

# Muddy Sandstone EOR (CCUS), Bell Creek Field, Montana

Drew Stump MS 2023



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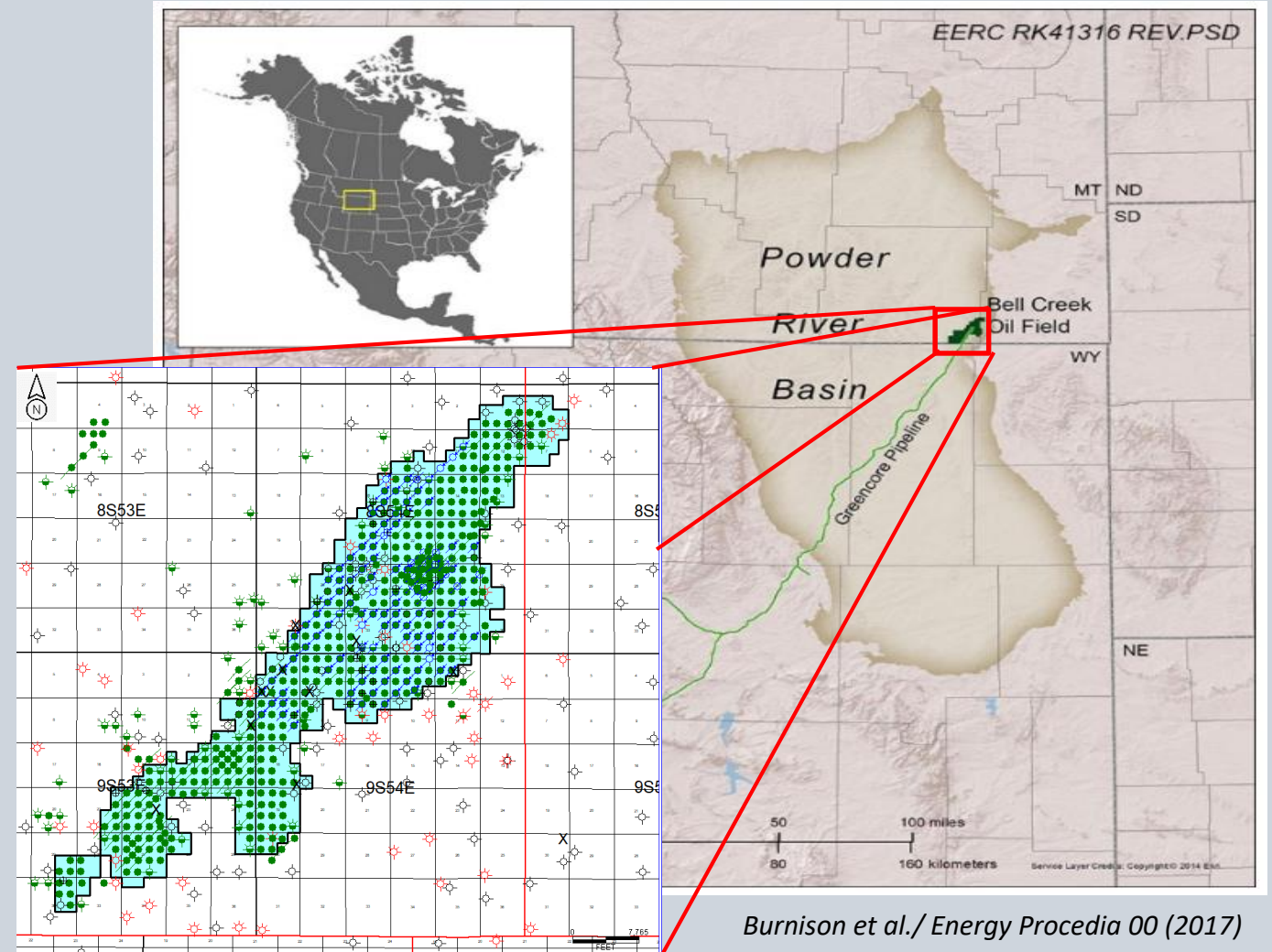
# Outline



1. Introduction
2. Field History
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4. Geologic Overview
5. Muddy Sandstone Log Correlation and Core Descriptions
6. Injection Over Time in the Muddy Sandstone
7. Summary
8. Conclusions
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# Introduction

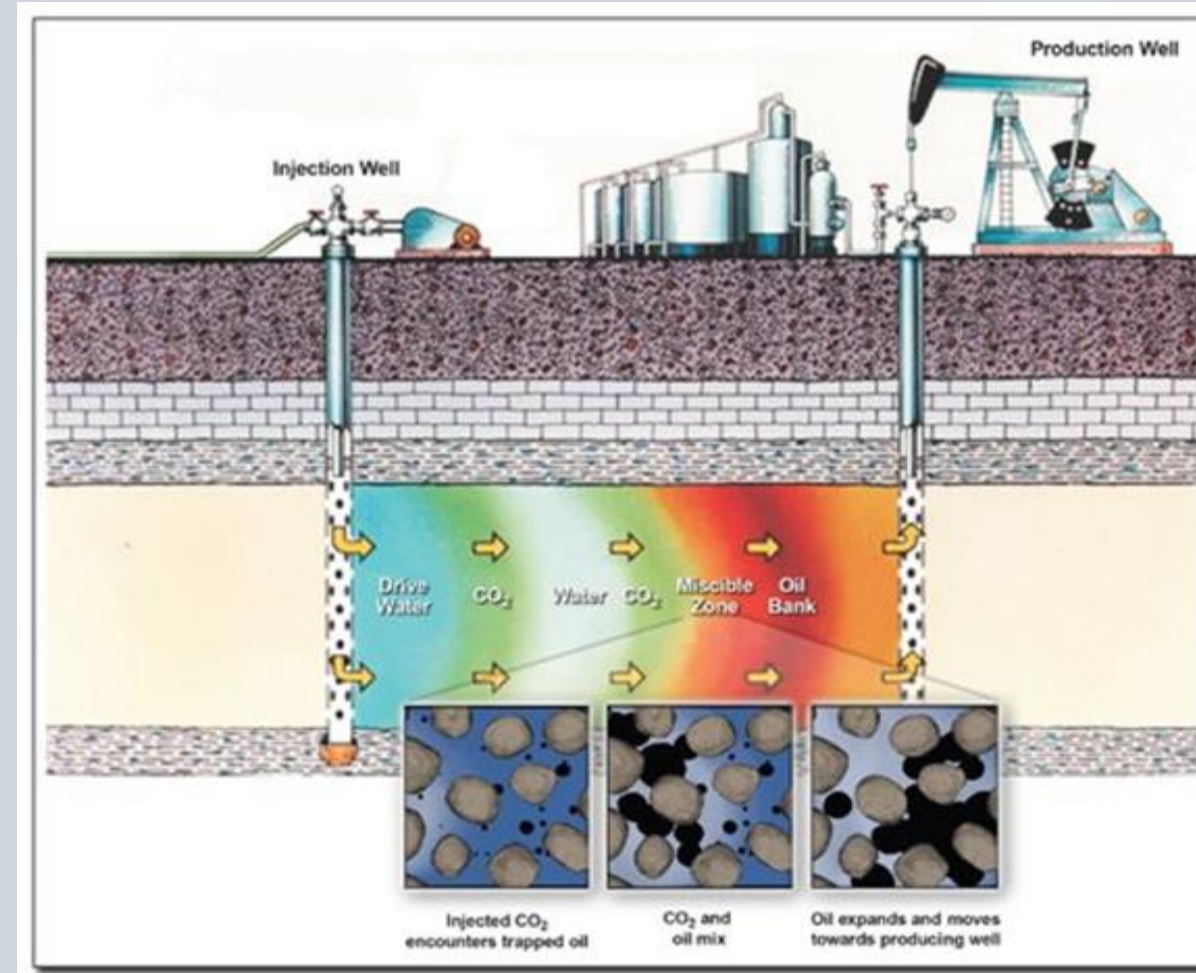
- Location of Bell Creek Field discovered in 1967 in the Powder River Basin, Southwestern Montana
- Major oil and gas field that has gone through waterflooding and currently going through enhanced oil recovery (EOR)
- Field contains over 450 oil wells; Cum Prod 147 MMBO
- Main reservoir formation is the Muddy Sandstone



*Burnison et al./ Energy Procedia 00 (2017)*

# Advantages of EOR

- Two major advantages CO<sub>2</sub> injection
  1. Additional hydrocarbon recovery
  2. Reduction in atmospheric emissions of CO<sub>2</sub> through storage
- Lithologies of every type can be used for CO<sub>2</sub> EOR if they have a seal and interconnected pore space
- Injected into reservoir as continuous gas or water-alternating-gas (WAG)

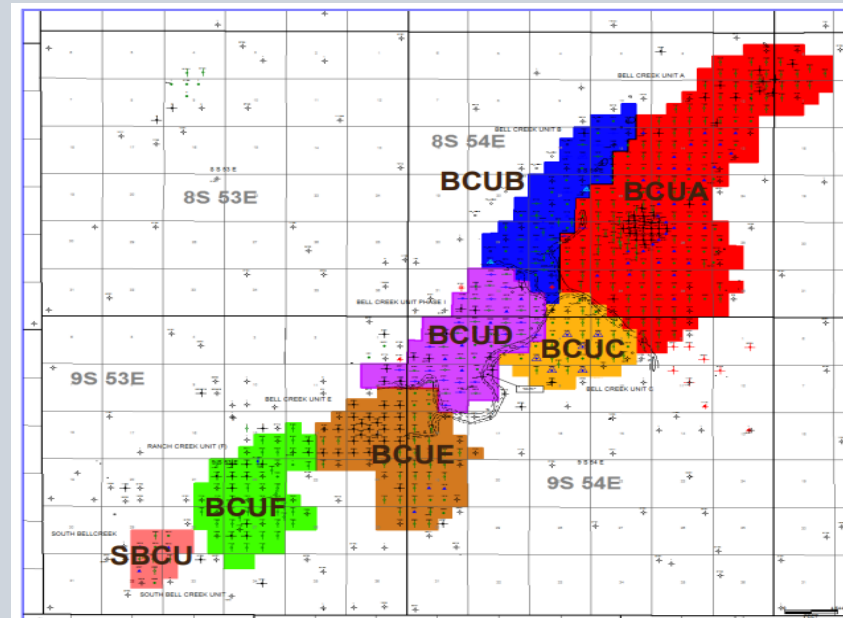


(Venma, 2015)

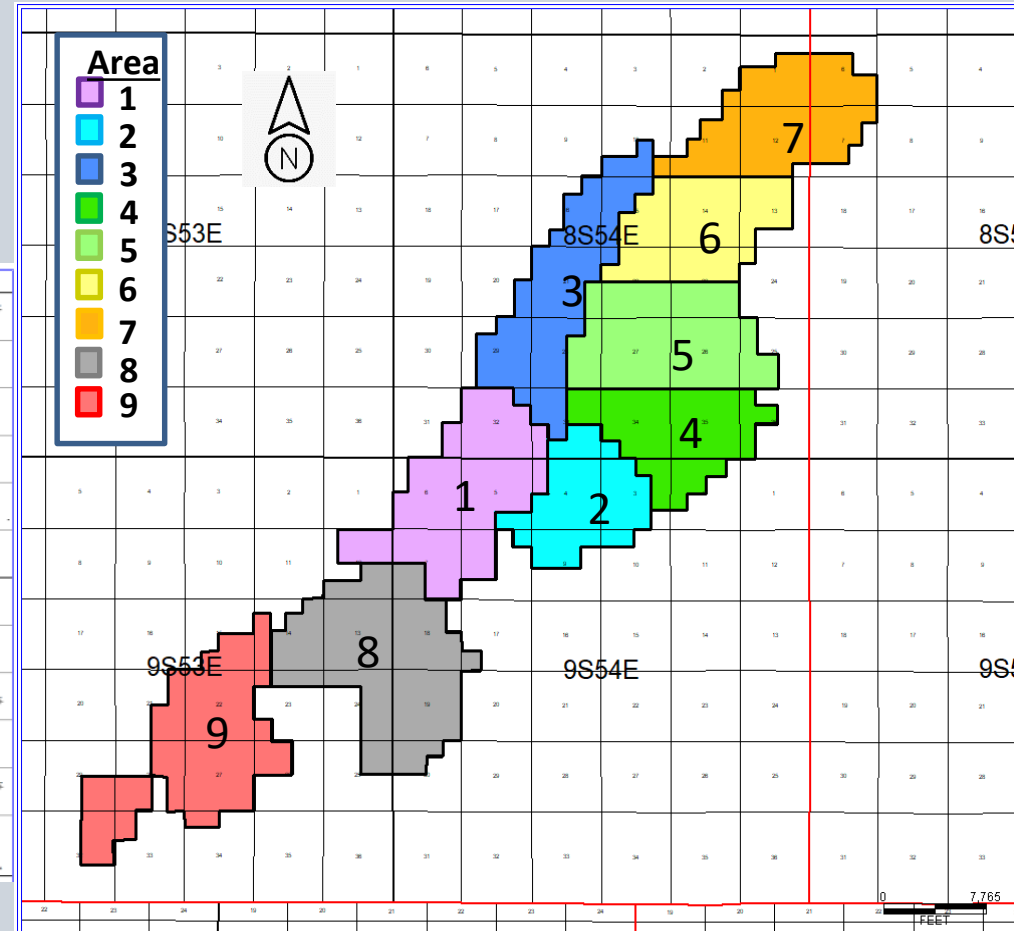
(Ryoo, 2015)

# Field History

- Discovered in June 1967 helping start off a new era of stratigraphic trap exploration
- Waterflooding in the field began in August 1970
- Field was originally split into 7 different areas for waterflooding
- Major carbon dioxide injection began in May 2013
- The field has since been split into 9 separate areas for water flooding and EOR



(Denbury, 2012)



# Production History

Historical Production  
Click and drag in the plot area to zoom in

Monthly

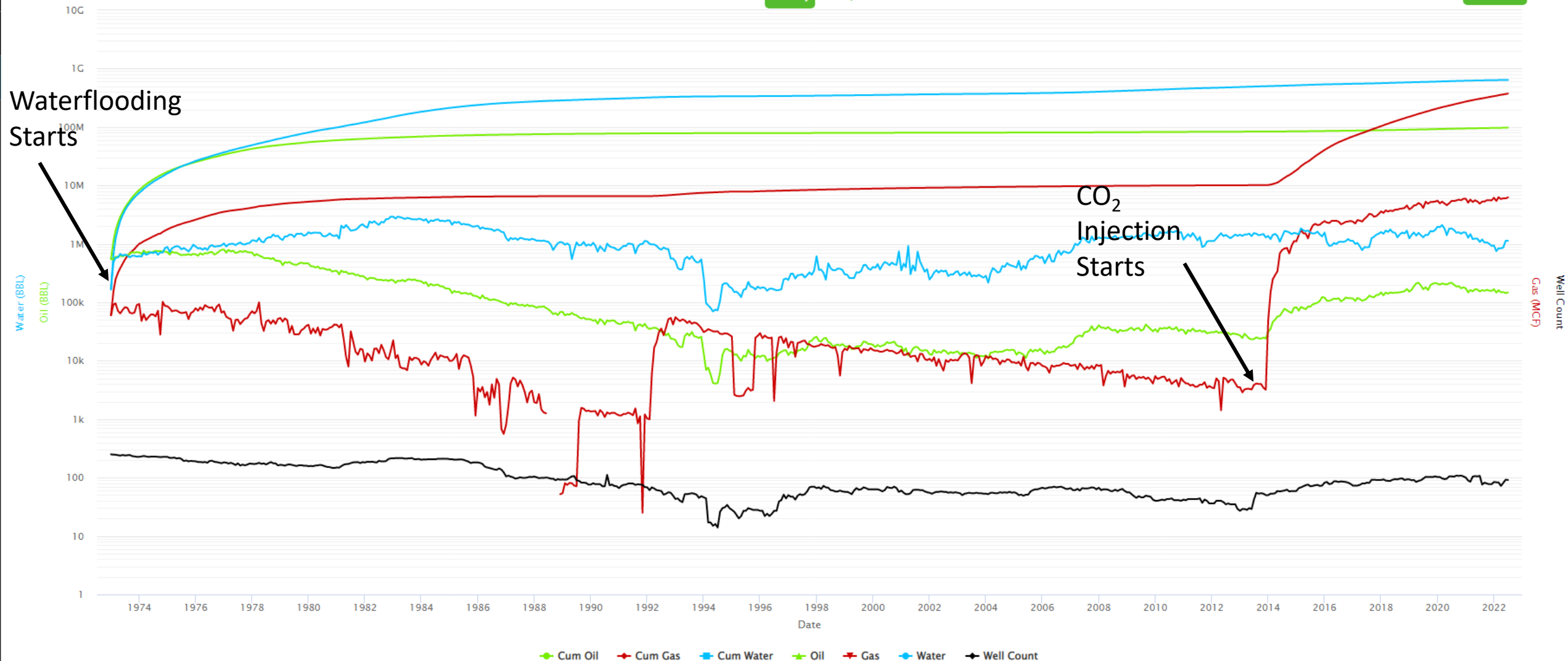
Daily

Linear

Logarithmic

Waterflooding  
Starts

CO<sub>2</sub>  
Injection  
Starts



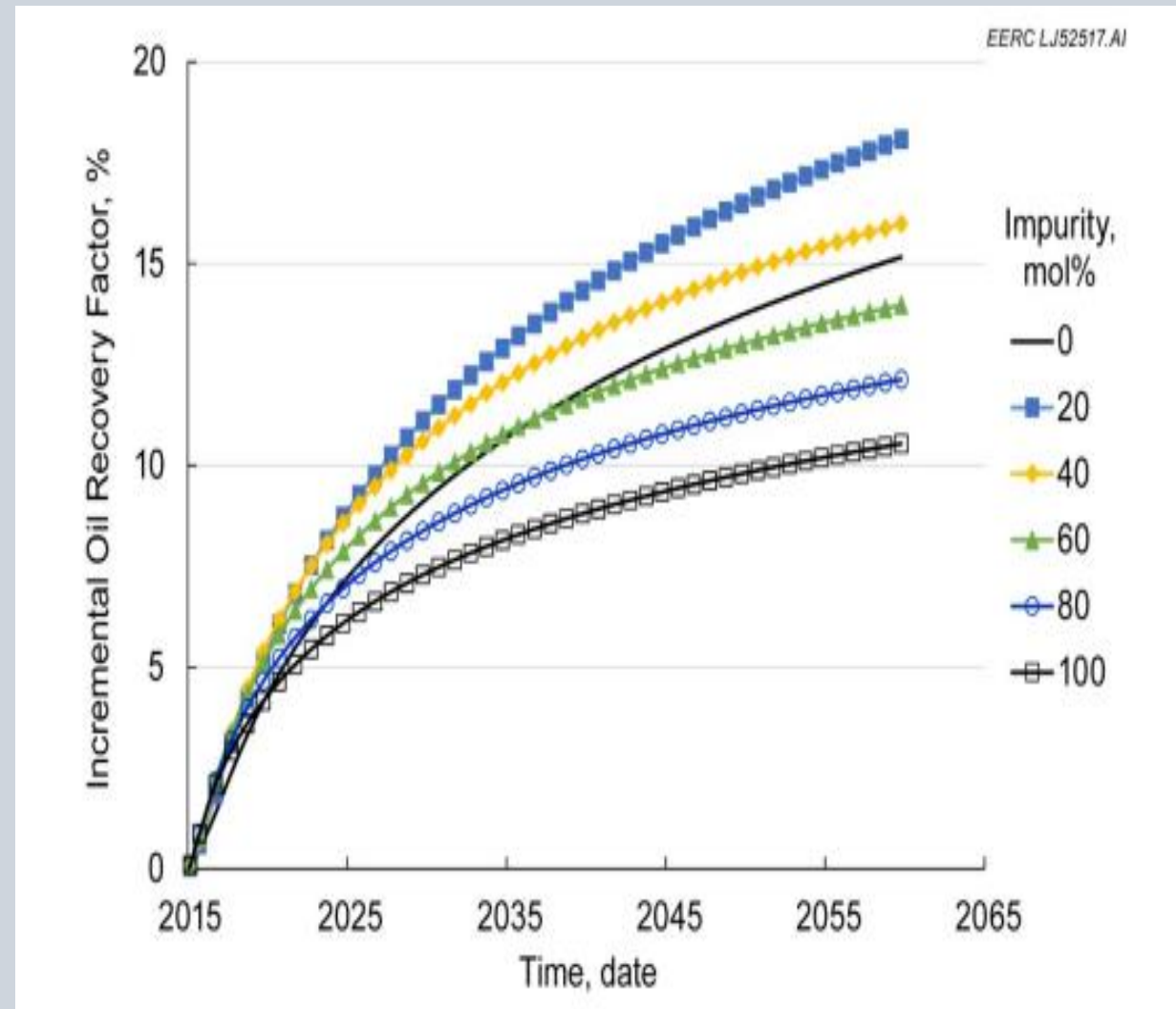
**CUM OIL: 147,535,972 BO**  
**CUM Water: 640 Million BO**

(Enverus, 2022)

Drillinginfo

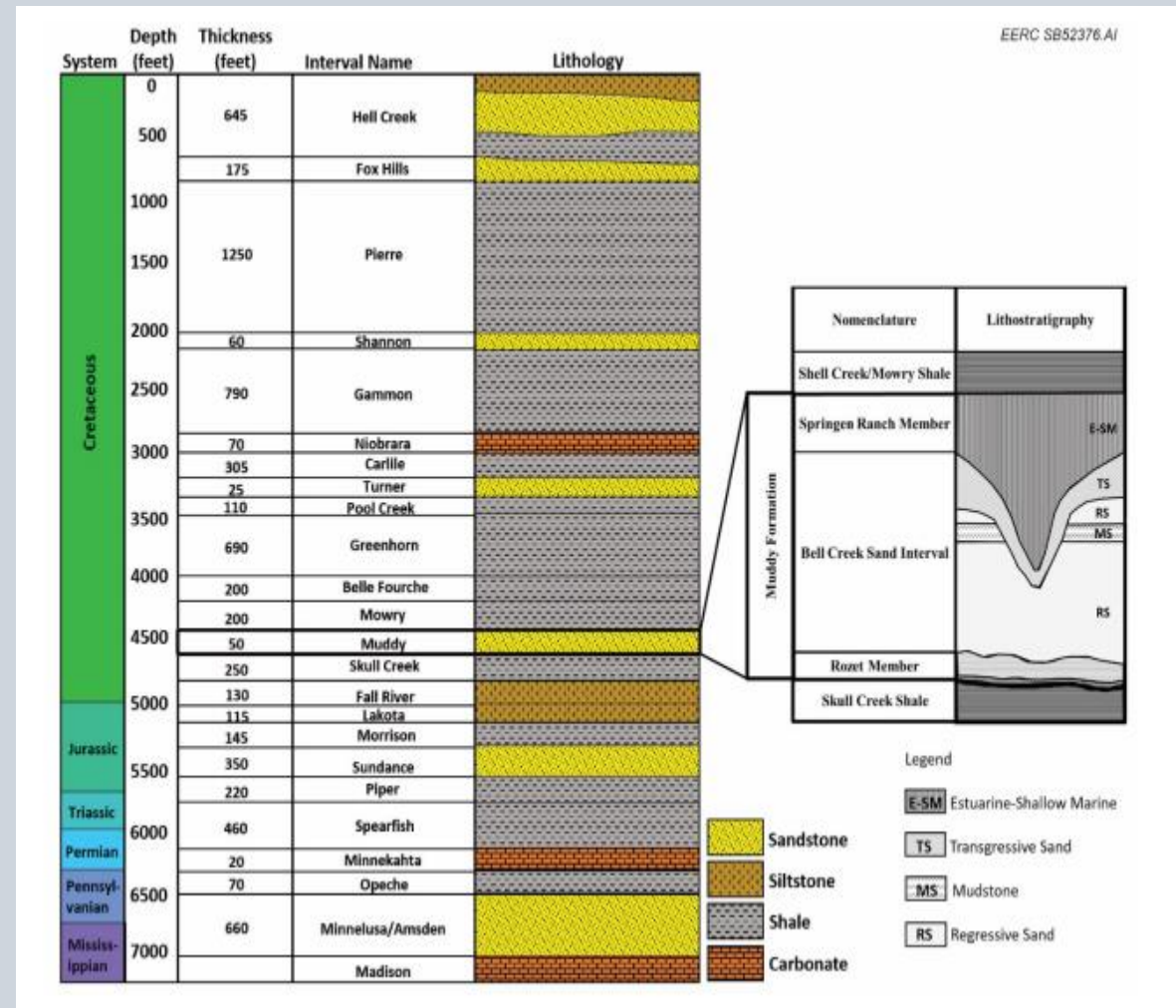
# CO<sub>2</sub> EOR History and Operations

- Injected CO<sub>2</sub> is primarily recycled gas
- 60% of injected CO<sub>2</sub> is either stored or sequestered into the formation (above average for EOR)
- Injected CO<sub>2</sub> has impurities within (4-6%) mostly being methane (CH<sub>4</sub>) of around 20% being ideal modeled amount to maximize production
- More than 15 million tones of CO<sub>2</sub> has been sequestered (not returning to surface).



# Geologic Overview of Field

- Starts during the Early Cretaceous during the Spread of the Western Interior Seaway
- Deposition of the Dakota formation represents the transition from continental to marine depositional environments.
- Muddy Sandstone (Lower Cretaceous) was deposited regionally across the Rocky Mountains including the eastern part of the Powder River Basin
- Sediments of a regressive shoreline were reworked into beaches, offshore bars, and





# Muddy Sandstone Geology

FORMATION	MEMBER	LITHOLOGY	THICK. (FEET)	E.O.D.	DESCRIPTION
MOWRY	CLAY SPUR	*****	2	MARINE	Bentonite
		[Dotted pattern]	200		Predominantly silver gray siliceous fissile shale with many fish scales & bones.
NEFSY		[Wavy pattern]	30	MARINE	Black to dark gray, clayey, fissile shale.
MUDDY	UPPER	[Dotted pattern]	10-20	TRANSITIONAL	Brown to tan silty, v.f.g. atz. ss. Parallel bedded to ripple lam. & frag. burrowed.
	LOWER	[Dotted pattern]	0-80	ALLUVIAL VALLEY DELTAIC-SHORELINE	Gray x-bed. f. to m.g. atz. ss. Int.-bd. w/rooled gry to grn. claystone & siltst. & blk. carb. siltst. & coal. Gray v.f.g. to f.g. well sorted atz. w/burr. along sh. breaks. Bell Creek ss.
SKULL CREEK	UPPER	[Dotted pattern]	80-160	MARINE	Black to dark gray clayey shale, abundant red brown siltstones are present in the lower member.
	LOWER	[Dotted pattern]	100		
FALL RIVER		[Dotted pattern]	100-160	MARINE TO NON-MARINE	Gray f.g. to m.g. ss. & gray f.tss. sh.; brown to black clayst & siltst. Int.-bd. w/ss.
LAKOTA		[Dotted pattern]	20-80	NON-MARINE	Gray congl. m.g. to c.g. ss. & congl. with int.-bd. vari-colored clayst. & siltst.

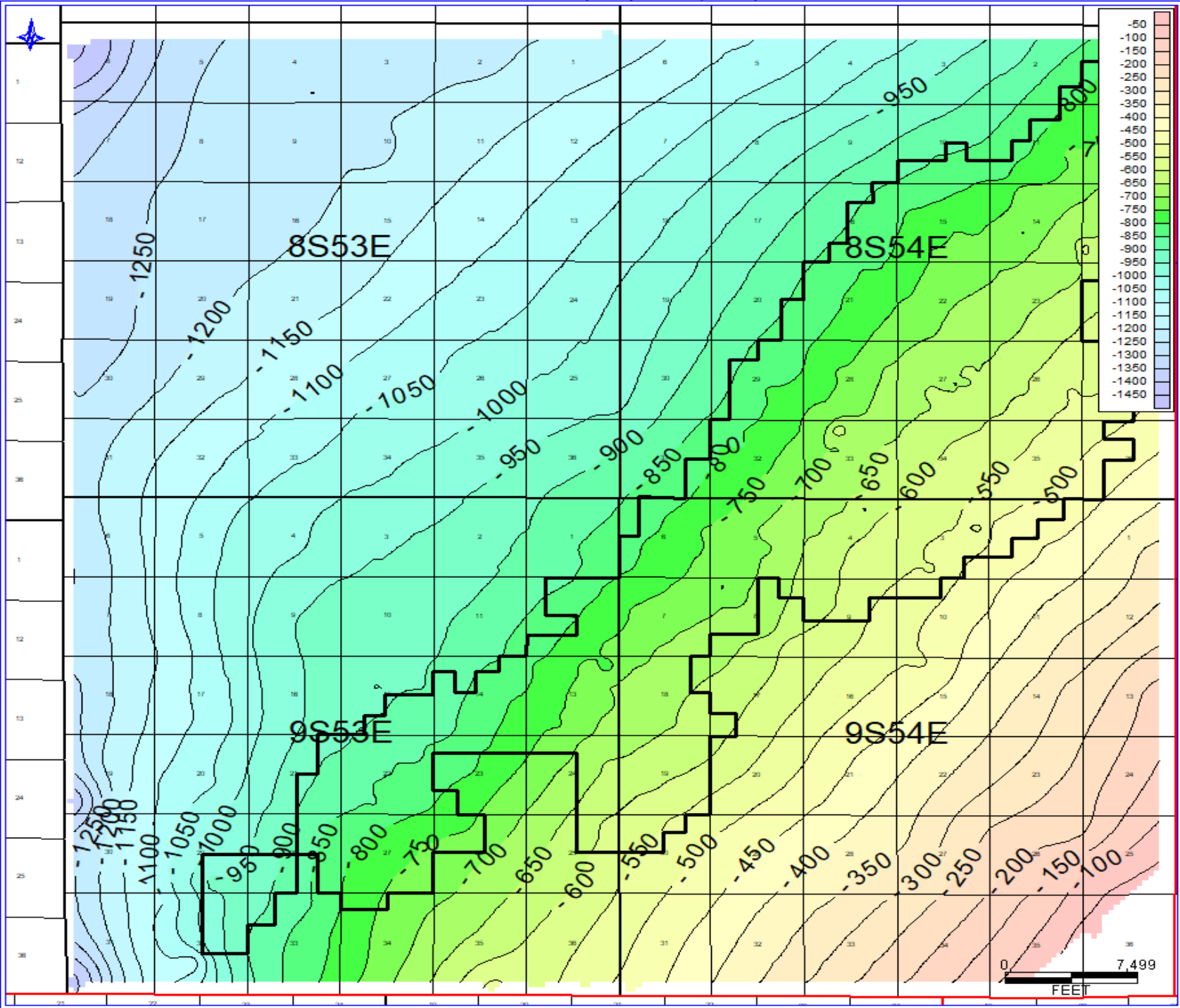
- The Muddy Sandstone is Lower Cretaceous in age and is overlain by the Nefsy/Mowry shale and overlays the Skull Creek Shale
- It consists of two members:
  - Older deposited in shoreline and nearshore marine environments (Bell Creek Sandstone)
  - Younger is a valley fill deposit of fluvial, estuarine and tidal flat deposits (Valley Fill Member)
- Both members distribution was controlled by relative sea level changes
- Deposited as a regressive sandstone during a high stand of sea level followed by a sea level

# Reservoir Characteristics Muddy SS

- Lithology: Very fine to fine grained, moderately sorted, quartz arenites, and sub arkose sands with illite and kaolinite
- Porosity Type: Intergranular and inter crystalline porosity
- Porosity: 6%-36%; average 28.5%
- Permeability: 0.1mD to 13 Darcies; average 2.25 Darcies
- Water Saturation: 20%-35%; average 26%
- Temperature: 110 degrees F
- Pay Thickness: average 26ft
- Original Reservoir Pressure: 1,204 psi



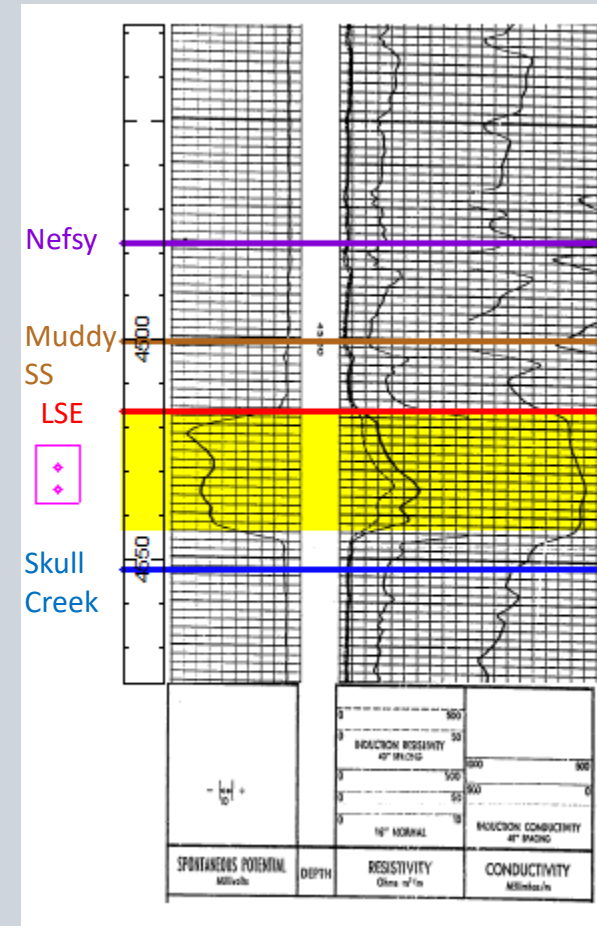
# Muddy Structure Map

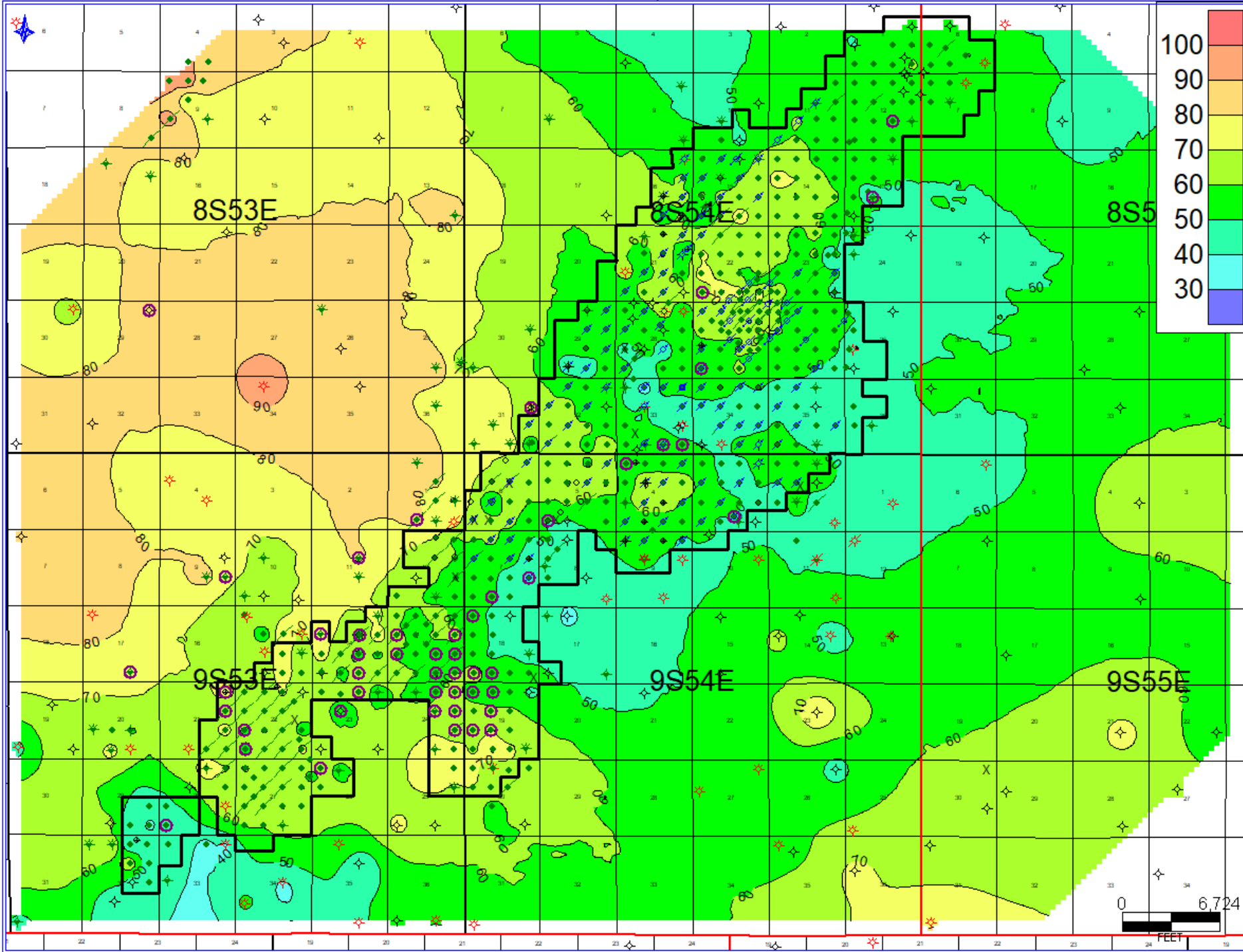


# Type Log

- **Discovery Well: 33-1Federal-McCarrel**

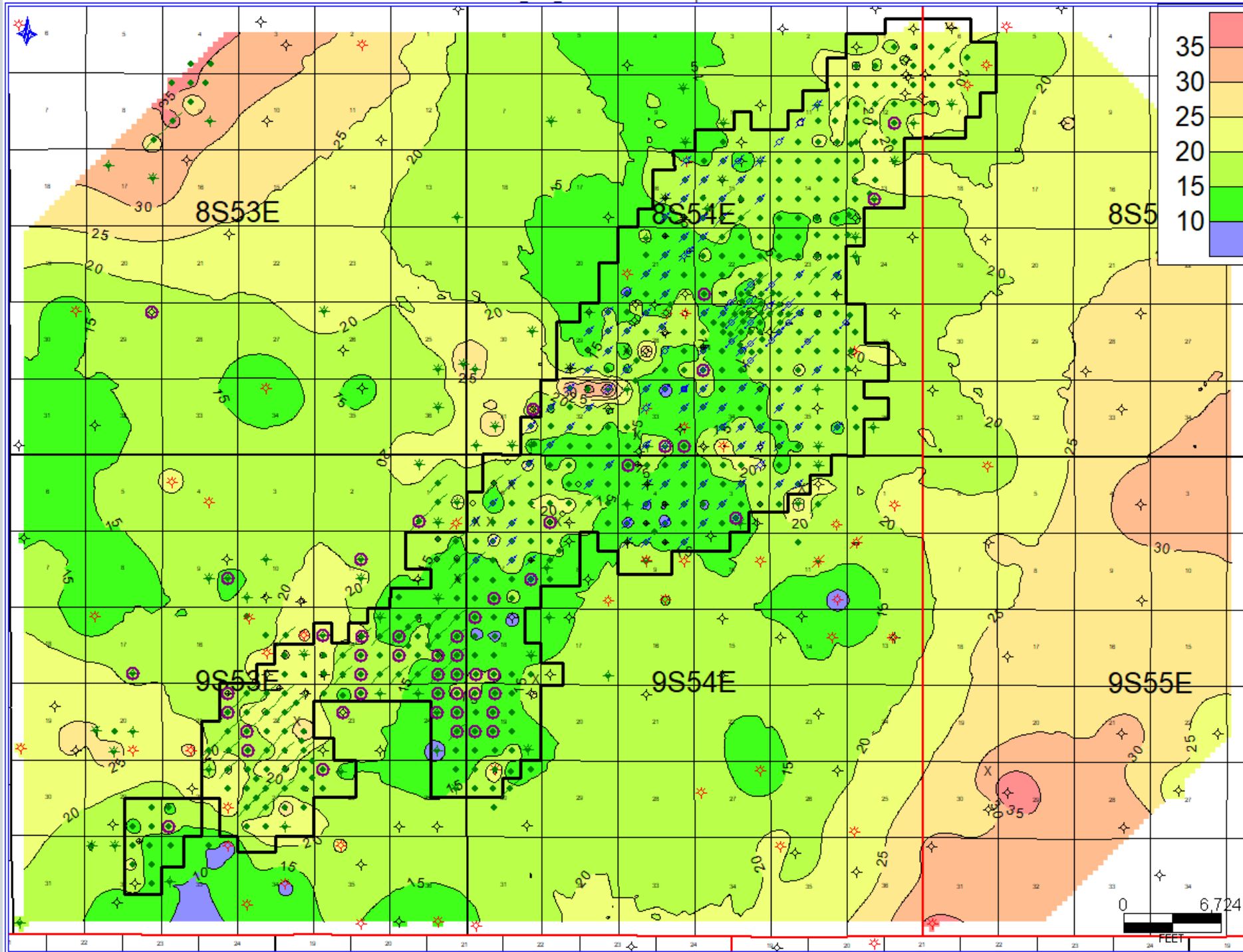
- Clear resistivity top markers throughout the field for consistent picking
- Seal: Nefsy and Upper member of the Muddy Sandstone
- Reservoir: Bell Creek Sandstone below the LSE
- Original Production: 206 BOPD





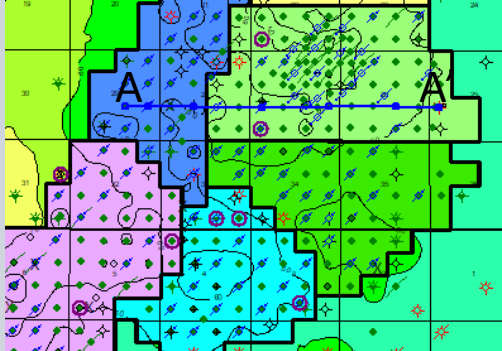
# Muddy SS Gross Interval Isopach CI: 10ft

○ Cored Wells



# Valley Fill Isopach CI: 5ft

○ Cored Wells

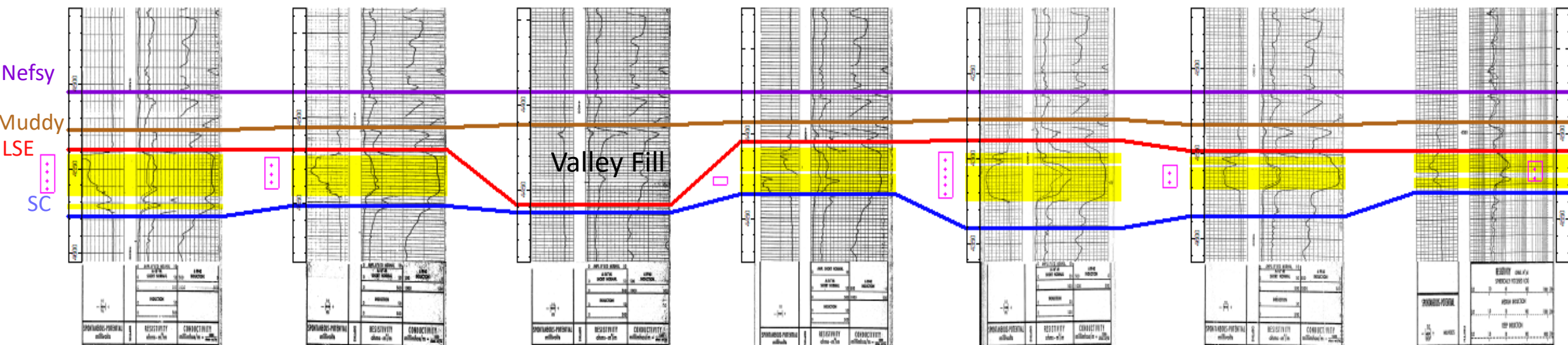
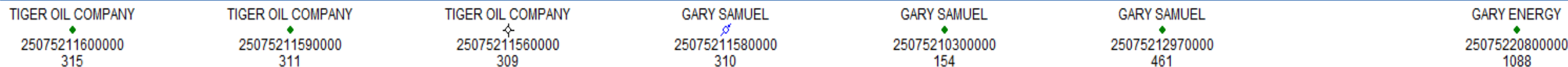


# Log Correlation showing Valley Fill

- The Valley Fill becomes thicker towards the middle of the field then thinning back out
- Clear resistivity top markers throughout the field for consistent picking

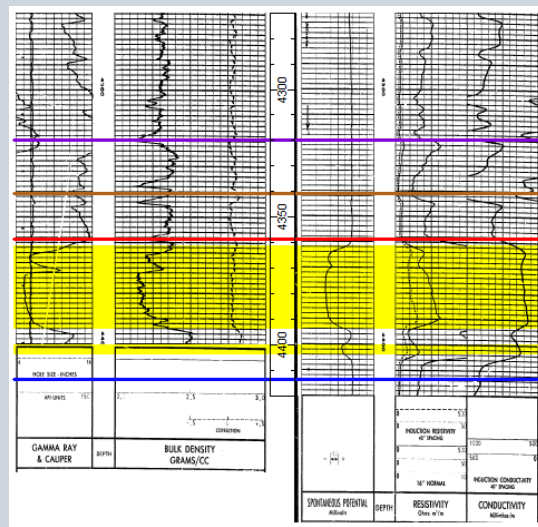
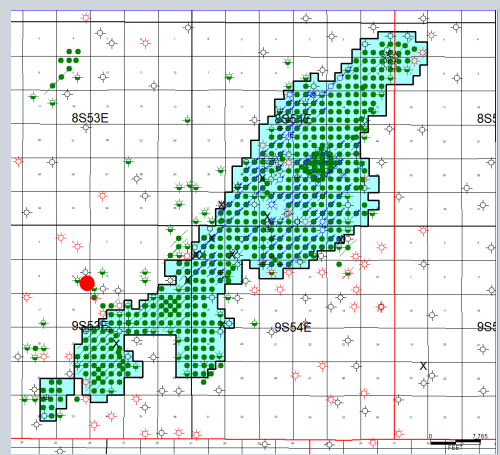
A

A'



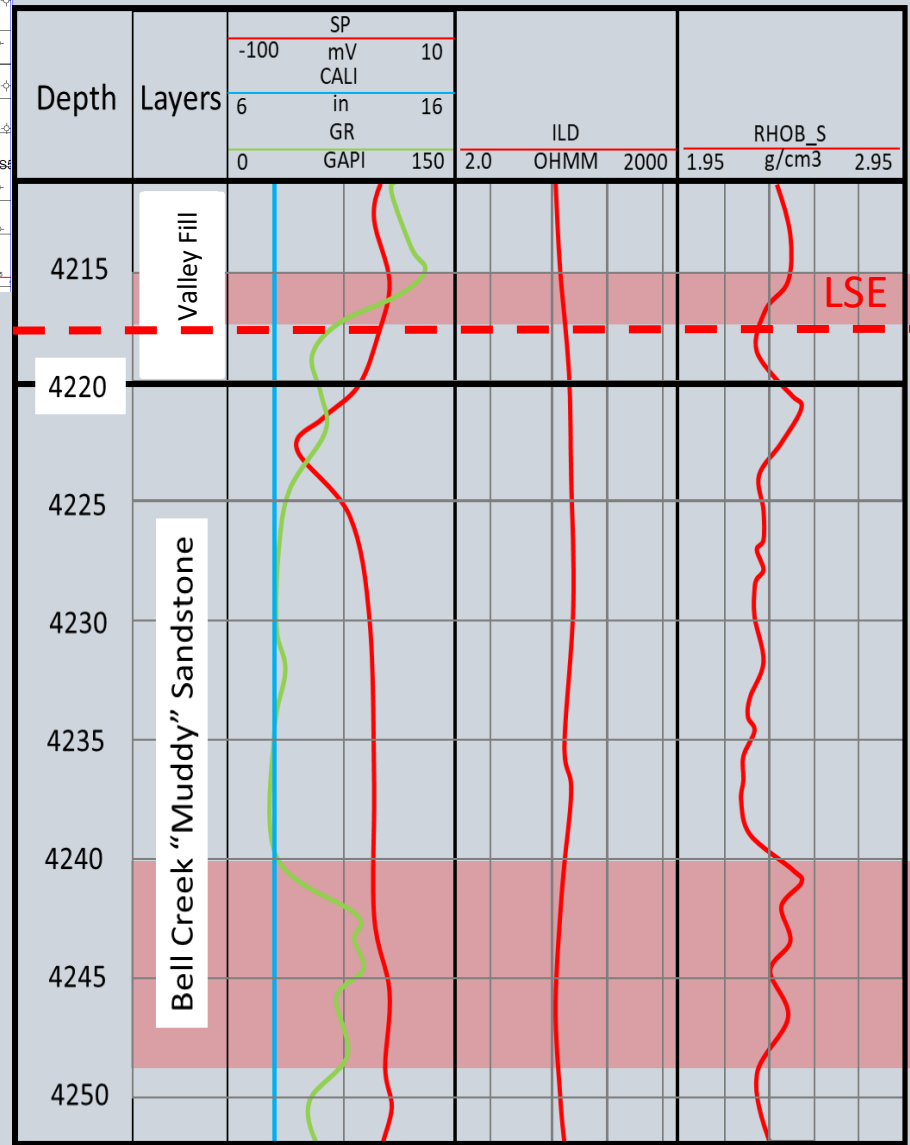
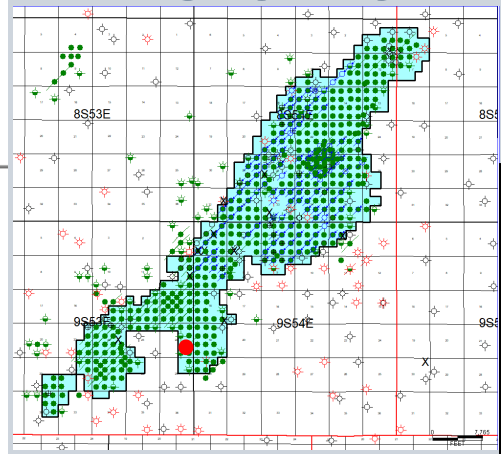
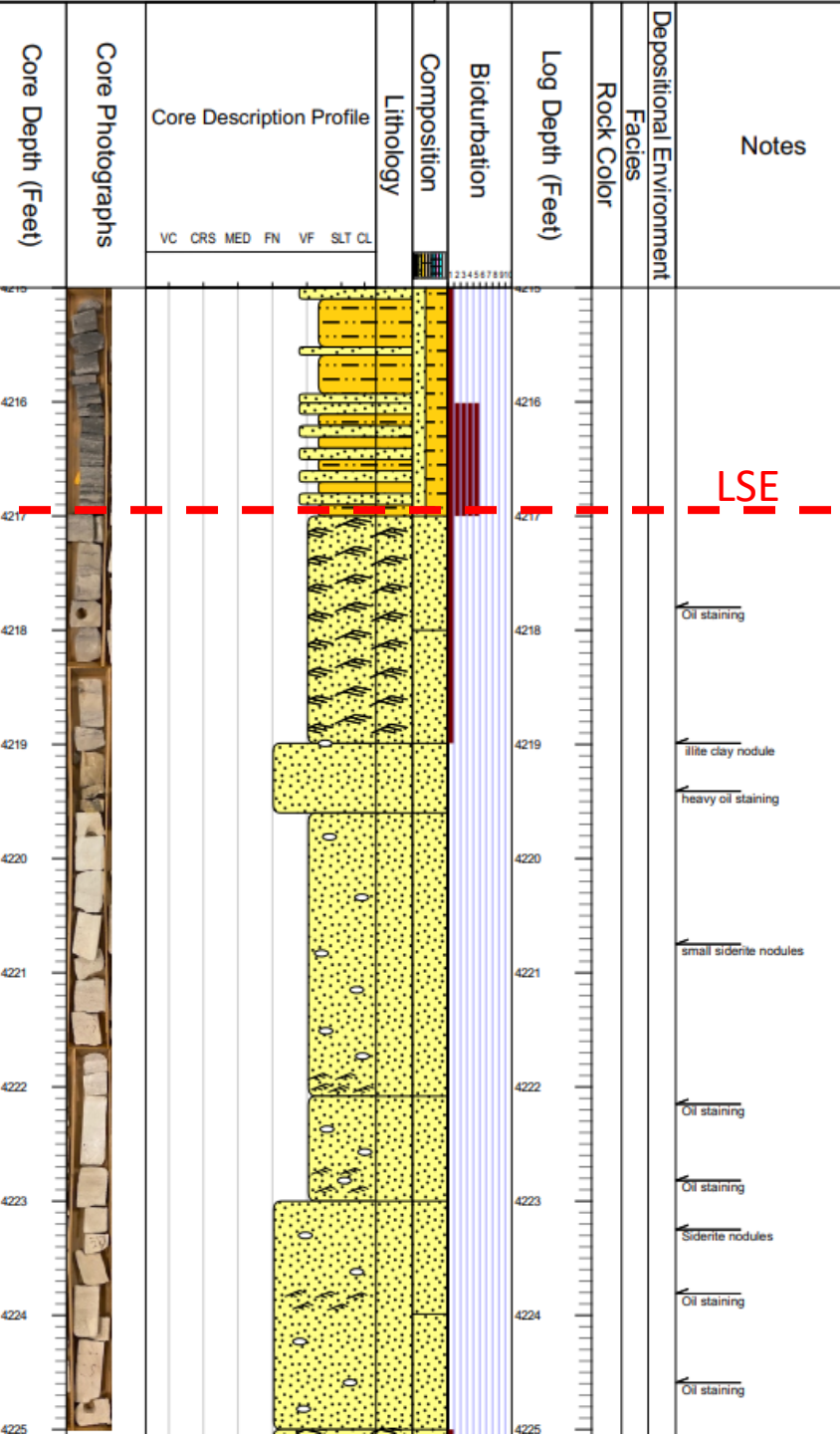
# Core Observation

- Muddy SS/  
Bell Creek SS
- Skull Creek SH

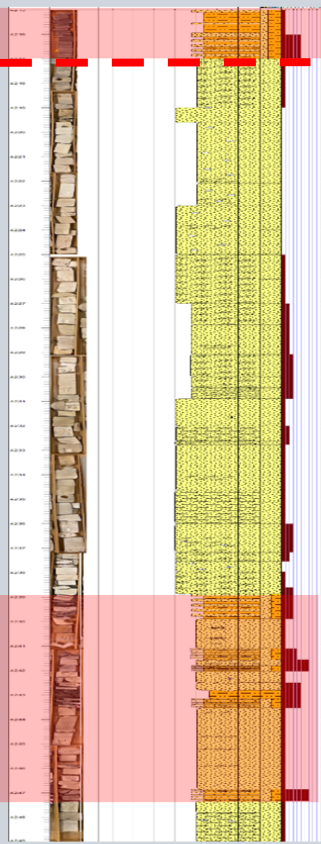




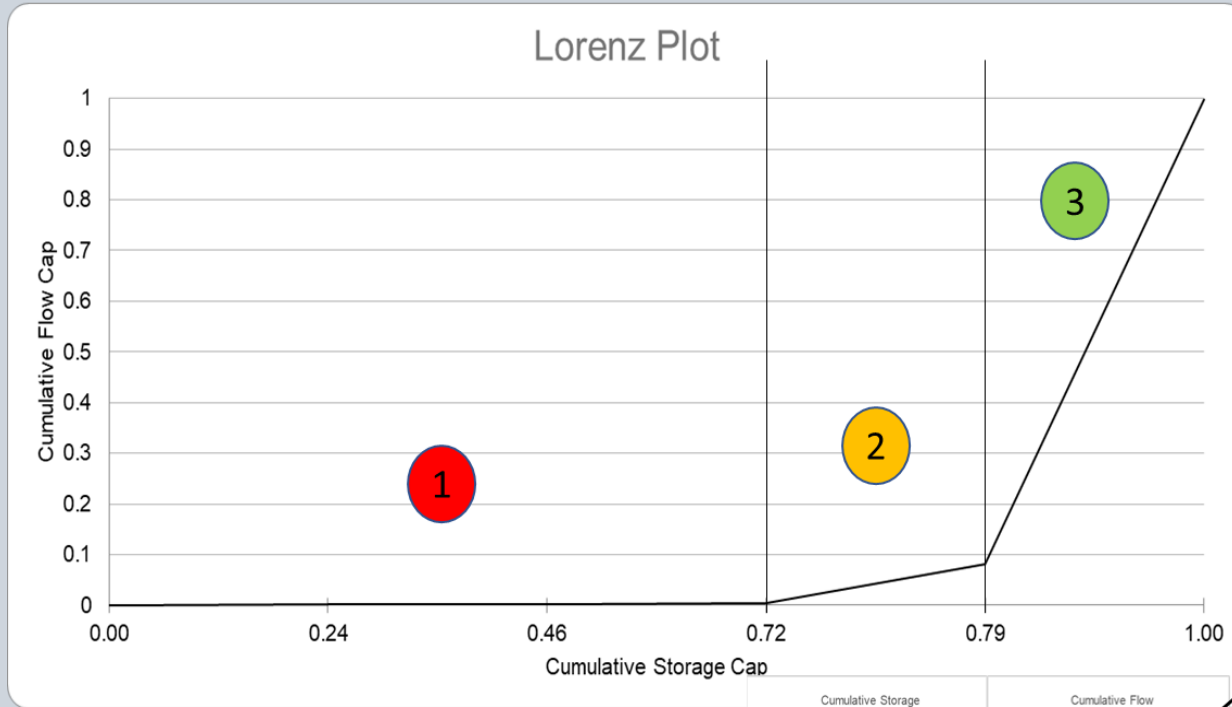
# Core Description



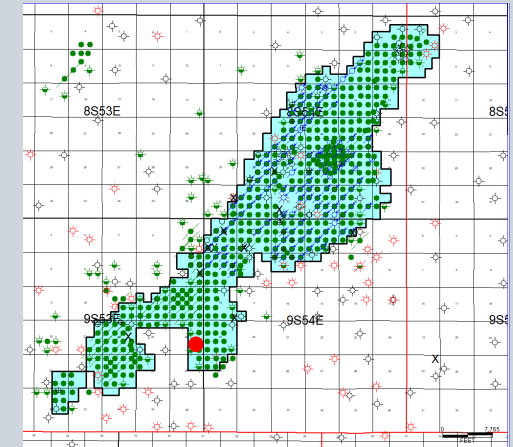
TAACK 25



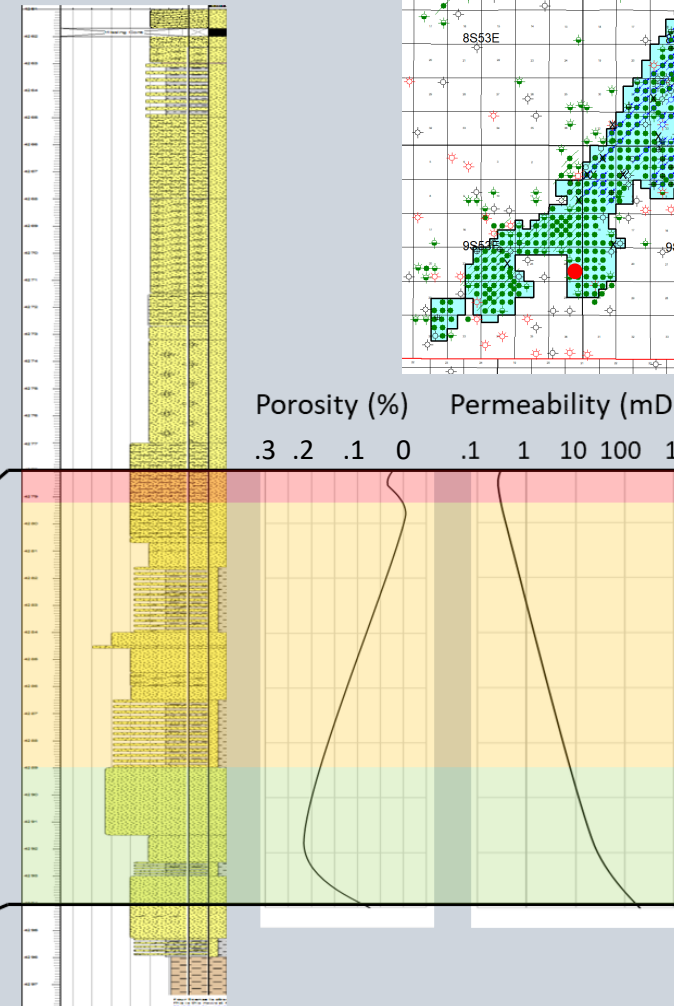
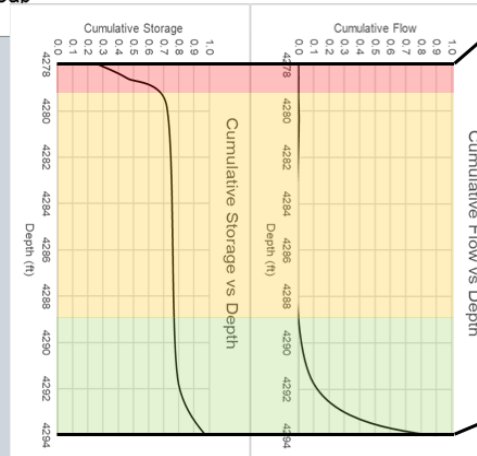
# Flow Units from Core



TAACK 15: 4278'-4294'  
- 5 Data Points

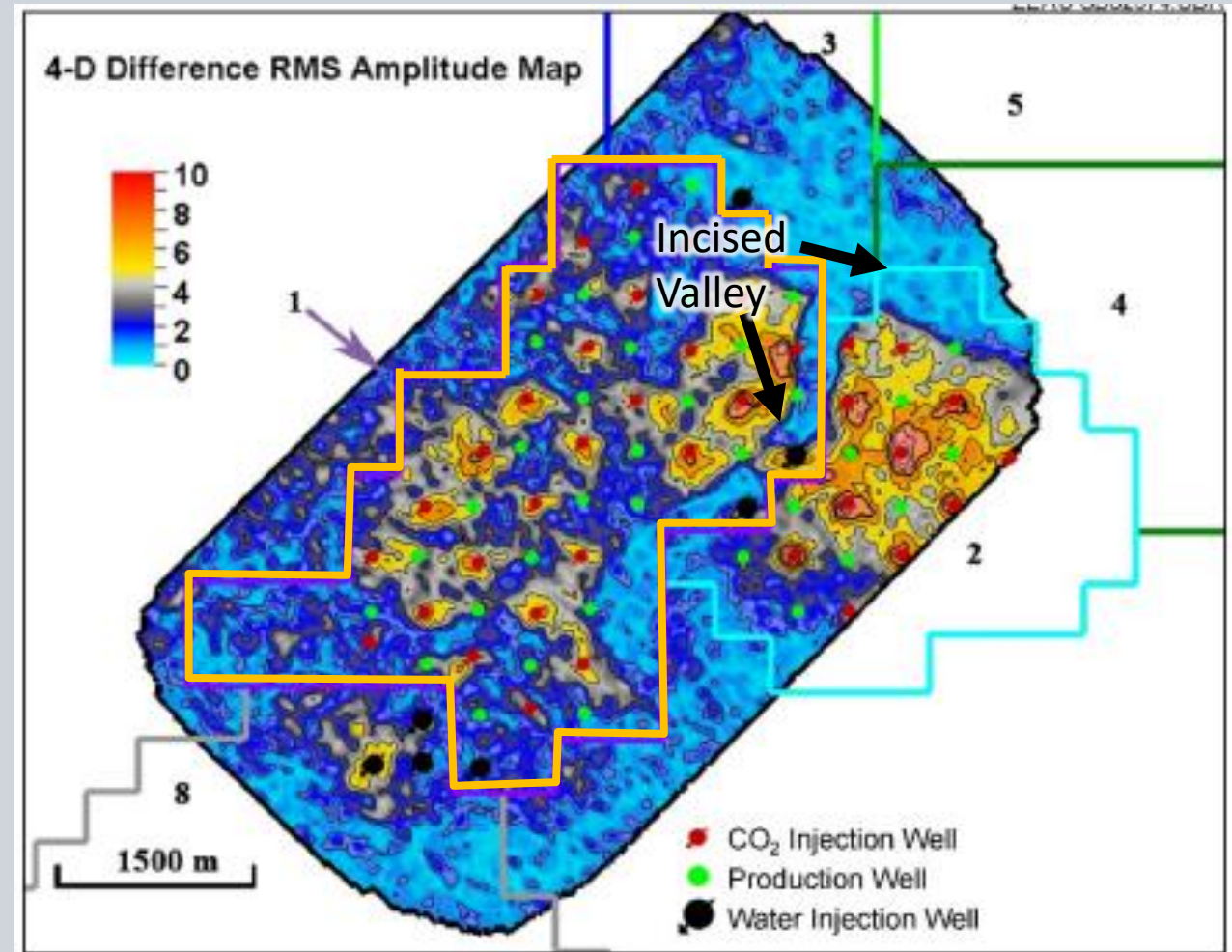


- 1 Poor Flow Unit
- 2 Good Flow Unit
- 3 Great Flow Unit



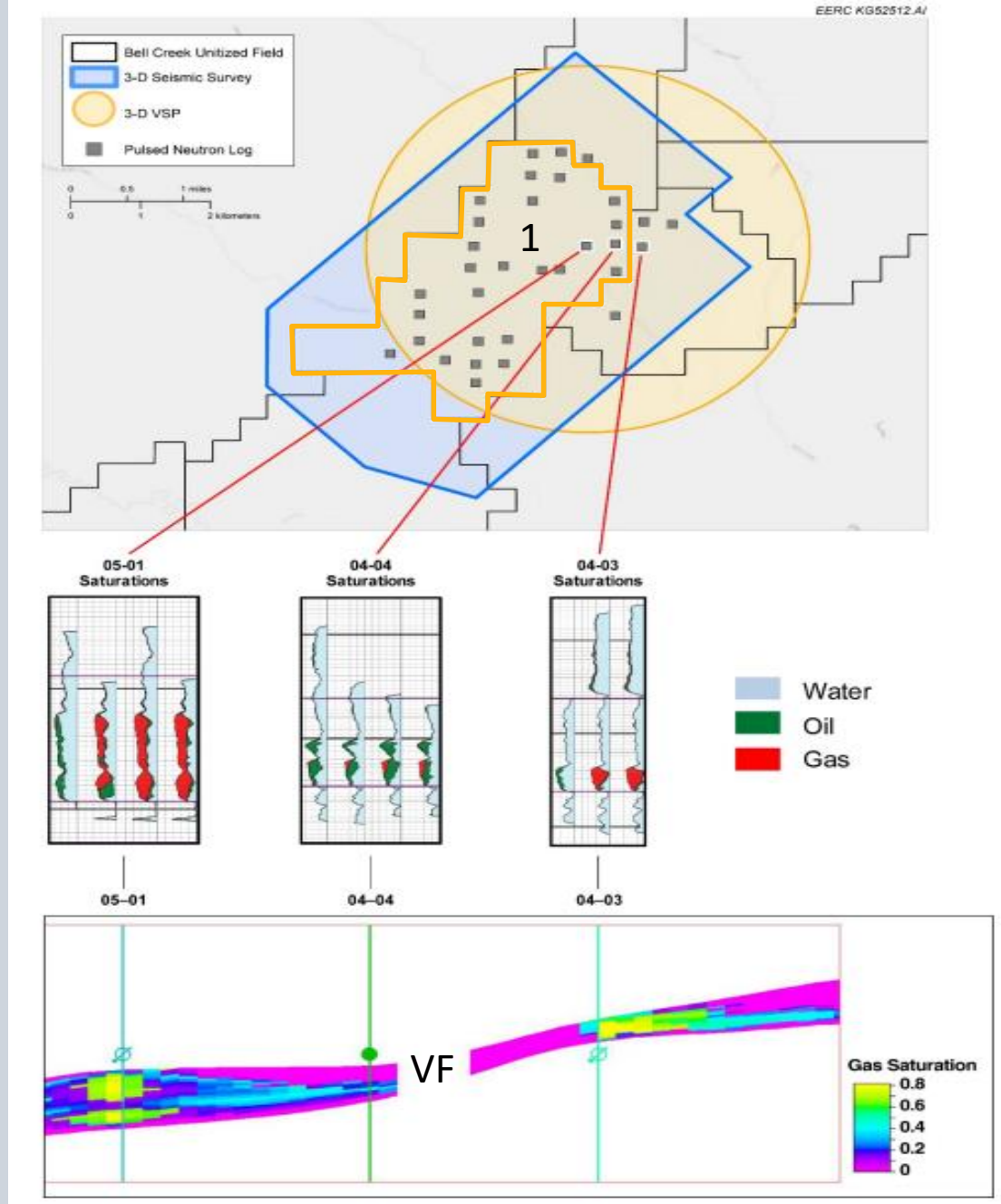
# 4D Seismic of Injection of CO<sub>2</sub>

- Map showing amplitude change from baseline 3D seismic to time lapsed 4D seismic
- Injections into the thicker parts of the Muddy Sandstone show an increase in Seismic amplitude from increased saturations of CO<sub>2</sub>



# Gas Saturation through Well Data

- Showing CO<sub>2</sub> migration of one injection well (05-01) to an oil Producing well (04-04).
- Time-lapsed cased pulse neutron logs showing changes in distribution with respect to fluids.
- Injection or production timeline from left to right



# Conclusion

- Bell Creek Field has shown to be a successful field for EOR and with noticeable increase in oil production
- The Bell Creek Member of the Muddy Sandstone has shown to have excellent flow rates for the injection of CO<sub>2</sub>
- Migration of CO<sub>2</sub> is effected by the type of depositional environment and in parts of the field hindered by the incised valley fill and confirmed through the use of 4D seismic
- Further study of core data in the field can show where the best flow rates are located and future prospects for injection

# Future Work

- Performing more core analysis to see varying flow rates in the Muddy(Bell Creek) Sandstone throughout the field
- Performing petrographic work on thin sections to analyze porosity and permeability distribution in the core
- Detailed mapping of the depositional units throughout the field
- Optimizing locations for future injection into the field

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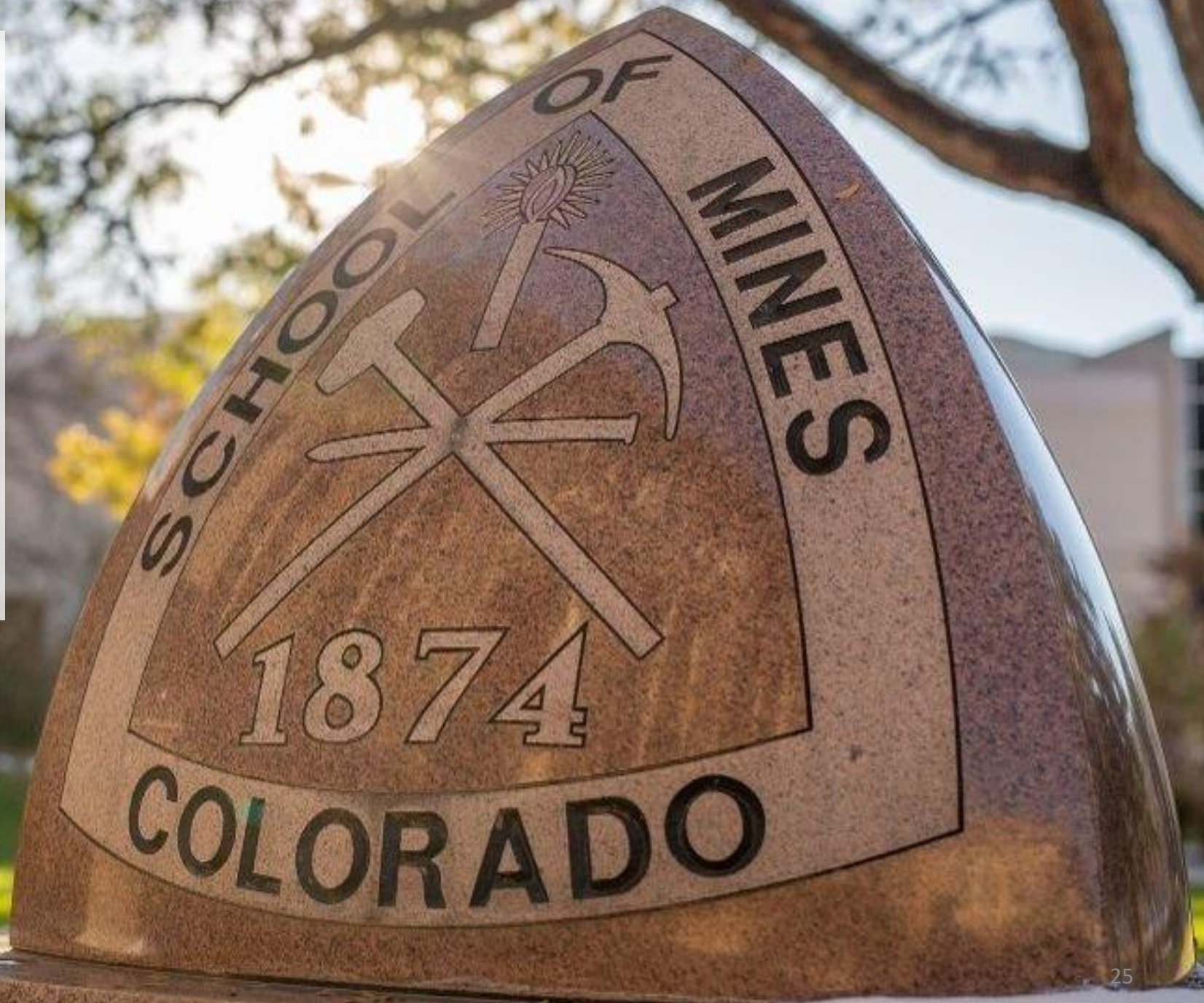
Mike Johnson & Associates







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# Pulsed Neutron Lifetime Log of Injector

