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Optimizing Lateral Placement and Production While Minimizing Completion Costs Using Downhole Geochemical Logging

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Abstract

Introduction

Shale plays are an extremely difficult arena in which to explore. Lack of heterogeneity is not the only problem. The Eagle Ford play, for example, has numerous hydrocarbon sources and multiple stacked zones. These multiple stacked pays result in mixed drilling success with both economic and noneconomic drilling results. In addition there are numerous migration pathways in various parts of the field and charge source or kitchen vary with placement in the field as well.

Towards that end, a variety of logging technologies provide information during drilling as to the presence of hydrocarbons. However, these logging technologies do not measure hydrocarbons directly, but rather measure hydrocarbon proxies and infer hydrocarbon presence and phase based on this data. These technologies, while sophisticated can lack specificity and sensitivity when trying to accurately identify hydrocarbons.

Additionally, some new technologies can monitor hydrocarbons from n-C_1 (methane) to n-C_8 (octane) and expand the scope of hydrocarbon detection. These new technologies can clearly detect gas range organics and can infer light oils and condensates. However, all of these technologies lack the ability to measure the heart of the oil or liquid hydrocarbon fingerprint of n-C_7 (heptane) to n-C_{15} (pentadecane). Thus, accurately characterizing and differentiating between multiple oil fingerprints becomes difficult, if not impossible, for current technologies. As such, these limitations negatively impact the ability of companies to properly assess zones of highest hydrocarbon richness and porosity. As a result, companies commonly have template completion and fracturing schemes that generate production, but are not optimal.

A presentation by Chris Fredd at the ***Second EAGE/SPE/AAPG Shale Gas Workshop*** in 2014 in Dubai reported that approximately 40% of all shale oil wells were not profitable because many of the frac stages in the lateral well were not effective. While there are many reasons for the lack of effectiveness, one of the most common reasons is the focus on efficiency over effectiveness. Once production drilling begins it is easy to understand the push to standardize drilling operation to preset well spacing, lateral lengths, the number of fracture stages, and preset fracture spacing to optimize operation and minimize costs. However, effectiveness also plays an important part in optimizing profitability. For example, setting fracture stages in zones of a lateral well that have little or no hydrocarbon concentration and low porosity increase completion costs without increasing production.

A relatively new technology, Downhole Geochemical Logging, analyzes downhole cutting samples to directly characterize the composition of hydrocarbons vertically through prospective sections. This methodology has the unique ability to look at a broad compound range from C_2 to C_{20}, which is significantly more expansive than the limited traditional ranges of C_1-C_5 or C_1-C_8 of most well gas logging techniques. The result is a broad characterization of petroleum phase contained in the stratigraphic intervals as well as addressing compartmentalization down the well.

Overview

Drill cuttings were collected in jars as the well was drilled, as seen in Figure 1. The cuttings samples were not washed, dried, or cleaned in any manner and no biocide was added to the collection jar. Sampling locations were chosen at regular 30 ft intervals, however, normally sampling intervals vary. Traditionally, sampling intervals are expanded to 100 ft intervals in low interest zones and then tightened to 25 ft ï 30 ft intervals across formation tops, thin zones, and zones of high interest. In lateral wells, sampling intervals are normally 100 ft.

Figure 1. Samples being collected from the shaker table while drilling. Also shown is the sample collection jar with the white proprietary sampling adsorbent modules that increase sensitivity by 1000-fold.

Once the collection jars were received, adsorbent pouches were placed in the jars to collect compounds from the cutting pore volume. The patented sampling device (US 5,235,863) is unique in the world and is not licensed by AGI to any other company. The adsorbent modules use a specially engineered hydrophobic adsorbent designed to collect a wide range of hydrocarbon compounds, approximately 85 compounds, ranging from ethane (n-C_2) to phytane (C_{20}). The adsorbent is protected by an inert polytetrafluoroethylene microporous membrane, which allows hydrocarbon vapors to pass through, but protects the adsorbent from dirt and liquid water. The result is a 1000-fold increase in hydrocarbon concentrations.

When the jars are opened to insert the adsorbent modules, the initial headspace gas is lost, see Figure 2. This allows the removal of potential contaminants that may have been entrained in the headspace gas as samples were collected in the field. The samples are allowed to sit for one hour as the cuttings off-gassed and recharged the headspace volume in the jar. Thus, the fresh off-gassed hydrocarbons were more reflective of the pore space hydrocarbons and, therefore, more reflective of the producible hydrocarbons.

Figure 2. The sample collection jar with the white proprietary sampling adsorbent modules that increase sensitivity by 1000-fold.

The adsorbent modules were then analyzed using thermal desorption followed by gas chromatography and mass spectroscopy to generate quantitative mass levels. The chemical fingerprint of each cutting sample was then interpreted using multivariate statistical techniques and geochemical analysis techniques to characterize the petroleum phase. Mud blanks were collected, as well, and used to calibrate the background influences from drilling mud, drilling additives, and entrained hydrocarbons from the formation as the drilling mud was recirculated.

Vertical Hydrocarbon Results

The first step in data processing was to perform Hierarchical Cluster Analysis (HCA). HCA is often called an "unsupervised" multivariate technique, since no additional information other than the data itself is required to perform the operation. That is, it is not necessary to identify "end-members" of the data or qualify the data in any manner in order to perform subsequent comparison or evaluation of the data, as is the case with multivariate classification techniques. HCA proceeds by grouping samples of like composition according to the values of all input variables. The result is a list of subsets of samples of the data, which are alike (forming "clusters" of similar samples). Since the input variables of the data are in the form of hydrocarbon compound intensities, the clusters are subsets of chemically similar samples (i.e. similar hydrocarbon signatures). The HCA method is used to determine the structure of a set of data independent of other geological or geophysical information.

The results of the HCA are seen in Figure 3. This chart shows the output from a hierarchical cluster analysis (HCA #1) using all of the samples (shown here in individual rows of data). The Y-axis is each individual cutting sample and the x-axis is the carbon range from C_2 – C_{20}. Generally speaking, the red indicates a positive hydrocarbon response at that carbon range and blue indicates a negative or background response at that carbon range. Thus, the process groups the samples together based on their similar geochemical signatures and does not look at what depth, lithology, or stratigraphy samples were taken from. It simply clusters samples based on similar signatures.

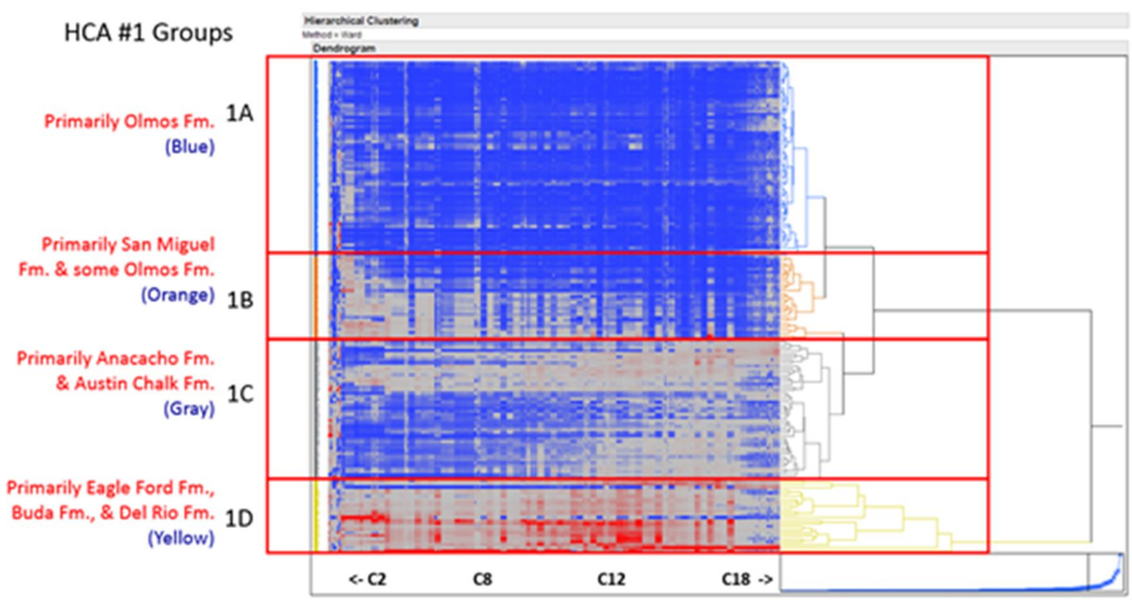

Figure 3. A Hierarchical Cluster Analysis of the Downhole Geochemical Data from an Eagle Ford well.

This HCA identified four main groups which are shown with the red rectangles and are numbered 1-4 on the far left. What is interesting about the data is when you begin to look at what samples comprise these 4 groups, you find a very interesting pattern. You find most of the Olmos Fm samples fall in Group 1A. Most of the samples from the San Miguel Fm samples fall collectively in Group 1B, the Group 1C samples are primarily comprised of samples from the Anacacho & Austin Chalk, while Group 1D is comprised of samples primarily taken from the deeper Eagle Ford, Buda, & Del Rio formations.

The hierarchical cluster results correlate to published sources for the Maverick Basin. Published data ascribes the lower Eagle Ford as a known hydrocarbon source which most likely charges the upper Eagle Ford, the Buda, and the Del Rio formations while the Austin Chalk formations is a source for the Austin Chalk & the overlying Anacacho. Additionally, the data indicates the San Miguel formation appears to be a third and distinct hydrocarbon signal while the Olmos formation is a background signature. HCA analysis is not easily performed on traditional headspace of gas composition analysis because there is insufficient numbers of hydrocarbon compounds in the data set to adequately distinguish between, not only between gas, condensate, and oil signatures, multiple gas or oil signatures that are similar.

Figure 4 shows two depth profile charts, with the addition of some select TIC (total ion chromatogram) signatures from various horizons. The gas components (C_2-C_6) are plotted verses depth on the left while the oil components (C_{10}-C_{18}) are plotted on the right. One of the first things that is notable is the dramatic difference in hydrocarbon signatures and intensity as you move down the well. The Olmos Fm signature does not appear to be a gas signature, but rather a background signature as seen in the lack of intensity in the gas and oil profiles charts and in TIC #1.

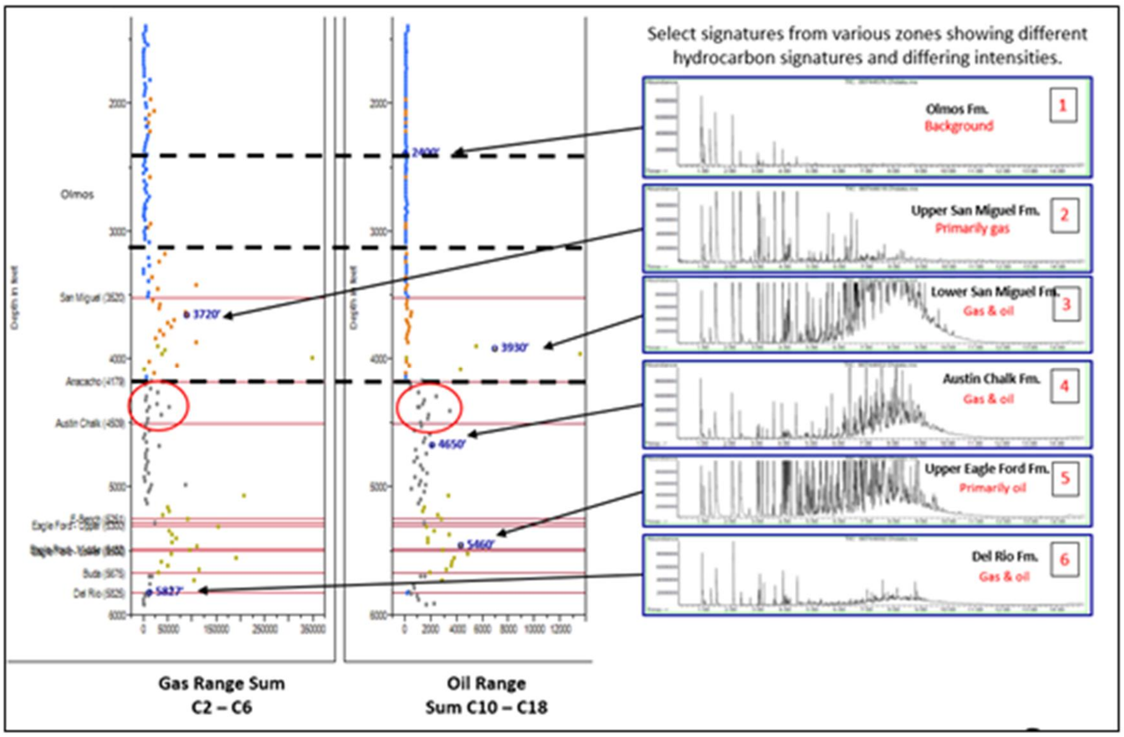

Figure 4. A hydrocarbon depth profile of the Eagle Ford well showing gas components (C_2-C_6) on the left and oil components (C_{10}-C_{18}) on the right

The Lower San Miguel shows a small amount of gas in the gas profile, but shows a very high intensity oil profile. This is corroborated by the TIC #3. It should be noted that the intensity of the oil profile for the Lower San Miguel is higher than any other formation in the well, including the Lower Eagle Ford. The maximum oil intensity in the Lower Eagle Ford is approximately 5,000 ng while the maximum oil intensity in the Lower San Miguel is approximately 15,000 ng, three times higher.

The Upper San Miguel shows a strong gas influence, with little liquid, as seen in the depth profiles and TIC #2. The orange coloration of the dots comes from the HCA in Figure 3. Note the orange dots related to the Upper San Miguel gas move into the Olmos formation. This implies there is no seal at the top of the San Miguel formation.

Note that all of the samples in the Austin Chalk formation and the Anacacho formation are colored gray indicating that the HCA statistical analyses indicated all of these samples had a similar hydrocarbon fingerprint. The depth profiles show some gas and liquid component in the hydrocarbons. The TIC #4 supports this and also shows a decrease in hydrocarbon intensity as well. Note also that there is a notable increase in intensity of both the gas and oil range components as you reach the top of the Anacacho formation. This implies that the Austin Chalk formation is most likely the source and the hydrocarbons have migrated vertically into the Anacacho and accumulated at the formation top where there is a seal.

The depth profiles also show as you move into the Eagle Ford formation that the hydrocarbon signature changes once again. There is a strong increase in both the gas and oil components and TIC #5 shows a dramatic increase in intensity as well.

Oil samples from the San Miguel, Austin Chalk, and Eagle Ford formations were plotted in a ternary plot of various C_6 compounds (i.e. hexane, cyclohexane, and benzene) as seen in Figure 5. The ternary plot serves to illuminate various differences (e.g. biodegradation, thermal maturity, water washing, etc.) between the oils from the three formations. The data shows grouping of the data into three general clusters associated with the formations which supports the previous assertions that there appears to be a seal between the Eagle Ford and the Austin Chalk and a seal between the Anacacho and the San Miguel formations.

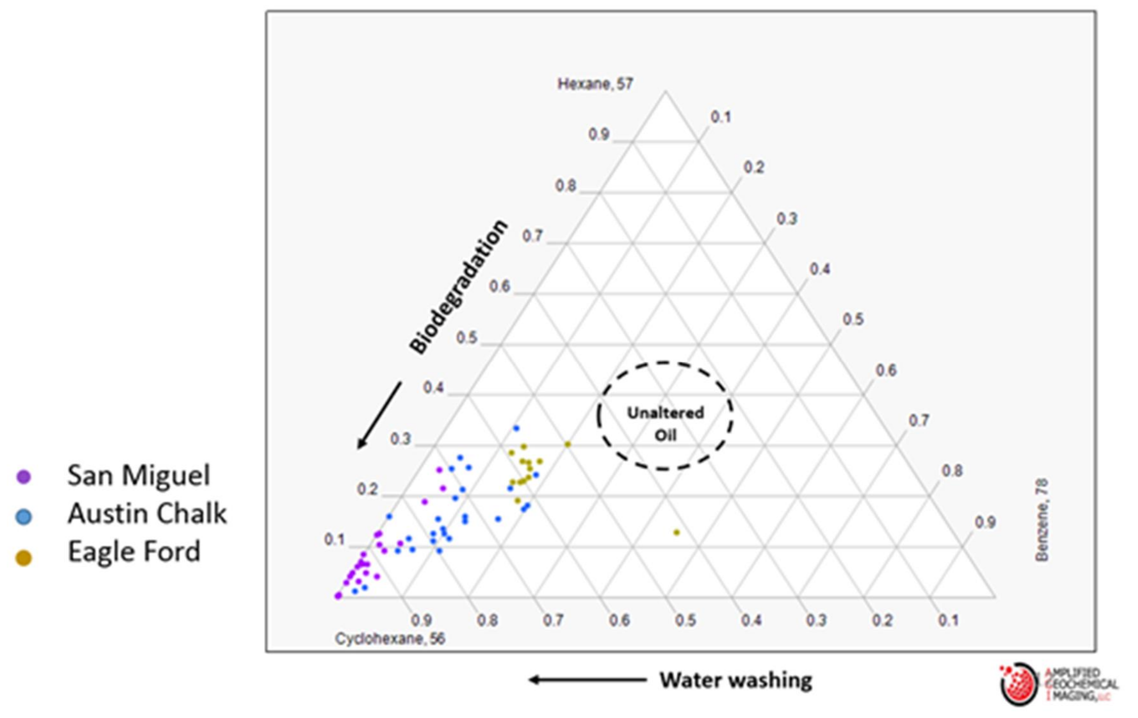

Figure 5. A ternary plot of three C6 compounds (hexane, cyclohexane, & benzene) to show chemical differences between the various oil signatures from the San Miguel, Austin Chalk, and Eagle Ford formations.

A focus on the lower portion of the Eagle Ford well (i.e. the Eagle Ford, Buda, and Del Rio formations) provides interesting insights, as seen in Figure 6. Once again the gas components (C_2-C_6) are plotted on the left and the oil components (C_{10}-C_{18}) are plotted in the middle with the sample TICs projected to the right of the depth profiles. The most notable item is associated with the TICs on the right of the figure. Note all of the TICs for Eagle Ford samples look almost exactly alike. When you combine this visual similarity with the Hierarchical Cluster Analysis results, it becomes quite evident that the oil throughout the Upper, Middle, and Lower Eagle Ford appear to be the same. Additionally, as you look at the oil depth profile you see that the highest oil intensity in the depth profile is in the Lower Eagle Ford, which implies that the Lower Eagle Ford is sourcing the entire section. Additionally, as you move down the Lower Eagle Ford you note the oil intensity decreases as you move towards the Buda formation with the lowest intensity displayed by a purple point just above the Buda formation. This is point is often called the false Buda because the mineralogy changes dramatically here and switches to a much higher clay content. The result, is an increase in ductility and reduction in pore space and hydrocarbons, as indicated by the oil depth profile.

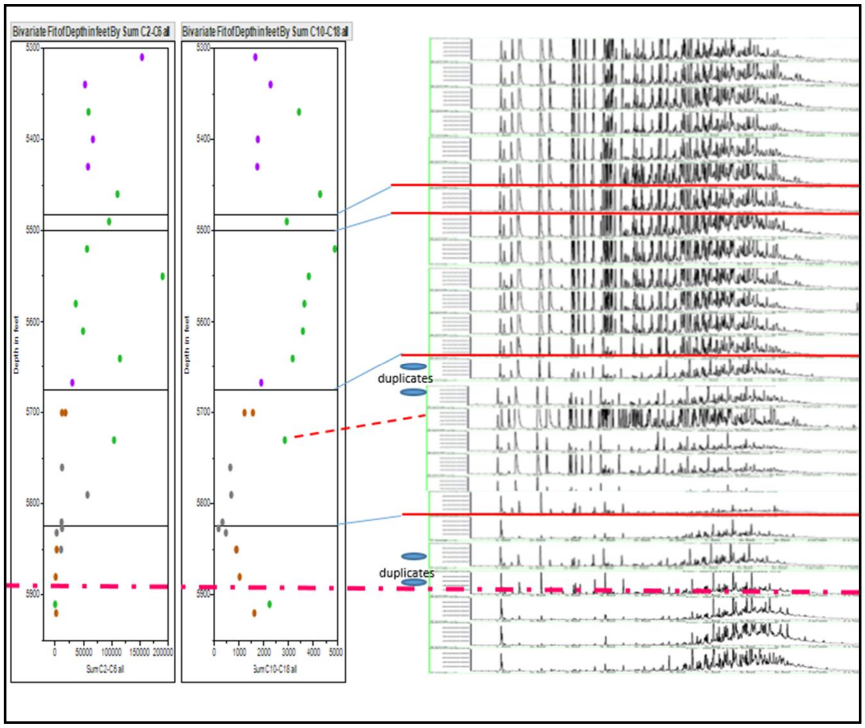

Figure 6. A hydrocarbon depth profile of the lower section of the Eagle Ford well showing gas components (C2-C6) on the left and oil components (C10-C18) on the right with Total Ion Chromatograms

The oil depth profile shows a continued decrease in liquid hydrocarbon intensity as you move through the Buda formation with the exception of one green data point, which appears to be a sweet spot in the Buda formation. The client indicated that they noted this on the resistivity logs at the time of drilling. At the juncture of the Buda and Del Rio formations the oil hydrocarbon intensity drops to its lowest level in the well, dropping almost to zero.

Given the oil depth profile, the Lower San Miguel may be the most hydrocarbon rich section in the well. However, this can almost be labeled as a by-passed pay and most clients predetermine that their preferential target zone is the Eagle Ford. Again this relates back to effective drilling verses efficient drilling.

In this case, the client chose to complete their lateral in the Buda formation at 5,730 ft because they felt there may be natural fractures that charged the Buda formation from the Eagle Ford. However, the hydrocarbon profile seen in Figure 7 does not support that conclusion. Even with a 500 ft potential drainage pattern above and below the Buda formation sweet spot, there still appears to be poor hydrocarbon intensity in this portion of the well. A proposed lateral is also shown in this Figure 7 at approximately 5,530 ft in the Lower Eagle Ford formation which shows a much higher hydrocarbon richness and increased porosity. It should be noted that the proposed lateral location is only based on areas with the best porosity and hydrocarbon richness and does not take into account other important factors such as mineralogy and brittleness.

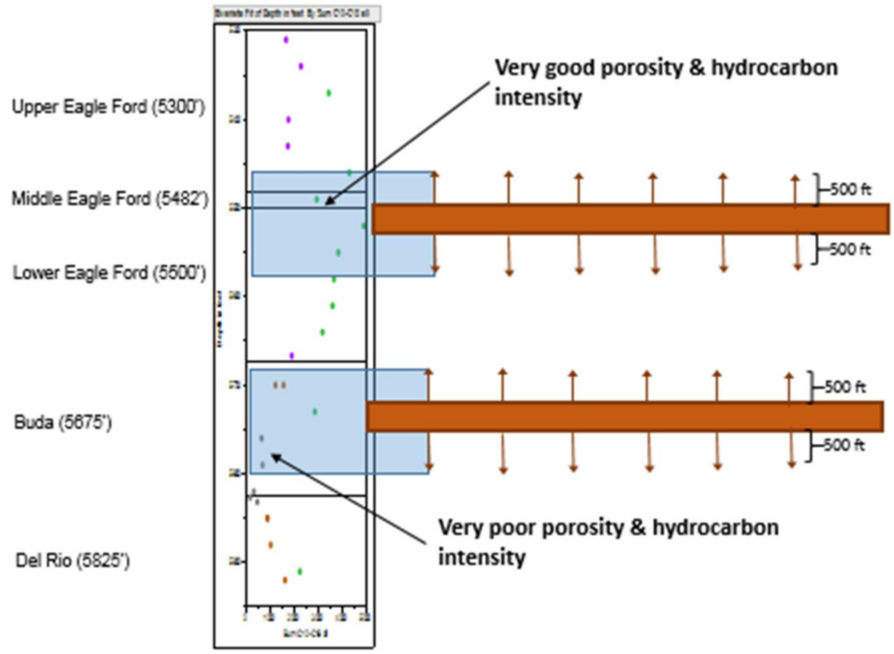

Figure 7. A hydrocarbon depth profile of the lower section of the Eagle Ford well showing the oil intensity plot. The figure also shows the actual lateral location in the Buda Fm and a proposed lateral location in the Eagle Ford Fm.

Lateral Hydrocarbon Results

For the lateral section samples were taken every 100 ft from 5,500 ft to 10,000 ft. Figure 8 shows the results of that data. The vertical well profile is shown on the right portion of the figure. The gas and oil intensity depth profiles are shown to the right of the vertical profile with the oil profile on top.

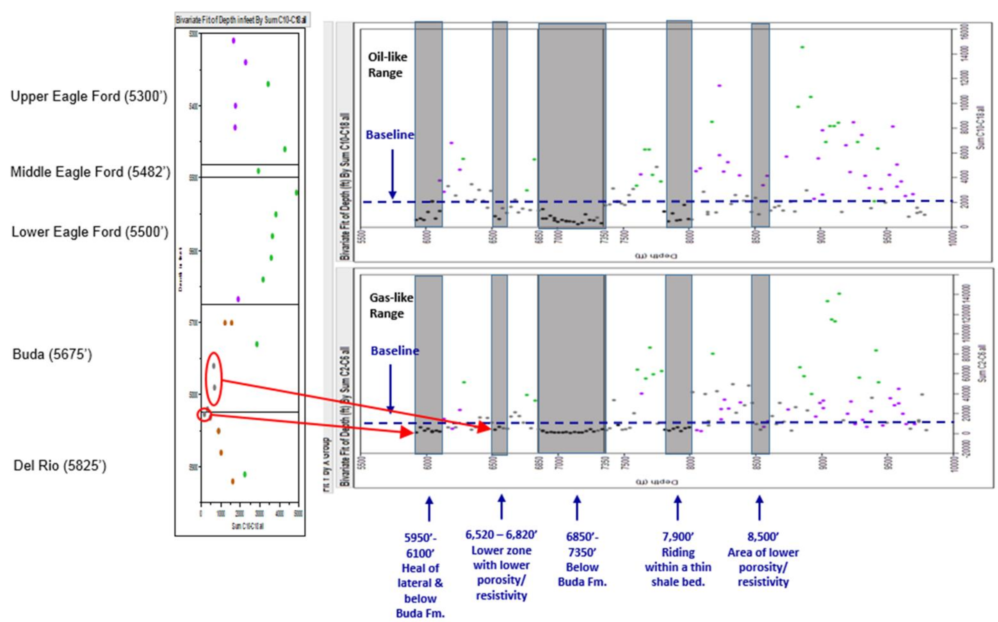

Figure 8. The vertical hydrocarbon profile is shown on the left. The gas and oil hydrocarbon profiles are shown stacked on the right with the oil profile on top.

The gas hydrocarbon profile, in particular, accentuates the extremely low hydrocarbon intensity from approximately 6,000 ft ï 7,500 ft, as indicated by the black dots right at the baseline, as indicated by the blue dashed line. When the client was asked if they could explain the extremely low hydrocarbon intensity they stated that the heel of the lateral at 6,000 ft went below the Buda formation crossing just into the top of the Del Rio formation. As seen in the vertical well profile to the right, and addressed earlier, the transition zone from the Buda formation to the Del Rio formation showed the lowest hydrocarbon richness in the entire well, thus explaining the low hydrocarbon intensities from approximately 6,000 ft ï 7,500 ft.

The target for the lateral well was the sweet spot at 5,730 ft as identified by the vertical hydrocarbon data. The client reached this zone at 8,250 ft. and at 8,800 ft ï 9,230 ft. Note this is correlates with the areas on the lateral depth profiles with the highest gas and oil intensities. At 9,500 ft the intensities for both the gas and oil profiles decrease. This decrease was due to the fact the client had entered into the bottom of the Lower Eagle Ford formation which was known, as previously discussed, as the false Buda with lower porosity and lower hydrocarbon richness. Thus the lateral hydrocarbon profile not only accurately mapped the hydrocarbon intensity or richness, but also matched with the vertical well profile to indicate the location of the geosteering.

While fracturing was not performed on this well, Figure 9 shows a proposed fracture plan for the well with fracture spacing set at 500 ft. This would entail eight fracture stages for this 10,000 ft lateral at a cost of $1.6 mm (this assumes $200,000 per fracture stage). However, the lateral hydrocarbon data shows a complete lack of hydrocarbon presence in the first 1,500 ft of the lateral well. Therefore, the lateral data showed similar production efficacy might have been obtained by using 5 fracture stages instead of 8 by using Downhole Geochemical Logging data, resulting in a potential cost savings of $600,000.

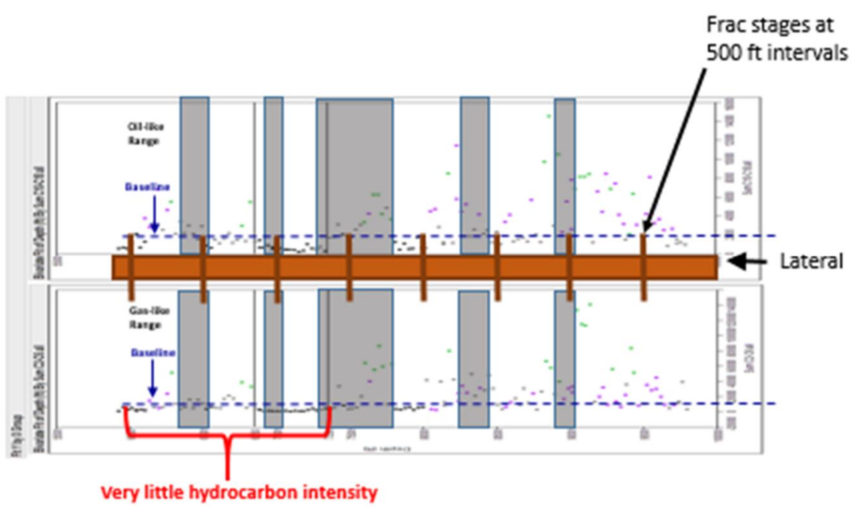

Figure 9. A proposed fracture program in the lateral well showing 8 potential fracture stages with oil hydrocarbon intensity data above the lateral and gas data below.

Conclusion

The case study shows how Downhole Geochemical Logging was used to create a granular hydrocarbon profile throughout the well. This enabled identification of optimum selection for placement of the horizontal well. Additionally, cutting analysis from the lateral well enabled identification of lateral sweet spots containing higher porosity and hydrocarbon intensity as opposed to areas with limited porosity and lower hydrocarbon content. The data was also able to aid the client in determining the optimum number of fracture stages required for the lateral well resulting in a potential savings of approximately $600,000 while maintaining similar production.

In summary the lateral well the data helped to:

- Improve production by focusing lateral well locations in hydrocarbon & porosity rich zones
- Reduce completion costs by optimizing the number of fracing stages
- Predict Sweet Spots of hydrocarbon concentration, and natural fracturing.
- Identify when drilling efforts are in or out of the target formation

In this vertical well the data helped to:

- Clearly distinguish between various hydrocarbon phases (i.e. gas, condensate, or oil)
- Differentiate between multiple gas or multiple oil signatures
- Infer separate sources in the San Miguel, Austin Chalk, and Lower Eagle Ford Fms
- Identify by-passed pay
- Infer compartmentalization and seals at the top of the Anacacho Fm and the top of the Eagle Ford Fm
- Infer there was no seal between the San Miguel Fm and the Olmos Fm
- Infer there was no seal throughout the Eagle Ford, Buda, and Del Rio Fms