objective II:** *Understand legacy development effects & how to mitigate them*
- **Objective III:** *Determine stage & cluster spacing that maximizes DSU economics*
- **Objective IV:** *Understand value of EOR for field implementation in a future phase of the project*
- **Objective V:** *Identify regional geological controls on petroleum system heterogeneity and well-scale reservoir deliverability*

Characterizing Geologic Heterogeneity

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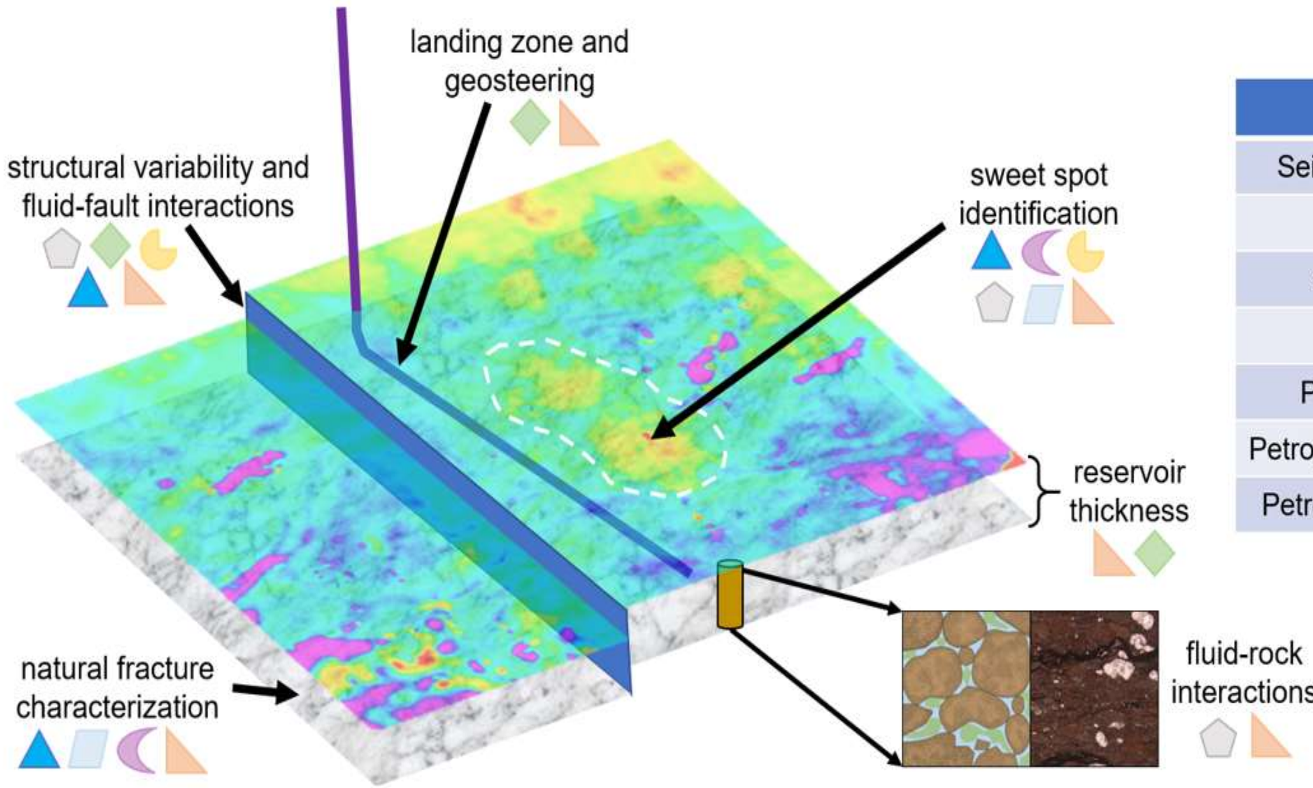
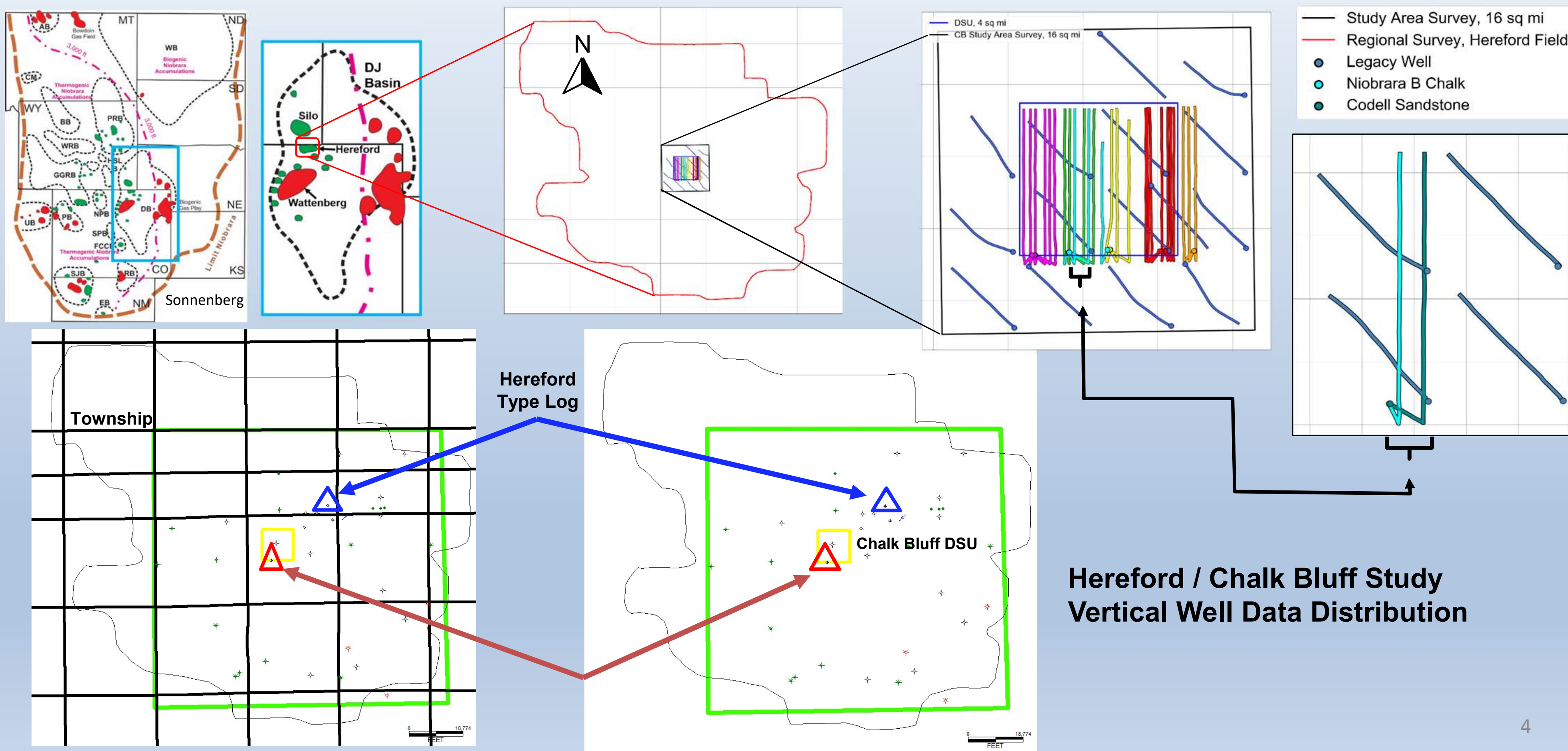


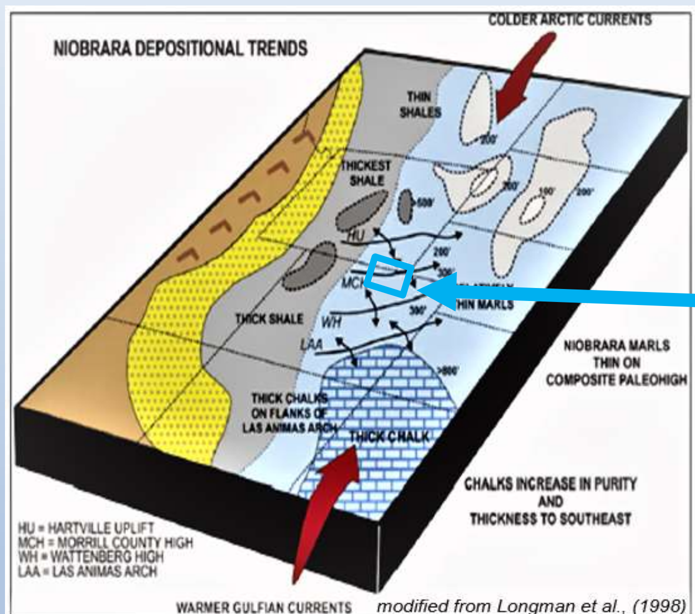
Method	Symbol
Seismic attribute analysis	
Image log analysis	
Structural modeling	
Seismic inversion	
Production evaluation	
Petrophysical characterization	
Petroleum systems analysis	

Hereford Area - Data Overview



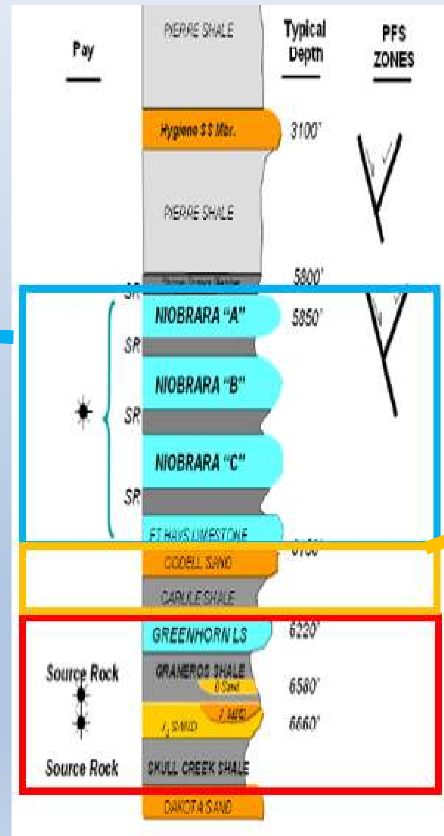
Hereford / Chalk Bluff Study Vertical Well Data Distribution

Hereford Depositional Context

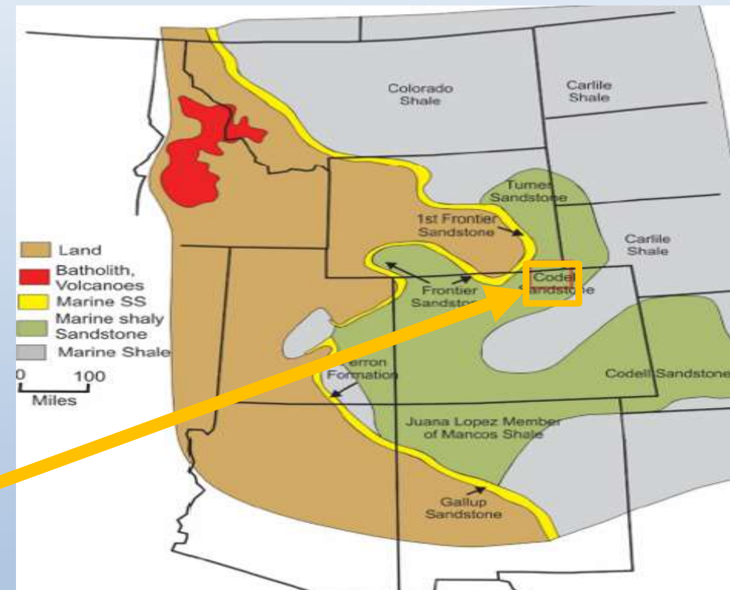


modified from Longman et al., (1998)

Niobrara Formation *(Santonian - Turonian Age)*



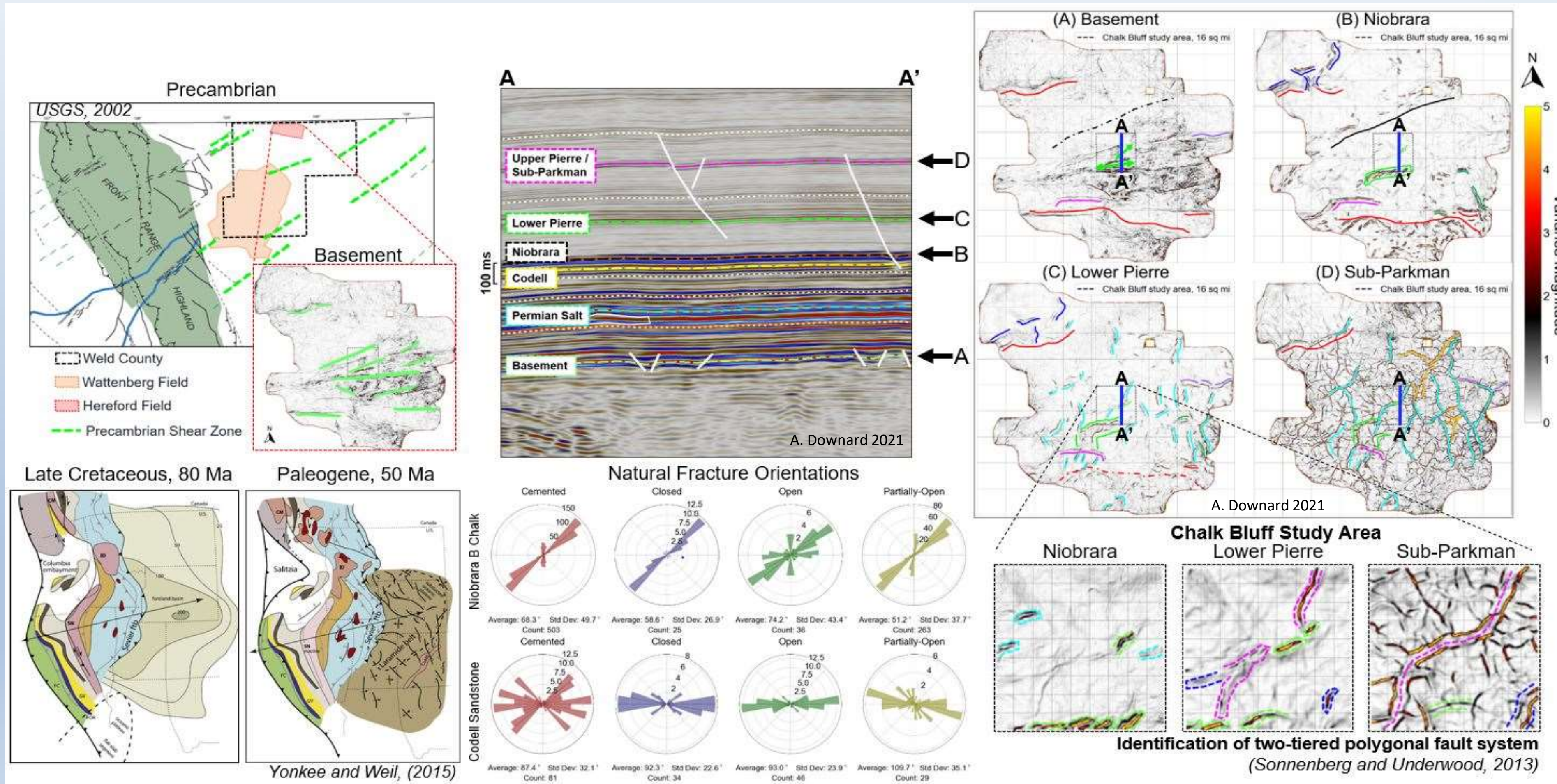
Modified from Sonnenberg, after Underwood, 2013



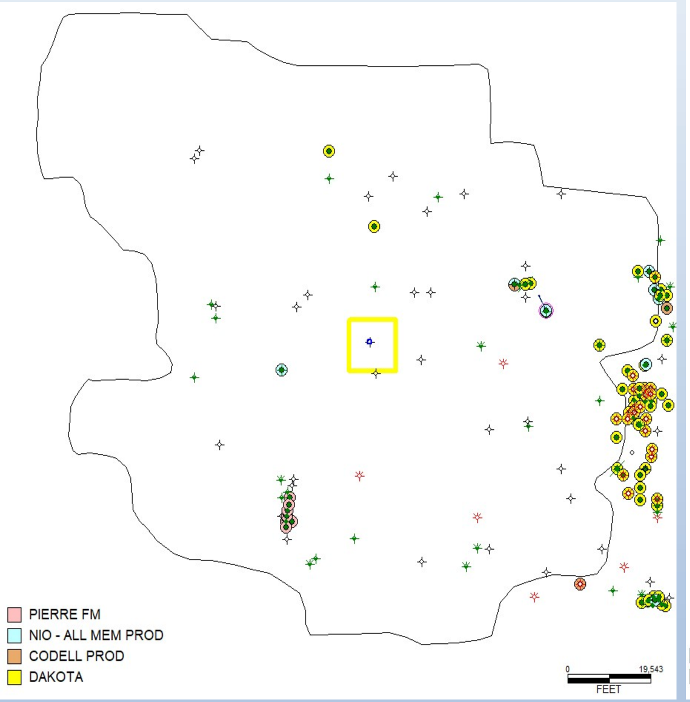
Modified from Haun et al., (1972)

Codell Sandstone *(Turonian Age)*

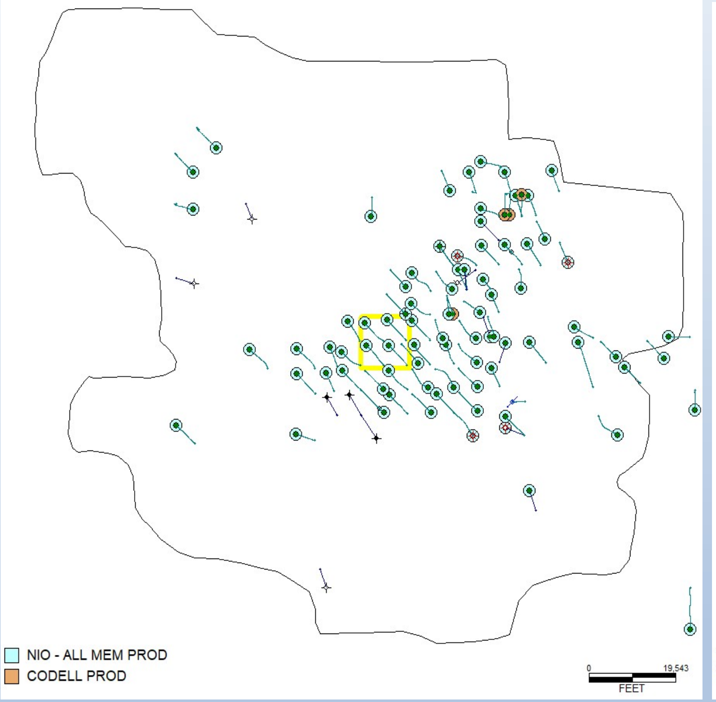
Hereford Structural Context



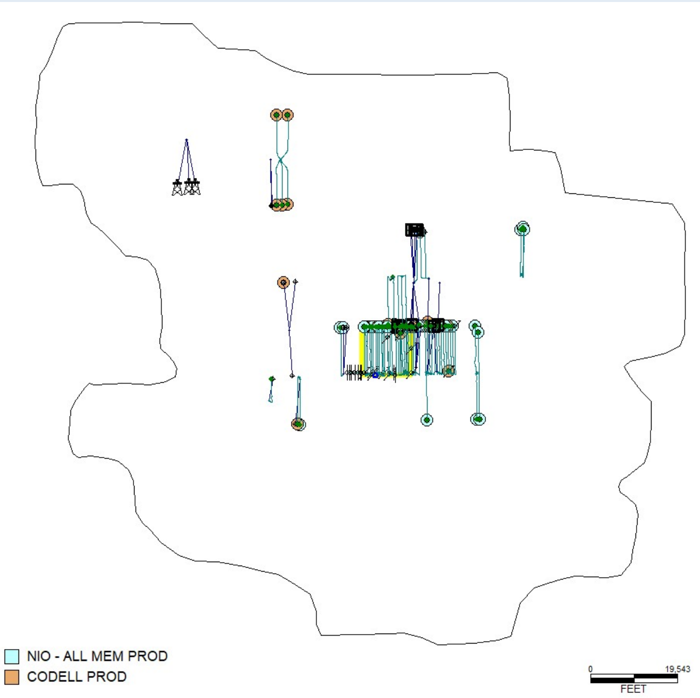
Hereford Field Production Evolution



1st Generation Conventional Wells



1st Generation Unconventional Wells, EOG
Uncemented Liner – Sliding Sleeve Completions (SRL)
(2009 - 2015)

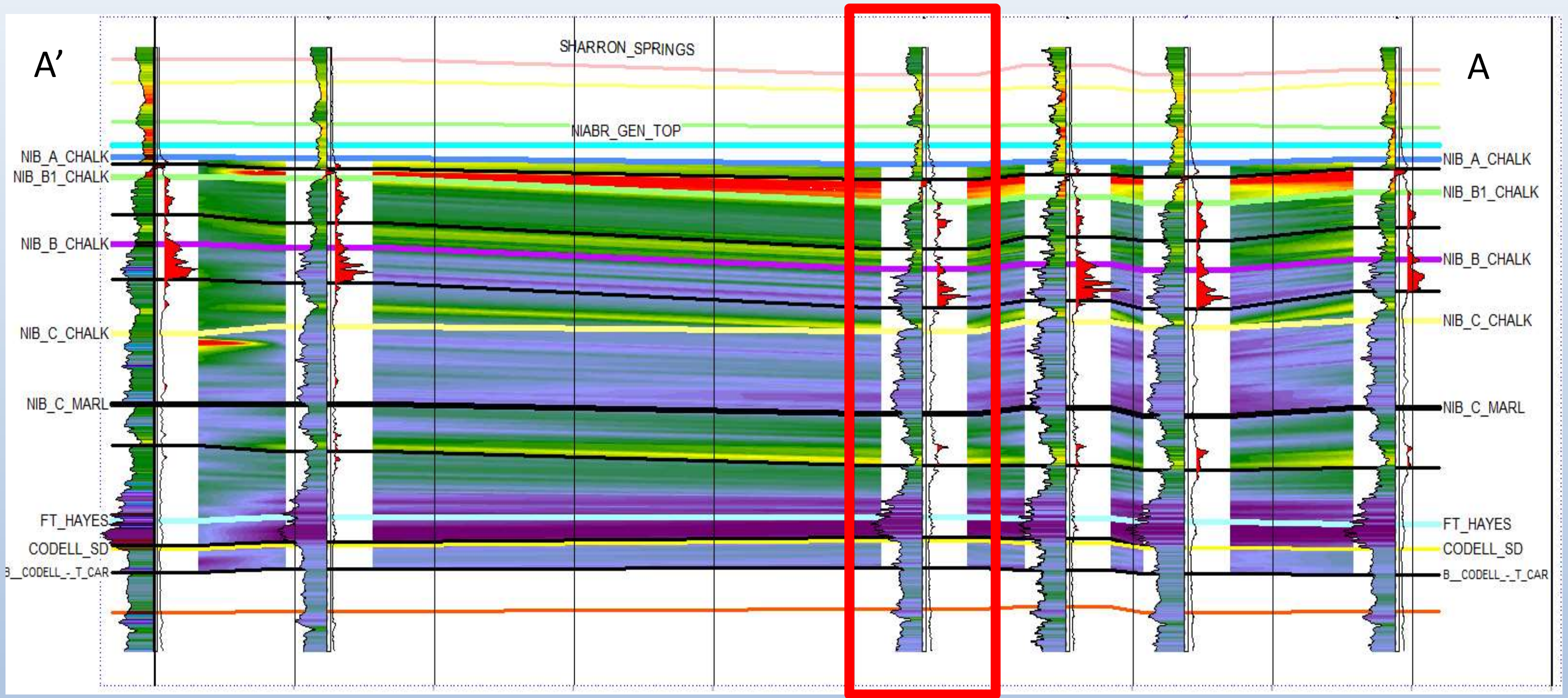


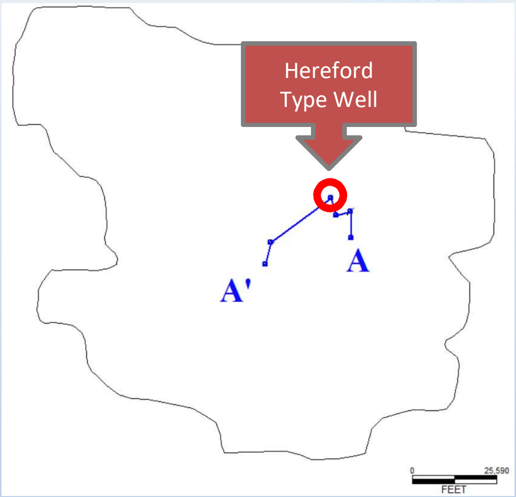
2nd & 3rd Generation Unconventional Wells
Fifth Creek & HighPoint Resources
Cemented with Plug and Perf Completion (SRL & XRL)
(2015 - 2021)

(Pre 2009)

High-Resolution Petrophysical Analysis and Reservoir Characterization

Hereford Unconventional Reservoir Systems





Index Map

Primary Reservoirs

- Niobrara B Chalk
- Codell Sandstone

Secondary Reservoirs

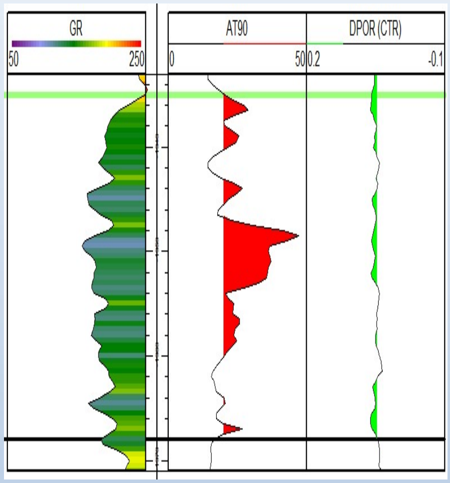
- Niobrara B1 Chalk
- Niobrara C Marl

Characterization Data:

- Sample and Core Geochem
- MICP data
- High Resolution Petrophysical Data
- Produced Fluids

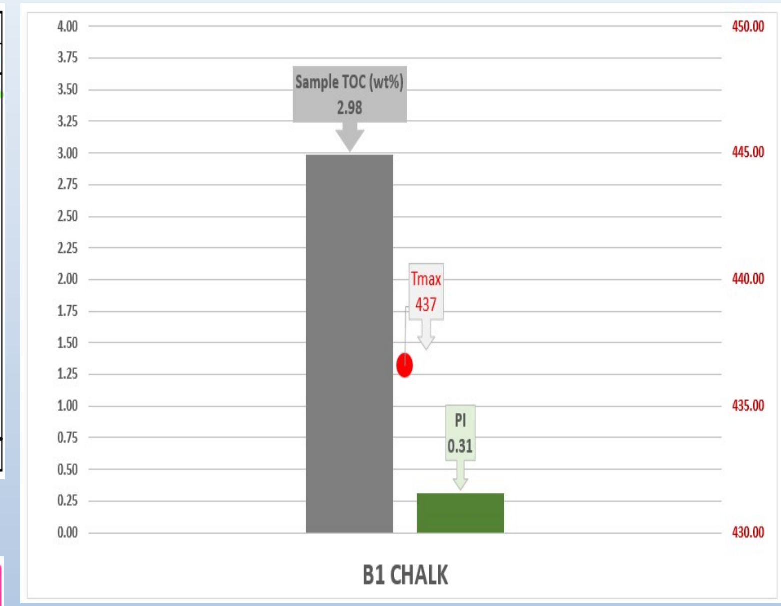
Hereford Niobrara Reservoirs

B1 Chalk – Geochemistry

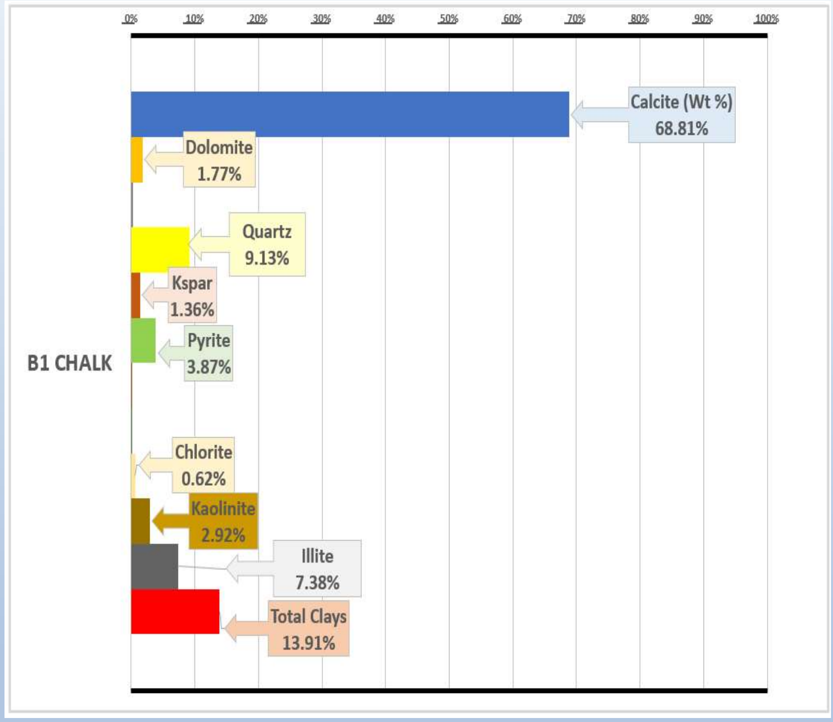


Hereford Type Log

B1 Chalk
- Avg Thickness: 29'
- Range (8 to 52')
- > / = 20 ohm/m (DIL): 0 - 34' (14' Ave)



B1 Chalk Pyrolysis
(Study well Ave)

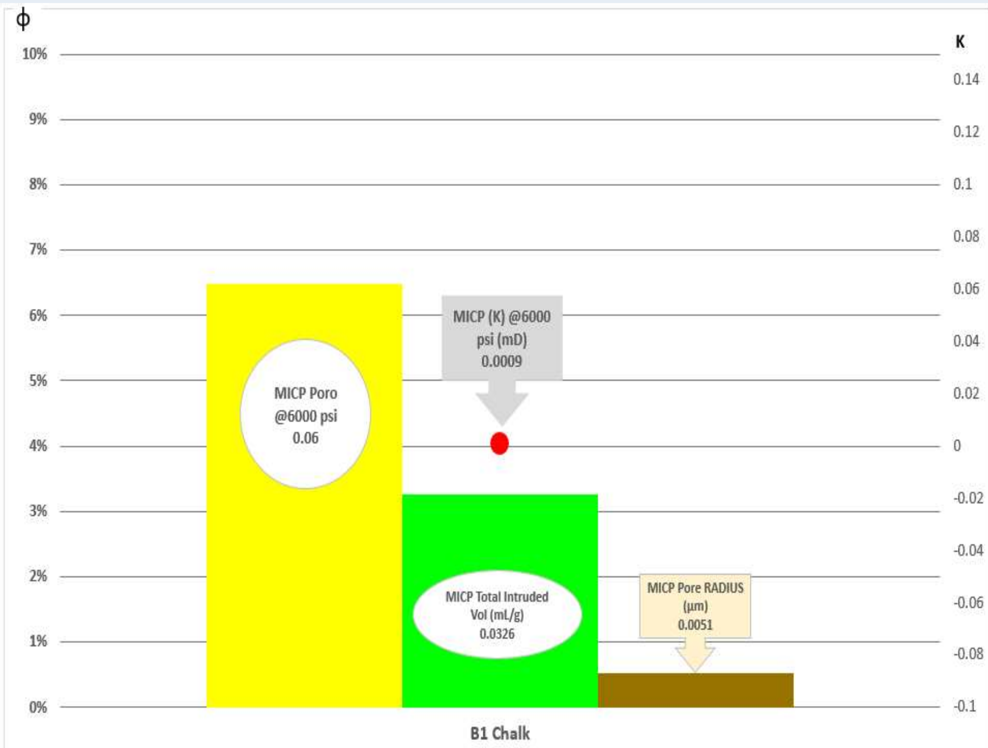


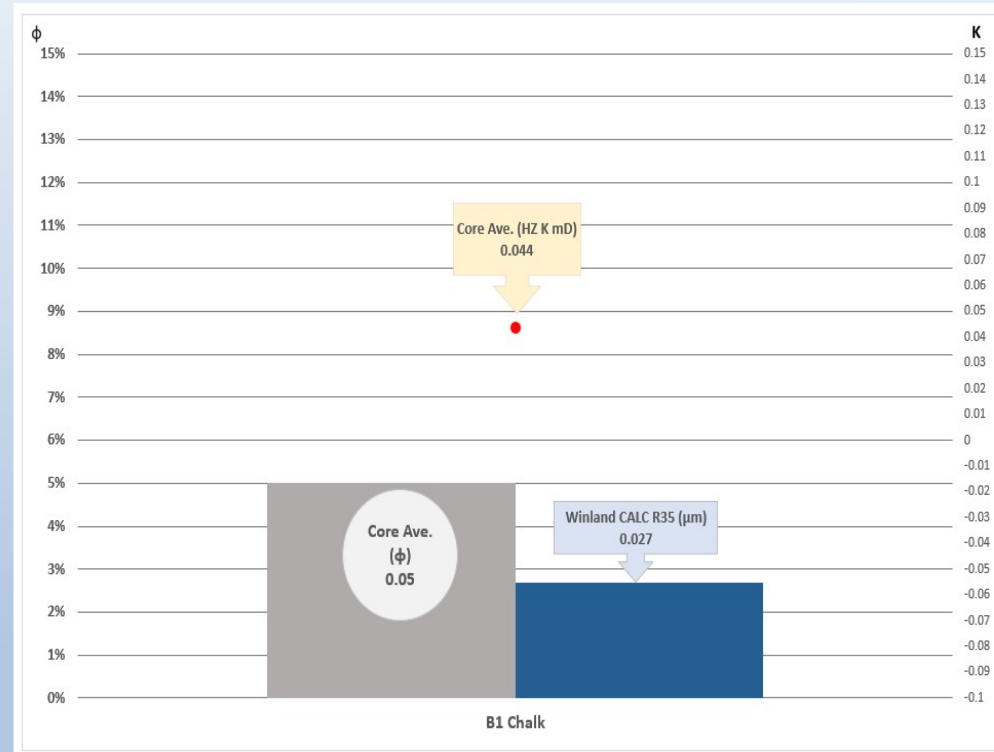
B1 Chalk Sample XRD
(Study Average)

- Lower overall calcite and higher clastic depositional input
- > 10% Clay Content
- High organic content and hydrocarbon generation potential

Hereford Niobrara Reservoirs

B1 Chalk – Core / MICP

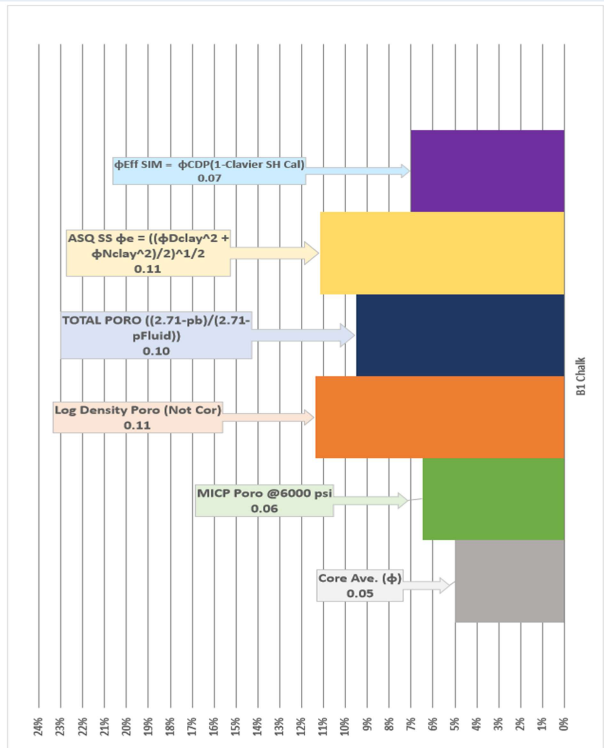




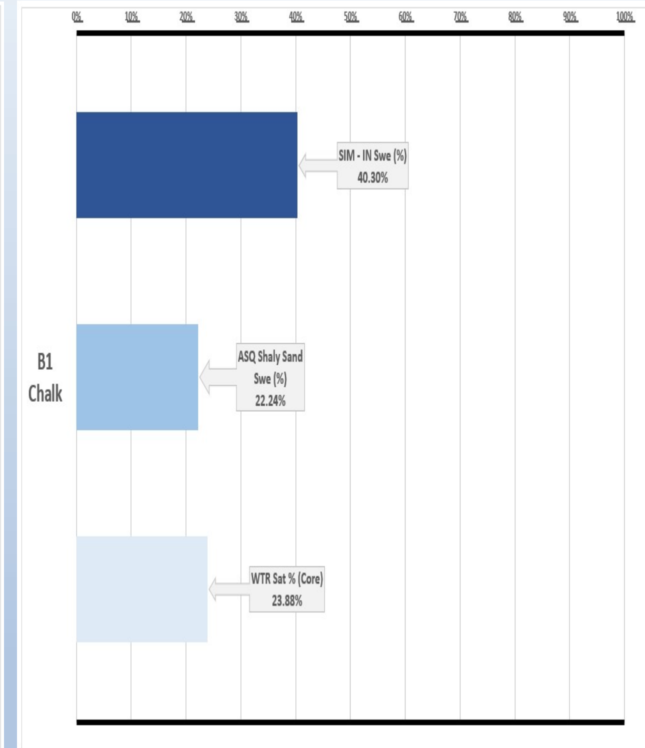
- B1 Chalk Study Averages:
  - (K): .0009 mD (MICP) & .044 mD (Core)
  - (ϕ): 6% (MICP) & 5% (Core)
  - Pore Throat Radius (µm) : .0051 (MICP) & .044 (Calculated)

Hereford Niobrara Reservoirs

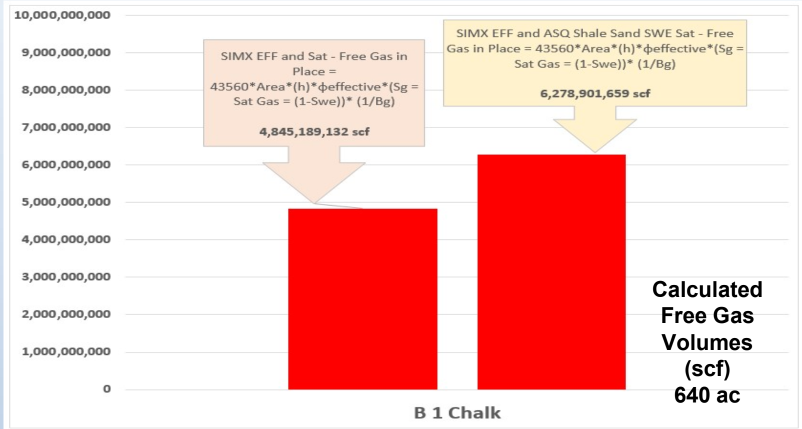
B1 Chalk – Petrophysics

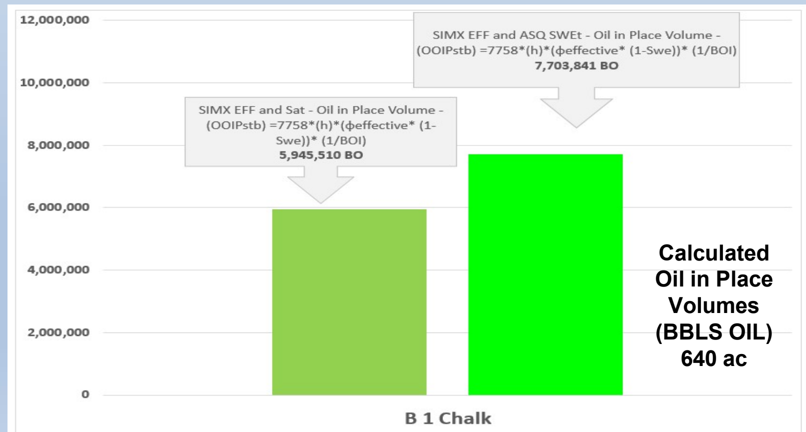


B1 Chalk Porosity
(Raw and Calculated)



B1 Chalk
Calculated Water
Saturations





- B1 Chalk – Average In-Place Reservoir Volumes (Est 640ac) :
  - Gas (High Case): **6.7 BCF** (Low Case): **4.8 BCF**
  - Oil (High Case): **7.7 MMBO** (Low Case): **5.9 MMBO**

Hereford Niobrara Reservoirs

B Chalk – Geochemistry

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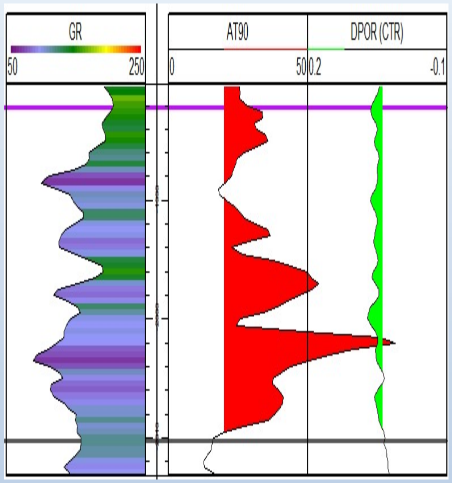
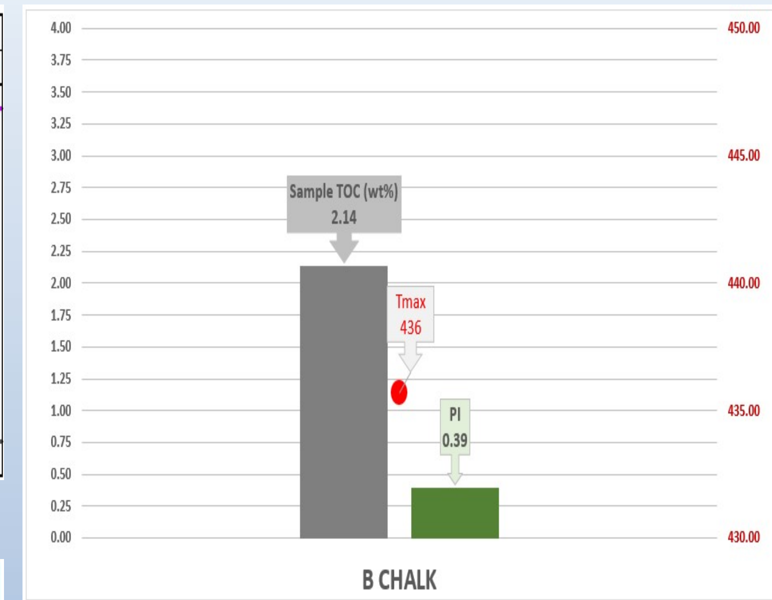
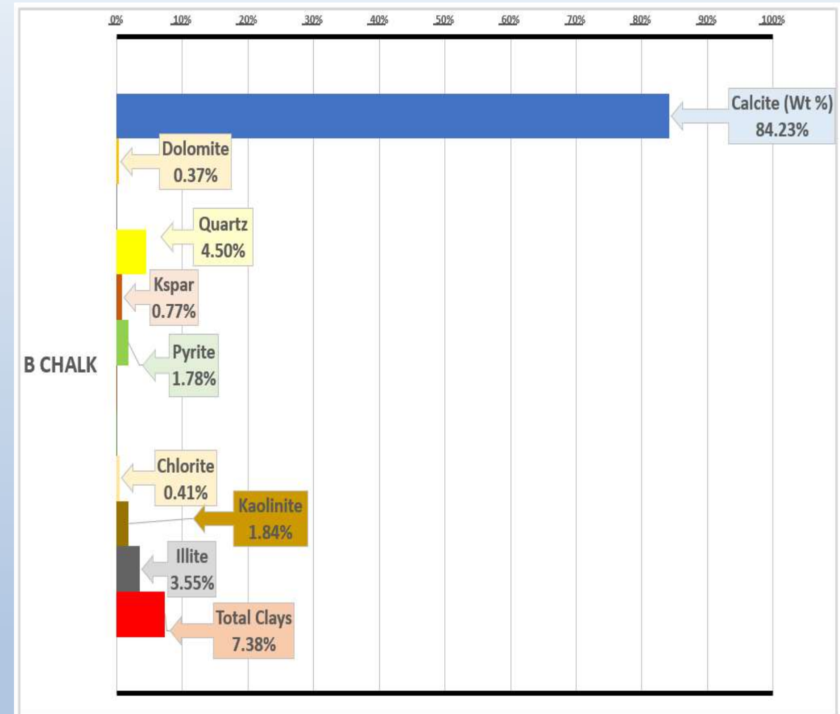


Hereford Type Log

B Chalk
- Avg Thickness: 36’
- Range (20 to 56’)
- > / = 20 ohm/m (DIL): 0 to 43’ (25’ Ave)



B Chalk Pyrolysis
(Study well Ave)

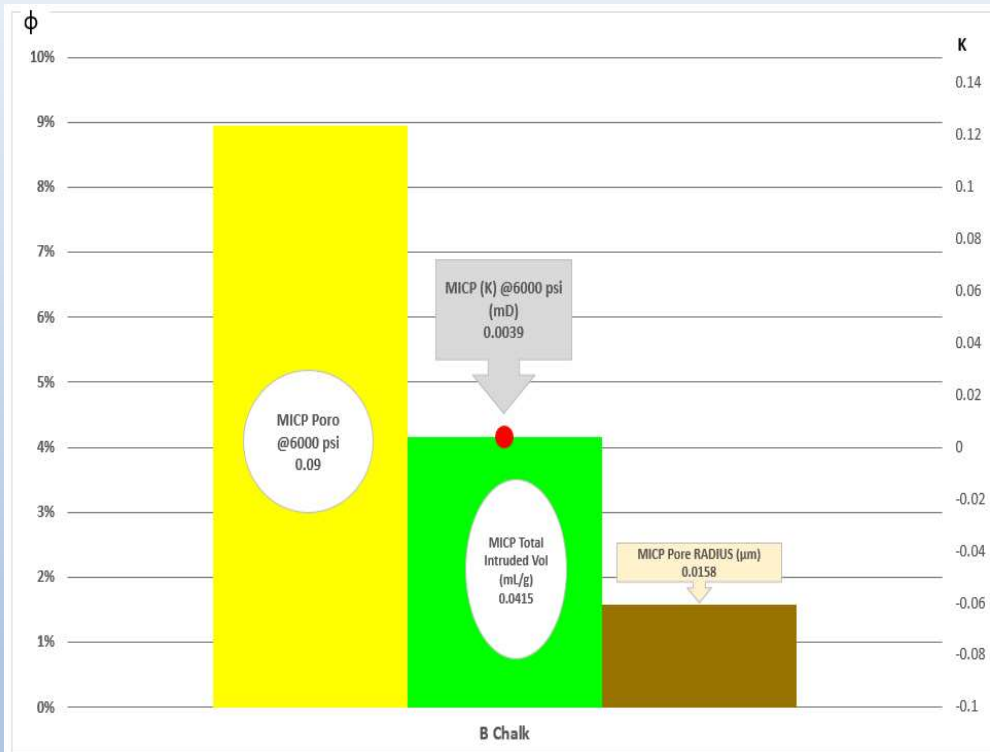


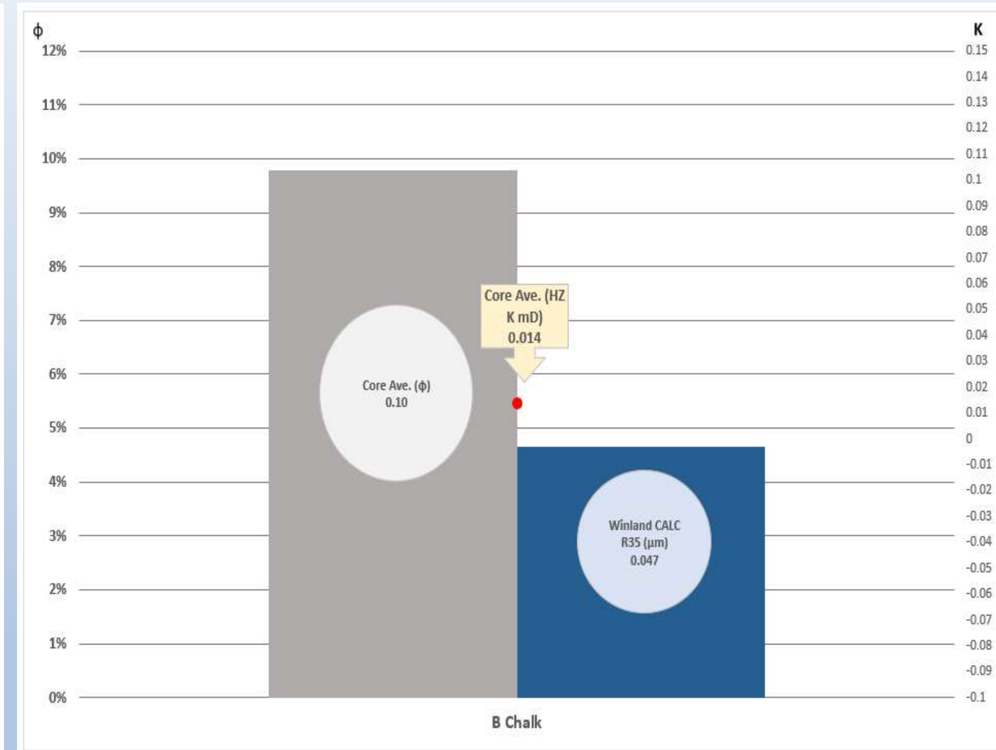
B Chalk Sample XRD
(Study Average)

- Highest calcite % of all Hereford Niobrara Chalks
- < 10% Clay Content
- Lower organic content but efficient transformation & hydrocarbon generation potential
- Lowest anoxic minerals

Hereford Niobrara Reservoirs

B Chalk – Core / MICP

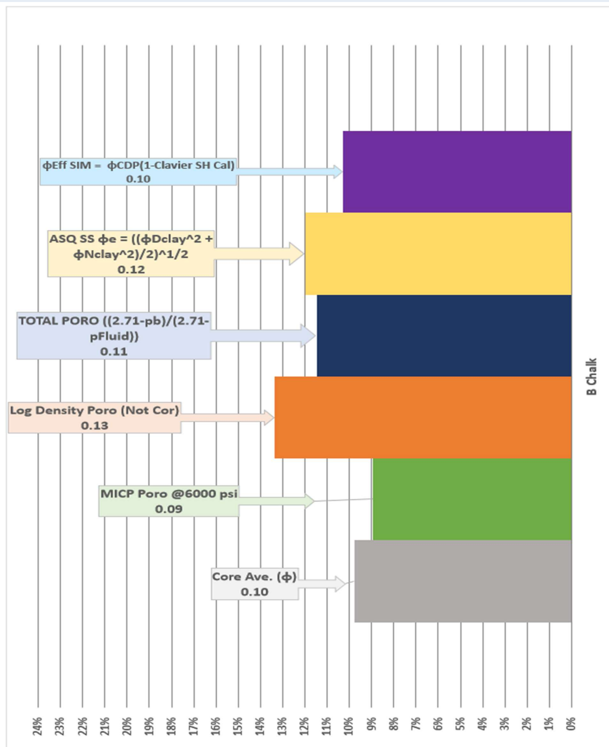




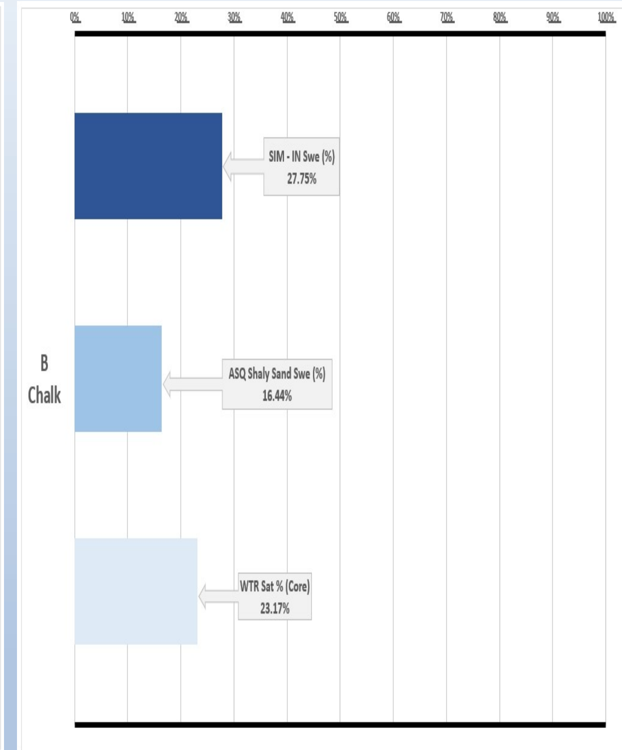
- B Chalk Study Averages:
  - (K): .0039 mD (MICP) & .014 mD (Core)
  - (ϕ): 9% (MICP) & 10% (Core)
  - Pore Throat Radius (µm) : .0158 (MICP) & .047 (Calculated)

Hereford Niobrara Reservoirs

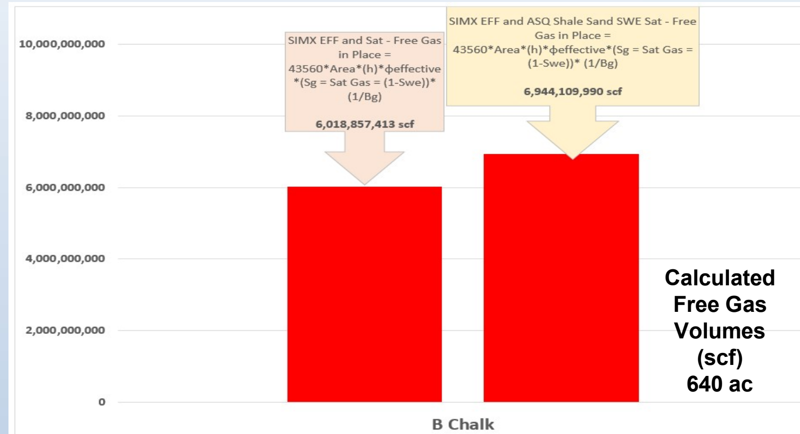
B Chalk – Petrophysics



B Chalk Porosity
(Raw and Calculated)



B Chalk
Calculated Water Saturations



Calculated Free Gas Volumes (scf) 640 ac

Calculated Oil in Place Volumes (BBLS OIL) 640 ac

- B Chalk – Average In-Place Reservoir Volumes (Est 640ac) :
  - Gas (High Case): **6.9 BCF** (Low Case): **6 BCF**
  - Oil (High Case): **8.5 MMBO** (Low Case): **7.4 MMBO**

Hereford Niobrara Reservoirs

C Marl – Geochemistry

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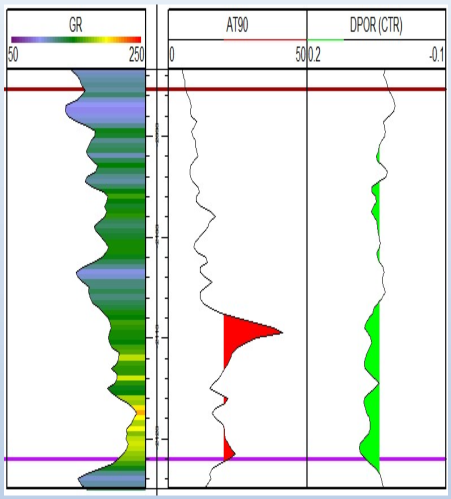
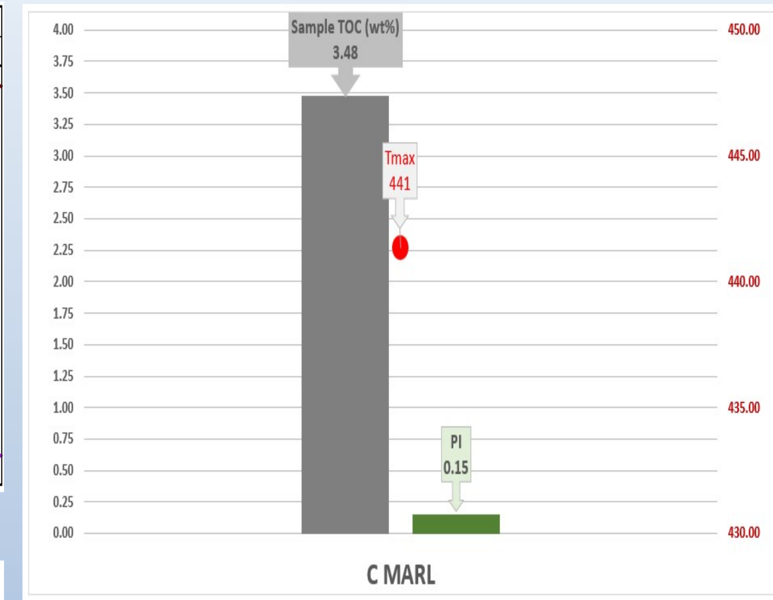
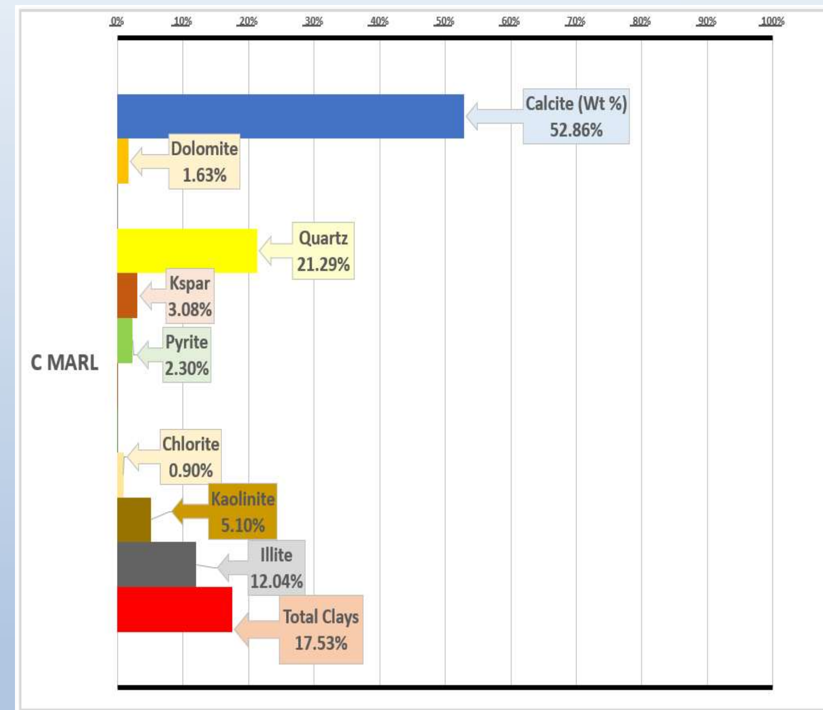


Hereford Type Log

C Marl
- Avg Thickness: 45’
- Range (10 to 72’)
- > / = 20 ohm/m (DIL): 0 to 26’ (5’ Ave)



C Marl Pyrolysis
(Study well Average)

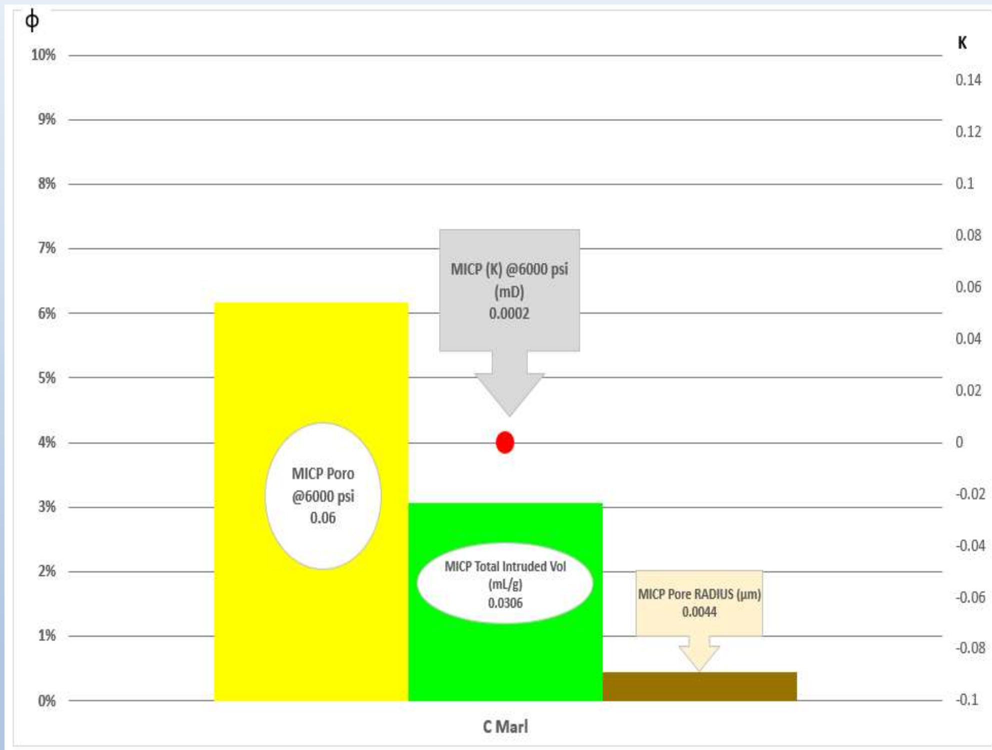


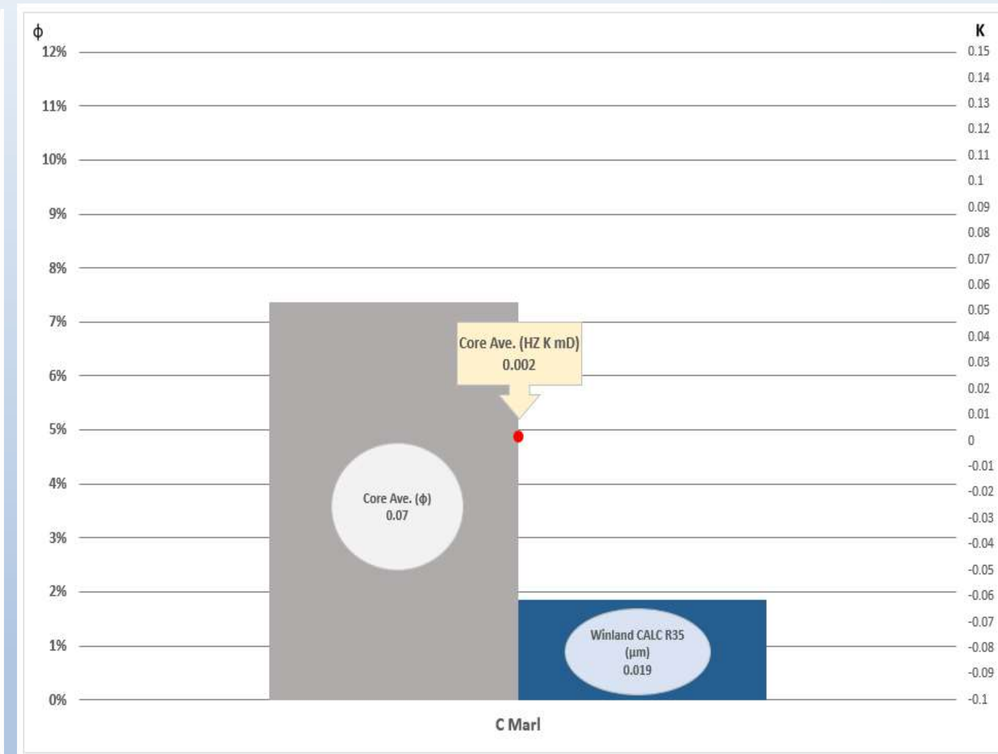
C Marl Sample XRD
(Study Average)

- Calcite lean (< 55%)
- >15% Clay Content -
- Excellent (>3% TOC) organic content but poor HC transformation – insulative mineralogy / poor heat flow?
- Highest potential for organic porosity domination & pore clogging bitumen

Hereford Niobrara Reservoirs

C Marl – Core / MICP

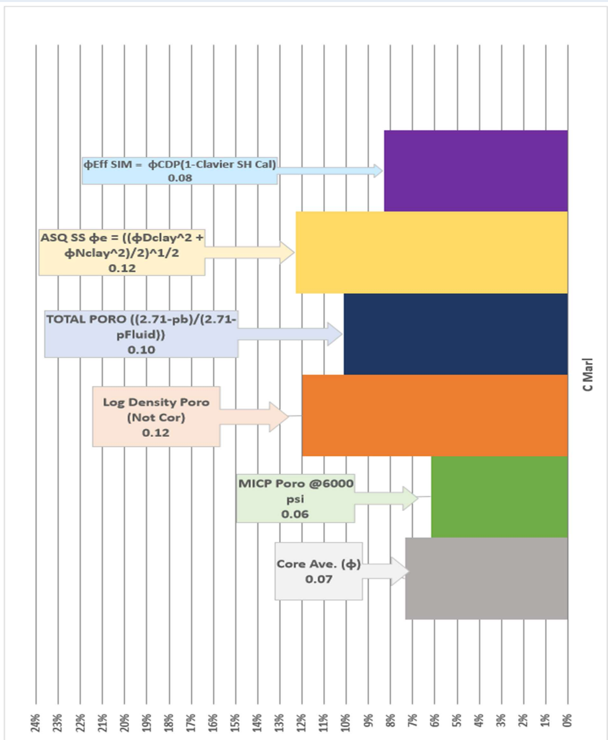




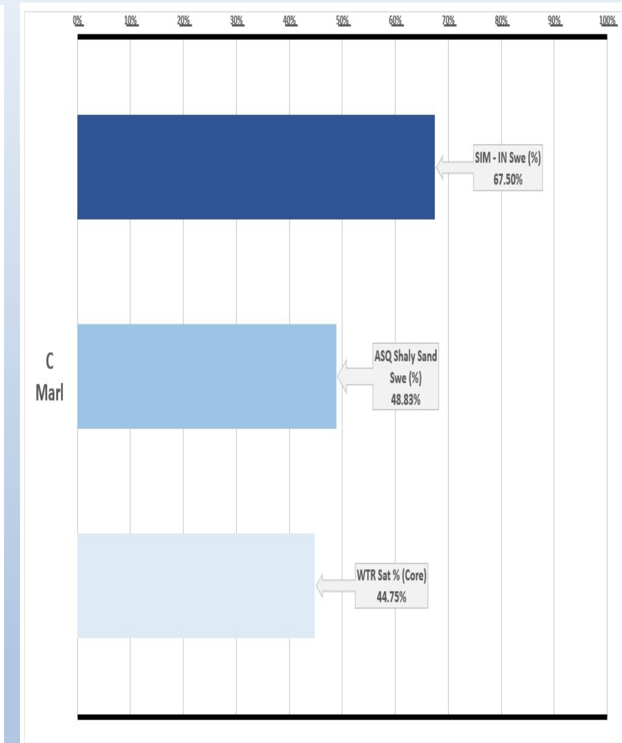
- C Marl Study Averages:
  - (K): .0002 mD (MICP) & .002 mD (Core)
  - (ϕ): 6% (MICP) & 7% (Core)
  - Pore Throat Radius (µm) : .0044 (MICP) & .019 (Calculated)

Hereford Niobrara Reservoirs

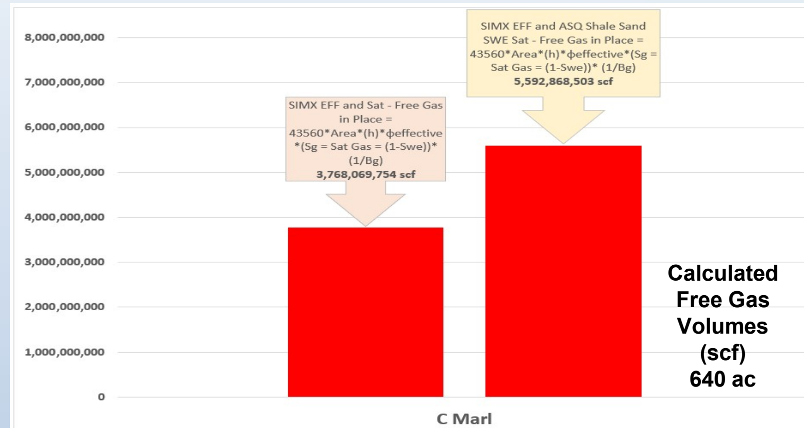
C Marl – Petrophysics



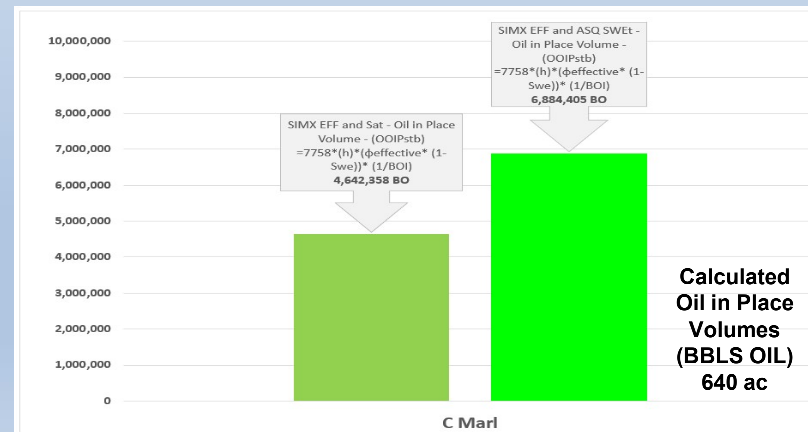
C Marl Porosity
(Raw and Calculated)



C Marl
Calculated Water
Saturations



Calculated
Free Gas
Volumes
(scf)
640 ac

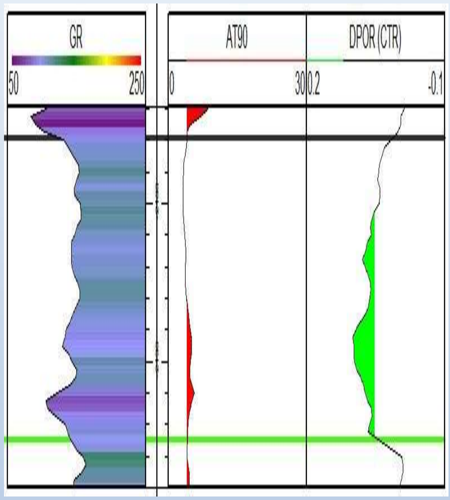


Calculated
Oil in Place
Volumes
(BBLS OIL)
640 ac

- C Marl – Average In-Place Reservoir Volumes (Est 640ac) :
  - Gas (High Case): **5.6 BCF** (Low Case): **3.8 BCF**
  - Oil (High Case): **6.9 MMBO** (Low Case): **4.6 MMBO**

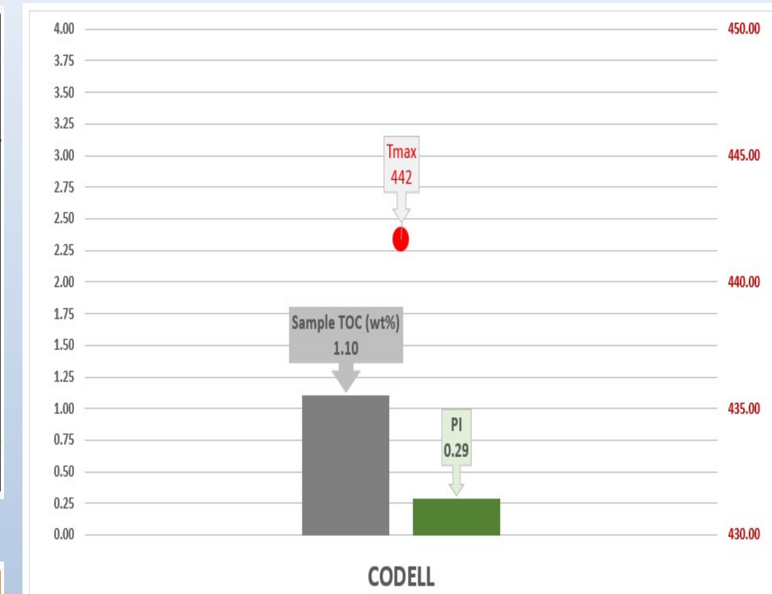
Hereford Codell Reservoir

Codell – Geochemistry

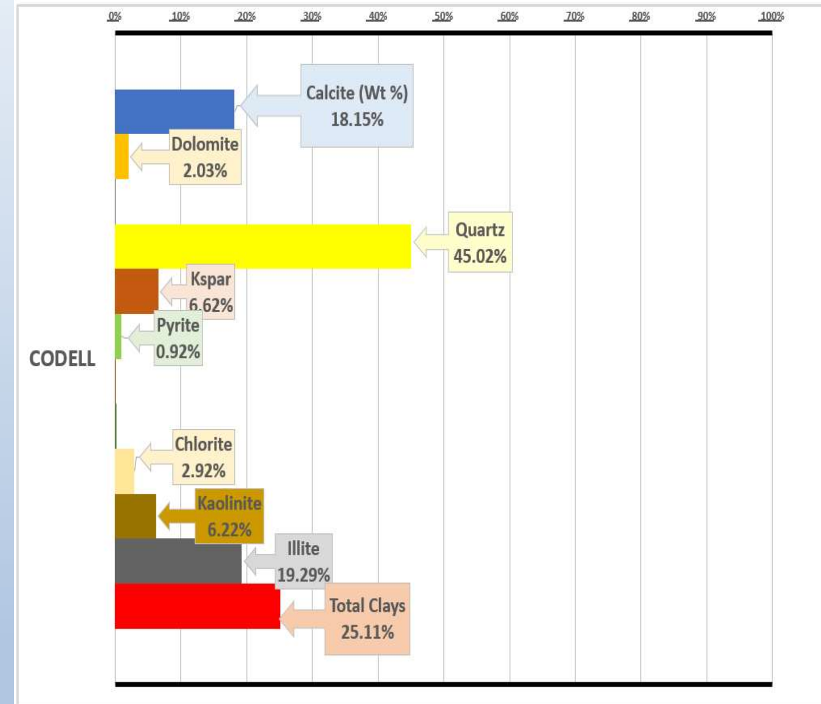


Hereford Type Log

Codell
- Avg Thickness: 16.5'
- Range (<1 to 25")
- > / = 4 ohm/m (DIL): <2 to >19 (7.4' Ave)



Codell Pyrolysis
(Study well Average)

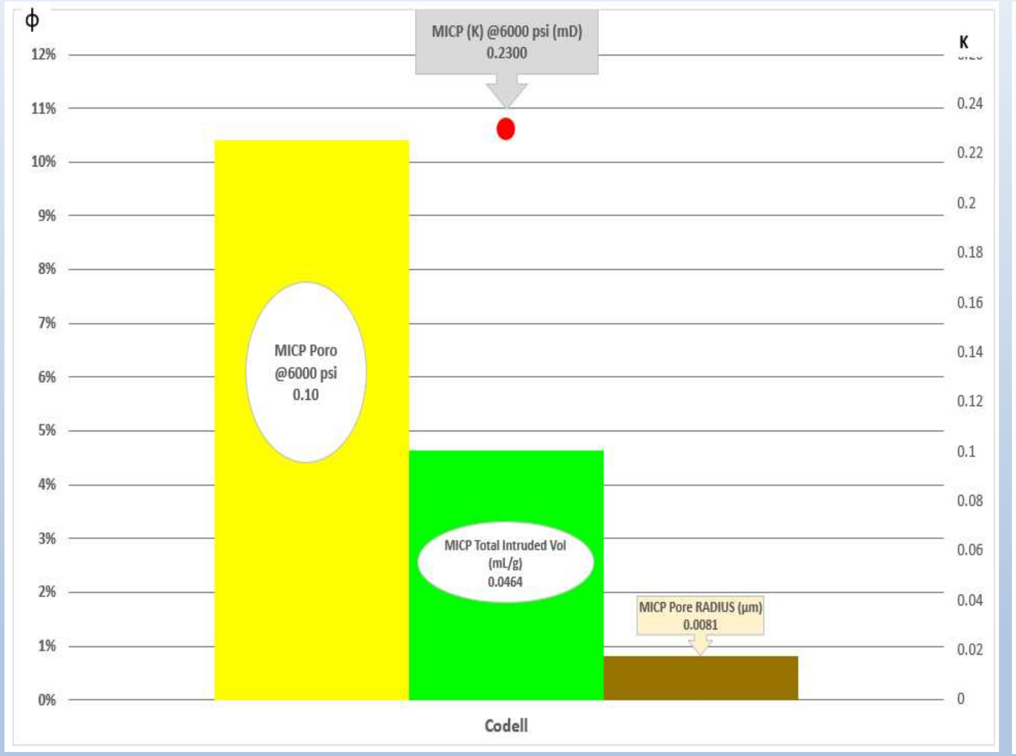


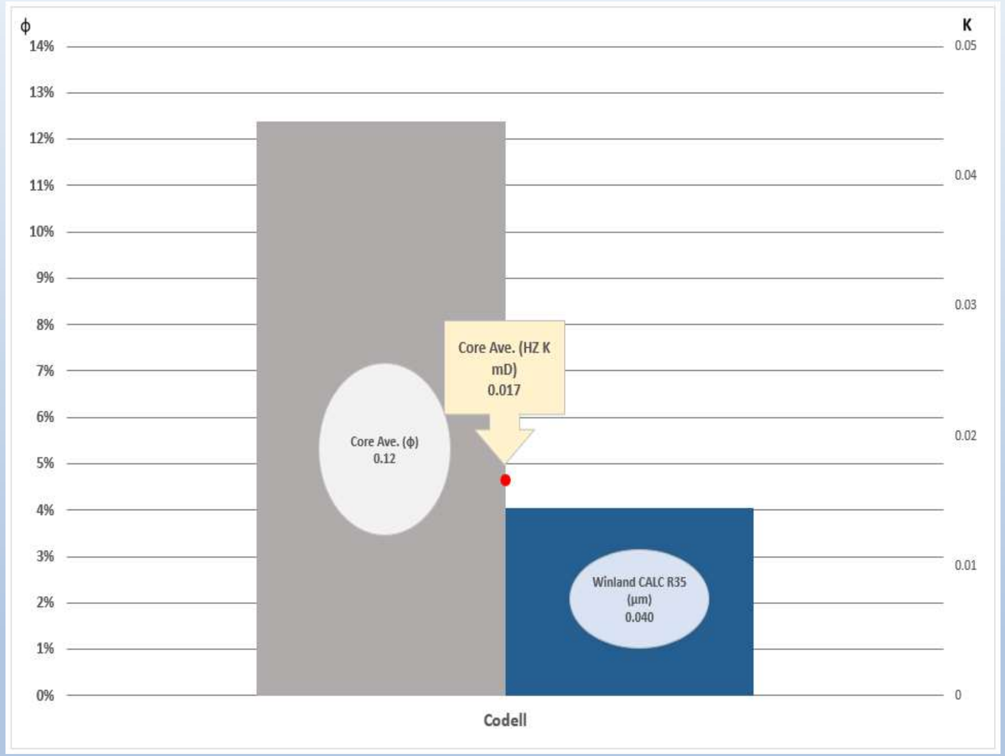
Codell Sample XRD
(Study Average)

- >25 % Clay Content – major impact on reservoir quality
- Illite dominated
- Low organic content but production index (PI) suggests some HC transformation – Potential for some level of self HC sourcing?
- XRD show increasing quartz and decreasing clay with corresponding reservoir quality in the lower half of the Codell - Upper shore face deposition

Hereford Codell Reservoir

Codell – Core / MICP

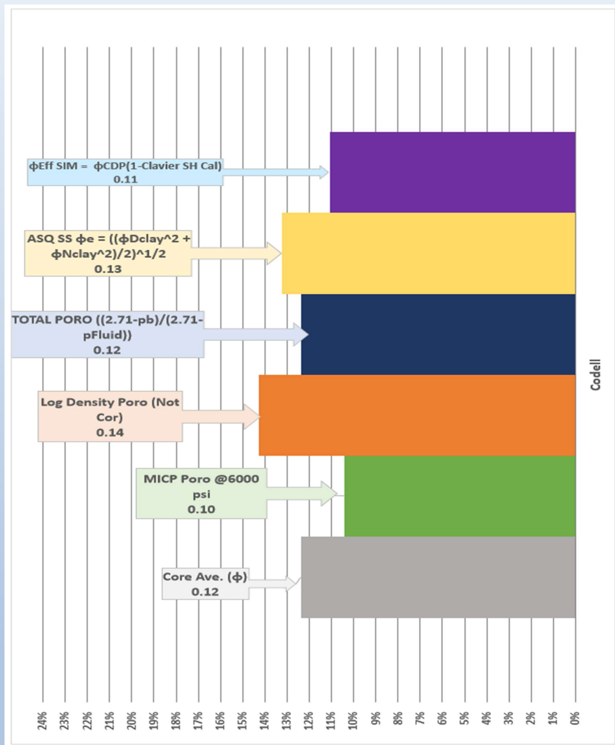




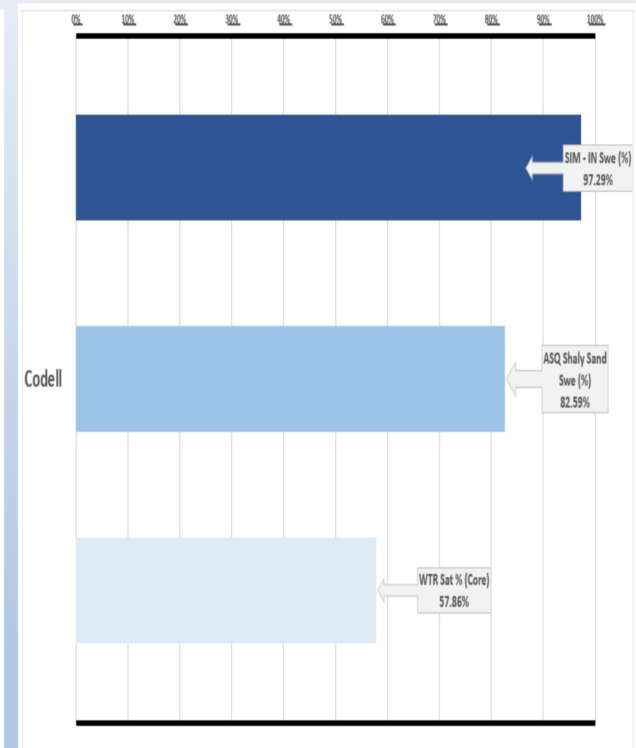
- Codell Study Averages:
  - (K): .23 mD (MICP) & .017 mD (Core)
  - (ϕ): 10% (MICP) & 12% (Core)
  - Pore Throat Radius (µm) : .0081 (MICP) & .04 (Calculated)

Hereford Codell Reservoirs

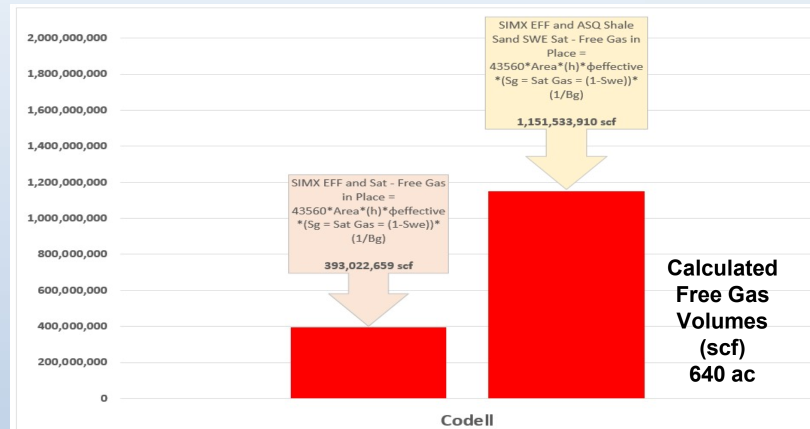
Codell – Petrophysics



Codell Porosity
(Raw and Calculated)



Codell
Calculated Water
Saturations



Calculated Free Gas Volumes (scf) 640 ac

Calculated Oil in Place Volumes (BBLS OIL) 640 ac

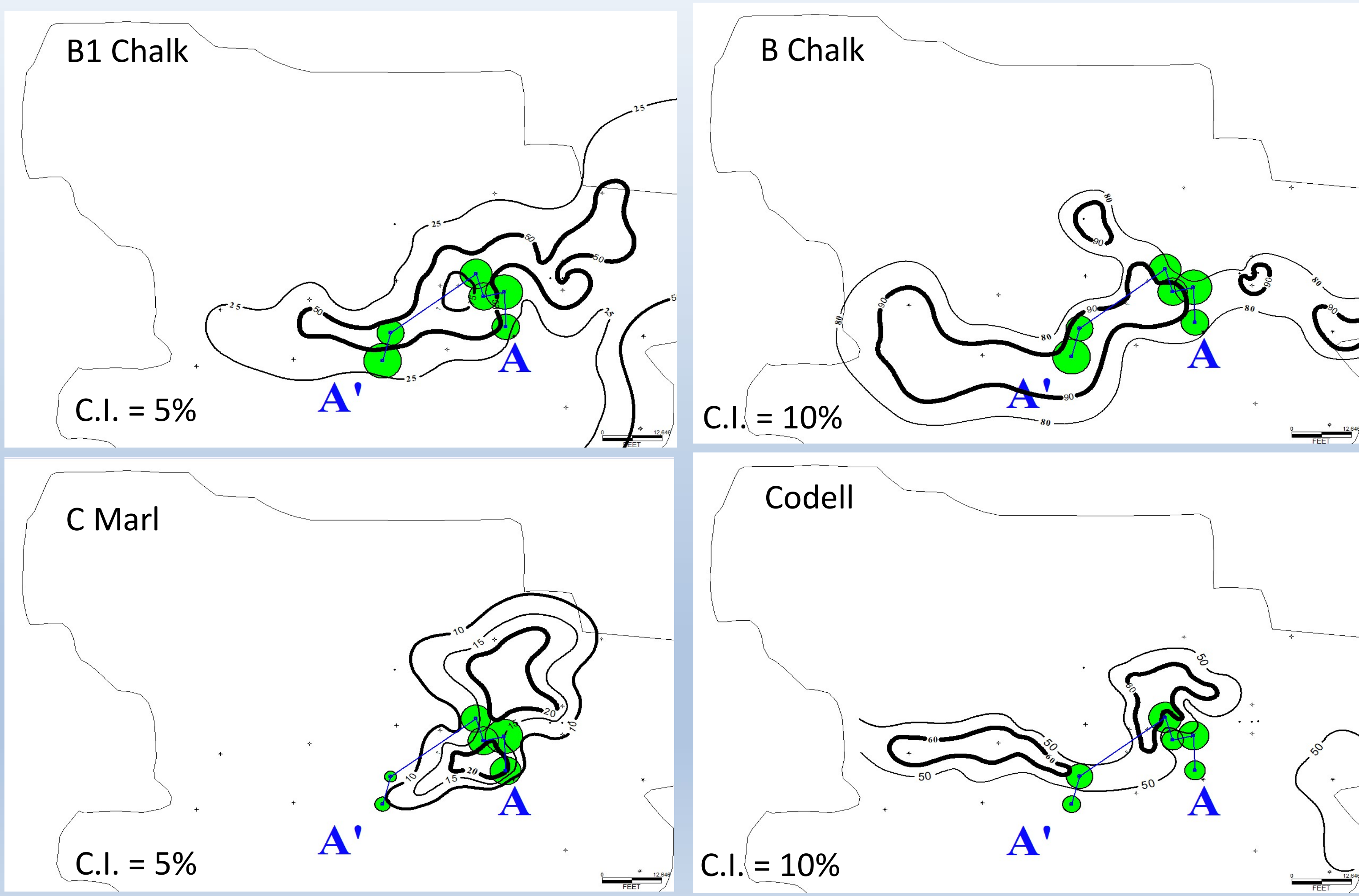
- Codell – Average In-Place Reservoir Volumes (Est 640ac) :
  - Gas (High Case): **1.2 BCF** (Low Case): **393 MMCF**
  - Oil (High Case): **1.5 MMBO** (Low Case): **514 MBO**

Reservoir

Quality and Deliverability

Reservoir Quality

Petrophysics - Resistivity Net to Gross Ratios



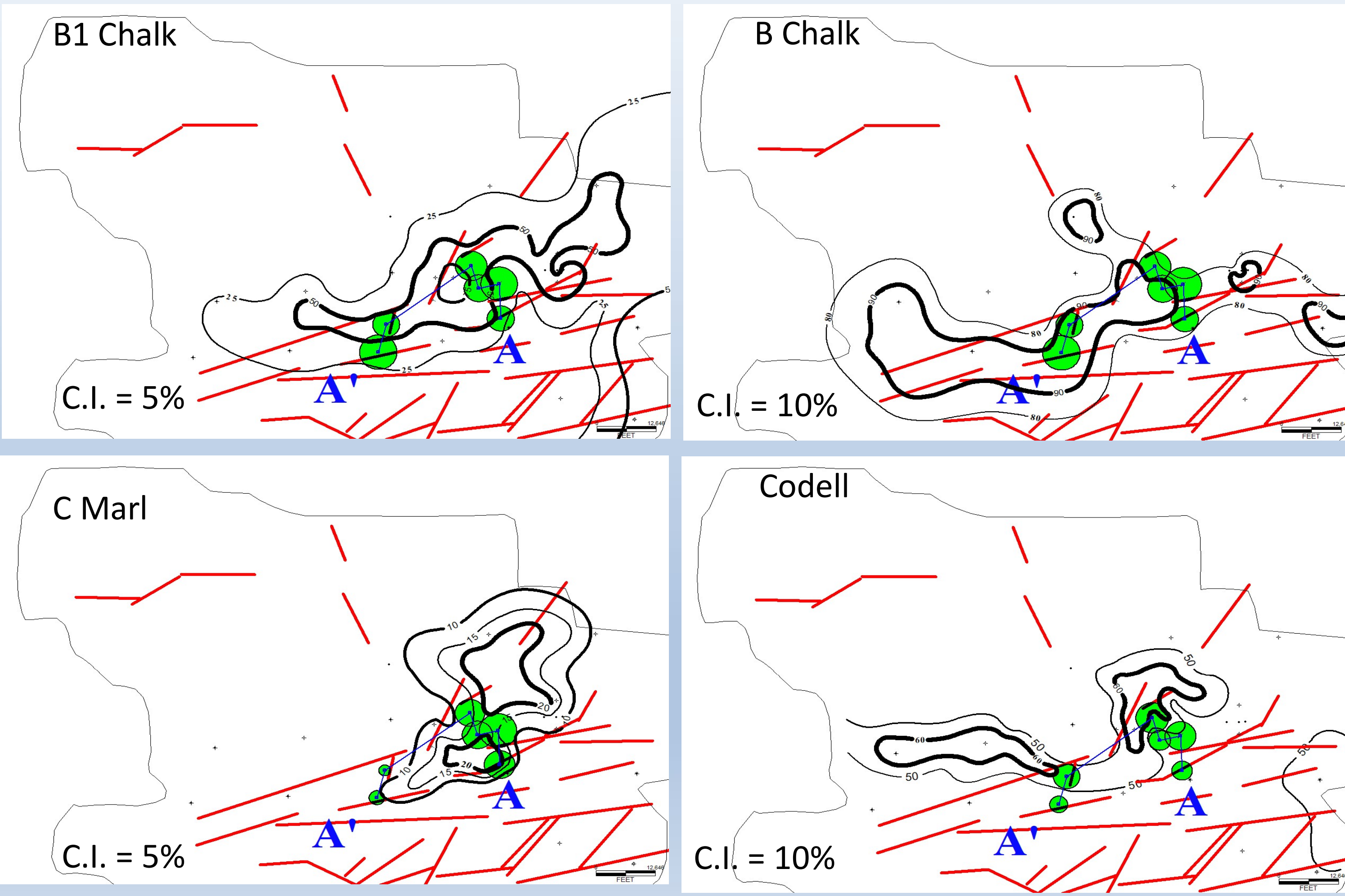
Bubbles = Calculated OOIP from High Case Oil (per formation)

Mapped % Formation Net to Gross

Niobrara Net = (>/=) 20 Ohm RT 80
Codell Net = (>/=) 4 Ohm RT 80

Reservoir Quality

Underlying Tectonic Component



Bubbles = Calculated OOIP from High Case Oil (per formation)

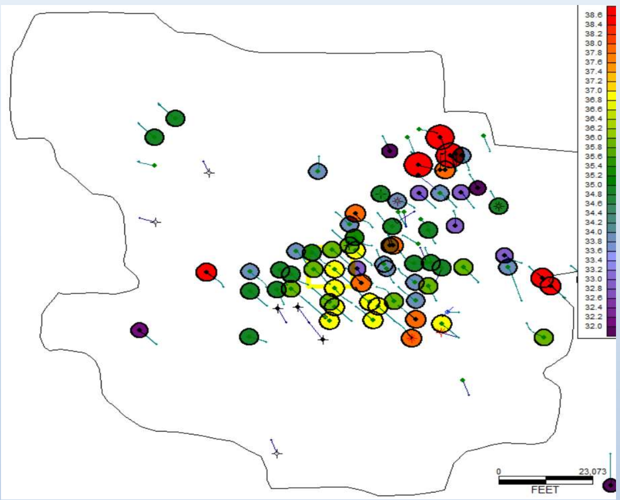
Mapped % Formation Net to Gross

Niobrara Net = (>/=) 20 Ohm RT 80
Codell Net = (>/=) 4 Ohm RT 80

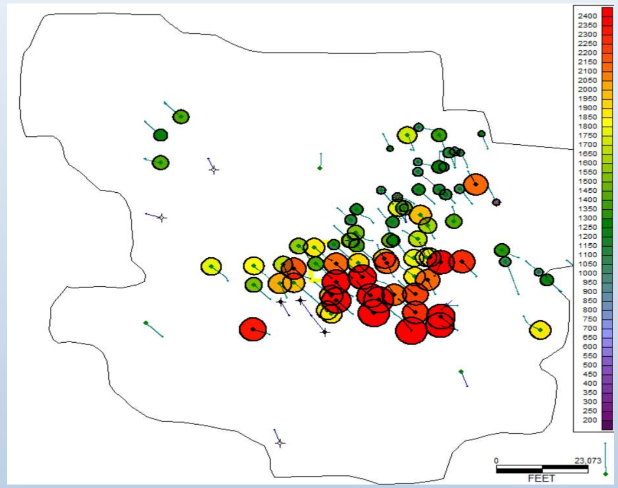
Red lines = Potential Faults
(Visually Picked from Basement Seismic Amplitudes)

Reservoir Quality

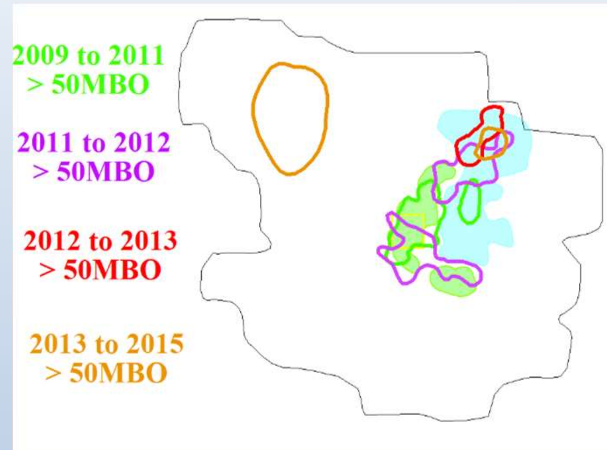
Reservoir Fluid Heterogeneity



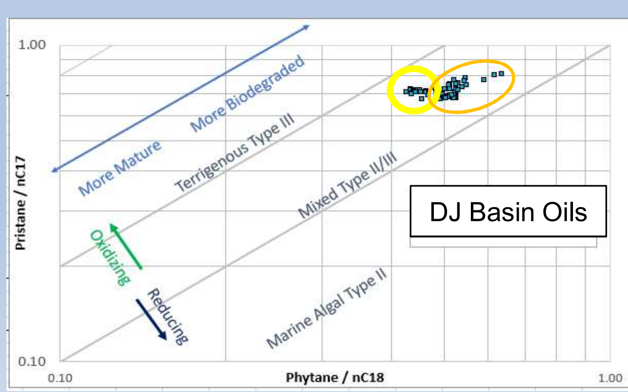
(1st Gen) IP Oil Gravity Bubble Map
(32 to 38 deg)

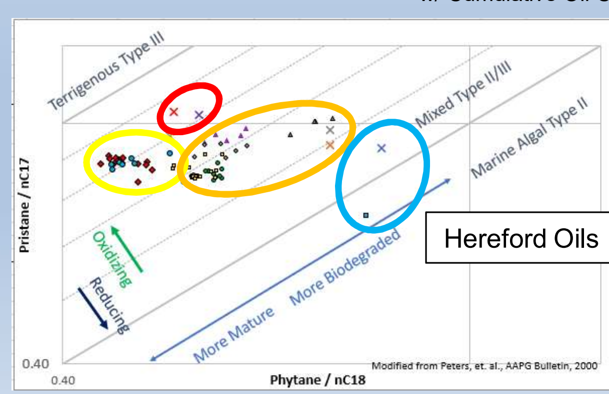


(1st Gen) CUM GOR Bubble Map
2400 to 200 (scf / BO deg)



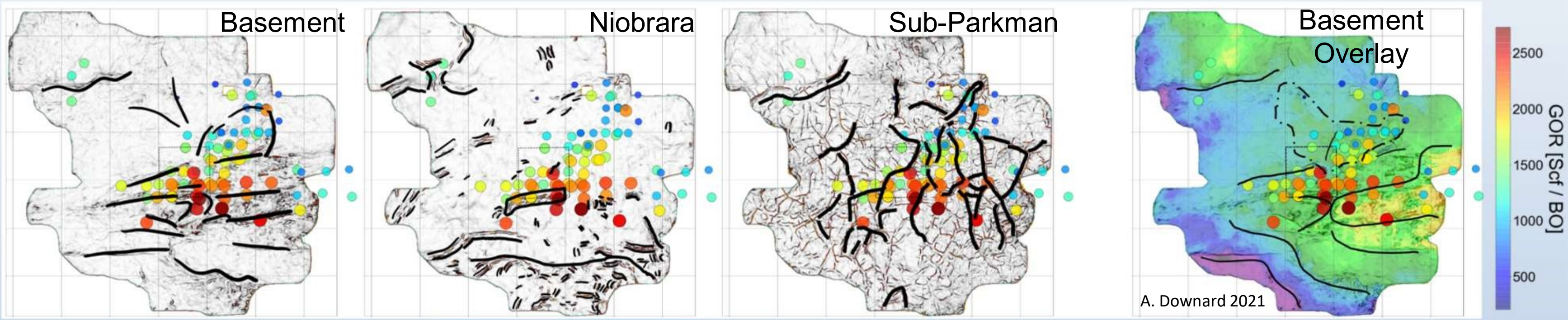
(1st Gen) Cumulative Oil – High Volume Production
w/ Cumulative Oil Cut Shading (Wells with cum oil > or = 50 MBO)

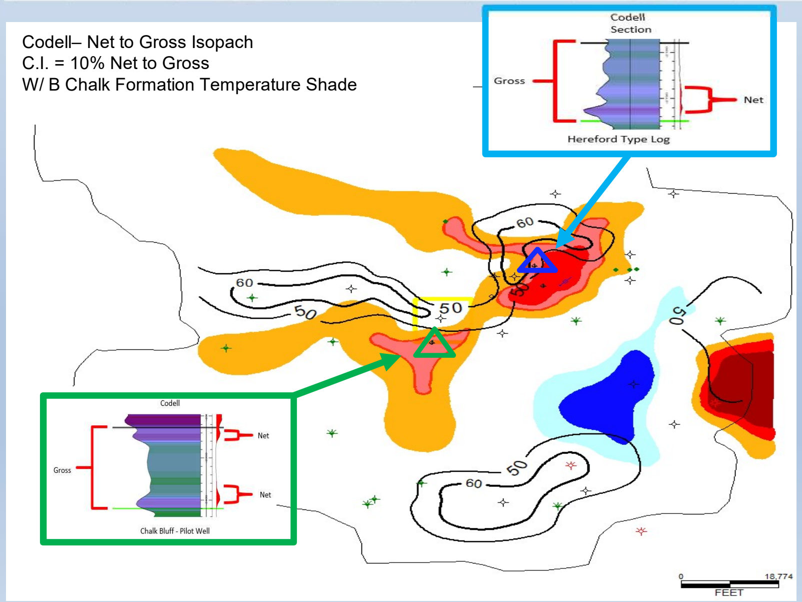


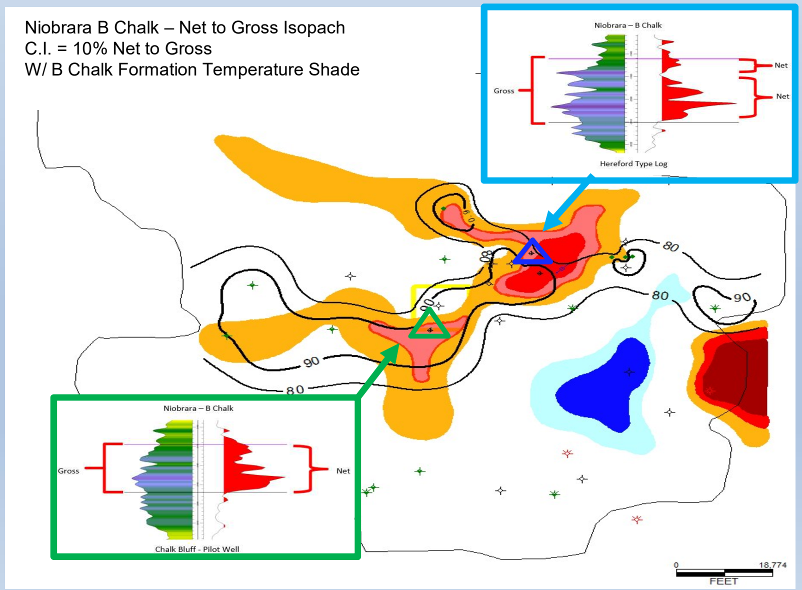


Reservoir Quality

Connecting Underlying Structure and Reservoir Fluids







Key to Understanding:

Tectonic Reservoir Fluid Controls

Fracture Density

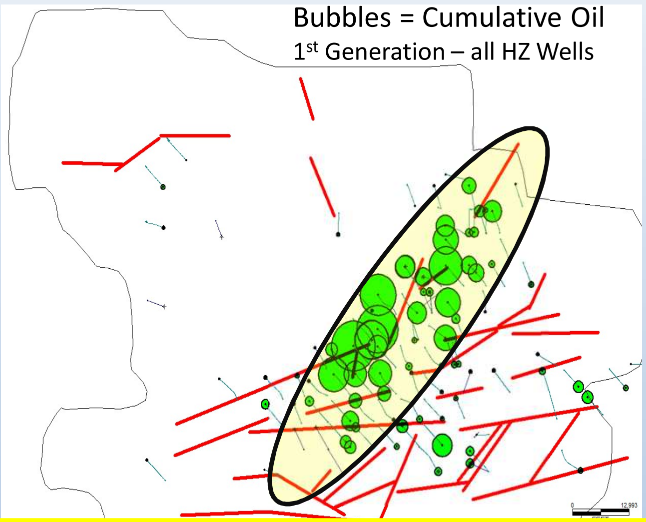
Secondary Fluid Migration

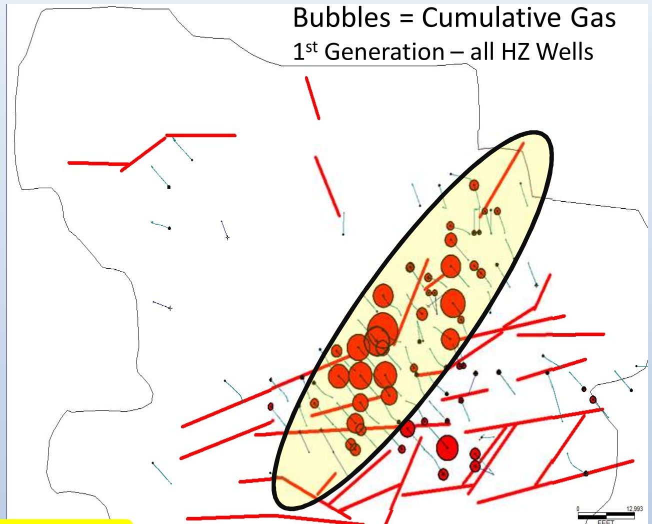
Reservoir Compaction

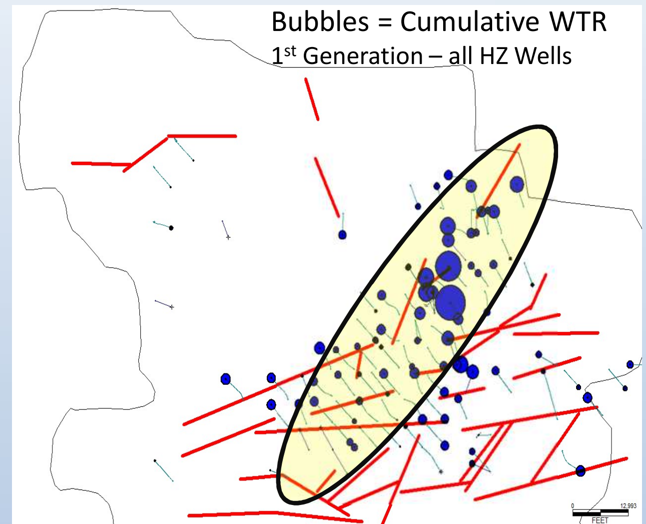
Reservoir Bubble Point Depletion

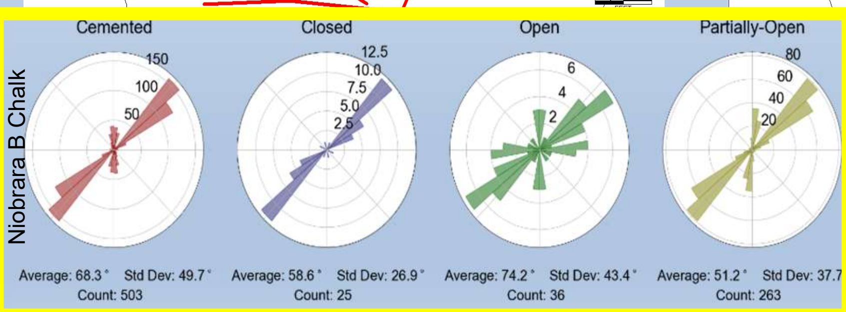
* Temp Gradients Calculated from raw wireline max temp

Hereford Reservoir Productivity





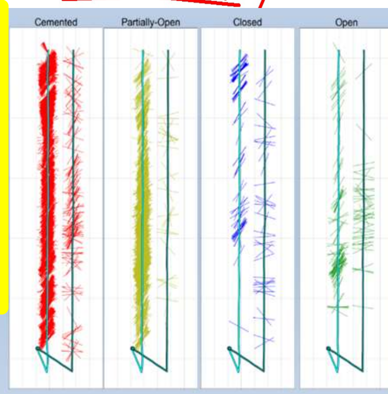




Niobrara B Chalk (total fiber well):

Cumulative fracture count: 827

Average Orientation Angle : 45 deg (= / -)



Natural Fracture Orientations

Codell (total fiber well):

Cumulative fracture count: 190

Average Orientation Angle : 91 deg (+ or -)

Hereford Summary

Niobrara

- Structurally-controlled
  - definable fracture fairways
- Fluid and **pressure** depletion of fractures
  - Relatively lower GOR → in-tact bubble point, larger volumes of legacy fluid produced
  - Relatively higher GOR → more bubble-point breakout, lower volumes of legacy fluid produced
  - Redefine reservoir quality for new phases of production
- Upside potential in the Niobrara
  - additional targets in the B1 Chalk and C Marl

Codell

- Stratigraphically-controlled
  - lower-Codell brittle (less clay, more quartz and calcite) pay zone
  - Contains >80% of oil saturation
- Non-Niobrara sourcing
  - Observable kerogen mixing → potential to develop deeper source intervals
- Upside potential
  - predictable pay across the region, mappable with well and seismic
  - Definable top and bottom-seal, good candidate for EOR

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