Hydrocarbon Contribution from the Lower Bakken Shale in Horizontal Wells Drilled in the Three Forks Formation in Divide County, ND

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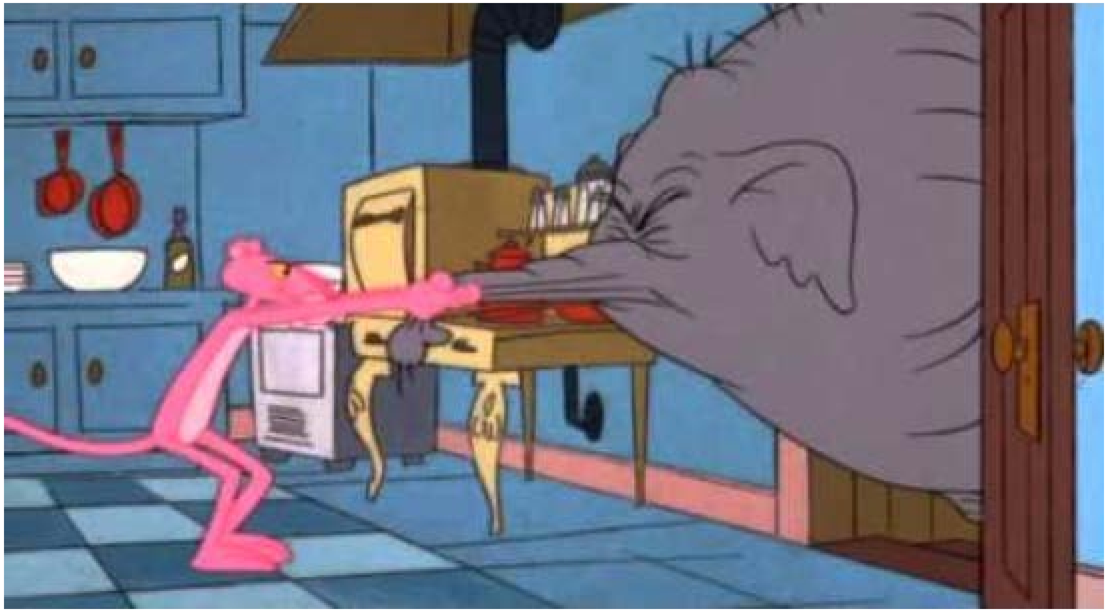
Executive Summary

Important Questions Exist About What Intervals Contribute in Three Forks Wells in Divide County

- Wells drilled in the Three Forks produce more oil than one might expect from the thin dolomites of the upper Three Forks

- Other formations within the Bakken Petroleum System are likely contributing

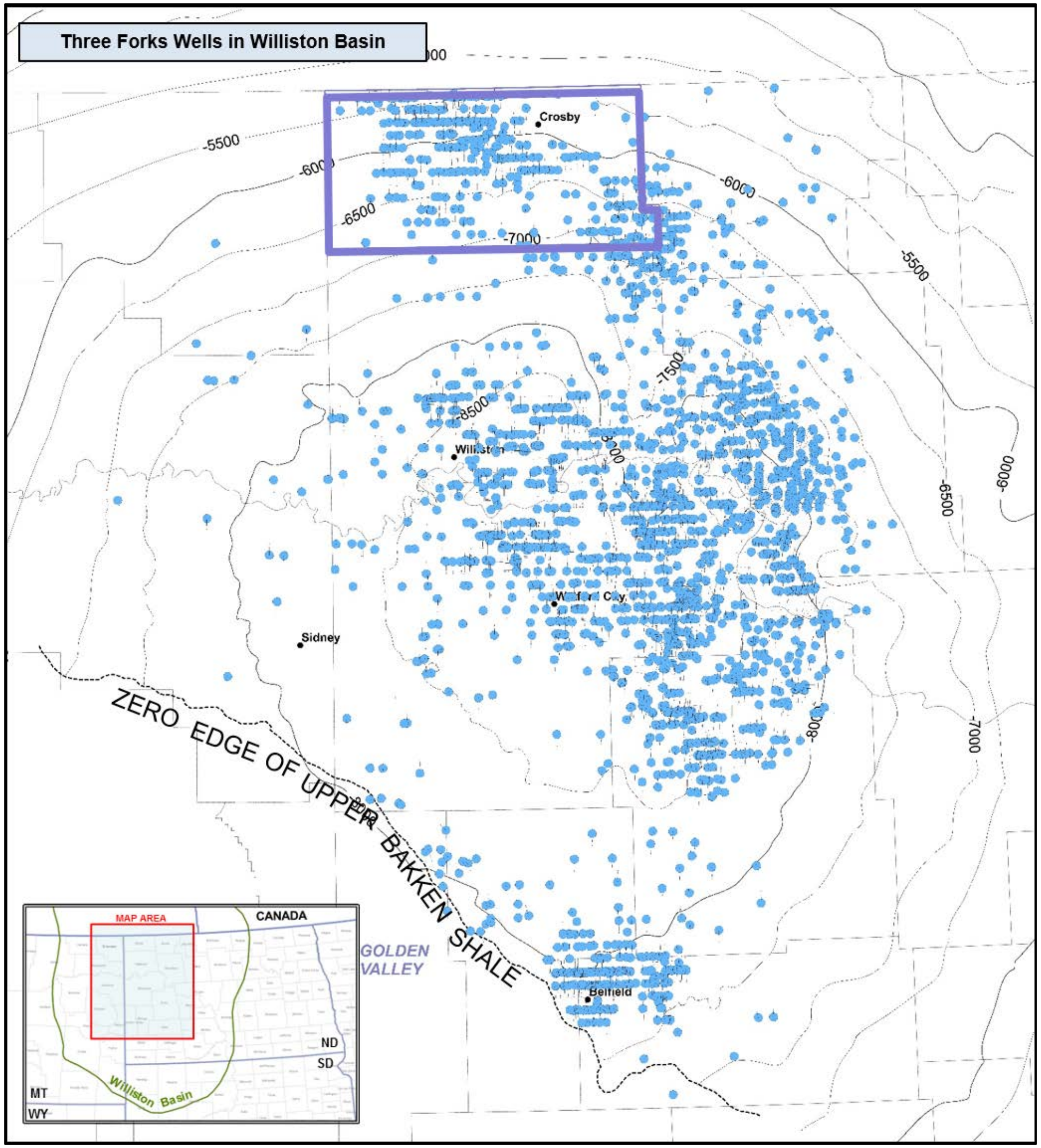


Executive Summary

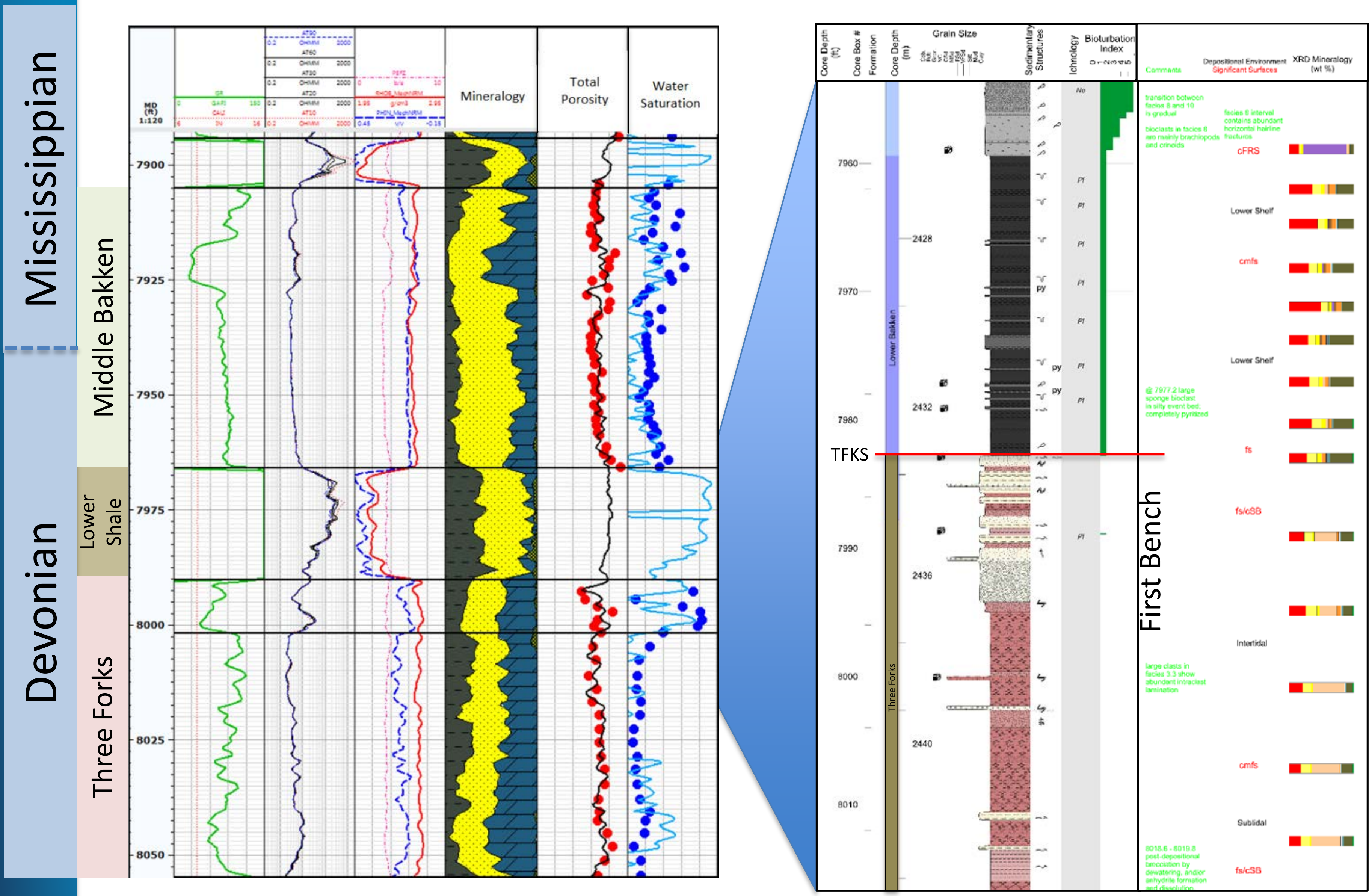
- Which stratigraphic intervals contribute to Three Forks wells in Divide County?
    - Three Forks stratigraphy and reservoir parameters
    - Well results
    - Volumetric Calculations
- How much does the Lower Bakken Shale contribute?
    - Maturity
    - SEM
    - Porosymmetry
    - XRD
    - Rock Mechanics

Location Map

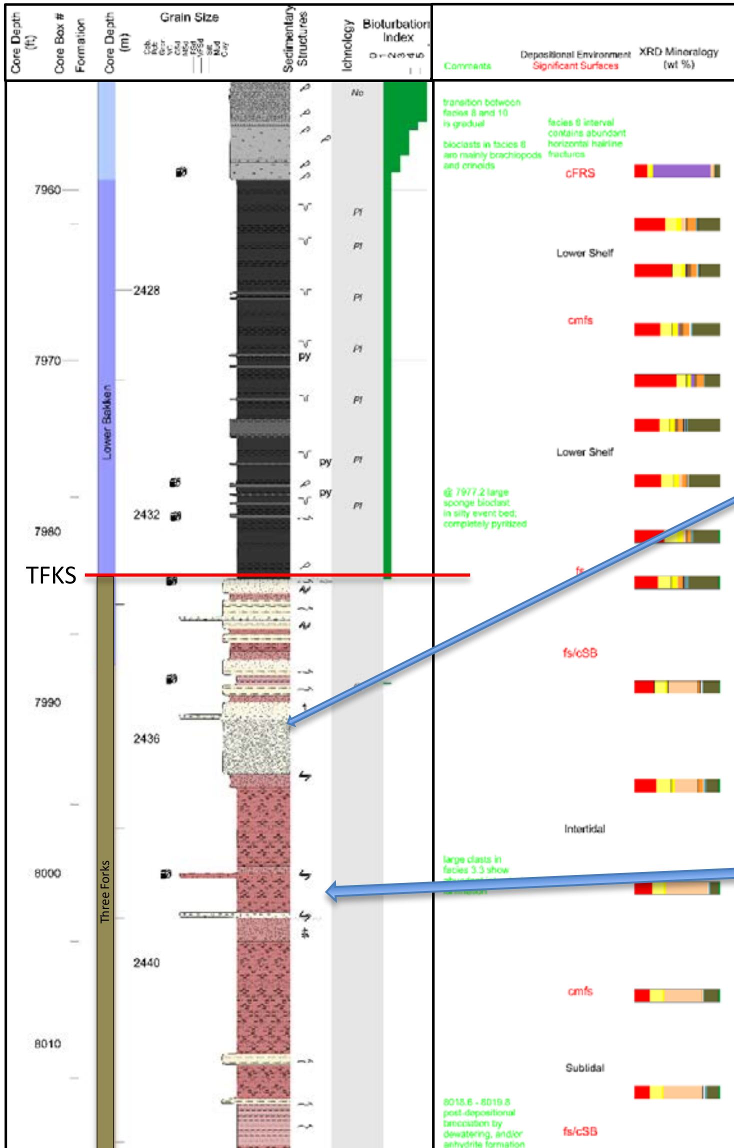
- The Three Forks has been targeted in Divide County since 2005
- ~35 MMBO produced so far from 389 wells



Three Forks Stratigraphy



Three Forks Stratigraphy



7991.7’

6.5% Phi 17% Sw

8003.85’

8.5% Phi 88.5% Sw

<u>End Member Lithologies</u>

Brown to tan, silty to sandy dolostone

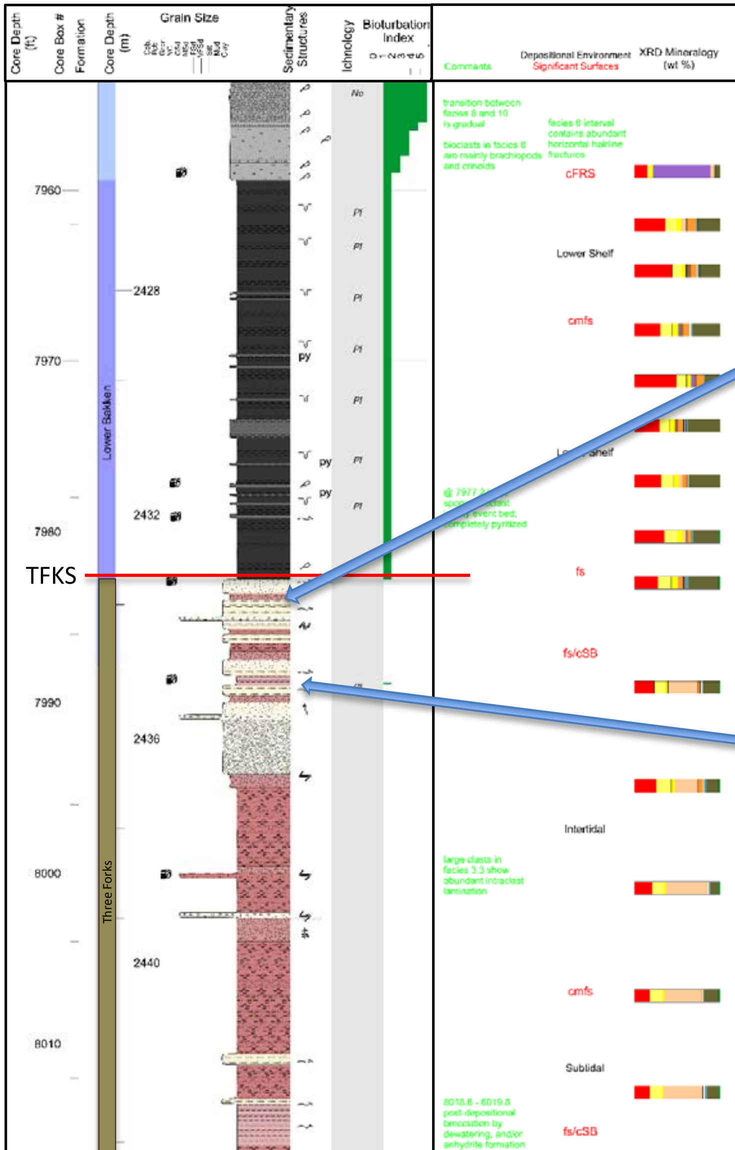
- Average composition
  - 63% dolomite
  - 30% quartz-feldspar
  - 3% illite

Green silty mudstone

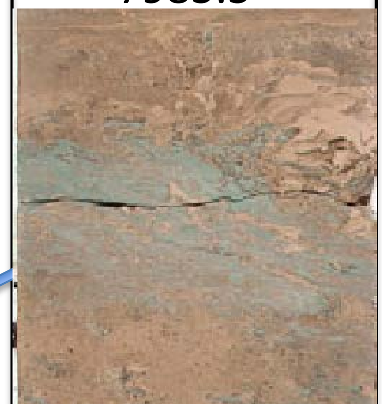
- Average composition
  - 36% dolomite
  - 30% quartz-feldspar
  - 30% clay minerals
  - 2% pyrite

Modified from Petty, 2014

Three Forks Stratigraphy



7985.5’



10.0% Phi 40% Sw

7988.75’

6.4% Phi 38.3% Sw

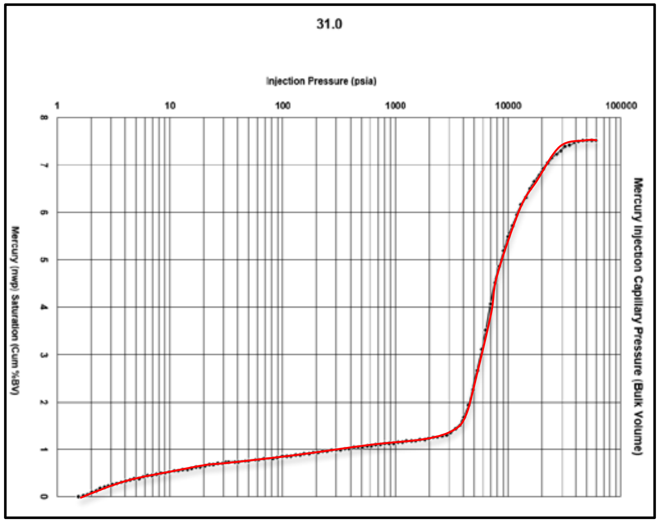
Mixed Lithologies

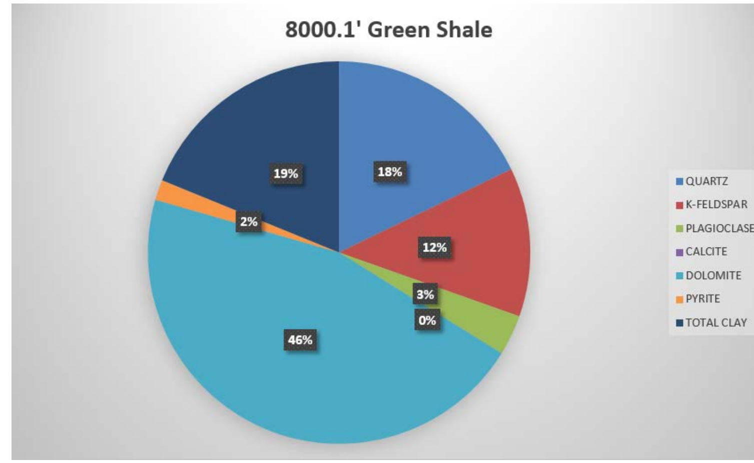
Mixed green and brown breccia

Mixed green and brown laminated

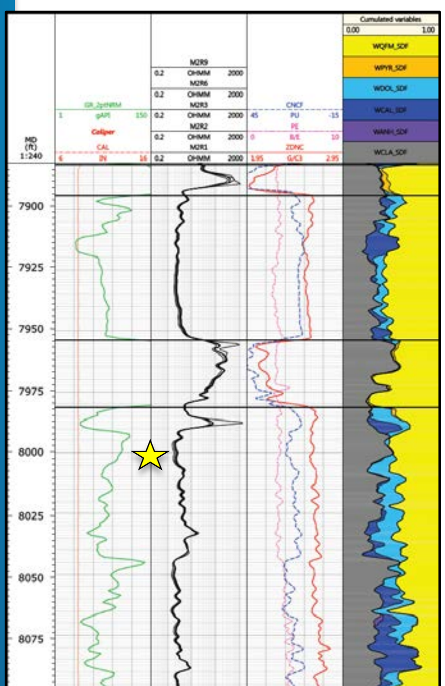
Modified from Petty, 2014

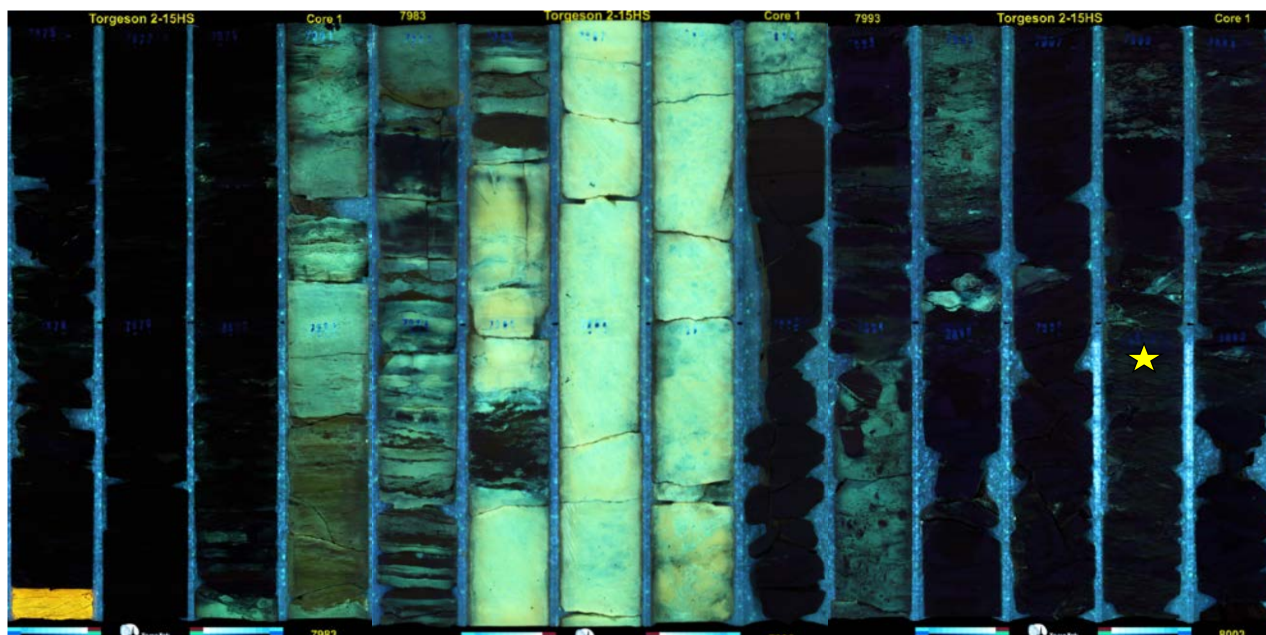
Core Fluorescence & Reservoir Quality





MICP Perm 0.000801 mD





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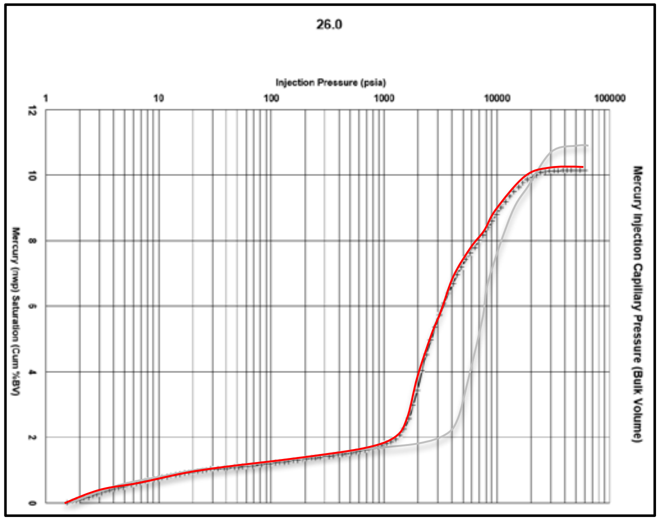

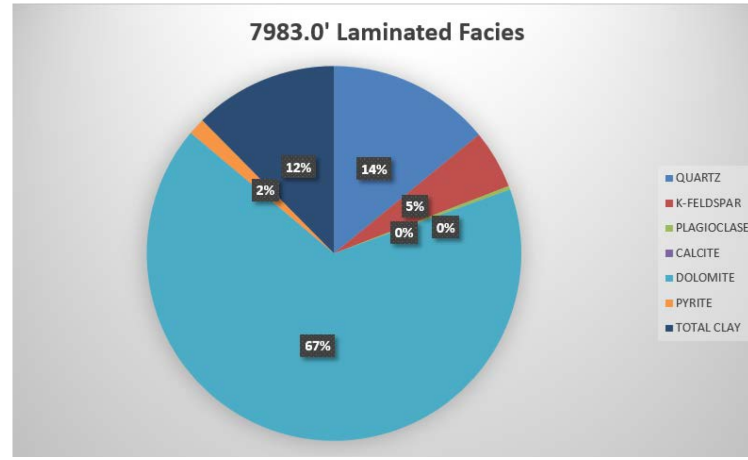

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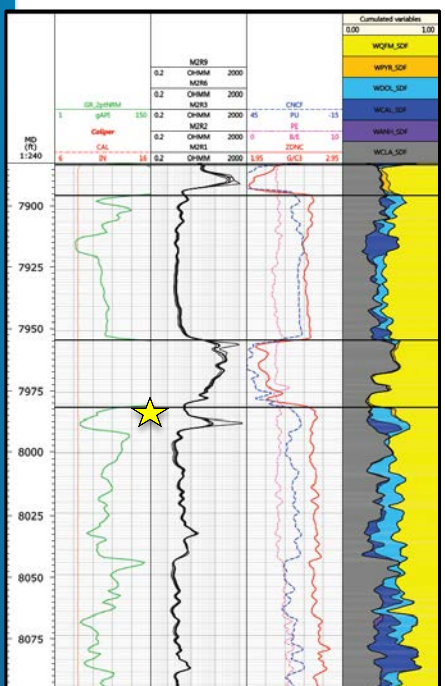

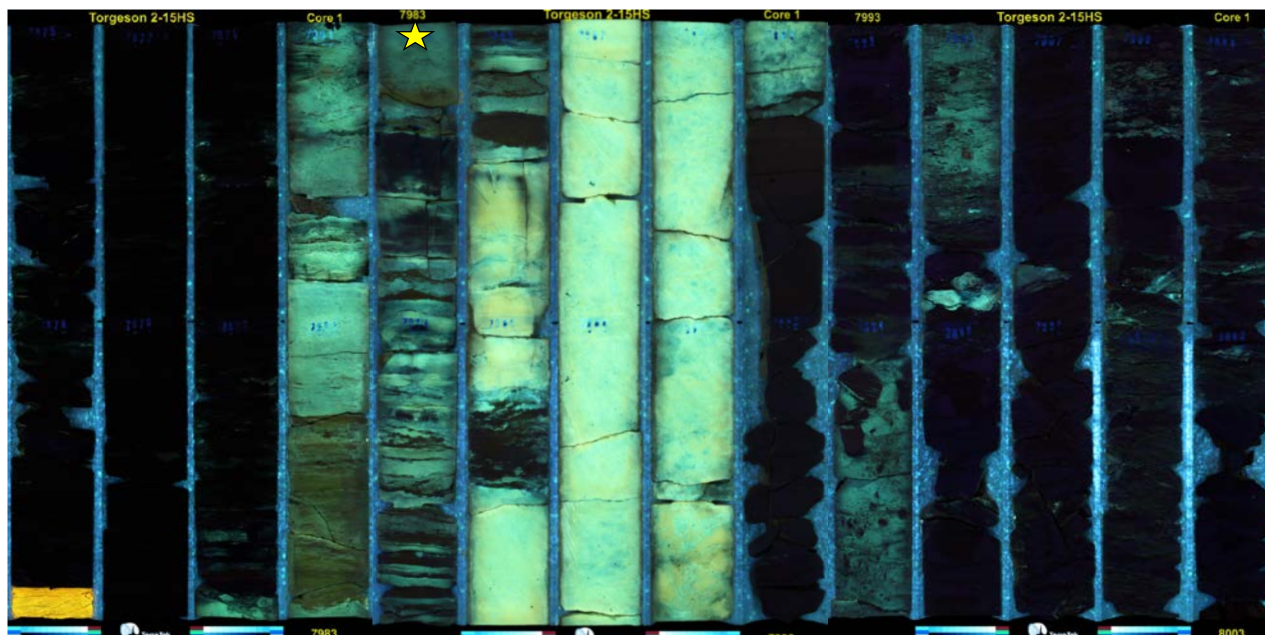

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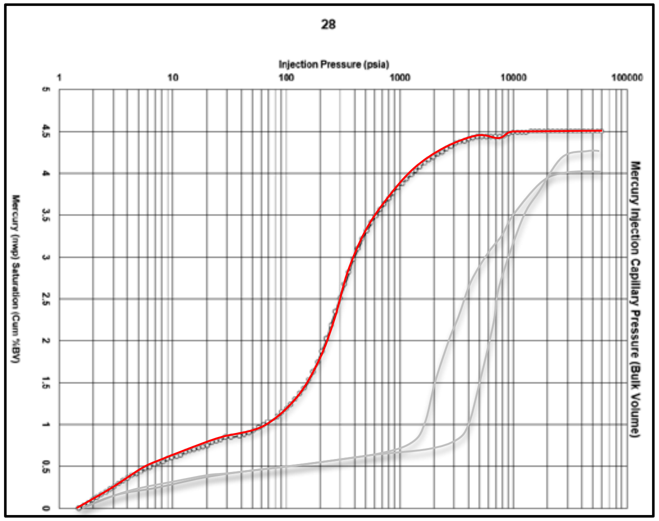
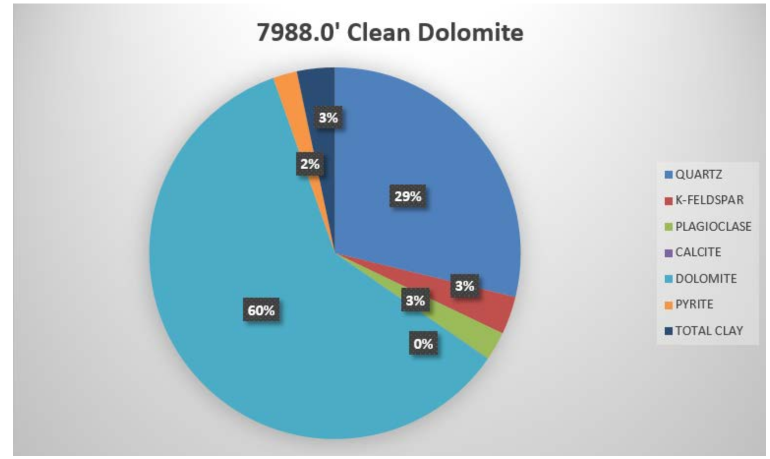
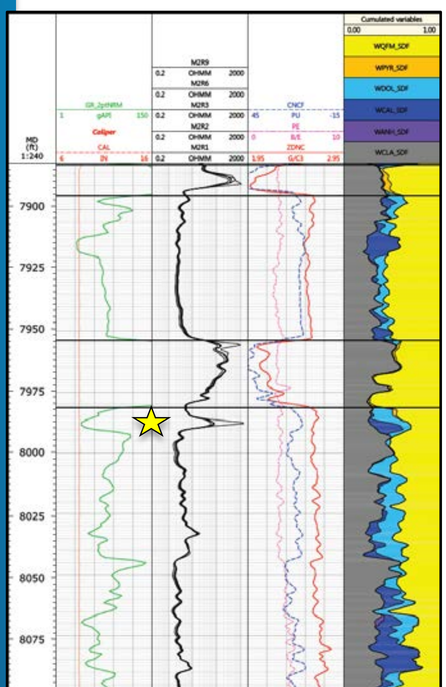
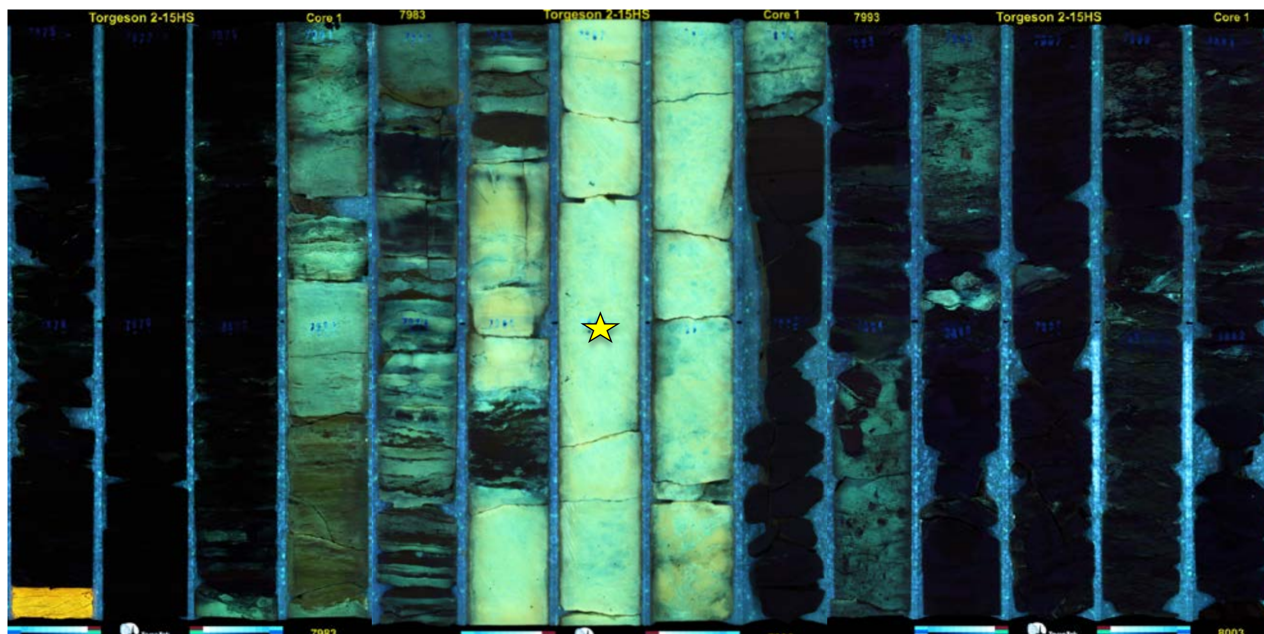




MICP Perm 0.0519 mD





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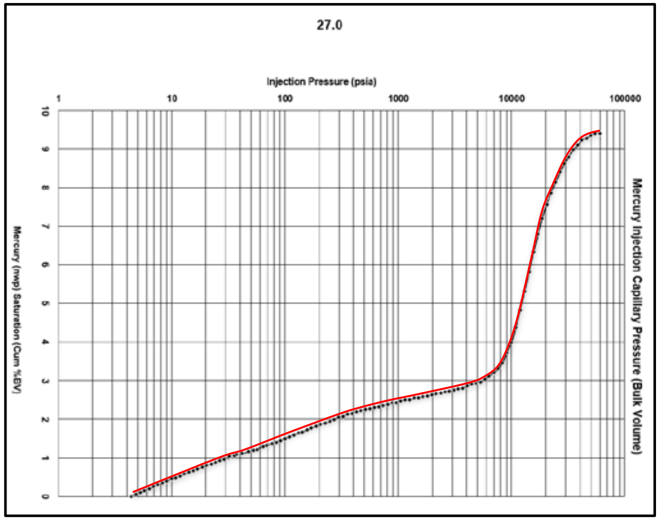

MICP Perm
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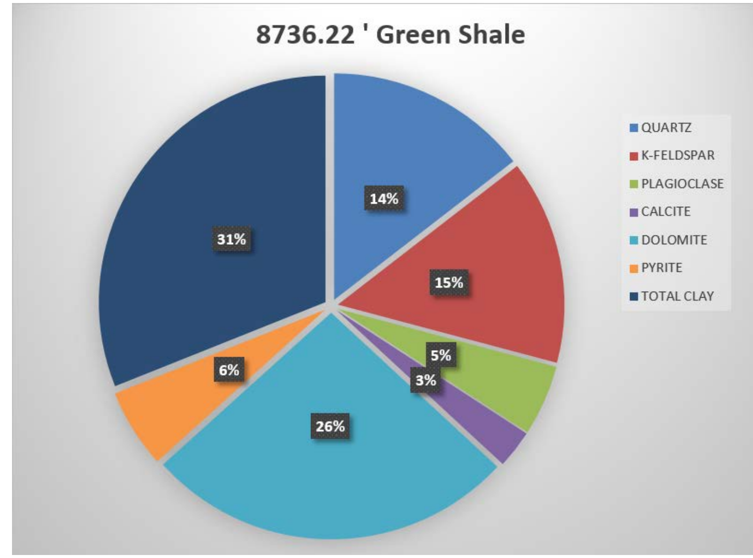

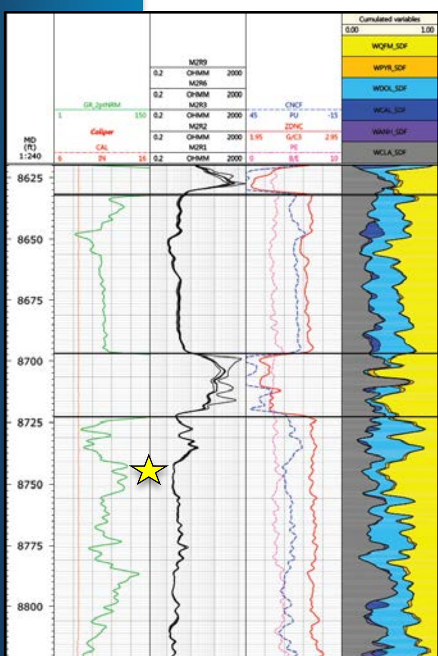

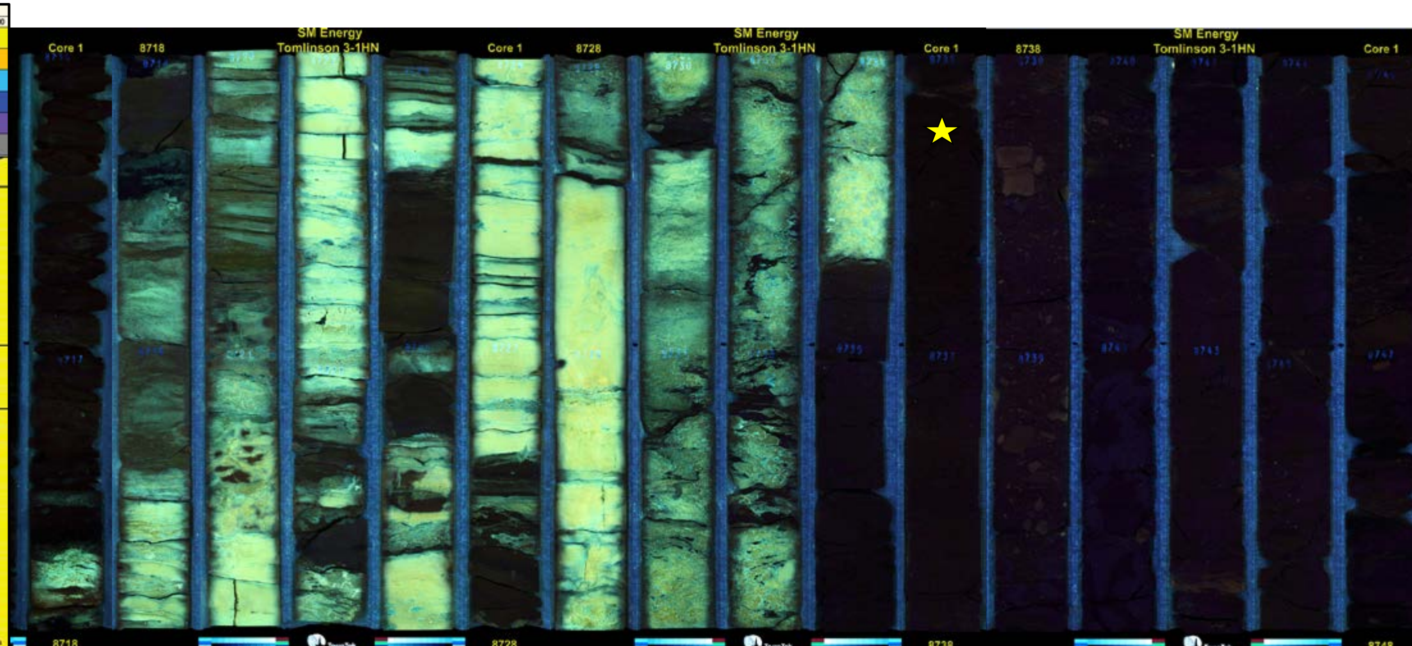

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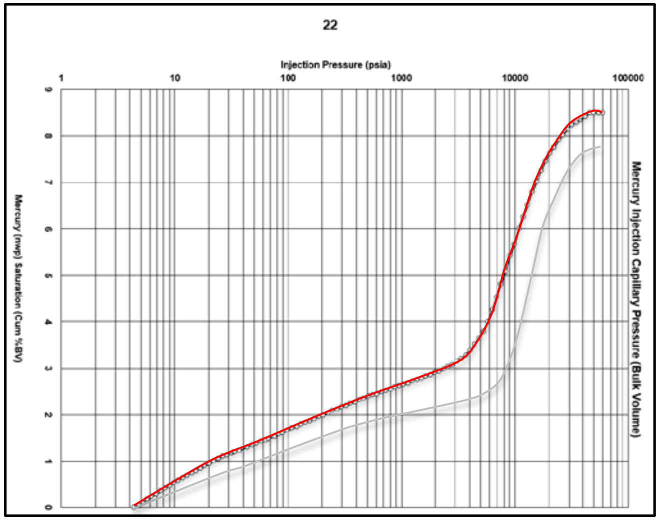

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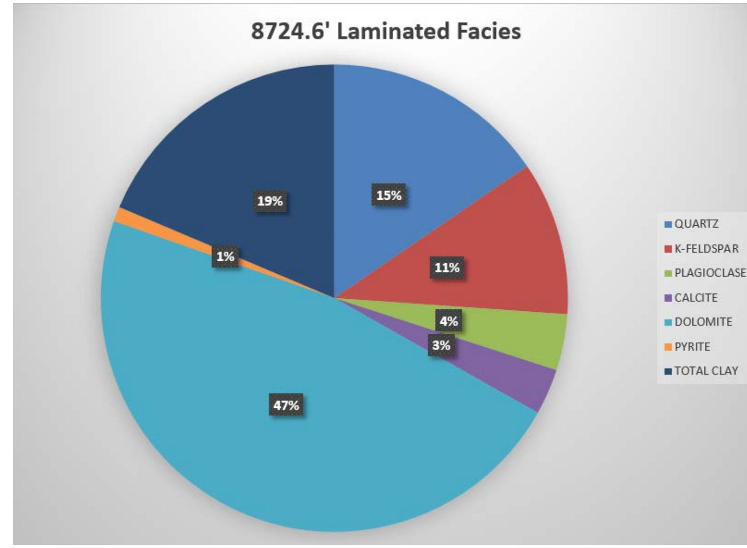

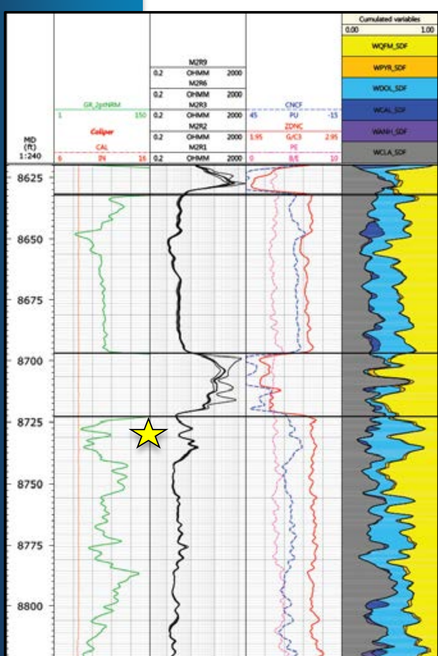

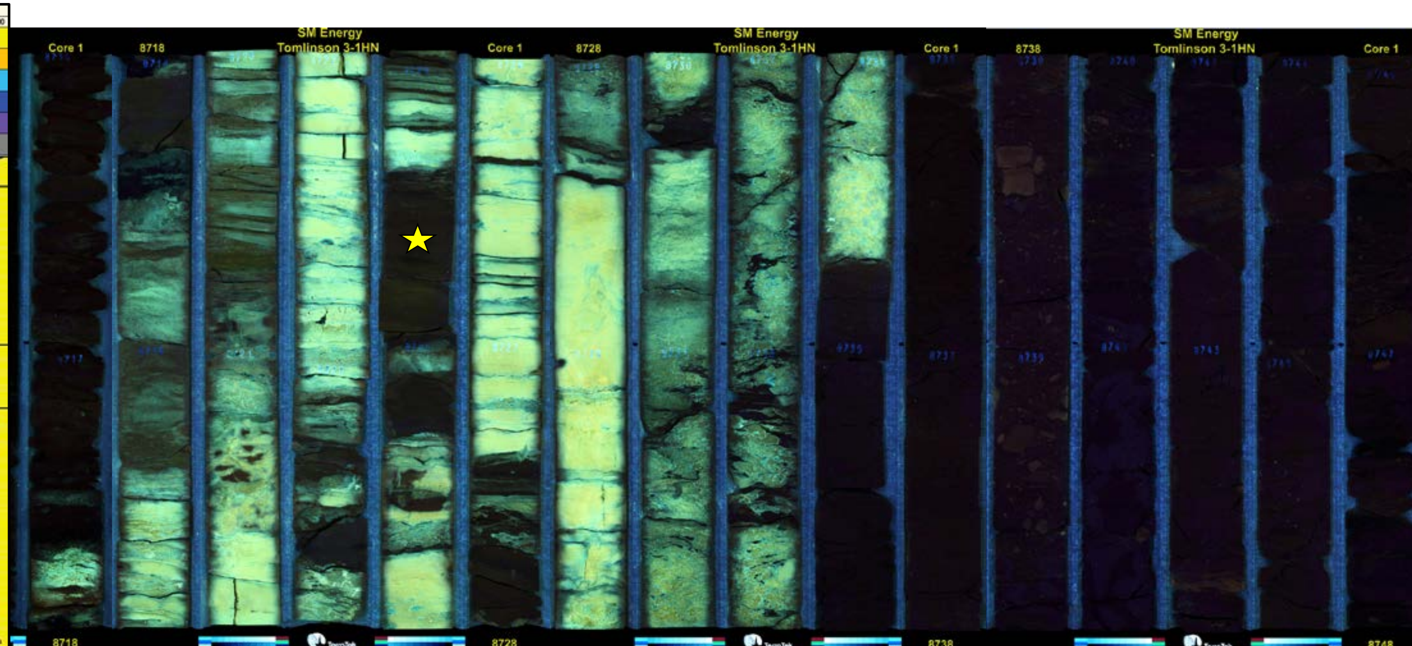

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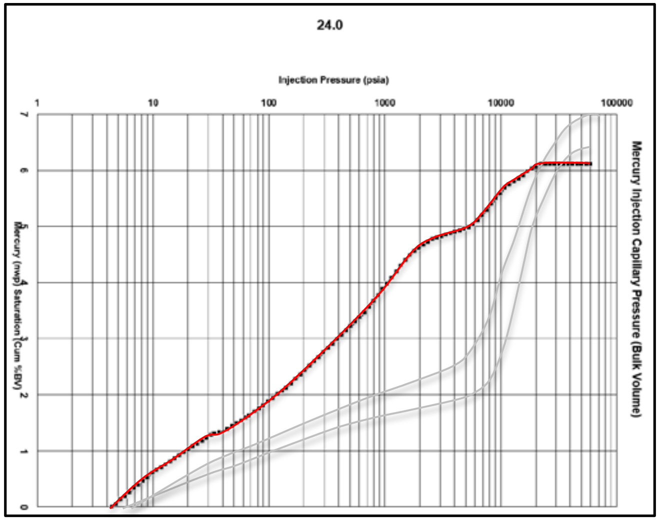

MICP Perm
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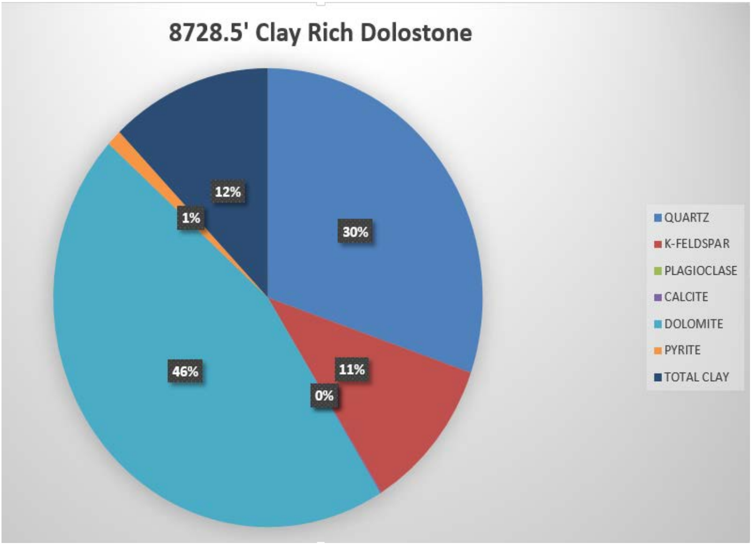

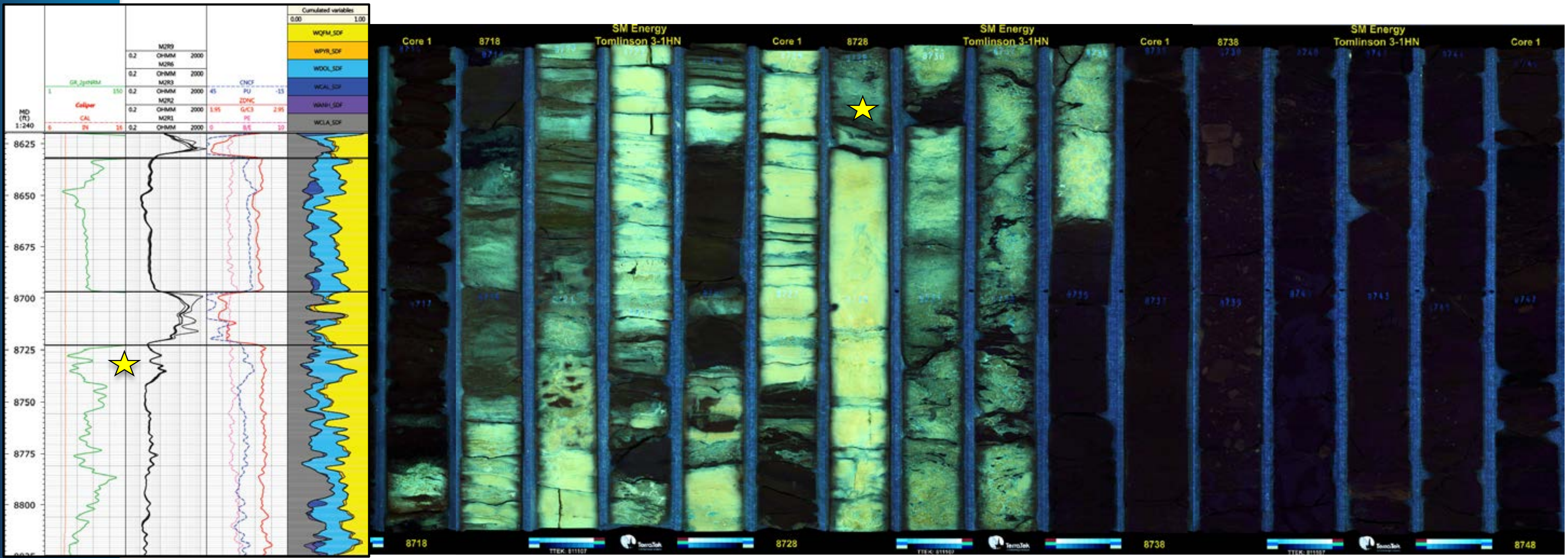

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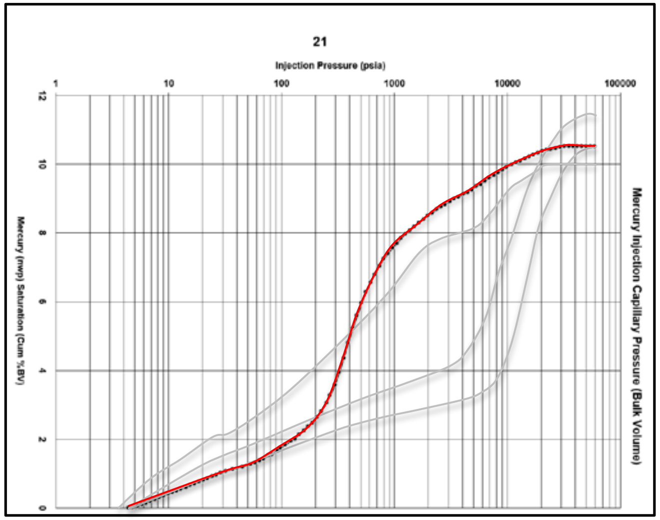

MICP Perm
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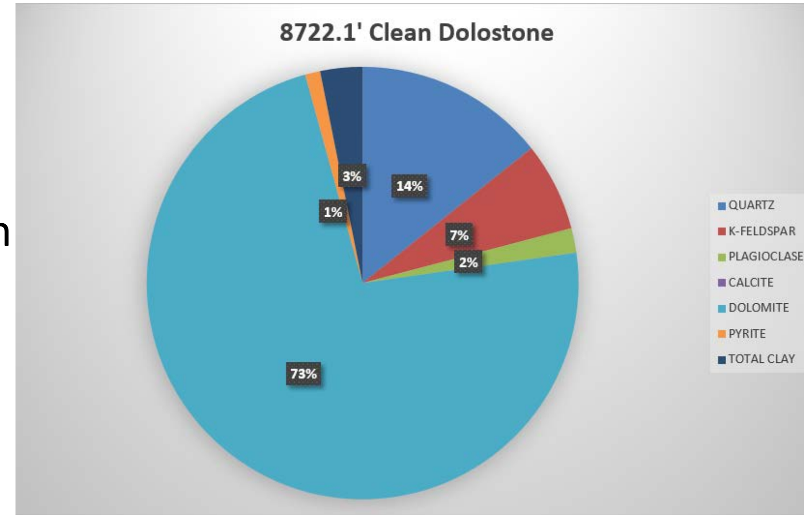
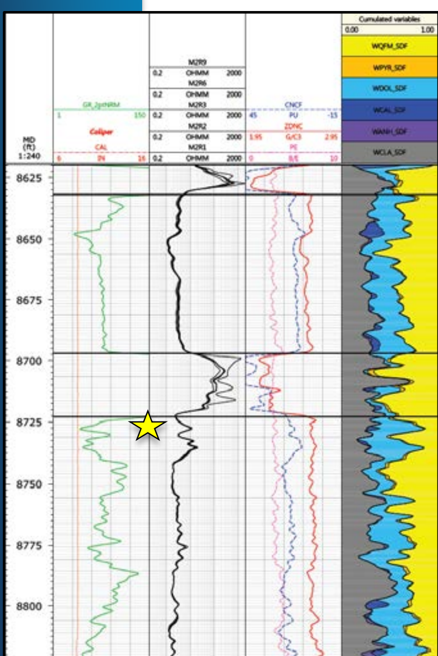
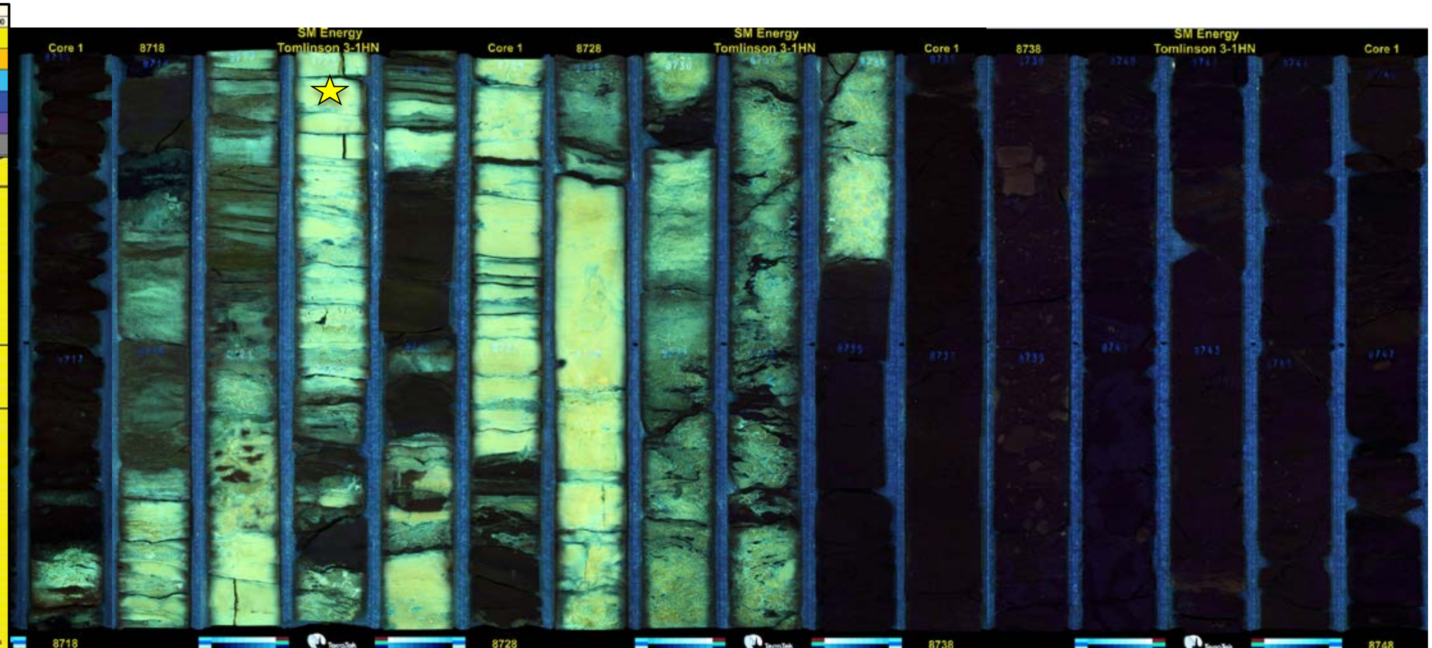
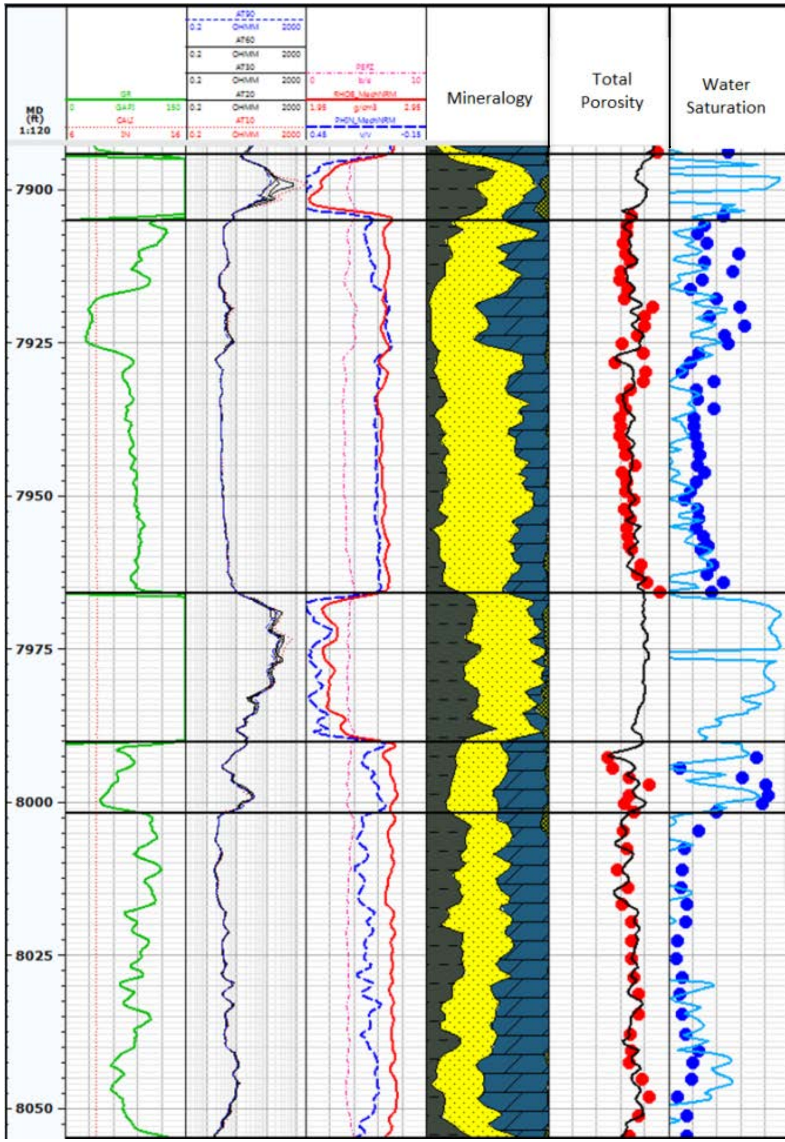




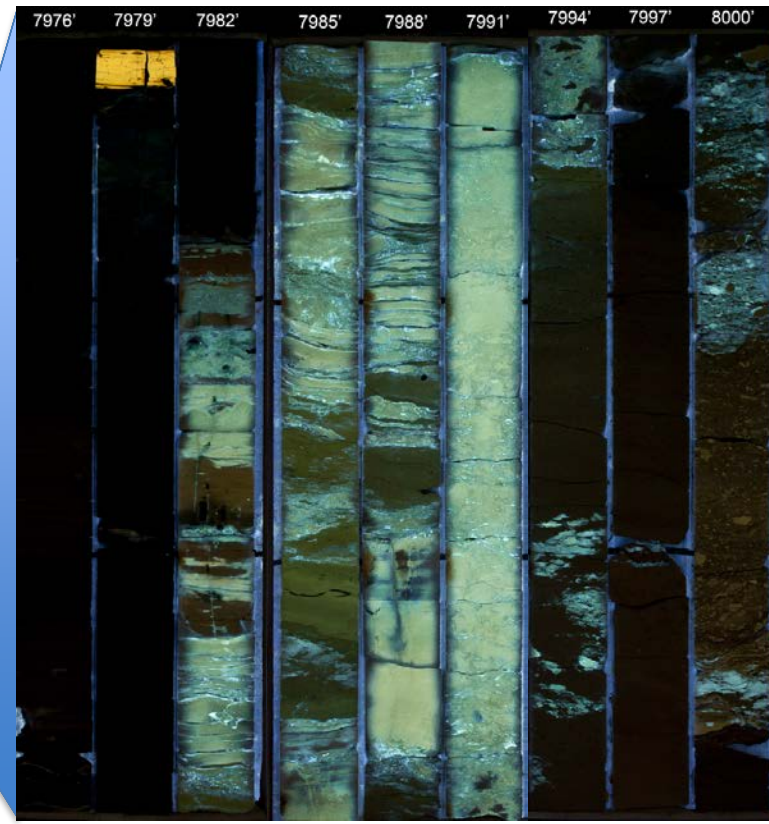


Which Intervals Contribute?

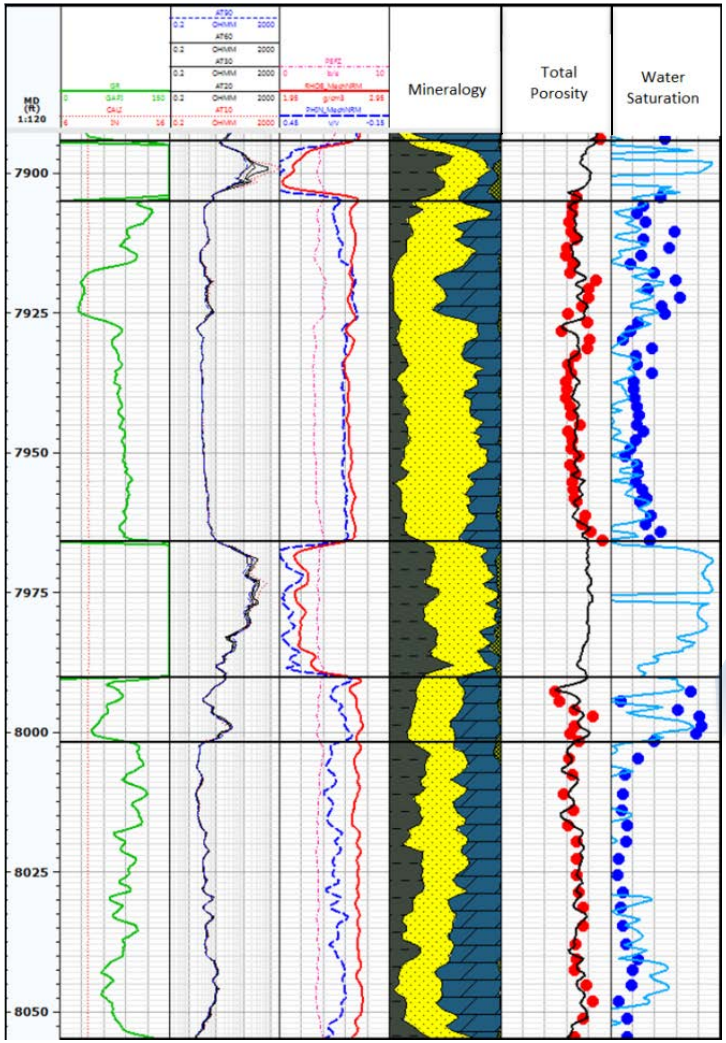


Using cutoffs of .001 mD (MICP) and 75% Sw, the well has ~8' of pay.

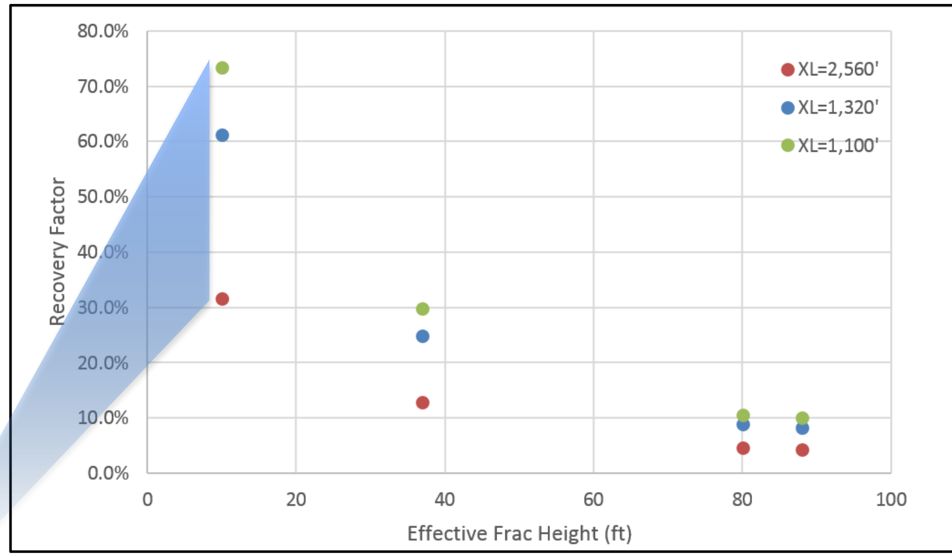
Pay zones equivalent to blue fluorescence



Effective Frac Height

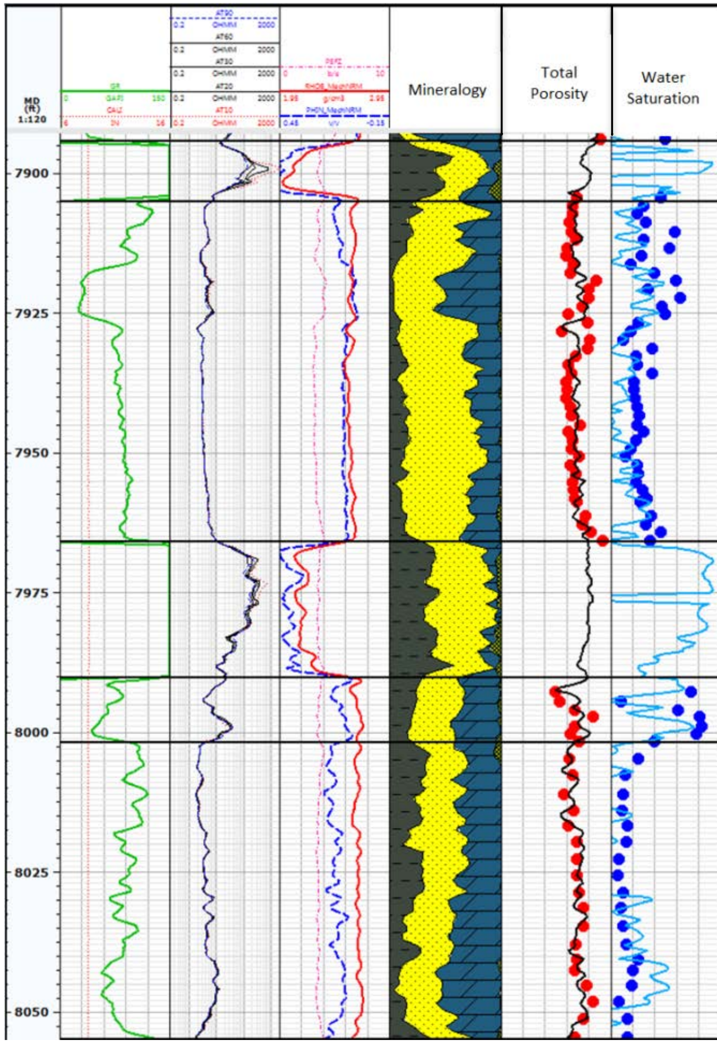


Plot below shows calculated recoveries from an average Three Forks well, depending on effective frac length and height



If the Three Forks produces by itself, then it must have a very high recovery factor

Effective Frac Height



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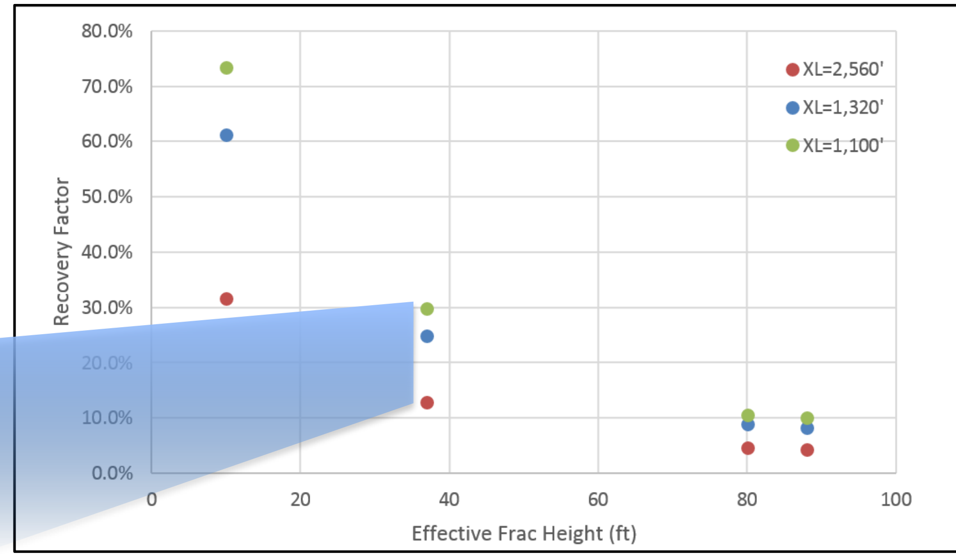
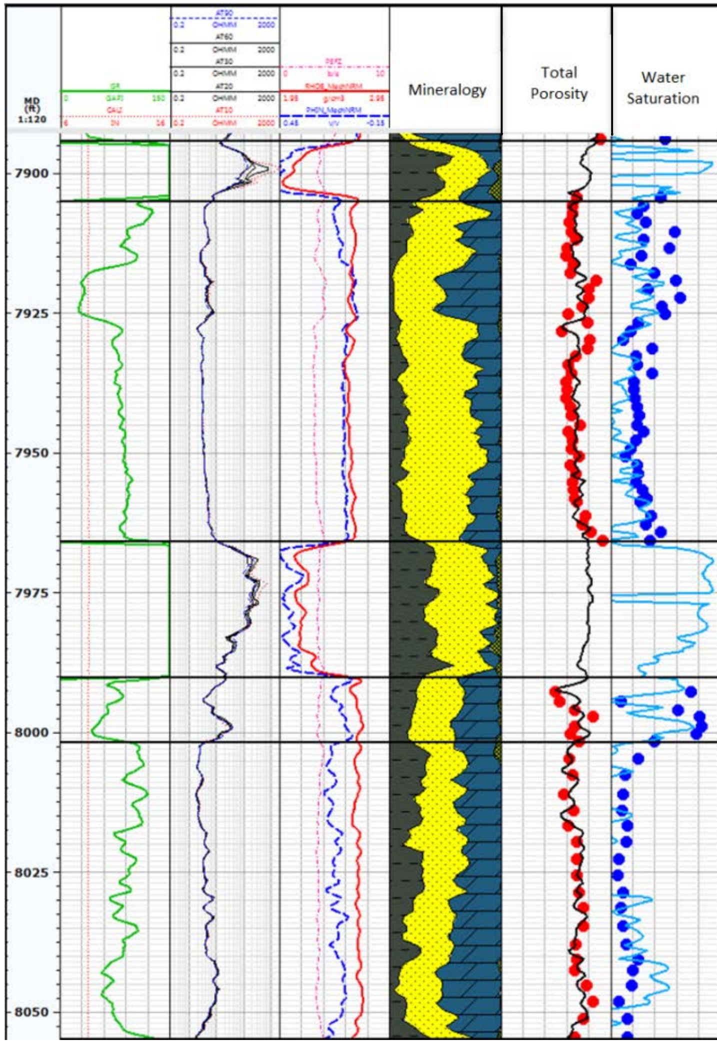
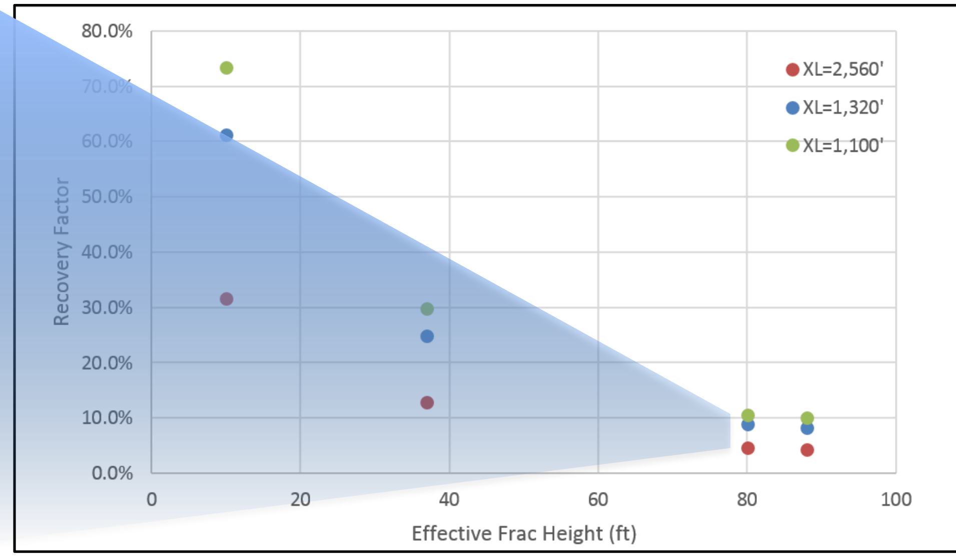


If the Lower Bakken Shale also is contributing, much lower recoveries are needed from both

Effective Frac Height



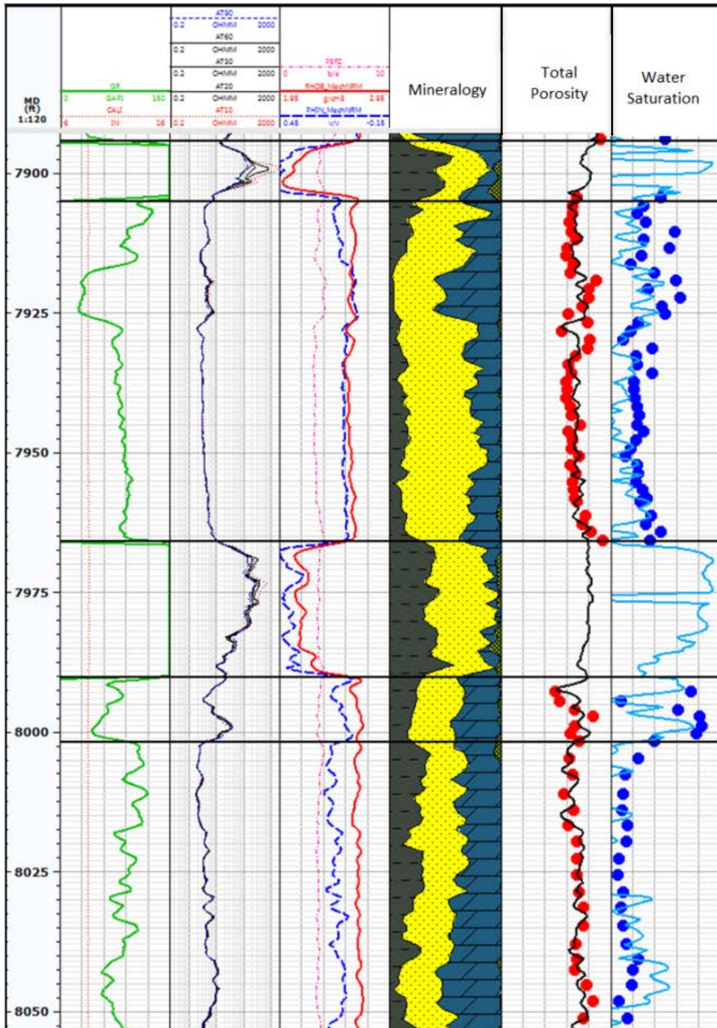
Plot below shows calculated recoveries from an average Three Forks well, depending on effective frac length and height



If the Middle Bakken is also contributing, then the enough oil is in place that frac lengths become less important

Recoveries are less than 10% for all intervals

Effective Frac Height



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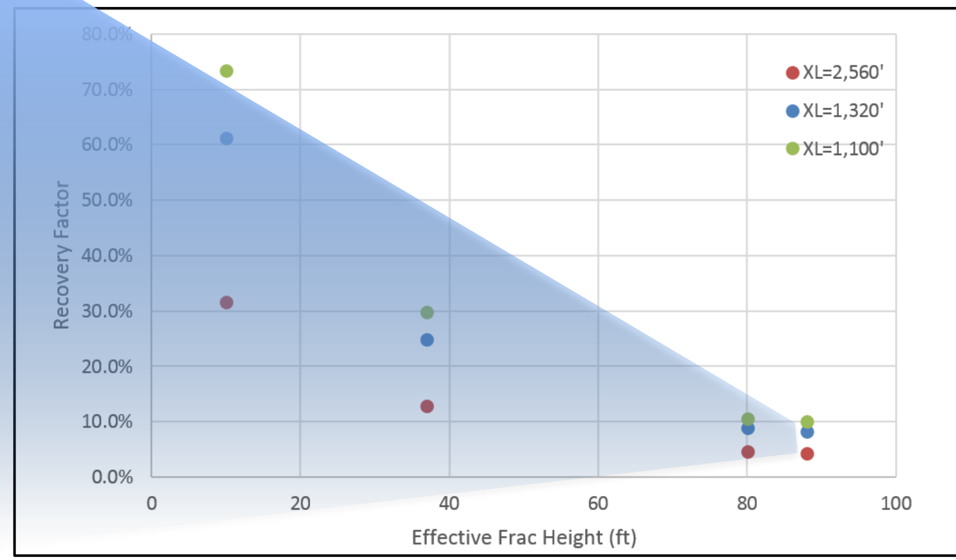
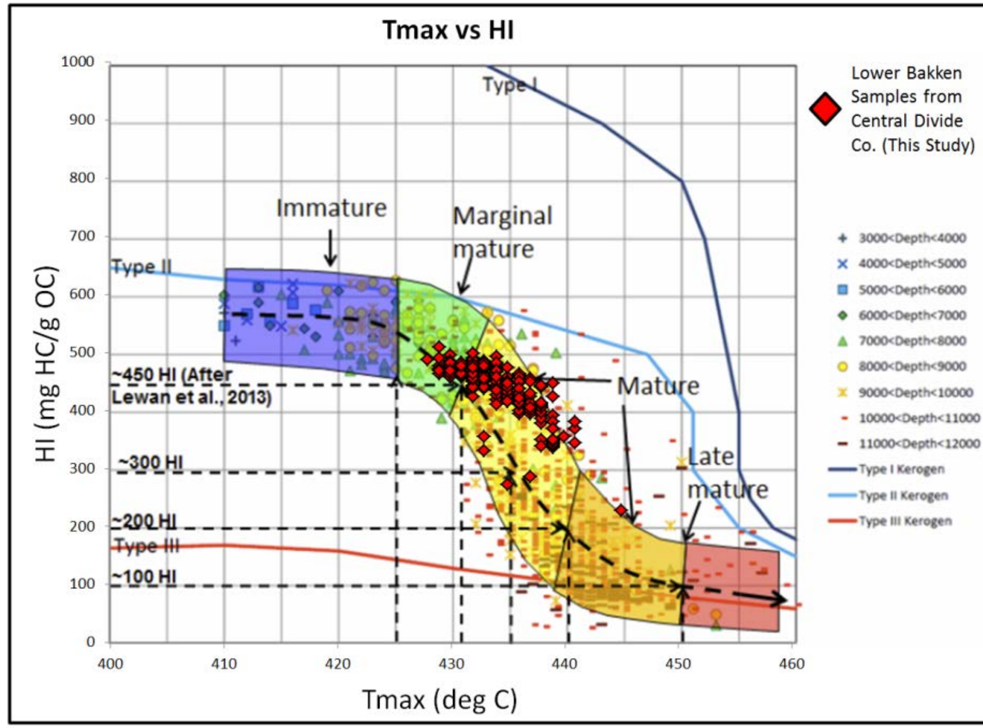


Adding the Upper Bakken Shale makes little difference as the bulk of the oil in place is in the Middle Bakken and the Lower Shale

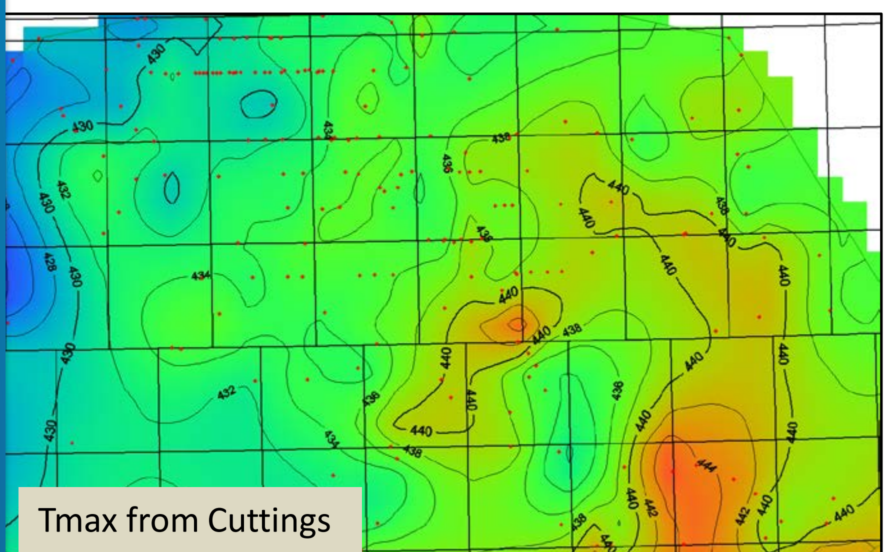
Kerogen Conversion

Pyrolysis derived hydrogen index (HI) and Tmax cross-plot

- HI falls as Tmax rises
- Demonstrates that kerogen is converted to hydrocarbons with maturity
- Red dots are Divide County samples showing significant hydrocarbon generation



Modified from Jin (2013)

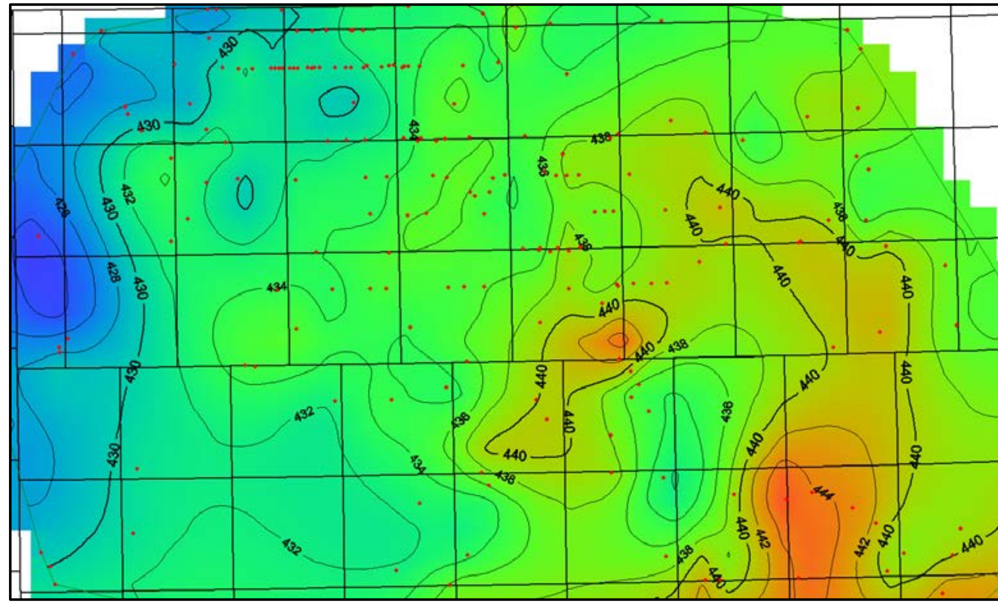


Tmaxs in Divide County range from 440 in the SE corner to 420 in the NW corner

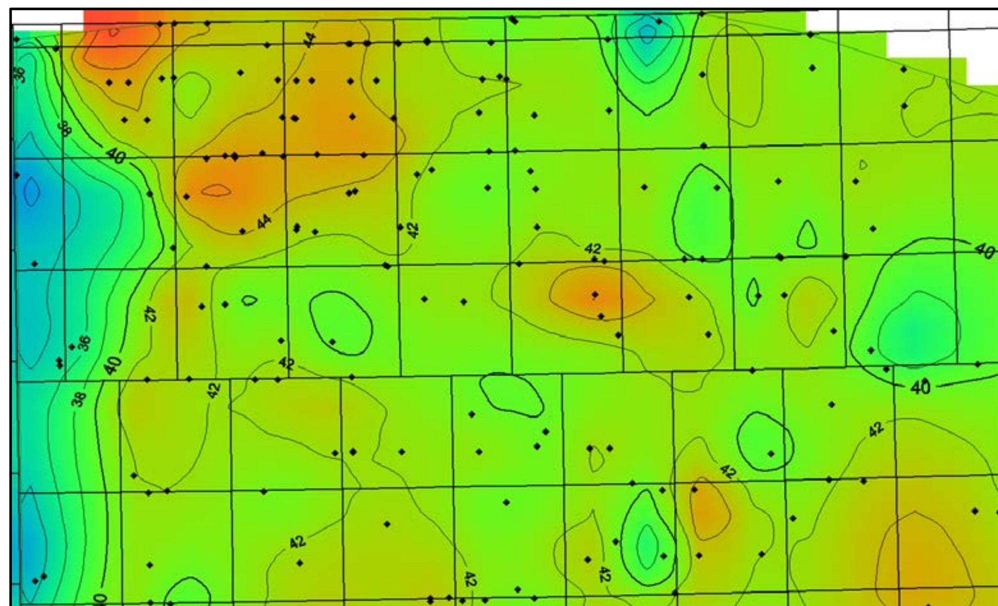
- Most of the Lower Bakken Shale in the county generated significant hydrocarbons

Maturity

Mismatch in measured maturity in the Lower Bakken Shale and the API gravity of oil produced from the Three Forks

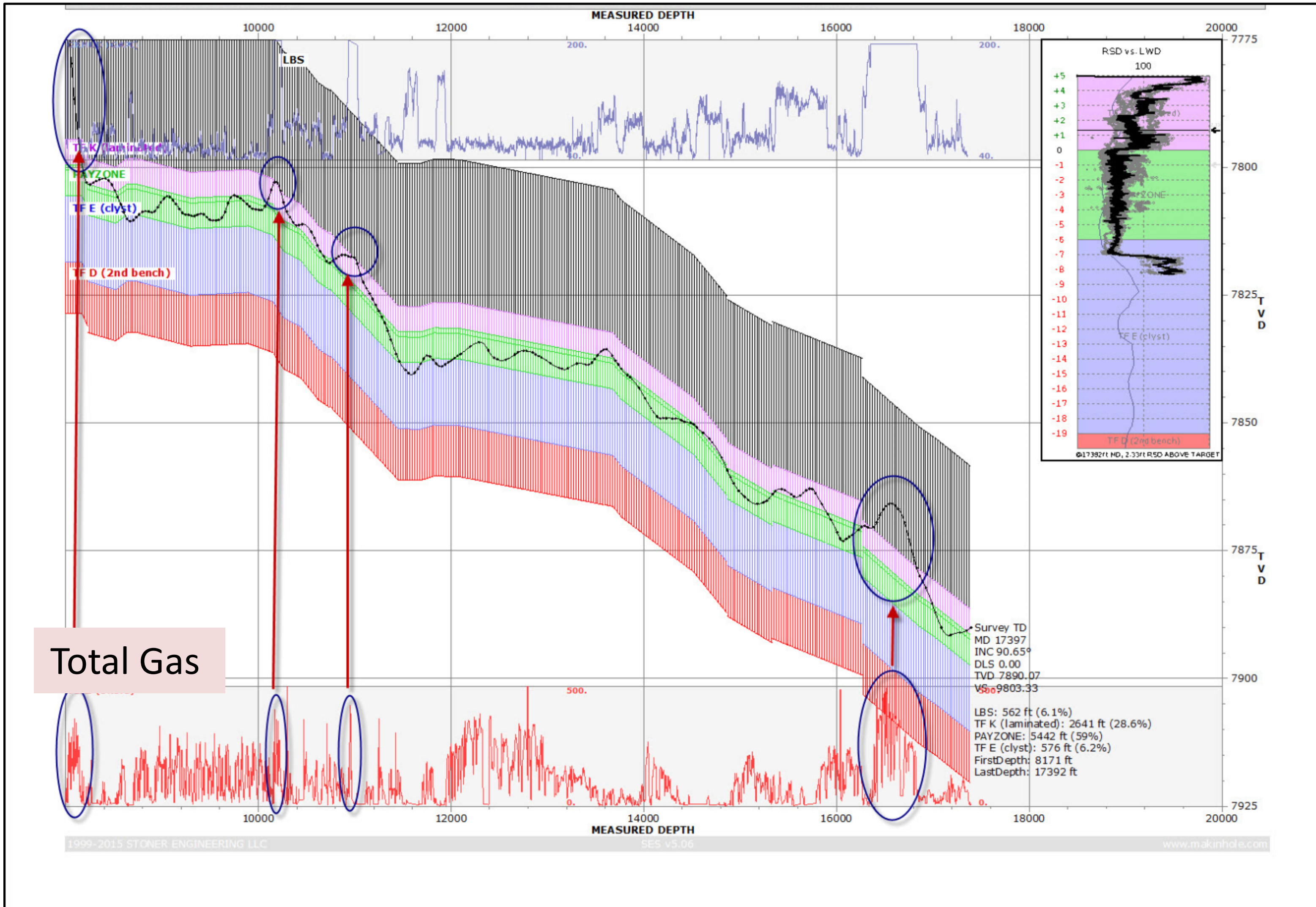


Tmax for the Lower Bakken Shale from Cuttings



Oil Gravity (API) from Completion Reports

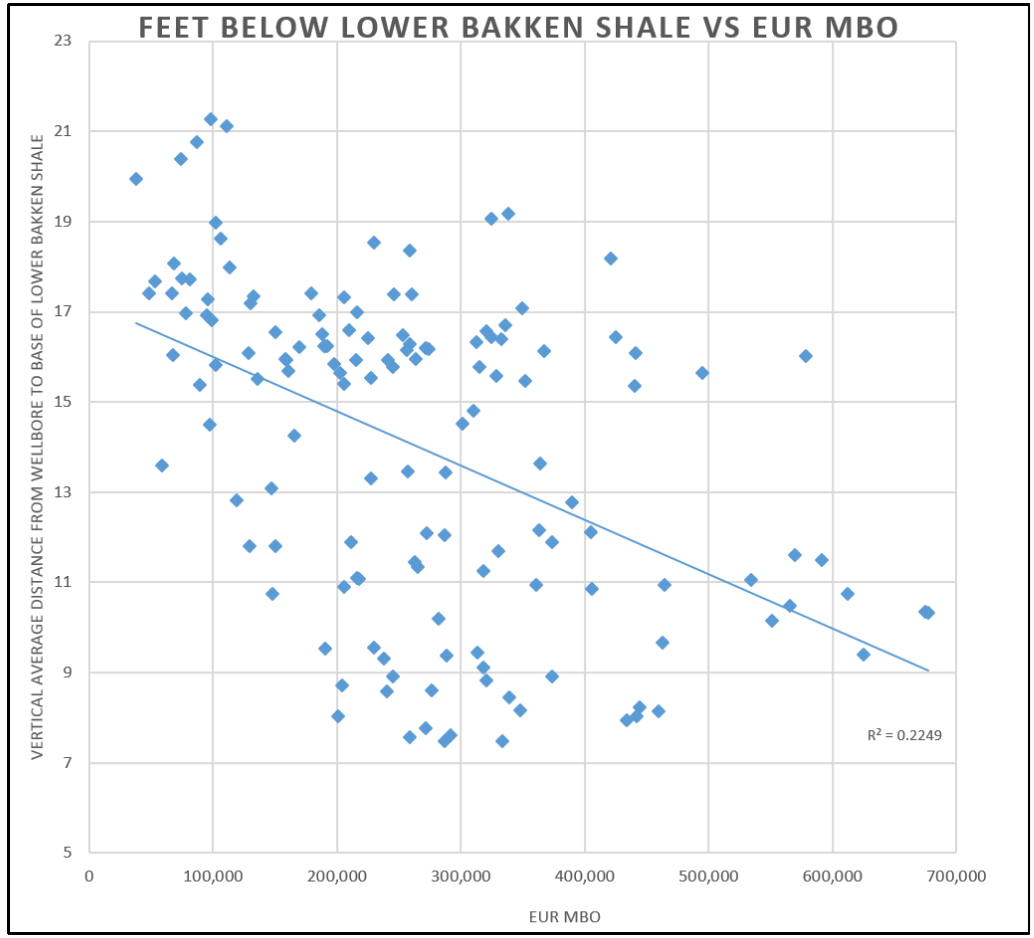
Gas Shows in the Lower Bakken Shale



Additional evidence of oil and gas generation is the superb gas shows operators encounter when drilling through the shale.

Distance from the Lower Bakken Shale Matters

- Rough Trend
  - Lots of un-normalized variables
  - Poor R-Squared
- The wells with the biggest EURs are the closest to the Lower Bakken Shale
- Greater vertical distance from the Lower Shale means the lateral is also further away from the Middle Bakken
  - The trend is non-unique



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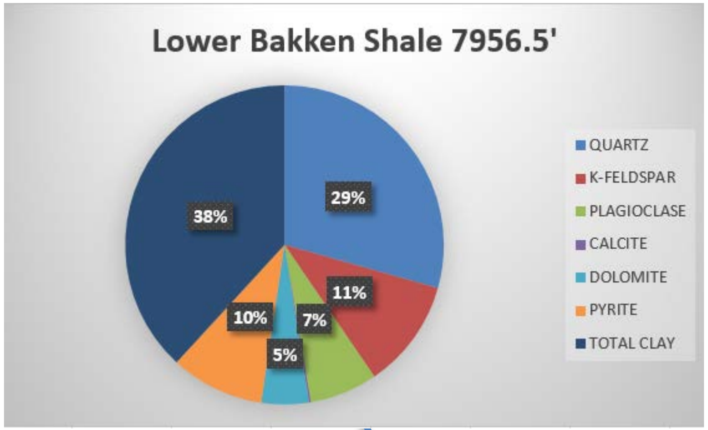
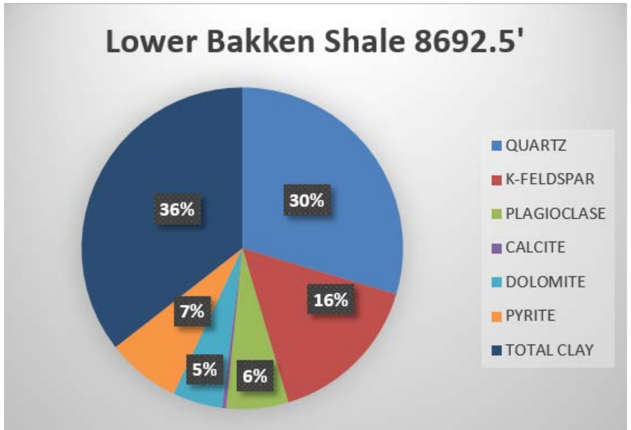
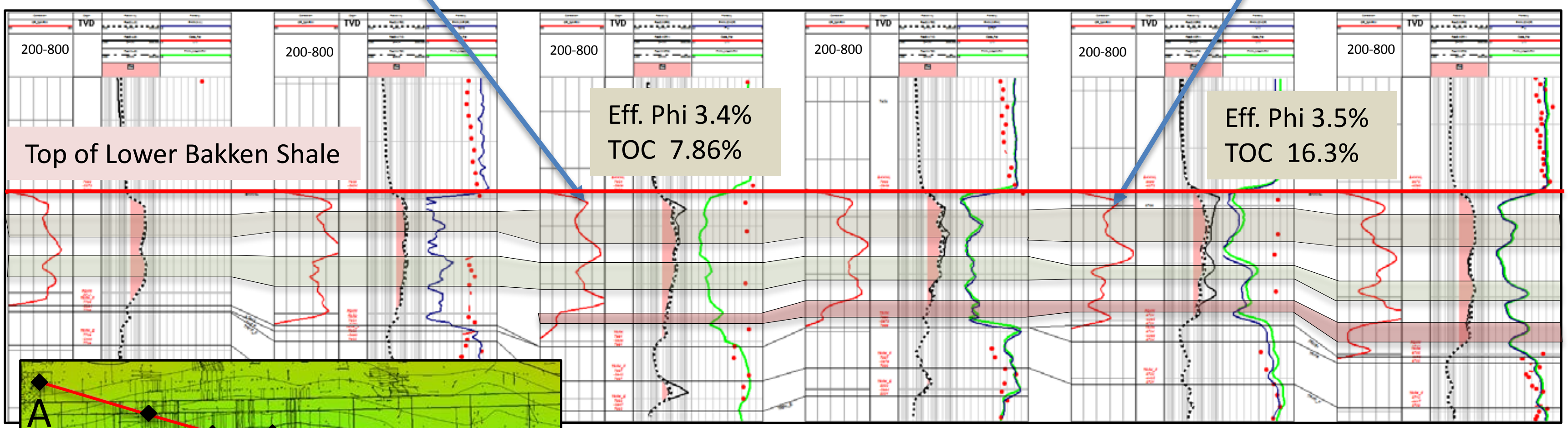
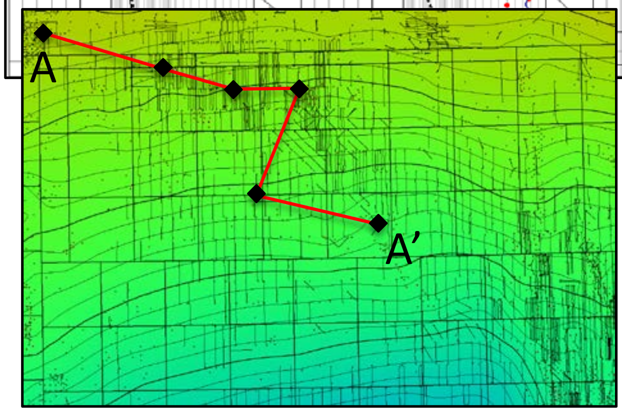
Lower Bakken Shale Stratigraphy









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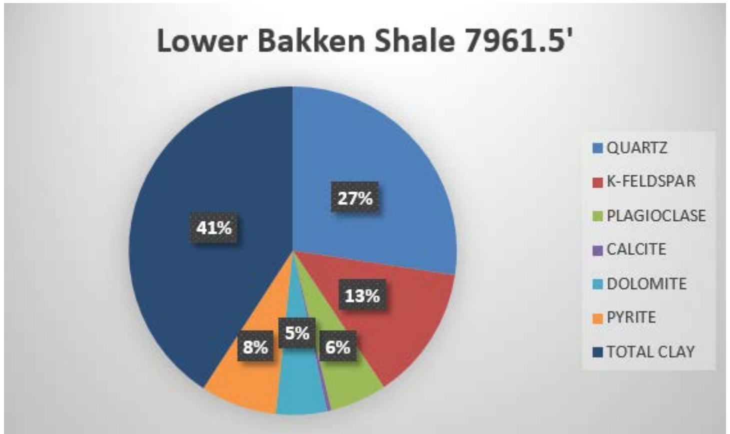

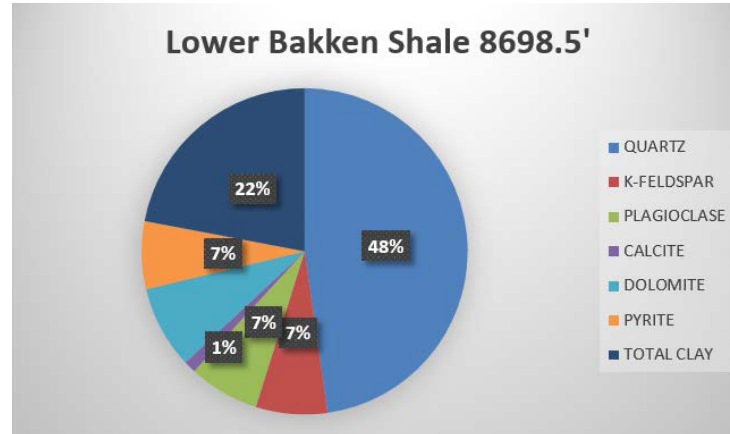

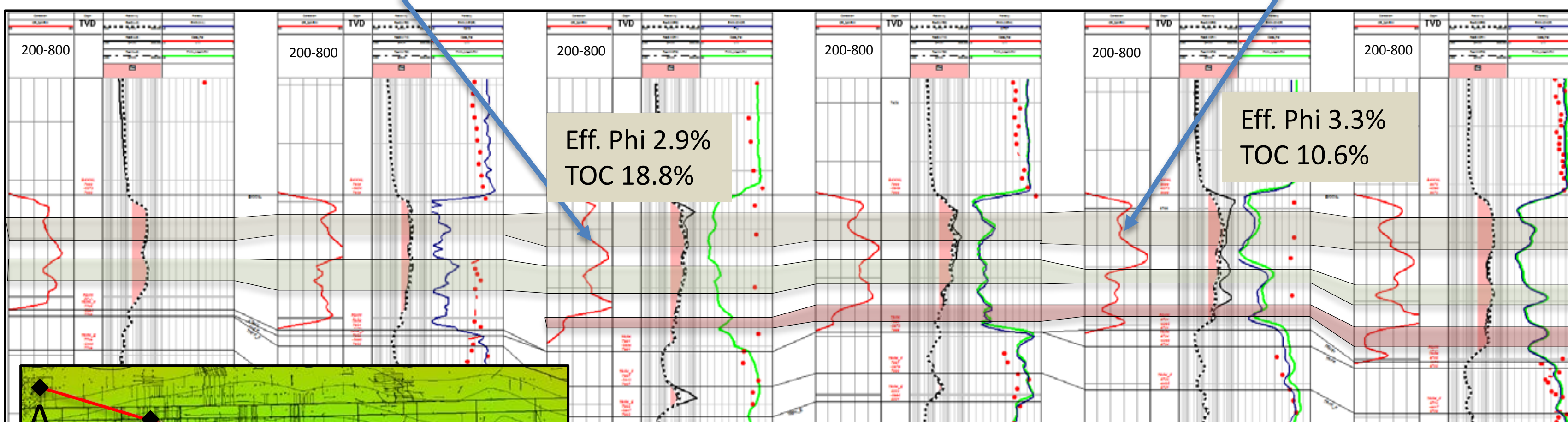

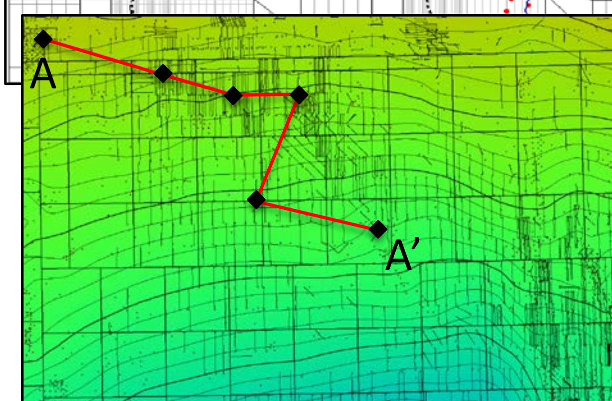

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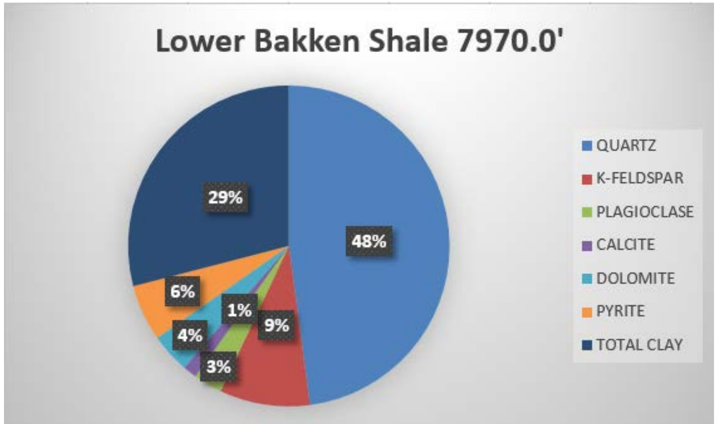

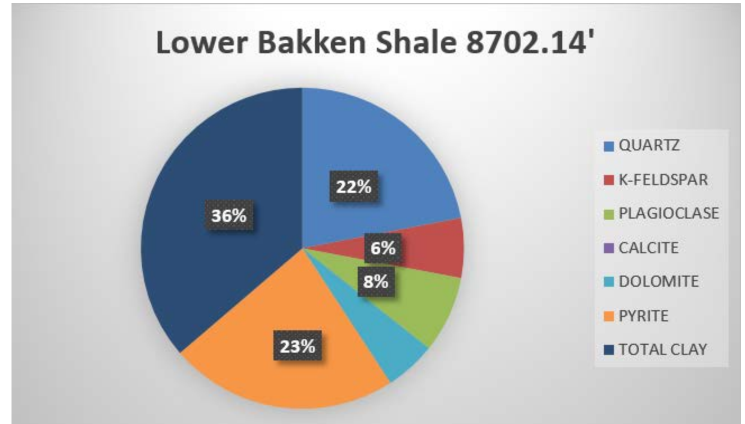

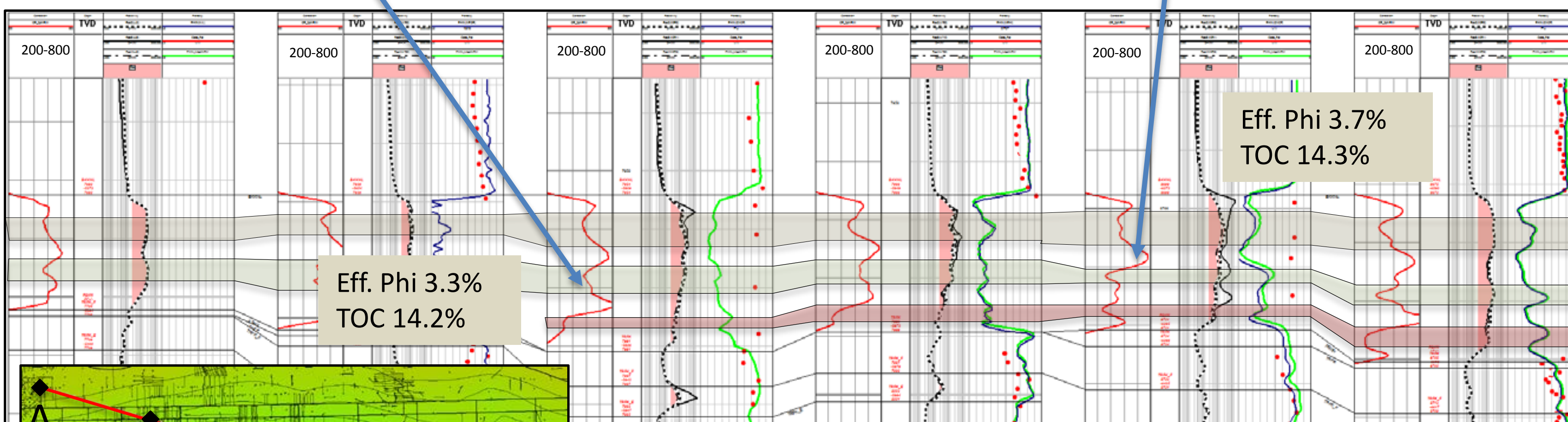

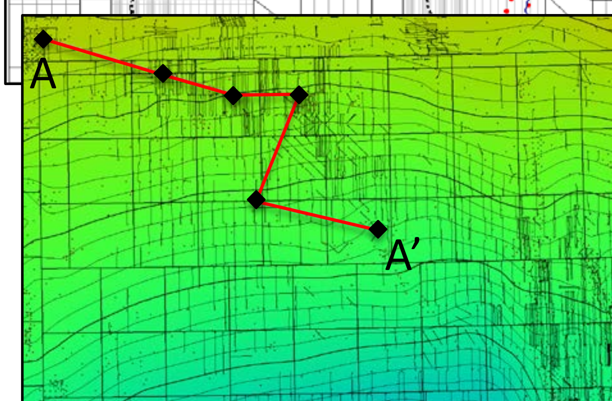

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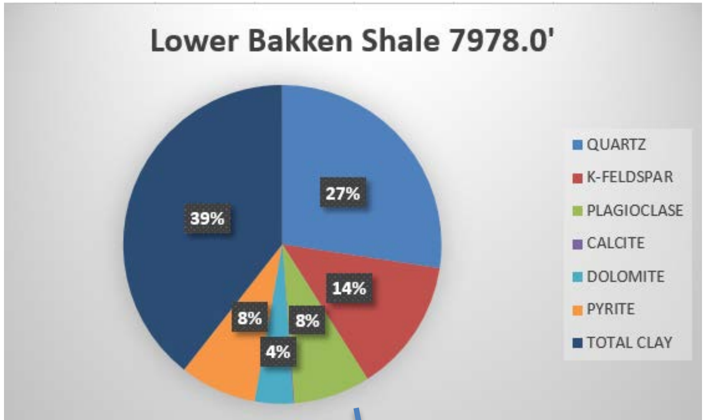

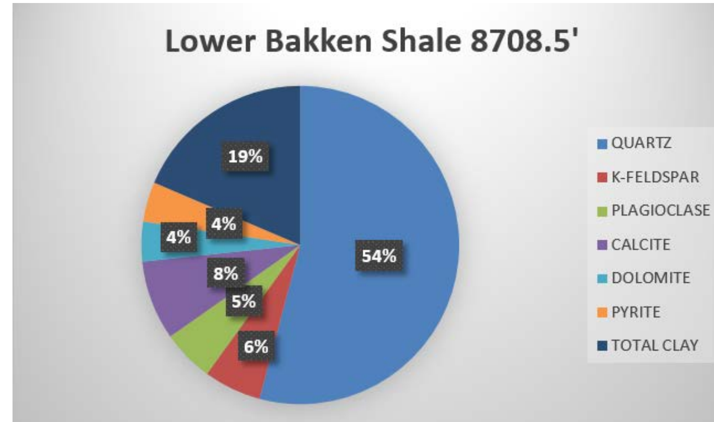

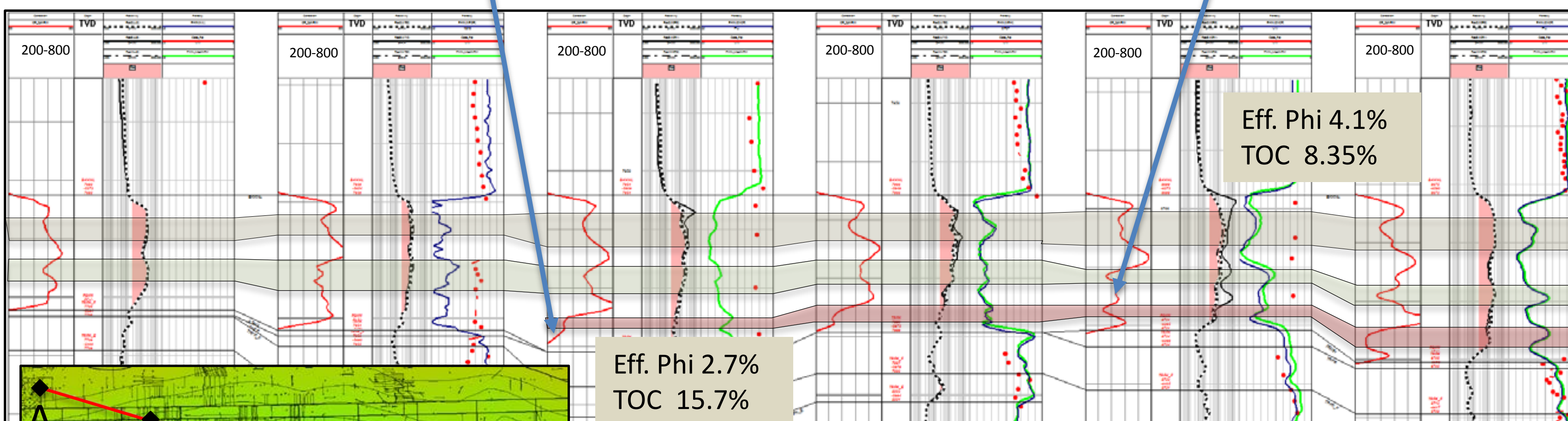

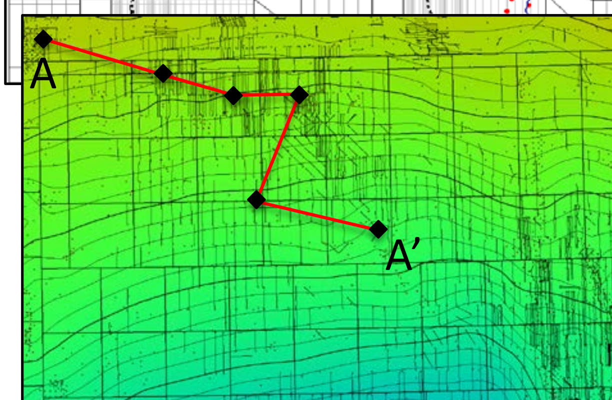

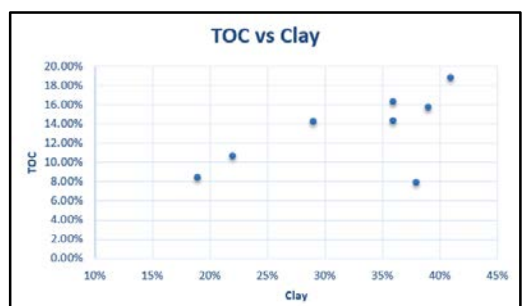

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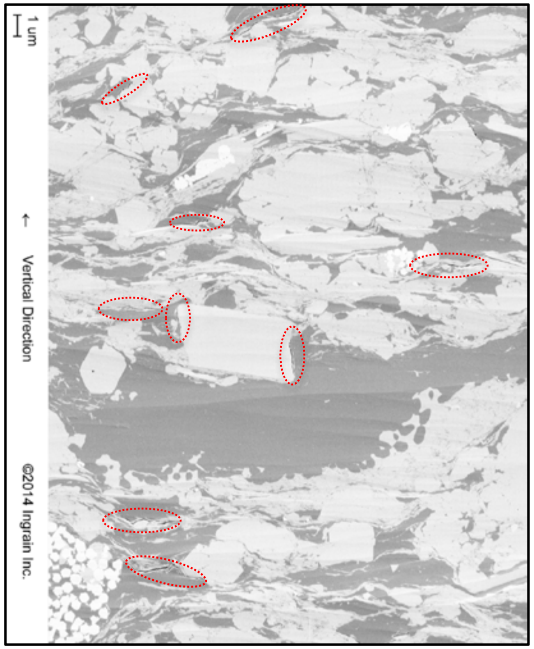
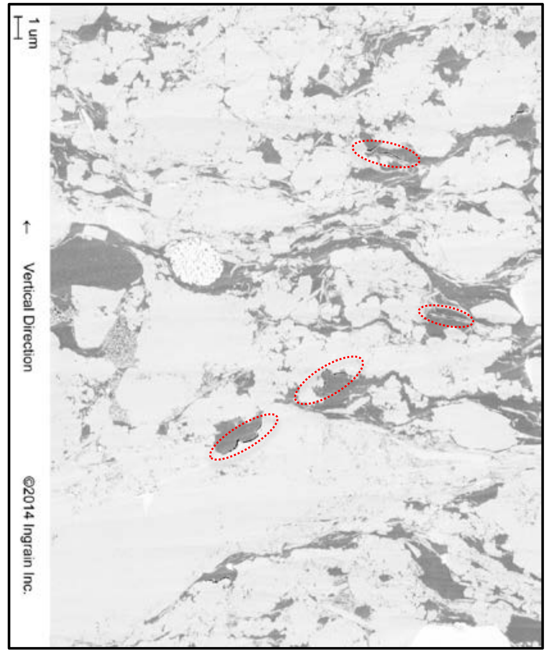
Problems Measuring Porosity

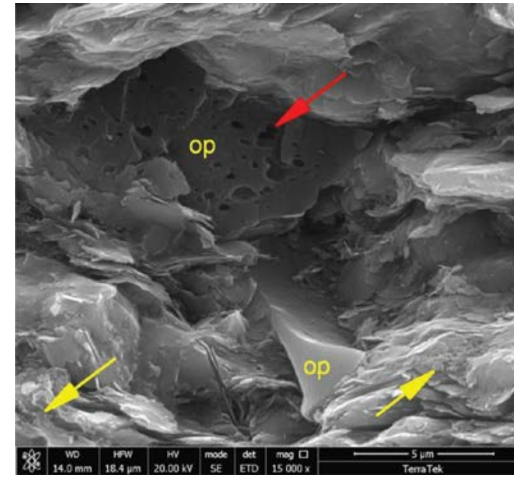
Lower Bakken Shale samples from three wells had porosity measured by GRI helium porosimetry and SEM techniques

- Results were very different
  - Helium porosimetry effective phi averaged 3-7% (16 measurements)
  - SEM measured average phi is 0.1-0.4% (21 measurements)

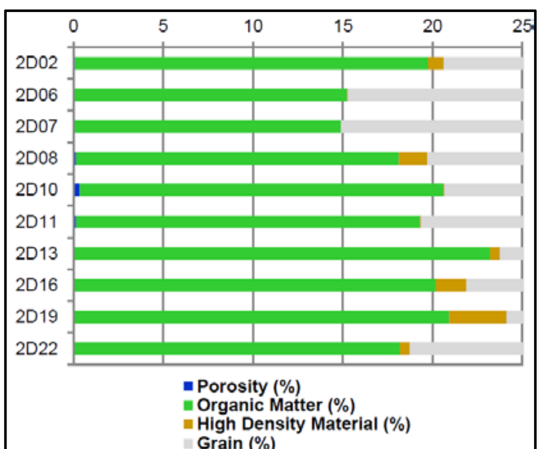
SEM Examination of the Shale

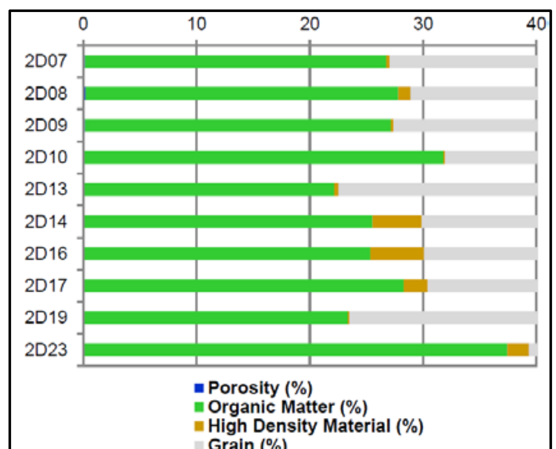






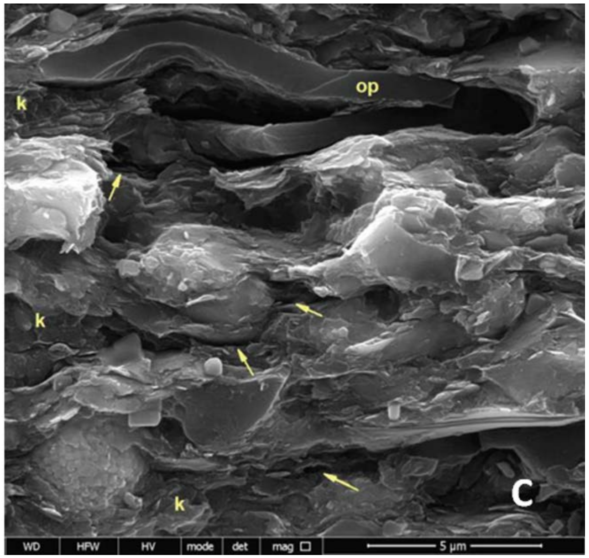
Sample from the basin center

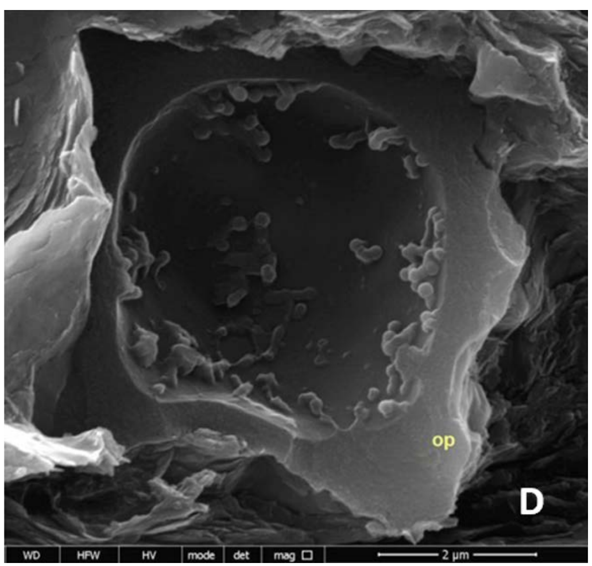




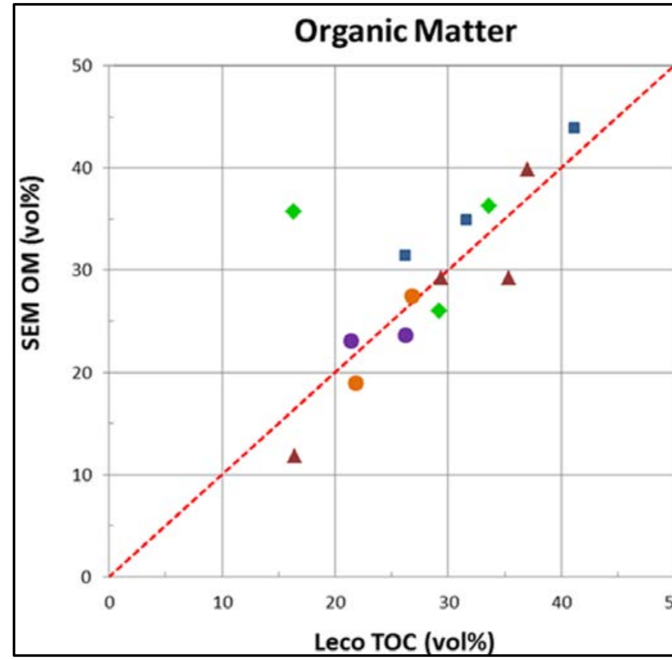
Very little porosity visible, and the little that is visible is from the shrinkage of the kerogen

SEM Examination of the Shale



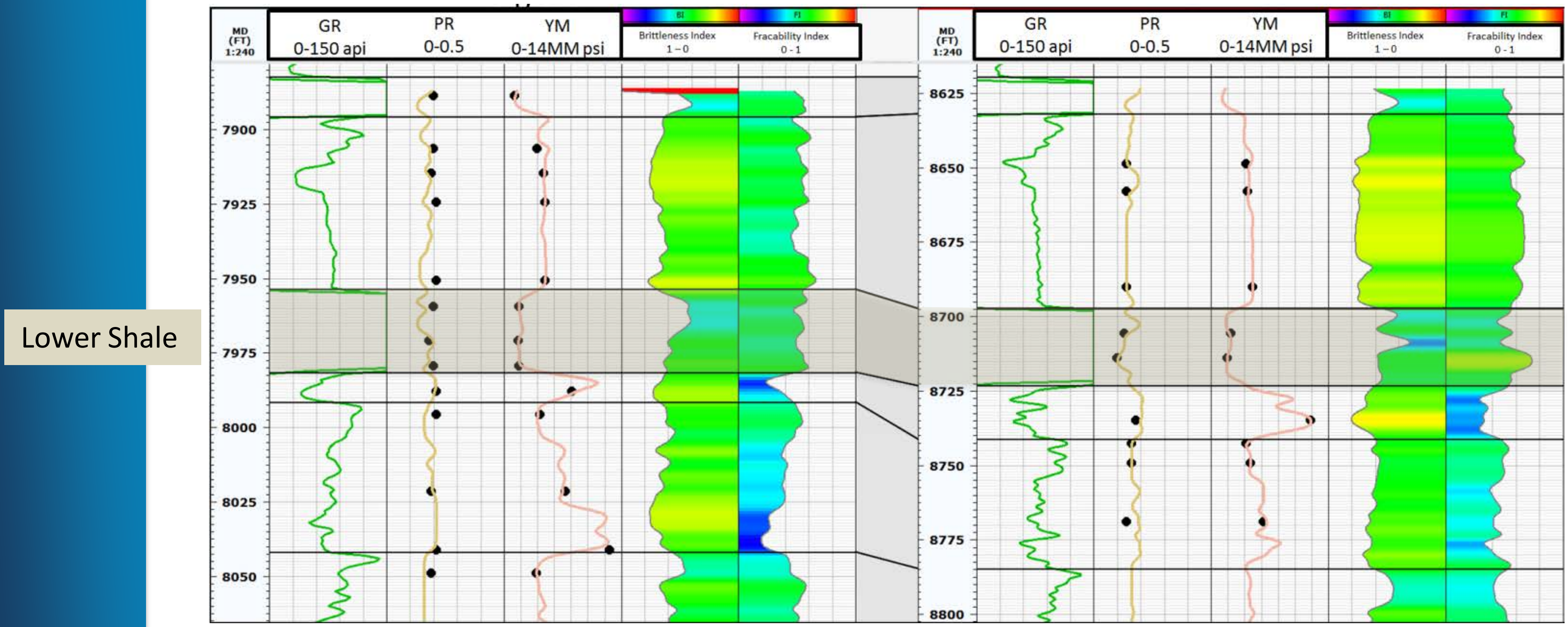


Broken SEM samples show the geometries of the organic particles and oil droplets oozing from the particles



Comparison of SEM-derived organic matter volume and LECO TOC (converted to volume %). Symbols indicate data from five wells in the study area.

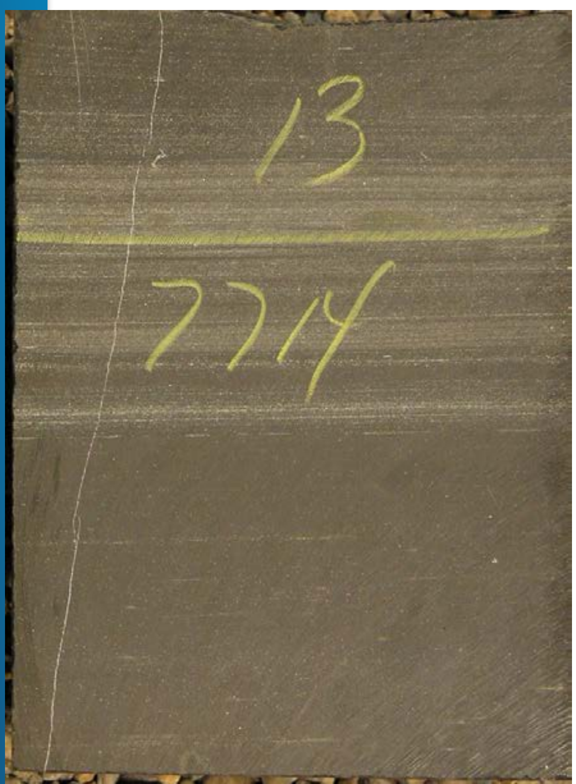
Fracture Complexity Index

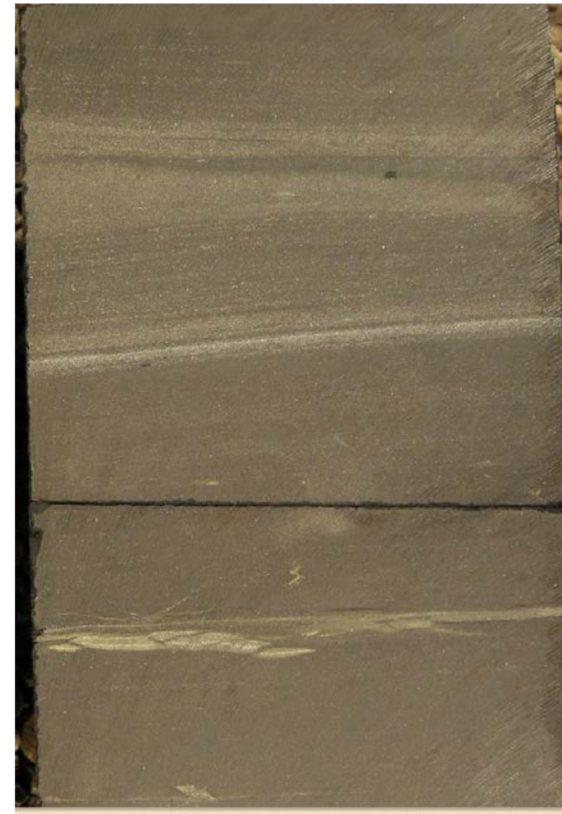


- This is an index that combines brittleness based on mineralogy, with vertical Poisson's Ration and Young's Modulus
- It indicates zones that we expect to create a complex fracture network (lots of surface area) vs zones that we do not
- Note that the Lower Bakken Shale has a high fracability index, higher than the clean dolostones of the first bench of the Three Forks
    - The very high Young's modulus of the clean dolomite leads to simple fractures with low complexity and surface area
    - The Lower Bakken Shale's high index values suggest that fractures that propagate through it are complex with a lot of surface area

Fractures are Common in the Lower Shale

Cemented fractures are common in the Shale, especially in the more silt rich intervals





Conclusion

- Multiple lines of evidence suggest that the Lower Bakken Shale contributes to hydrocarbon production in Three Forks wells in Divide County
- Oil production is too substantial to be sourced exclusively from the Three Forks without resorting to optimistic recovery factors
- The overlying source beds of the Lower Bakken Shale are nearest substantial accumulation of oil that could contribute
- Oil saturated porosity is observed in cores, and mudlog gas shows are observed while drilling through the Lower Bakken Shale
- Modelling of mechanical properties suggests that fracturing is likely to occur in the shale during artificial stimulation

This study provides insight into the role of the Lower Bakken shale as both a source and reservoir in the Bakken/Three Forks Petroleum System. Future work should seek to confirm and quantify the shale's contribution.

Questions?

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