Muddy Sandstone Enhanced Oil Recovery (Carbon Capture Utilization and Sequestration), Bell Creek Field, Montana

COLORADO SCHOOL OF MINES
MUDTOC

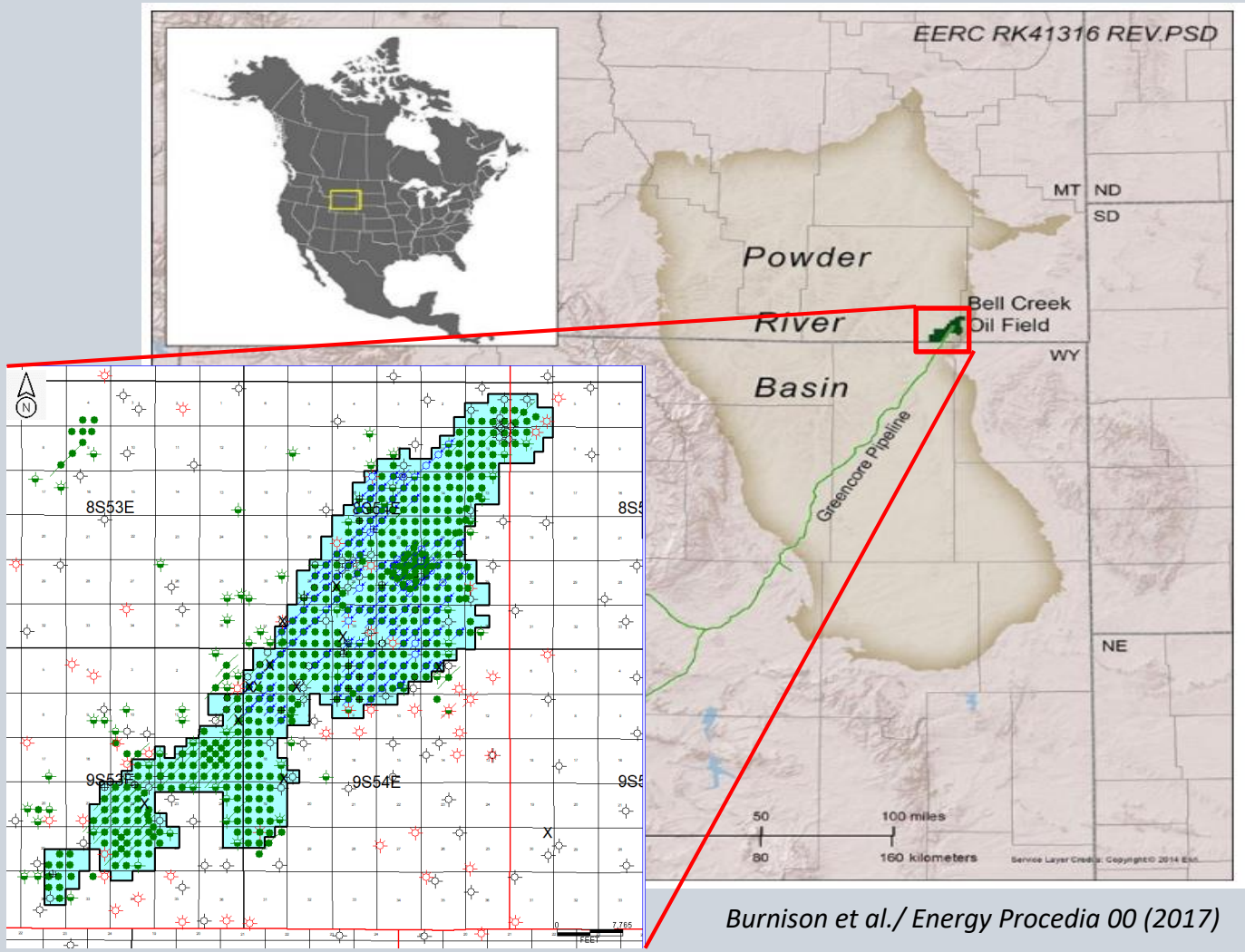
Drew Stump
MS 2023

Outline

1. Introduction
2. Field History
3. Production/Injection History
4. Geologic Overview
5. Muddy Sandstone Log Correlation, Thin Sections, and Core Descriptions
6. Injection Over Time in the Muddy Sandstone
7. Conclusions
8. Future Work

Introduction

- Location of Bell Creek Field discovered in 1967 in the Powder River Basin, Southeastern 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



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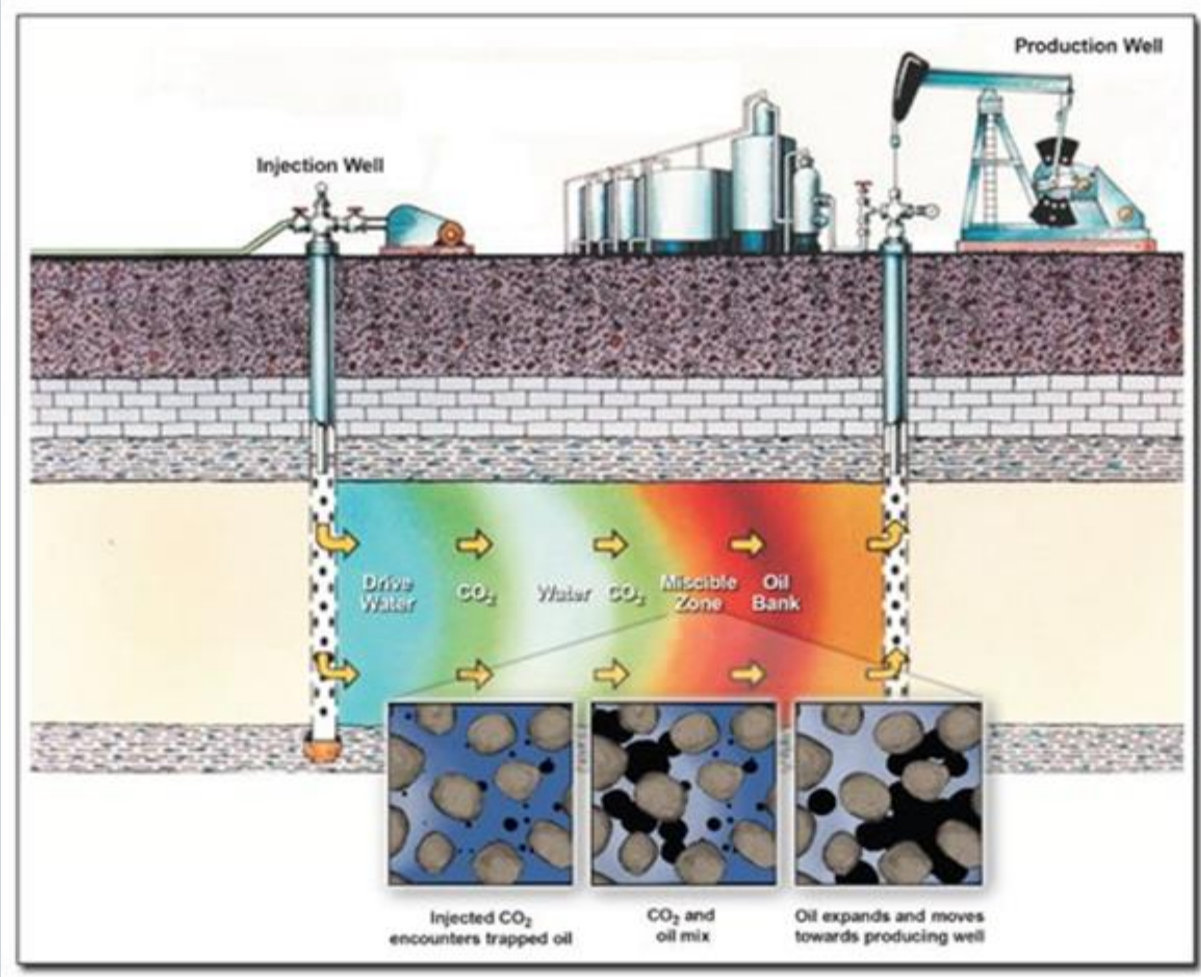
Advantages of EOR

- Two major advantages CO_2 injection
  1. Additional hydrocarbon recovery
  2. Reduction in atmospheric emissions of CO_2 through storage

- Lithologies of every type can be used for CO_2 EOR if they have a seal and interconnected pore space

- Injected into reservoir as continuous gas or water-alternating–gas (WAG)

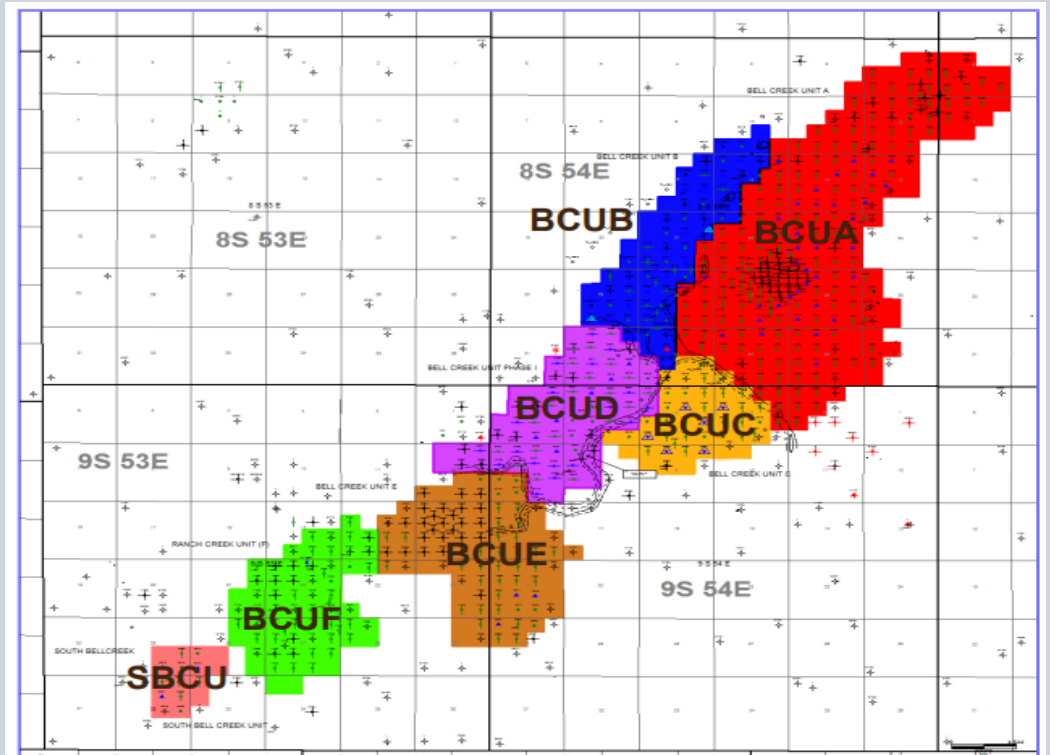
(Venma, 2015)



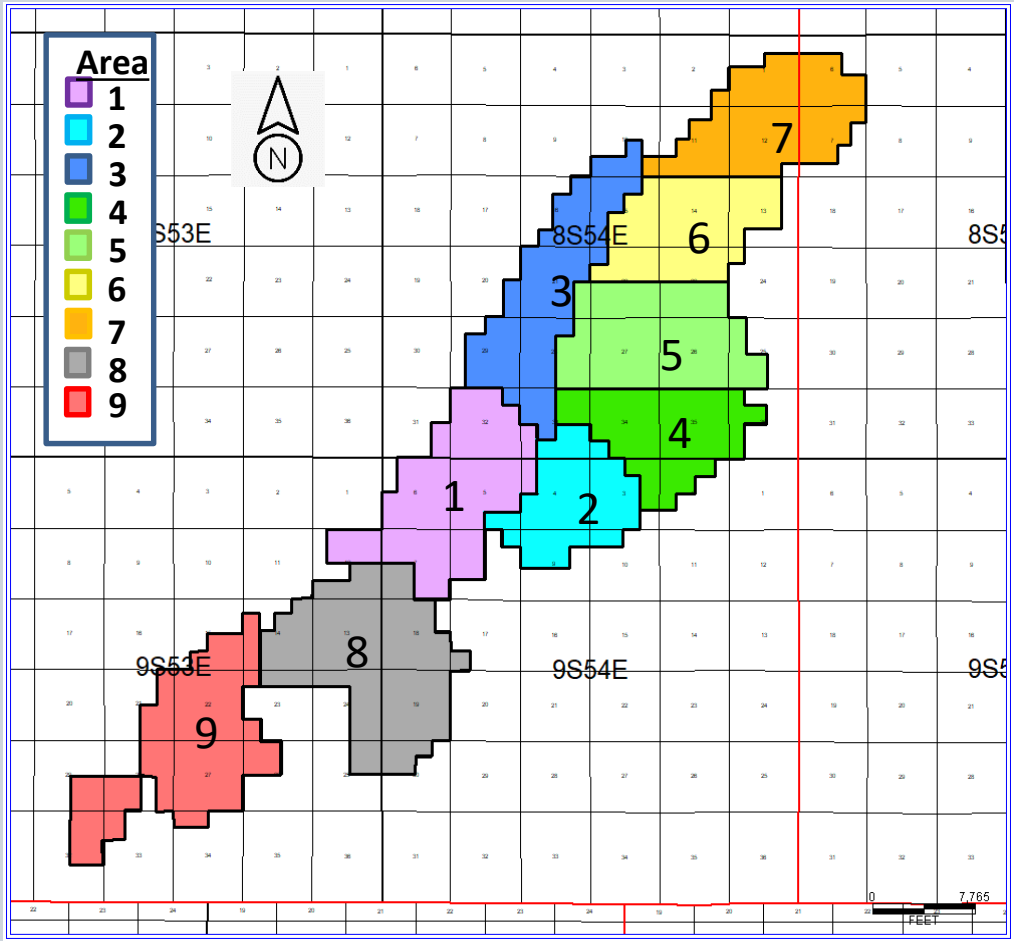
(Ryoo, 2015)

Field History

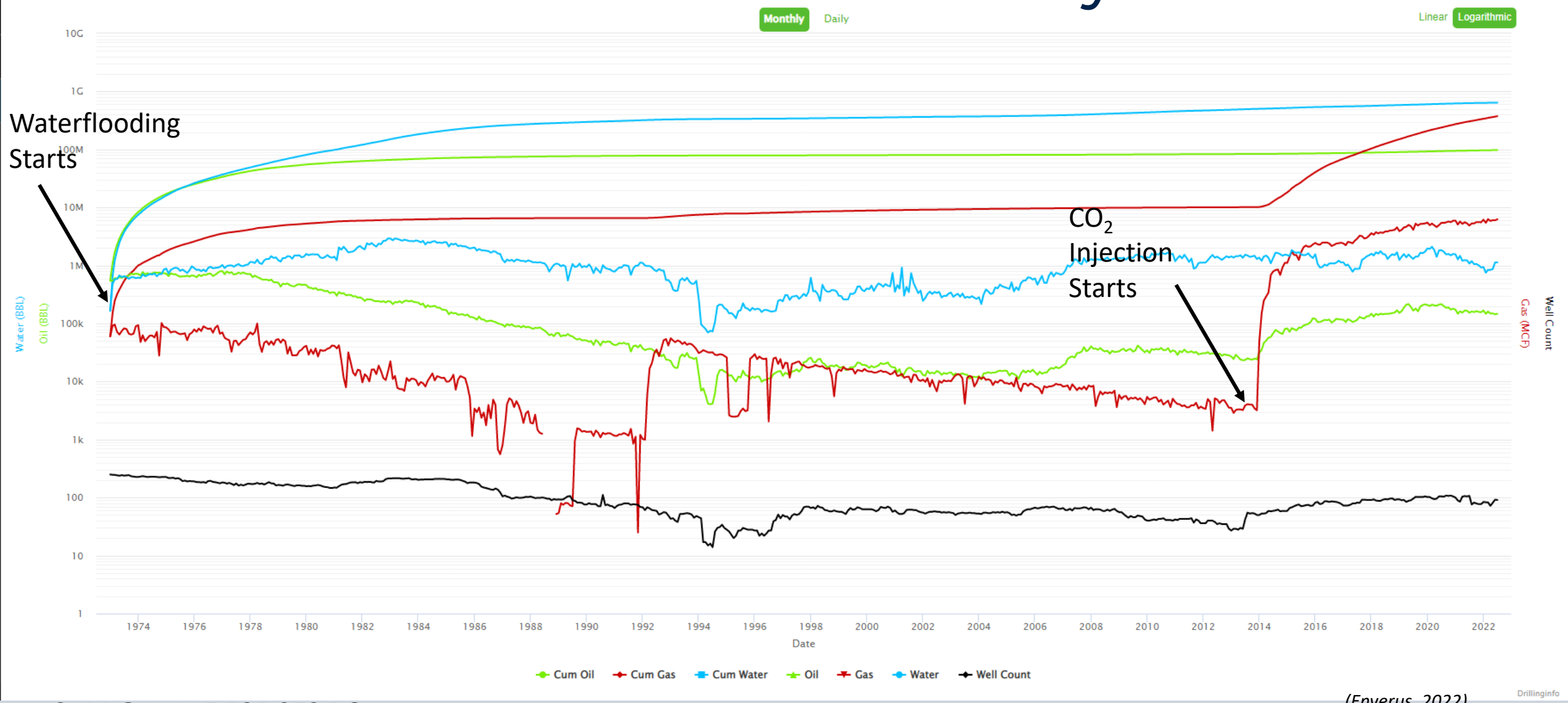
- Discovered in June 1967 helping start off a new era of stratigraphic trap exploration
- Waterflooding in the field began in August 1970
- Field was originally split into 7 different areas for waterflooding
- Major carbon dioxide injection began in May 2013
- The field has since been split into 9 separate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



(Denbury, 2012)



Production History



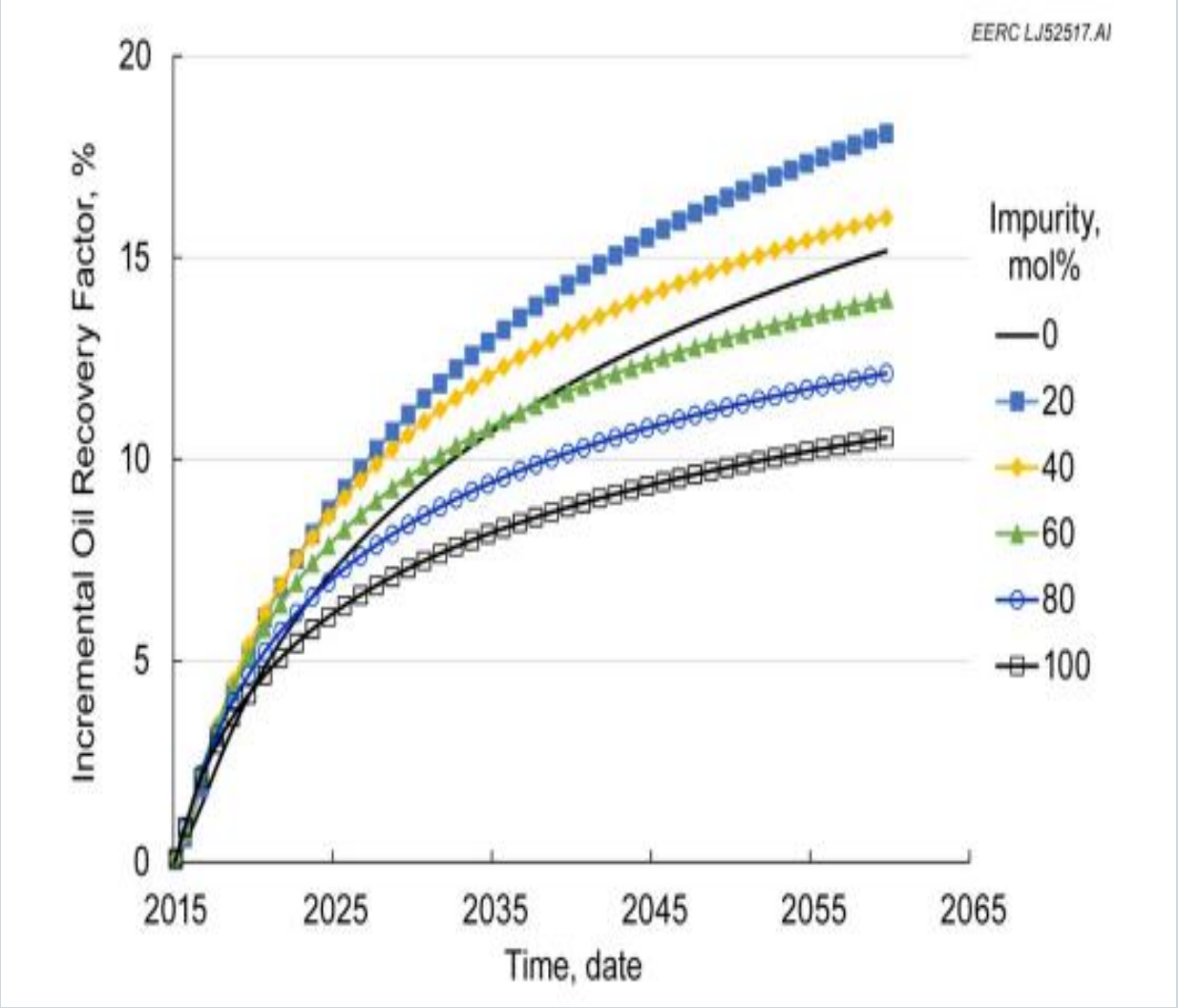
(Enverus, 2022)

CUM OIL: 147,535,972 BO

CUM Water: 640 Million BO

CO_2 EOR History and Operations

- Injected CO_2 is primarily recycled gas
- 60% of injected CO_2 is either stored or sequestered into the formation (above average for EOR)
- Injected CO_2 has impurities within (4-6%) mostly being methane (CH4) of around 20% being ideal modeled amount to maximize production
- More than 15 million tones of CO_2 has been sequestered (not returning to surface).



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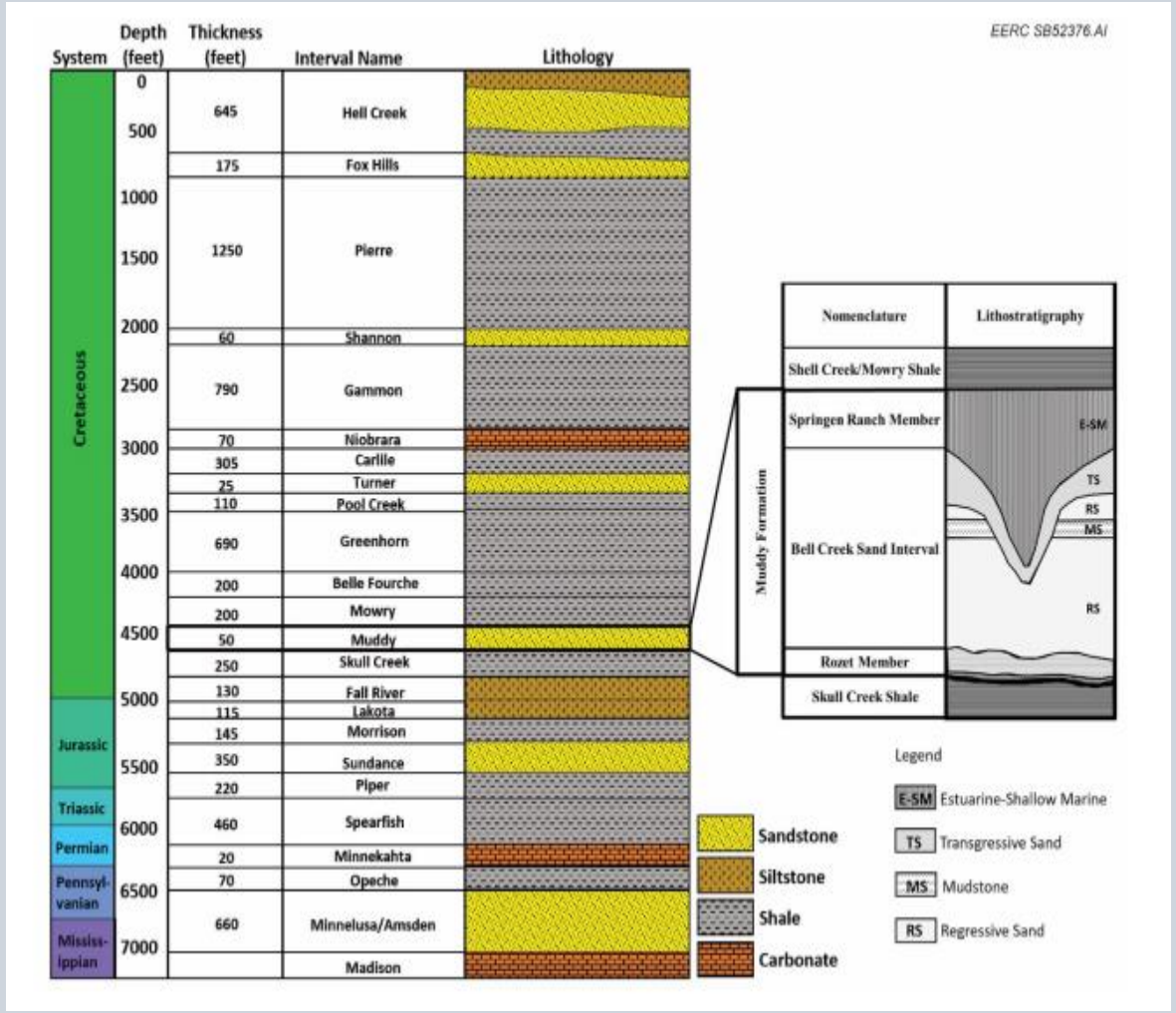
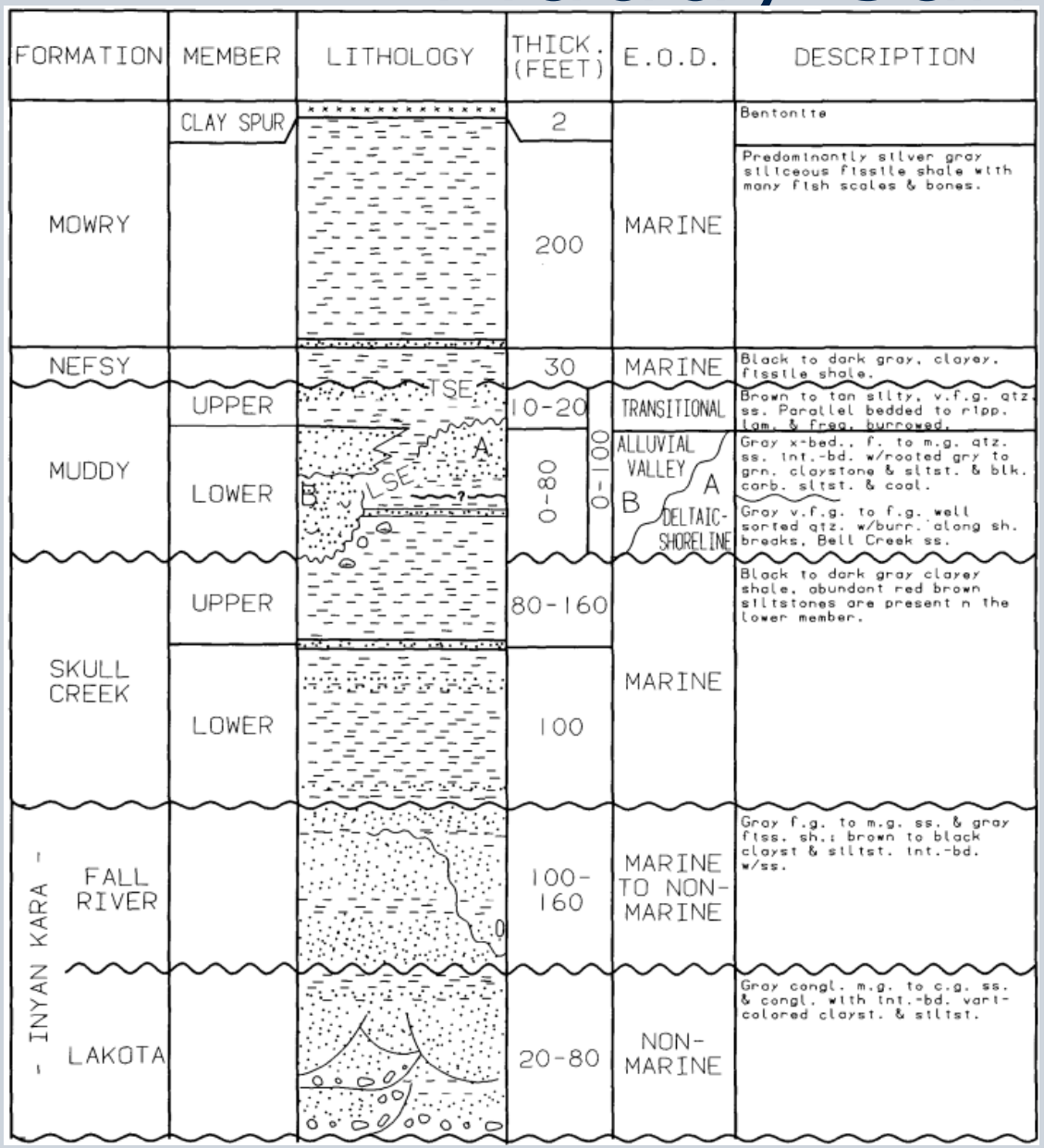
Geologic Overview of Field

- 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 barrier



Muddy Sandstone Geology

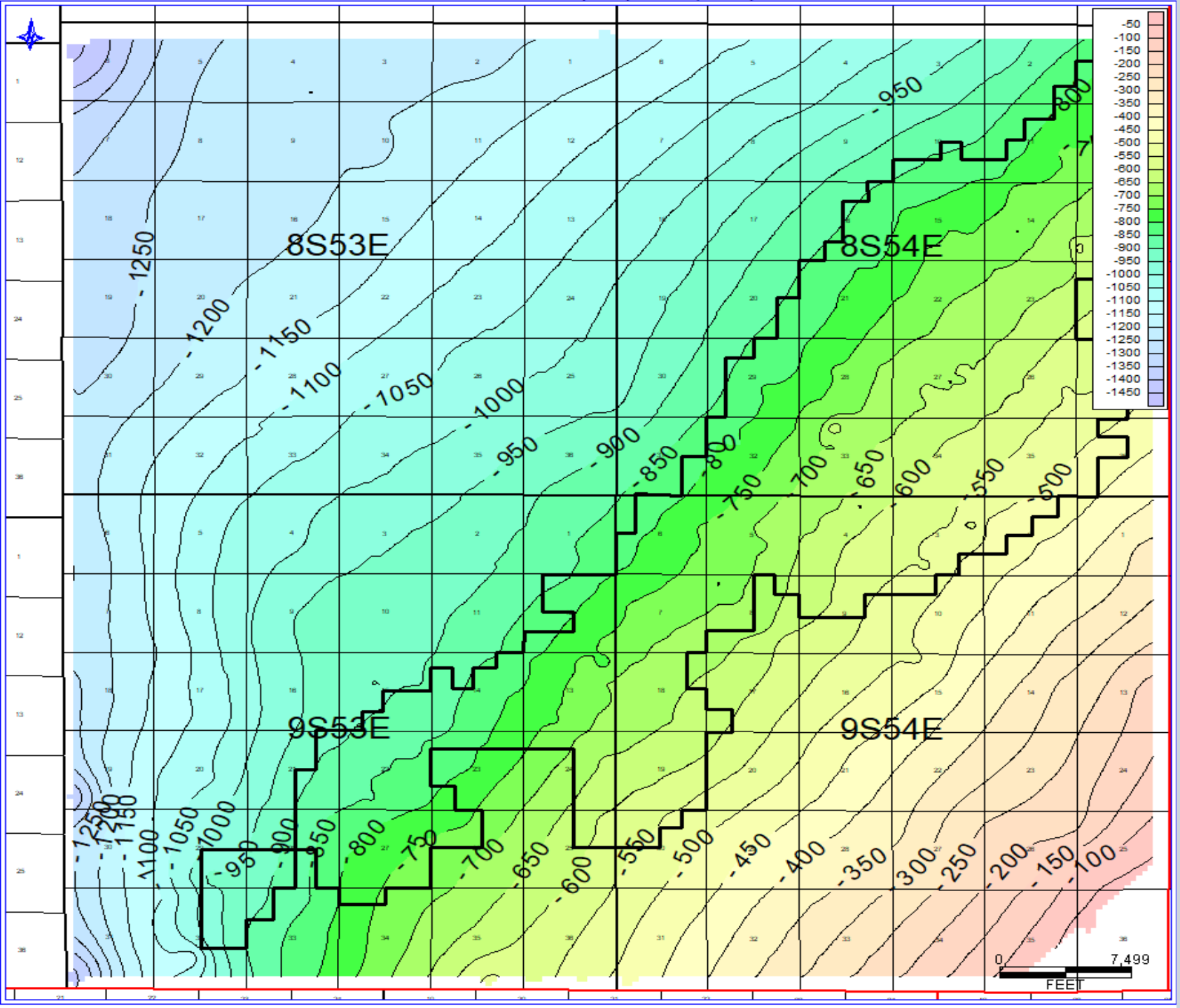


- The Muddy Sandstone is Lower Cretaceous in age and is overlain by the Nefsy/Mowry shale and overlays the Skull Creek Shale
- It consists of two members:
  1. Older deposited in shoreline and nearshore marine environments (Bell Creek Sandstone)
  2. Younger is a valley fill deposit of fluvial, estuarine 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

(Weimer, 1988)

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



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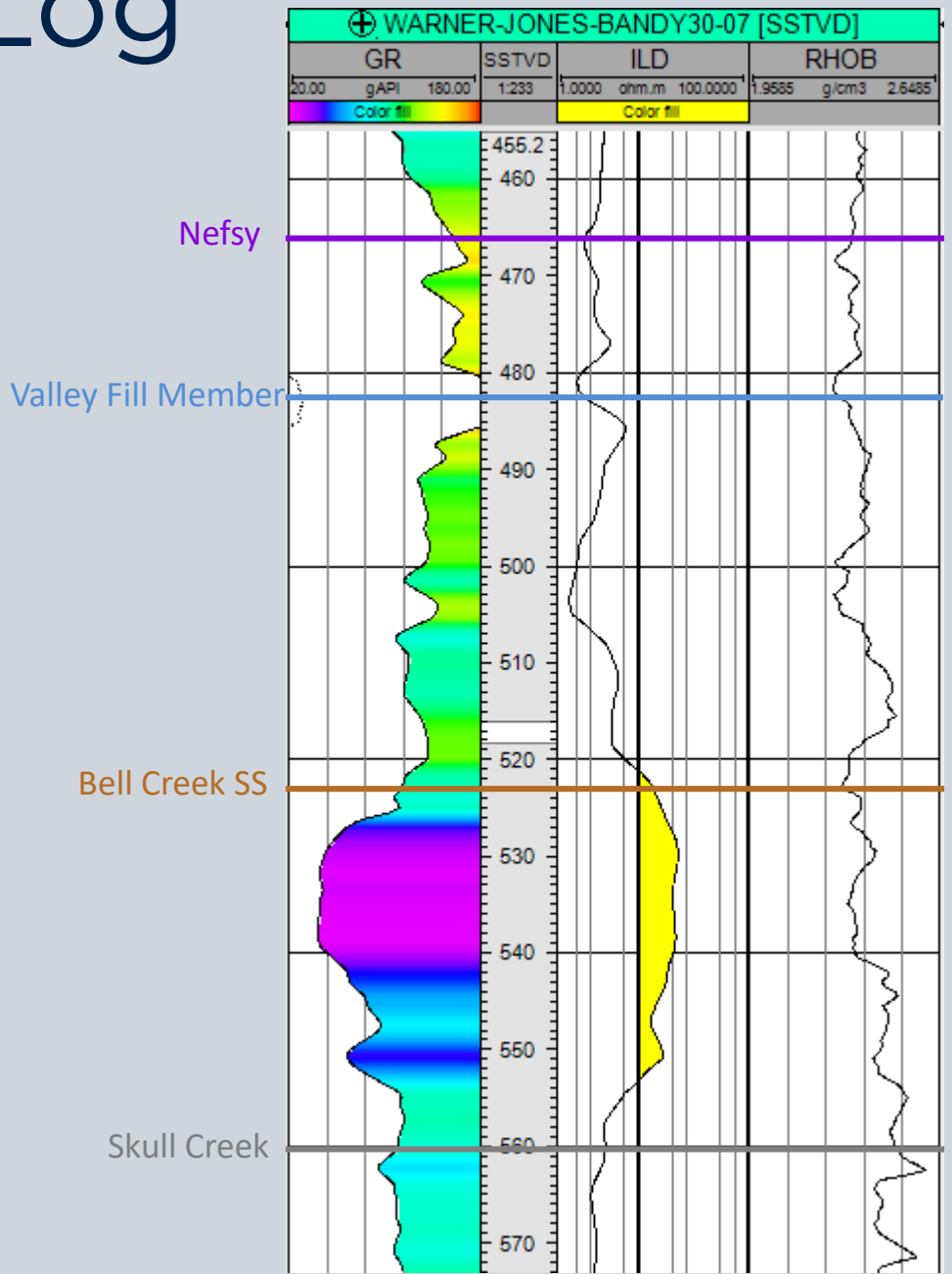
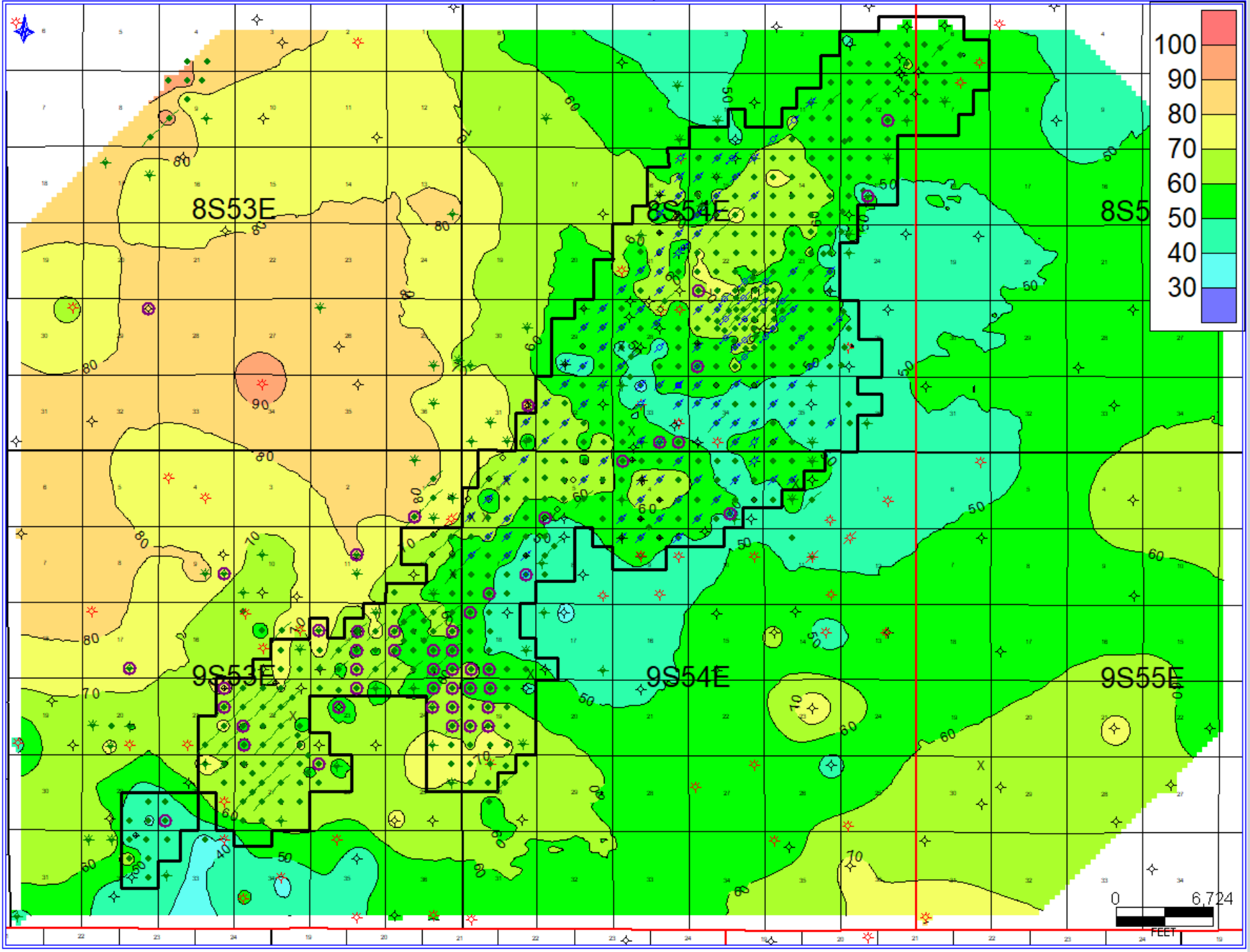
Muddy Structure Map

Type Log

- **Well:** Warner-Jones-Bandy 30-7

- Using gamma, resistivity, and bulk density top markers throughout the field for consistent picking
- Seal: Nefsy and Valley Fill member of the Muddy Sandstone
- Reservoir: Bell Creek Sandstone below the LSE





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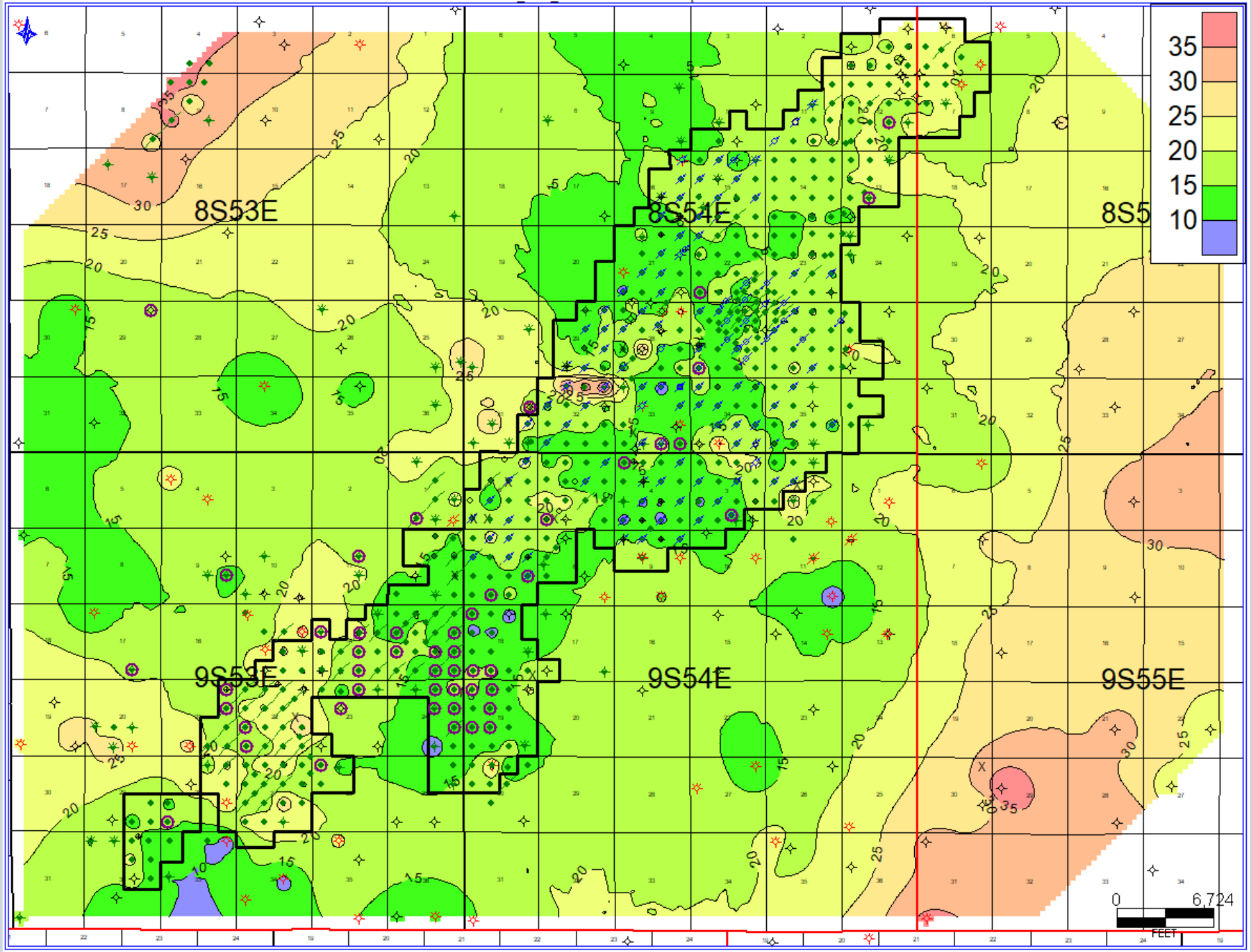
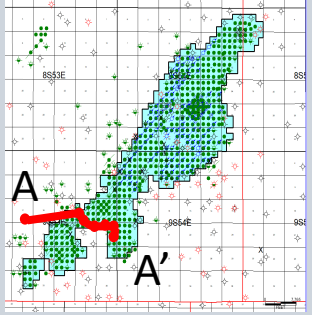
Muddy SS Gross Interval Isopach CI: 10ft

- Cored Wells



Valley Fill Isopach CI: 5ft

○ Cored Wells



Log Correlation showing Valley Fill

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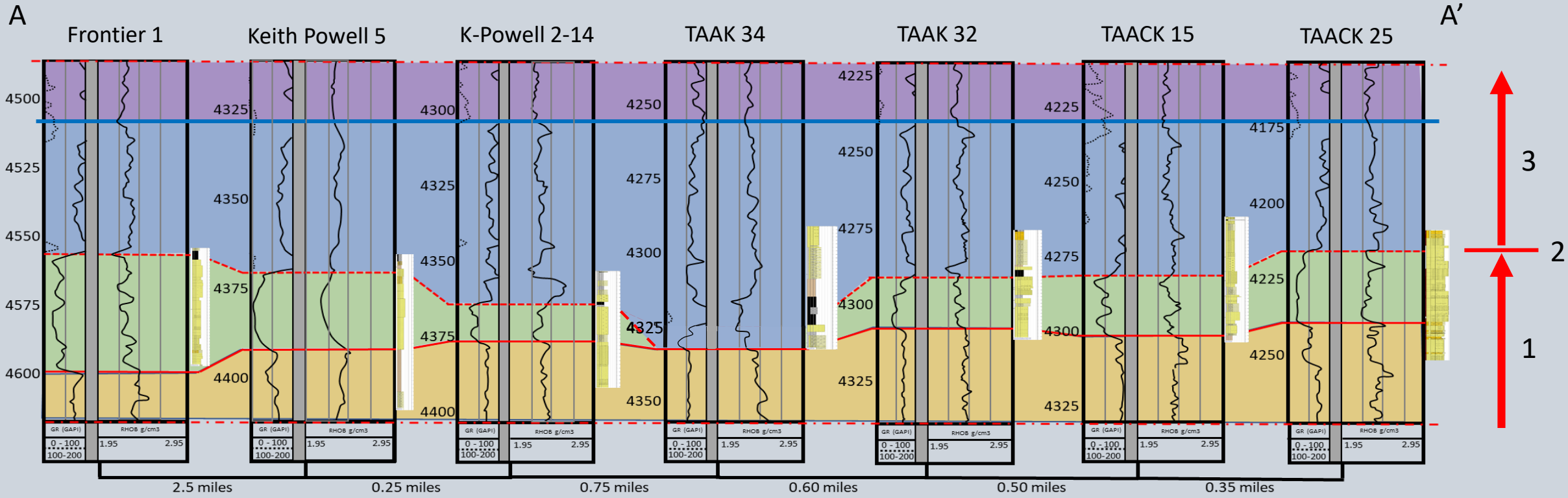


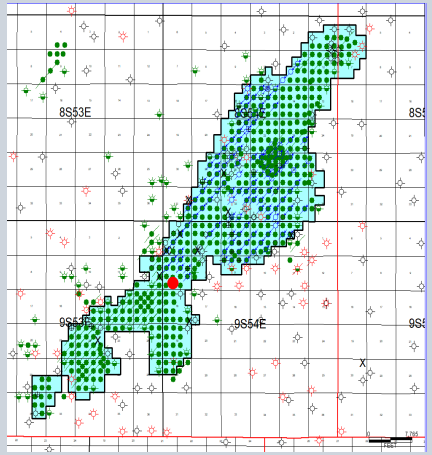
- Nefsy Shale
- Valley Fill Member
- Bell Creek Unit
- Skull Creek Shale
- Interpreted
- LSE
- BC/SC
- Datum- Base of Nefsy

Purple: Marine
Blue: Transitional Valley Fill
Green: Deltaic Shoreline
Orange: Marine

(1) - Sea Level Fall
(2) - Erosion
(3) - Sea Level Rise

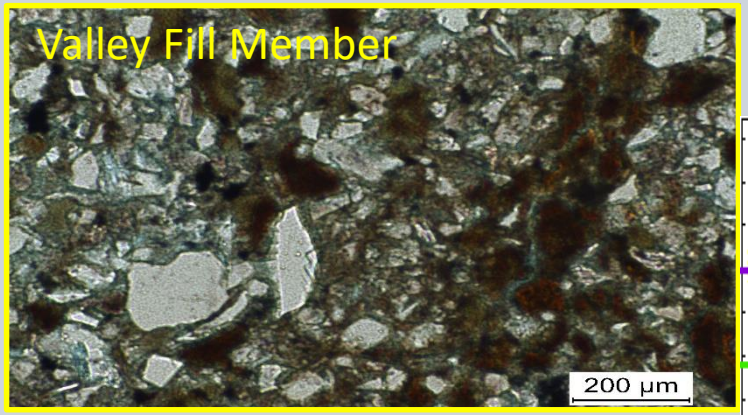
ore/Thin Section Observation

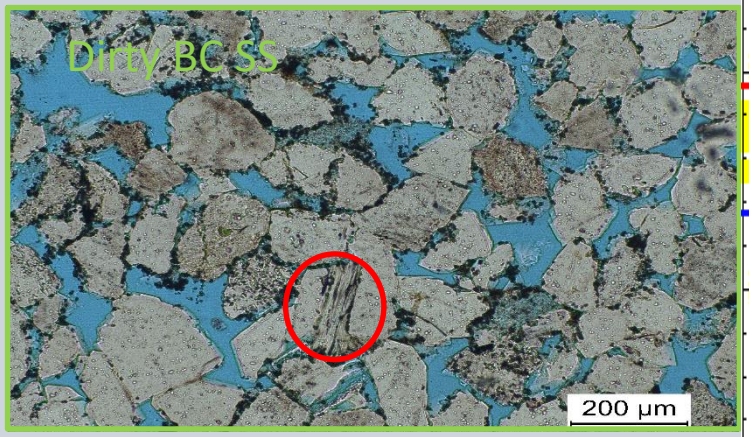
Gary Samuel 7-14

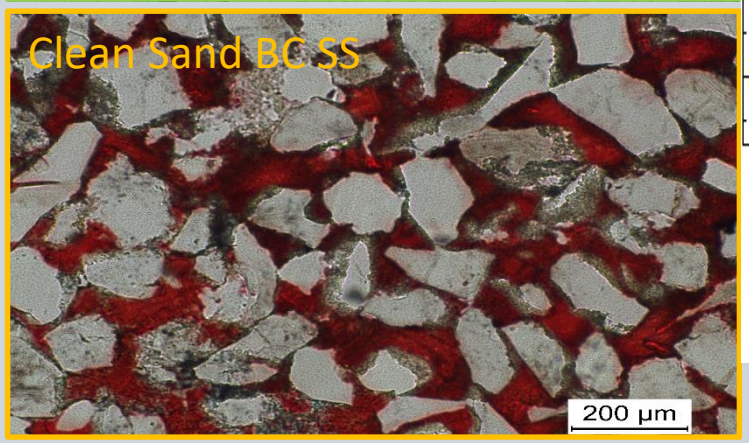


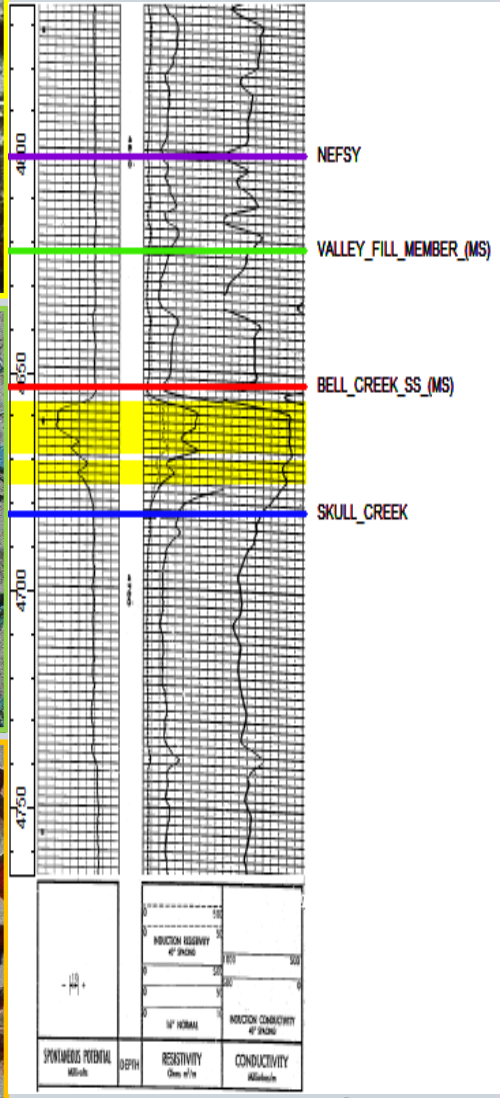
Valley Fill Member

Bell Creek Unit

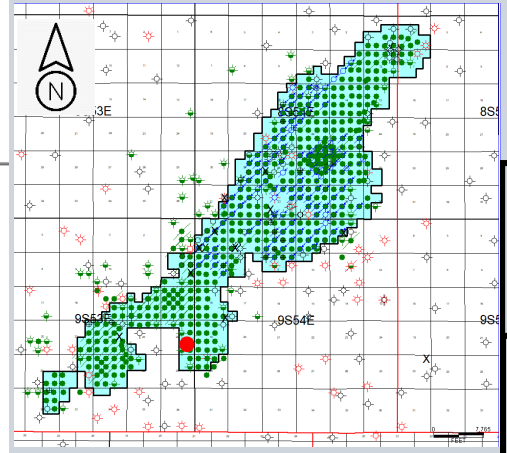


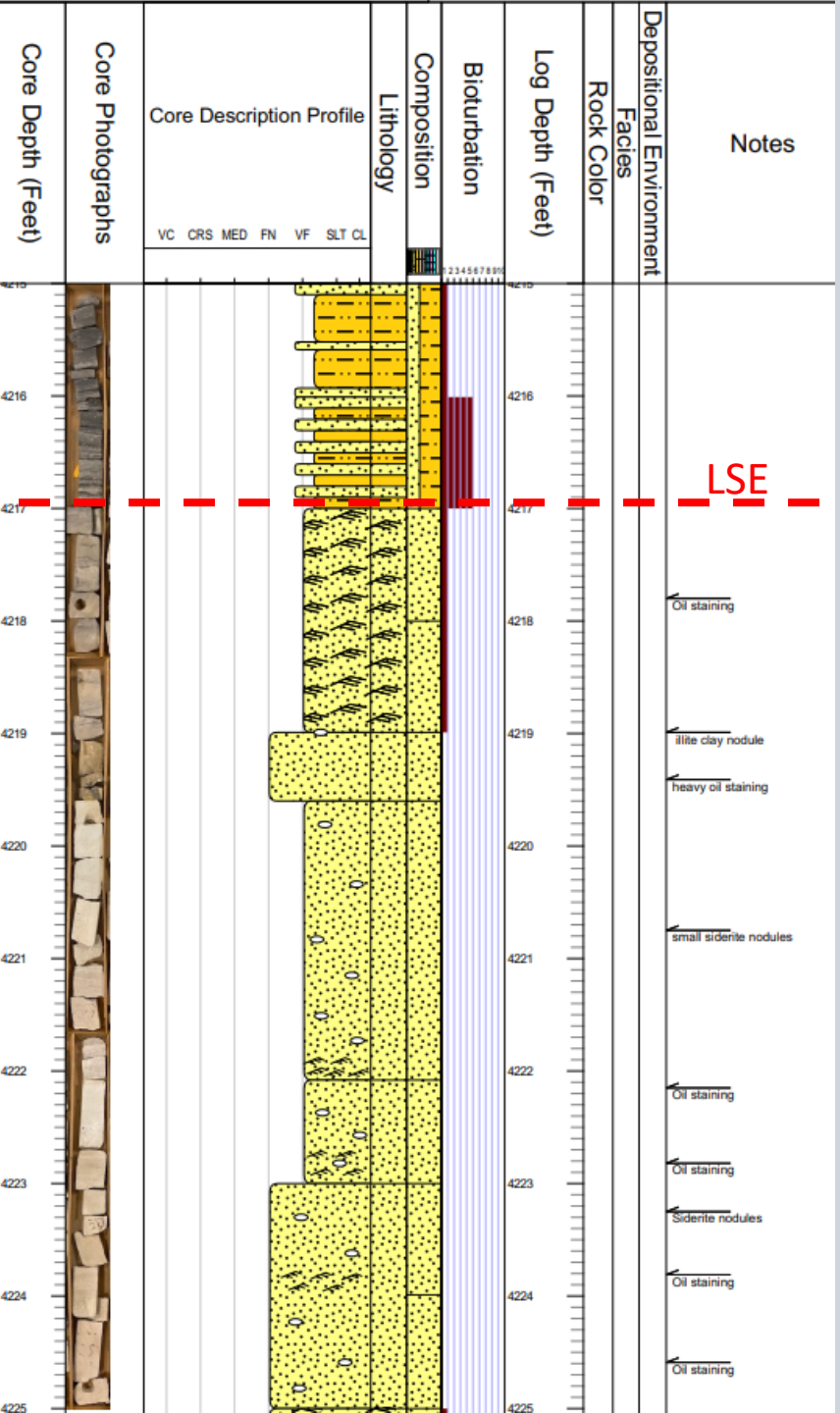


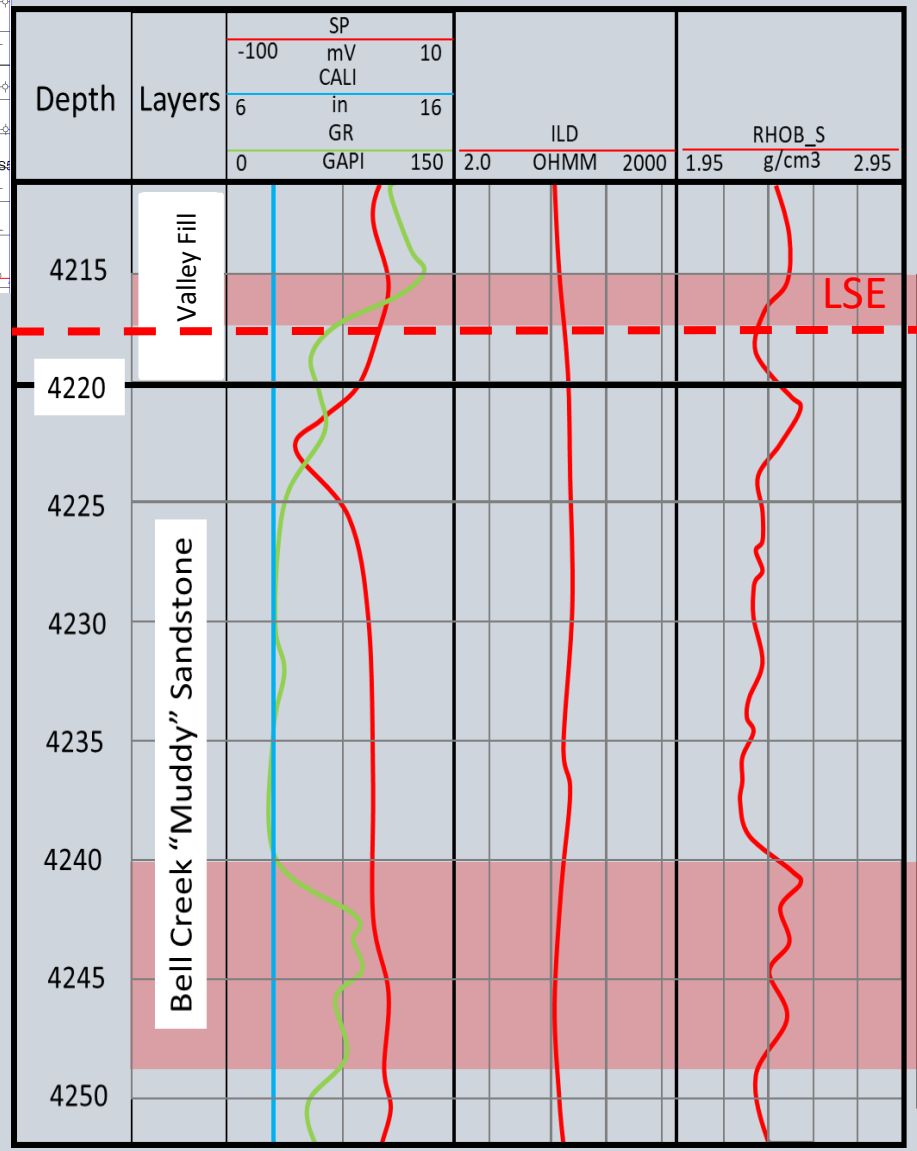




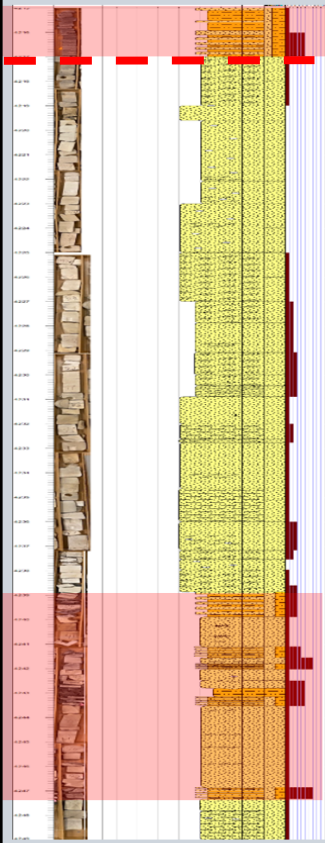
Core Description





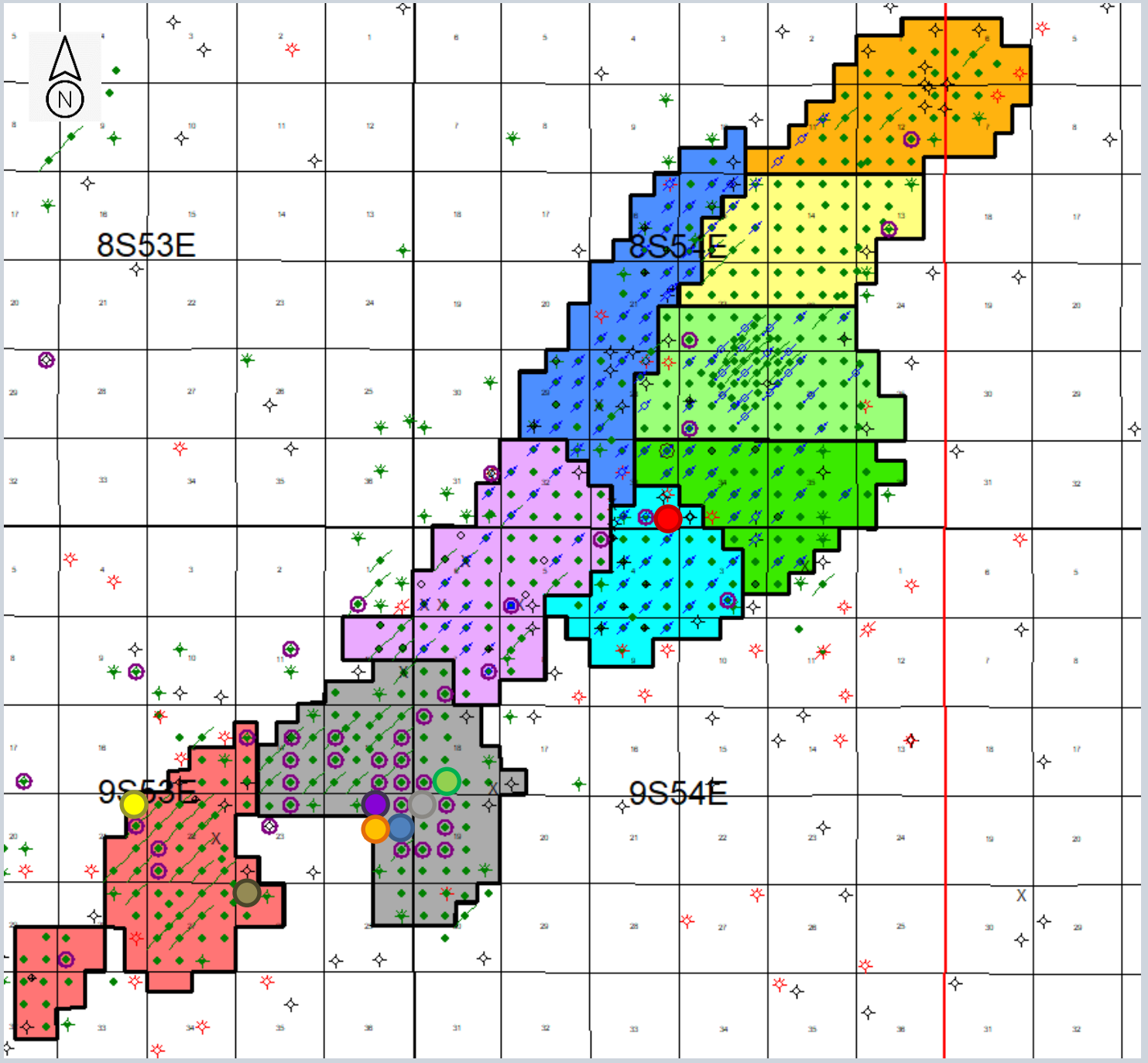


TAACK 25



Well Locations

- TAACK 25
- 12-33 Biddle Land
- TAACK 26
- 21-1 Marie Clements
- TAACK 16
- TAACK 15
- TAACK 23
- 26-4 Keith B Powell



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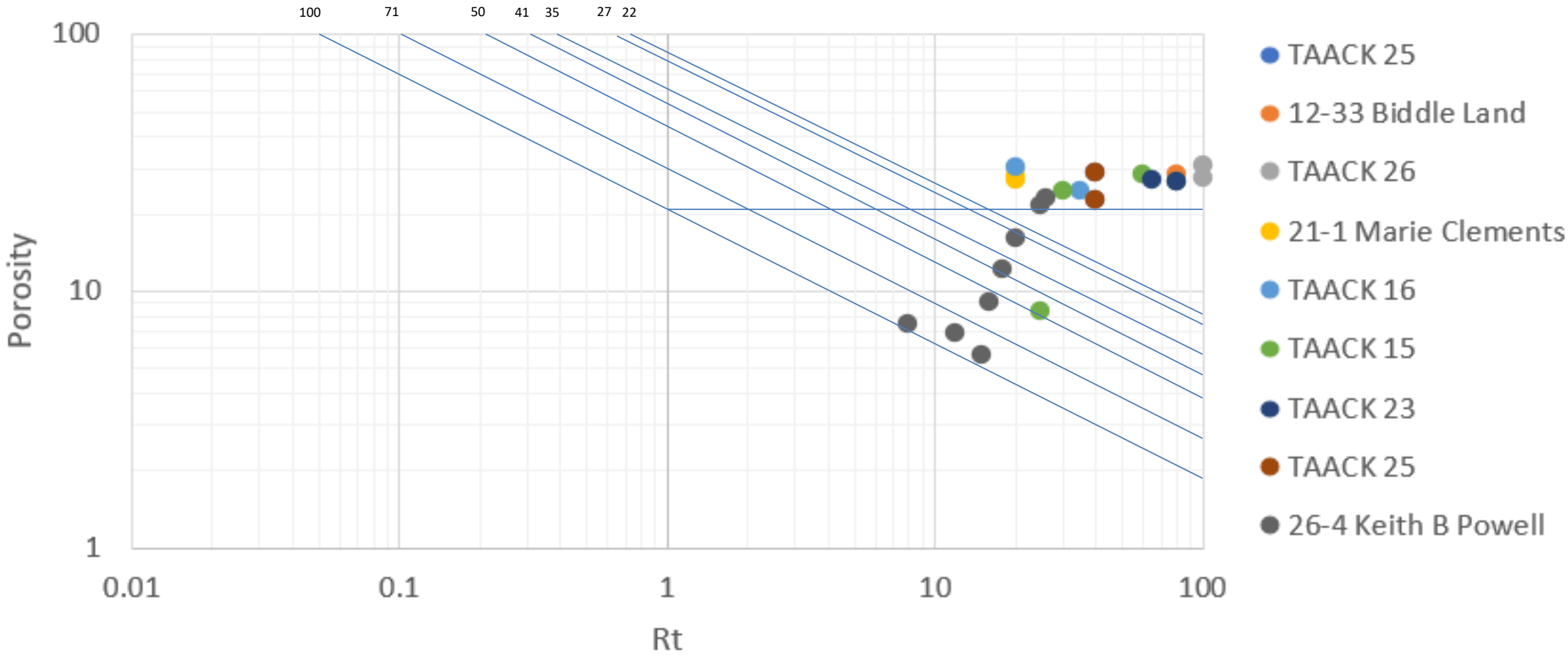
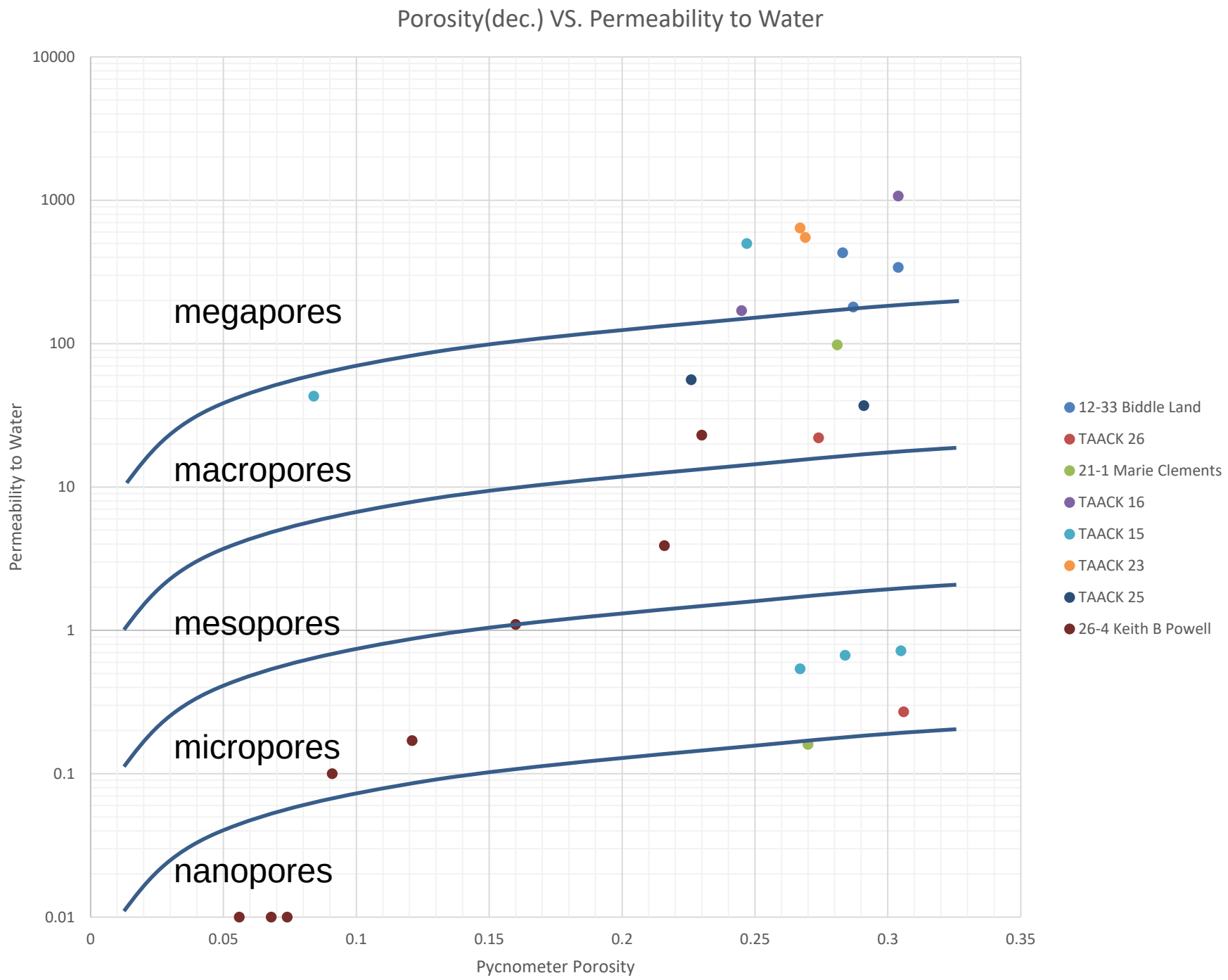
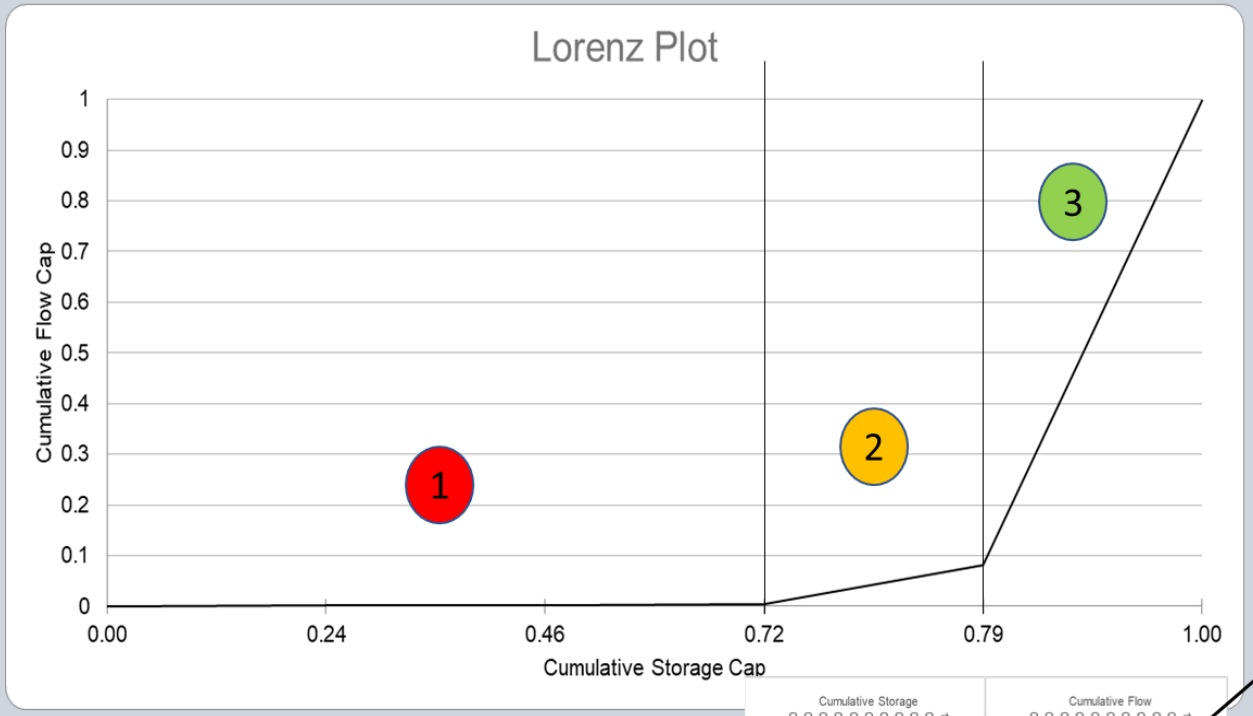
Pickett Plot

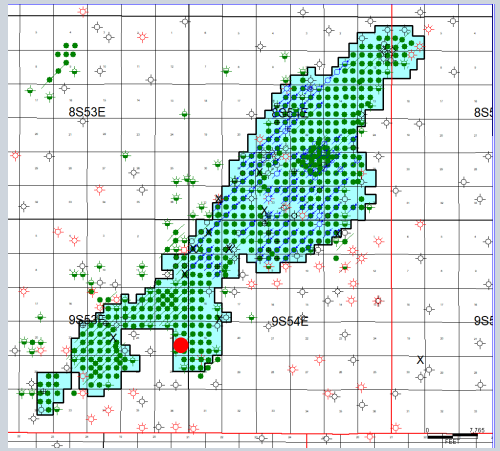


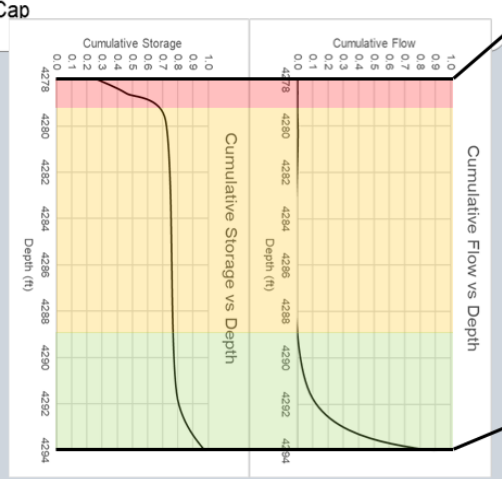

Porosity(dec.) VS. Permeability to Water
Permeability to Water
10000
1000
100
10
1
0.1
0.01
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
Pycnometer Porosity
megapores
macropores
mesopores
micropores
nanopores
12-33 Biddle Land
TAACK 26
21-1 Marie Clements
TAACK 16
TAACK 15
TAACK 23
TAACK 25
26-4 Keith B Powell

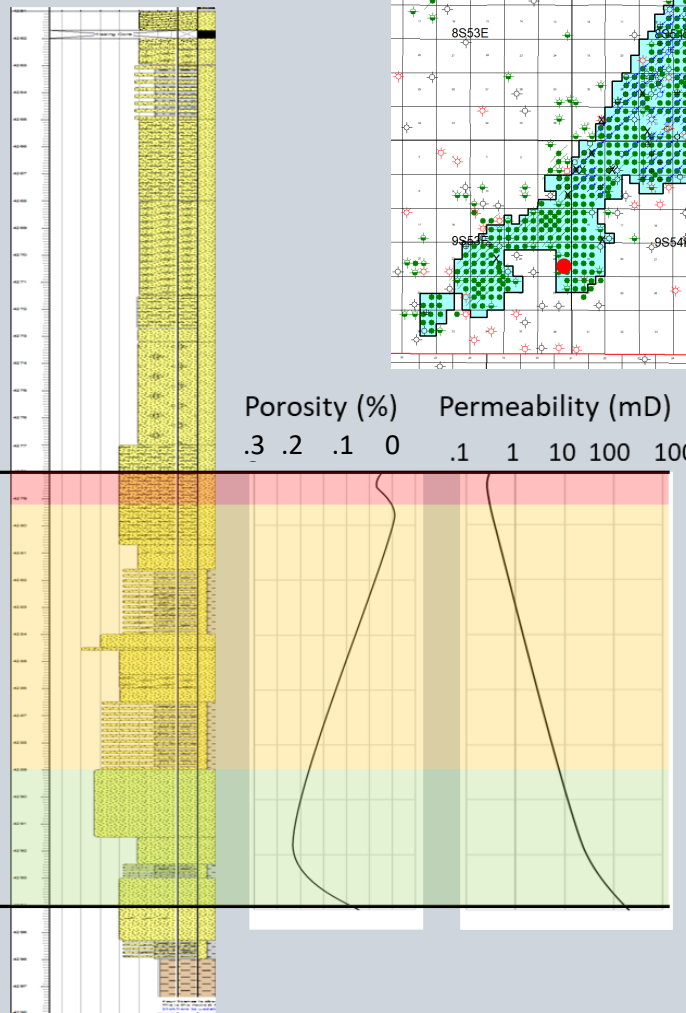
Flow Units from Core



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







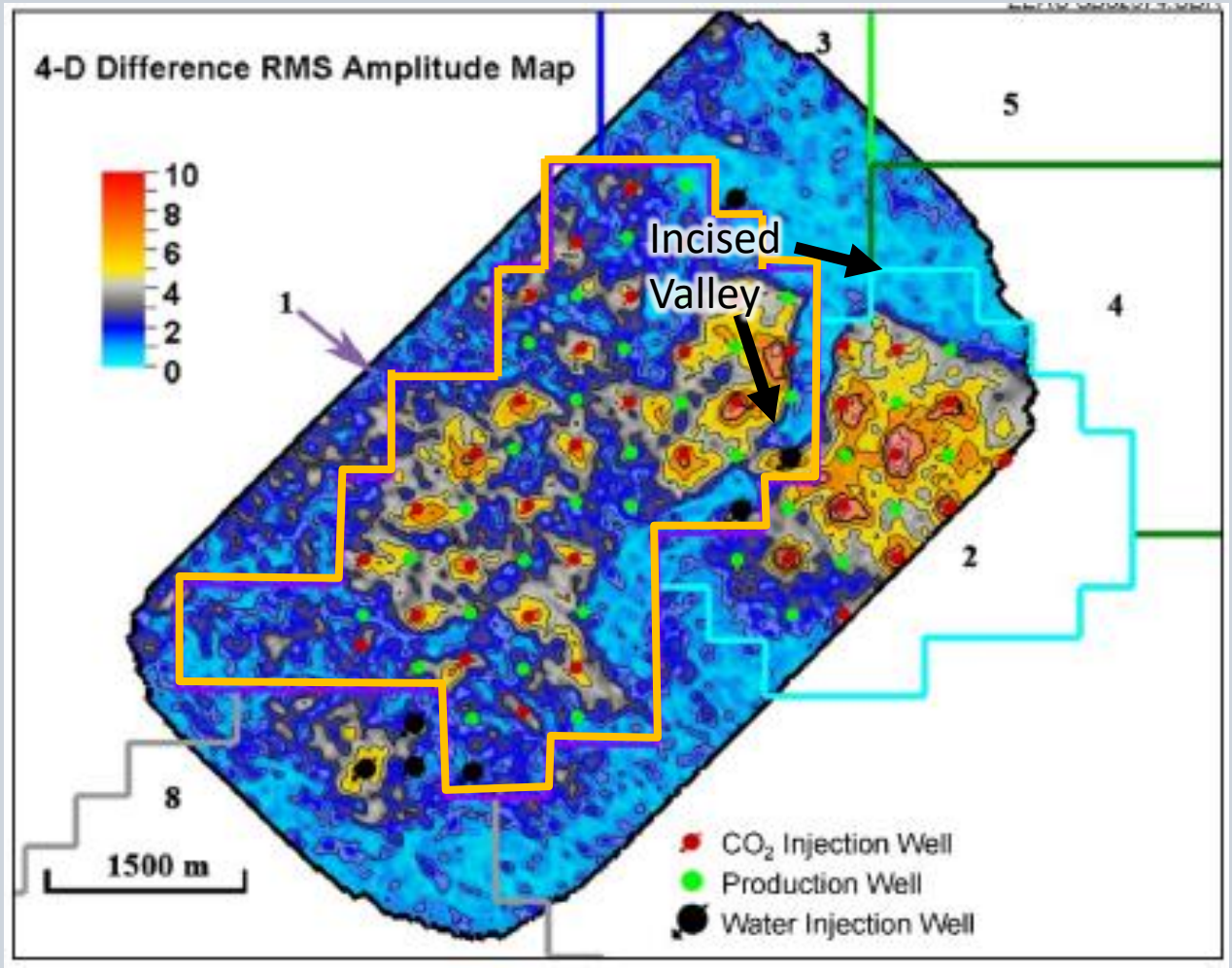
1 Poor Flow Unit

2 Good Flow Unit

3 Great Flow Unit

4D Seismic of Injection of CO_2

- 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_2



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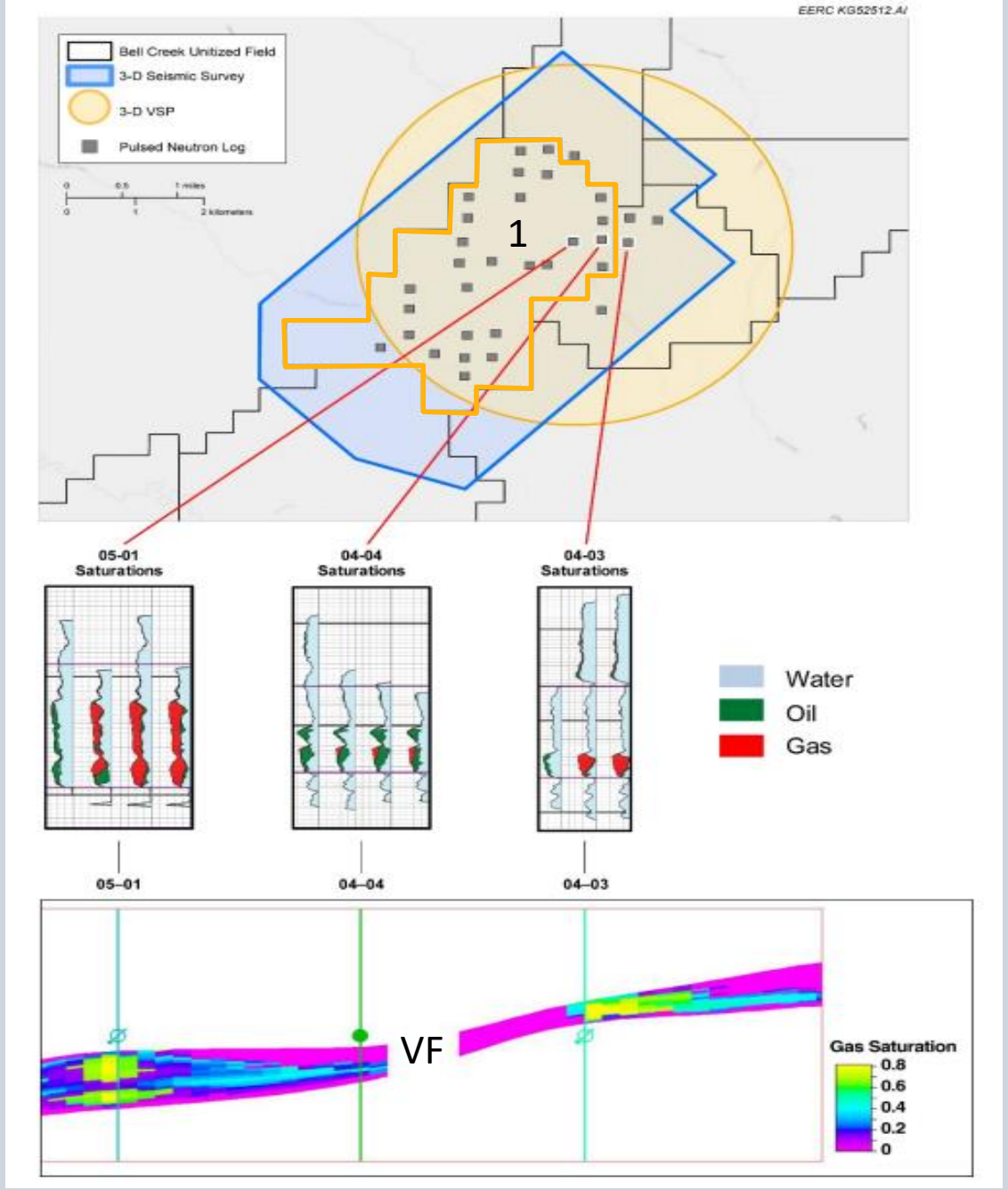
Gas Saturation through Well Data

- Showing CO_2 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



Hamling / Energy Procedia 00 (2017) 000–000)

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_2
- Migration of CO_2 is affected 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 can accurately identify the split of the Valley Fill Member and the Bell Creek Sandstone

Future Work

- Continue performing petrographic work on thin sections to analyze porosity and permeability distribution in the core and mineralogical difference between the lower Valley Fill Member sand and the upper Bell Creek Unit sand.
- Remapping the Bell Creek Sandstone based off core location and matching the log patterns
- Optimizing locations for future injection into the field

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