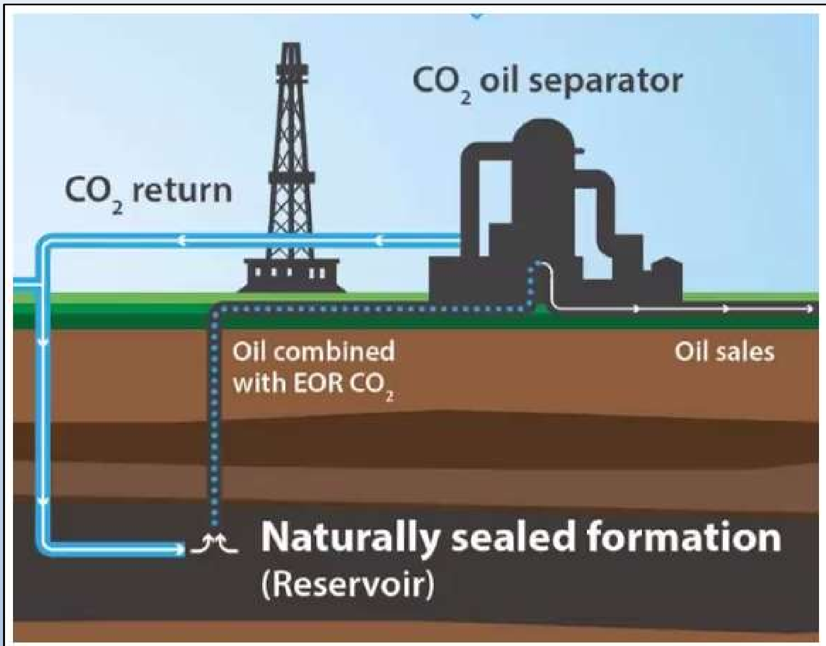
Chris Beliveau, M.S. Geology Candidate, December 2022

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

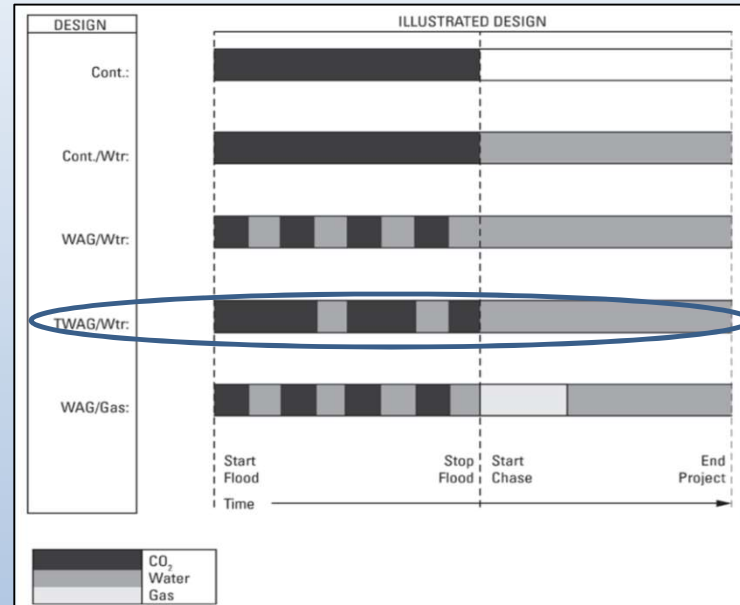
Outline

- CCUS Overview
- Lower Eagle Ford Enhanced Oil Recovery Project as Analog
- Petrophysical Overview of the Niobrara
- Structural Maps
- Study Area and Overview of Redtail Field Production by Bench
- Lab Work and Future Work

Carbon Capture Utilization and Storage (CCUS) Process



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



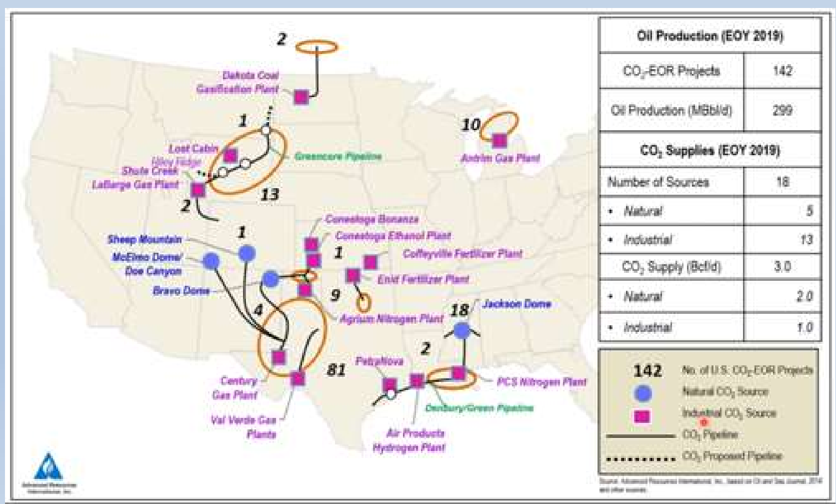
CO_2 *Flood and Injection Designs Schematic (Jarrell et al., 2002)*

- CCUS is the process of capturing carbon dioxide (CO_2), injecting it into reservoirs to enhance oil and gas production, and safely/permanently storing it in the subsurface
- 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

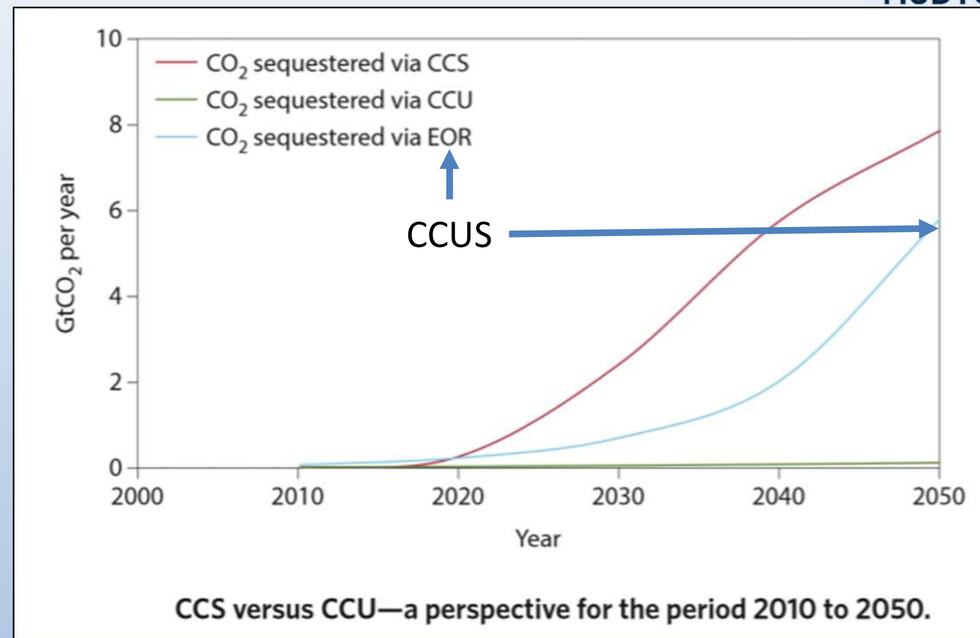
CCUS Projects, Operators, Projections

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 (Advanced Resources International, Inc., 2020)*



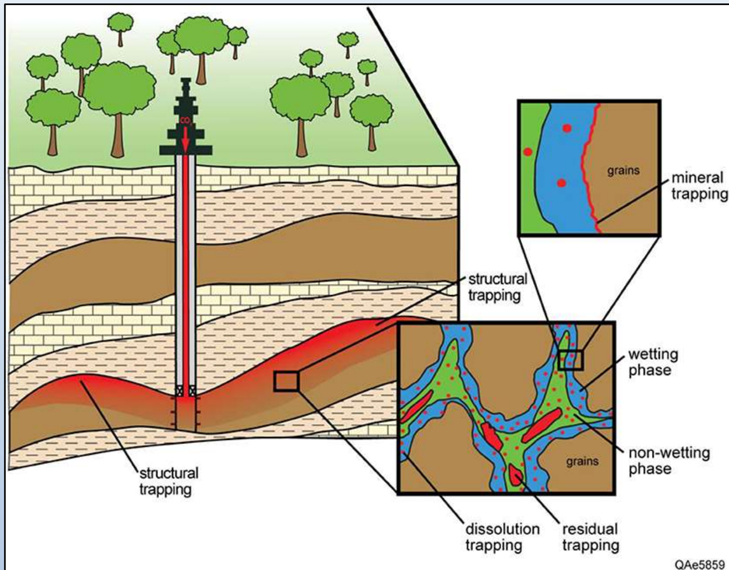
Status of U.S. for CO_2 *EOR Projects EOY 2019 (Advanced Resources International, Inc., 2020)*



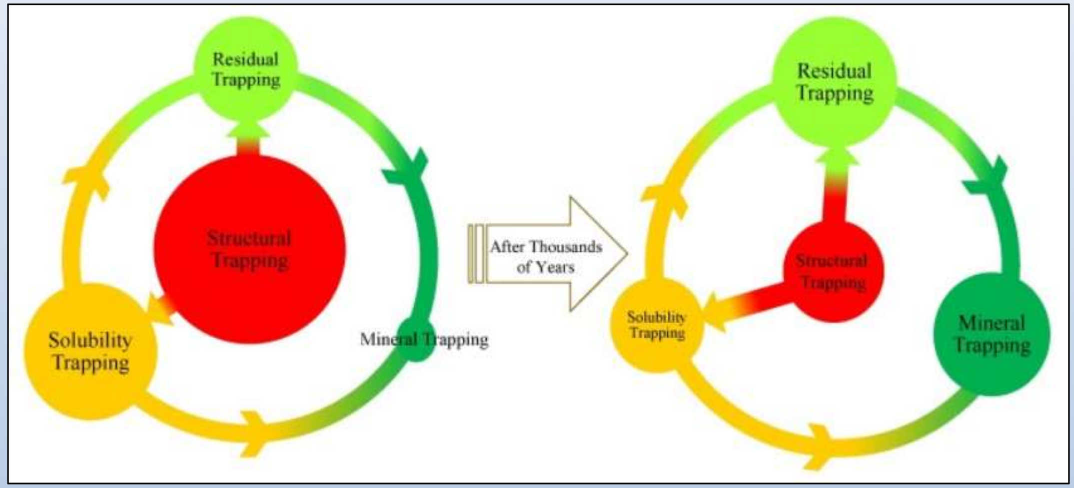
Projections of CO_2 *Sequestration by Method Modified* (Serdoner, 2019)

- The world released ~31.5 gigatons of CO_2 in 2020 and ~33 gigatons of CO_2 in 2021
- Projections show ~6 gigatons per year of CO_2 captured by 2050

CO_2 Trapping Mechanisms



CO2 trapping mechanisms (Hosseininoosheri, Hosseini, Nuñez-López, & and Lake, 2018)



Structural trapping change overtime showing (Hosseininoosheri, Hosseini, Nuñez-López, & and Lake, 2018)

- Four main trapping mechanisms for CO_2: Structural/stratigraphic trapping, Residual/permeability trapping, Dissolution/solubility trapping, and Mineralization trapping
- Stratigraphic trapping represents the highest chance of leakage while mineralization is the safest
- The trapping mechanism for CCUS in the Niobrara should be mostly structural, so understanding fracturing is important

CCUS Geologic Parameters

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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

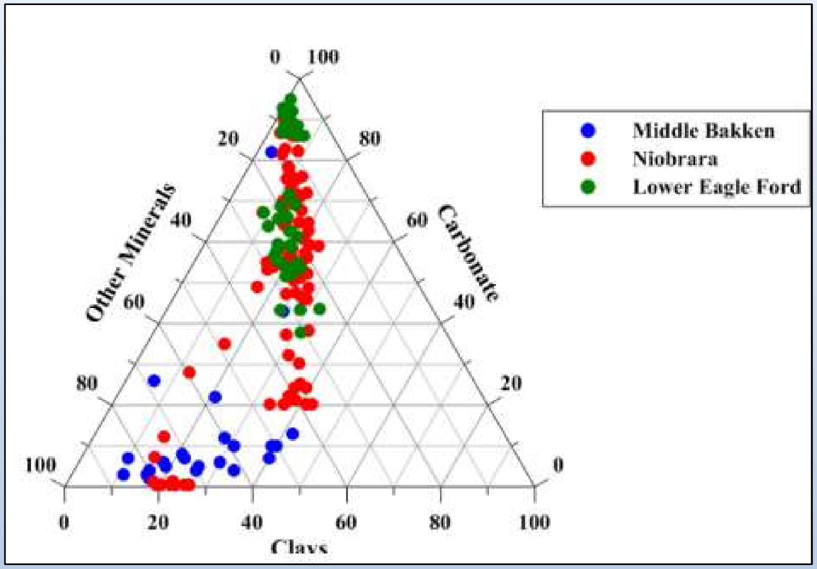
Table Showing EOR Projects Broken into Lithology, Porosity, Permeability, etc. (Koottungal, 2012)

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	35-40	35-40	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

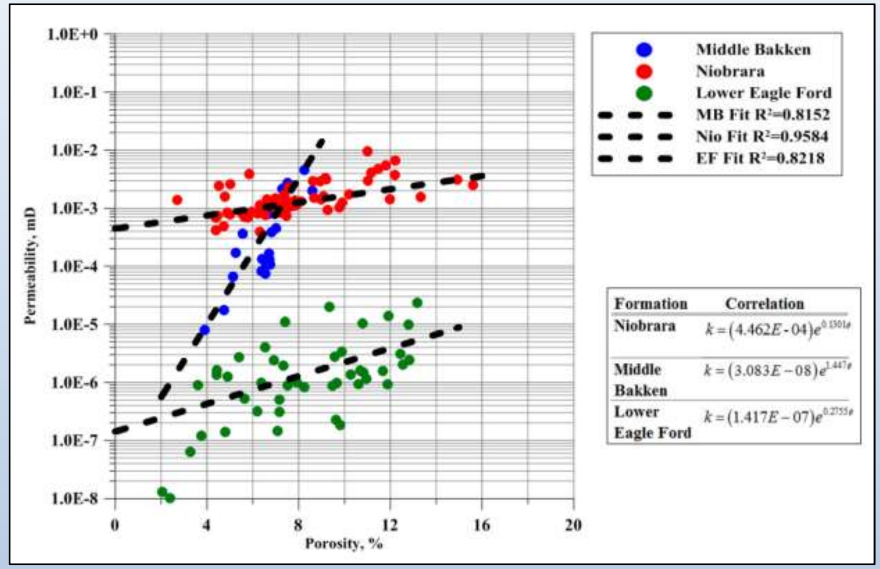
Amended Chart Weighing the Various Parameters for EOR (Gozalpour, Ren, & Tohidi, 2005)

- All types of reservoirs (siliciclastic, 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

Niobrara and Lower Eagle Ford Similarities



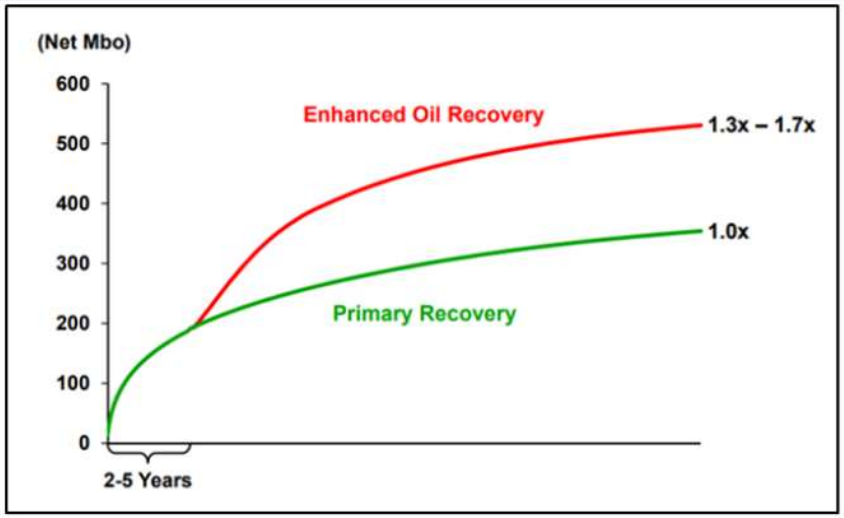
Ternary plot showing comparison of mineralogy from the Niobrara, Lower Eagle Ford, and Middle Bakken (Cho, Eker, Uzun, Yin, & Kazemi, 2016)



Crushed core porosity to permeability relationship from the Niobrara, Lower Eagle Ford, and Middle Bakken (Cho, Eker, Uzun, Yin, & Kazemi, 2016)

- The Lower Eagle Ford has a similar mineralogical composition to the Niobrara
- Mineralogical data from XRD shows similar composition in the Niobrara and Lower Eagle Ford where the dominant clay is illite, and an illite-smectite mixture is frequently found in both
- Lower Eagle Ford has a lower (~2x) permeability compared to the Niobrara, but similar relationship looking at the permeability to porosity relatively

CCUS Lower Eagle Ford Project as Analog



EOG Projected EOR Uplift (EOG Resources, 2016)

Screening Reservoirs for CO2 EOR Suitability	
Depth, ft	2,000 to 9,800
Temperature, °F	>250
Pressure, *psia*	above 1,200
Permeability, *mD*	above 1
Oil gravity, °API	above 27
Viscosity, cp	below 12
S_{or}, fraction of pore space (after waterflood)	>0.25

Reservoir Screening for CCUS Suitability (Rice University, 2019)

- *2016 EOG project in Gonzalez county with 41 wells in development area with 32 wells used for huff-n-puff injection
- Compared to EOG estimation, analysis showed uplift of ~1.36x (American Resource International)
- CCUS projects often use geological screening
- Comparing parameters, the Niobrara A and B GOR is ~1,800-2,300 and API is ~32.0°- 40.0°

Comparison	GOR Range	API°
Eagle Ford Project	~1,000-3,000	~46-52
Niobrara	~1,800-2,300	~35-40
Niobrara Notes	In Range	Below Range

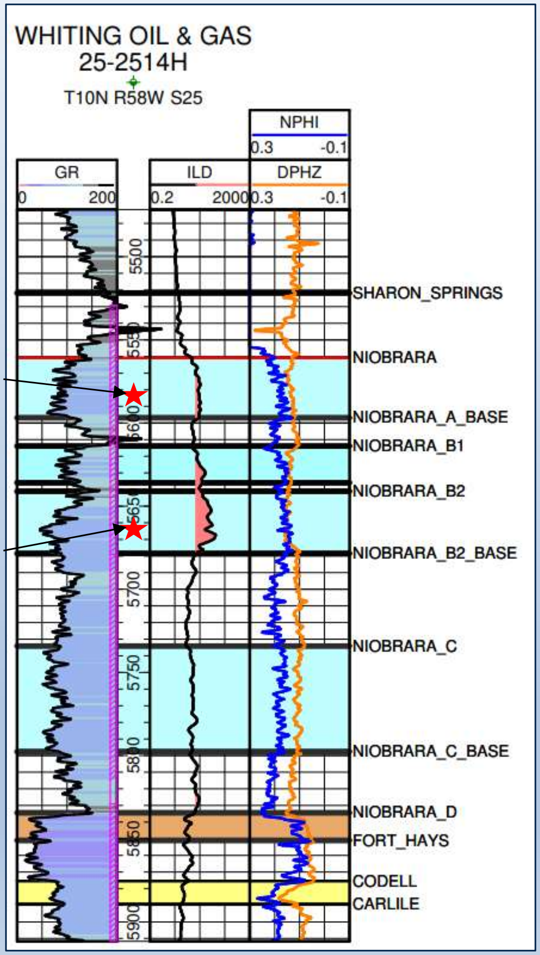
Geologic Data from EOG EOR Eagle Ford Project Compared to the Niobrara (Rice University, 2019)

**Inferred, limited information on study (Hoffman, 2018)*

Petrophysical Properties Overview

4 Niobrara A Core Plugs

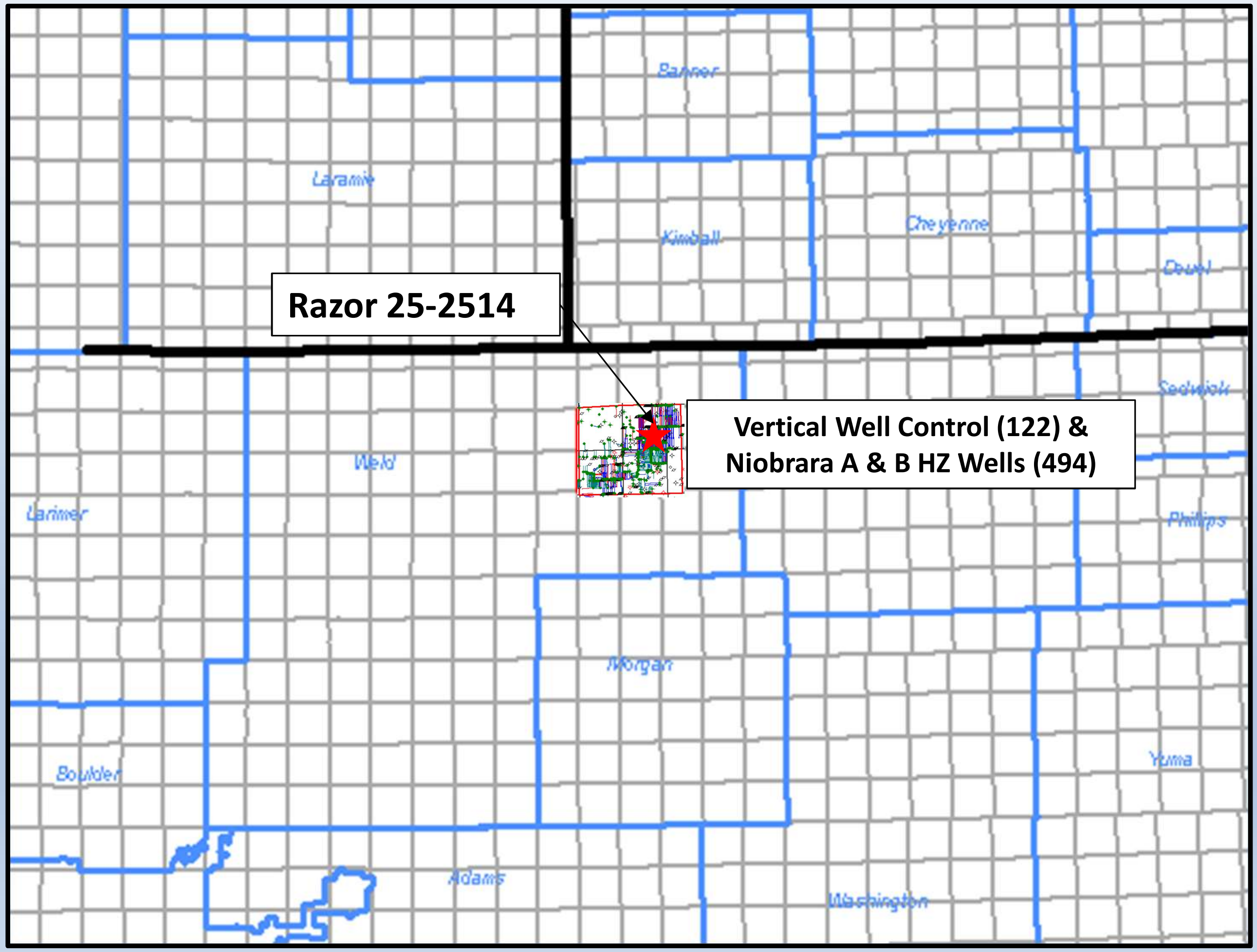
5 Niobrara B Core Plugs



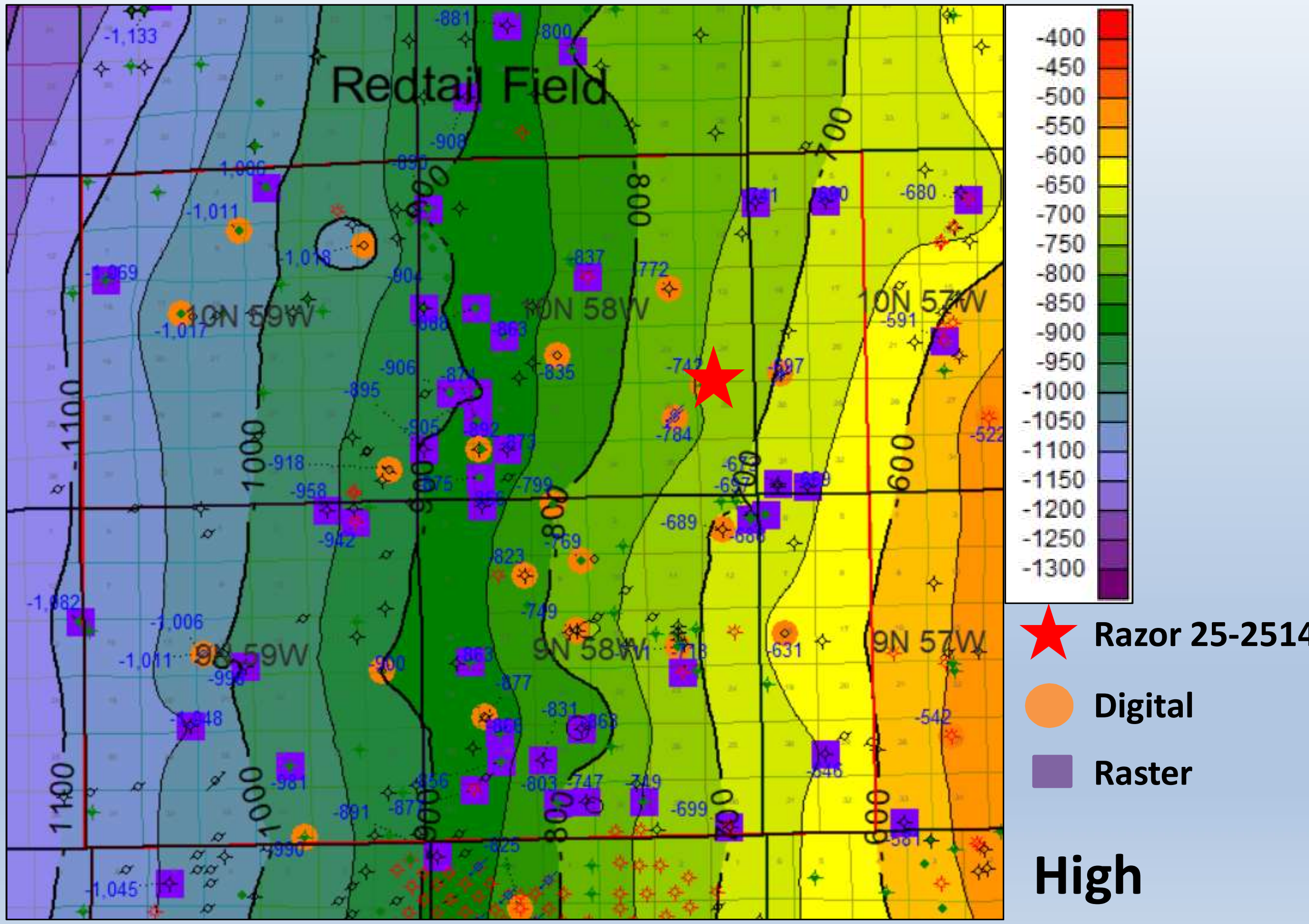
Petrophysical Overview for the Razor 25-2514H

- 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

High

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

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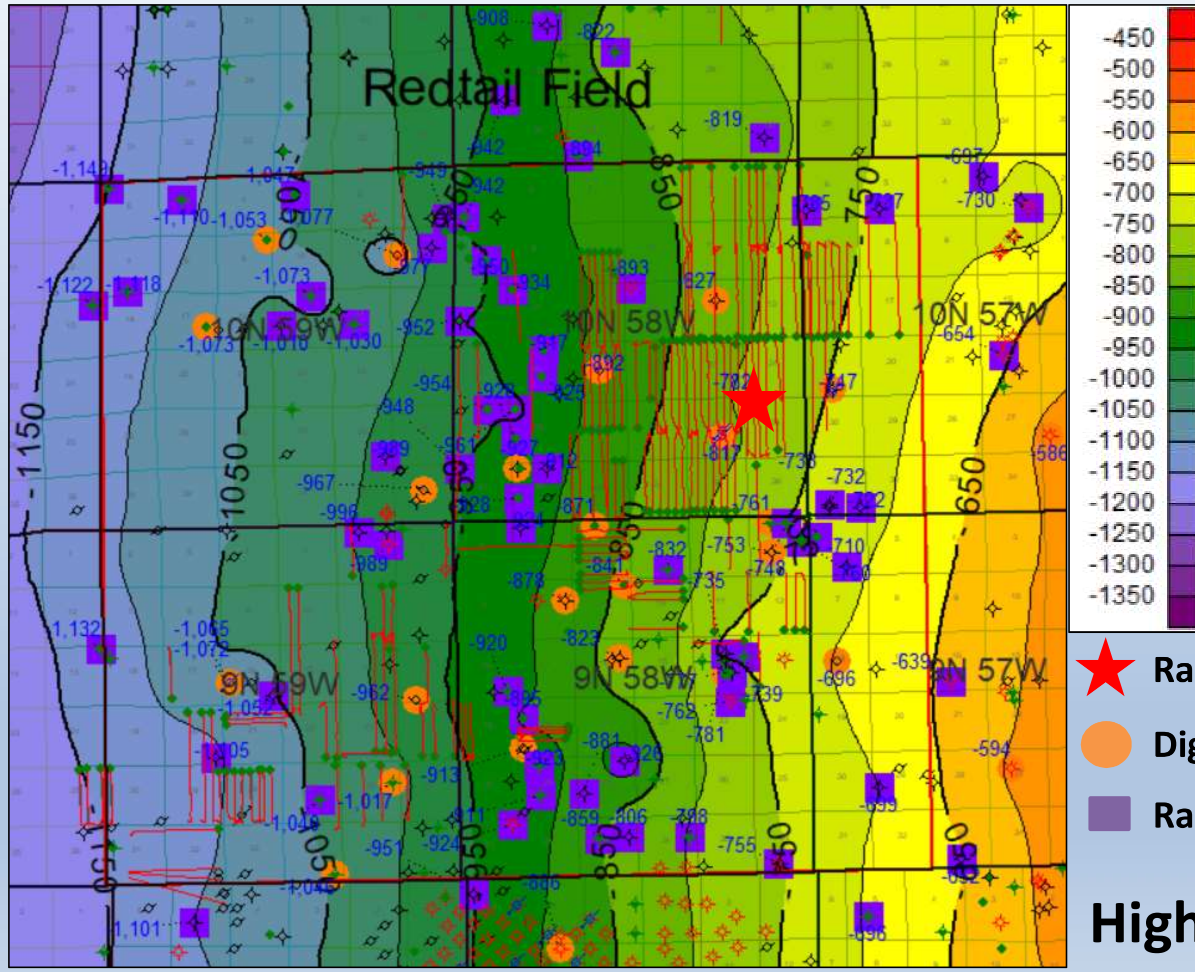
Niobrara A Structure Map



Low

High

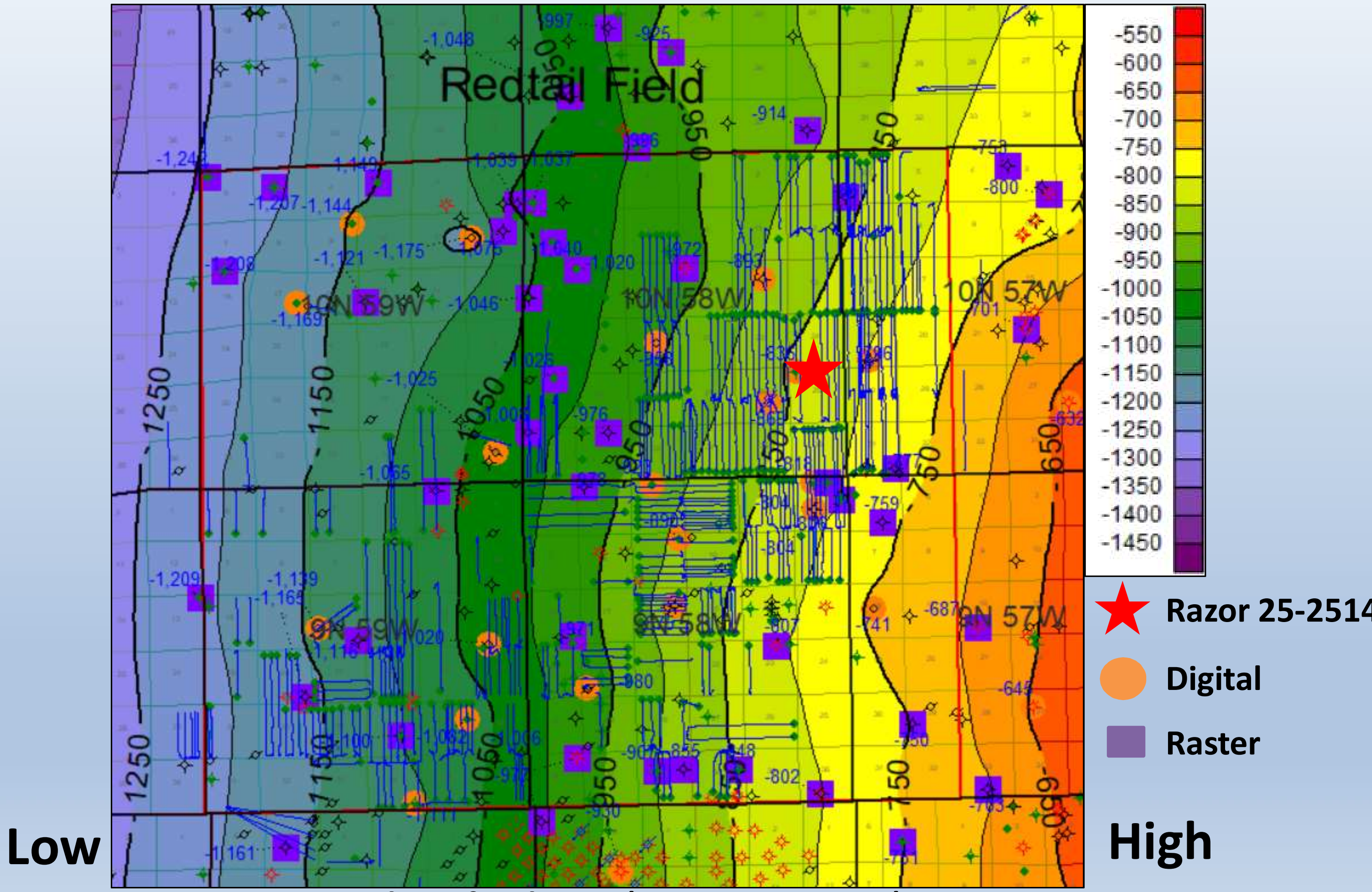
Razor 25-2514

Digital

Raster

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

Niobrara B Structure Map



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

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Redtail/East Pony Field Production

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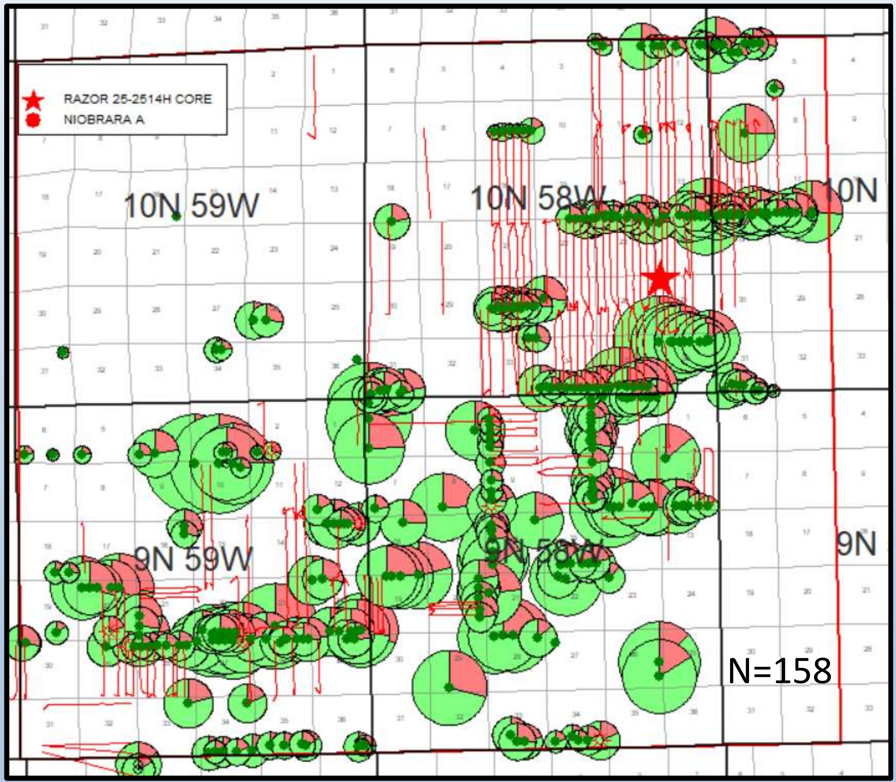
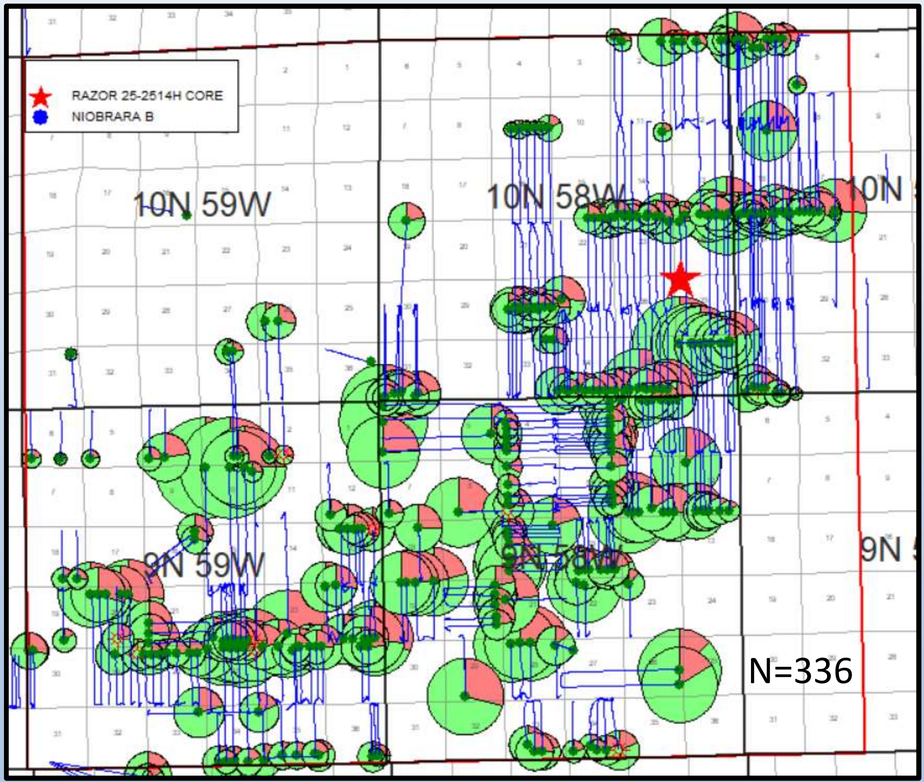
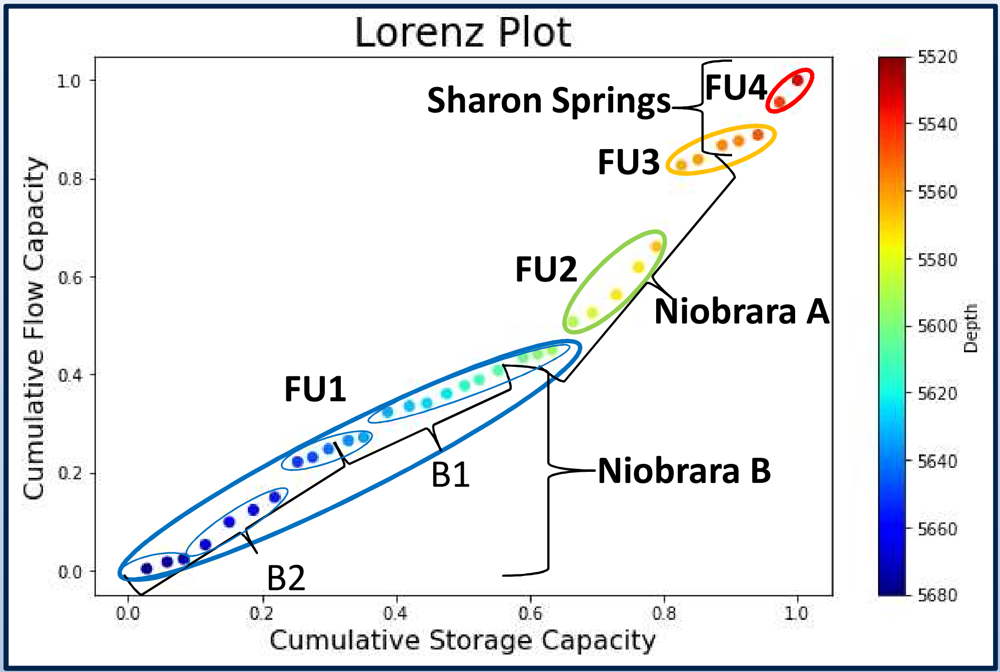


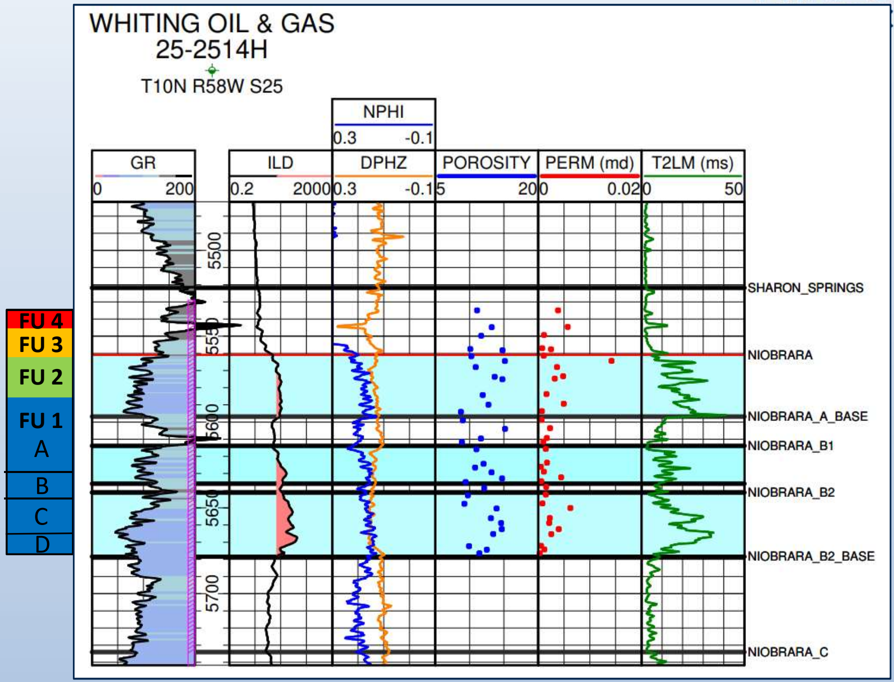
- ~18MM BO Produced
- ~40MM MCF Gas Produced
- **2,296 GOR** (~25% higher than B, C, Codell)



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

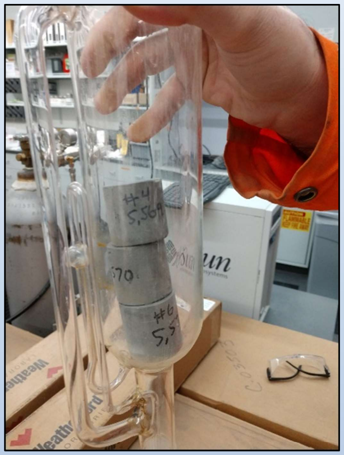
Flow Units of Razor Over Niobrara A & B





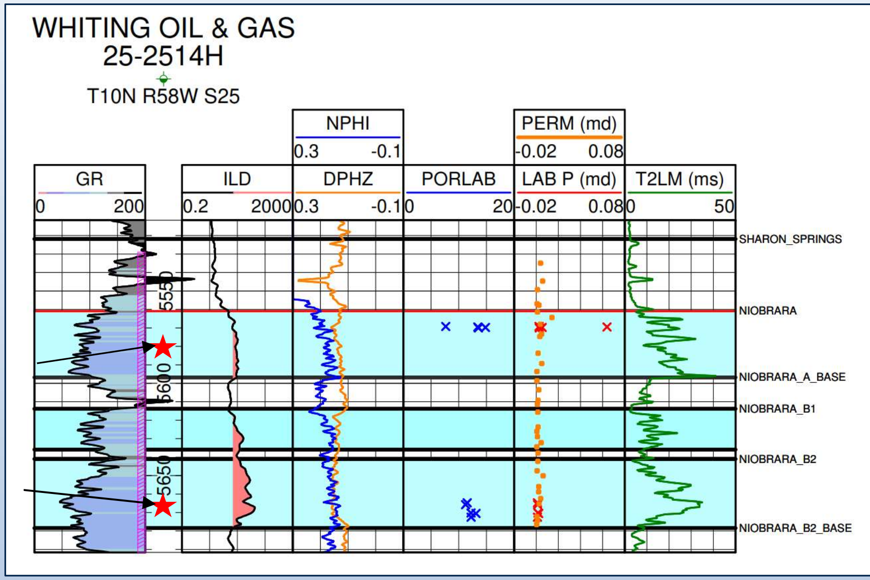
- T2LM curve highly correlated (as expected) with permeability measurements and further defines payzones
- Flow Unit 1 generally defines the payzone of the Niobrara A and B
- Flow Unit 2 defines the middle to upper hydrocarbon bearing zone of the upper Niobrara A
- Flow Unit 3 defines just above the 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 CMS-300 Experiment

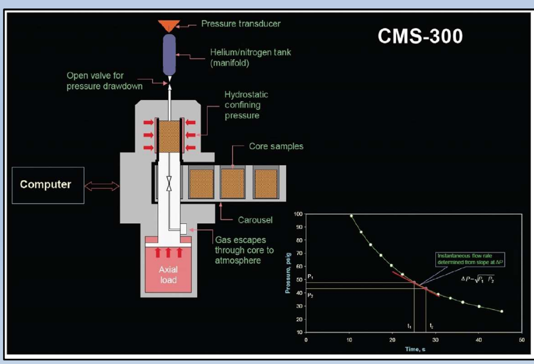


4 Niobrara A Core Plugs

5 Niobrara B Core Plugs



Sample #	Porosity	Permeabity	Formation
1	7.64	0.00256	Niobrara A
2	13.44	**0.0639**	Niobrara A
3	14.82	0.00544	Niobrara A
4	13.54	0.00261	Niobrara A
5	11.51	0.0011	Niobrara B
6	11.23	0.00116	Niobrara B
7	12.2	0.00149	Niobrara B
8	13.11	0.00214	Niobrara B
9	12.22	0.00112	Niobrara B



Core Laboratories CMS-300 Test (Uzun, 2018)

- 9 (~1.5” diameter, ~2” tall) core plugs were chemically cleaned for experiment and analyzed by the CMS-300 at a confining pressure of 2,000 psi
- Porosity ranged from ~11-15% and permeability mostly matched CoreLab data
- Outlier permeability value that is “near” an outlier from CoreLab measurements
- Core plugs used for additional tests (7 for FRT 6100 and 2 for LBNL Core Flood)

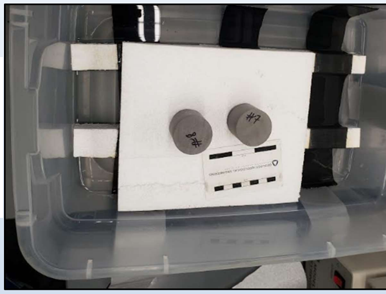
Lab Work: Formation Response Tester 6100

- Chandler's Formation Response Tester (FRT) Model 6100 allows CO_2 to be flowed across N-Dodecane saturated core to simulate flow or injection treatments
- N-Dodecane is a clear/colorless oily hydrocarbon less subject to variable imperfections compared to oil found in formation
- Used to look at reaction to flow where LBNL test is a pressurization-depressurization compression test

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

Lab Work: LBNL Core Flooding System

1. Water Container
2. Weigh



Prepare Cores for Experiment

1. Moisturize cores with water vapor (~2 days)
2. Weigh (lightly water vapor saturated) core samples

Force Saturation of Cores

3. Saturate core with N-Dodecane in reactor container and weigh saturated core

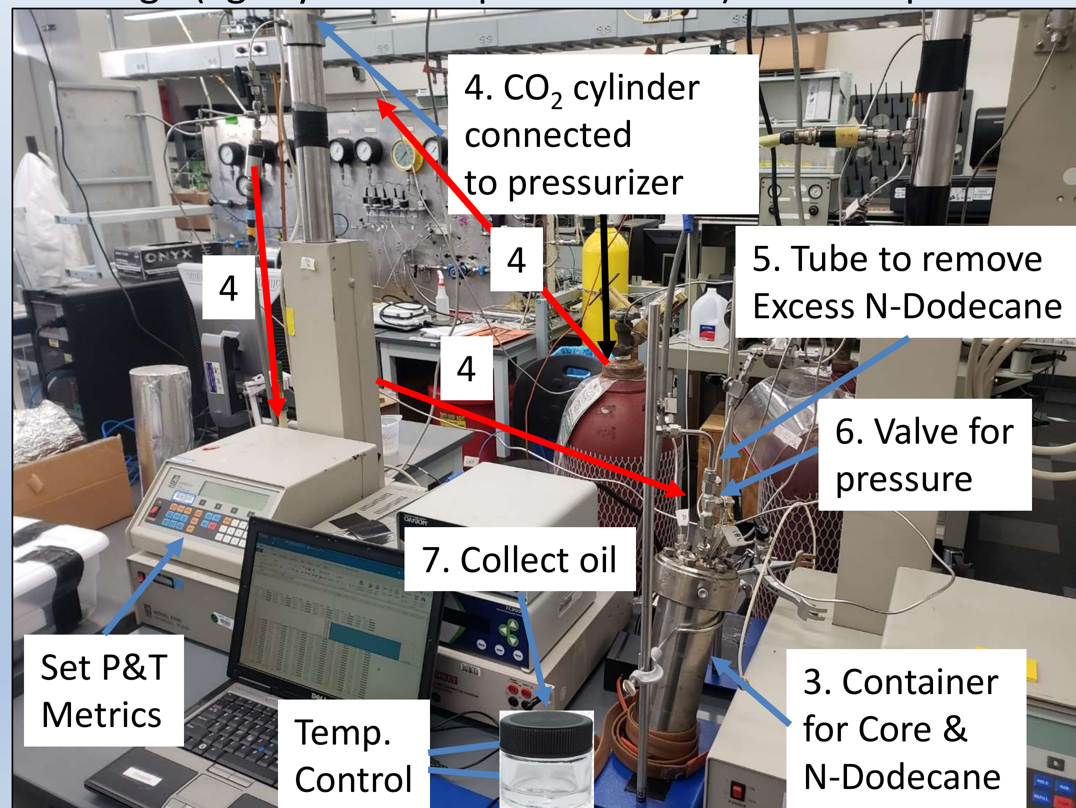
4. Connect to CO_2 cylinder and pressurize to 1,500 PSI at ~150°F (~2-3 weeks)
   -Pressure creates fractures for gas to saturate matrix

5. Remove all excess N-Dodecane

Replicate Production

6. Re-pressurize back to 1,500 PSI and slowly de-pressurize to replicate production (~2 days)

7. Collect expunged N-Dodecane from de-pressurization in container and calculate



Research Moving Forward

- Finish lab work
- 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
- Identify key geologic parameters for CCUS and determine feasibility of CCUS in Redtail Field

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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.
- Rice University. (2019). CCUS Workshop: Opportunities for CO2 EOR in Unconventional Reservoirs.
- 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)