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 well 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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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

- Cuttings are collected in polypropylene jars, directly from the shaker table during drilling
- Analyses normally done in 2 weeks

1,000 time more sensitive than traditional methods

Focuses on hydrocarbon fluids in various zones
- Measures from the C₂ to C₂₀ carbon range
- Easily differentiates between multiple phases
- Identifies reservoir compartmentalization
- Identify by-passed pay
Conventional Downhole Analyses

Traditional gas range of C1 – C5

AGI range C2 ÷ C20

Geochem Lab range of C15 ÷ C35
Canadian-1 Well – Canadian County

Mud wt. = 9.1
Canadian-1 Hydrocarbon Profile

- 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.

- Poor gas prospectivity in the Upper Chester.
Canadian-1 Hydrocarbon Profile

Strong oil levels at:
• the bottom of the Chester Fm.,
• throughout the U. Meramec Fm.,
• the top of the L. Meramec Fm.

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

Highest oil levels in the Woodford Fm.

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

Lower Osage Fm. not prospective for oil.

Poor oil prospectivity in the Upper Chester.
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.
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.

This infers the same hydrocarbons are found in the Lower Chester, Meramec, & Osage formations.
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.

The Cluster data indicates the Woodford hydrocarbons are different than oils upsection, implying a seal.

The data also indicates the Woodford Fm. top may be higher than indicated.
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.

The Cluster data also indicates the Upper Woodford hydrocarbons may be different than the Lower Woodford Fm.
The Pristane/Phytane isoprenoid ratio evaluates the oxic conditions of the depositional environment. The Pr/Ph ratio can increase with depth due to 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
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 hydrocarbons 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.

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**Blaine-3 Well**
Liquid Range C6 – C15

- 10650’ – Chester
- 11350’ – Manning

**Blaine-2 Well**
Liquid Range C6 – C15

- 11209’ – Chester
- 11700’ – Manning

**Blaine-1 Well**
Liquid Range C6 – C15

- 10621’ – Chester
- 11103’ – Manning

**Canadian-1 Well**
Liquid Range C6 – C15

- 8640’ – Chester
- 9312’ – Upper Meramec
- 9558’ – Lower Meramec
- 9644’ – Osage
- 9716’ – Woodford

~7,400 ng

~8,000 ng

~7,400 ng

~10,000 ng

~10,000 ng

~15,400 ng

~12,600 ng

~17,400 ng
Selected Sample Signatures – Blaine-1 Well

Baseline signature with low gas & low oil

Drilling mud contribution

Gas Range  Cond Range  Liquid Range

10621’ – Chester

11103’ – Manning

11554’ – Upper Meramec

11810’ – Lower Meramec

12080’ – Osage

12311’ – Woodford

12457’ – Hutton
Selected Sample Signatures – Blaine-1 Well

Indicates a gas condensate or light oil hydrocarbon composition

Signature with moderate gas & high oil

Baseline signature with low gas & low oil

Drilling mud contribution

Signature with moderate gas & moderate oil

Gas Range
Cond Range
Liquid Range

10621’ – Chester
11103’ – Manning
11554’ – Upper Meramec
11840’ – Lower Meramec
12080’ – Osage
12311’ – Woodford
12457’ – Hutton
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 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.
The 200-acre drainage 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 ~9850 feet and 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 won’t be productive.
The Upper Meramec Fm. appears to have the best hydrocarbon richness with a 200'-drainage between ~11,630 ft – 11,830 ft.

The Lower Meramec Fm. appears to have the next best hydrocarbon richness with a 200'-drainage between ~11,940 ft – 12,140 ft.

The Woodford Fm has moderate hydrocarbon richness with a 200'-drainage between ~12,270 ft – 12,470 ft.

However, this does not take into account many other important factors like porosity, permeability, ductility, fracability, pressure, hydrocarbon phase, etc.
Landing the Lateral in the Blaine-2

Plot of Total Hydrocarbons (C<sub>2</sub>-C<sub>15</sub>) vs depth

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

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

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

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

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

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

Â There is a thermal maturity transition from SE to NW.

Â Hydrocarbon intensities decrease as you move from SE to NW. **This is not a function of drilling mud weight.**

Â 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.**

Â Possible seal at the top of the Upper Meramec. However, the hydrocarbons in the Manning & Upper Meramec appear to be similar.

Â 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.

Â The one sample from the Springer Fm. in the Blaine-2 Well appeared different from all the deeper formation samples.

Â In the Canadian-1 well the data **infers 3 possible hydrocarbon sources and 3 possible seals.**

Â In the Blaine-1 the data indicators infer a single hydrocarbon source throughout the well.
**Project Summary**

<table>
<thead>
<tr>
<th>Blaine-3 Well</th>
<th>Blaine-2 Well</th>
<th>Blaine-1 Well</th>
<th>Canadian-1 Well</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Most prospective hydrocarbon zone: the Manning &amp; Lower Meramec Fms.</td>
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<td>- Most prospective hydrocarbon zone: the Upper Meramec Fm.</td>
<td>- Most prospective hydrocarbon zone: the Woodford Fm.</td>
</tr>
<tr>
<td>- The well has low liquid potential &amp; is primarily a gas well</td>
<td>- The well has low liquid potential &amp; is primarily a gas well</td>
<td>- Second most prospective hydrocarbon zone: the Lower Meramec Fm.</td>
<td>- Excellent hydrocarbon intensity and very low water saturation.</td>
</tr>
<tr>
<td>- May have had recirculation problems with the collection of the cutting samples resulting in possibly artificially low results below the Manning Fm.</td>
<td>- Good hydrocarbon intensity and low water saturation in the Meramec.</td>
<td>- Good hydrocarbon intensity and low water saturation in the Woodford &amp; Hunton.</td>
<td>- Second most prospective hydrocarbon zone: the Upper Meramec Fm.</td>
</tr>
<tr>
<td>- High water saturation in the Woodford &amp; Hunton.</td>
<td></td>
<td></td>
<td>- Excellent hydrocarbon intensity and low water saturation.</td>
</tr>
</tbody>
</table>

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!