Chris Beliveau, M.S. Geology Candidate, Spring, 2022

# CCUS POTENTIAL FOR THE NIOBRARA A AND B INTERVALS AT REDTAIL FIELD, WELD COUNTY, COLORADO

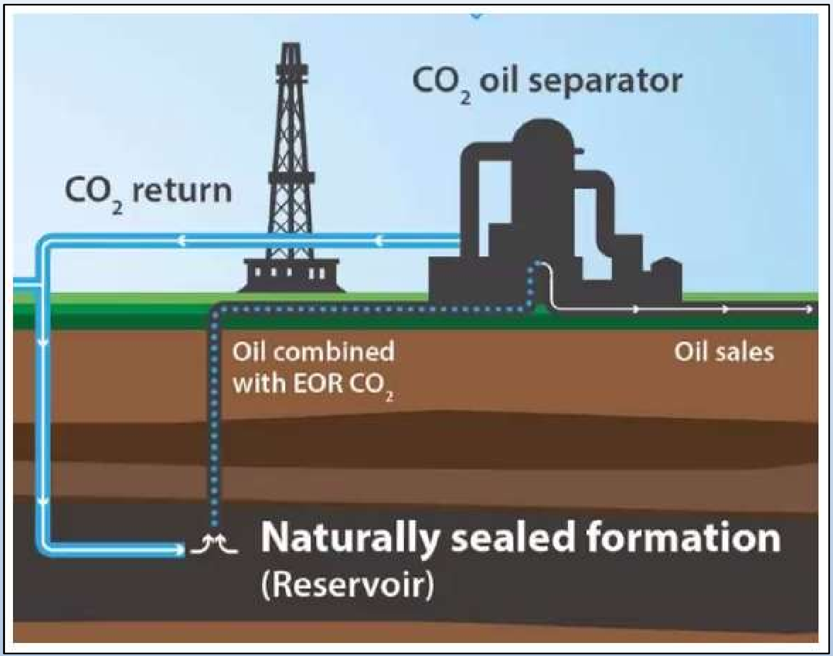
# Outline

- CCUS Overview and Current Projects
- Brief Geologic History of the Niobrara
- Structural Maps for the Sharon Springs, Niobrara A, and Niobrara B as Well as Mapping Work Moving Forward
- Study Area and Overview of Redtail Field Production by Bench
- Lab Work and Techniques Going Forward to Examining the Feasibility of CCUS

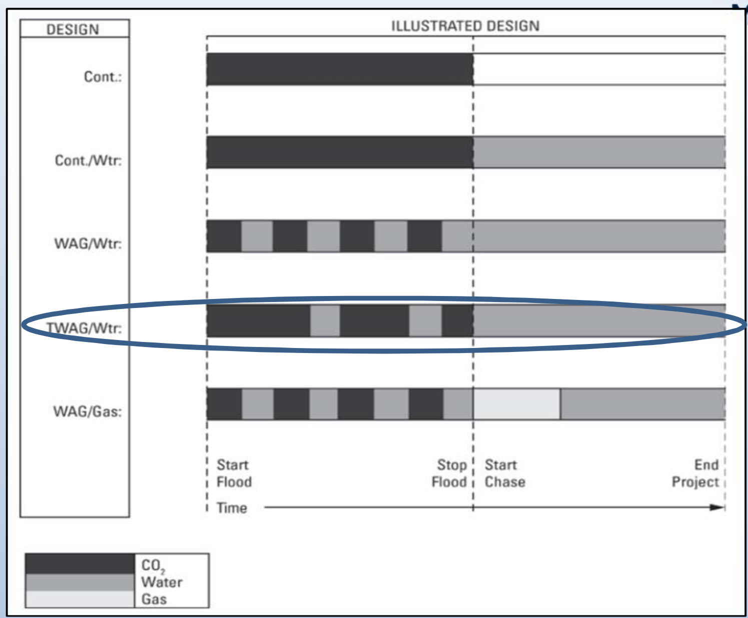
# CCUS Overview

- CCUS is the is the process to capture $CO_2$ from gas, utilize that carbon in some way, and find a safe, permanent storage option
- $CO_2$ can and has been used successfully by the oil and gas industry for enhanced recovery techniques, most notably, Enhanced Oil Recovery (EOR)
  - Up to 80% of oil can be left in place after primary and secondary recovery methods
- Four major types of enhanced recovery are:
  - **Enhanced Oil Recovery (EOR)**
  - Enhanced Coalbed Methane Recovery (ECBM)
  - Enhanced Gas Recovery (EGR)
  - Enhanced Shale Gas Recovery (ESGR)
- 45Q tax credit introduced in 2008 originally provided \$10/t$CO_2$ stored via CCUS and \$20/t$CO_2$ stored via CCS
  - Since increased to \$35/t$CO_2$ stored via CCUS and \$50/t$CO_2$ stored via CCS
- Hydrocarbon gas injection also increasingly being used

# CCUS Process




CCUS Process *Schematic (University of North Dakota EERC, 2021)*




$CO_2$ *Flood and Injection Designs Schematic (Jarrell et al., 2002)*

- Tapered Water Alternating Gas or TWAG is the most common technique where the water acts as a "slug" pushing the hydrocarbons through the reservoir to production
- $CO_2$ has ~60% success factor in remaining stored

# CCUS Geologic Parameters

COLORADO SCHOOL OF MINES MUDTOC

| Number of projects | Lithology | Porosity (percent) | Perm. (md) | Depth (feet) | Gravity (°API) | Viscosity (cp) | Temp. (°F) |
|---|---|---|---|---|---|---|---|
| | | | Miscible | | | | |
| 42 | ss. | 7–26 | 16–280 | 1,600–11,950 | 30–45 | 0.6–3.0 | 82–257 |
| 2 | ss./ls.-dol. | 10 | 4–5 | 5,400–6,400 | 35 | 1 | 170–181 |
| 41 | dol. | 7–5 | 2–28 | 4,000–11,100 | 28–42 | 0.6–6.0 | 86–232 |
| 12 | dol./ls. | 3–12 | 2–5 | 4,900–6,700 | 31–44 | 0.4–1.8 | 100–139 |
| 6 | ls. | 4–20 | 5–70 | 5,600–6,800 | 39–43 | 0.4–1.5 | 125–135 |
| 1 | dol./trip. chert | 13.5 | 9 | 8,000 | 40 | NA | 122 |
| 7 | tripolite | 18–24 | 2–5 | 5,200–7,500 | 40–44 | 0.4–1.0 | 101–123 |
| 1 | | | | inadequate data | | | |
| | | | Immiscible | | | | |
| 8 | ss. | 17–30 | 30–1,000 | 1,500–8,500 | 11–35 | 0.6–45 | 99–198 |
| 1 | dol. | 17 | 175 | 1,400 | 30 | 6 | 82 |

*Table Showing EOR Projects Broken into Lithology, Porosity, Permeability, etc.* (Koottungal, 2012)

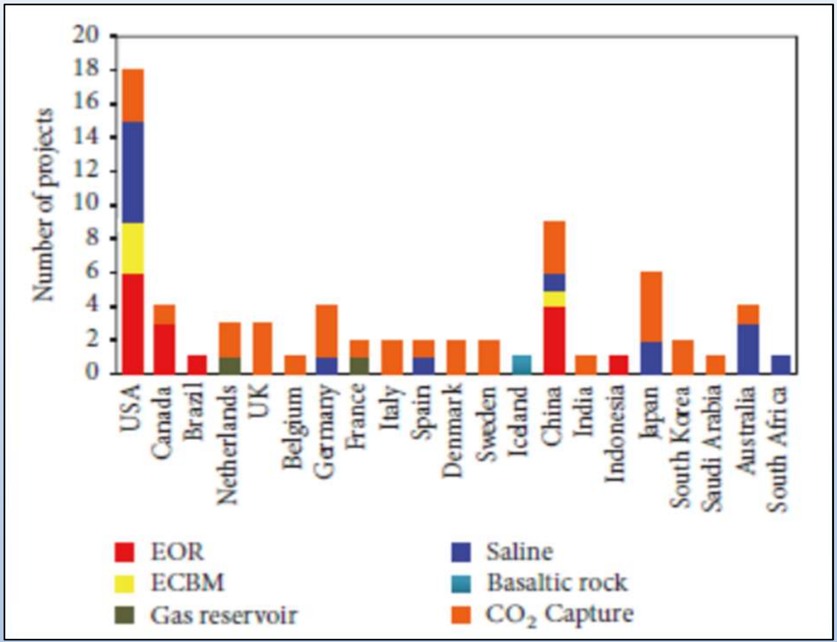
**Optimum Reservoir Parameters and Weighting Factors for Ranking Oil Reservoirs Suitable for CO2 EOR**

| Reservoir Parameters | "Optimum Values" | Niobrara A | Niobrara B | Parametric Weight |
|---|---|---|---|---|
| API Gravity (°API) | 37 | 31.95-39.45 | Working | 0.24 |
| Remaining Oil Saturation | 60% | Working | Working | 0.20 |
| Pressure Over MMP (Mpa) | 1.4 | Working | Working | 0.19 |
| Temperature (°C) | 71 | 60-90 | 60-90 | 0.14 |
| Net Oil Thickness (ft) | 49 | 10-25 | 40-60 | 0.11 |
| Permeability (mD) | 300 | .002-.005 | .002-.005 | 0.07 |
| Reservoir Dip | 20 | 0.36 | 0.36 | 0.03 |
| Porosity | 20% | 13-15% | 11-13% | 0.02 |

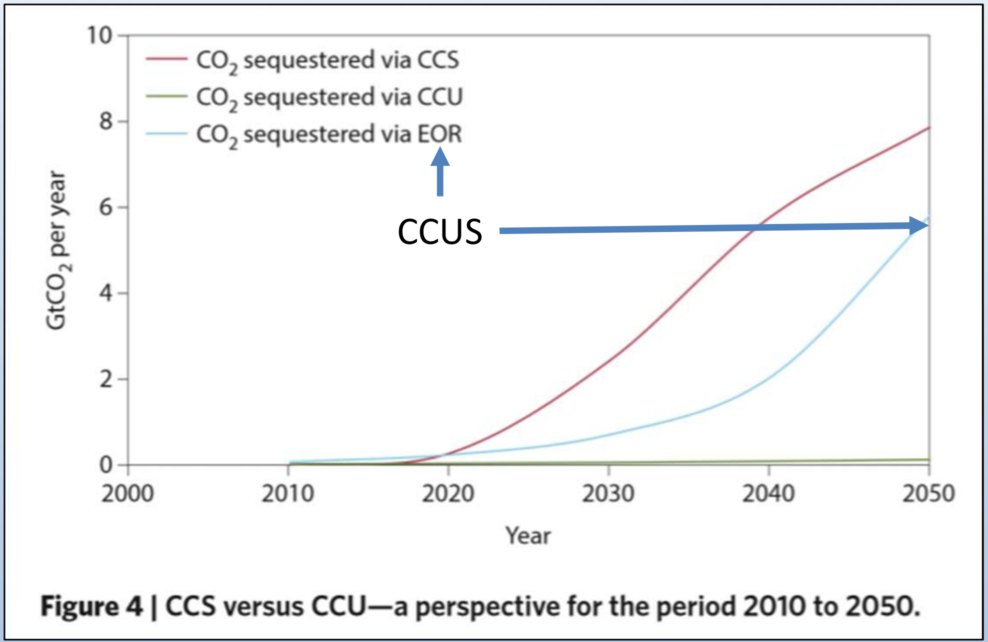
*Amended Chart Weighing the Various Parameters for EOR* (Gozalpour, Ren, & Tohidi, 2005)

- All types of reservoirs (siliclastic, carbonate, etc.) are suitable for EOR
- Most of the applications of EOR have been with medium to light gravity oils
- As shown, the API of oil, OIP, pressure and temperature matter more than other geologic parameters though permeability is important and imperative
- Miscible (where $CO_2$ mixes with oil) is preferred as that better facilitates production

# CCUS– Where Are We Today?




*Graph from* (Liu, et al., 2017) *Showing CC(U)S Projects by Country*




*Projections of* $CO_2$ *Sequestration by Method Modified* (Serdoner, 2019)

- Most of the CCUS projects are in the United States and most of those are EOR
- To put the graph on the right in perspective, the world released ~33 gigatons of $CO_2$ in 2019 and ~31.5 gigatons of $CO_2$ in 2020

# CCUS Projects and Operators

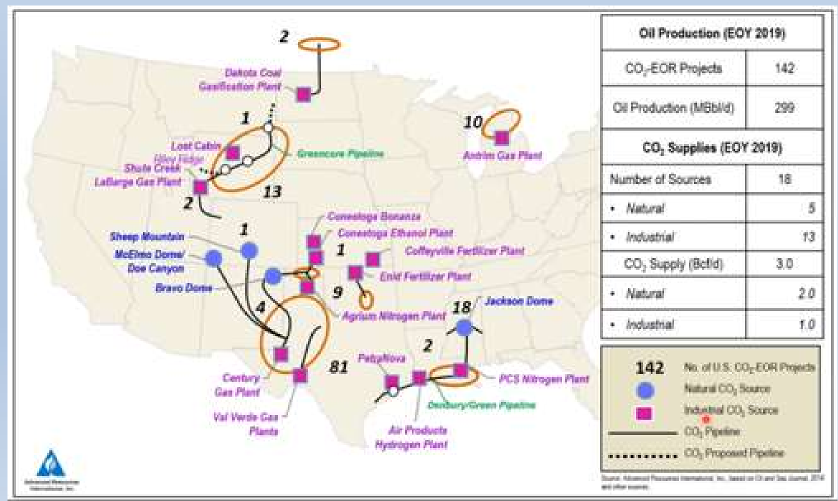
| Region | Projects | Operators |
|---|---|---|
| Permian (TX, NM) | 80 | Apache, Chevron, ConocoPhillips, Fasken, Four Corners Petroleum, George R. Brown, Great Western Drilling, KinderMorgan, Oxy, OrlaPetco, Remnant, Sabinal, Tabula Rasa, XTO |
| Gulf Coast (MS, LA, TX) | 25 | Denbury, Hillcorp, Tellus, TMR Exploration |
| Rockies (WY, UT, MT, CO) | 17 | Amplify Energy, Chevron, Denbury, Devon, Elk Petroleum, Fleur De Lis |
| Mid Continent (OK, KS) | 10 | Daylight Petroleum, Maverick Energy, Perdure Petroleum, PetroSantander |
| Mid West (MI) | 10 | Core Energy |
| Total | 142 | |

*Table of CCUS Projects by Region and Operator (CCUS)*

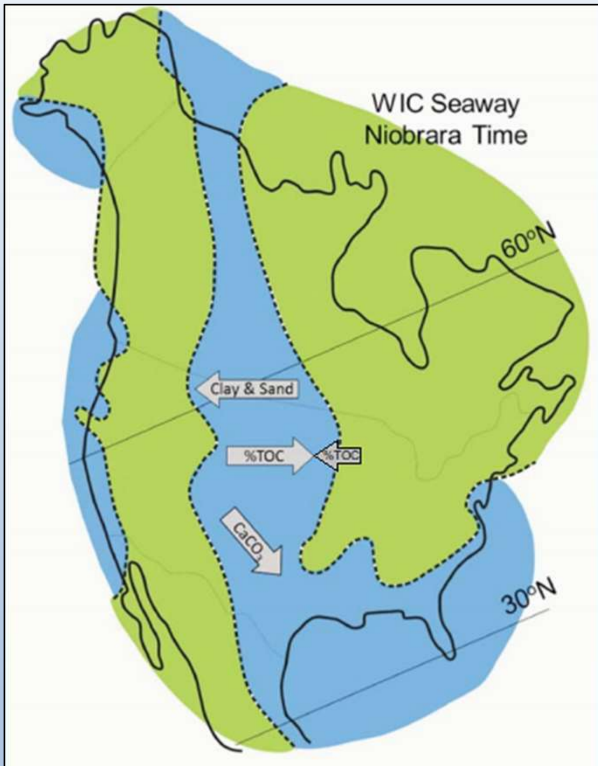
| Region | Updated U.S. $CO_2$ EOR Survey (EOY 2019) | | |
|---|---|---|---|
| | No. Projects | Enhanced Recovery* (MB/D) | $CO_2$ Supply (MMcf/D) |
| Permian Basin (W TX, NM) | 80 | 204.4 | 1,830 |
| Gulf Coast (MS, LA, E TX) | 25 | 43.3 | 600 |
| Rockies (CO, WY, MT, UT) | 17 | 38.8 | 445 |
| Mid Continent (OK) | 10 | 11.3 | 135 |
| Mid West (MI) | 10 | 1.4 | 20 |
| Total | 142 | 299.3 | 3,030 |

*Table of CCUS Projects by Enhanced Recovery and $CO_2$ Supply (CCUS)*

**The Status of U.S. $CO_2$ EOR (EOY 2019)**

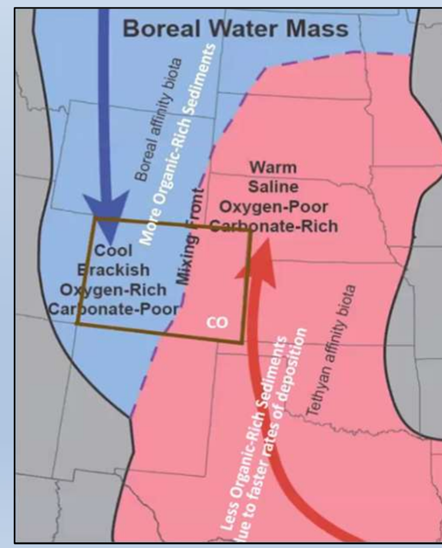


# Brief Niobrara Background



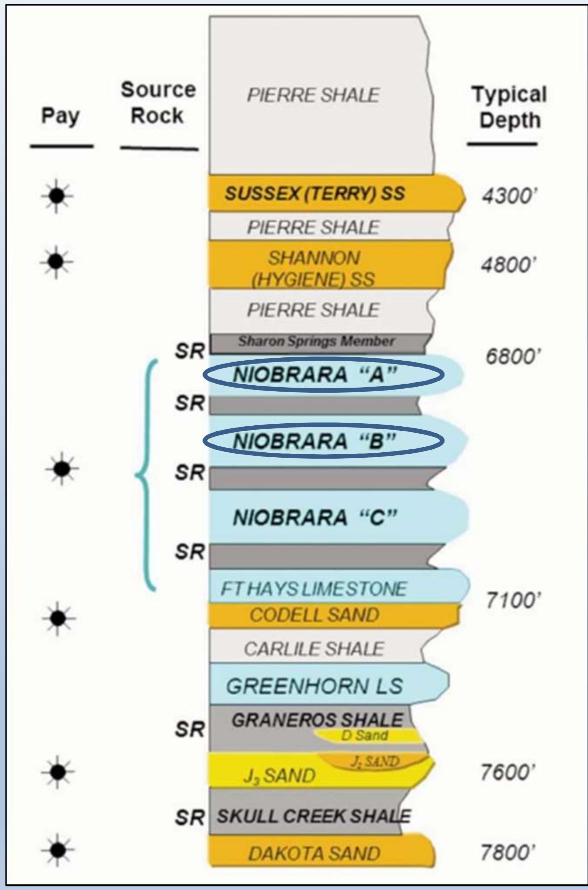

*Schematic of the Western Interior Cretaceous Basin during the Niobrara time modified from* (Longman, Luneau, & Landon, 1998)

- Increasing TOC% to the east to a certain extent though we now know TOC% extending into Kansas and Nebraska is not as high as once thought
- Asymmetric, with the thickest part of WIC (Western Interior Cretaceous) Basin along the Western Margin
- Cooler, nutrient rich, carbonate poor arctic water from the north mixed with warmer, oxygen poor, carbonate rich chalk-rich water from the Gulf of Mexico

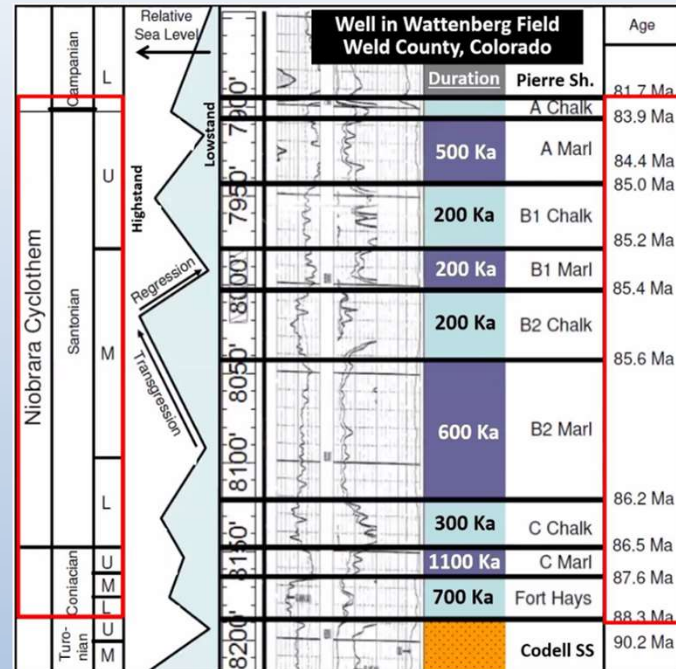



*Schematic of the Western Interior Cretaceous Basin water mixture during the Niobrara time* (Lowery et al. 2017)

# Niobrara Stratigraphic Column




*Stratigraphic column for the Niobrara specifically for the Wattenberg Area* (Sonnenberg, 2011)



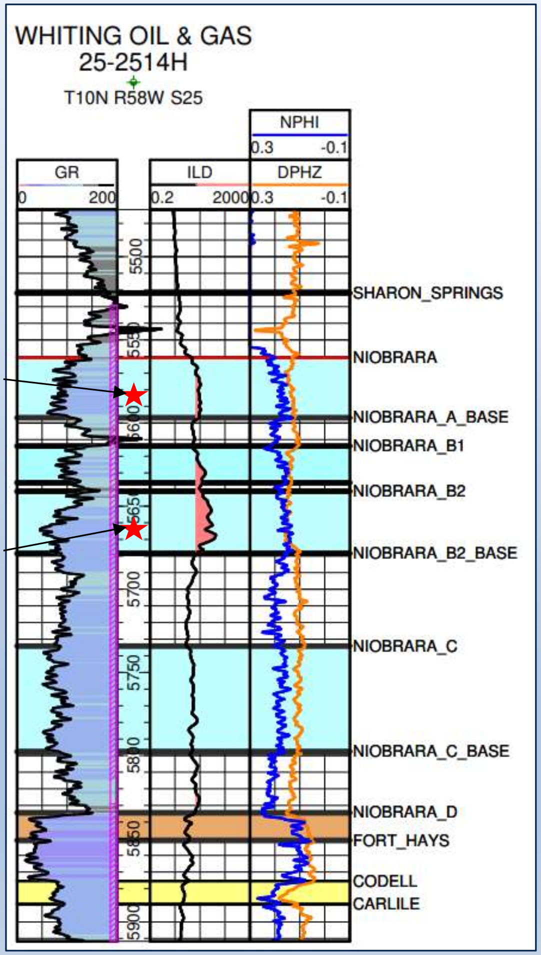

*Stratigraphic column for the Niobrara showing relative sea level, duration of deposit, and age of deposit.* (Longman & Luneau, 2020)

- Warmer gulfian currents dominated the B Chalk through a strong transgression as shown
- In the B2 Marl, we see a large amount of deposition in a relatively short period of time

# Petrophysical Properties Overview

4 Niobrara A Core Plugs

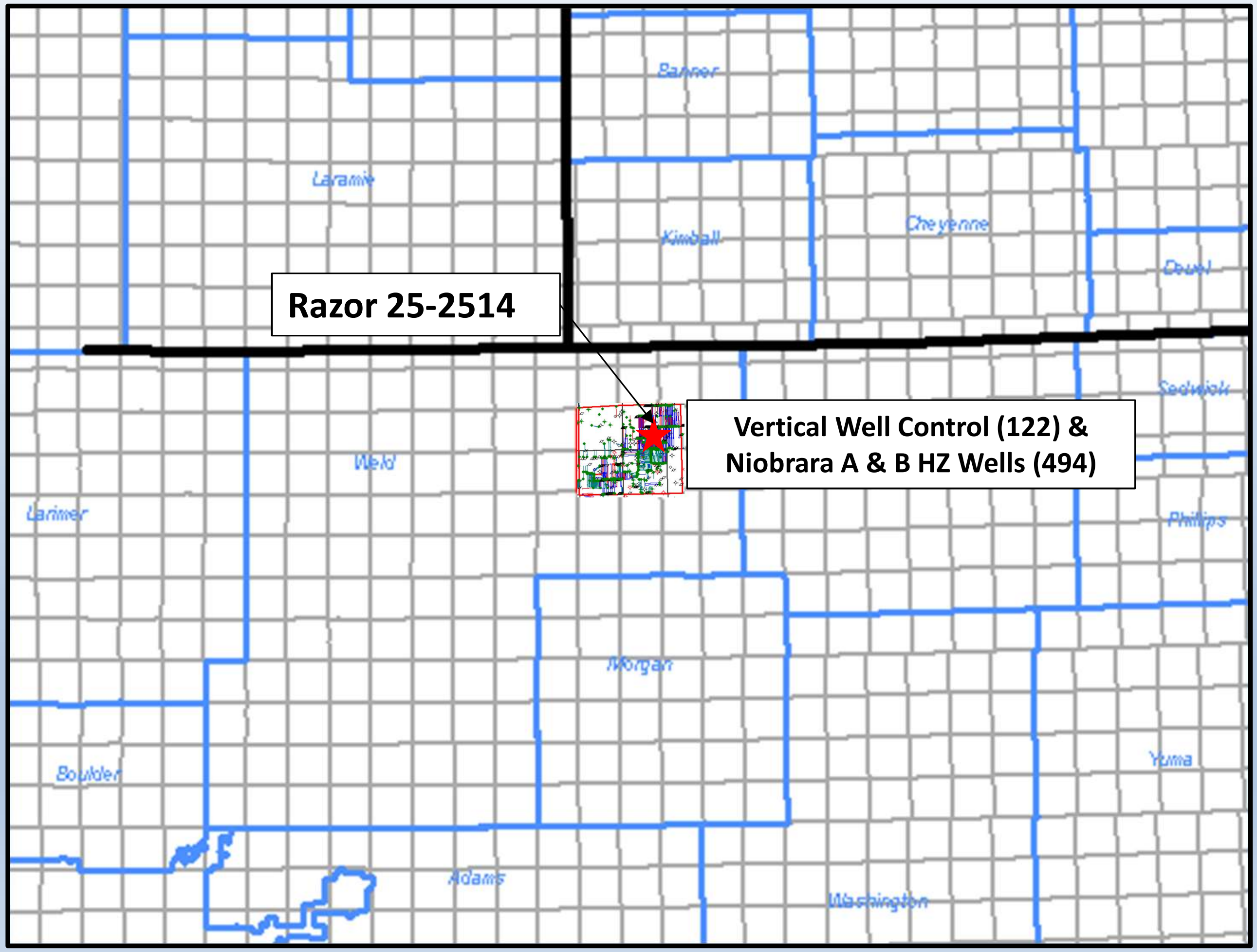
5 Niobrara B Core Plugs




*Petrophysical Overview for the Razor 25-2514H*

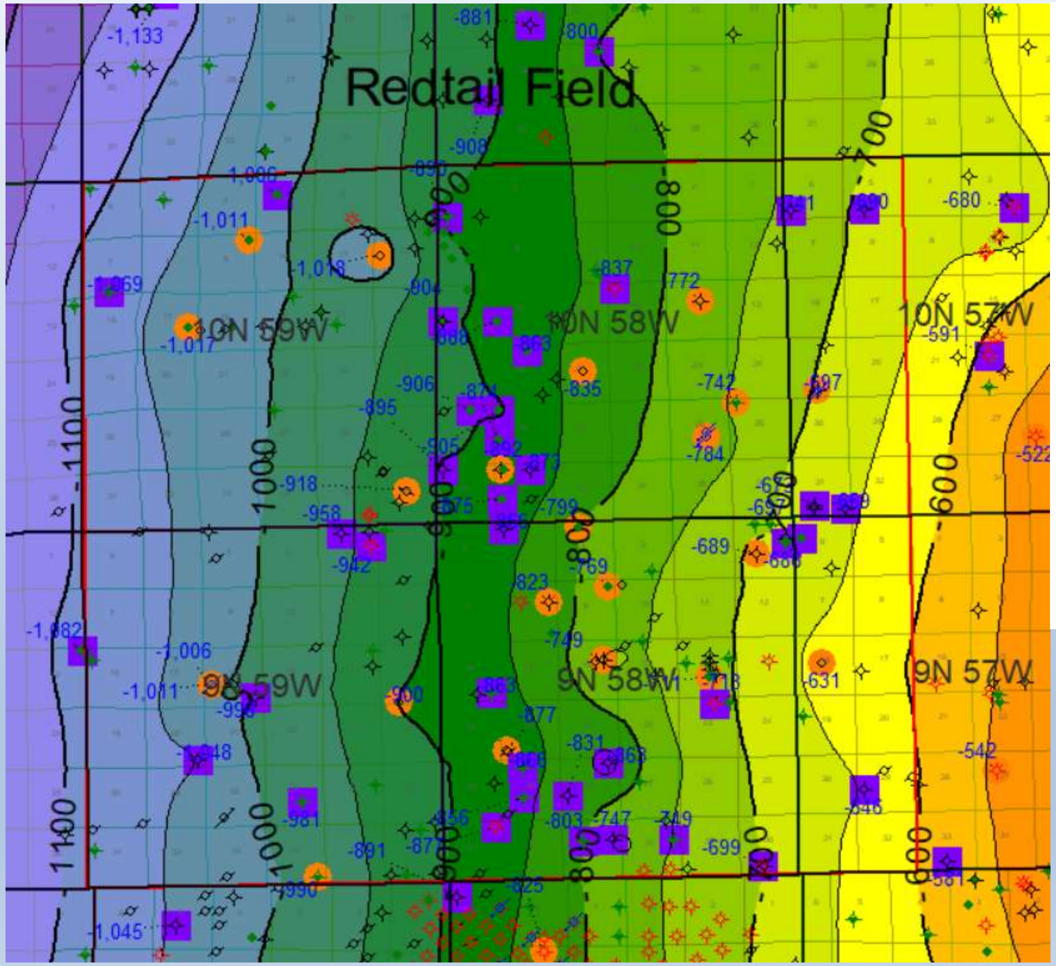
- Most favorable petrophysical properties are over the Niobrara A and B (particularly the B2) with increased resistivity and porosity
- Niobrara C and Codell are targeted in certain parts of the Redtail Field as well
- Resistivity shaded at 15 ohms

# Redtail Field Study Area



# Sharon Springs Structure Map

Low



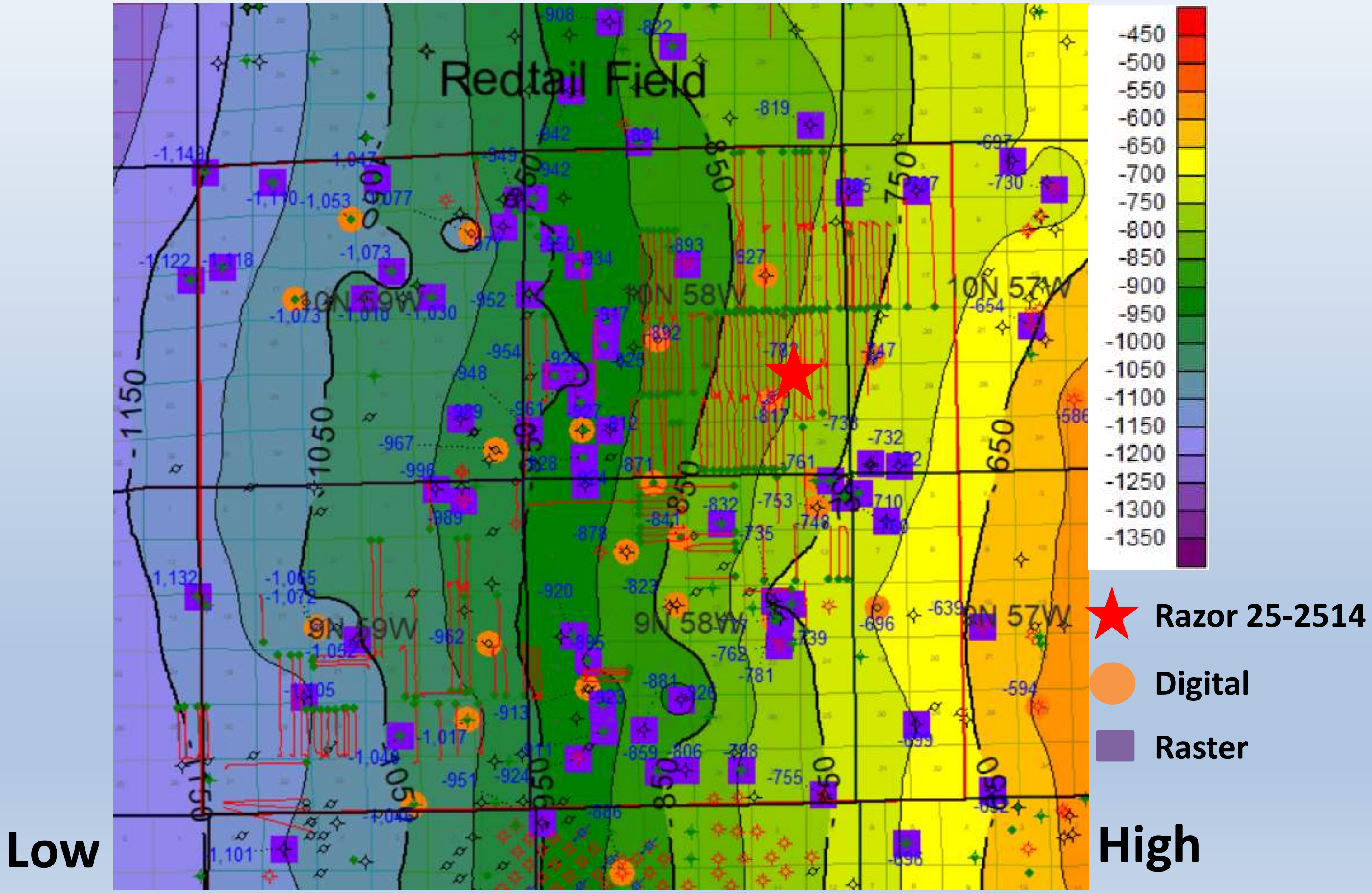

-400
-450
-500
-550
-600
-650
-700
-750
-800
-850
-900
-950
-1000
-1050
-1100
-1150
-1200
-1250
-1300

- Razor 25-2514
- Digital
- Raster

High

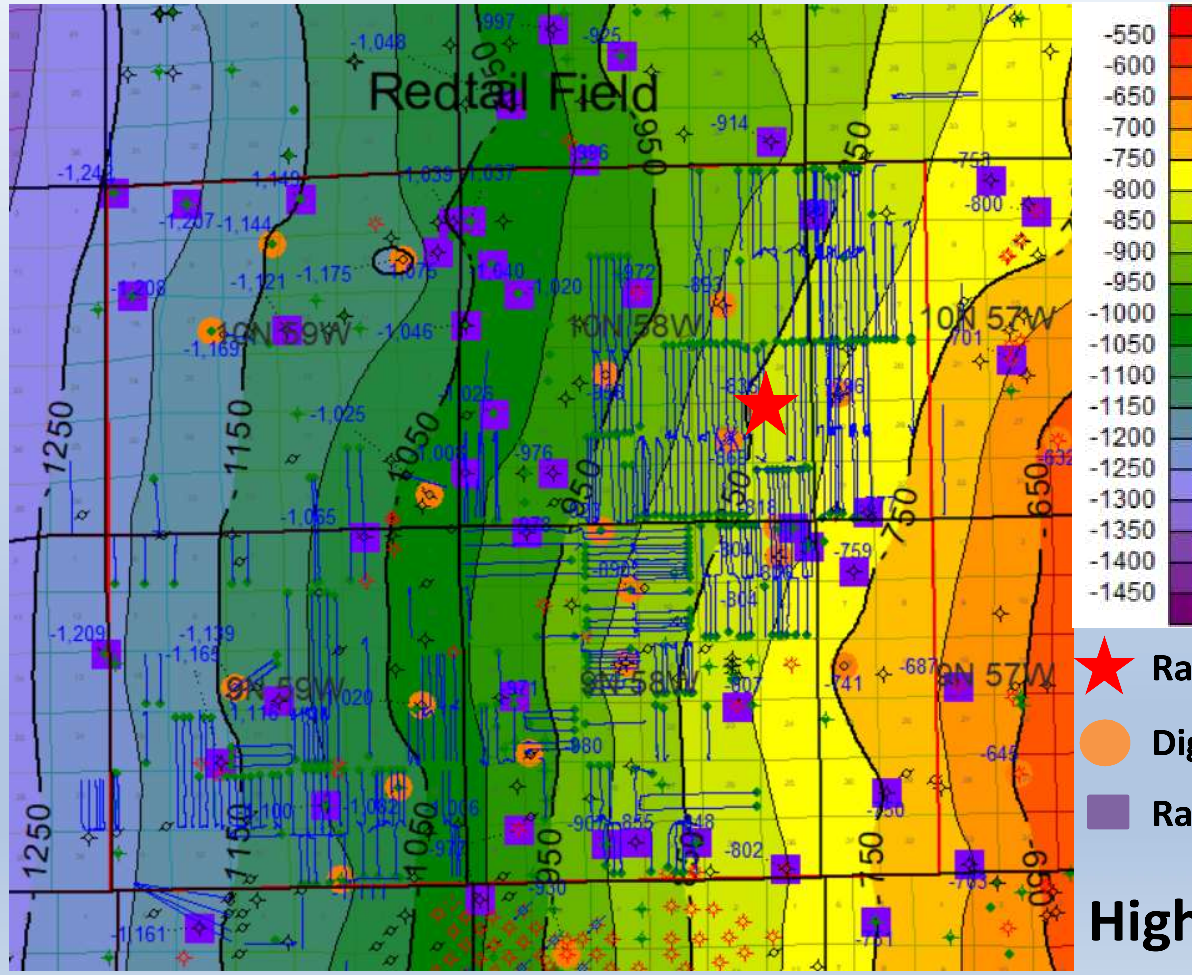
Number of Pick = 93 (37 LAS, 56 Raster)

# Niobrara A Structure Map




Number of Pick = 119 (38 LAS, 81 Raster)

# Niobrara B Structure Map




Razor 25-2514

Digital

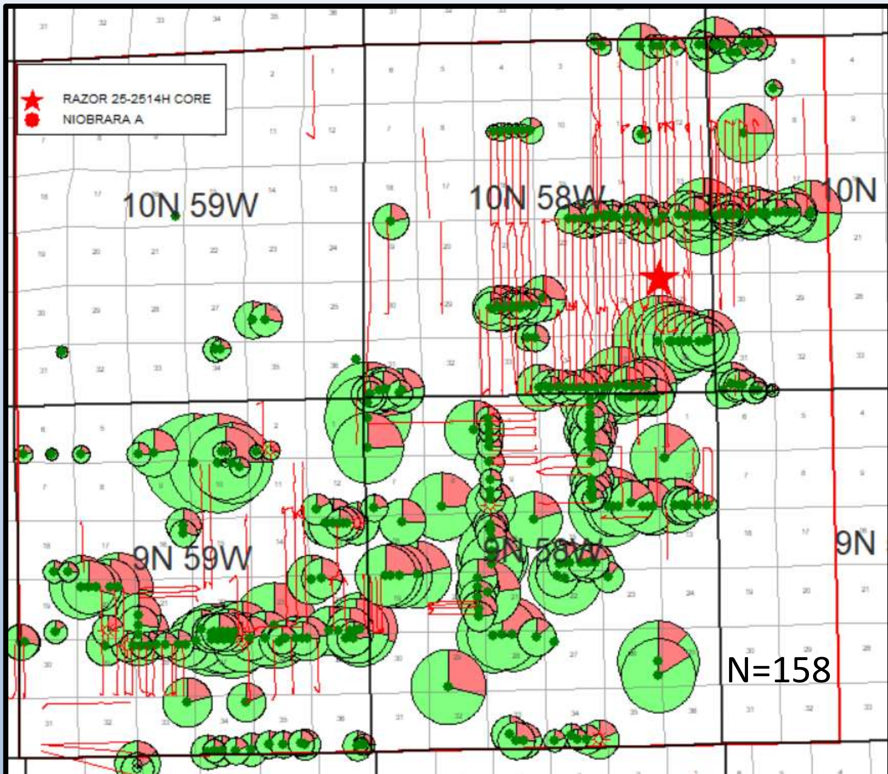
Raster

**Low**

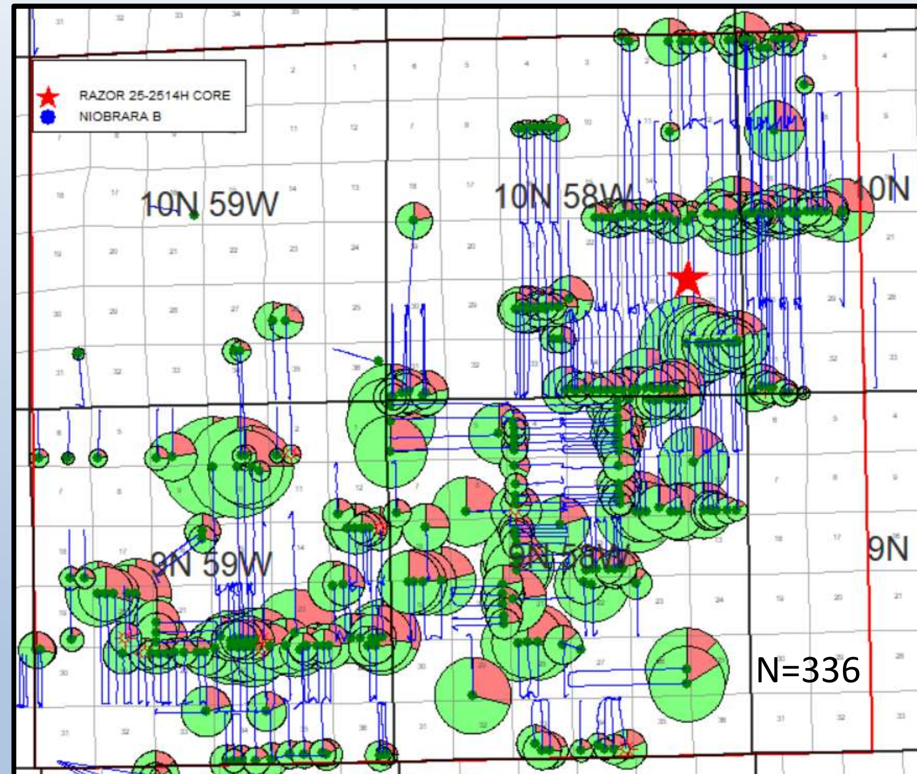
**High**

**Number of Pick = 91 (34 LAS, 57 Raster)**

# Redtail/East Pony Field Production

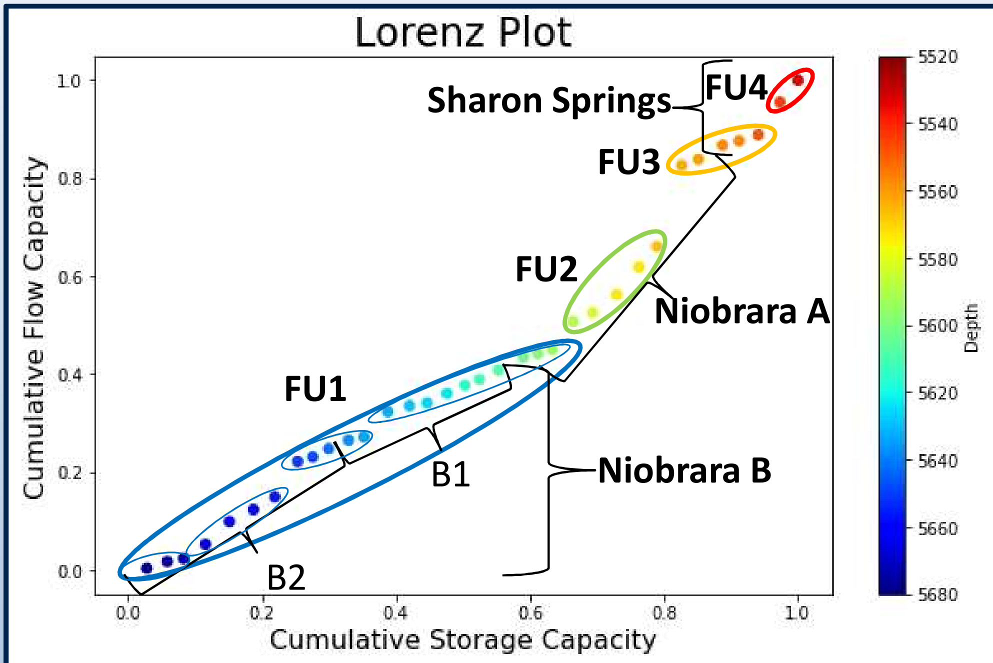


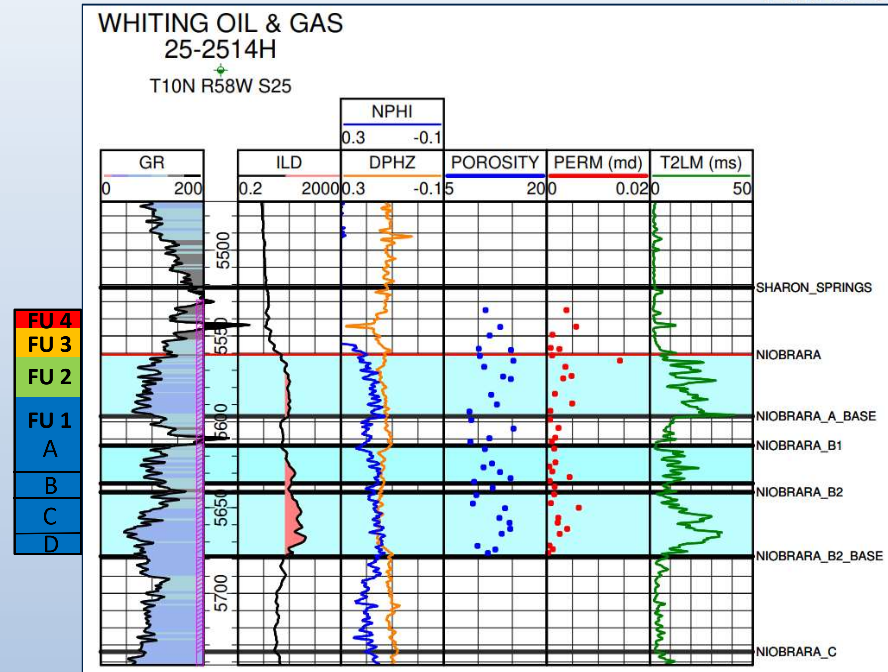

- ~18MM BO Produced
- ~40MM MCF Gas Produced
- **2,296 GOR** (~25% higher than B, C, Codell)




- **~43MM BO Produced** (~2x A, C, Codell)
- **~78MM MCF Produced** (~2x A, C, Codell)
- 1,856 GOR

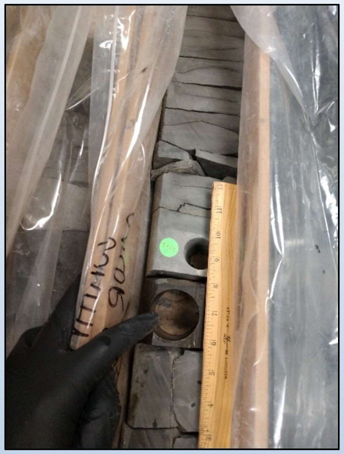
# Flow Units of Razor Over Niobrara A & B

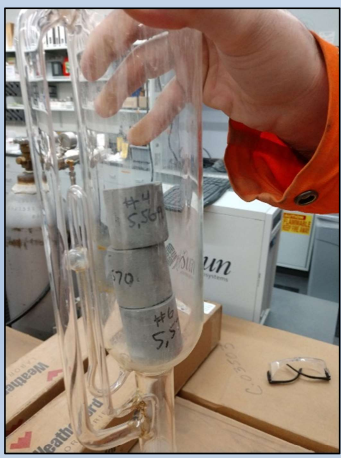



- Flow Unit 1 generally defines the payzone of the Niobrara A and B
- Flow Unit 2 defines the middle to upper hydrocarbon bearing zone of the upper Niobrara A
- Flow Unit 3 defines just above the Niobrara A which is a low permeability to porosity interval
- Flow Unit 4, just 2 data points, is the Sharon Springs above the hot shale marker

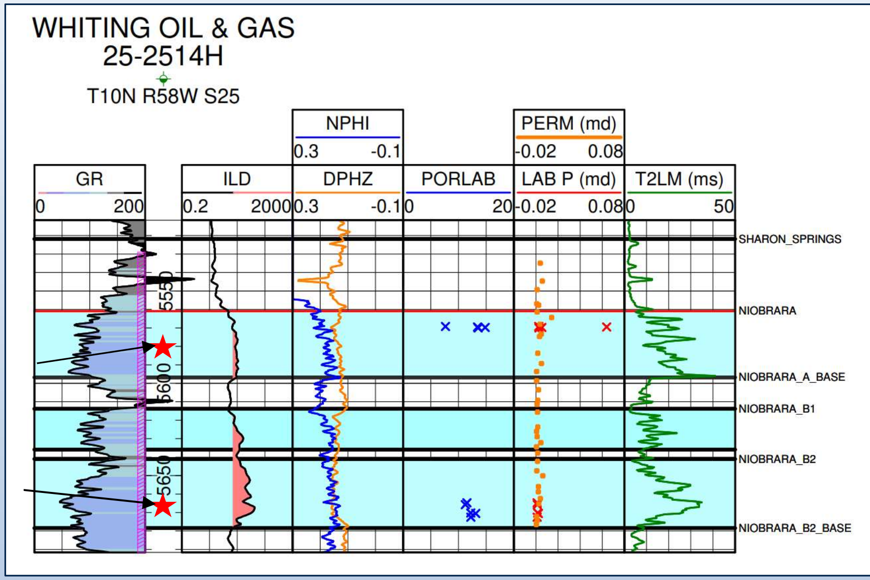
# P&P Data from CMS300 Experiment





4 Niobrara A Core Plugs

5 Niobrara B Core Plugs

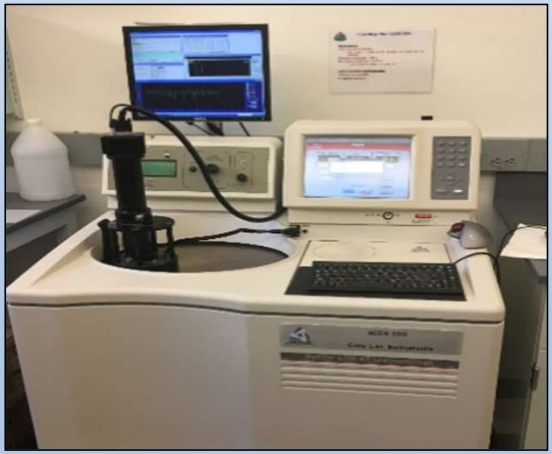



| Sample # | Depth | Porosity | Permeability | Formation |
|---|---|---|---|---|
| 1 | 5569.25 | 7.64 | 0.00256 | Niobrara A |
| 2 | 5569.50 | 13.44 | **0.0639** | Niobrara A |
| 3 | 5569.75 | 14.82 | 0.00544 | Niobrara A |
| 4 | 5570.00 | 13.54 | 0.00261 | Niobrara A |
| 5 | 5664.75 | 11.51 | 0.0011 | Niobrara B |
| 6 | 5665.75 | 11.23 | 0.00116 | Niobrara B |
| 7 | 5670.25 | 12.20 | 0.00149 | Niobrara B |
| 8 | 5670.50 | 13.11 | 0.00214 | Niobrara B |
| 9 | 5672.50 | 12.22 | 0.00112 | Niobrara B |

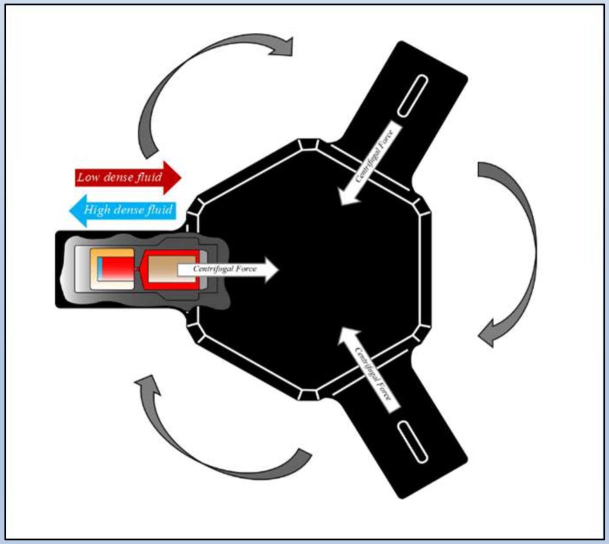
- 9 1.5” diameter, 2” tall core plugs where chemically cleaned for experimentation
- Ran experiment at a confining pressure of 2,000 psi
- Porosity generally ranged from ~11-15% and permeability mostly matched CoreLab data
- Outlier permeability value that is “near” an outlier from CoreLab measurements as well

# Continued Methodology of Lab Work

- Use the Beckman ultra-fast centrifuge (ACES-200) to surround and oil saturated core plug with another type of fluid (such as $CO_2$ or methane) to displace the fluid inside the core observing changes quantitatively and qualitatively
- A high resolution camera and captures the fluid interaction and data is collected looking at changes in oil saturation



*Core Laboratories ACES-200 ultra-high-speed centrifuge (Uzun 2018)*




*Schematic of Centrifuge (Uzun 2018)*

# Continued Methodology of Lab Work

- Chandler's Formation Response Tester (FRT) Model 6100 allows $CO_2$ to be flowed across the core to observe permeability changes
  - Can look at both potential production flow or injection treatments


*Chandler's FRT Model 6100 (Chandler Engineering, 2020)*

# Research Moving Forward

- Continue running aforementioned lab tests (ACES 200 and RT 6100)
- Detailed mapping work in the Redtail field, particularly for resistivity, gross/net thickness, API gravity, OOIP, and porosity to understand the Niobrara A and B
- Examine the Sharon Springs as it's important to mitigate $CO_2$ leakage while considering permeability, thickness, top seal potential, and ductility
- Look at the latest research papers on CCUS ($CO_2$ EOR)
- Tie in lab results to log data to make this process repeatable in lieu of core

# MUDTOC Consortium Sponsors
# Fall 2021

COLORADO SCHOOL OF MINES MUDTOC

## Sponsoring Member Companies

Anschutz Exploration Corporation
Antero Resources
Bonanza Creek
Chevron
Cimarex
Crestone Peak Resources
devon
Enverus
EOG Resources
GMT Exploration Company LLC
OXY
Red Willow Production Company
White Eagle Exploration
Whiting

## In-Kind Supporting Companies

GeoMark
IHS
Mike Johnson & Associates
MJ Logs
PRA Platte River Associates, Inc.
Schlumberger

# References


- Beck, L. (2020). *The US Section 45Q Tax Credit for Carbon Oxide Sequestration.* Global CCS Institute.
- Chandler Engineering. (2020). https://www.chandlereng.com/products/reservoiranalysis/core-flow/formation-damage/model-6100
- Frailey, S. (2021, March 23). Operational Monitoring for Storage Performance. *Illinois Geological Survey.* AAPG.
- Gozalpour, F., Ren, S., & Tohidi, B. (2005). *CO2 EOR and Storage in Oil Reservoirs.* Oil & Gas Science and Technology - Rev. IFP, Vol. 60 (2005), No. 3, pp. 537-546.
- Jarrell, P., Fox, C., Stein, M., & Webb, S. (2002). *Practical aspects of CO2 flooding.* Richardson, Tex., Society of Petroleum Engineers Monograph Series, v. 22, 220 p.
- Koottungal, L. (2012). *2012 Worldwide EOR survey.* Oil and Gas Journal, v. 110, issue 4, April 2.
- Liu, H. J., Were, P., Li, Q., Gou, Y., & Hou, Z. (2017). *Worldwide Status of CCUS Technologies and Their Development and Challenges in China.* Hindawi Geofluids.
- Longman, M. W., Luneau, B. A., & Landon, S. M. (1998). Nature and Distribution of Niobrara Lithologies in the Cretaceous Western Interior Seaway of the Rocky Mountain Region. *The Mountain Geologist, v. 35*, 137-170.
- Longman, M., & Luneau, B. (2020, May 13). Revisiting the Upper Cretaceous Niobrara Petroleum System in the Rocky Mountain Region. Denver, Colorado: RMAG Online Presentation.
- Lowery, C. M., Leckie R. M., Bryant, R., Elderbak, K., Parker, A., Polyak, D. E., Schmidt, M., Snoeyenbos-West, O., Sternizer, E. (2017). *The Later Cretaceous Interior Seaway as a model for oxygenation change in epicontinental restricted basins.* ELSEVIER, Earth-Science Reviews 177, pp. 545-564
- Manwaring, S. (2021). The Reservoir Characteristics and Production of the Niobrara A Interval at Redtail Field: Weld County, Denver Basin, Colorado MS thesis, Colorado School of Mines, Golden, Colorado (May 2021)
- Mcphee, C., Reed, J., and Zubizarreta, I. (2015). Routine Core Analysis. Developments in Petroleum Science Core Analysis: A Best Practice Guide, first edition Chapt. 5, 181-268. Oxford, United Kingdom: Elsevier.
- Serdoner, A. (2019). *Climate Accounts for various CCUS measures.* Bellona Europa.
- Sonnenberg, S. A. (2017, July 24-26). *Keys to Niobrara and Codell Production, East Pony/Redtail Area, Denver Basin, Colorado*. Austin, Texas: Unconventional Resources Technology Conference.
- Total. (2018, January 15). Retrieved from Total - What is CCUS?: https://www.youtube.com/watch?v=HSvWrjviqZM
- University of North Dakota. (2021, March 4). Emerging Opportunities & Marketplace for CO2 Sequestration: University of North Dakota EERC Leading the Way on Carbon Capture, Utilization and Storage. RMAG Presentation.
- Uzun, O. (2018). Determining Osmotic Pressure in Niobrara Chalk and Codell Sandstone Using High-Speed Centrifuge. MS thesis, Colorado School of Mines, Golden, Colorado (December 2018)