Optimizing Lateral Placement and Production While Minimizing Completion Costs in the STACK*

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Abstract

Shale plays are an extremely difficult arena in which to explore. Lack of heterogeneity is not the only problem. Numerous hydrocarbon sources and multiple stacked zones that vary considerably across the play result in mixed drilling success in the Oklahoma STACK (the Sooner Trend (oilfield) Anadarko (basin), found primarily in the Canadian and Kingfisher counties).Conventional logging technologies provide important information while drilling to infer the presence or absence of hydrocarbons. However, these logging technologies do not measure hydrocarbons directly, but rather measure hydrocarbon proxies and infer hydrocarbon presence and phase based on the aforementioned data. These technologies, while sophisticated, can lack specificity and sensitivity when trying to accurately identify hydrocarbon source, hydrocarbon families, hydrocarbon mixing, or compartmentalization.

Downhole Geochemical Logging (DGL) provides an ultra-sensitive assessment of the hydrocarbons in a well by analyzing cutting samples to directly characterize the composition of hydrocarbons vertically and laterally through prospective sections. This methodology has the unique ability to look at a broad compound range from C2 to C20, which is significantly more expansive than the limited traditional ranges of C1-C5 from mud logs or C1-C9 from laboratory analyses. The result is a detailed granular hydrocarbon characterization in stratigraphic intervals that is a thousand times more sensitive than other methods. This sensitivity and extended carbon range not only allow extensive characterization of reservoir and pore space hydrocarbon fluids, but also for the identification of possible seals.

The purpose of the project, given this was a relatively frontier acreage with little well control, was to not only provide granular hydrocarbon characterization and compartmentalization information in the various vertical stratigraphic intervals in multiple wells, but also compare those formation hydrocarbons laterally across the field. In particular, there was interest in the number of unique hydrocarbon fingerprints or hydrocarbon families as well as hydrocarbon mixing, both vertically and laterally across the field.

The primary formations of interest were the Chester, the Upper Meramec, the Lower Meramec, the Osage, and Woodford formations. Of particular interest was understanding possible compartmentalization within the Meramec formation.

It was also known that the DGL technology could determine a water saturation (Sw) proxy by ratioing specific C6 and C7 aromatic and n-alkane compounds. Thus, there was particular interest in evaluating water saturation vertically in the various formations as wells as from well to well.

In conclusion, the data helped to:

- Clearly distinguish between multiple gas, condensate, and oil signatures vertically and laterally in the field,
- Infer separate hydrocarbon sources,
- Identify by-passed pay,
- Increase production by focusing completion placement in hydrocarbon rich and porosity rich zones,
- Infer mixing vertically in wells and laterally across the field,
- Identify zones with high water saturation, which would increase production costs,
- Compare water saturation levels laterally across the field.

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October 2, 2017

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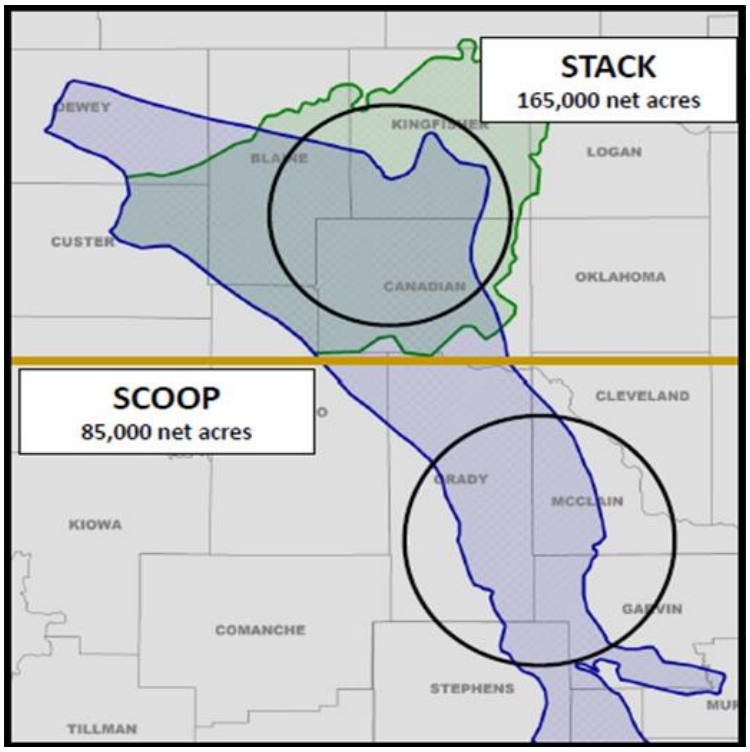
Objectives

Use Downhole Geochemical Logging (DGL) to:

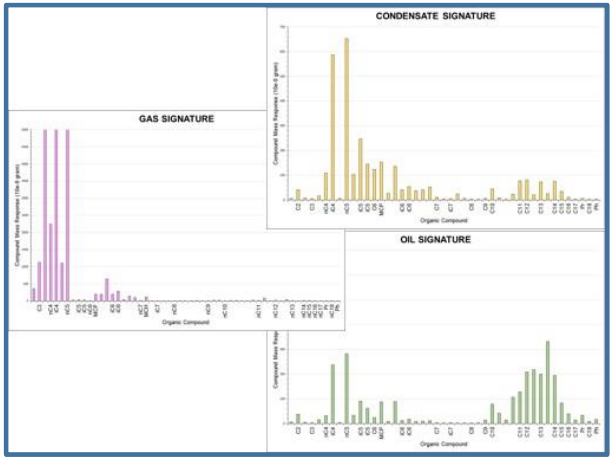
- Confirm the validity of the STACK play in the area,
- Provide granular hydrocarbon characterization of the various stratigraphic intervals,
- Evaluate the prospectivity of the Chester, Manning, Meramec, Osage & Woodford formations with respect to hydrocarbon phase and richness,
- Identify the most prospective zones for completion,
- Understand the possible compartmentalization in the Meramec Fm.,
- Evaluate water saturation in various zones,
- Evaluate variation of produced hydrocarbon samples and water vs pre-drill samples.



Downhole Geochemical Logging

ÅCuttings are collected in polypropylene jars, directly from the shaker table during drilling

ÅAnalyses normally done in 2 weeks

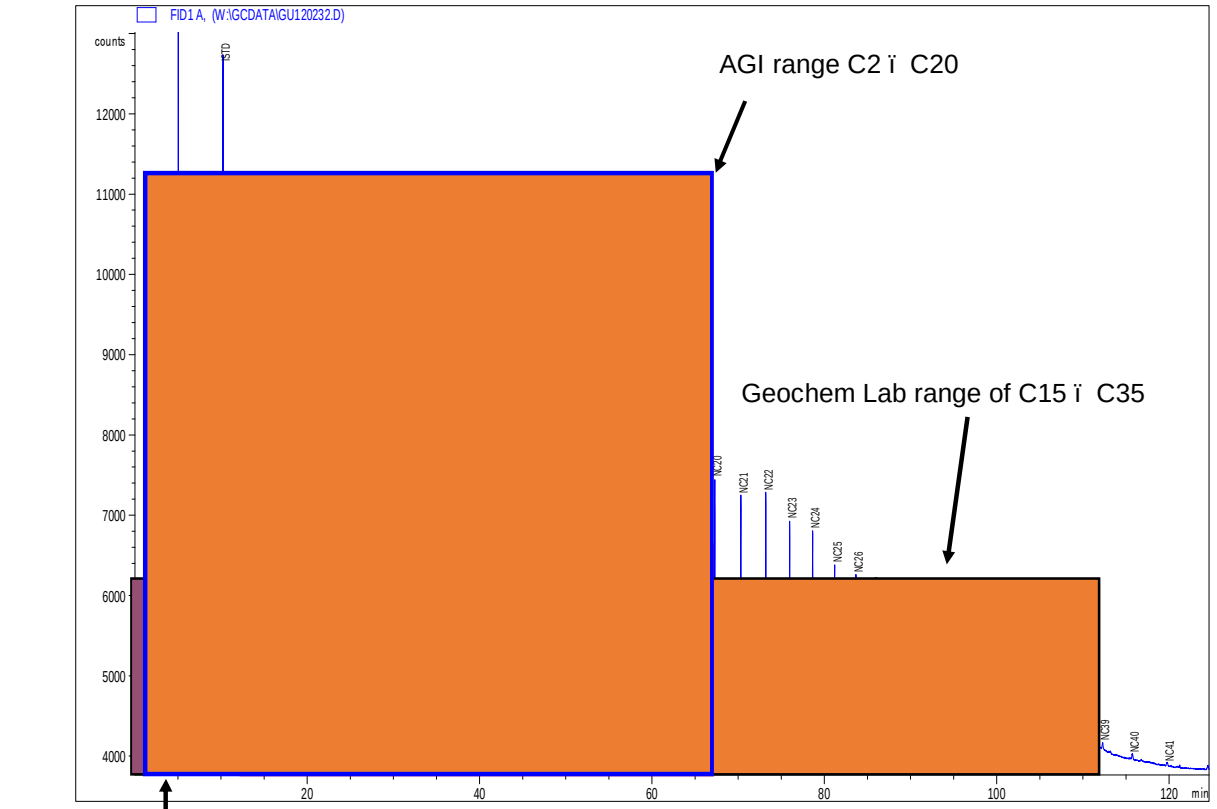


1,000 time more sensitive than traditional methods

Focuses on hydrocarbon fluids in various zones

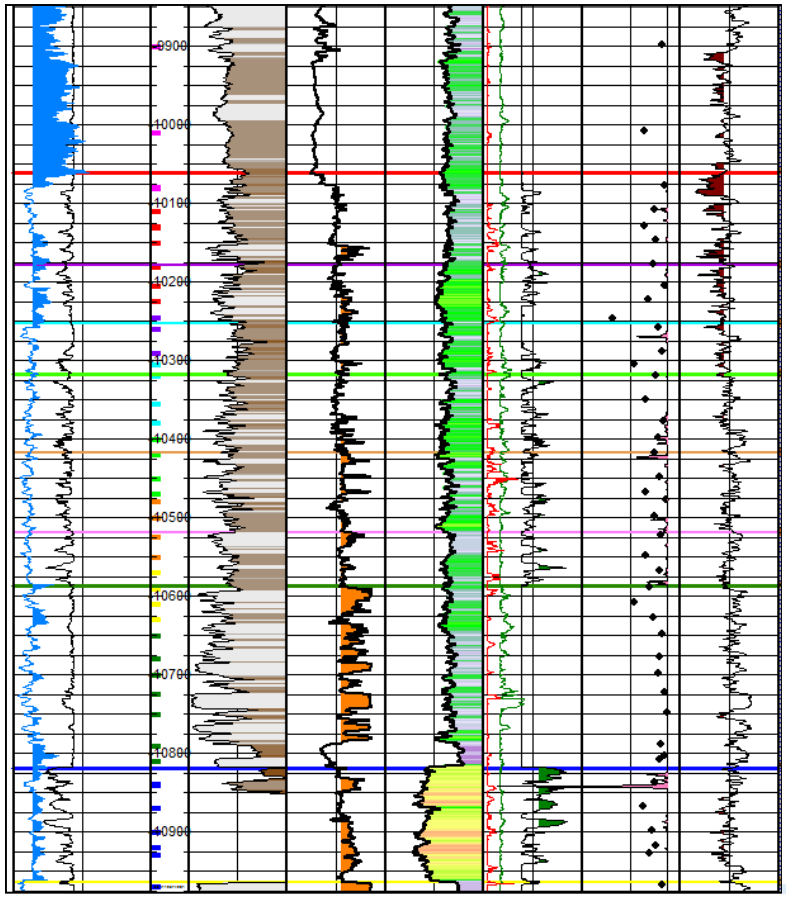
- Measures from the C_2 to C_{20} carbon range
- Easily differentiates between multiple phases
- Identifies reservoir compartmentalization
- Identify by-passed pay

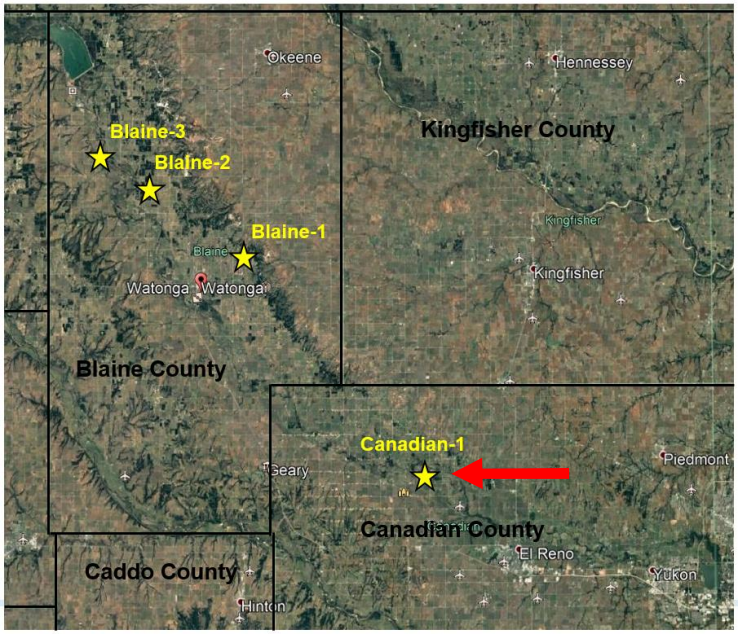
Conventional Downhole Analyses



Canadian-1 Well – Canadian County

Well Logs

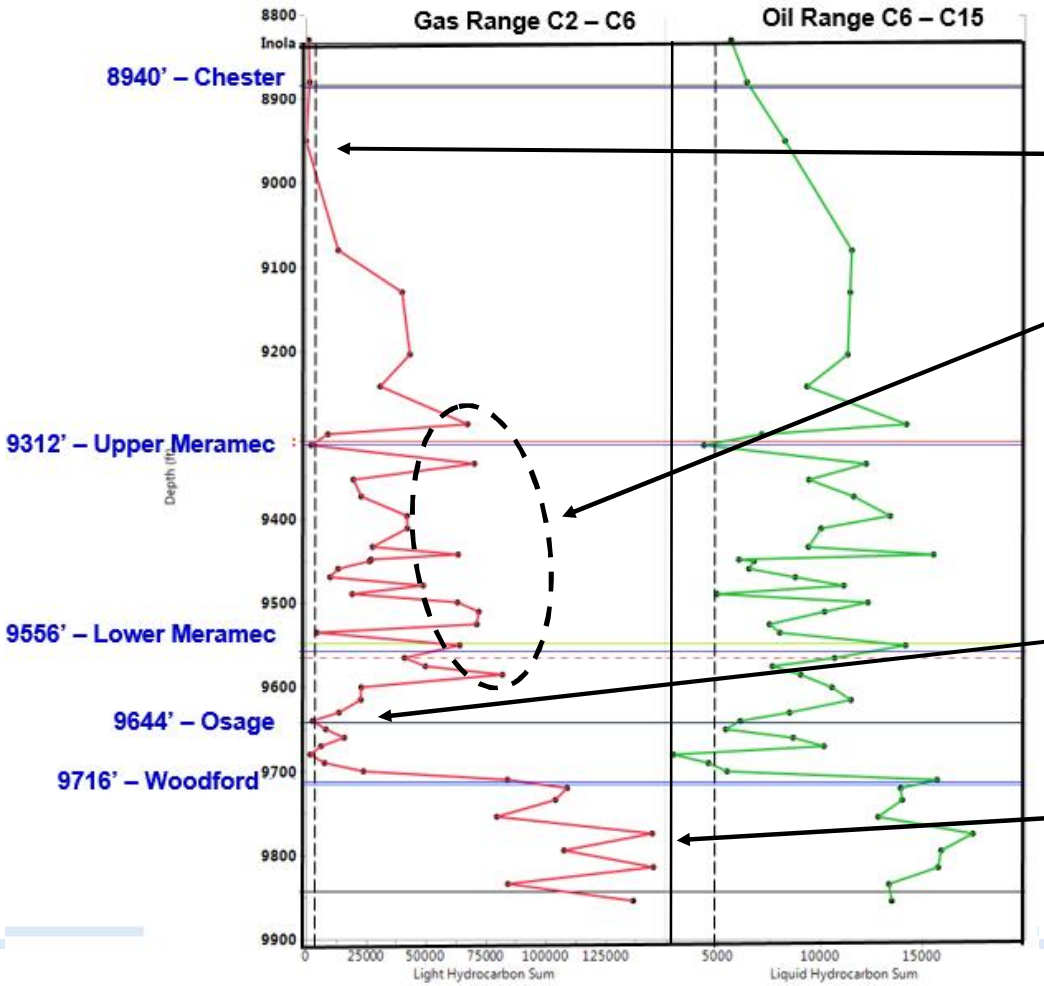




Canadian-1 well in Canadian County.

Mud wt. = 9.1

Canadian-1 Hydrocarbon Profile



Poor gas prospectivity in the Upper Chester.

Strong gas levels at:

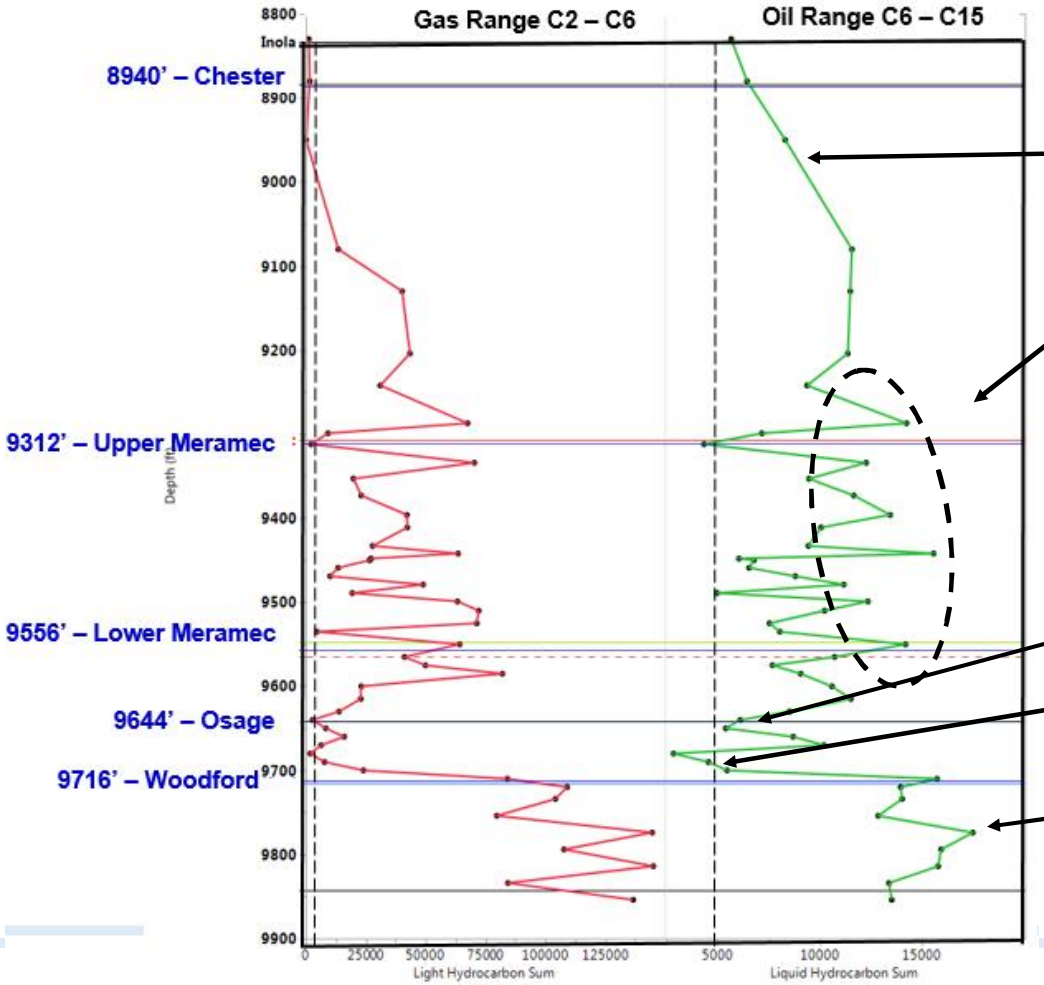
- **the bottom of the Chester Fm.,**
- **throughout the U. Meramec Fm.,**
- **the top of the L. Meramec Fm.**

Notice the gas composition drops dramatically at the bottom of the L. Meramec Fm. and goes to baseline in the Osage Fm.

Osage Fm. not prospective for gas.

Highest gas levels in the Woodford Fm.

Canadian-1 Hydrocarbon Profile



Poor oil prospectivity in the Upper Chester.

Strong oil levels at:

- the bottom of the Chester Fm.,
- throughout the U. Meramec Fm.,
- the top of the L. Meramec Fm.

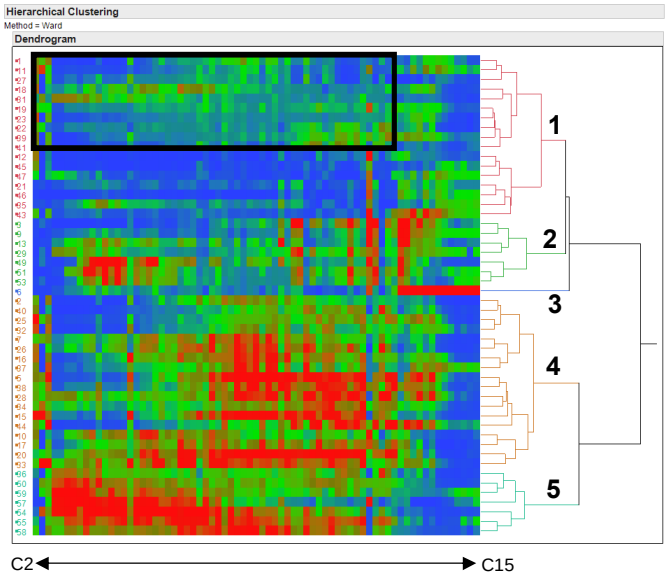
The data may suggest no seal between the Upper & Lower Meramec Fms.

Notice the oil composition goes to baseline at the top of the Osage Fm. but then kicks-up.

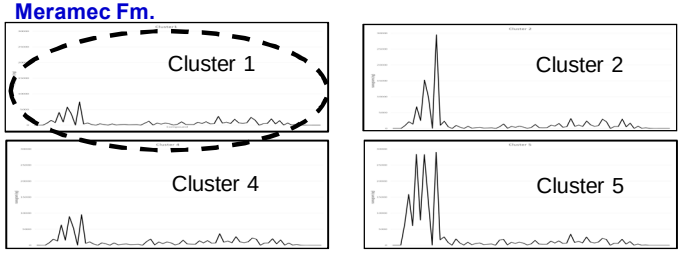
Lower Osage Fm. not prospective for oil.

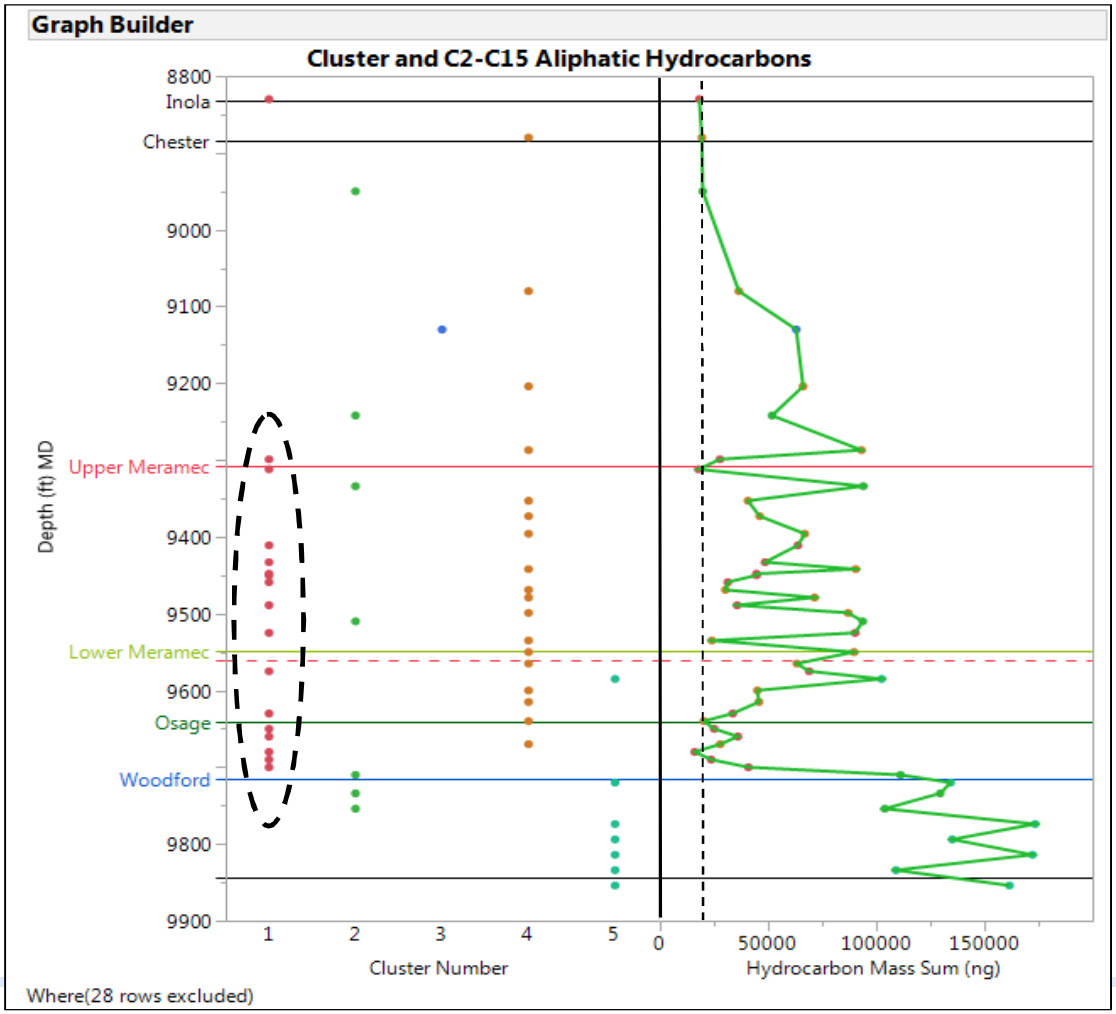
Highest oil levels in the Woodford Fm.

Canadian-1 Cluster & Hydrocarbon Profile

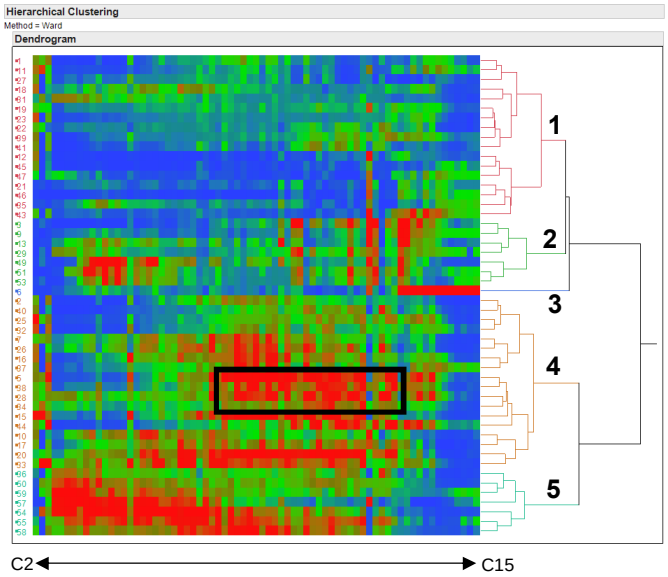


Cluster 5 mainly associated with the Woodford Fm has both high gas and liquid components associated with it (red area). Cluster 4 has high liquid components but less gas and is mainly associated with zones in the Meramec, Target Line, and Chester. **Cluster 1 which is the least hydrocarbon rich cluster is mainly associated with the Osage and portions of the Meramec Fm.**





Canadian-1 Cluster & Hydrocarbon Profile



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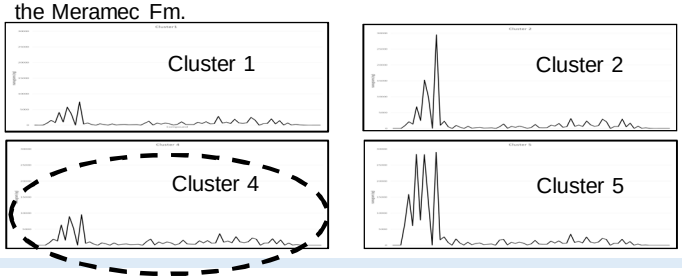

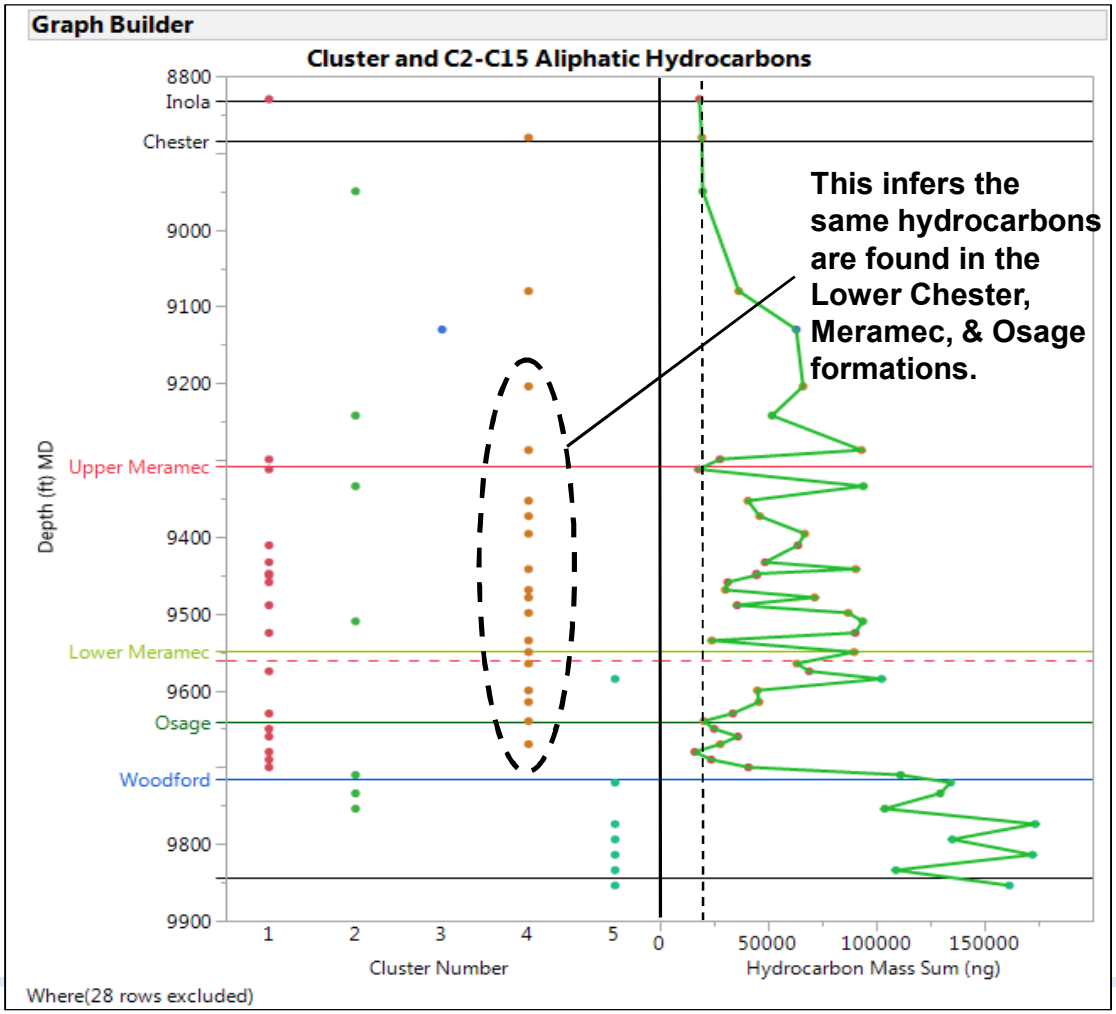

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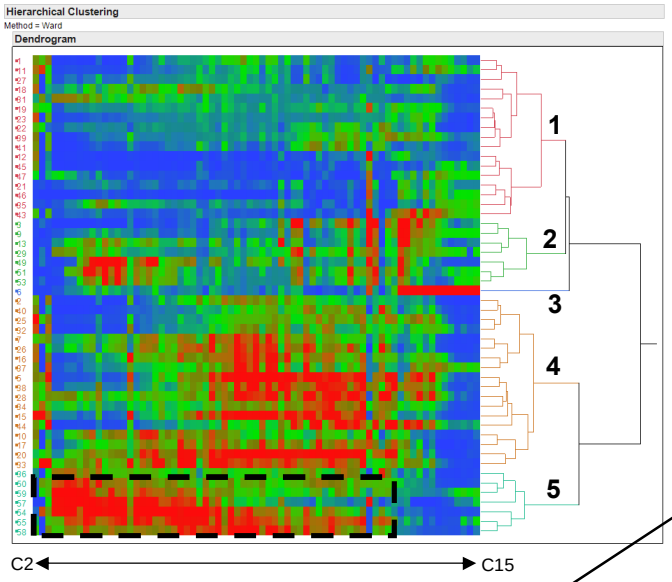

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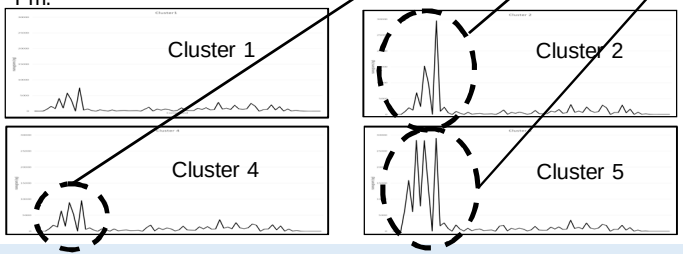

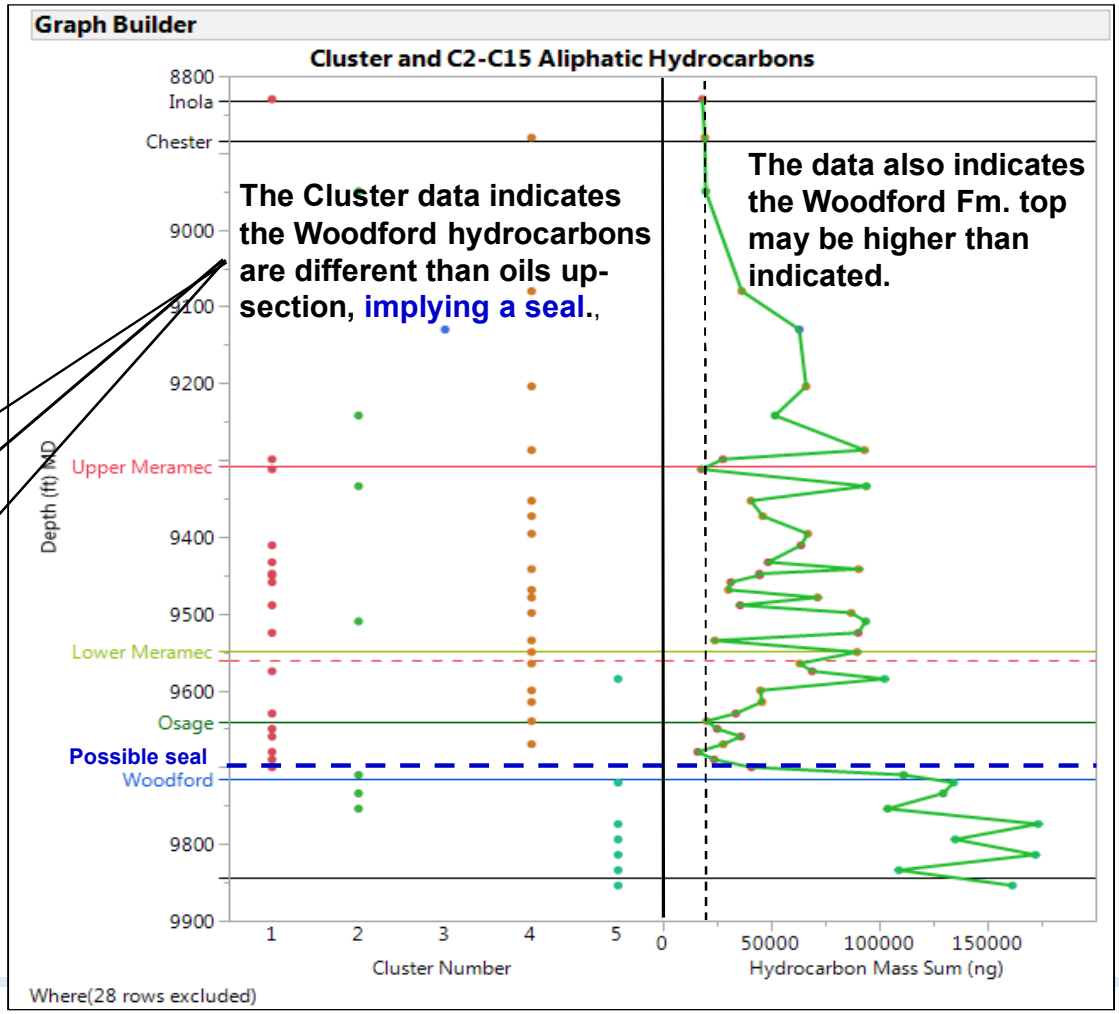

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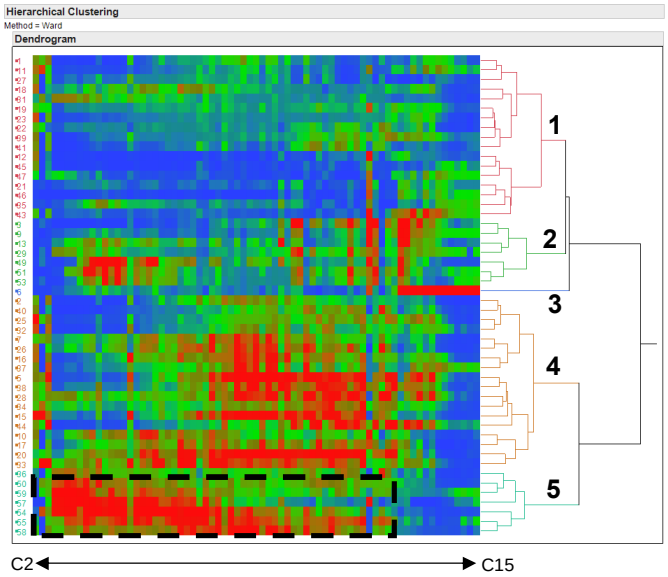

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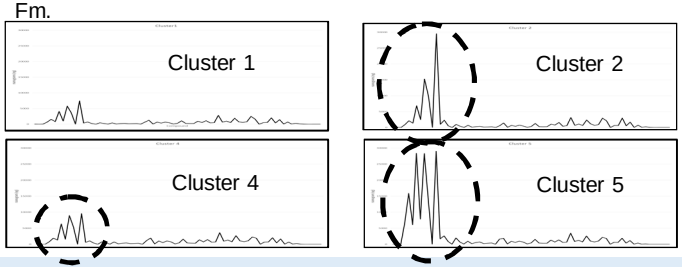
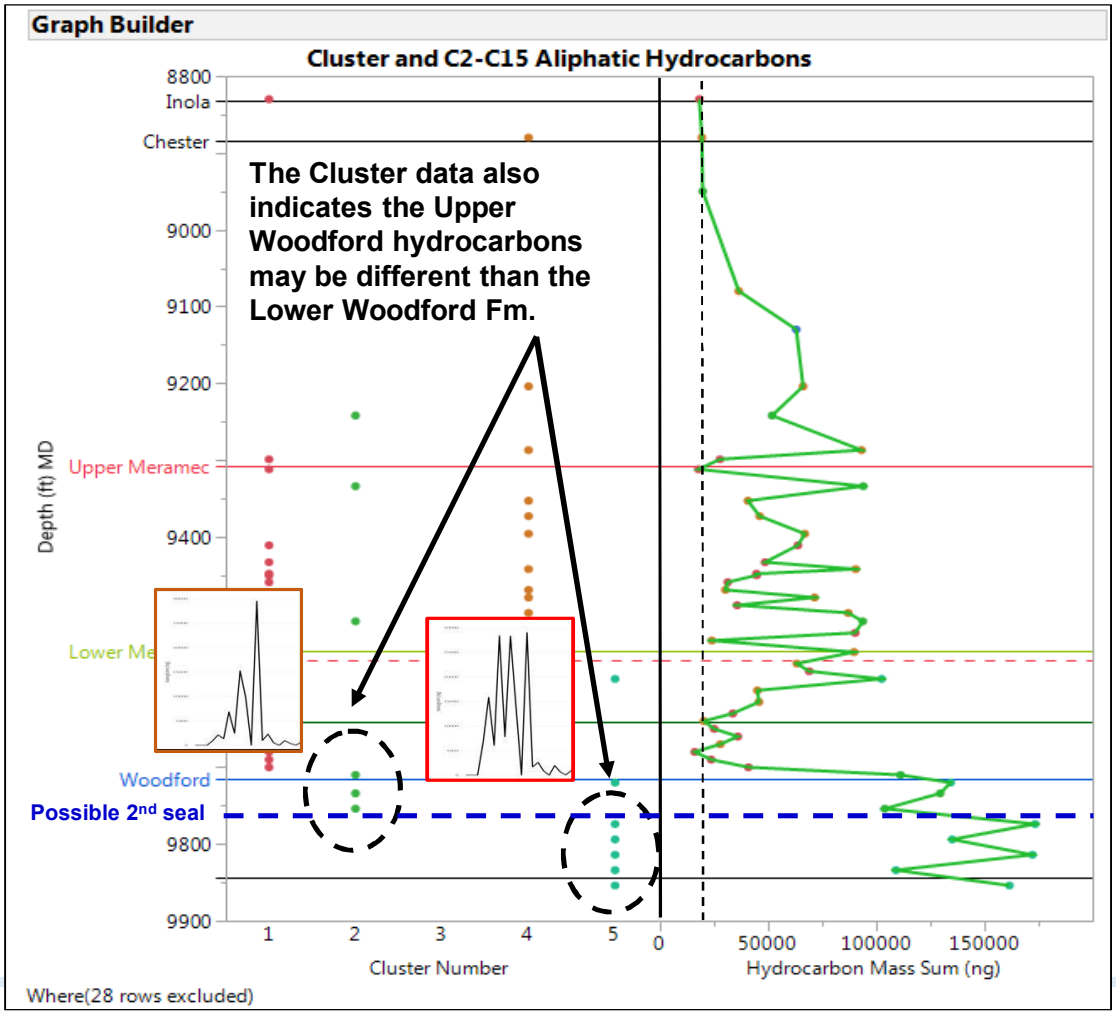
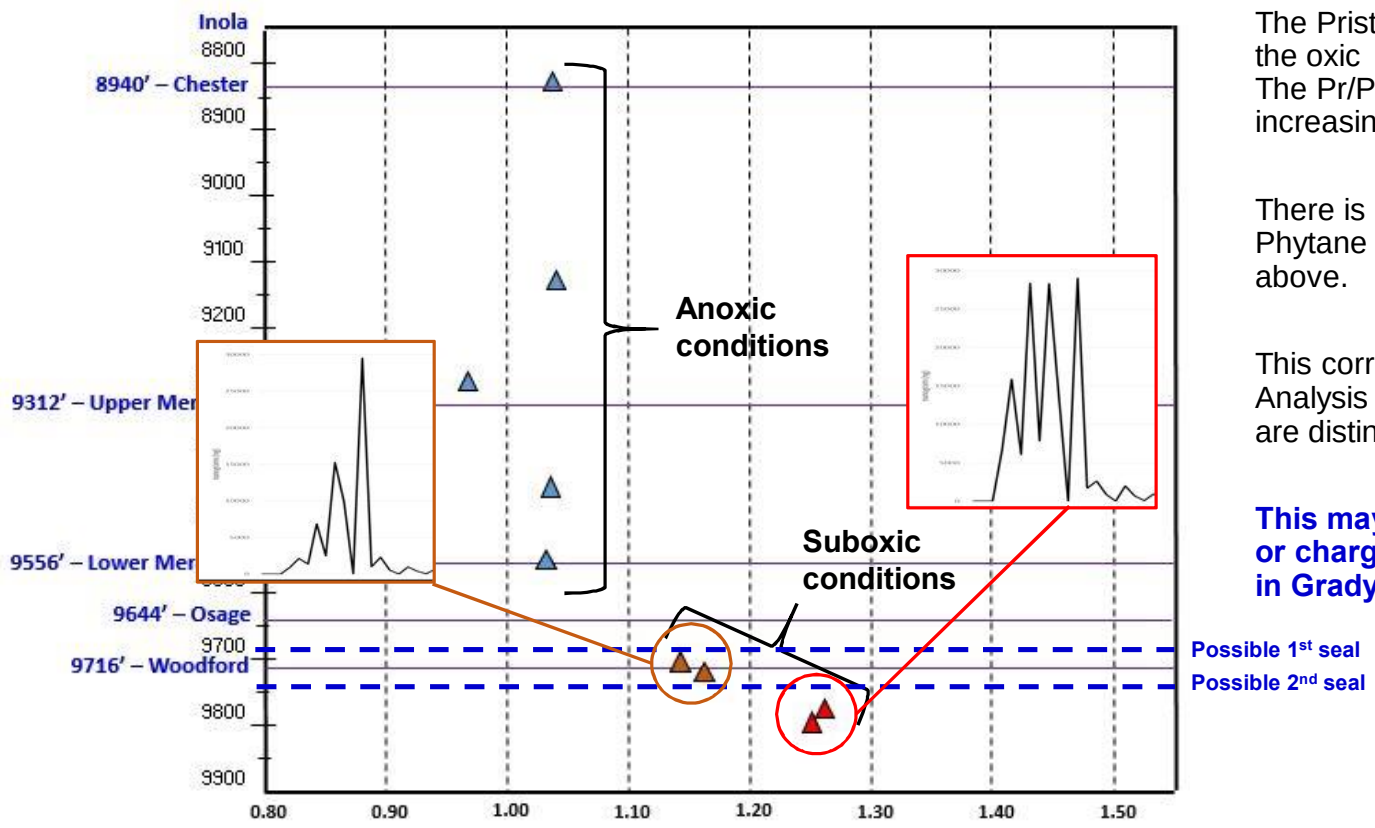




Pristane-Phytane Ratio vs Depth



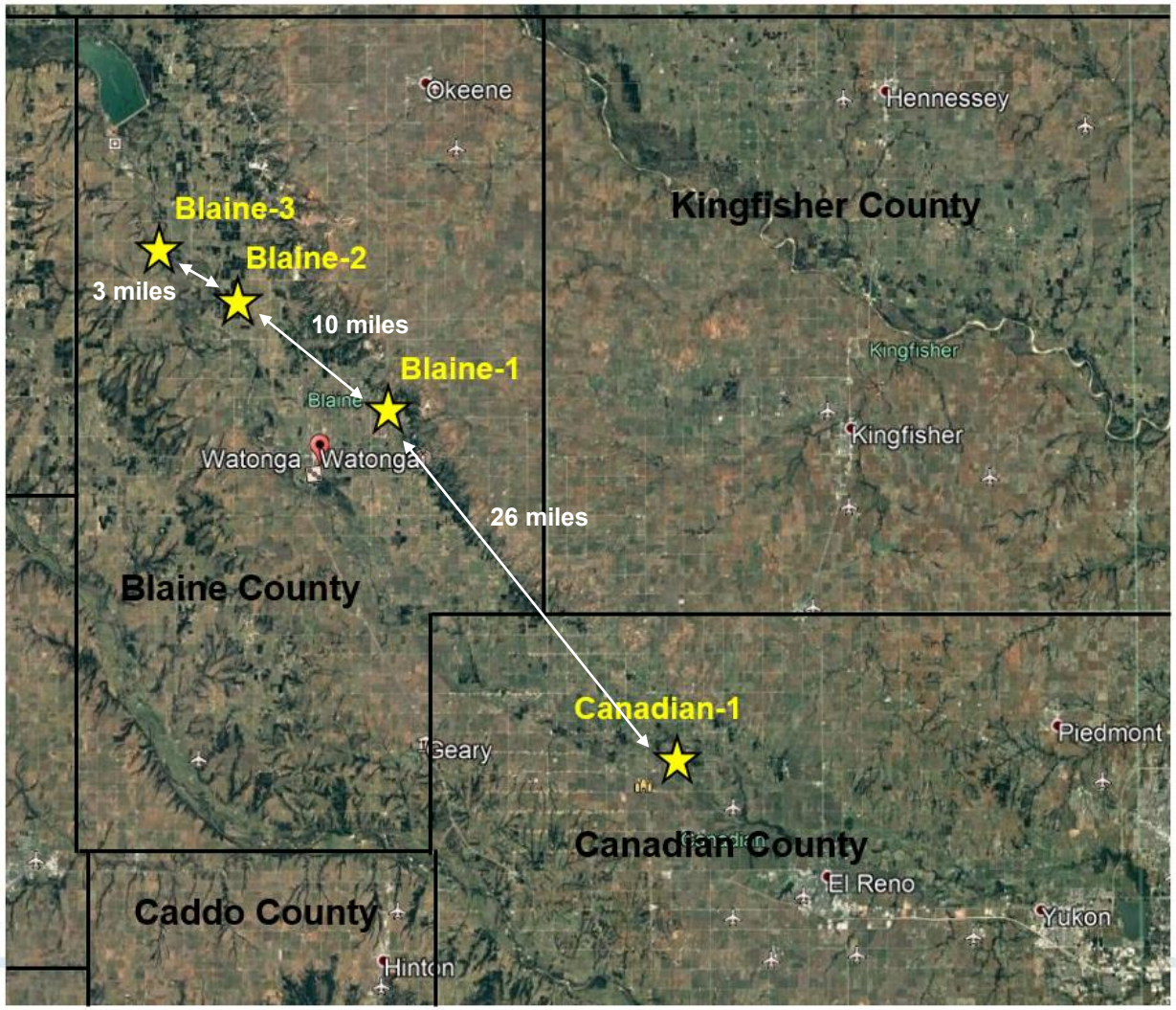
The Pristane/ Phytane isoprenoid ratio evaluates the oxic conditions of the depositional environment. The Pr/Ph ratio can increase with depth due increasing thermal maturity (Somer, 1988).

There is a definite distinction between the Pristane/ Phytane ratio in the Woodford and the formations above.

This correlates with the Hierarchical Cluster Analysis (HCA) that indicated the Woodford Fm oils are distinct from the Meramec oils.

This may indicate the Meramec is self-sourcing or charged from another source (e.g. the Osage in Grady County).

Additional Wells



Blaine-1 well is ~26 miles NW of the Canadian-1 well

Blaine-2 well is ~10 miles NW of the Blaine-1 well

Blaine-3 well is ~3 miles NW of the Blaine 2 well.

Blaine County wells were deeper & higher pressure than the Canadian-1.

Avg. mud wt. in Blaine County wells = ~13.9

Mud wt. in the Canadian-1 well = ~9.1

Gas Comparison for All Wells

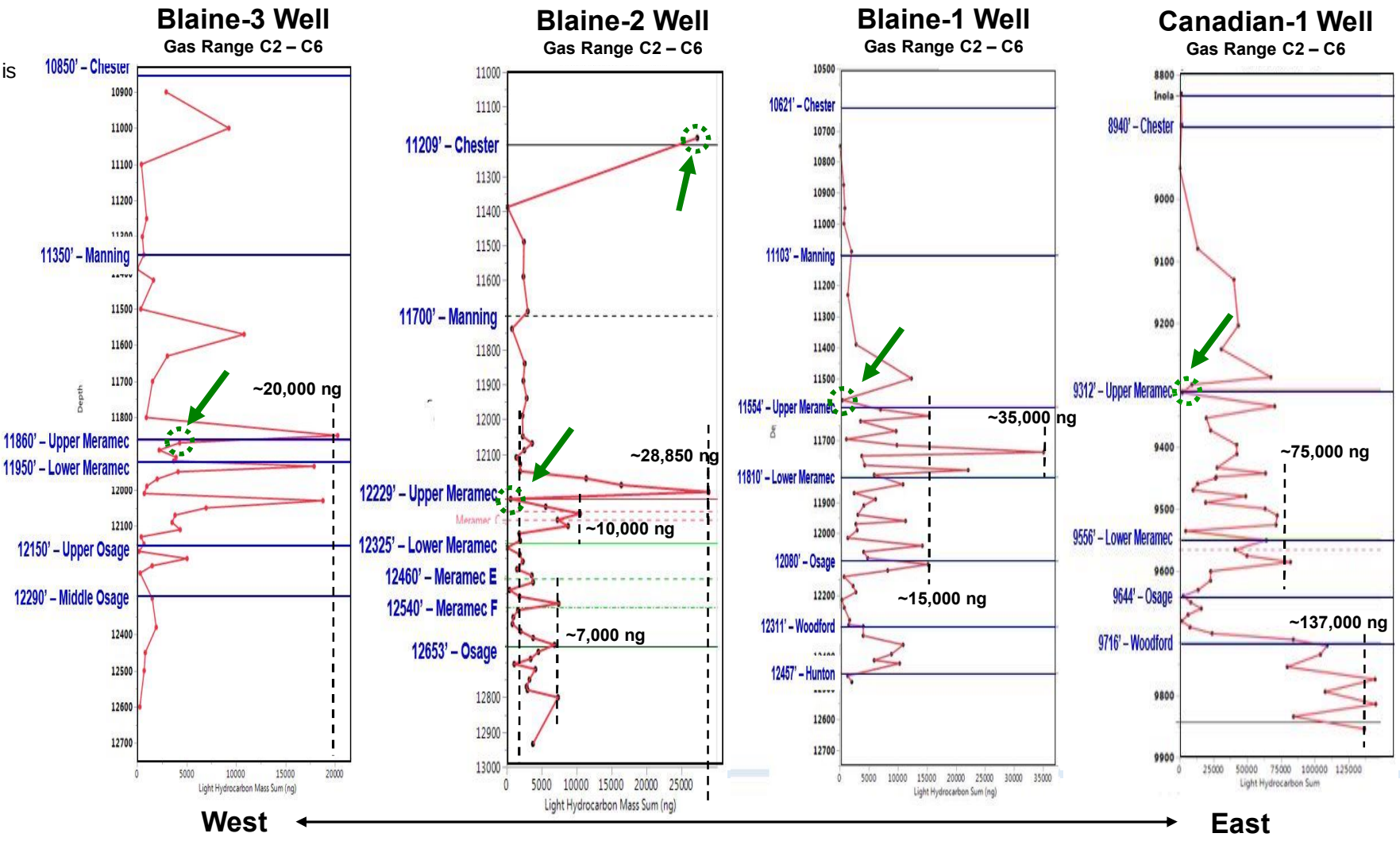
Blaine-2: the single gas sample in the Springer Fm. is different than all the other samples below.

You see the gas concentrations come to baseline at the top of the U. Meramec in every well. **Is that a seal?**

Notice the different distribution of hydro-carbons in the Manning, U. Meramec, & L. Meramec across the wells.

All of the wells show some gas response at the top of the Osage, but just above the Woodford all wells show low prospectivity. **Is that the Kinderhook Fm. with high clay content & poor porosity?**

Note the decrease in gas concentration as you move from SE to NW across the wells.



Oil Comparison for All Wells

Canadian-1: highest oil concentrations in the Woodford.

Similar concentrations between the U. & L. Meramec

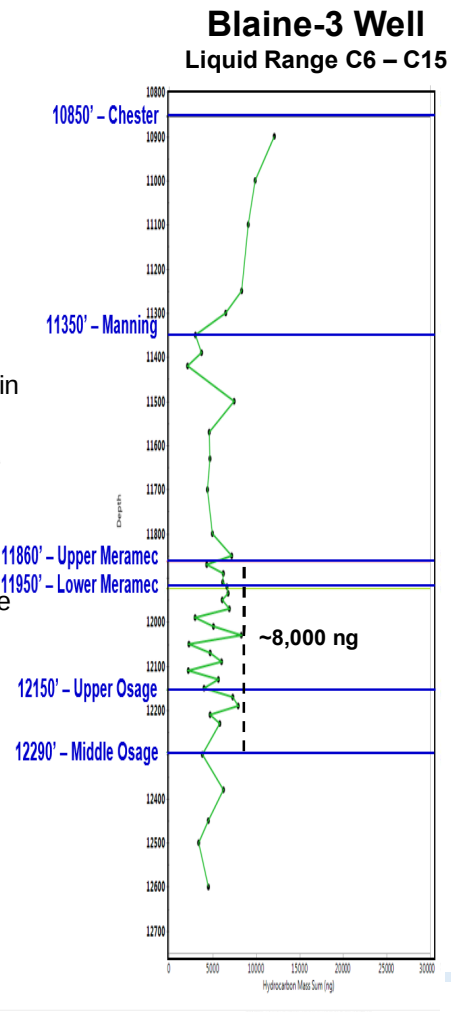
Blaine-1: Reduced oil concentrations as compared to the Canadian-1, particularly in the Woodford Fm.

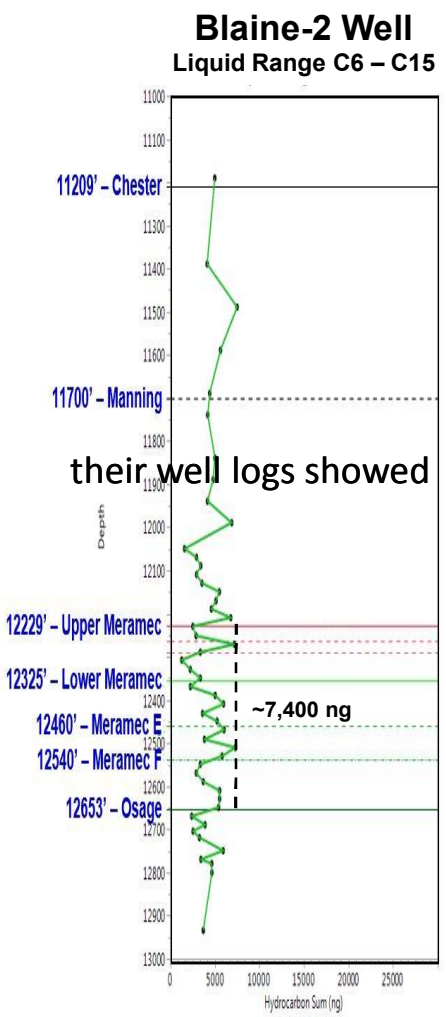
Highest intensities at the top of the Osage.

Cluster analysis shows the oil in the Meramec, Osage, & Woodford to be the same family.

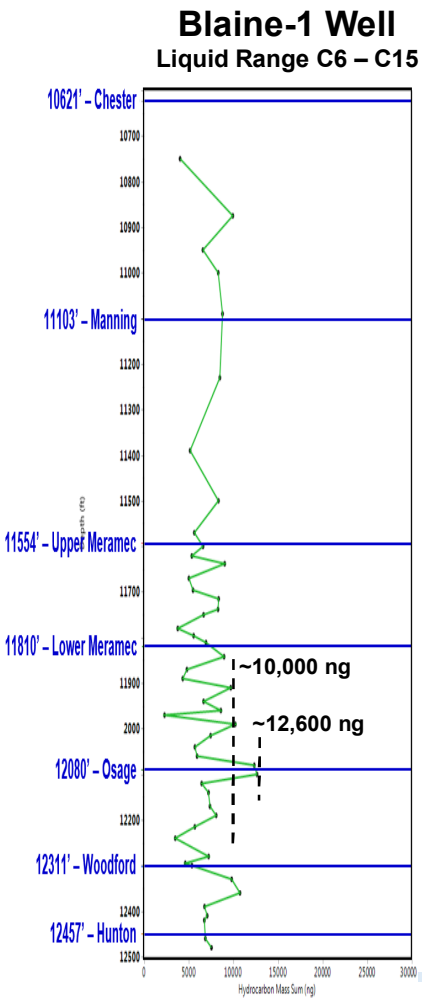
Blaine-2 & Blaine-3: oil concentrations are primarily due to OBM contributions.

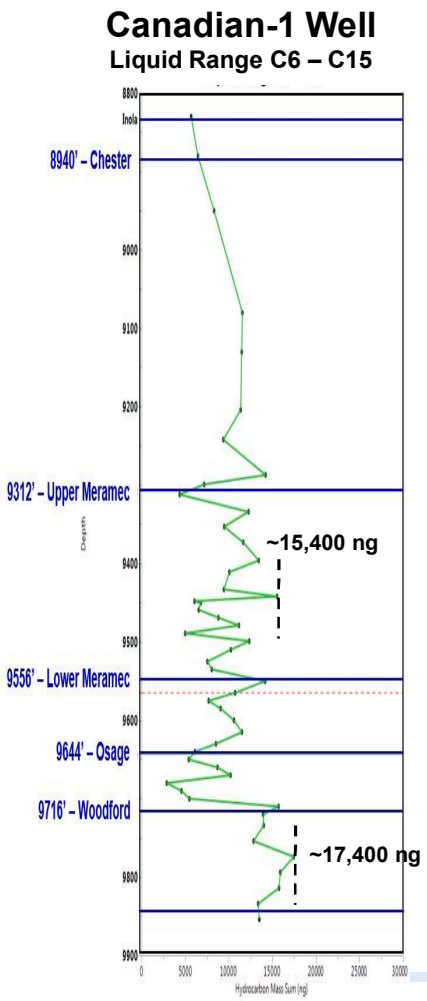
These are primarily gas wells.





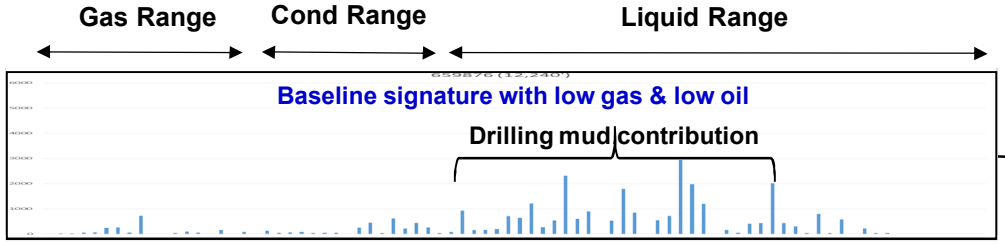
their well logs showed

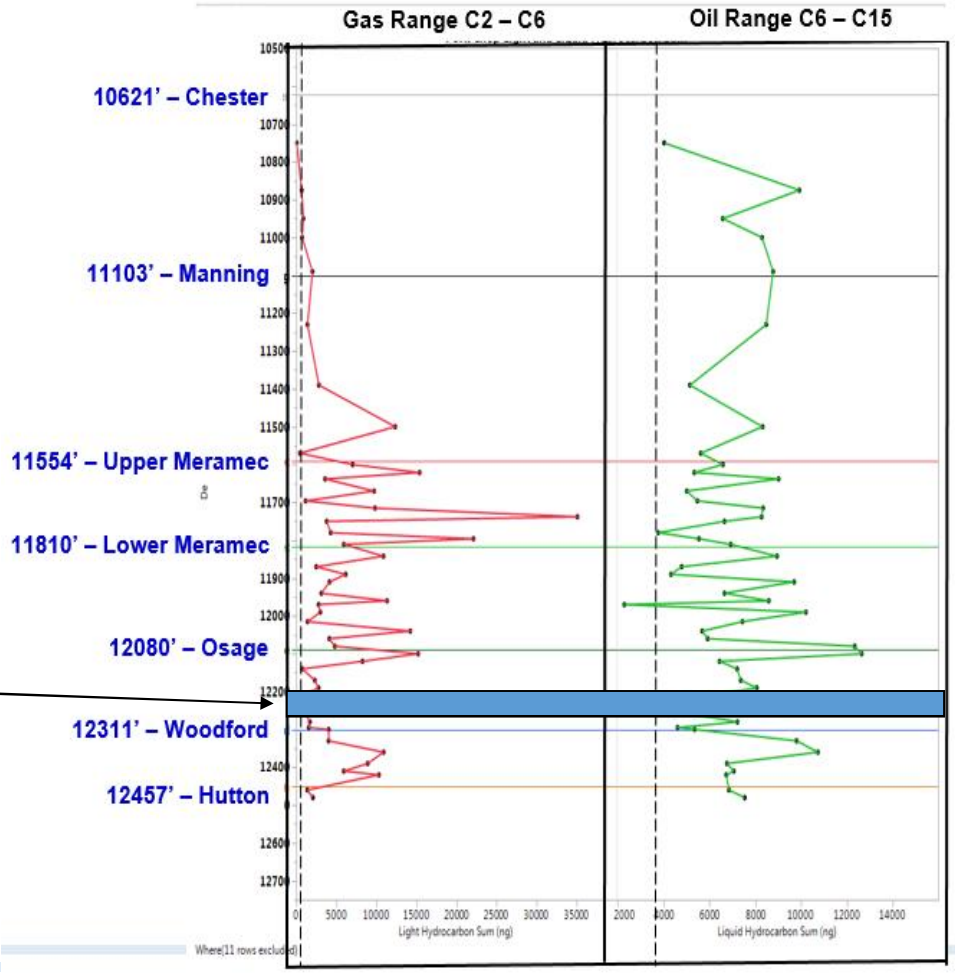




West ⟷ East

Selected Sample Signatures – Blaine-1 Well





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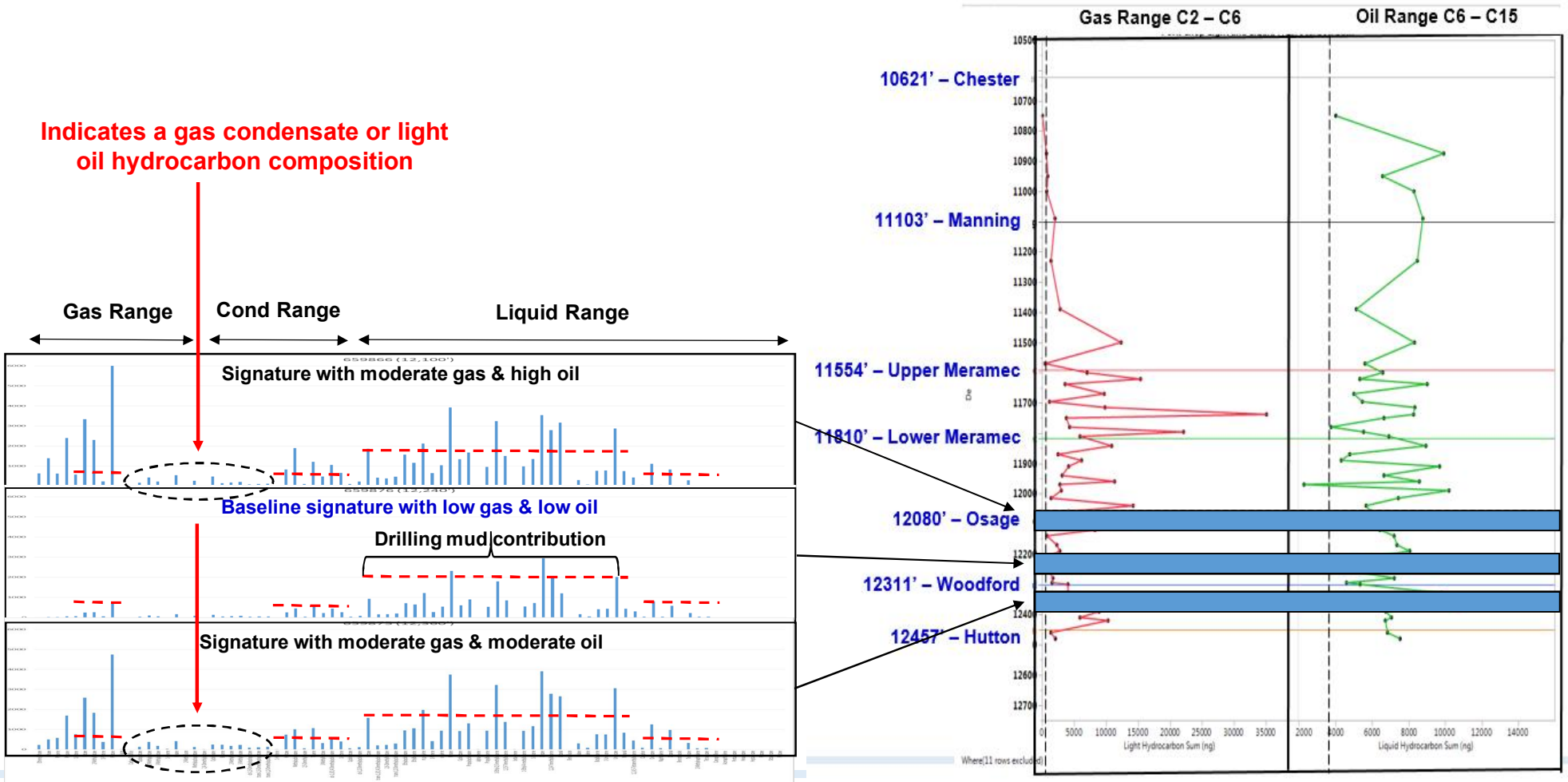


Benzene / Hexane Sw Proxy Plots

The C6 ratio of benzene/hexane potentially reflective of water saturation

Canadian-1: The **Lowest Sw (ratio ~0.1 - 0.2) and highest oil concentrations found in the Woodford, inferring highest economics & prospectivity**.

Low Sw throughout the U. & L. Meramec and Osage Fms ï for the most part.

The slight reduction in hydrocarbon richness in the Meramec may be due to a slight increase in water saturation in the pore space.

Highest Sw found in the Inola (ratio ~0.6).

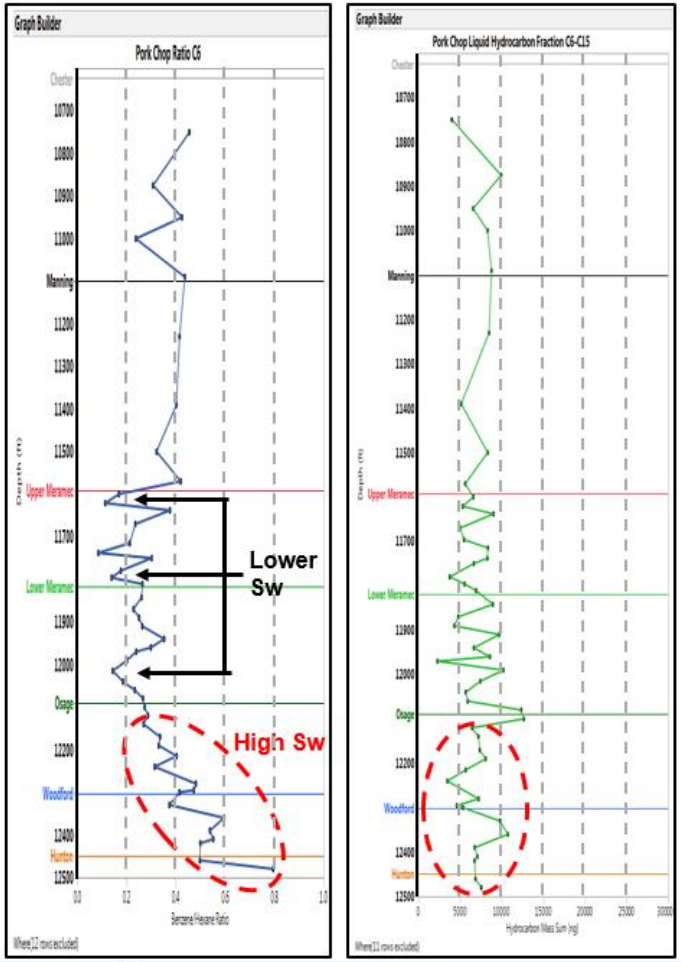
This is similar to a well done in Garfield Co. where the Sw proxy was ~0.2 in the Woodford & ~0.6 - 0.8 in the Miss Lime (**real Sw = ~15%**).

Blaine-1: The Sw proxy indicates that the deeper sections of this well (particularly the Woodford and Hunton Fms.) may have higher water saturation.

One map indicates a basement fault just south of the well. This fault may be bringing water up from the Hunton Fm., which often has high water saturation, into other formations.

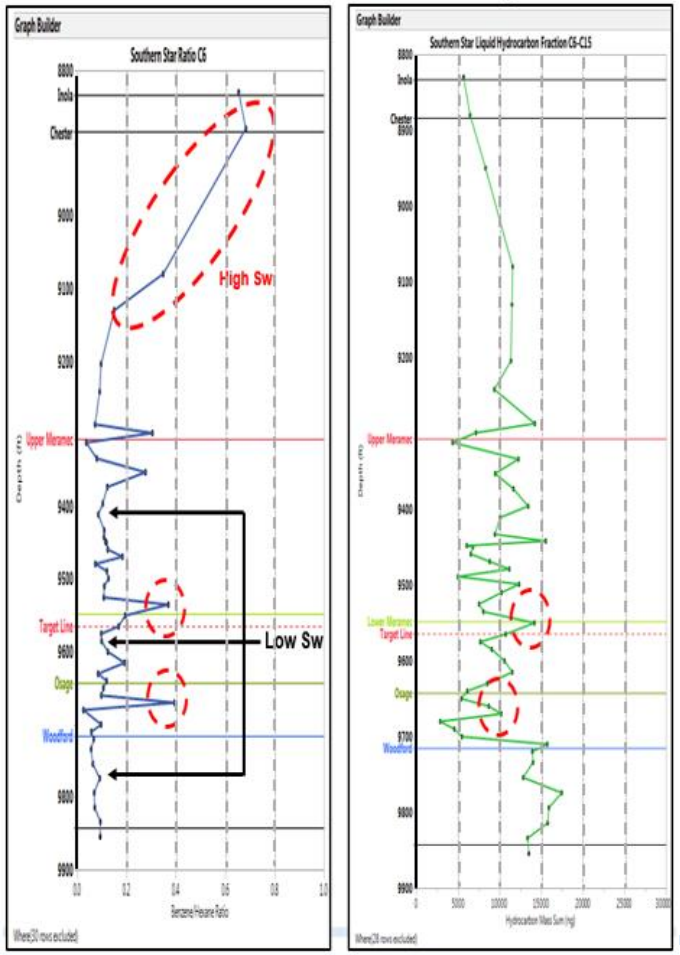
The Woodford Fm exhibits similar liquid intensities to the Upper & Lower Meramec formations, but has an increased water saturation level.

Blaine-1 Well Water Saturation & Liquid Plot



Sw proxy (Benzene/Hexane) | Liquid Hydrocarbons (C6 – C15)

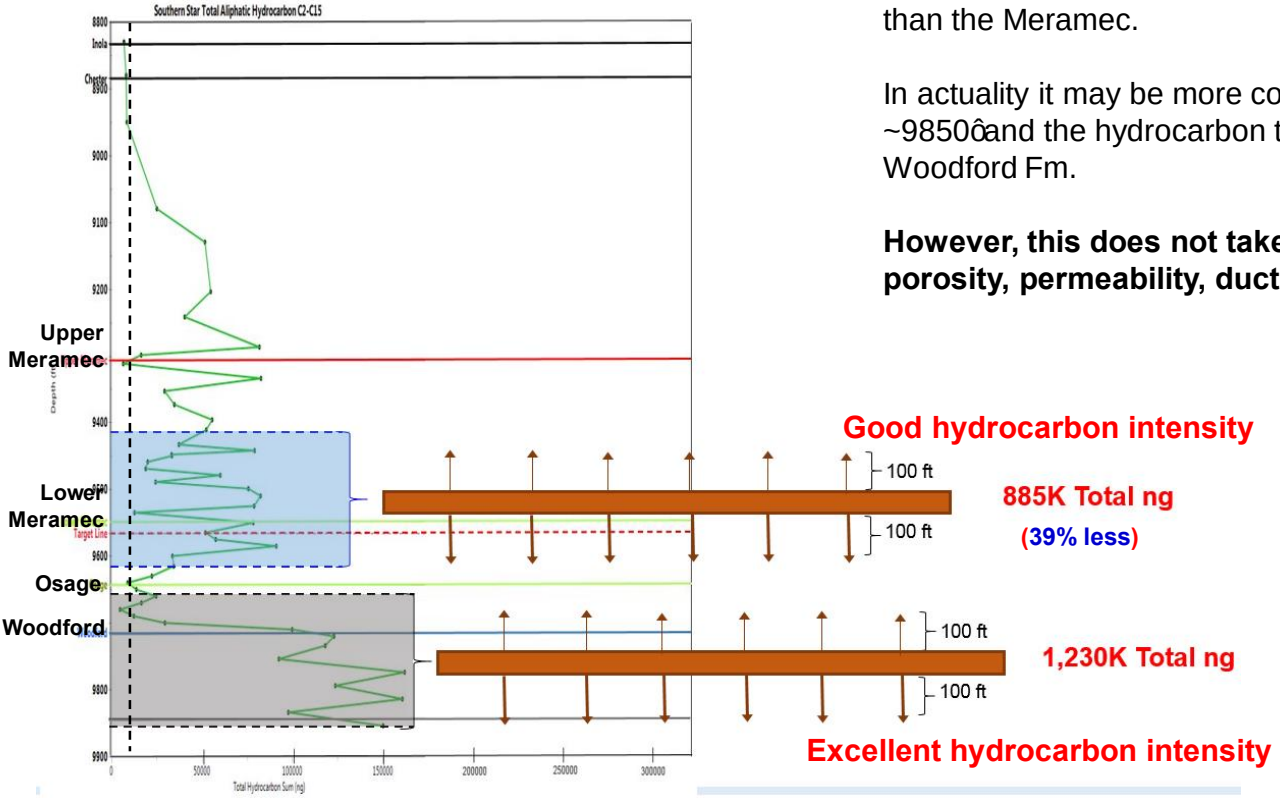
Canadian-1 Well Water Saturation & Liquid Plot



Sw proxy (Benzene/Hexane) | Liquid Hydrocarbons (C6 – C15)

Landing the Lateral in the Canadian-1

Plot of MS Total Hydrocarbons (C_2-C_{15}) vs depth



The 200ôdrainage in the Woodford Fm. has **a 39% higher hydrocarbon content** than the Meramec.

In actuality it may be more considering our sampling the Woodford Fm. stopped at ~9850ôand the hydrocarbon trend data showed continuing elevated levels in the Woodford Fm.

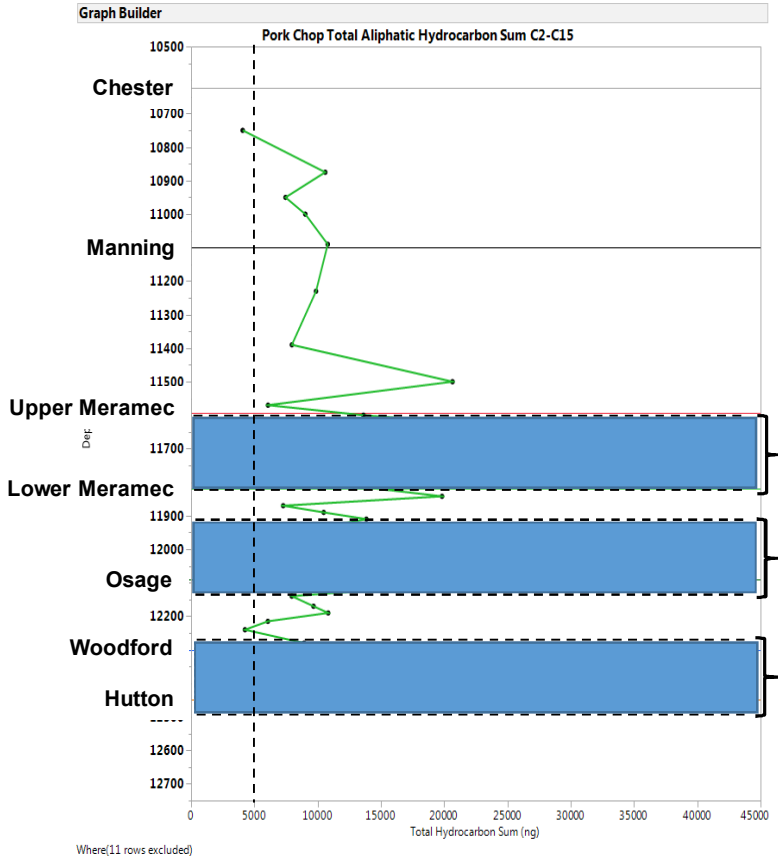
However, this does not take into account many other important factors like porosity, permeability, ductility, fracability, pressure, hydrocarbon phase, etc.

But, DGL does provide comparison hydrocarbon richness data to add to all of the aforementioned data sets because hydrocarbon richness is important too.

For example, the Osage could have outstanding rankings in all of the aforementioned data sets, but if it is devoid of hydrocarbons the well still wonôt be productive.

Landing the Lateral in the Blaine-1

Plot of MS Total Hydrocarbons (C_2-C_{15}) vs depth

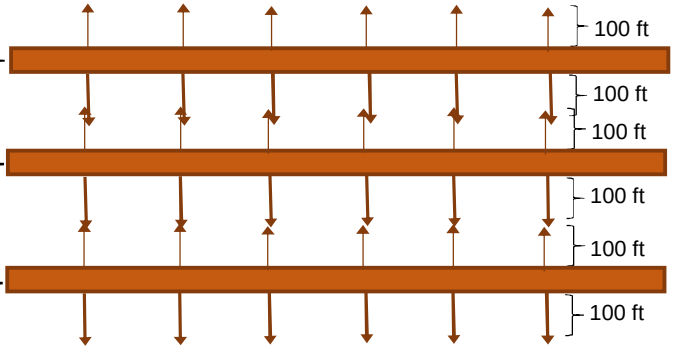


The Upper Meramec Fm. appears to have the best hydrocarbon richness with a 200ôdrainage between ~11,630 ï 11,830ô.

The Lower Meramec Fm. appears to have the next best hydrocarbon richness with a 200ôdrainage between ~11,940 ï 12,140ô

The Woodford Fm has moderate hydrocarbon richness with a 200ôdrainage between ~12,270 ï 12,470ô

However, this does not take into account many other important factors like porosity, permeability, ductility, fracability, pressure, hydrocarbon phase, etc.



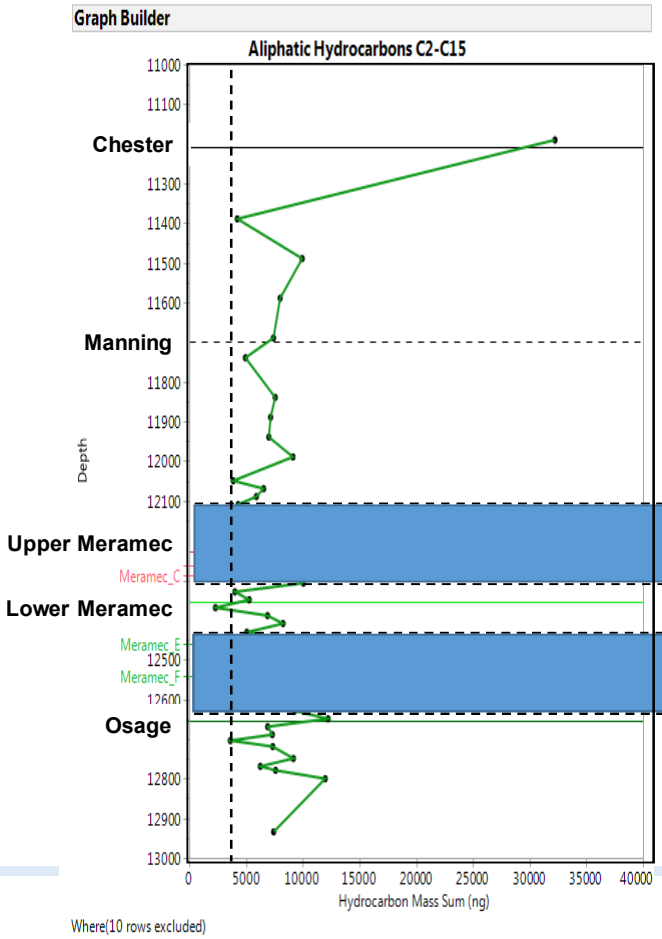
Very good hydrocarbon intensity
172,800 Total ng

Good hydrocarbon intensity
146,000 Total ng (18% less)

Moderate hydrocarbon intensity
121,900 Total ng (42% less)

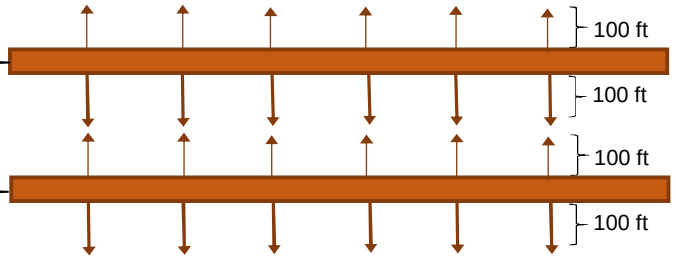
Landing the Lateral in the Blaine-2

Plot of Total Hydrocarbons (C_2-C_{15}) vs depth



The lower part of the Manning Fm. & the Upper Meramec appear to have the best hydrocarbon richness with a 200ô drainage between ~12,100 ï 12,300ô.

However, this does not take into account many other important factors like porosity, permeability, ductility, fracability, pressure, hydrocarbon phase, etc.

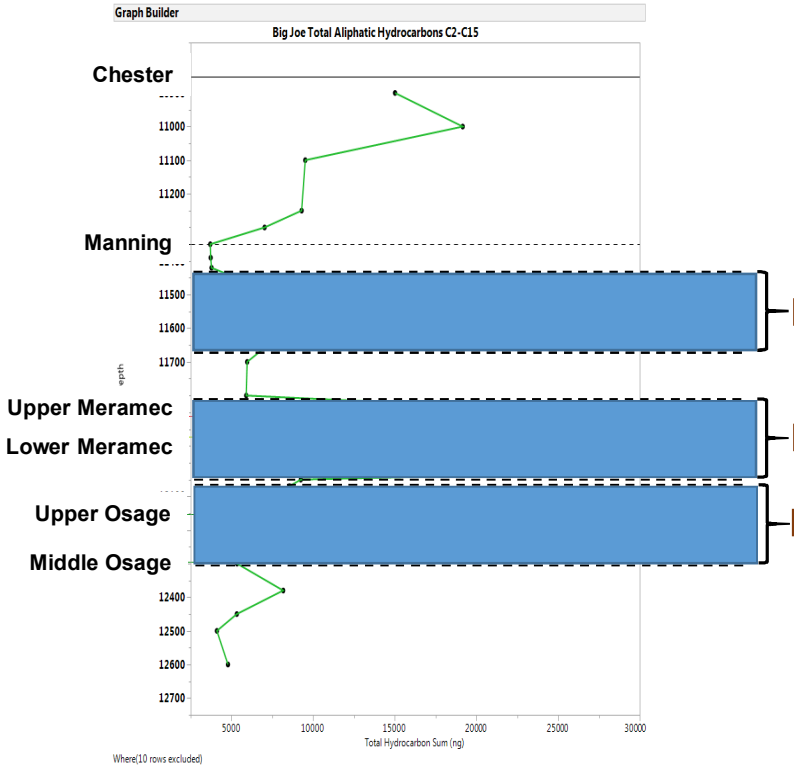


Good hydrocarbon intensity
128,500 Total ng

Poor hydrocarbon intensity
72,200 Total ng (78% less)

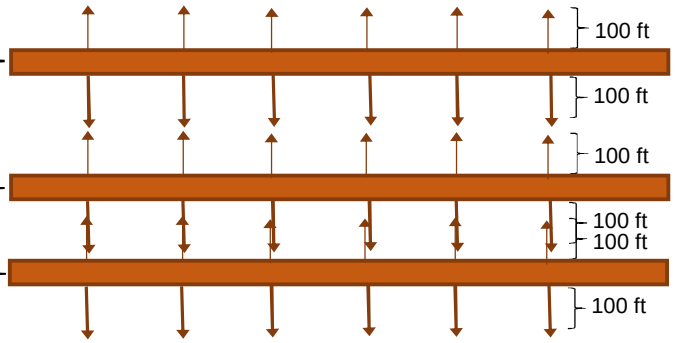
Landing the Lateral in the Blaine-3

Plot of Total Hydrocarbons (C_2-C_{15}) vs depth



The lower part of the Upper Meramec Fm. & the Lower Meramec appear to have the best hydrocarbon richness with a 200ôdrainage between ~11,820 ï 12,020ô.

The Manning Fm. appears to have the next best hydrocarbon richness with a 200ô drainage between ~11,460ôï 11,660ô but sampling resolution is poor.



Low hydrocarbon intensity
89,200 Total ng (60% less)

Good hydrocarbon intensity
141,900 Total ng

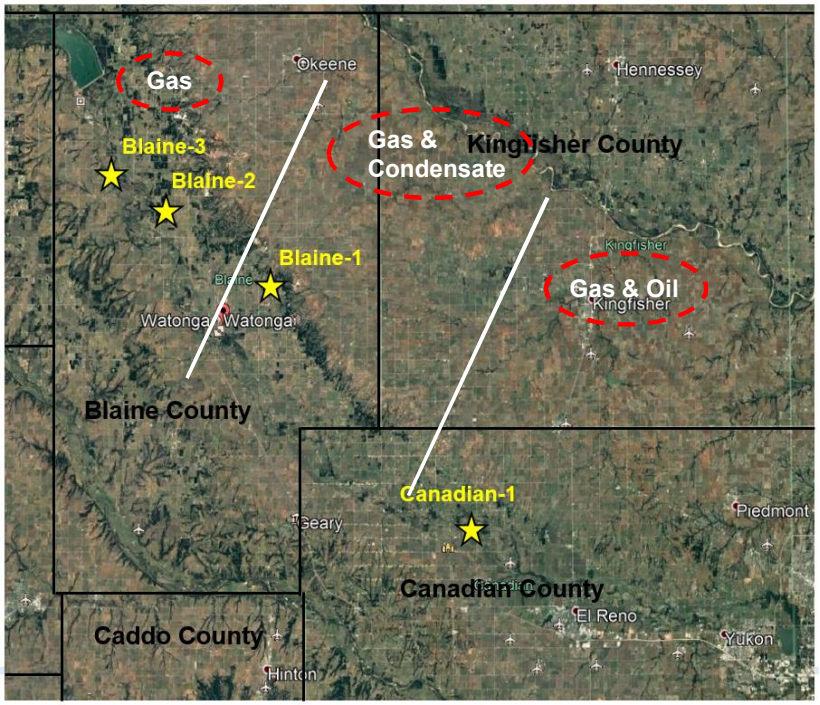
Poor hydrocarbon intensity
70,600 Total ng (100% less)

The lower part of the Lower Meramec Fm. & the Upper Osage Fm. appear to have minor amounts of hydrocarbon richness with a 200ôdrainage between ~12,100 ï 12,300ô

However, this does not take into account many other important factors like porosity, permeability, ductility, fracability, pressure, hydrocarbon phase, etc.

Project Summary

- There is a thermal maturity transition from SE to NW.
- Hydrocarbon intensities decrease as you move from SE to NW. **This is not a function of drilling mud weight**.
- The Sw proxy showed the Canadian-1 well with very low Sw in the Woodford, but **very high Sw in the Hunton & Woodford in the Blaine-1 well.**
- Possible seal at the top of the Upper Meramec. However, the hydrocarbons in the Manning & Upper Meramec appear to be similar.
- All wells the gas intensities drop at the base of the Osage. This **may be a result of entering the Kinderhook Fm**. which tends to be more clay rich with poor porosity.
- The one sample from the Springer Fm. in the Blaine-2 Well appeared different from all the deeper formation samples.
- In the Canadian-1 well the data **infers 3 possible hydrocarbon sources and 3 possible seals**.
- In the Blaine-1 the data indicators infer a single hydrocarbon source throughout the well.



Project Summary

Blaine-3 Well

- Most prospective hydrocarbon zone: the **Manning & Lower Meramec Fms**.
- The well has low liquid potential & is primarily a gas well

Blaine-2 Well

- Most prospective hydrocarbon zone: the **Manning & Upper Meramec Fms**.
- The well has low liquid potential & is primarily a gas well
- May have had recirculation problems with the collection of the cutting samples resulting in possibly artificially low results below the Manning Fm.

Blaine-1 Well

- Most prospective hydrocarbon zone: the **Upper Meramec Fm**.
- Second most prospective hydrocarbon zone: the **Lower Meramec Fm**.
- **Good** hydrocarbon intensity and **low water saturation in the Meramec**.
- **High water saturation in the Woodford & Hunton**.

Canadian-1 Well

- Most prospective hydrocarbon zone: the **Woodford Fm**.
- **Excellent** hydrocarbon intensity and **very low water saturation**.
- Second most prospective hydrocarbon zone: the **Upper Meramec Fm**.
- **Excellent** hydrocarbon intensity and **low water saturation**.

There is a different hydrocarbon sweet spot in every well – even wells just 3 miles apart.

Conclusion: These wells show quite a bit of vertical complexity.

You must integrate all data types to optimize horizontal well bore placement.

What Did the Client Learn

The detailed granular hydrocarbon characterization through the Springer, Chester, Manning, Meramec, and Woodford intervals spanned 39 miles in the STACK.

The data was able to:

- The data **coincided well with their well logs and gave them more confidence** and a better understanding of their logs.
- They found the water saturation proxy (i.e. the benzene / hexane) ratio to be very important because it **related to economics** (i.e. the more water in a zone the less profitable the zone).
- Our water saturation proxy **coincided well with moveable water** in their logs.
- **Told them things they were not aware of** (i.e. an increasing gas trend in the Lower Manning Fm or higher Sw in deeper formations in the Blaine-2 well).
- Our increased hydrocarbon intensities seemed to **correlate well with moveable oil and better porosity** in their well logs.
- After seeing our data, concerning lateral placement, they went back and **looked at their well logs and saw things they had not noticed before**.

Thank You!