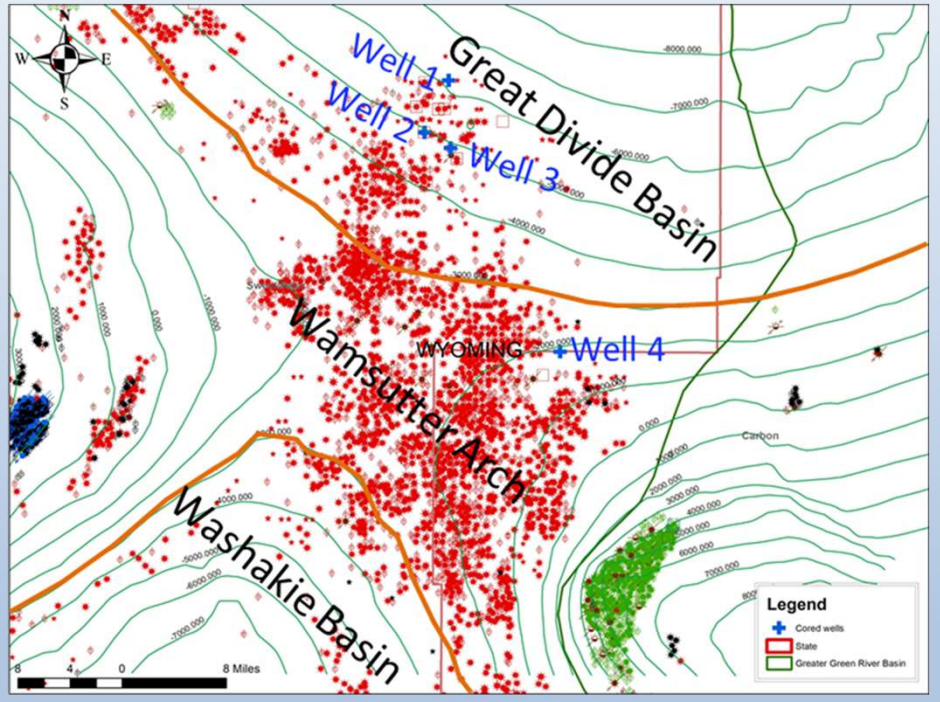
Carolina Mayorga G, PhD, Spring, 2022

RESERVOIR QUALITY AND WELL PERFORMANCE ANALYSIS IN THE MIDDLE MEMBER OF THE LEWIS SHALE, GREATER GREEN RIVER BASIN, WYOMING

Objectives

- Develop a high-resolution reservoir characterization:
  - Identify the best intervals for development.
  - Determine possible challenges and risks related to mineralogy, diagenetic processes.
  - Compare the most common completion techniques.

- To add information on the Great Divide Basin where there is scarce well control.

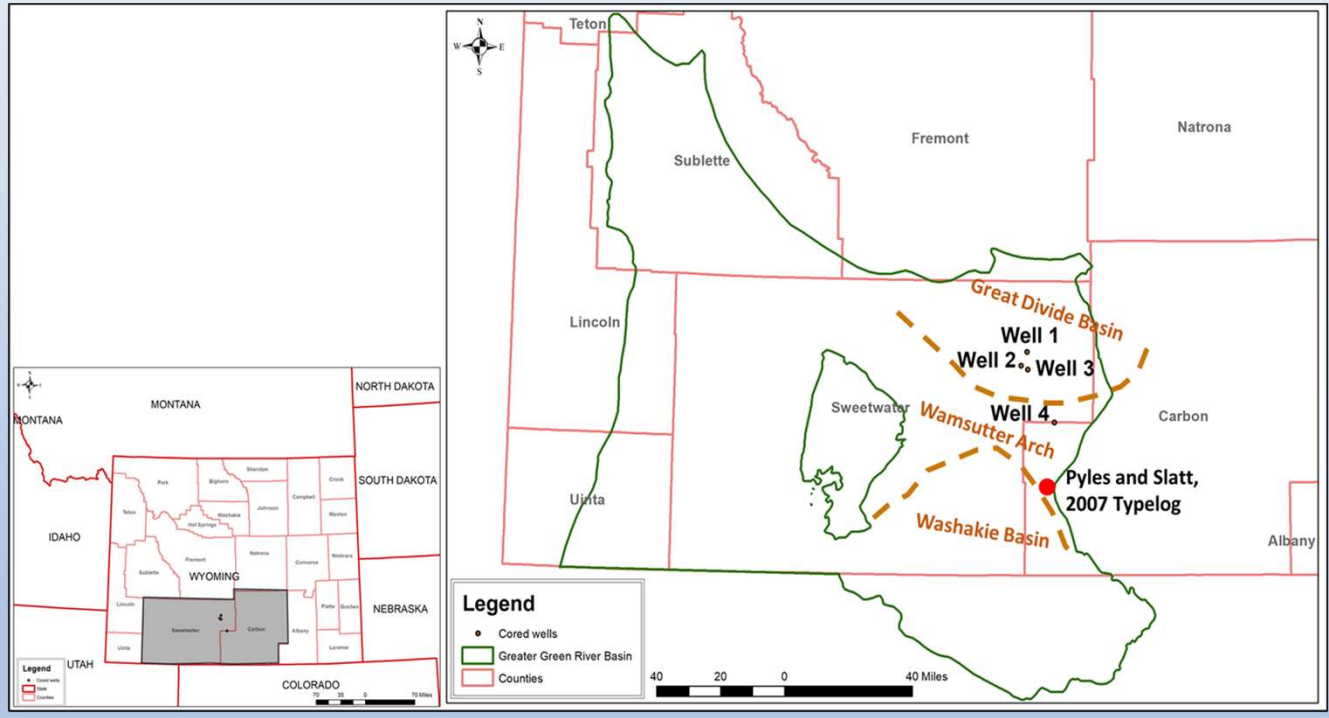


Outline

- Location and methods
- Geological setting
- Paper 1
  - Core description and facies
  - Petrographic and mineralogical analyses
  - Chemostratigraphy
  - Subsurface Mapping
- Paper 2
  - Petrophysical model
- Paper 3
  - Environmental Stipulations
  - Completion techniques and production

Location of study area and methods

- ~ 1800 wells correlated in the basin.
  - Isopach maps



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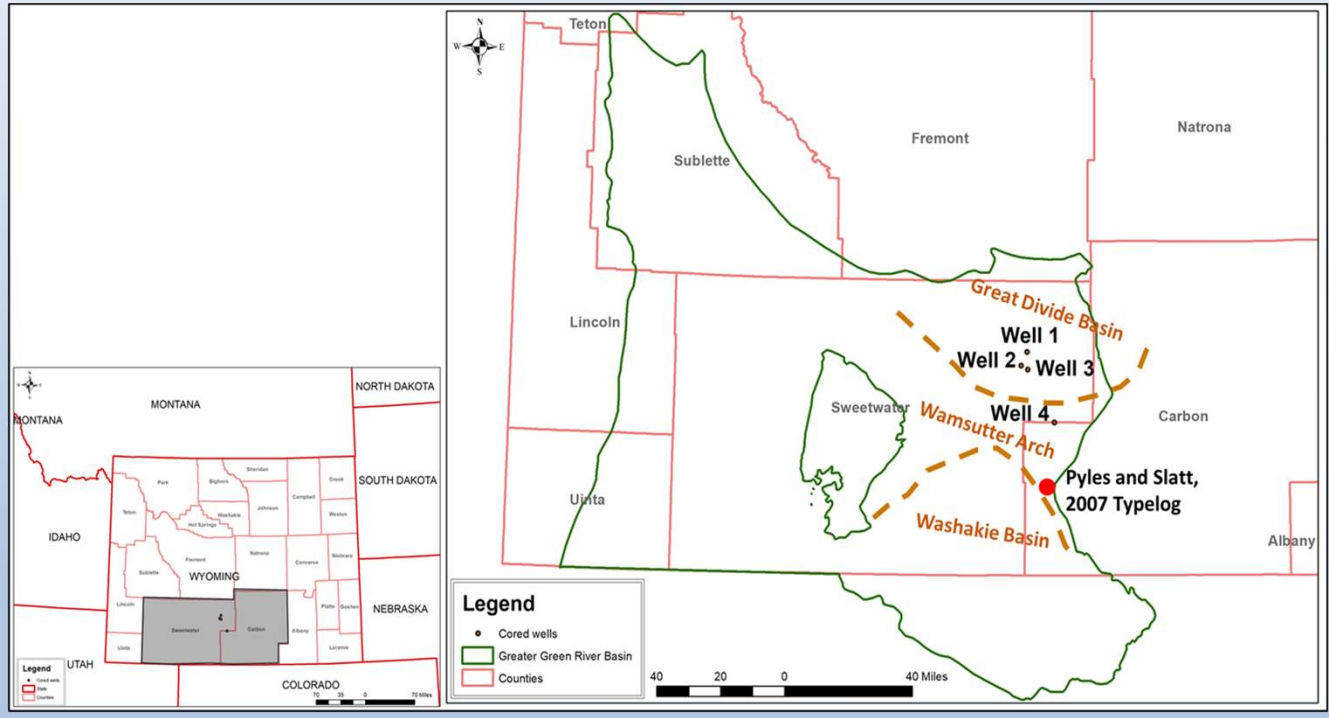
- 3 cores on the Great Divide Basin.
  - Well 1: 457 ft
  - Well 2: 92 ft
  - Well 3: 177 ft



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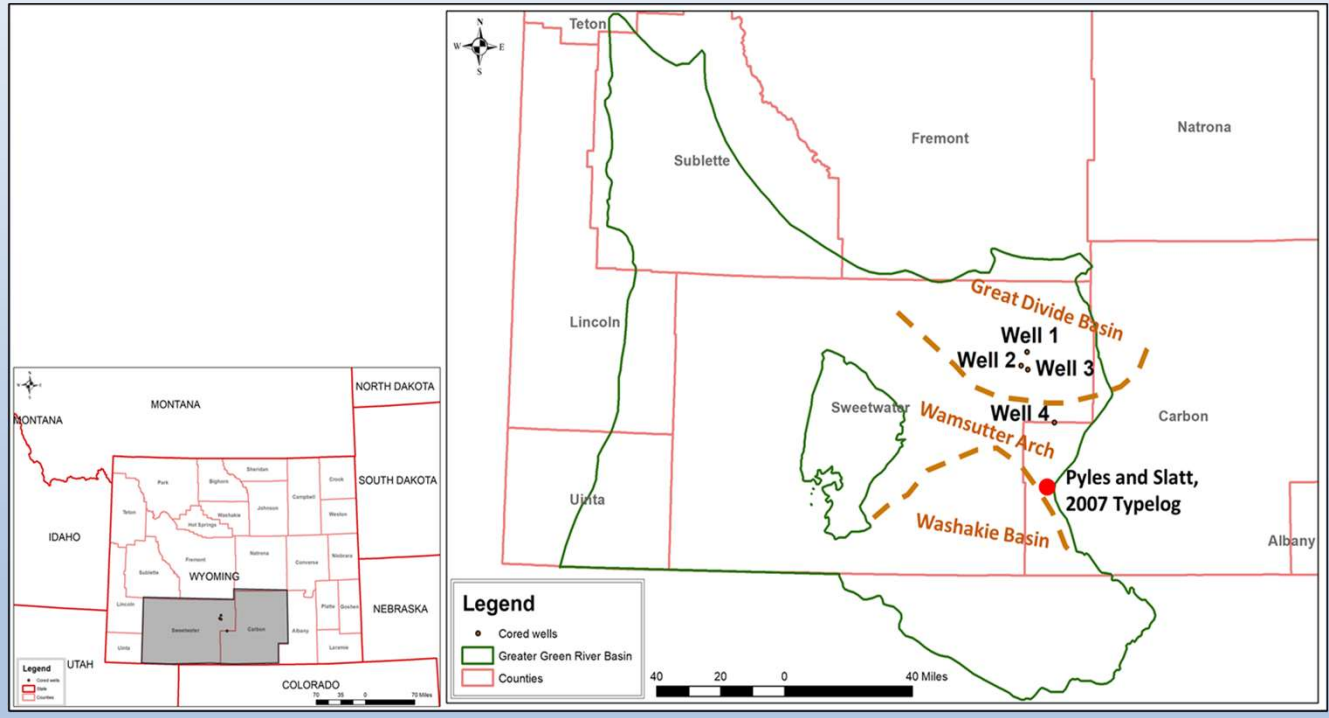
- 1 core on Wamsutter Arch.
  - Well 4: 90 ft
- Total= 816 ft of core.



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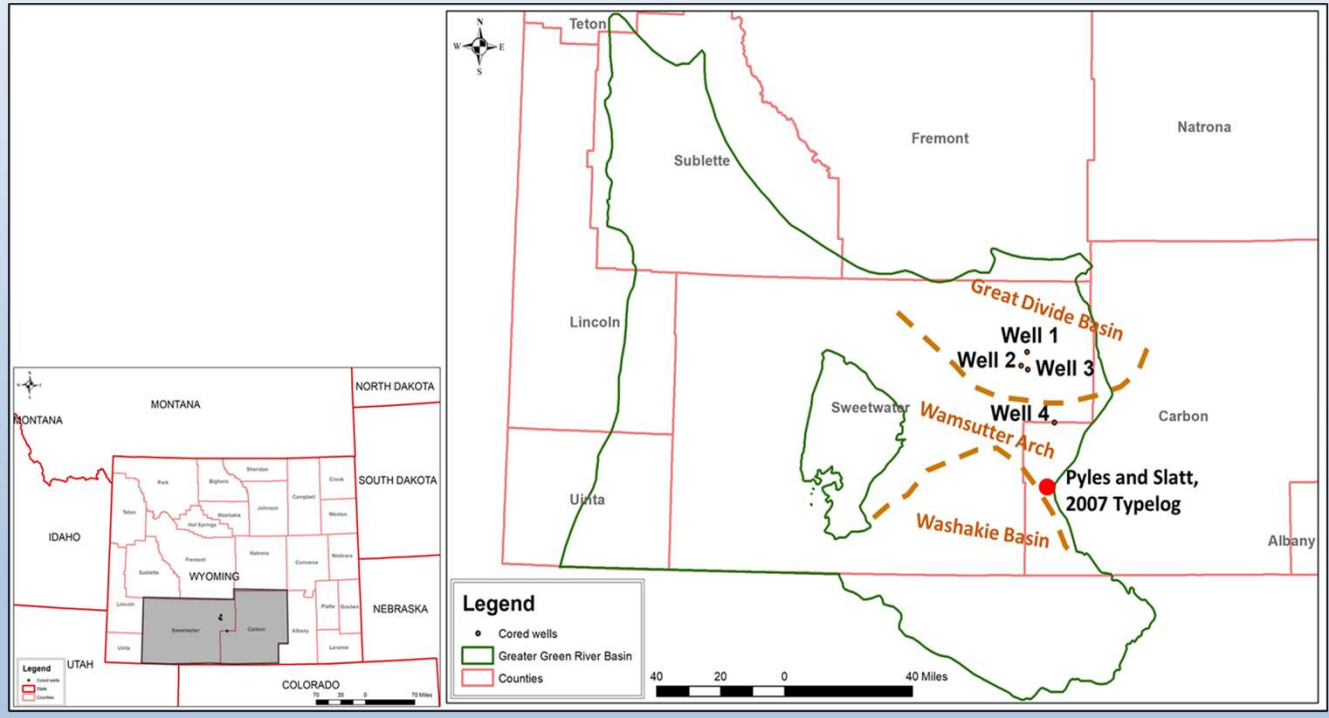
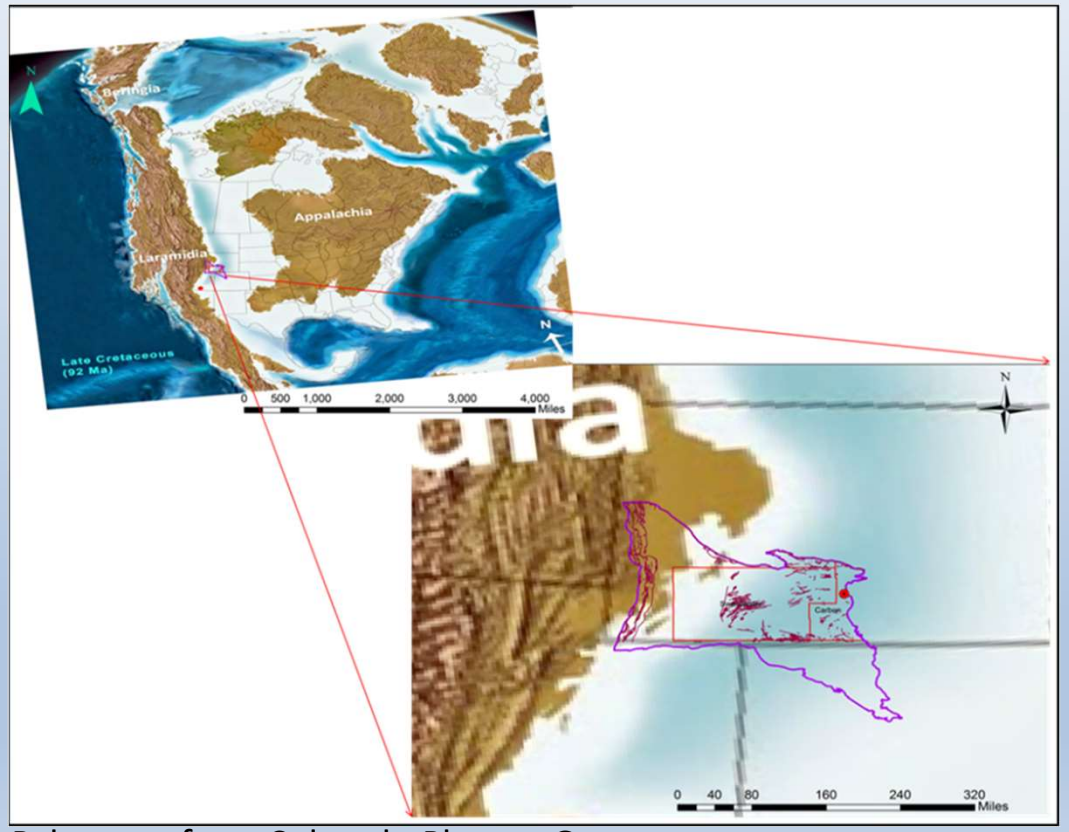
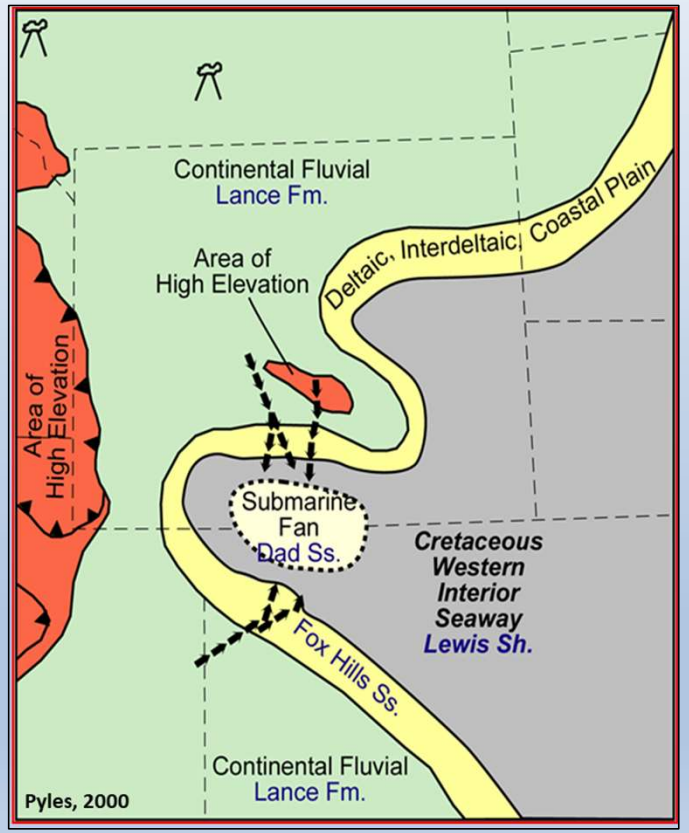
- Total= 816 ft of core.
- XRF measurements every 0.5 ft in each core (1632 in total).
- 57 XRD analyses in total.
- 42 thin sections in total.
- 176 RCA in total.
- Production data for 33 horizontal wells in the area near the cored wells.



Geological setting



Paleomap from Colorado Plateau Geosystems Blakey, 2004



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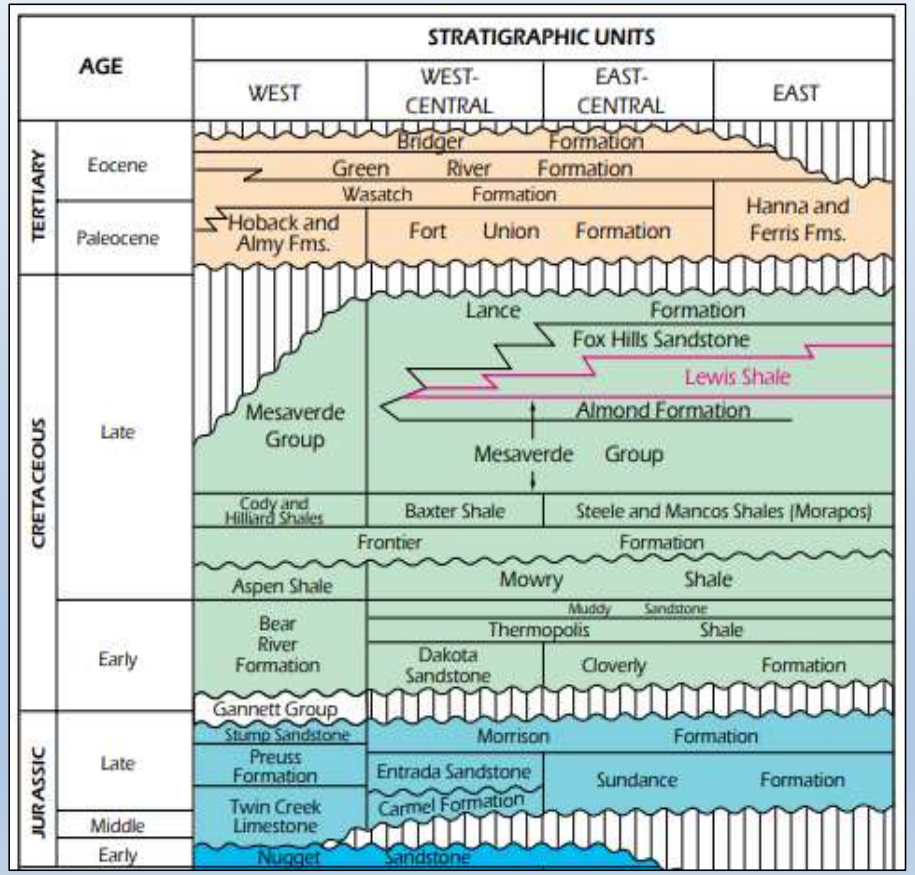
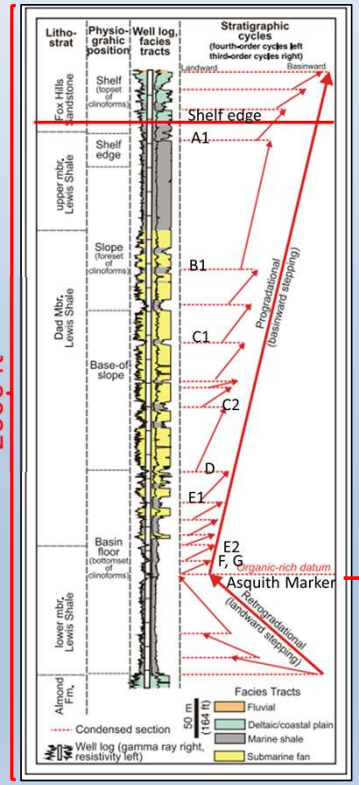
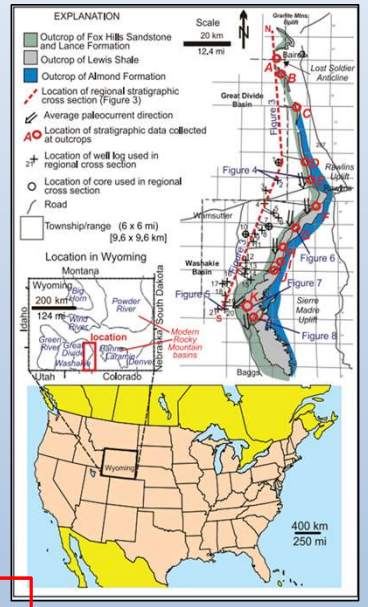


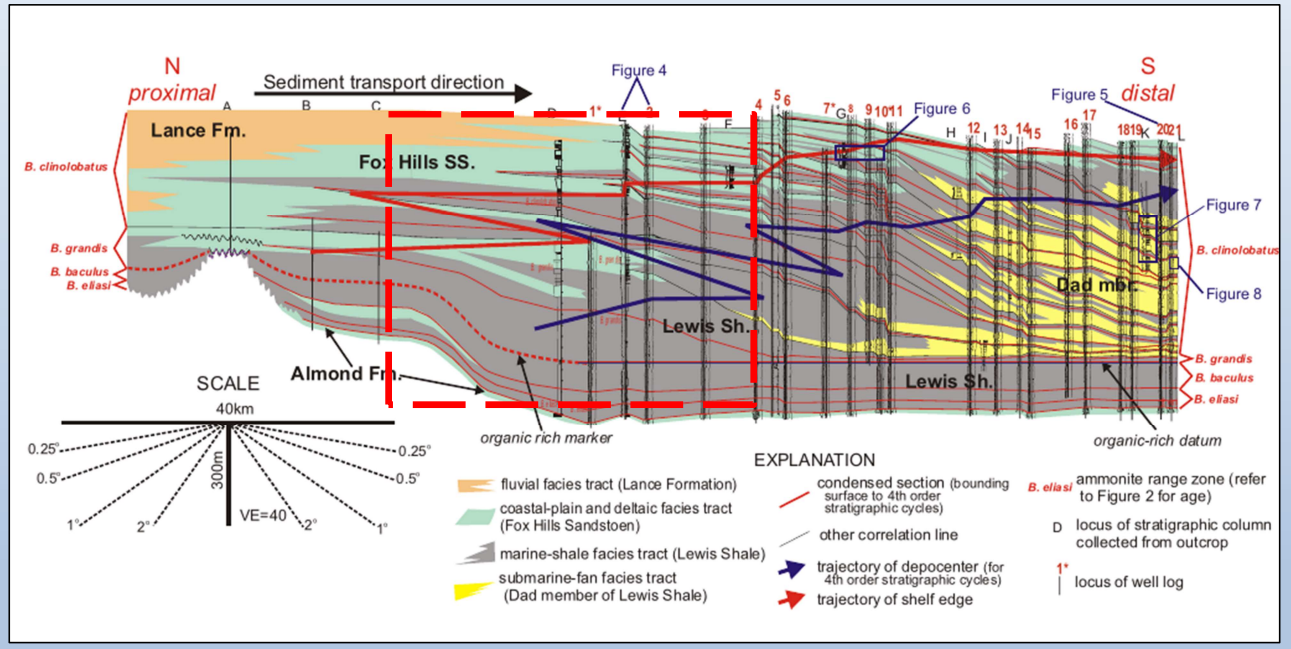
Hettinger and Roberts, 2005.

Sequence stratigraphic framework





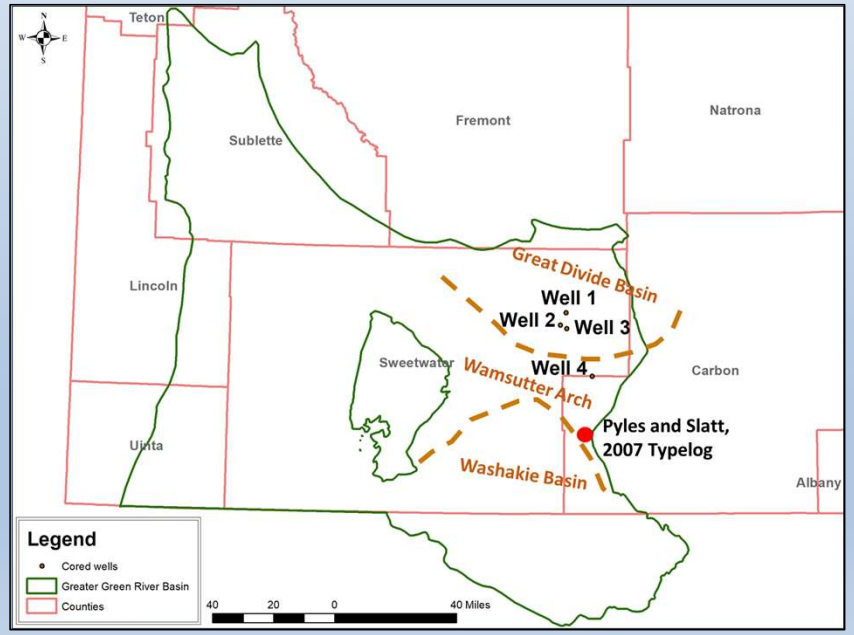
mfs
TOC: 0.5-3.89%
Ro%:0.72-1.25

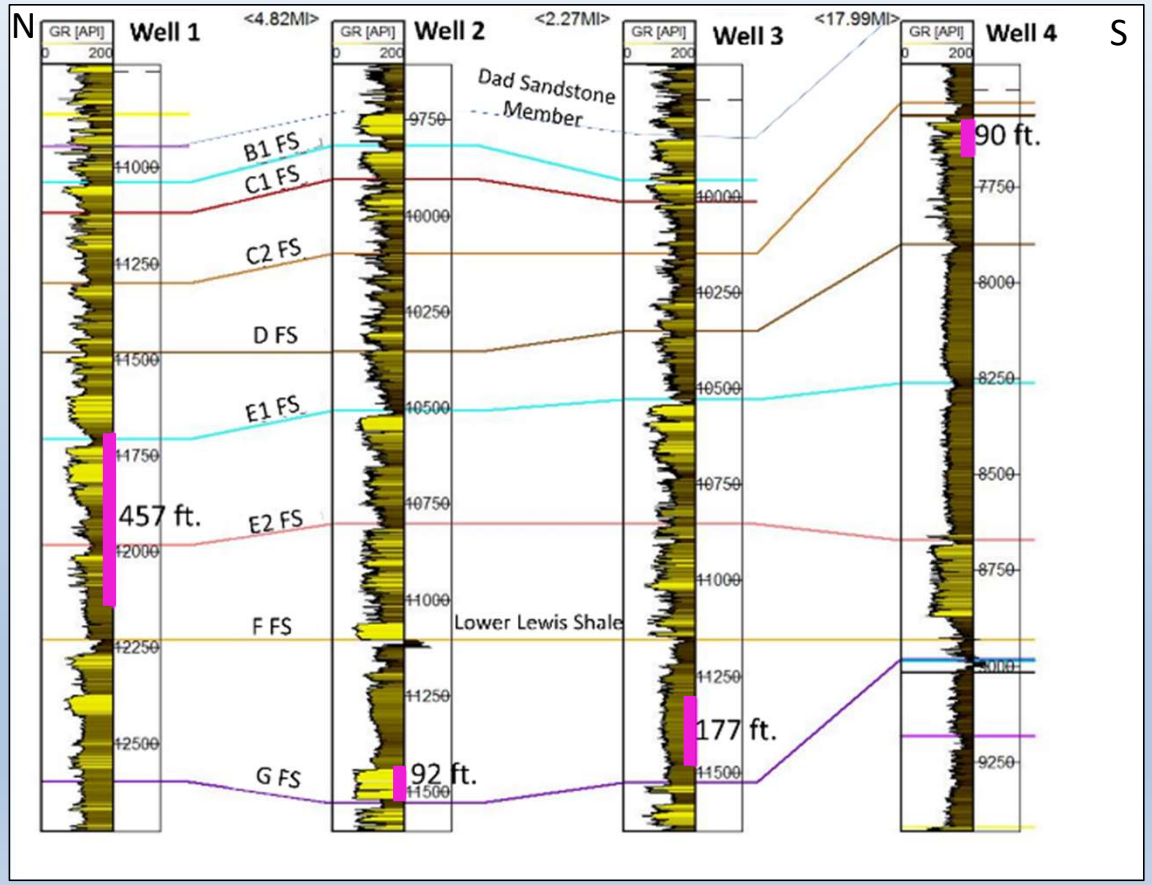


Modified from Pyles and Slatt, 2007

Correlated cored packages

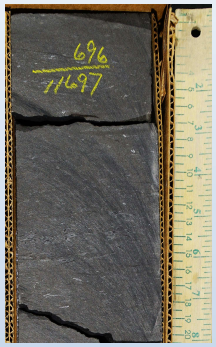
G wells :183,287 bbls
G wells gas: 1,075,529 MCF (From 2019-2021)
F wells: 177,068 bbls
F wells gas: 3,109,929 MCF (From 2019-2021)
API: 50-60



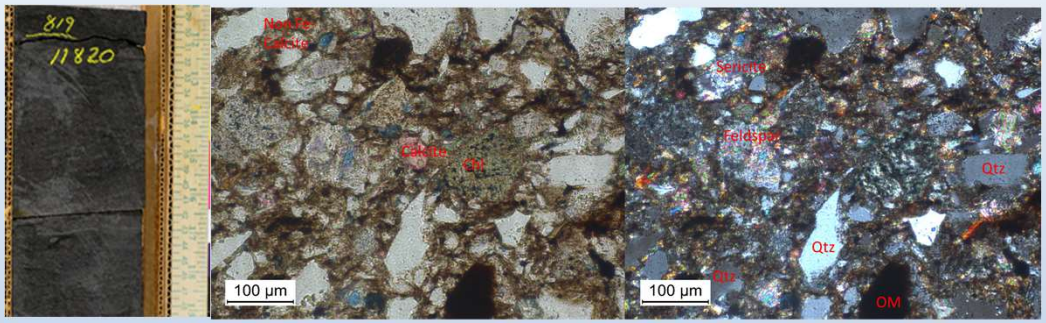


Reservoir characterization

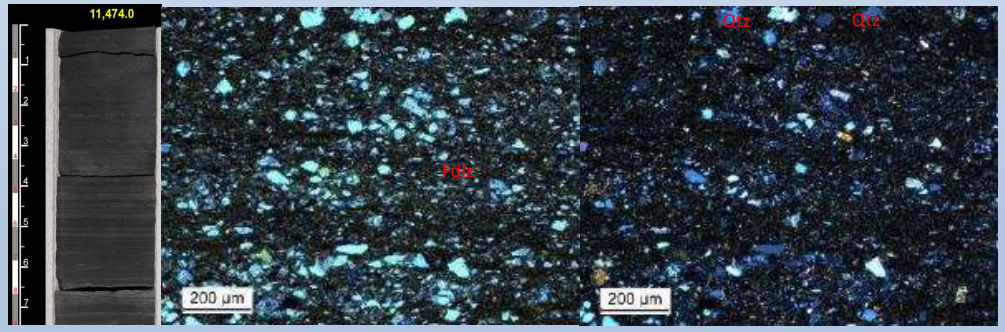
Facies classification



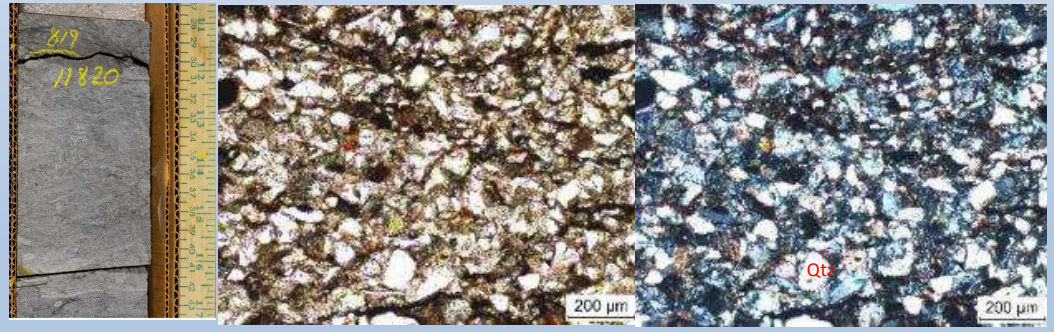
(Facies 1) Bioturbated Siliceous Mudstone.



(Facies 2) Bioturbated sandy Siltstone.



(Facies 3) Finely laminated bioturbated Siltstone.

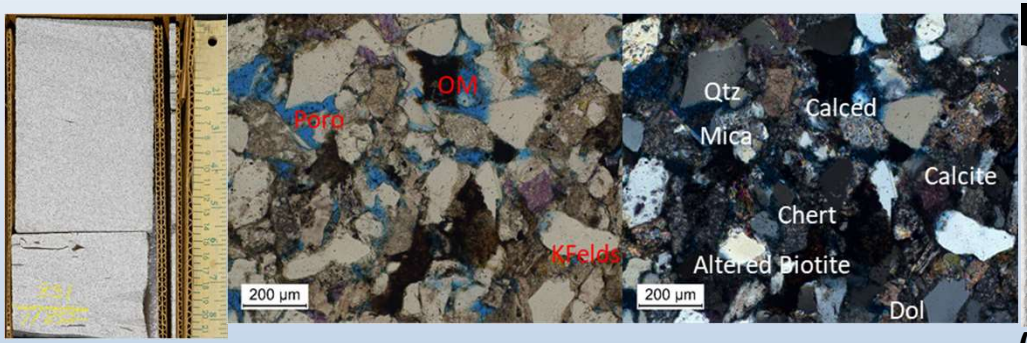


(Facies 4) Bioturbated Silty Sandstone.

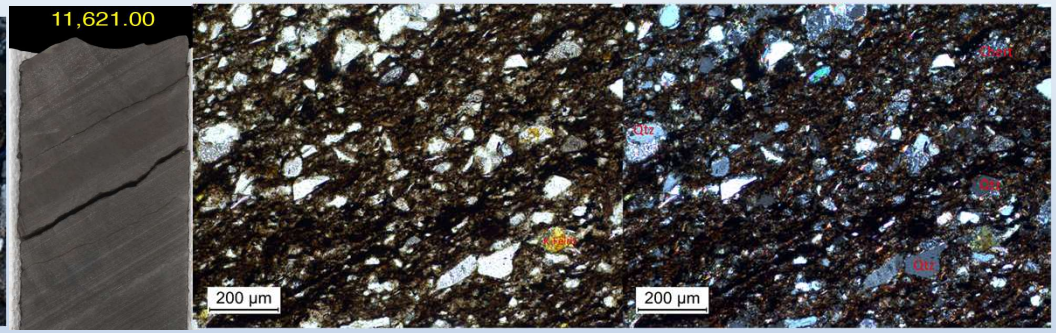
- Massive sandstone
- Finely Laminated sandy siltstone
- Bioturbated Sandy Siltsone
- Finely Laminated bioturbated Siltstone
- Finely laminated silty sandstone
- Contorted Beds
- Bioturbated Silty Sandstone
- Bioturbated Siliceous Mudstone

- Channel
- levee-Overbank
- Channel-levee

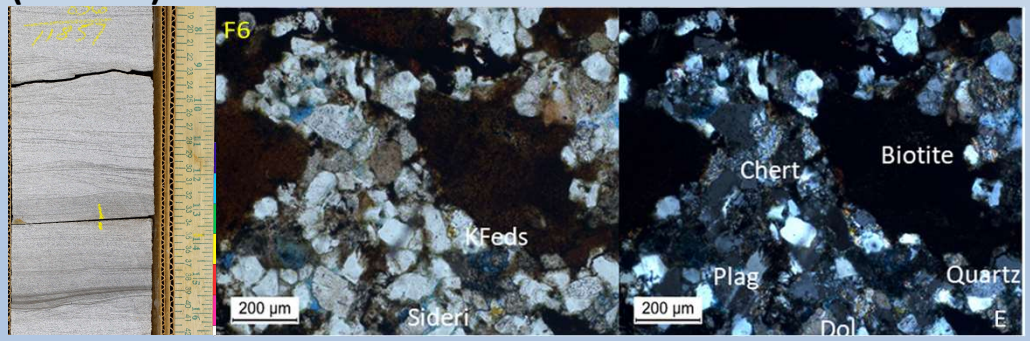
Facies classification



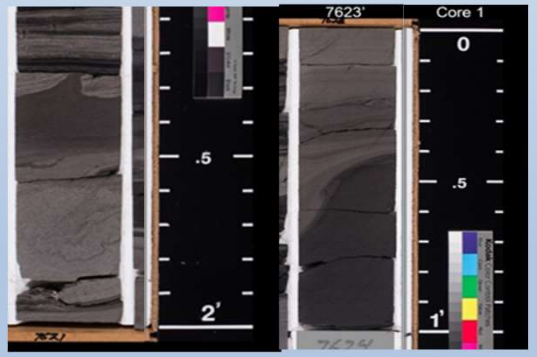
(Facies 5) Massive Sandstone.



(Facies 6) Finely laminated Sandy Siltstone.



(Facies 7) Finely laminated silty Sandstone.

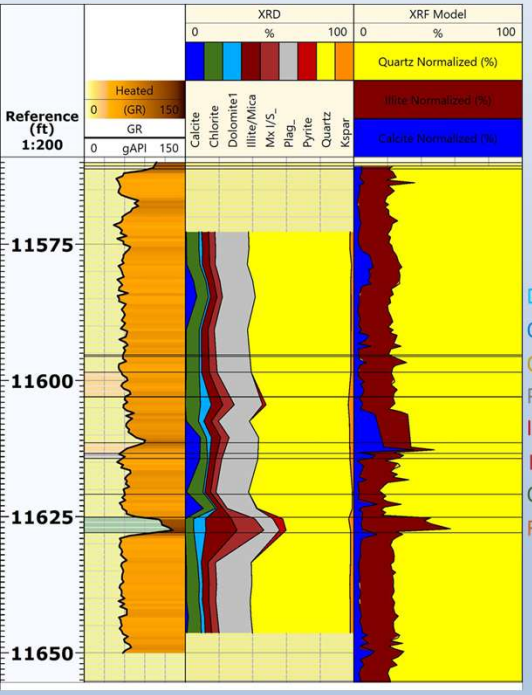


(Facies 8) Contorted beds.

- Massive sandstone
- Finely Laminated sandy siltstone
- Bioturbated Sandy Siltsone
- Finely Laminated bioturbated Siltstone
- Finely laminated silty sandstone
- Contorted Beds
- Bioturbated Silty Sandstone
- Bioturbated Siliceous Mudstone
- Channel
- Channel-levee
- levee-Overbank

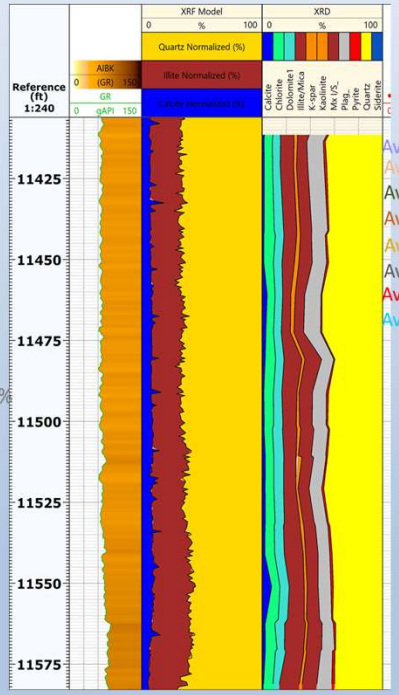
Petrographic and mineralogical analyses

Well 2



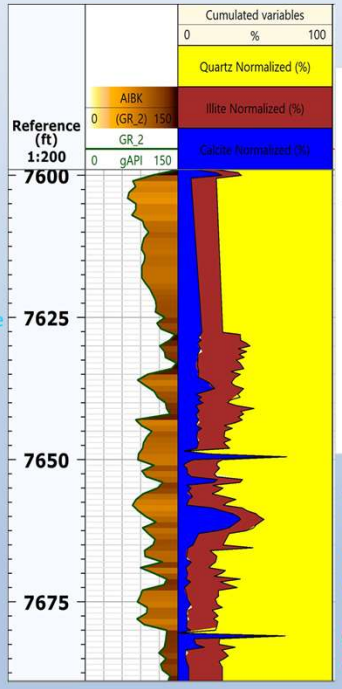
Dolomite Average: 2.53%
Calcite Average: 2.49%
Quartz Average: 56.1%
Plagioclase Average: 18.54%
Illite/Mica Average: 5.54%
Illite/S Average: 5.11%
Chlorite Average: 7.05%
Feldspar Average: 2.05%

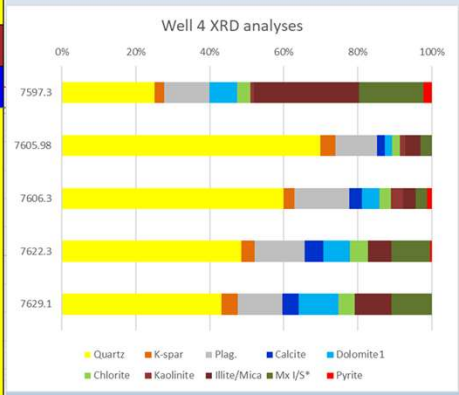
Well 3



Average 2.33% Calcite
Average 11.7% Illite
Average 7.7% Chlorite
Average 2.74% K-spar
Average 45% Quartz
Average 11.8% Plag
Average 1.33% Pyrite
Average 7.17 % Dolomite

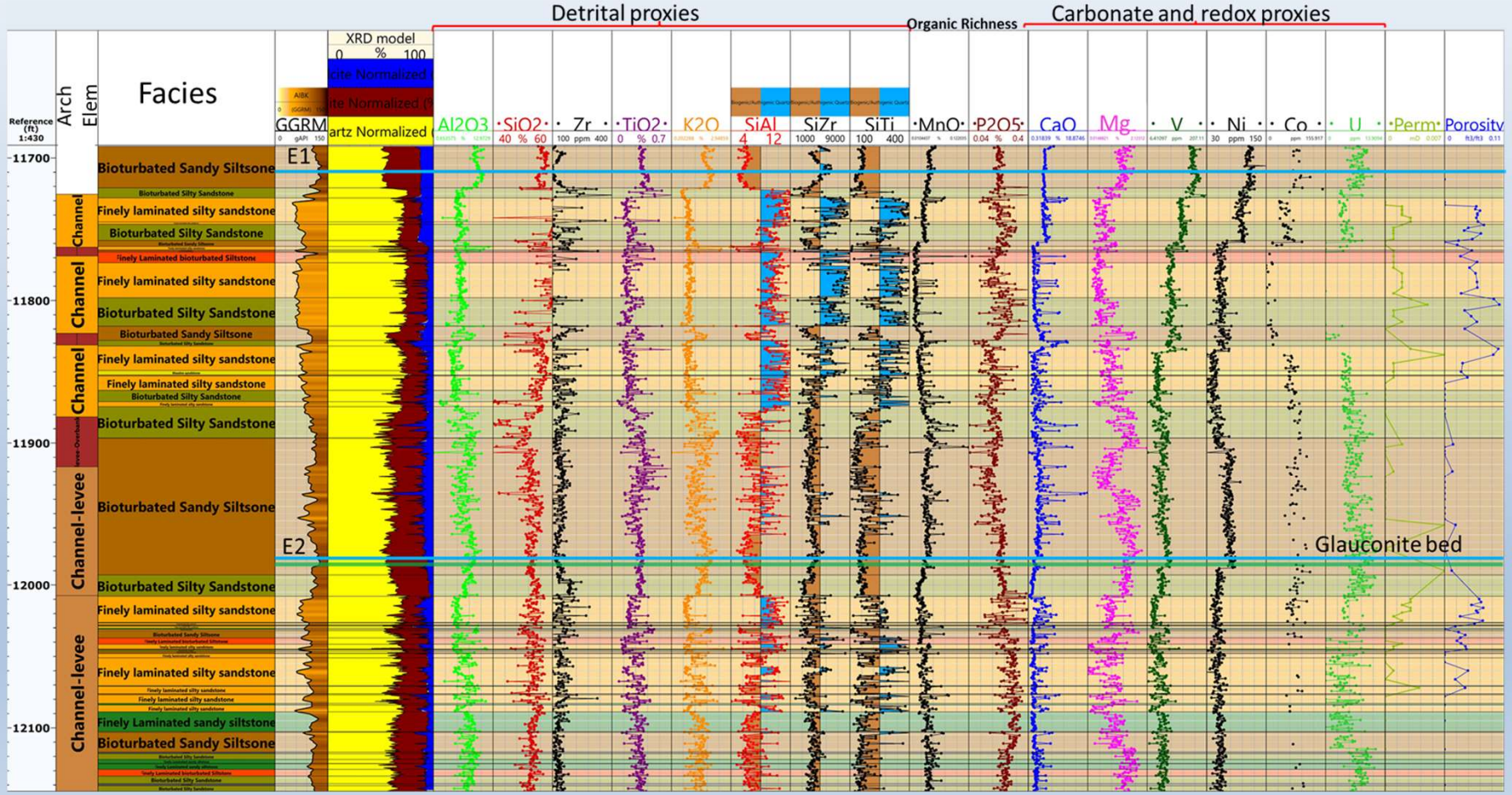
Well 4





Average 3.4 % Calcite
Average 3.57 % Illite
Average 3.2% Chlorite
Average 3.58 % K-spar
Average 52% Quartz
Average 12.28% Plag
Average 0.8% Pyrite
Average 5 % Dolomite

Well 1 Chemostratigraphy



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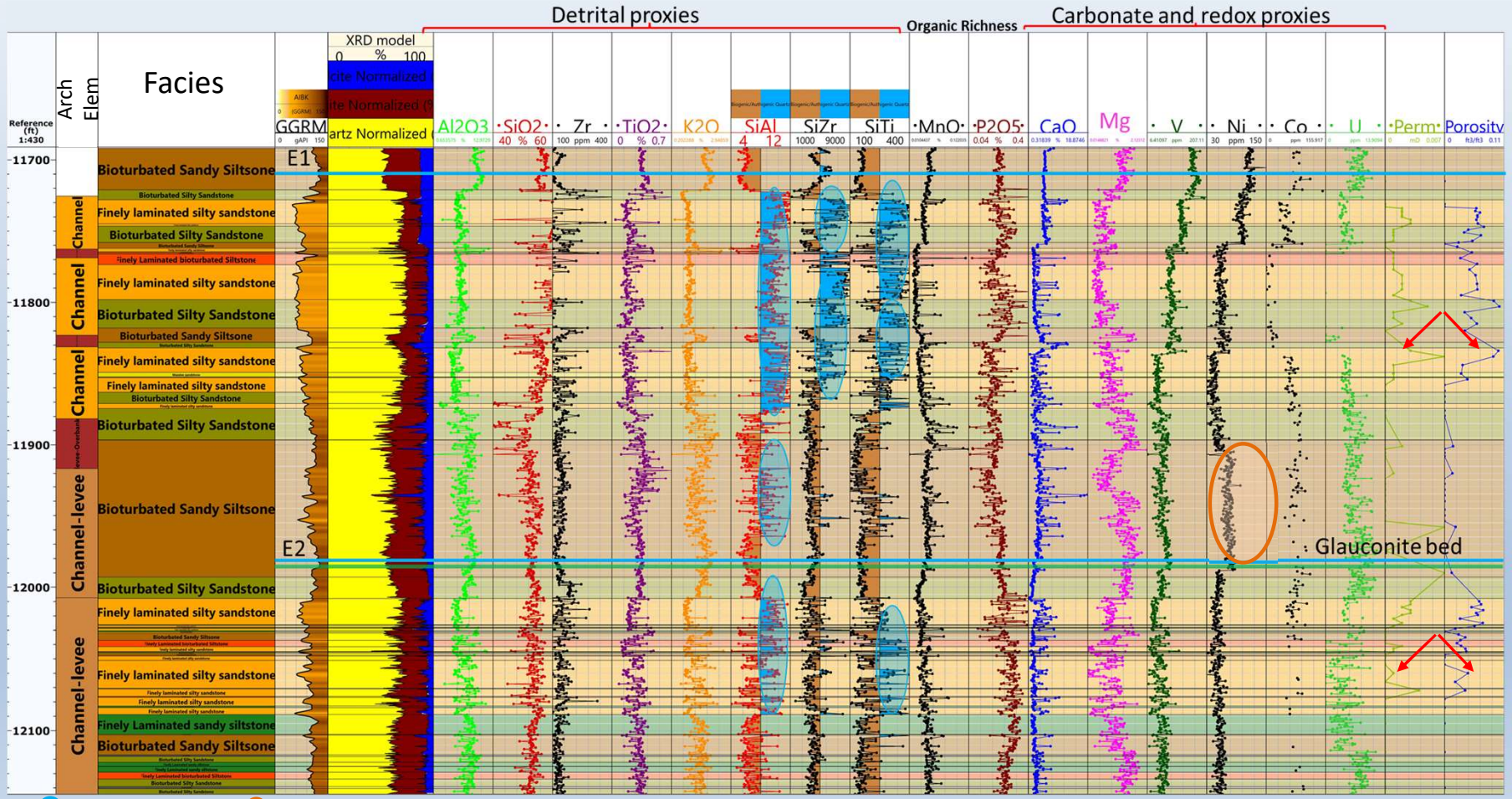
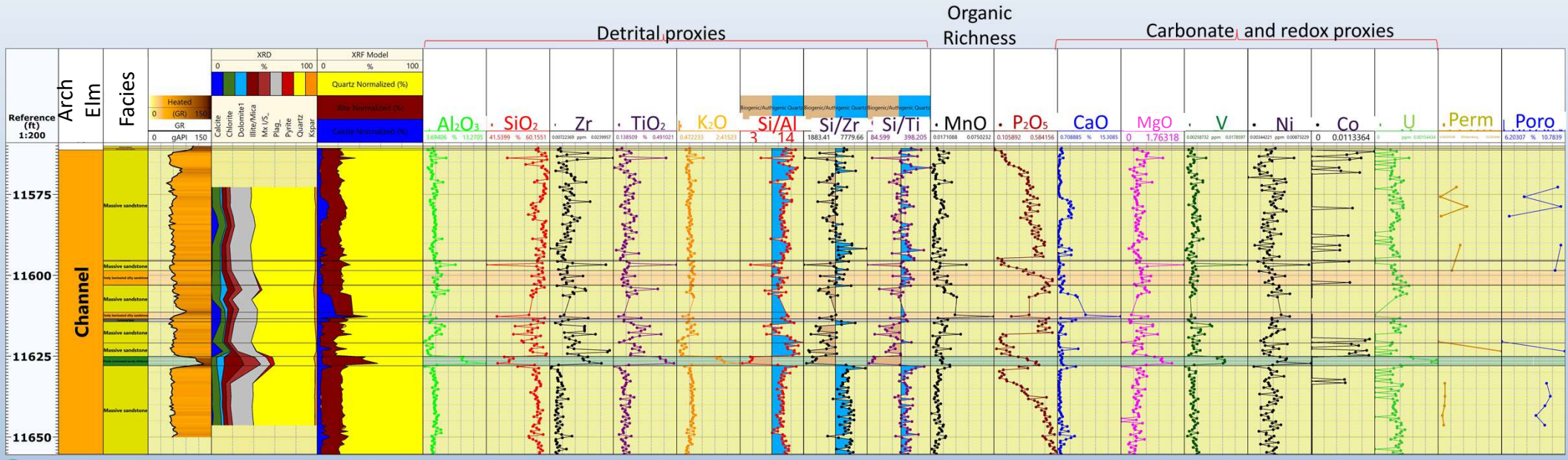
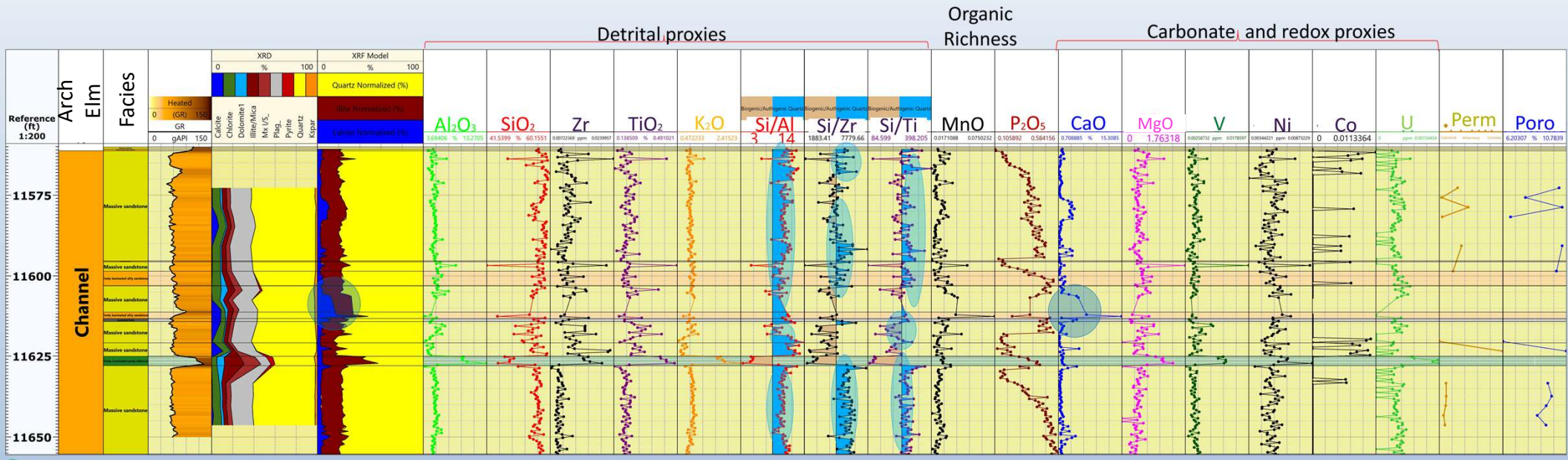


Well 2 Chemostratigraphy



- Increase in clay content
- Authigenic Quartz
- Carbonate content increase

Well 2 Chemostratigraphy



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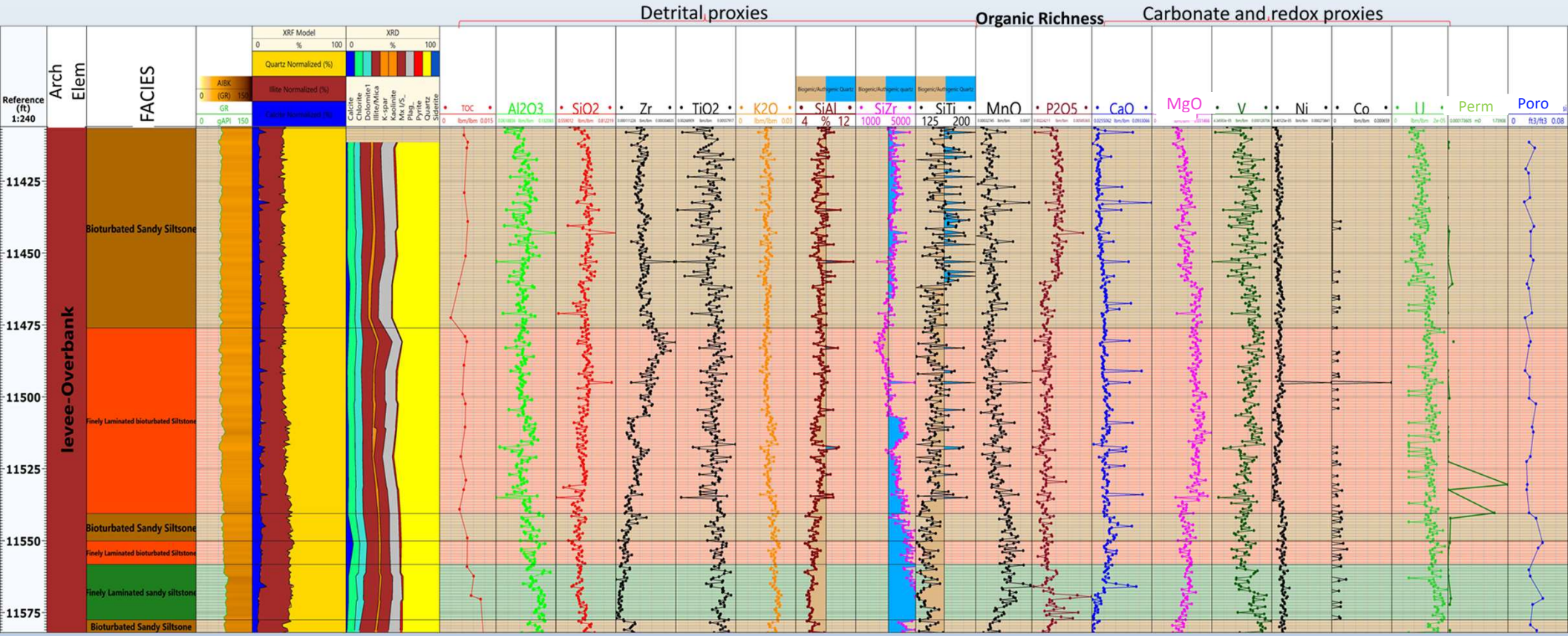

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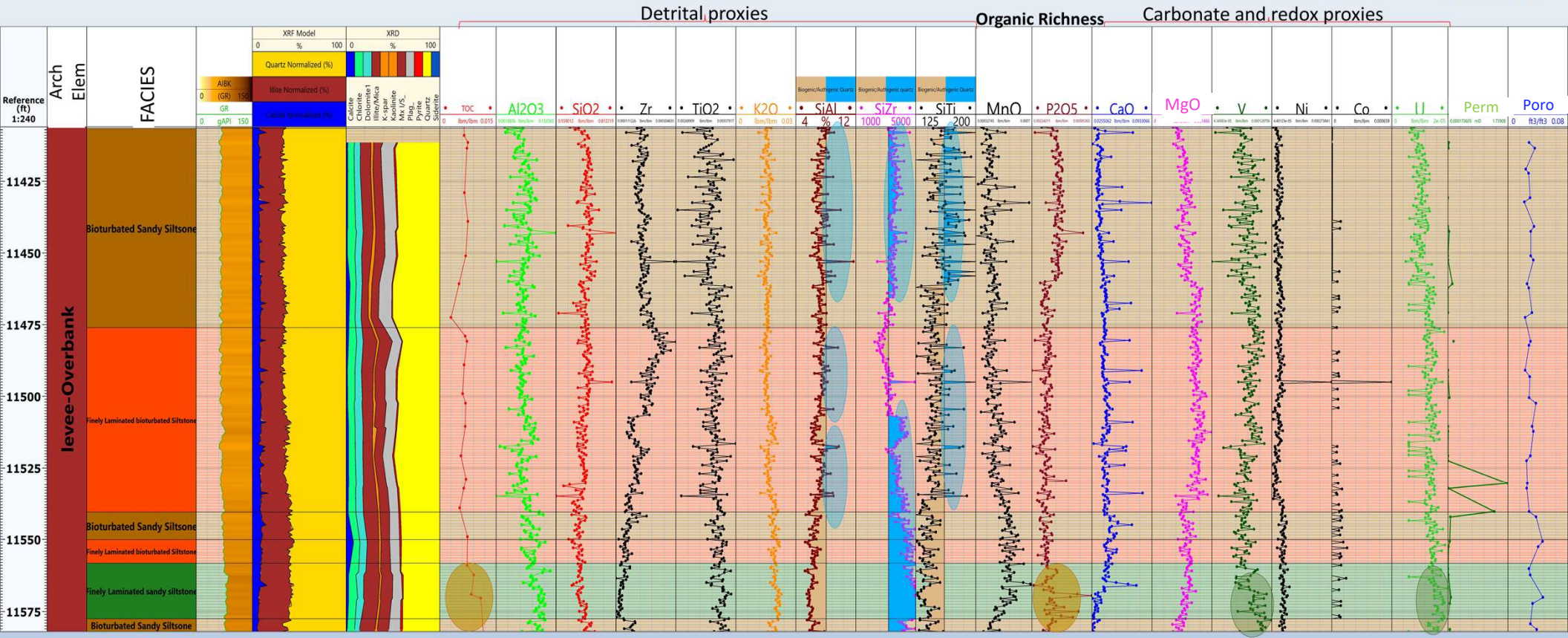
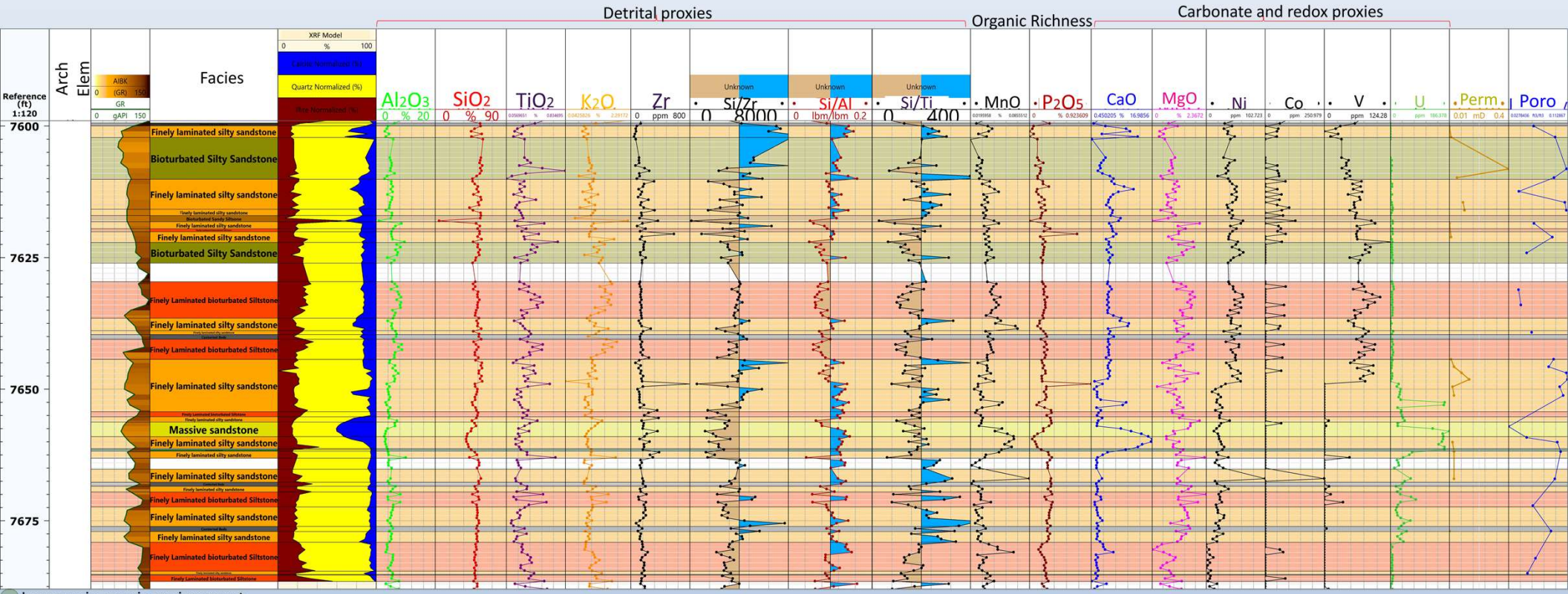


Increase in redox environment

Excess Silica

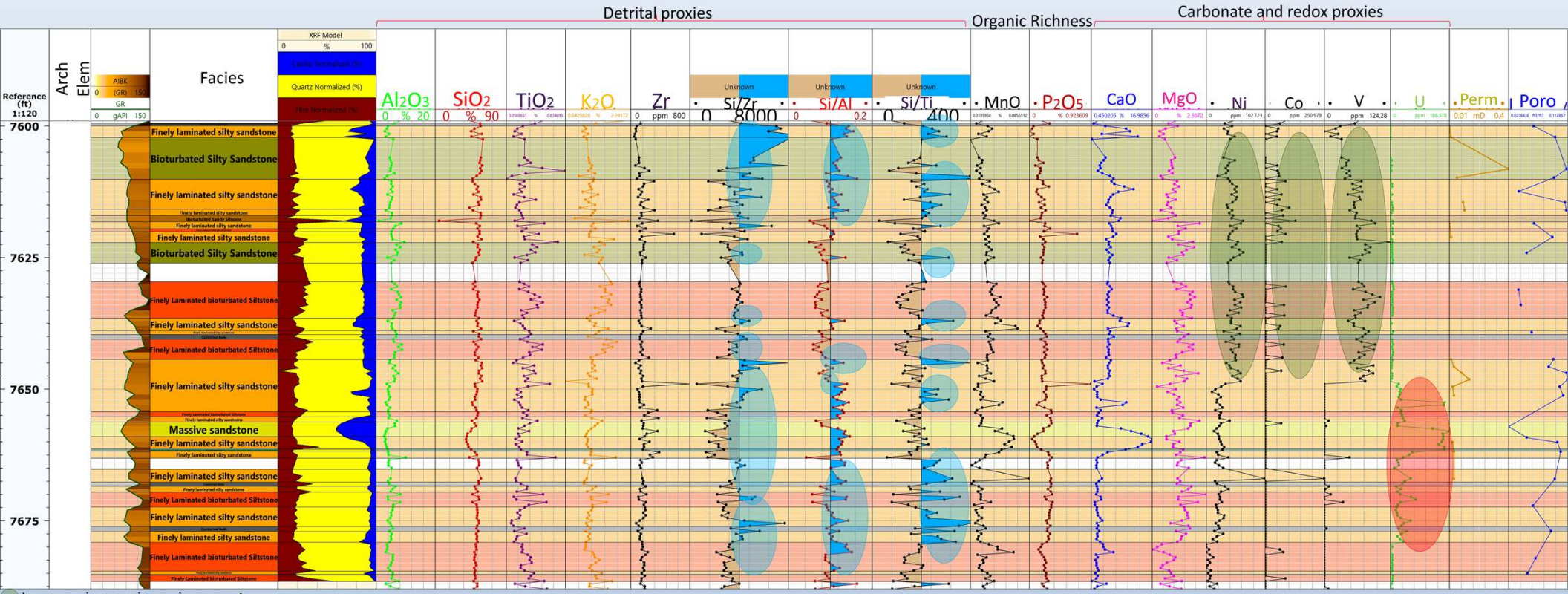
Increase in Organic richness

Well 4 Chemostratigraphy



- Increase in anoxic environment
- Excess Silica
- Unreliable Data

Well 4 Chemostratigraphy

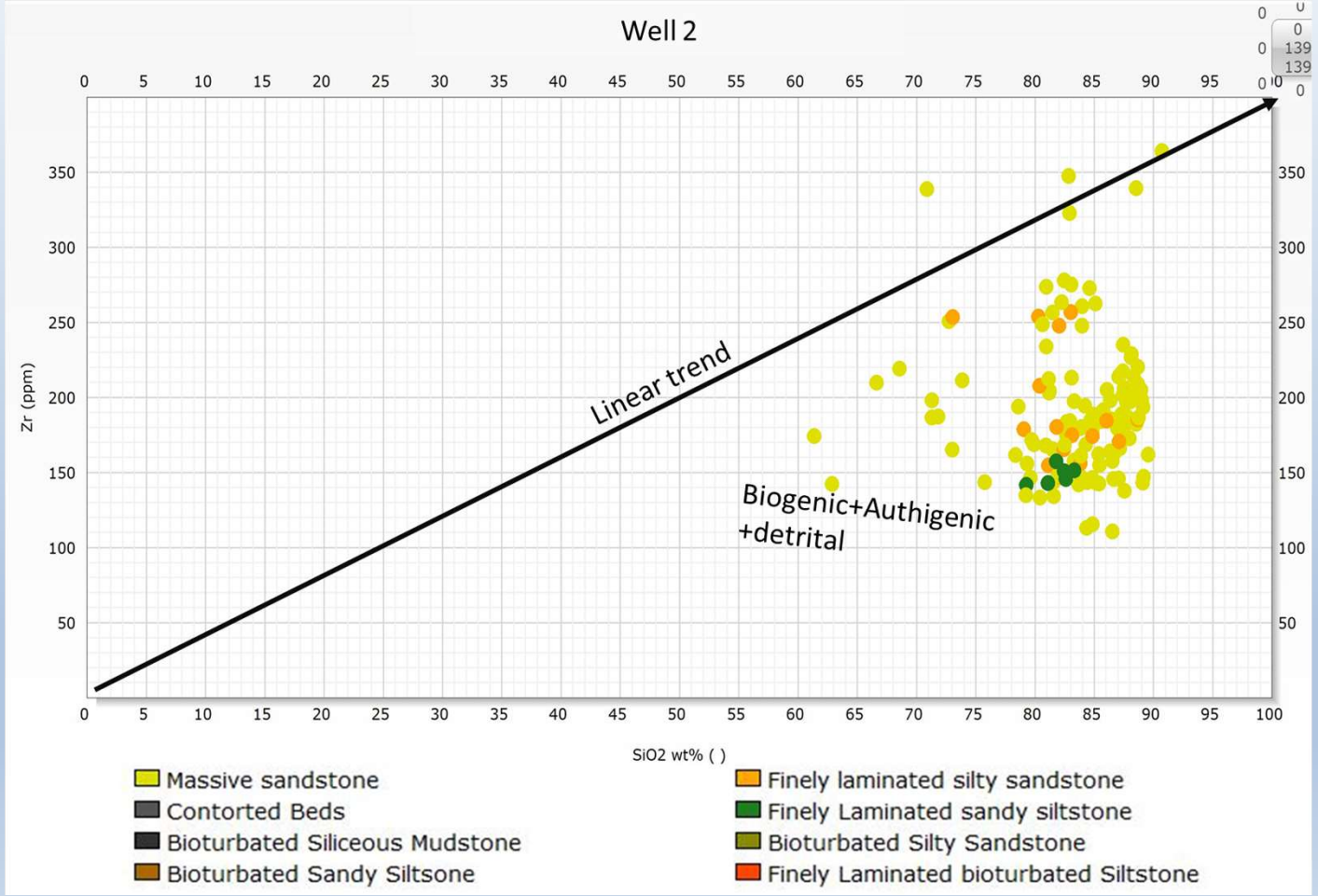


Increase in anoxic environment

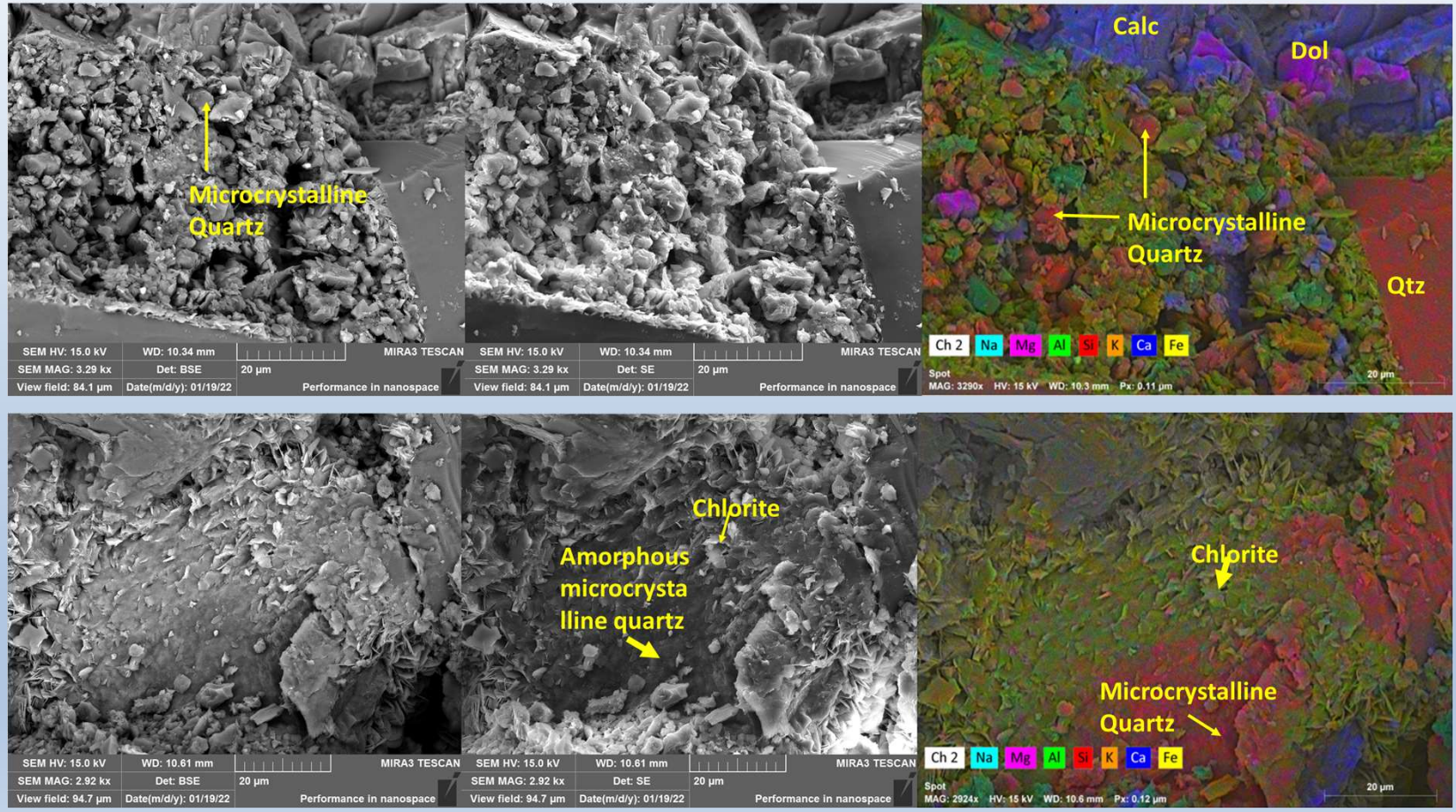
Excess Silica

Unreliable Data

Excess silica



Excess silica



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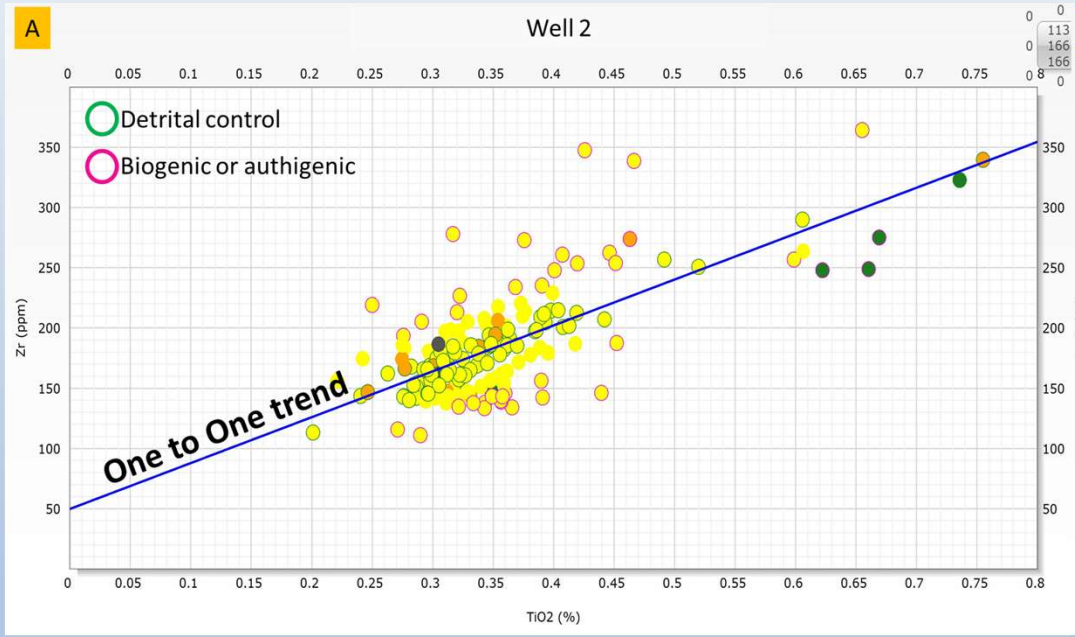
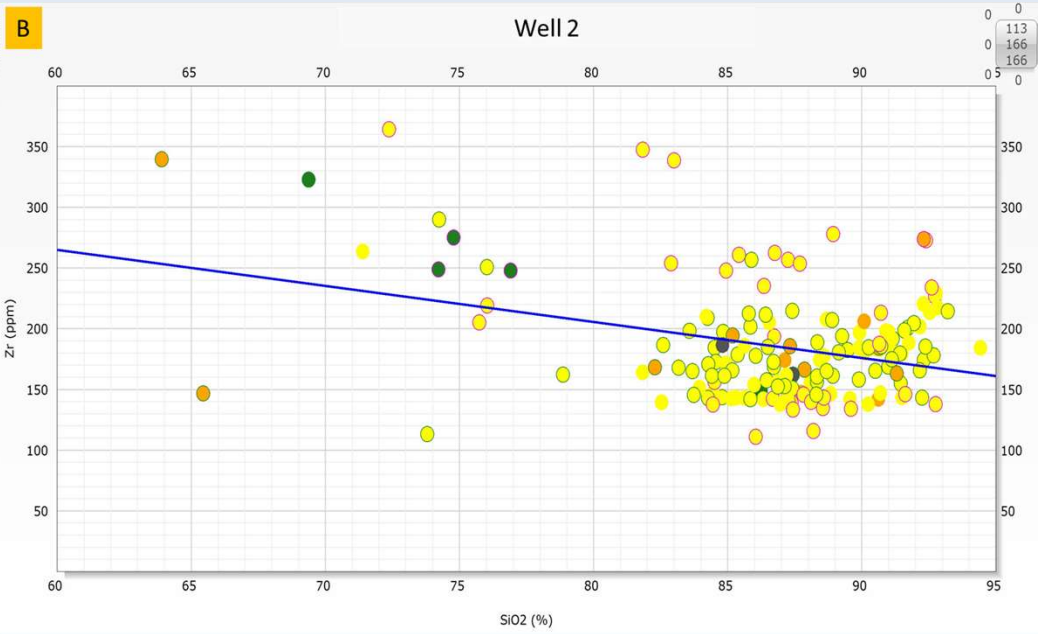
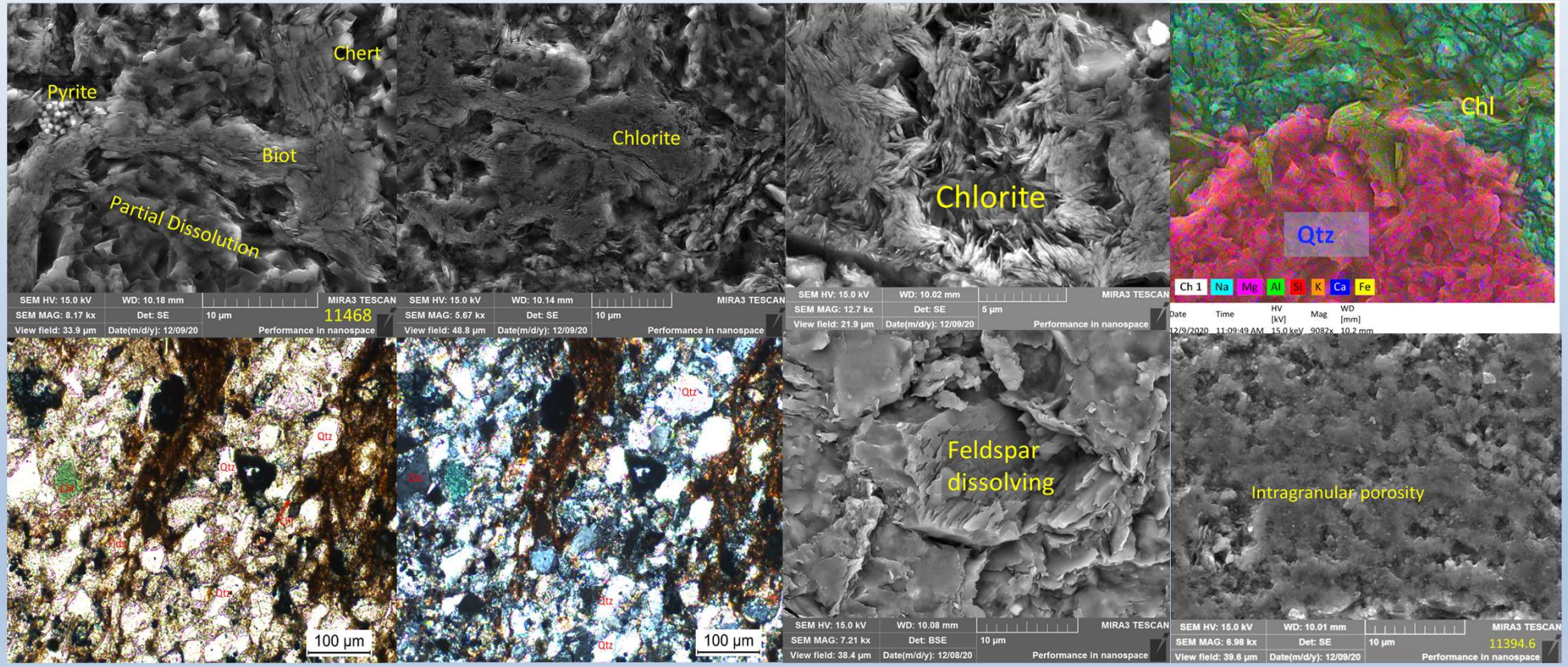
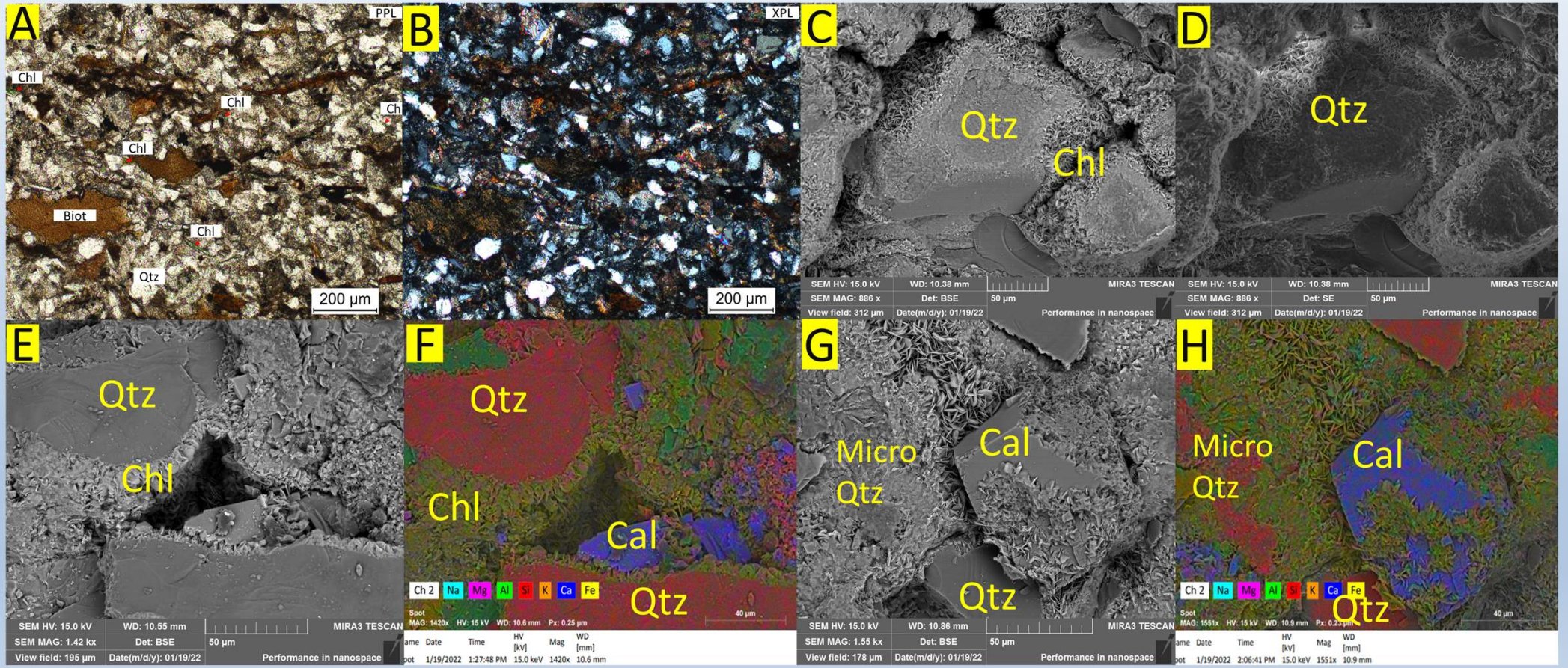




Reservoir quality

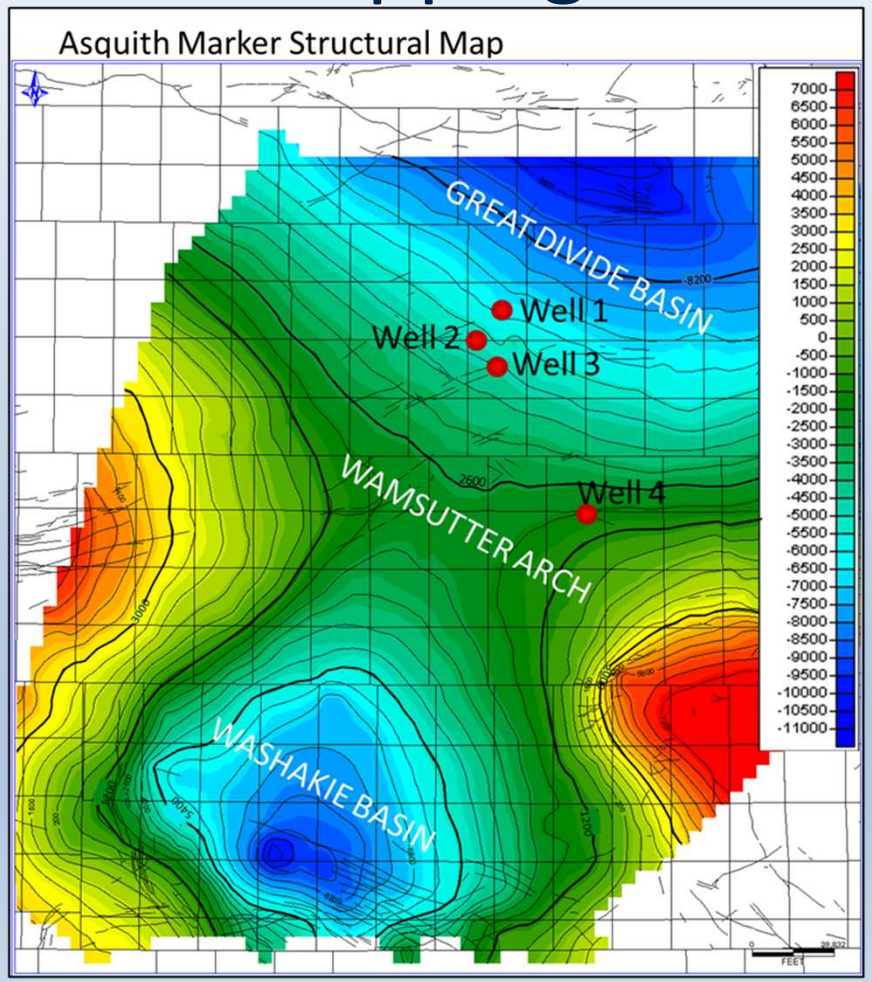


Reservoir Quality

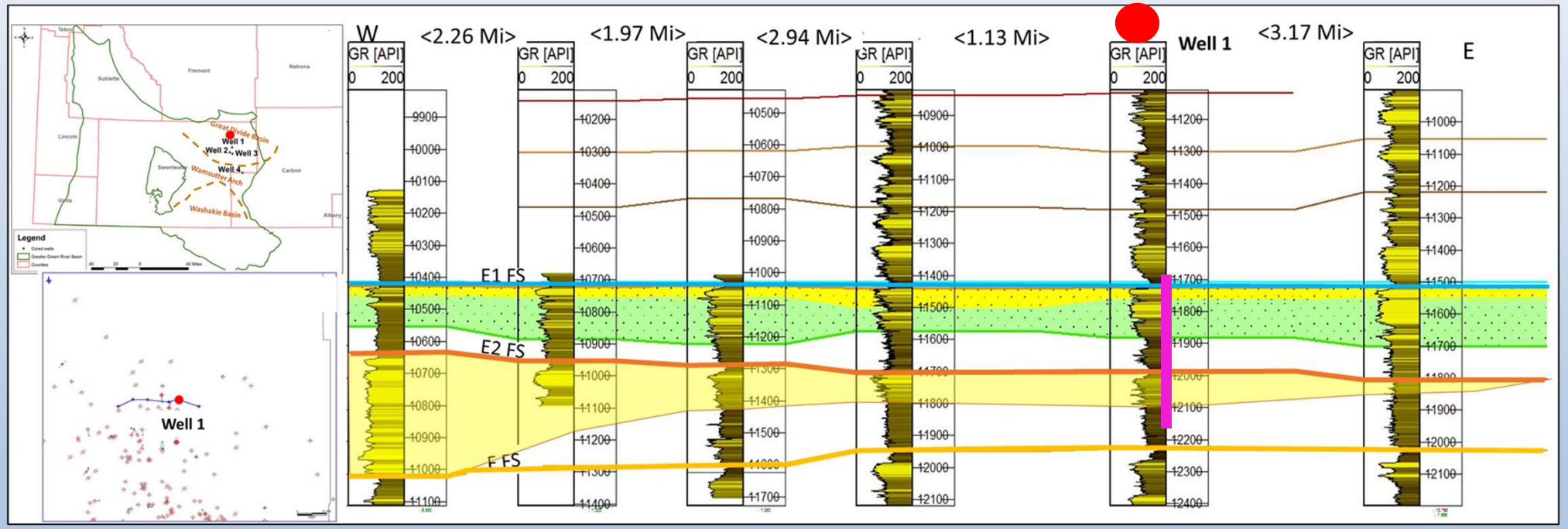


Mapping

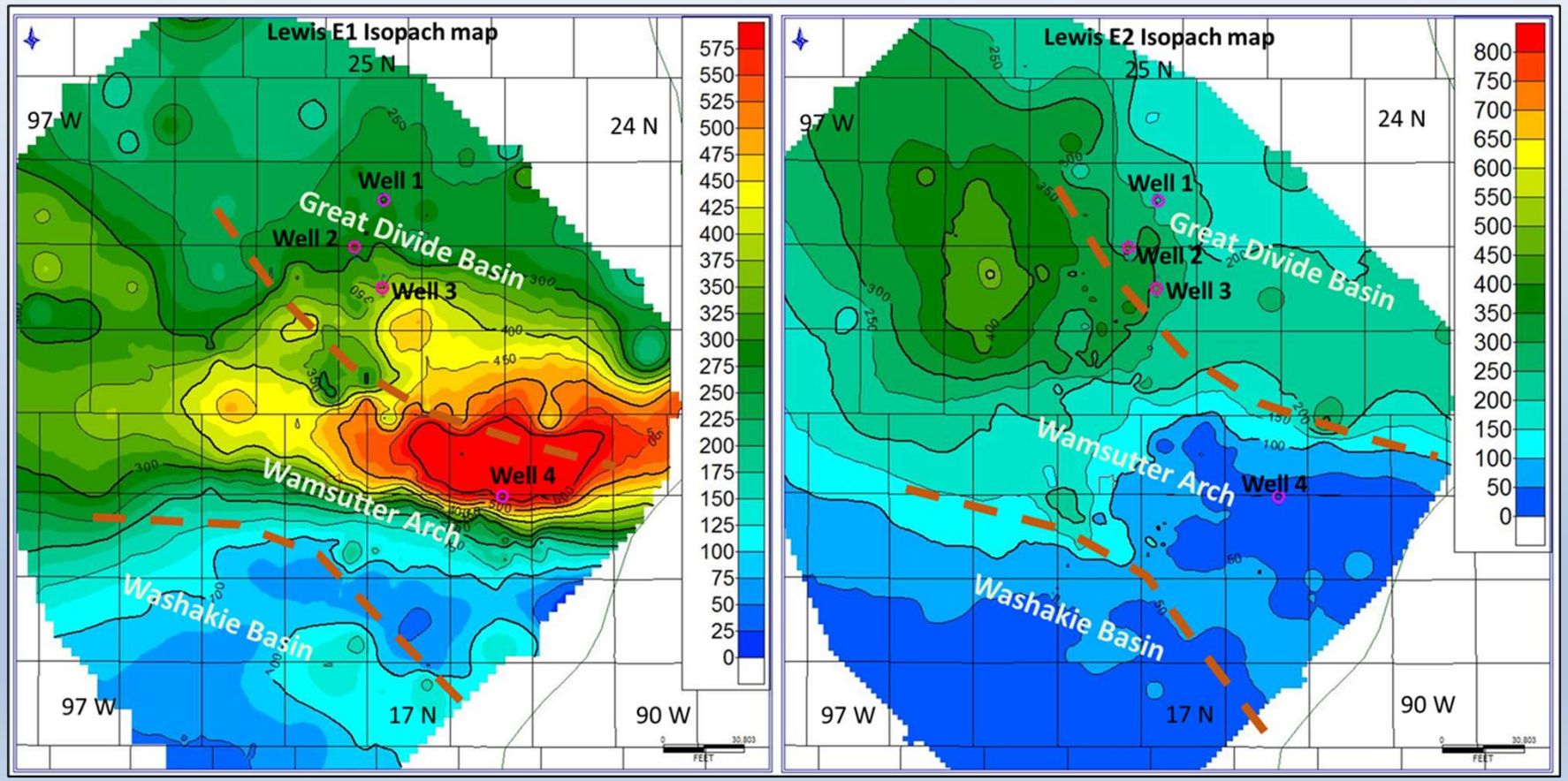
~1800 wells correlated based on GR



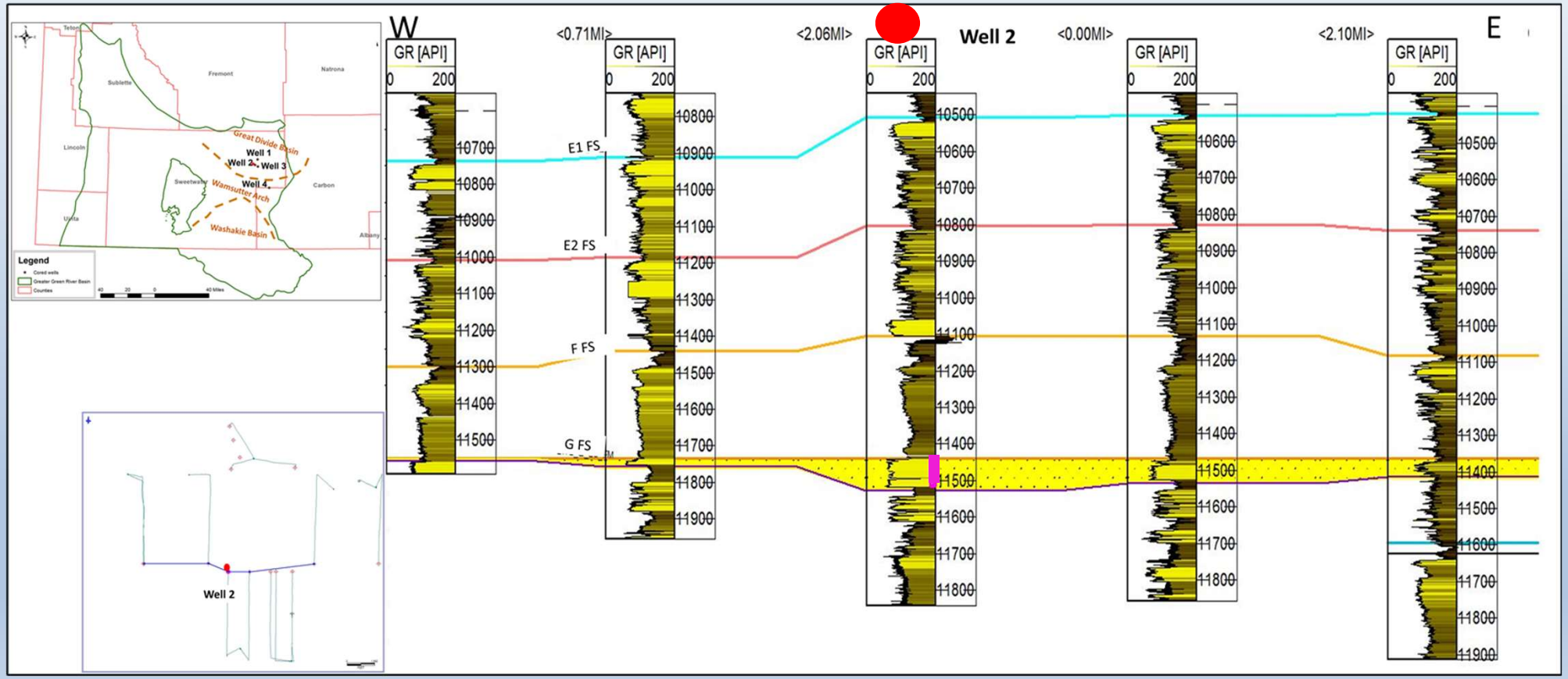
Correlation Well 1 core area



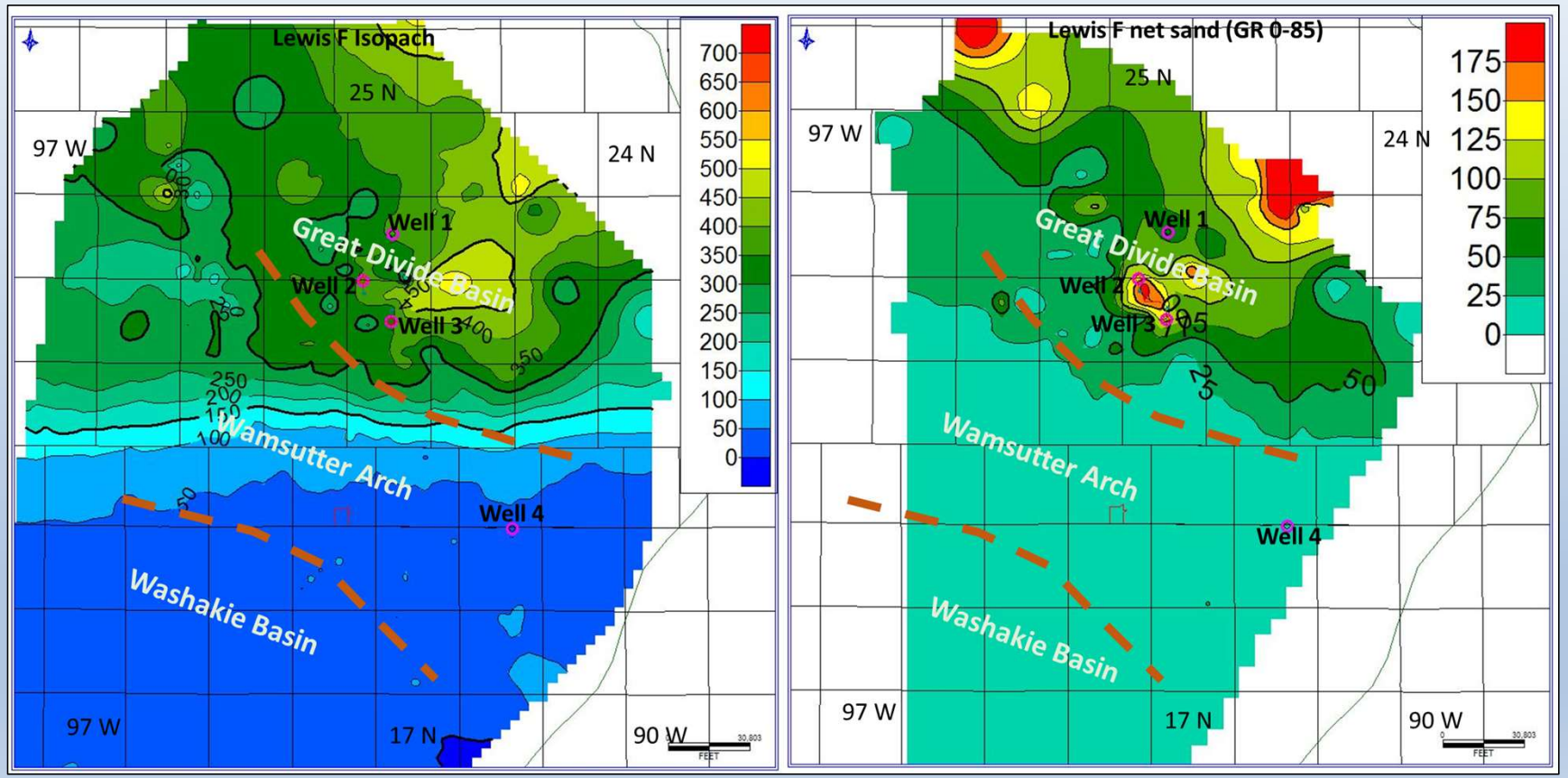
Well 1 cored interval isopach



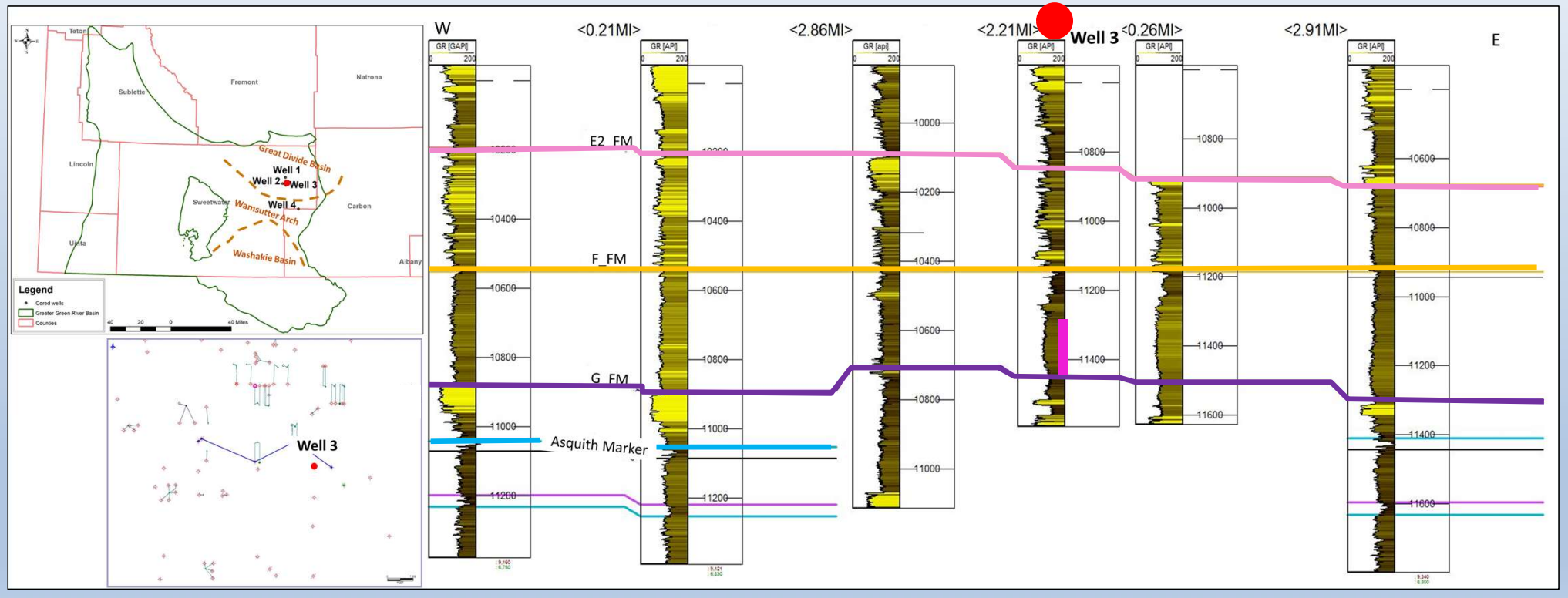
Correlation Well 2 area



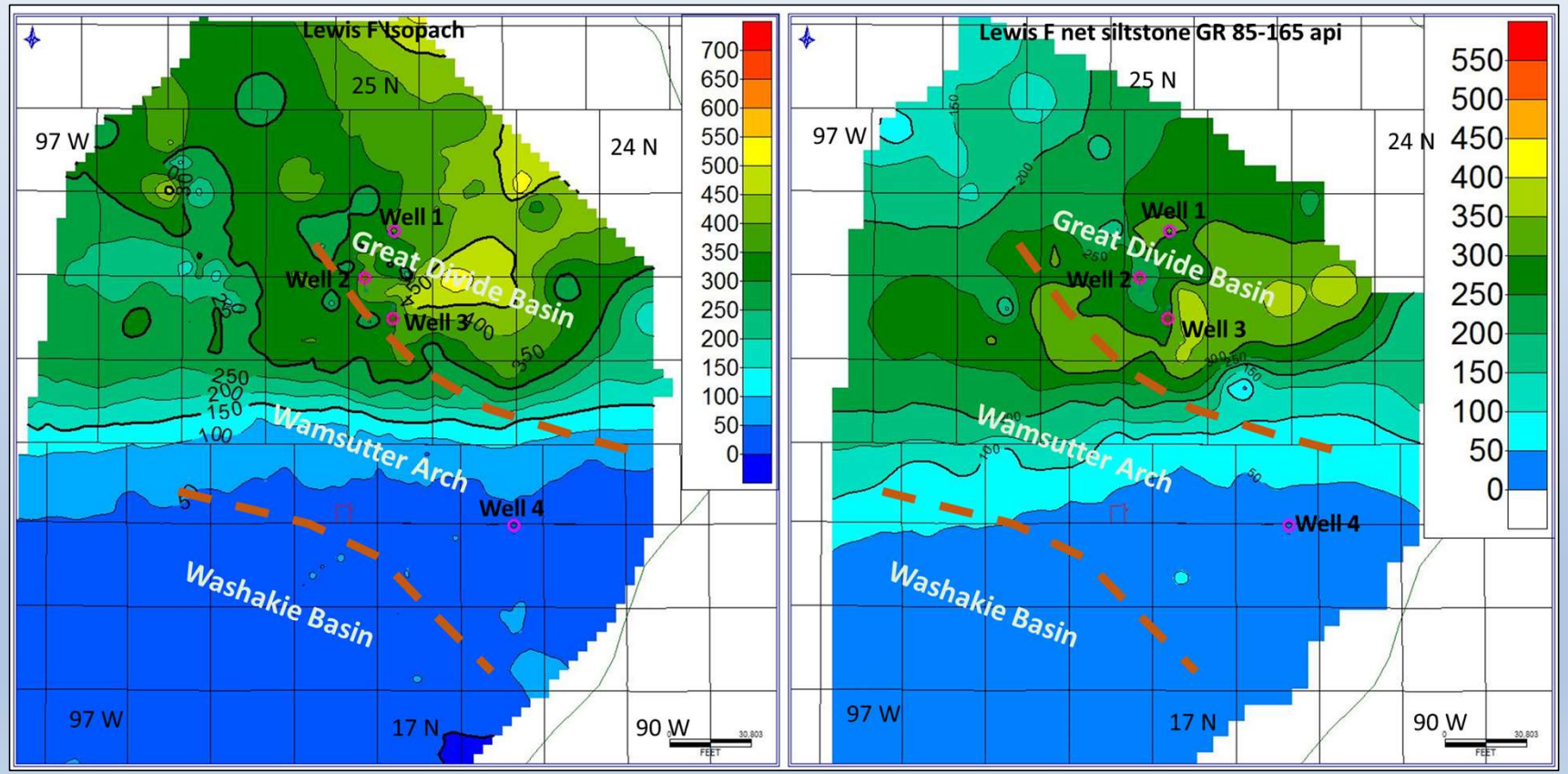
Well 2 interval isopach



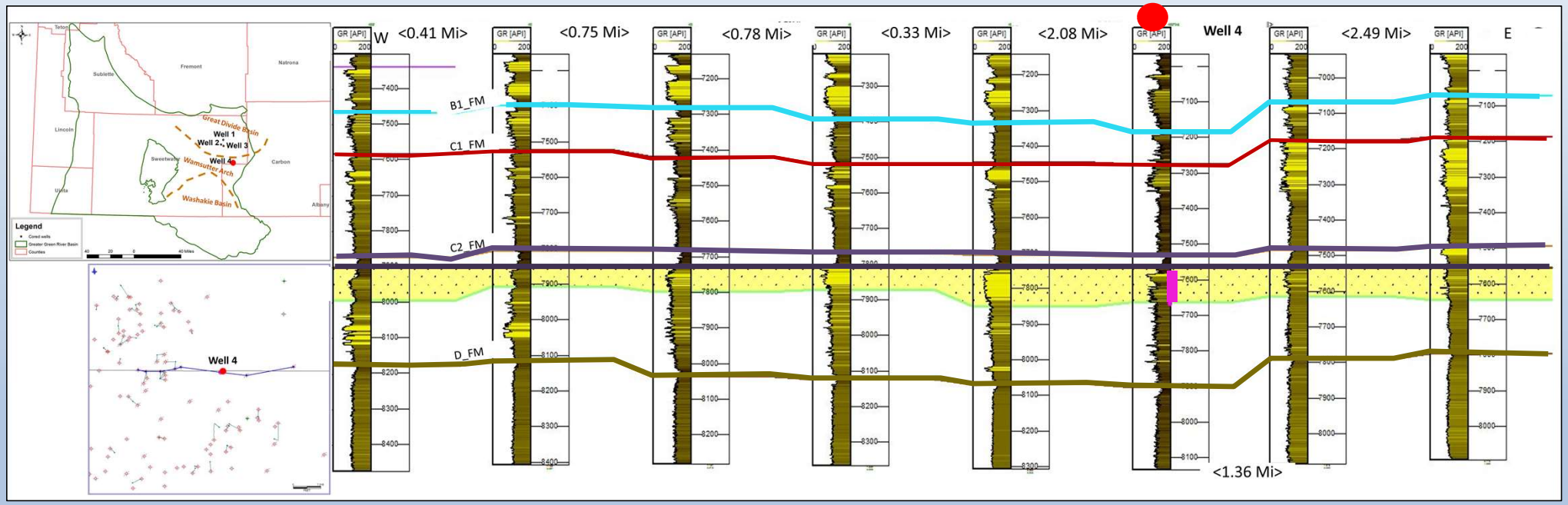
Correlation Well 3 core area



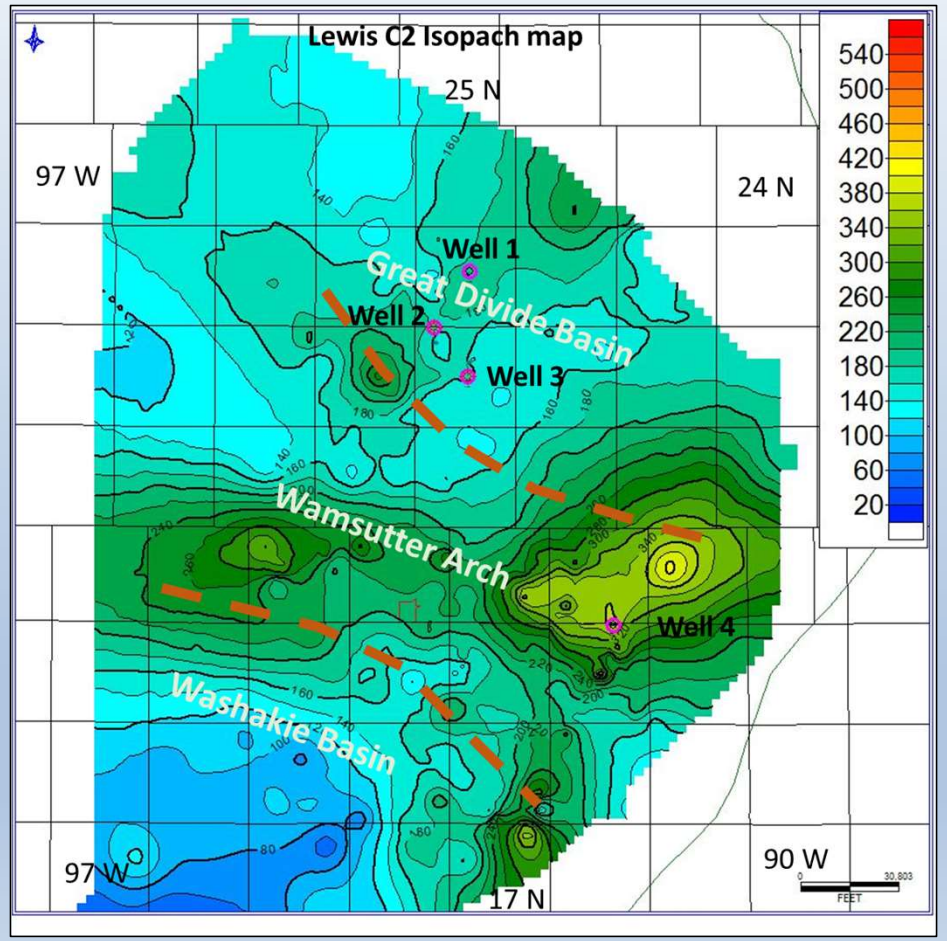
Well 3 interval isopach



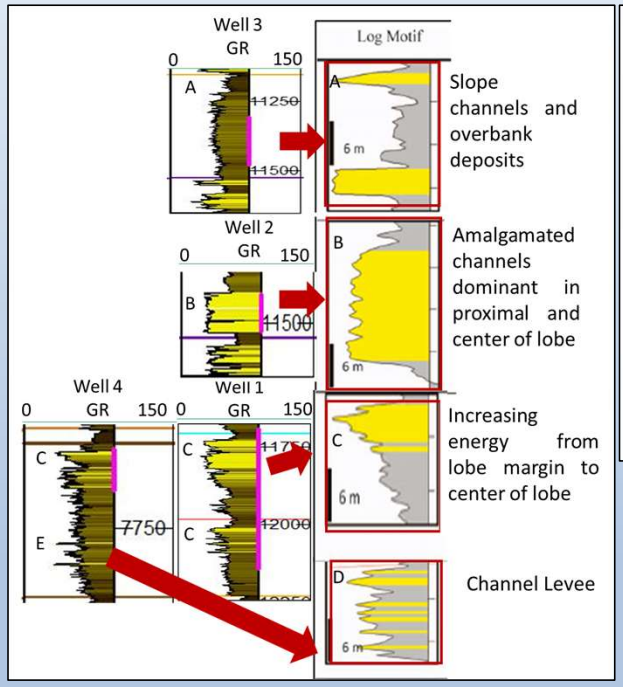
Correlation Well 4 core area



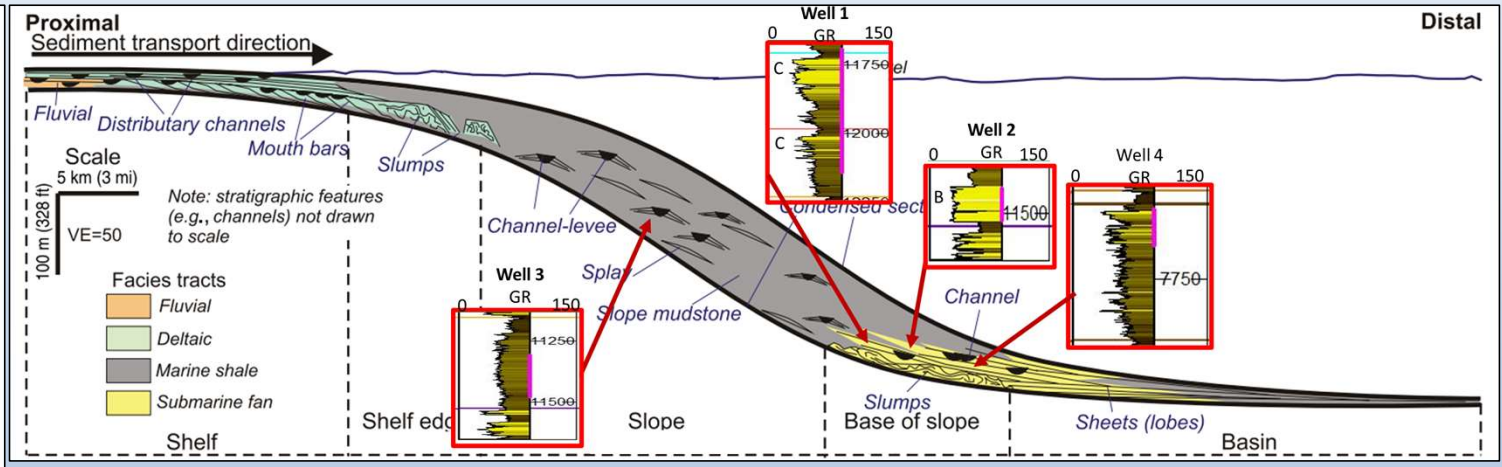
Well 4 interval isopach



Architectural elements and depositional environment



Koo et al., 2016



Pyles and Slatt, 2007

Petrophysical model

Petrophysical model

Well	Temperature Gradient (°F/ft)	Rw from produced water at Ts (ohm-m)	Surface temperature Ts (°F)	Water Resistivity at formation T (Rfm) (ohm-m)
Well 1	0.0111	0.168	73.6	0.062
Well 2	0.0087	0.168	68.0	0.071
Well 4	0.0100	0.168	68.0	0.087

$$Rfm = \frac{Rw * (Ts + 6.77)}{(Tfm + 6.77)}$$

$$\emptyset density = \frac{\delta matrix - \delta bulk}{\delta matrix - \delta fluid}$$

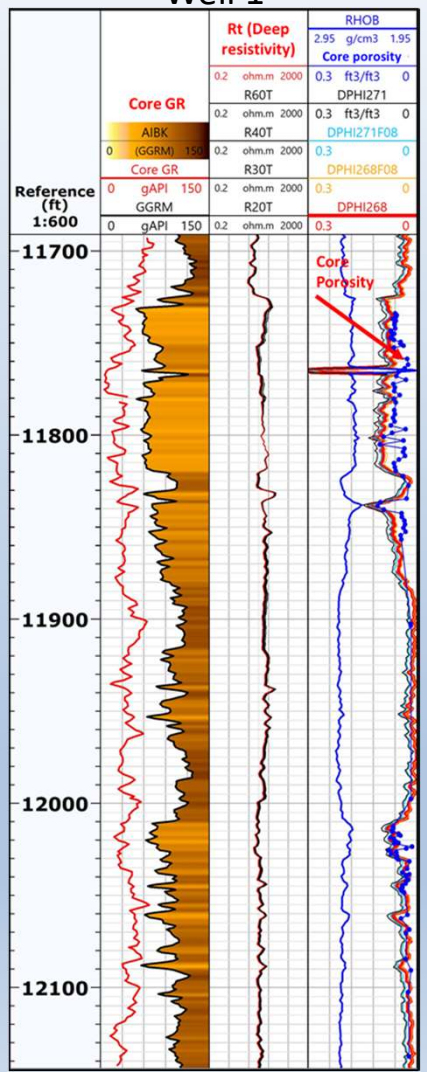
Fluid density=0.8
Bulk Dens=RHOB
Den matrix= 2.68 or 2.71

$$Sw = \left(\frac{a * Rw}{RT * \emptyset^{m}}\right)^{1/n}$$

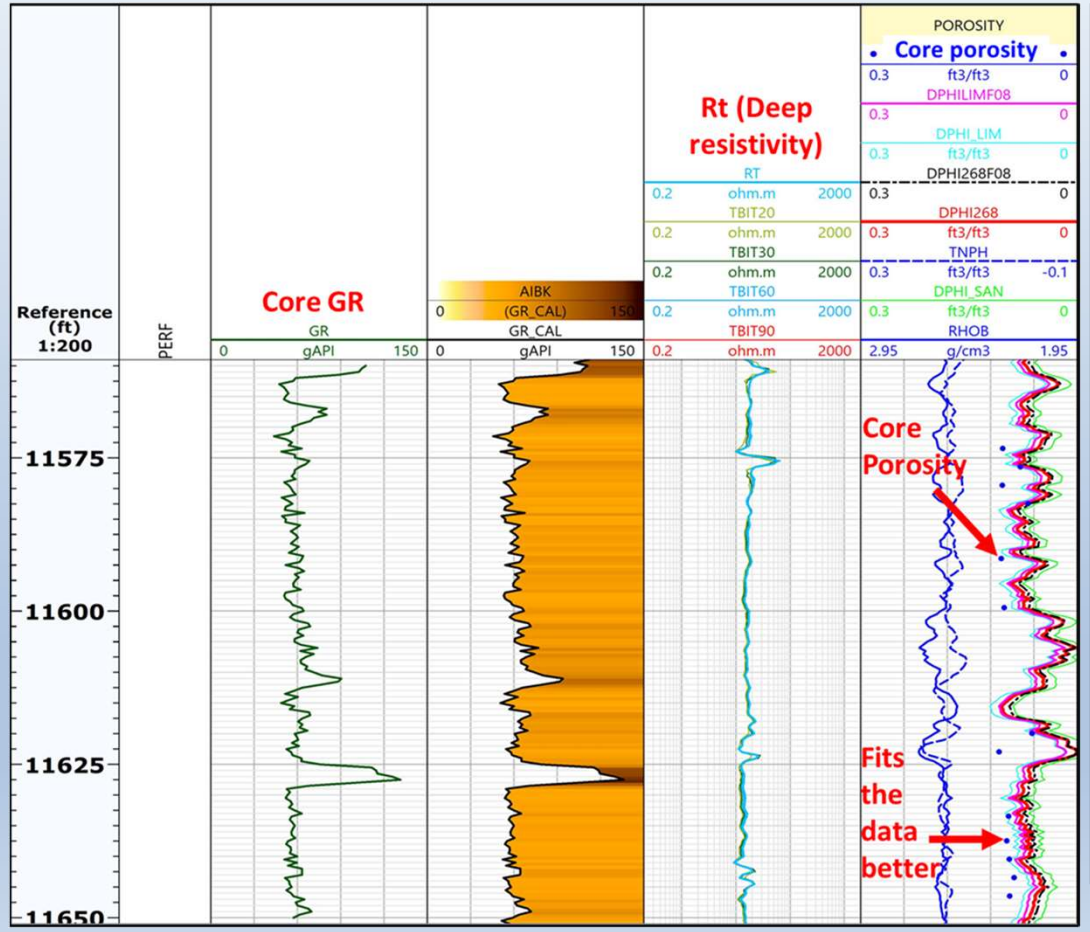
a= 1
m=1.8
n= 2

Porosity model

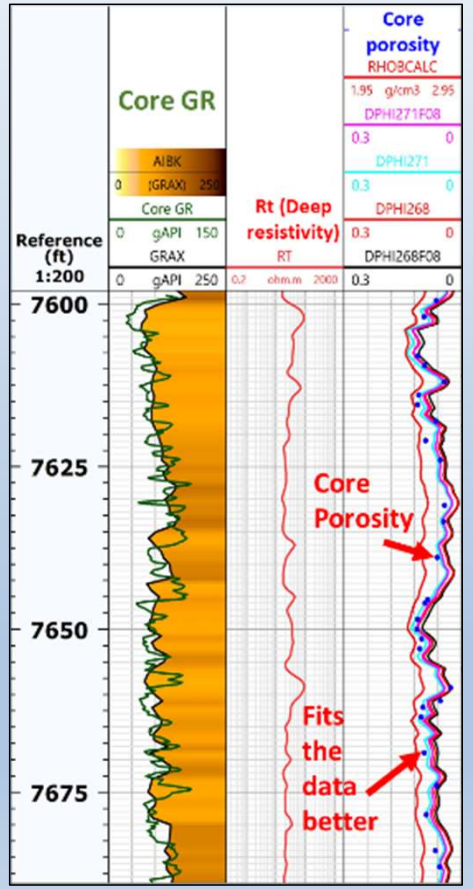
Well 1



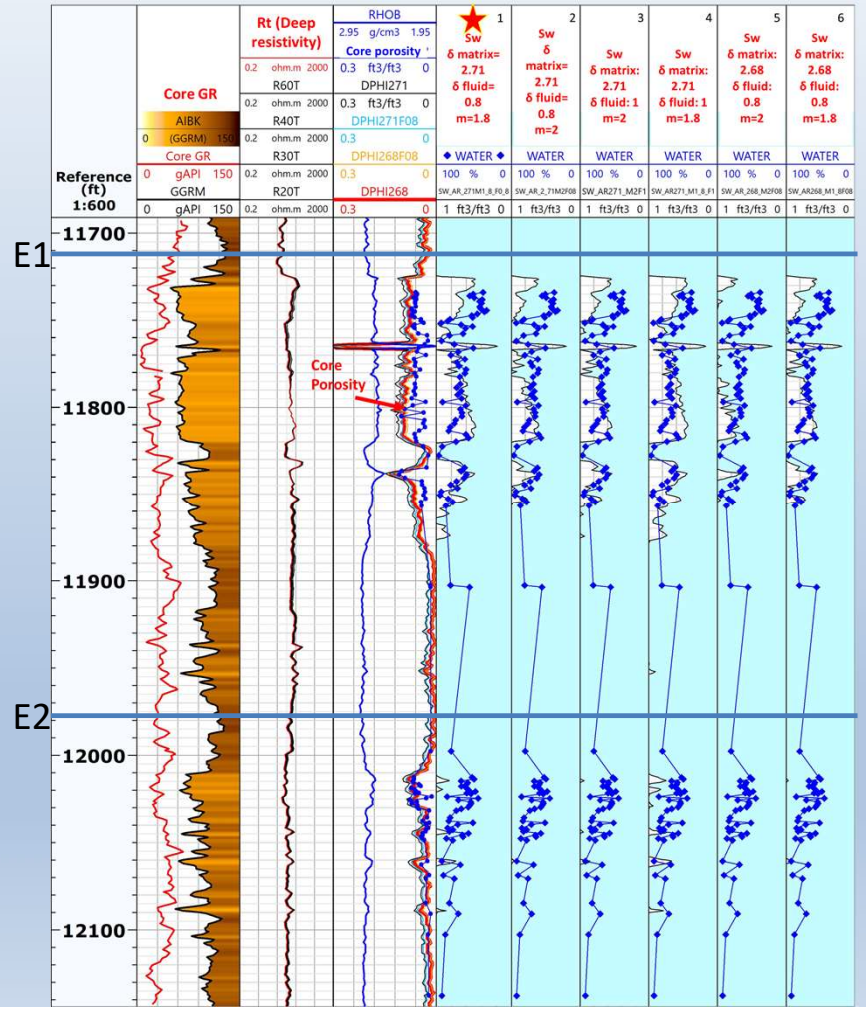
Well 2



Well 4

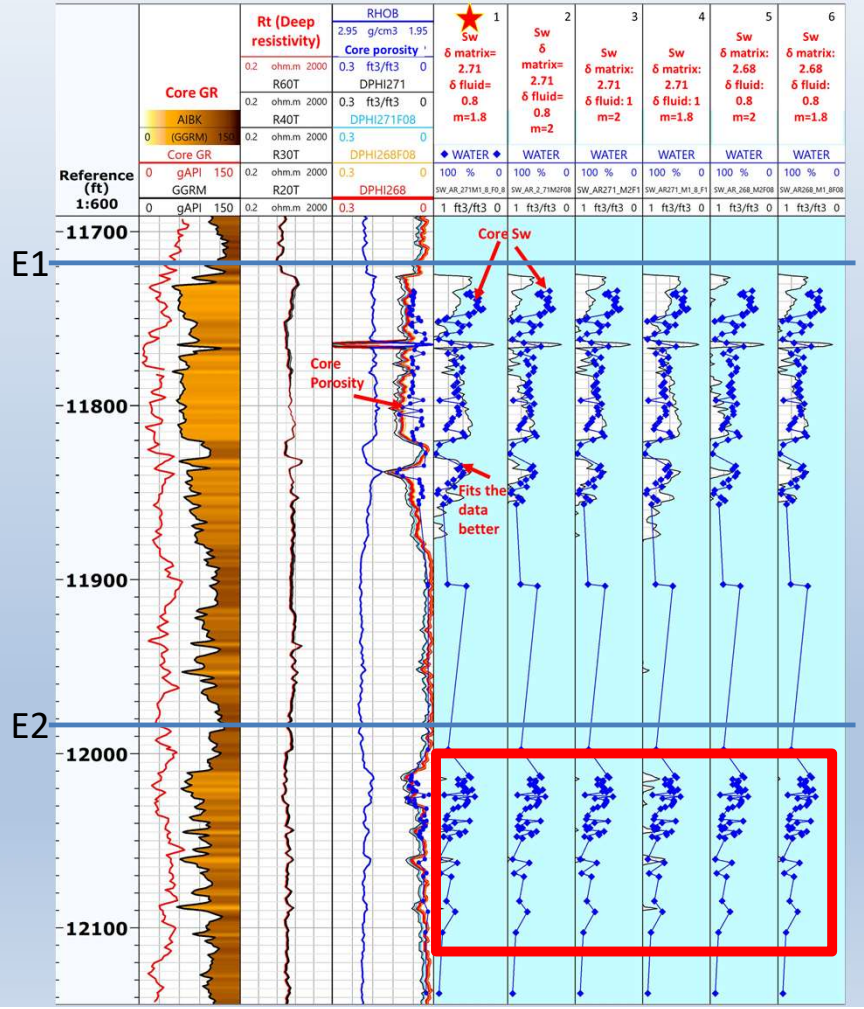


Well 1 saturation models



1. Grain density equal to 2.71 g/cc, fluid density of 0.8, and m=1.8.
2. Grain density equal to 2.71 g/cc, fluid density of 0.8, and m=2.
3. Grain density 2.71 g/cc, and fluid density of 1 g/cc, and m=2
4. Grain density, 2.71 g/cc, and fluid density of 1 g/cc, and m=1.8
5. Grain density, 2.68 g/cc, fluid density of 0.8, and m=2
6. Grain density, 2.68 g/cc, fluid density of 0.8, and m=2.

Well 1 saturation models



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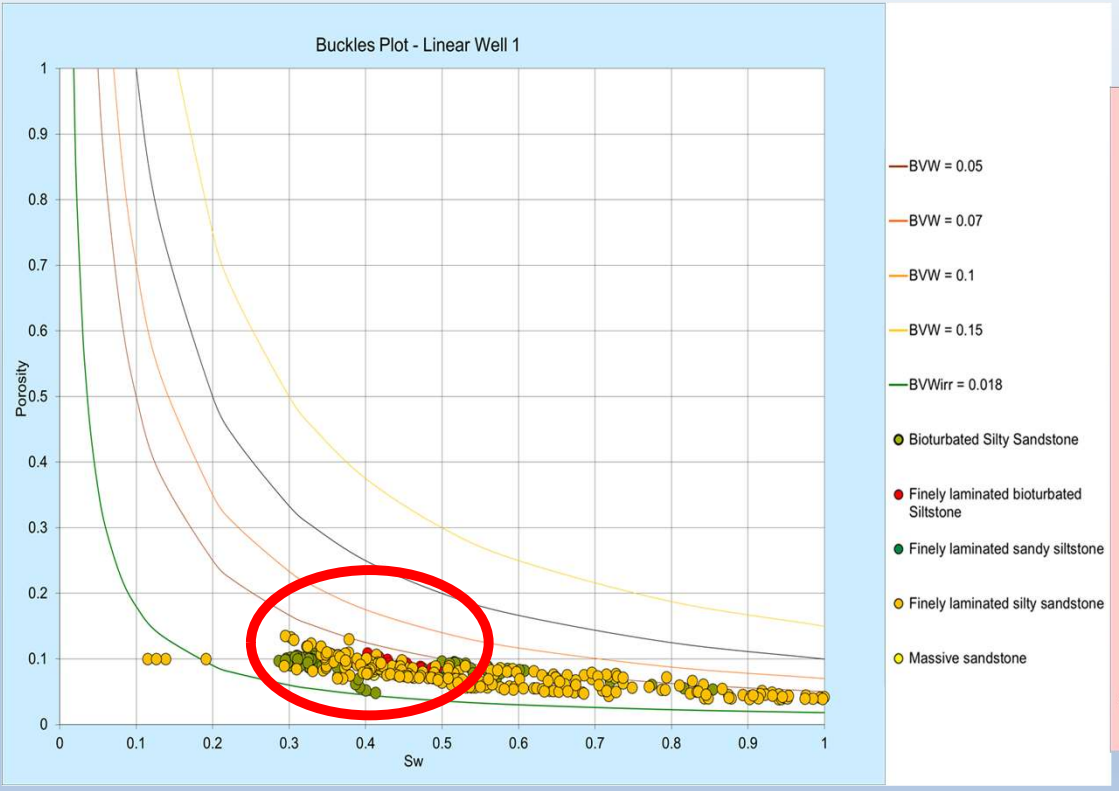
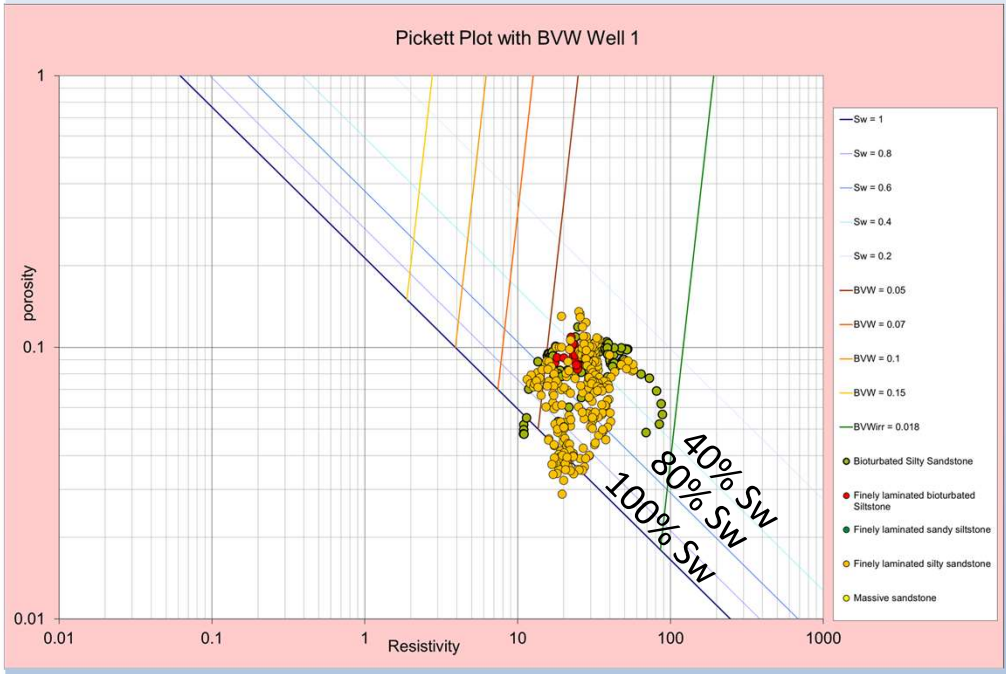
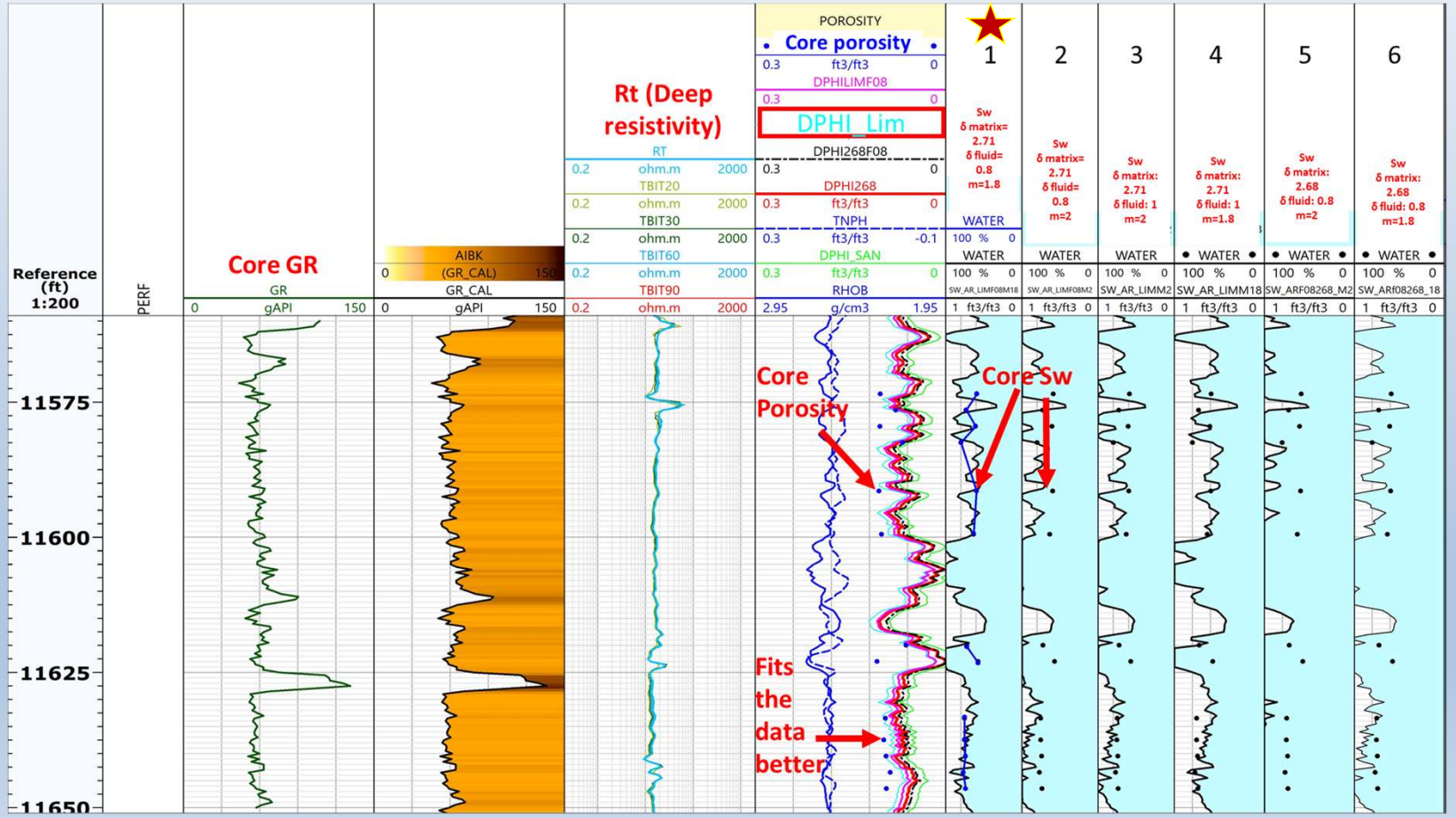
Well 1 Buckles and Pickett plots





Well 2 petrophysical model



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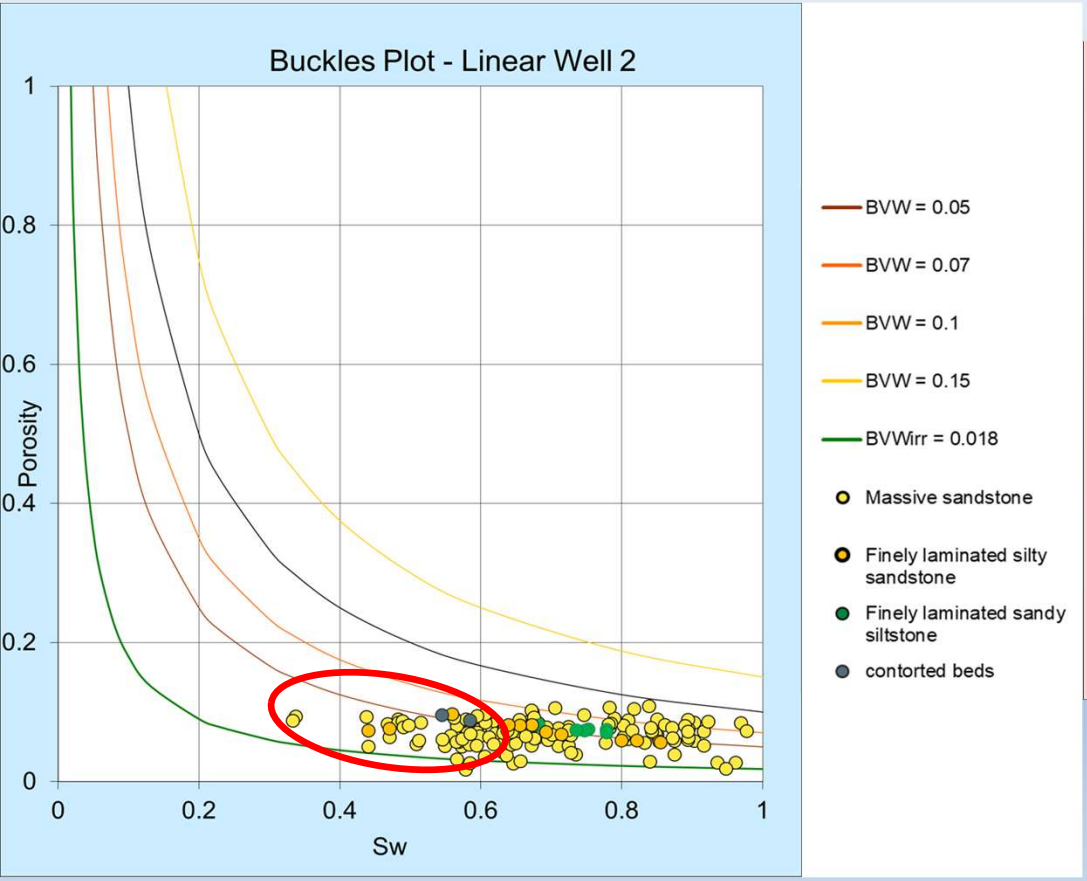
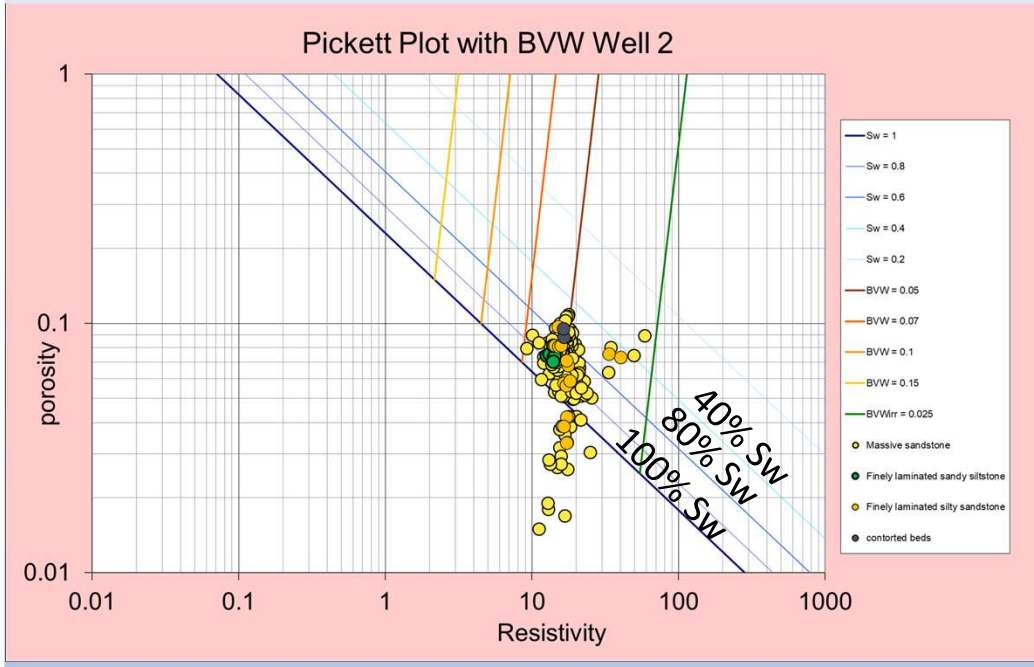
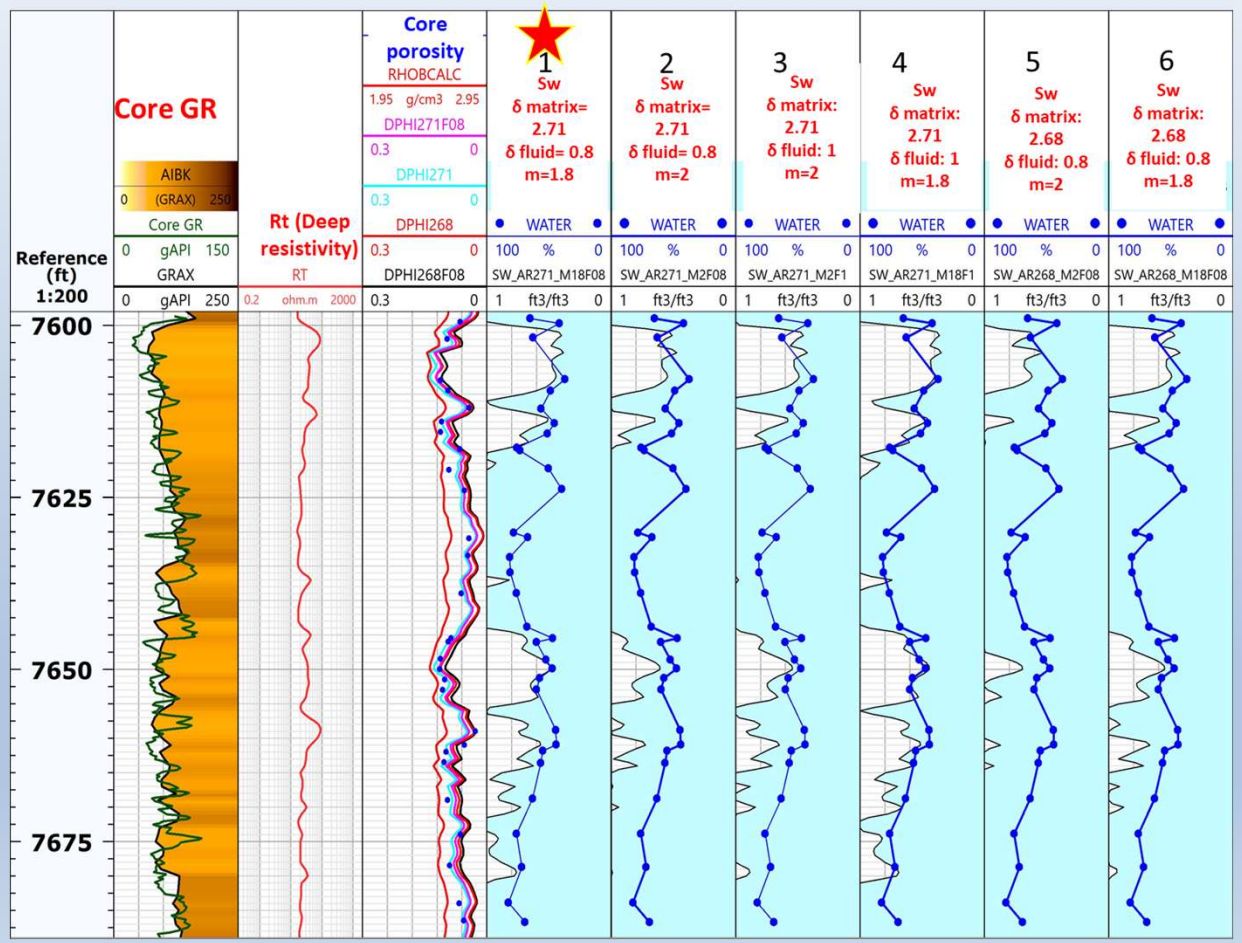
6. Grain density, 2.68 g/cc, fluid density of 0.8, and m=2.

Well 2 Buckles and Pickett plots





Well 4 saturation models



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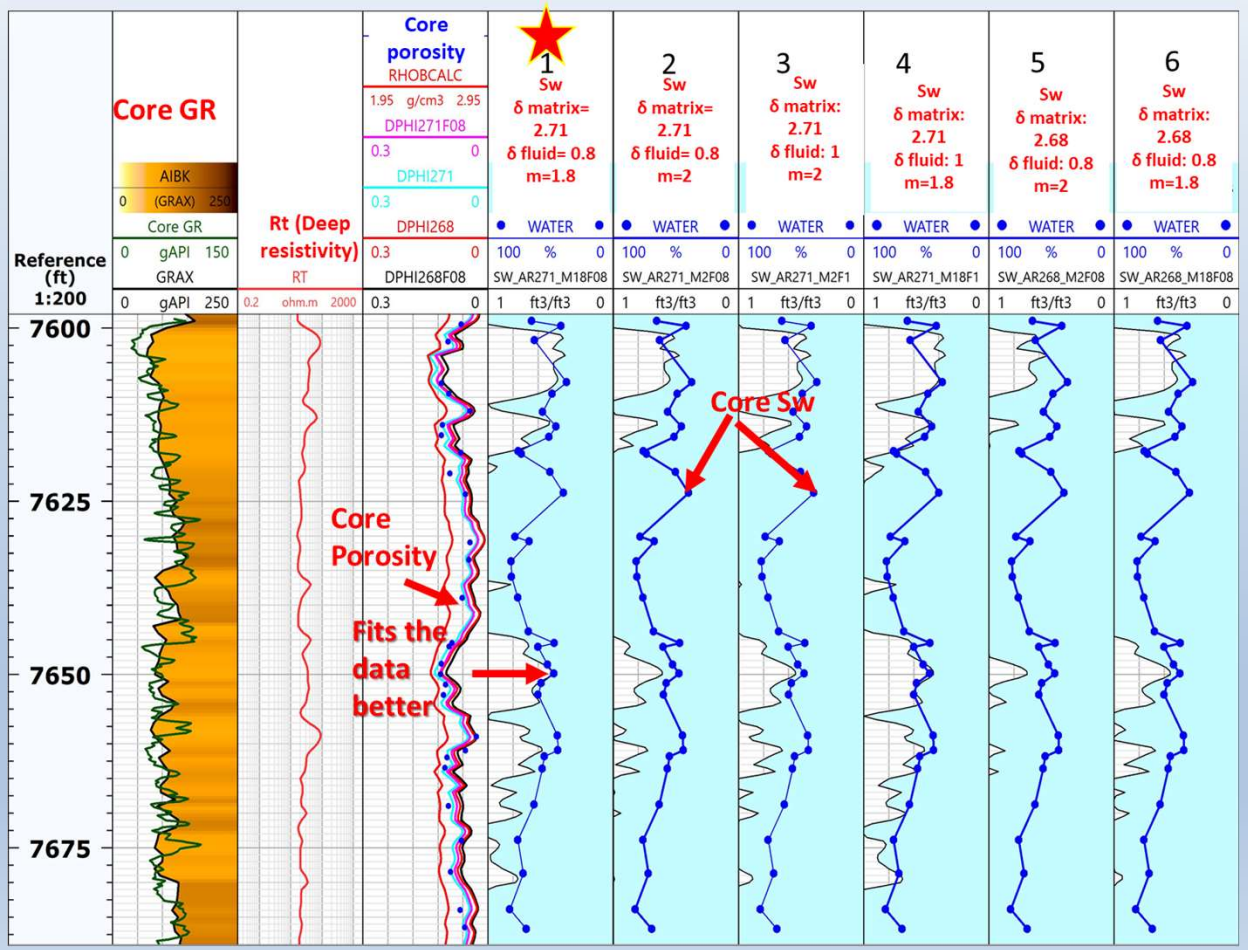
Well 4 saturation models



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3. Grain density 2.71 g/cc, and fluid density of 1 g/cc, and m=2
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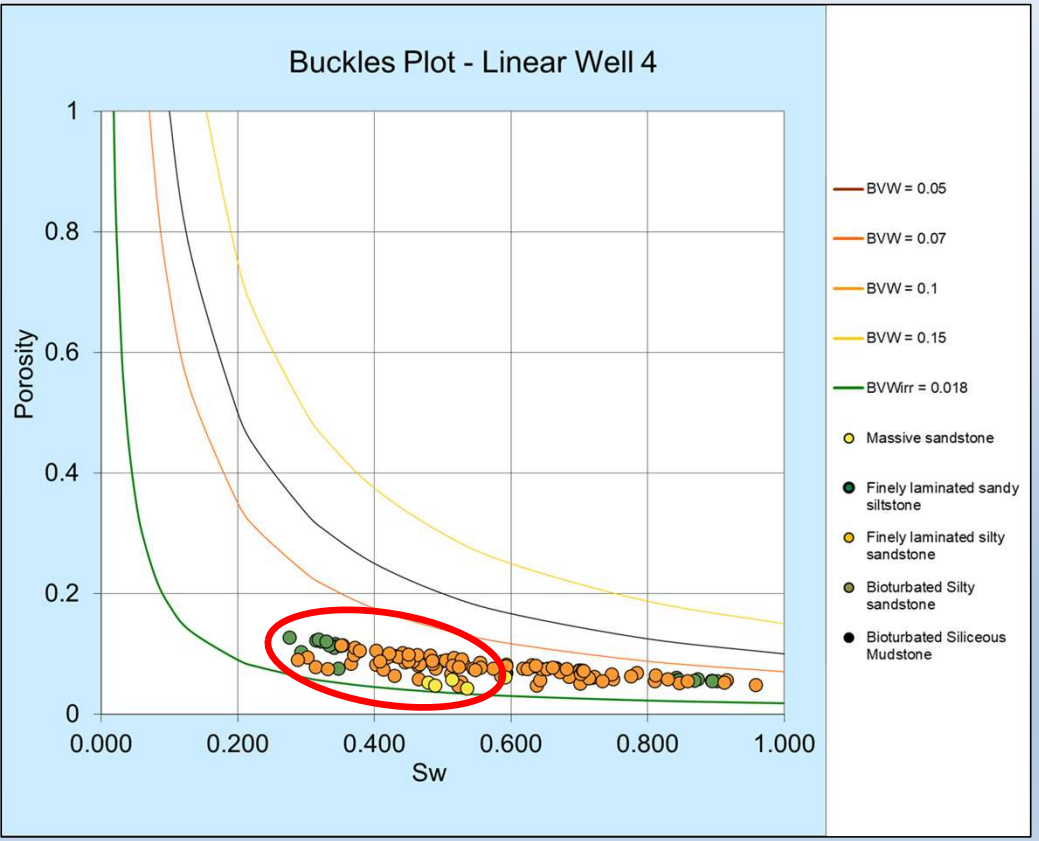
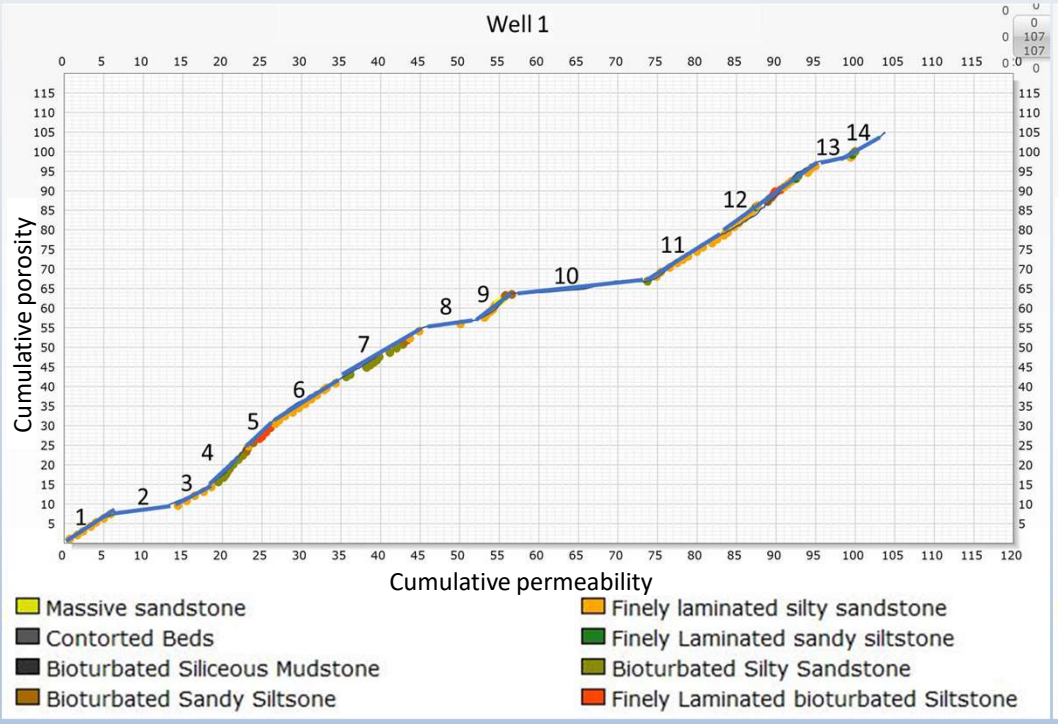
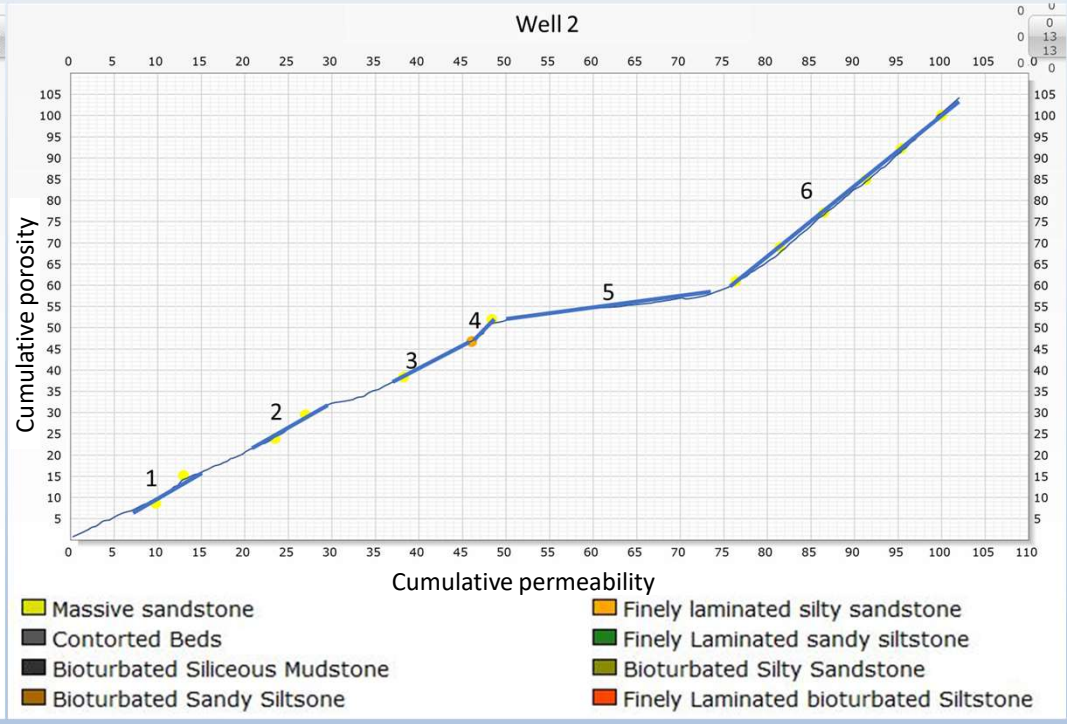
Well 4 Buckles and Pickett plots

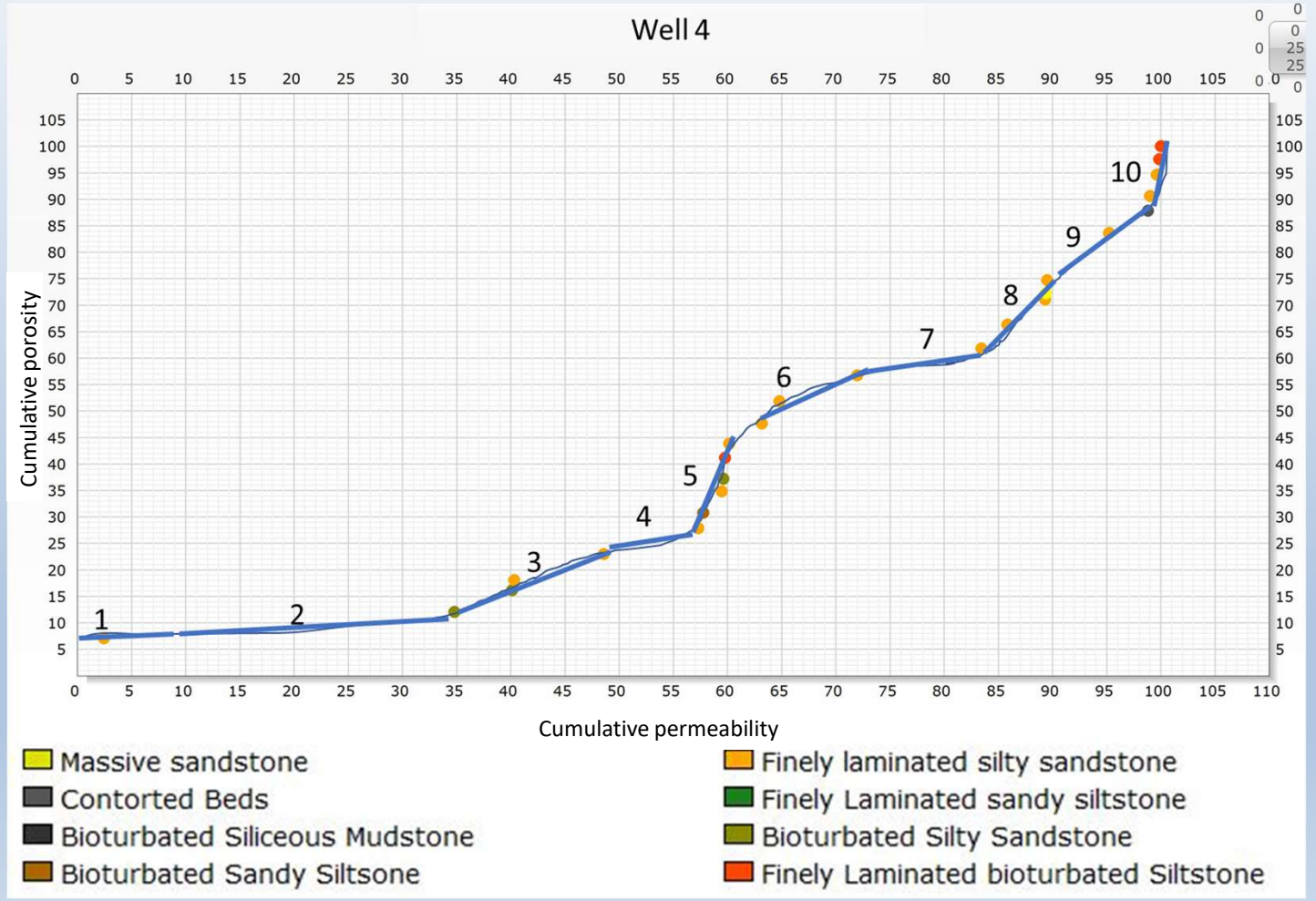


Well 1 and 2 Flow Units



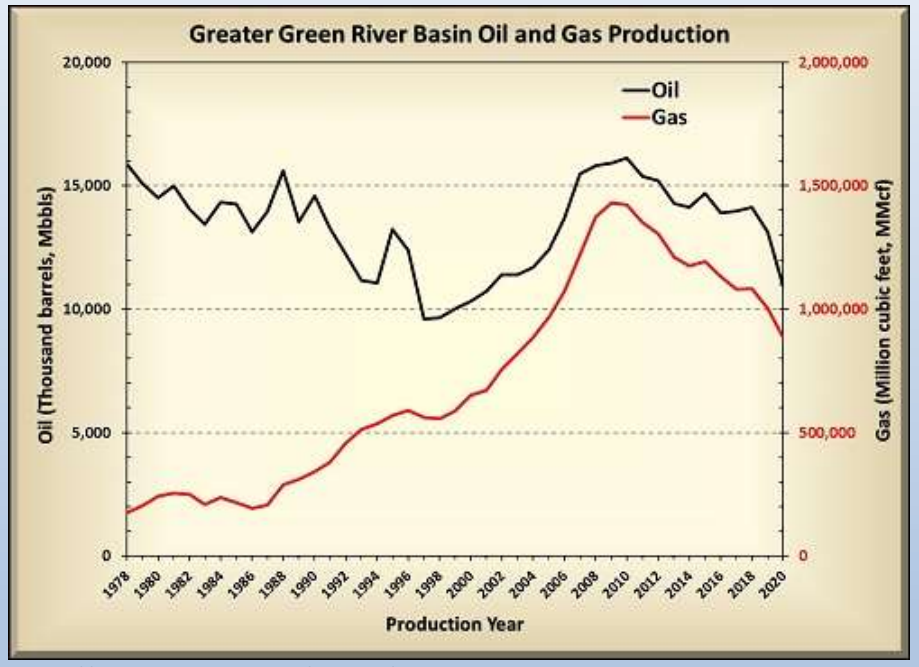


Well 4 Flow units

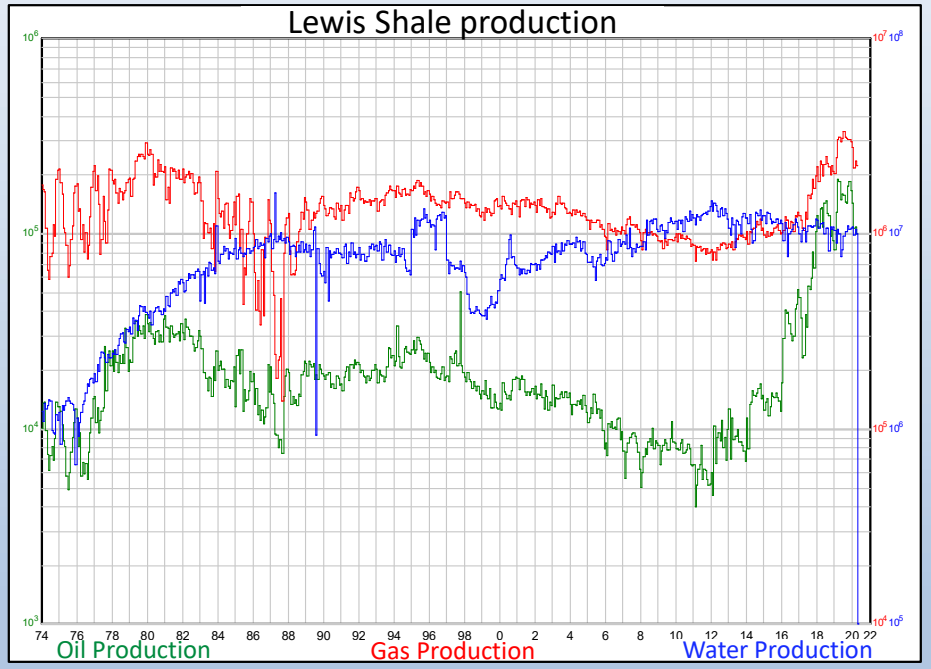


Well development challenges and production analysis

Production on the Greater Green River Basin



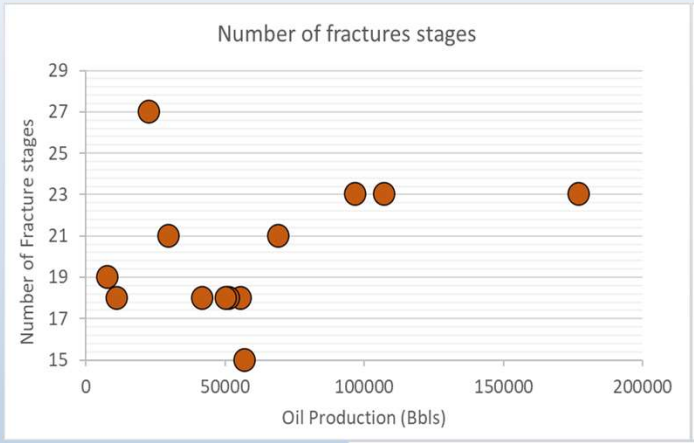
https://www.wsgs.wyo.gov/energy/oil-gas-basins.aspx

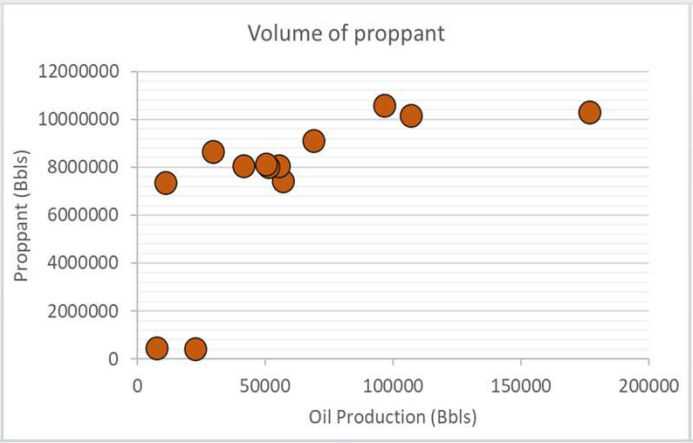


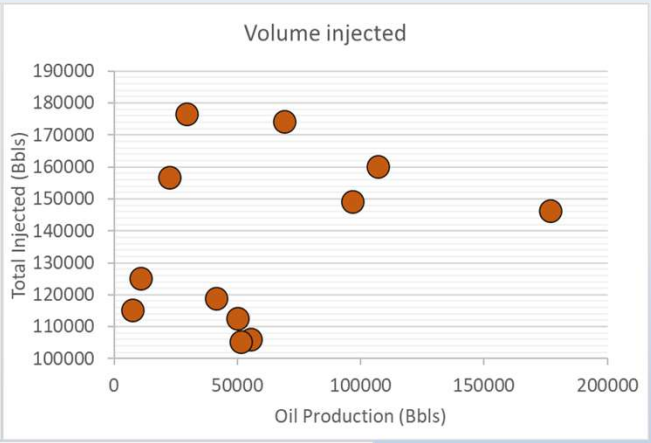
Data provided by Enverus.

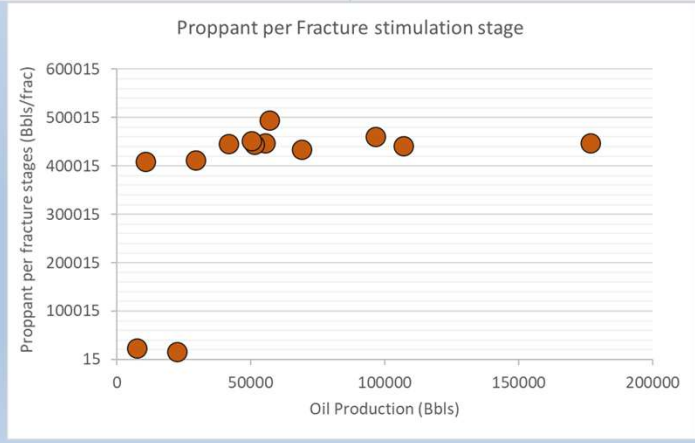
- It is mainly gas producer with some potential for liquid hydrocarbons.
- Between 600 and 675 BCFG with some minor amounts of oil have been produced since 1974.

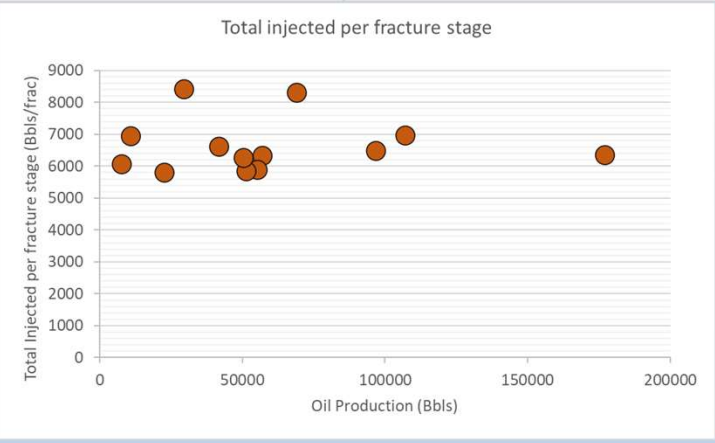
Production analysis interval F



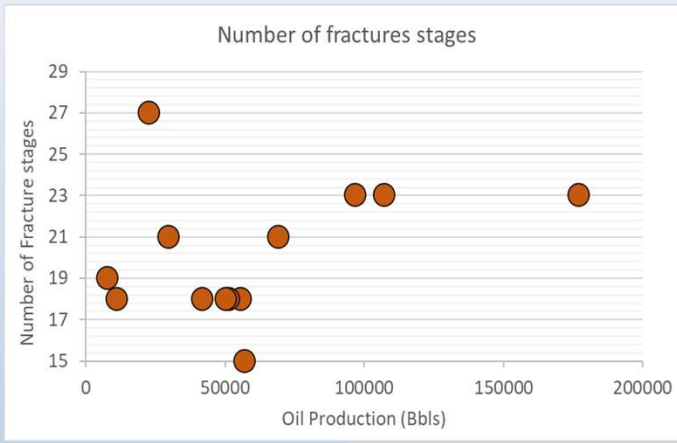


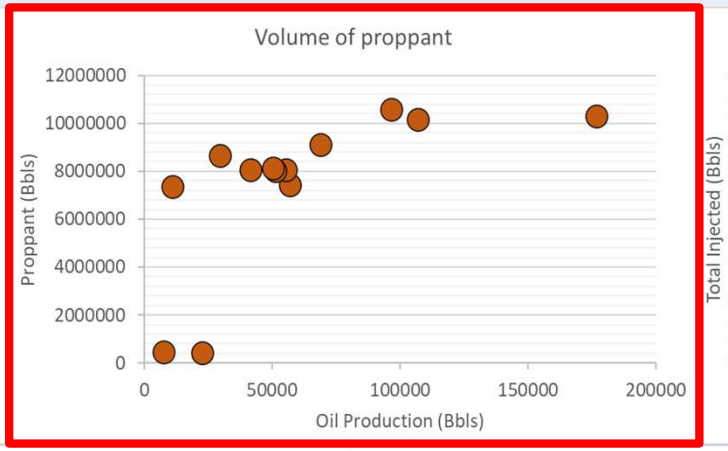


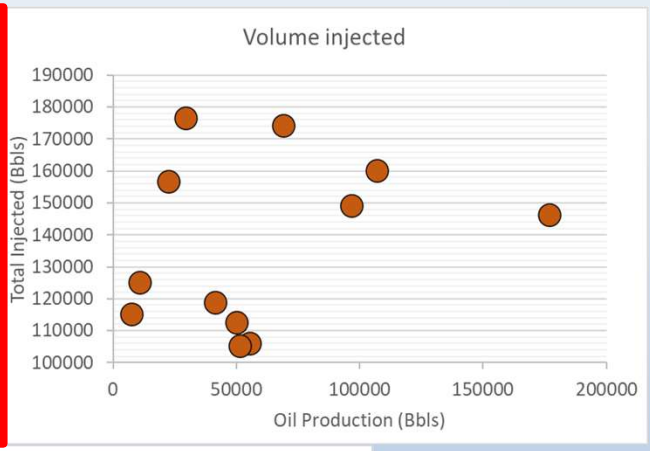


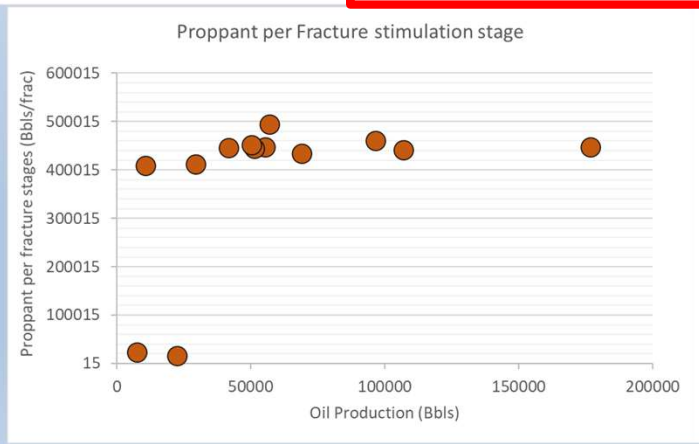


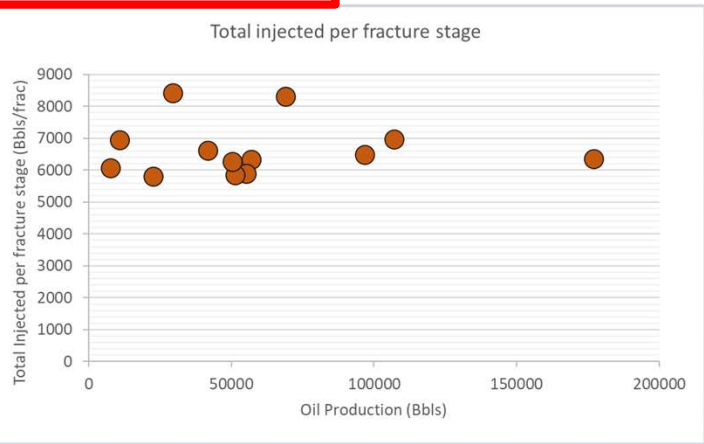
Production analysis interval F











Wildlife in Wyoming

- 87 species of mammals
- 297 species of birds
- 63 species of fish, reptiles and amphibians

1) avoid the impact 2) minimize the impact through appropriate planning and management actions; 3) mitigate the impact by providing replacement or substitute resources; and 4) provide financial compensation only when no reasonable alternative is available to avoid, minimize or mitigate the impact.

Black-footed Ferret

https://www.nature.org/en-us/newsroom/saving-black-footed-ferrets-in-wyoming/

Prairie Falcon

https://wgfd.wyo.gov/WGFD/media/content/PDF/Habitat/SWAP/Birds/Peregrine-Falcon.pdf

Prairie Dog

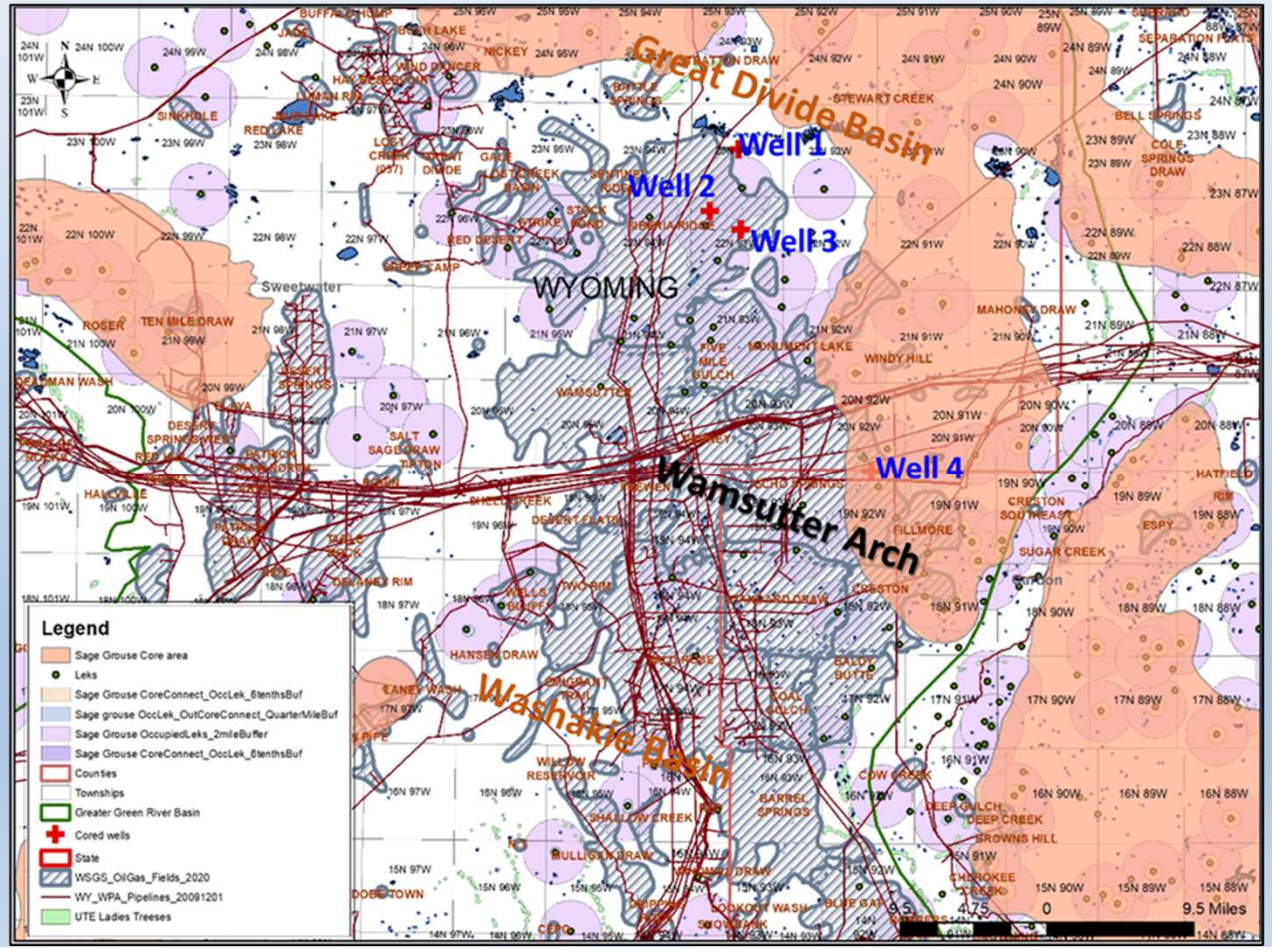
https://www.fws.gov/mountain-prairie/es/whiteTailedPrairieDog.php

Sage Grouse

https://wgfd.wyo.gov/Habitat/Sage-Grouse-Management

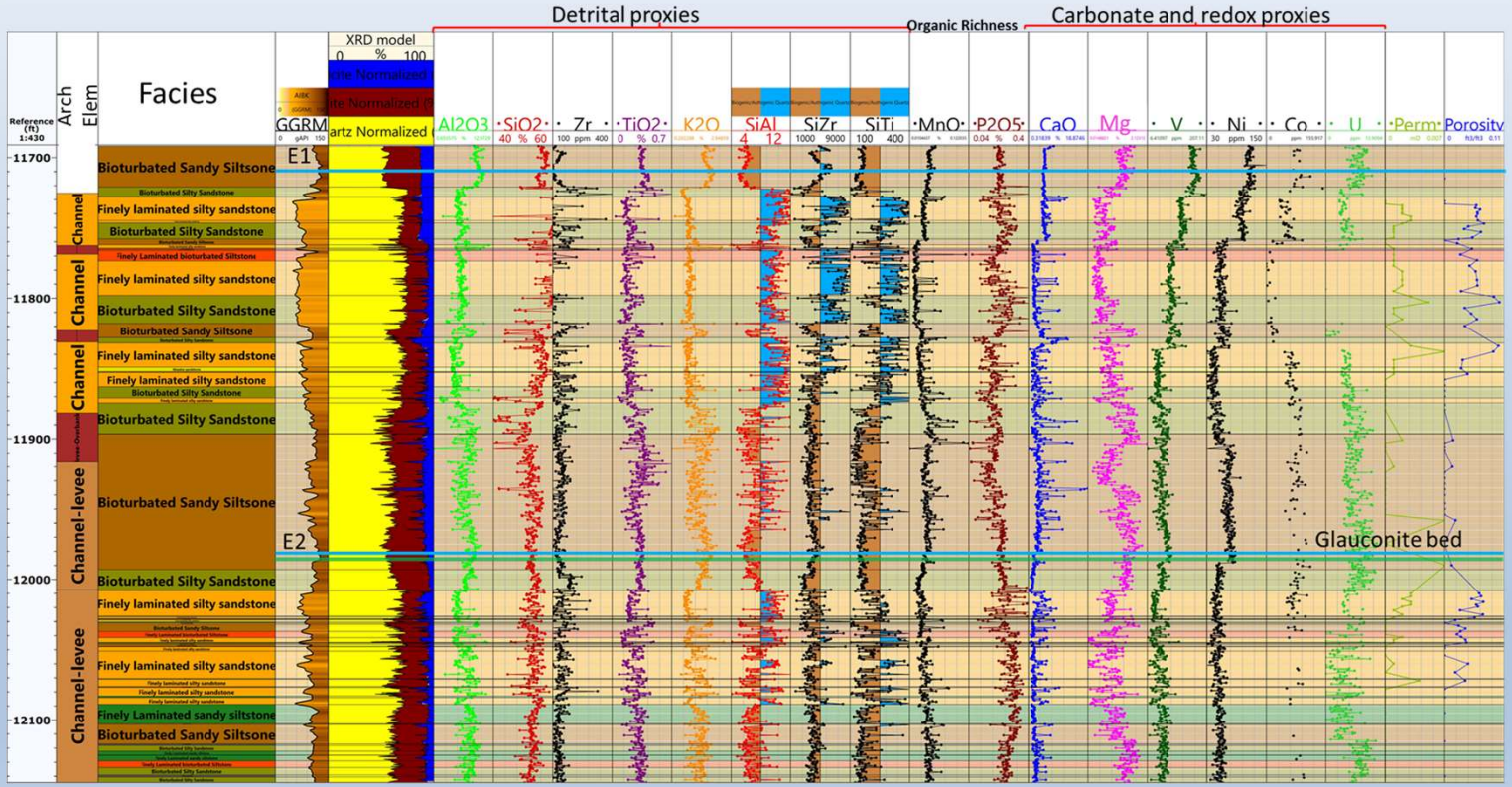
Ute Ladies Tresses

Environmental stipulations



Conclusions

- With this research some of the most important findings
- Excess silica was identified using XRF elemental data. Authigenic, biogenic, and chert from Paleozoic carbonates.
- Chlorite enhances reservoir properties and preserves porosity and permeability.
- The best facies are the finely laminated silty sandstone and the bioturbated silty sandstone. Rather than the clean, massive sandstones.
- Intervals with fewer interbedding have fewer risks



Conclusions

- Petrophysical models calibrated with core data proved crucial to having an accurate model.
- Some of the risks are associated with lateral pinch-outs, buffers, and baffles.
- Important to keep in mind environmental restrictions and communicate with BLM and government entities.

COLORADO SCHOOL OF MINES MUDTOC

QUESTIONS?

MUDTOC Consortium Sponsors
Spring 2022

Colorado School of Mines MUDTOC

Sponsoring Member Companies

Anschutz Exploration Corporation

Antero Resources

Bonanza Creek

Chevron

COTERRA

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

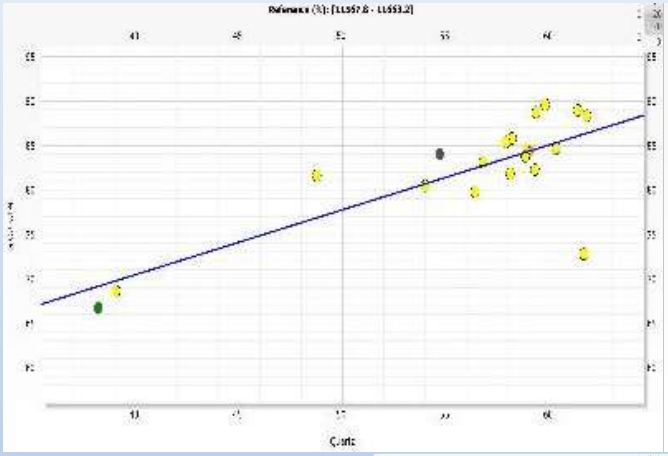
PRA Platte River Associates, Inc.

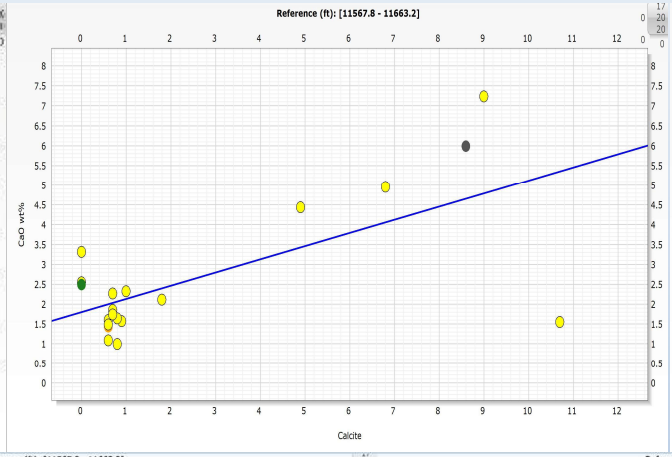
Schlumberger

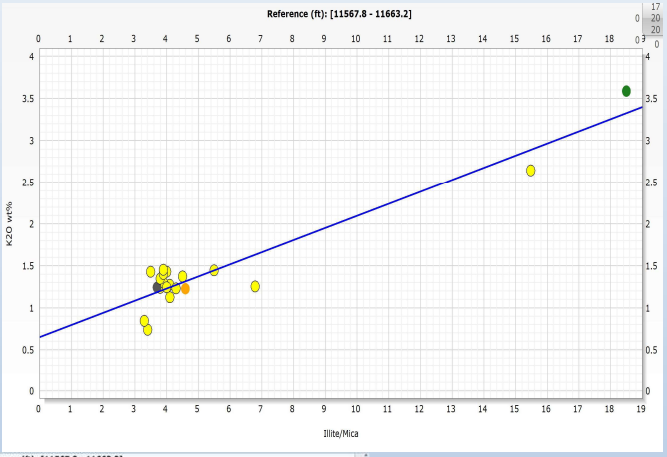
Future work

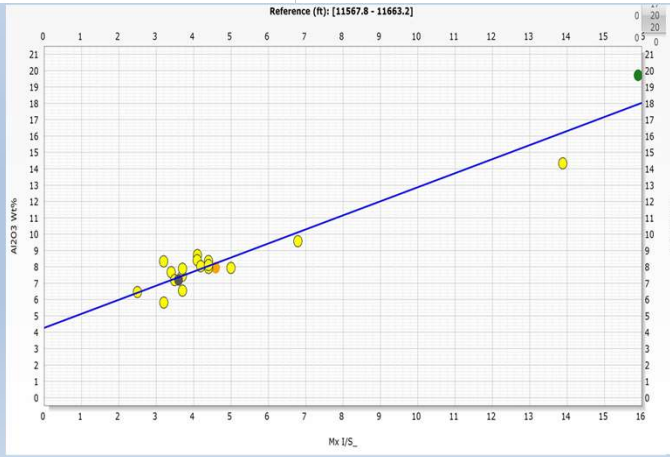
- Further investigate the effects of chlorite on porosity and permeability on the sandstones and at which percentage it enhances or decreases reservoir quality.
- Identify chert provenance.
- Extrapolate de petrophysical models to wells around the cored area when more data becomes available.
- Obtain more production data and perform rate transient analysis and decline curve analyses.

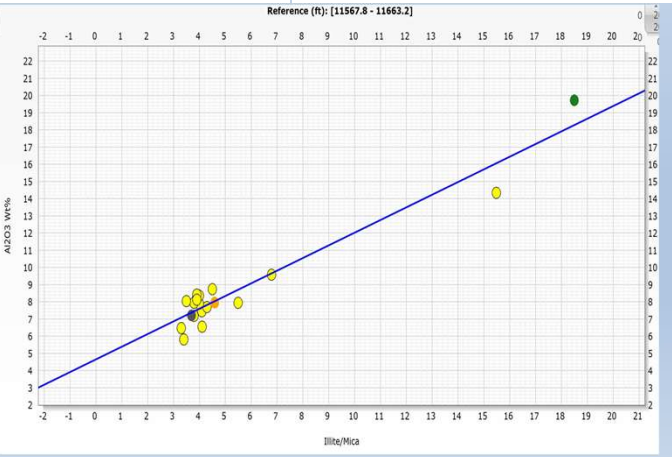
Best linear fit



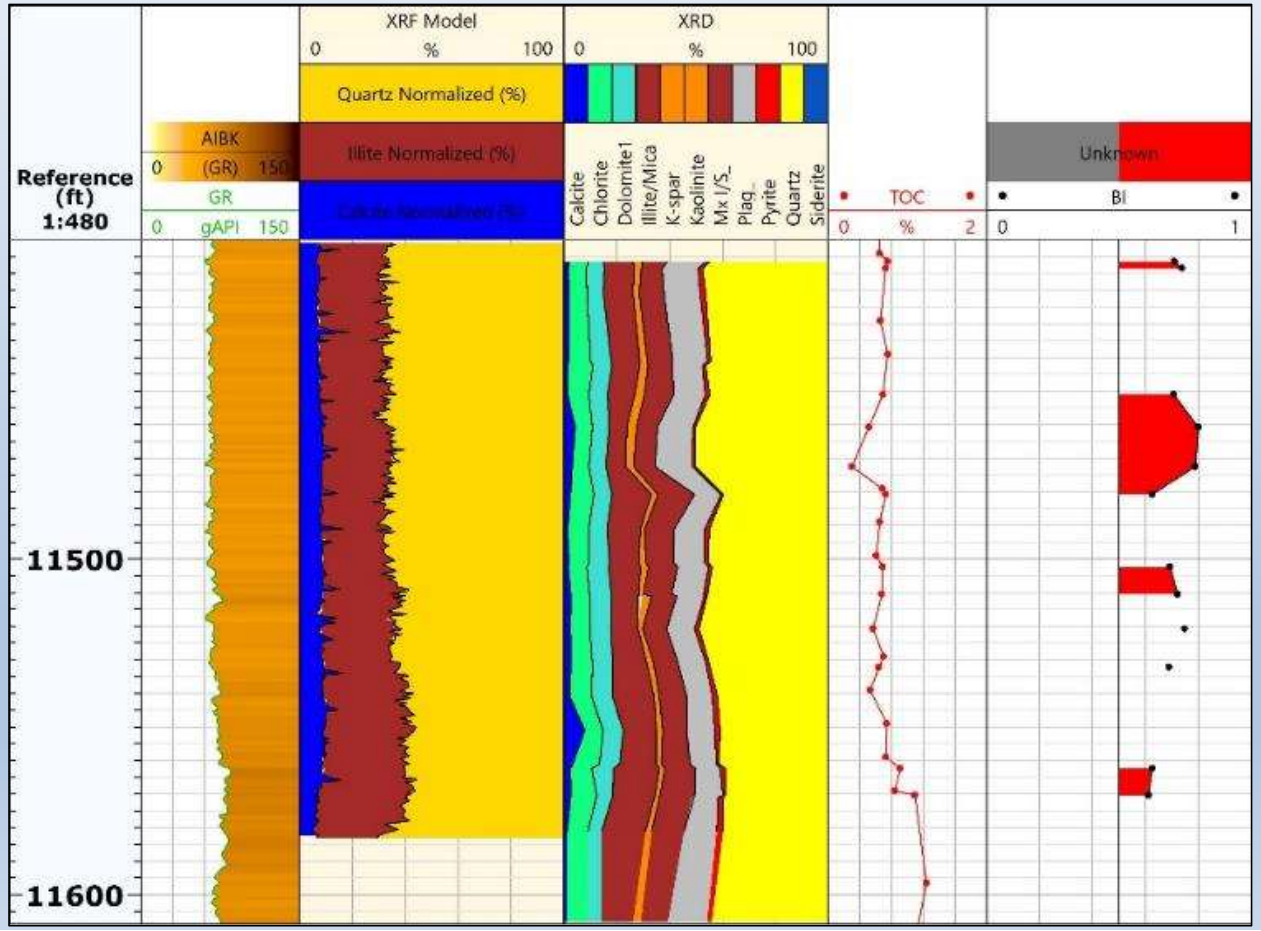






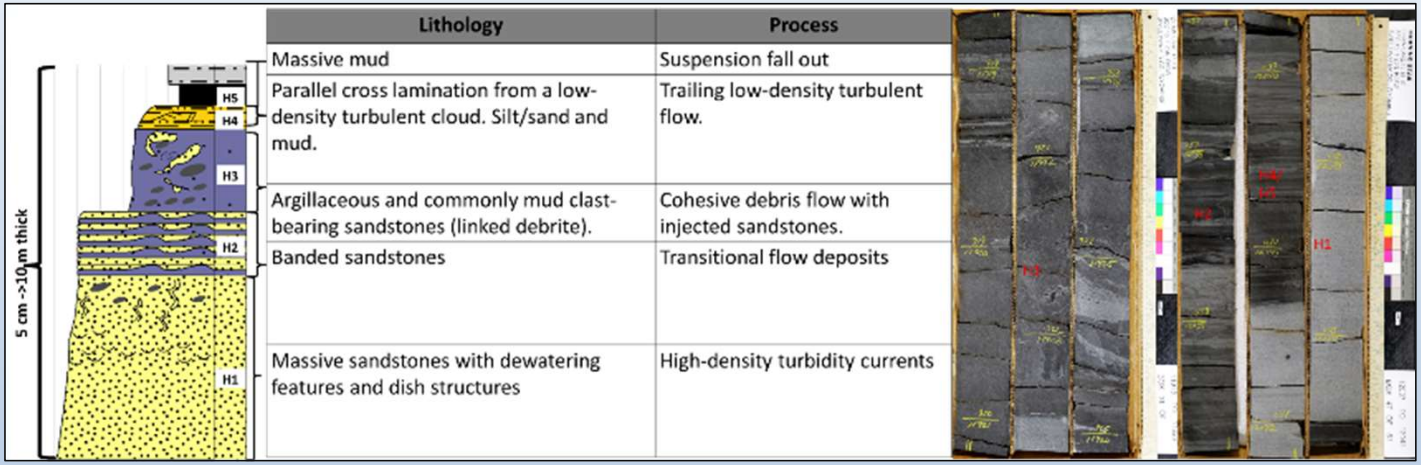


Brittleness Index



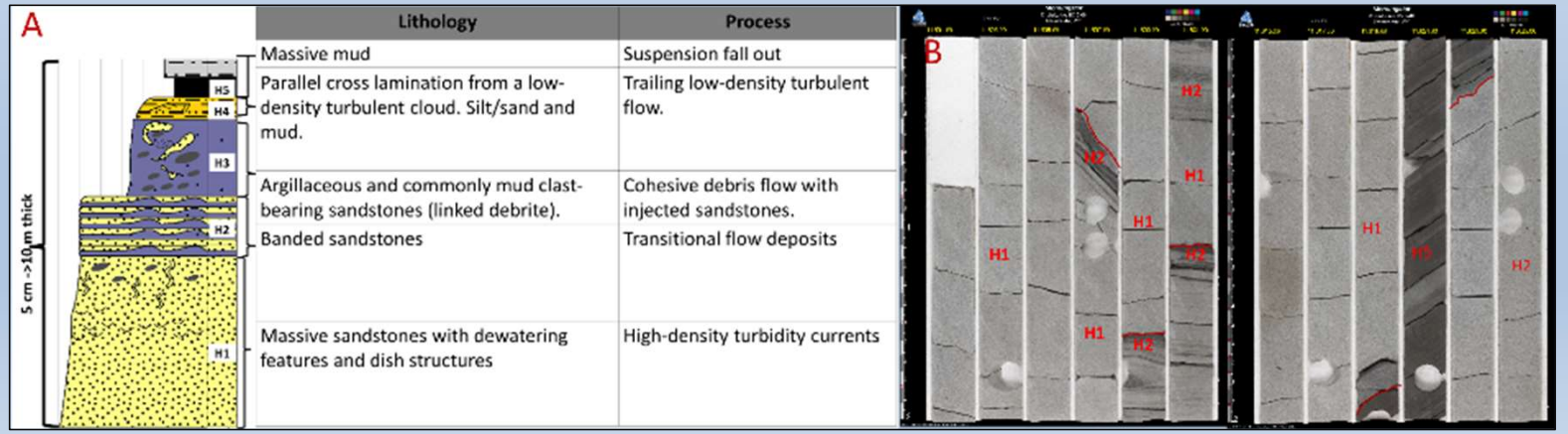
Gravity sediment flows

Well 1



Lithology	Process
Massive mud	Suspension fall out
Parallel cross lamination from a low-density turbulent cloud. Silt/sand and mud.	Trailing low-density turbulent flow.
Argillaceous and commonly mud clast-bearing sandstones (linked debrite).	Cohesive debris flow with injected sandstones.
Banded sandstones	Transitional flow deposits
Massive sandstones with dewatering features and dish structures	High-density turbidity currents

Well 2



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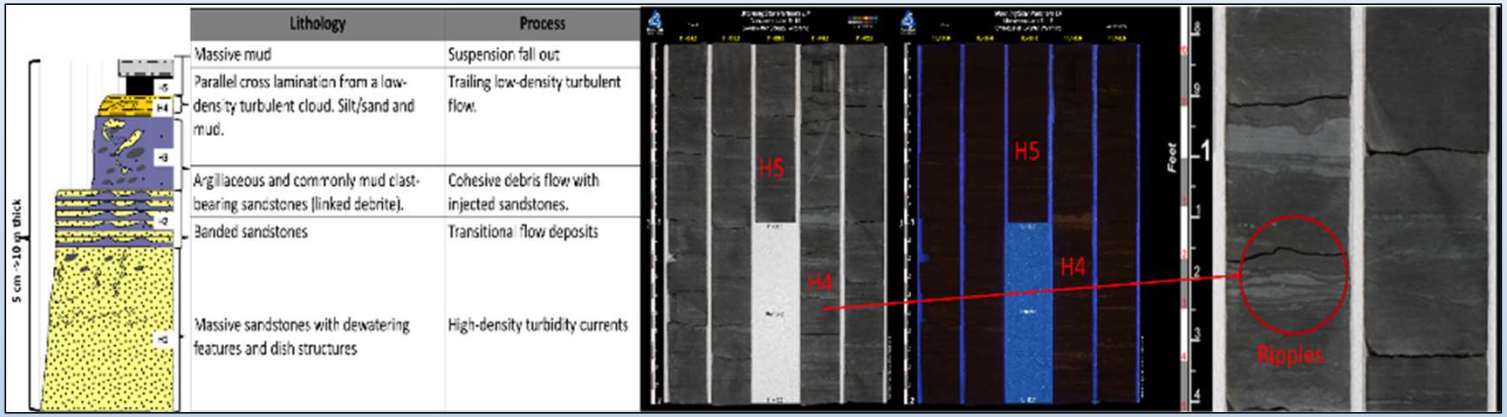
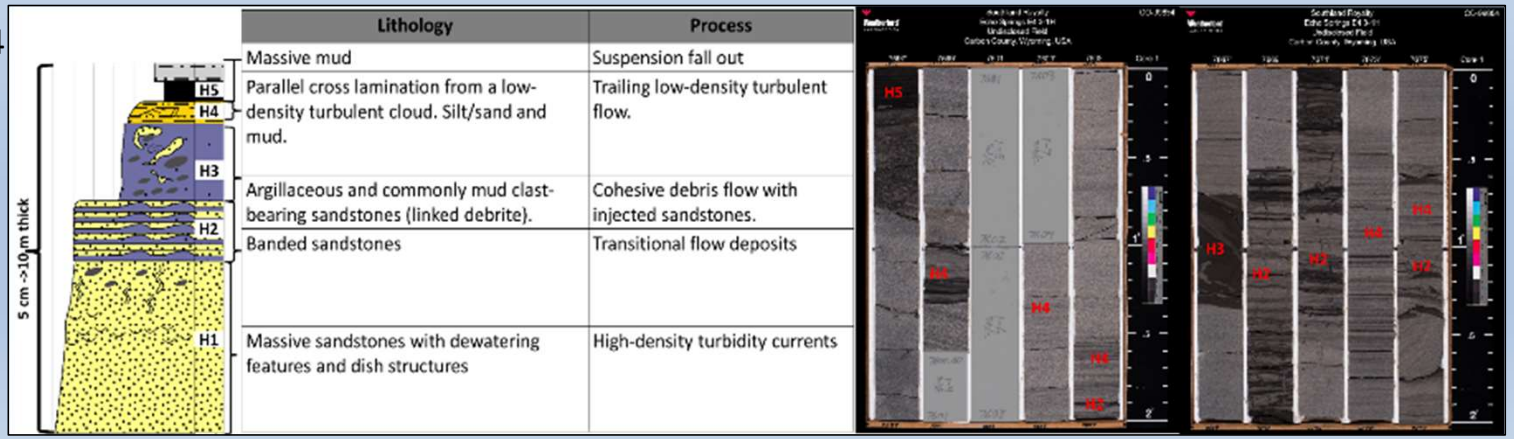
Banded sandstones	Transitional flow deposits
Massive sandstones with dewatering features and dish structures	High-density turbidity currents

Gravity sediment flows

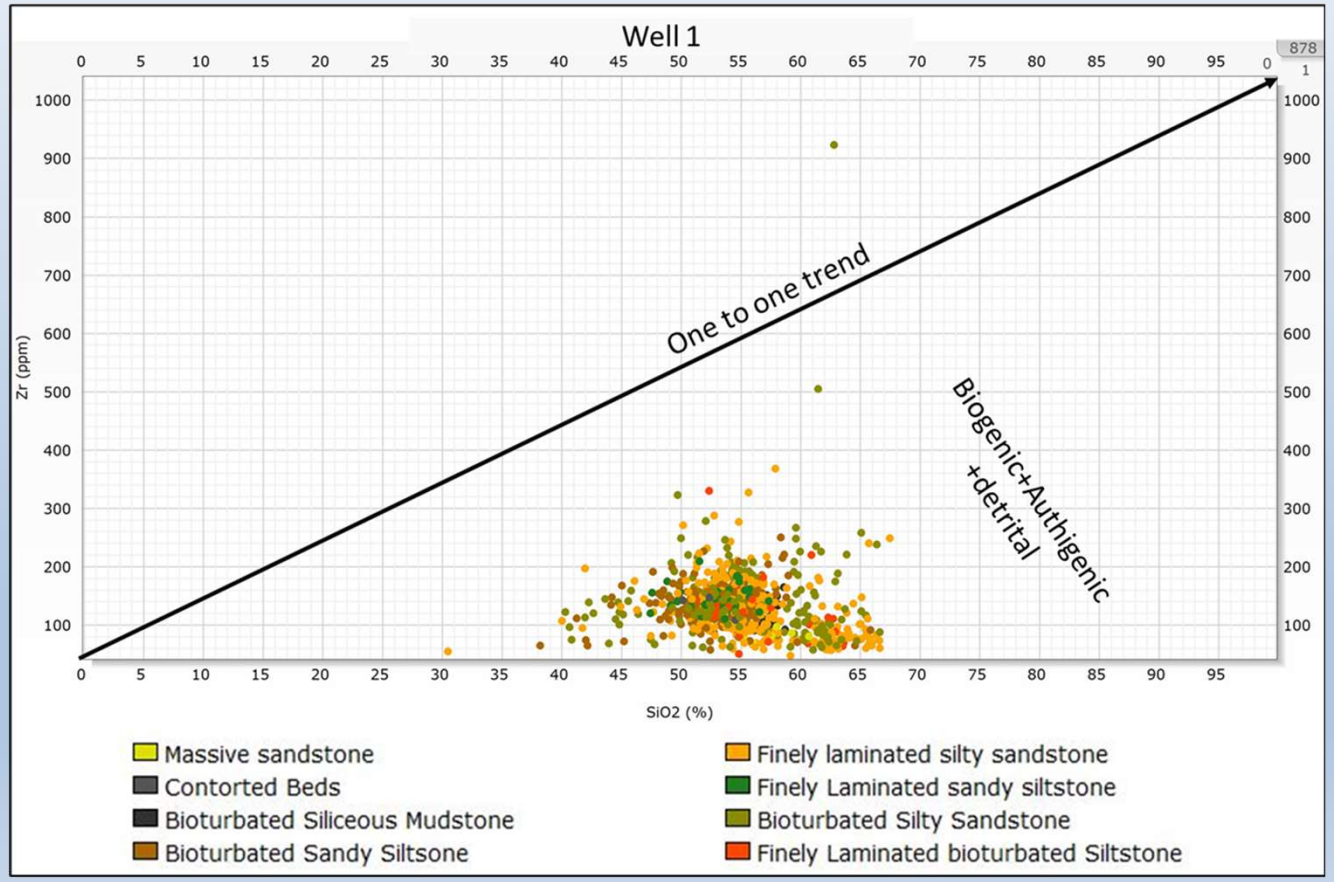
Well 3



Well 4



Excess Silica



Excess Silica