Reservoir Evaluation and DRV Analysis in Unconventional Reservoirs across Multiple Basins of North America

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Summary

A unique geochemical data-driven method is introduced that reveals both static reservoir characteristics such as reservoir quality and oil saturation, as well as dynamic reservoir performance such as hydrocarbon contribution by zone, drainage height, and well communication throughout the lifecycle of unconventional reservoir development. This workflow involves static reservoir characterization using a group of Reservoir Characterization Indices (RCI) derived from geochemical information of oil extracted from rock samples to provide key reservoir properties such as permeability and oil saturation. Quantitative oil production allocation is then performed by building a regression model to allocate the produced oil back to its contributing zones and provide vertical drainage frac heights. In this paper, case studies across multiple basins are presented and include the following conclusions: 1) reservoir characterization using geochemistry data derived from oil extracted from core/cuttings is a fast and effective way in providing essential information for reservoir evaluation and target selection, when combined with time-lapse production allocation, we gain an understanding of how targeting and reservoir properties effect zonal contribution through the life of the well; 2) production allocation based on high-resolution GCXGC data provides quantitative zonal contribution information and identifies how much shared contribution stacked wells have, aiding in proper targeting and stacking; 3) geochemistry-based reservoir monitoring is a powerful and practical tool that can aide in optimal full field development, it provides quantitative zonal contribution and vertical frac height data through time to aid in data-driven decision with finer granularity and less operational risk than other tools; 4) wells in different landing zones have different vertical drainage patterns, by incorporating landing zone into fitted curves of production allocation, we can determine when a target is not draining the intended zone; 5) the impact of frac hits to parent wells can be quantified using time-lapse production allocation, frac hit impacts can cause significant change and last for several weeks to months.

Theory / Method / Workflow

Oil fingerprinting technology has been studied and applied as a monitoring tool in conventional reservoirs for decades. In recent years, the industry has started to explore potential applications of geochemical fingerprinting technology to monitor production in unconventional reservoirs (Rasdi et al. 2012, Jweda et al. 2017, Liu et al. 2017, Liu et al. 2019, Wright et al. 2019). Traditionally a 1D GC (Gas Chromatogram) was used which separates the compounds in oil based on boiling point and delivers a chromatogram with peak heights; it can identify ~100 compounds. This methodology uses a comprehensive multi-dimensional GC (or GCXGC) which separates the compounds based on two chemical properties: boiling point and aromaticity. The resultant chromatogram is 3D and able to identify over 2000 compounds including alkanes, cycloalkanes, alkyl-benzenes, aromatic and saturated biomarkers which can function as natural tracers in oil samples; each compound appears as a blob on the 3D chromatogram.

In these case studies, both rock (cuttings and core) and oil samples are collected onsite and shipped to the lab for analysis. Oils are extracted from the rock samples to establish a baseline; a baseline is a well, used to create a standard against which produced oil samples will be compared to. This process involves Physical Extraction (a patented technology of RevoChem) and multidimensional gas chromatography (GCXGC). Oil samples are also analyzed using GCXGC.

Once GCXGC data are collected from rock and oil samples, the data is processed using an in-house software package including preprocessing (alignment of chromatograms from both rock and oil samples, 3D blob detection), data screening to identify unique geochemical patterns, and production allocation calculation (Liu et al. 2020).

Geochemical information extracted from rock samples are used to calculate Reservoir Characterization Indices (RCI) including the Oil-in-Place Index (OIPI) and the Reservoir Quality Index (RQI). The OIPI represents oil saturation while RQI indicates reservoir permeability.
Production monitoring can then be conducted by building a regression model and back-allocating oil samples to their contributing formations quantitatively. Production allocation (PA) results are also visualized using Fitted Drainage Frac Curve (FDFC) to provide drainage frac heights.

Results and Discussion

Case Study 1

The first case study in the Eagle Ford play (Figure 1(a)) was built to answer three main questions for the operator: 1) Can we use quantitative drainage information to make data driven decisions on well placement (e.g.; Can Units C and E be co-developed or is individual development needed?); 2) What is the vertical frac height and how does the vertical drainage change through time; and 3) Is the lower targeted well receiving contribution from the upper formation? The GCXGC high resolution tool, along with proprietary laboratory methods and data analytics procedures, allow for a comprehensive and insightful answer for these questions. In the following figures we will utilize pseudo names for compounds, such as “Blob#”, for confidentiality purposes.

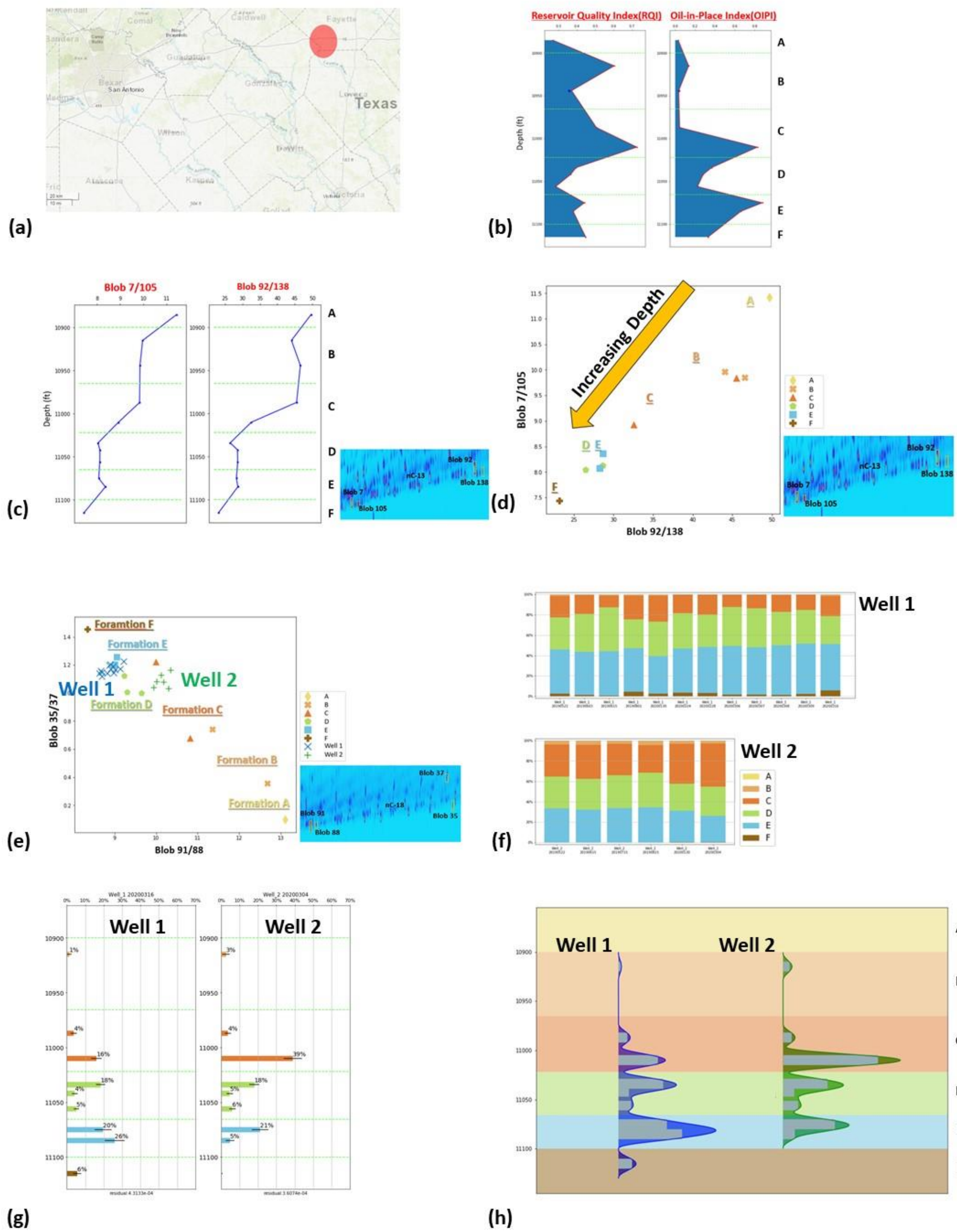


Figure 1: Workflow of Case 1. (a) Location of Case 1 in Eagle Ford basin. (b) Reservoir Quality Index (RQI) and Oil-in-Place-Index (OIPI). (c) Vertical geochemical profiles showing geochemical variation among different formations using diagnostic

geochemical ratio Blob 7/105 and Blob 92/138. Lower-right: GCXGC chromatogram showing the illustrated blobs. (d) Cross plot of two diagnostic geochemical ratios demonstrating a depth trend of geochemical variation from shallow to deep zones. Lower-right: GCXGC chromatogram showing the illustrated blobs. (e) Geochemical ratio cross plot of produced oil samples (marker: line symbols) overlaying cuttings samples (marker: solid symbols). Lower-right: GCXGC chromatogram showing the illustrated blobs. (f) Stack plots of geochemical fingerprint-based production allocation results of Well 1 and Well 2. (g) Bar charts illustrating production allocation results of the latest oil samples (collected on 03/16/2020 in Well 1 and 03/04/2020 in Well 2) against depths represented by the cutting samples of the baseline. The black bar on each production allocation result represents standard deviation covering 90% confidence range (i.e. P90). (h) Fitted curves of production allocation results on a cross sectional plot using the latest oil samples from each well (collected on 03/16/2020 in Well 1 and 03/04/2020 in Well 2).

Figure 1(b) shows the RCI vertical profiles which include Reservoir Quality Index (RQI) and Oil-in-Place Index (OIPI) generated from the 11 core samples in Case 1. Geochemically calculated RQI and OIPI have been independently verified by core-based and other petrophysical data, they provide critical information in a fast and effective way. When determining ideal landing zones, many factors are considered such as permeability, porosity, hydrocarbon saturation, zone thickness, fracability, etc. OIPI and RQI provide information on several of these key parameters and can aide in target selection. A significant amount of hydrocarbons are indicated in the Lower Formation C and in E from the OIPI. In terms of RQI, upper Formation B and lower C have the highest permeability; Formations E and F have moderate permeability. Lower Formation C and Formation E appear to be the best landing zones considering both permeability and oil saturation reflected in the RCIs.

Figures1(c) and 1(d) demonstrate there exists good geochemical vertical variation among all the formations. These vertical profiles of geochemical distinction then serve as the baseline for production allocation. Just as the core samples, oil samples were analyzed using GCXGC after being collected from the horizontal wells. By overlaying oil samples on the core sample geochemical ratio cross-plots (Figure 1(e)), we can determine contributions from each formation in one oil sample using our regression model. Oil samples from each well naturally cluster together on the cross plot of diagnostic geochemical ratios (Figure 1(e)). In this case, oils from both wells overlap within Formations C, D, and E of rock samples, indicating drainage is constrained to these three zones and Well 1 is draining deeper. Many geochemical ratio cross plots are used to constrain produced oil to the zone it is draining from, Figure 1(e) is only two of hundreds of geochemical ratios that effectively distinguish oils from different wells.

Figures 1(f) and 1(g) show quantitative, time-lapse production allocation in stacked and detailed bar charts. Well 1 targeted lower than Well 2, drilling in the upper half of Unit D. On average, contributions are: Unit C ~20%, Unit D ~30-40% and Unit E ~40%; Units B and F have marginal contribution. In Well 1, from 05/22/2019 to ~06/15/2019, Unit D contribution is increasing as Unit C input is decreasing. By 08/01/2019, the production trend reversed with an increase in Unit C contribution and decrease in Unit D contribution. Unit C contribution is smallest on 03/06/2020, at only ~12%, but steadily increased to ~20% again by 03/16/2020. Unit F increases contribution in the last sample to ~5%.

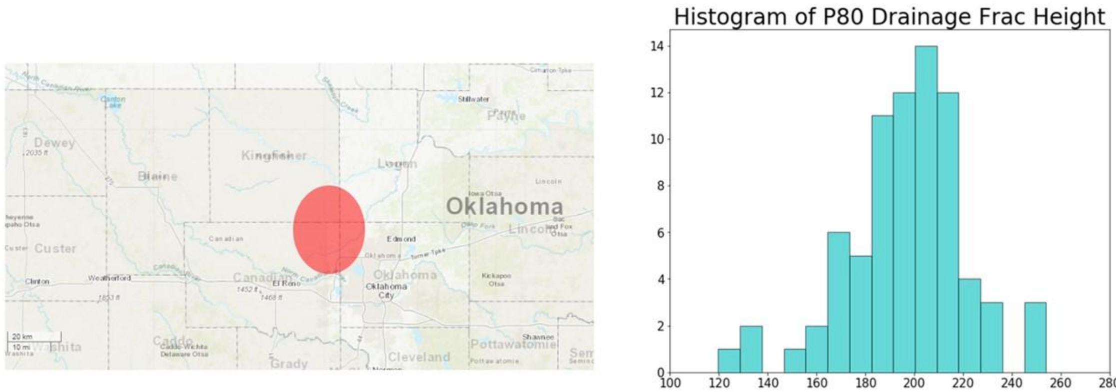
Well 2 landed in the lower half of Formation C. Correspondingly, it has stronger input from Formations B and C, and less input from Formations D and E. On average, contributions are: Formation C ~30-40%, Formation D ~30-35%, Formation E ~30% and Formation B contributes the least at ~3-4%. Though not as strong as seen in Well 1, Well 2 also observes a reversal after 08/15/2019 Unit D and E contribution had been steadily increasing but by 01/30/2020 it is reduced and replaced by a noticeable increase in Unit C contribution; Unit C contribution continues to increase by the last sample date, 03/04/2020.

Time-lapse Production Allocation has proven to be especially useful for operators looking to understand how offset operations impact and influence already producing wells. It is also very useful in combination with the OIPI and RQI, not only to identify main contributing intervals but also to understand how different zones contribute through time. For example, highest RQI (permeability) zones are often the biggest early time contributors, but as the high permeability zones lessen in reservoir pressure, tighter rock increases in contribution. However, this case is a bit different. Well 1 landed in a tighter interval and time-lapse production allocation shows out-of-zone contribution increases from 5/22/2019 to 3/16/2020 (i.e., the higher OIPI and RQI Unit E steadily increases in contribution through time). Well 2, landed in the higher OIPI and RQI of Unit C, shows a different time-lapse story. Earlier production time (5/22/2019 – 8/15/2019) shows more even contribution throughout units C, D and E, but later time (1/30/2020 – 3/4/2020) shows an increase in in-zone drainage; this is logical as Unit C, the unit the well is drilled in, has the best OIPI and RQI seen in the baseline.

The original questions asked by the operator are clearly answered by this unique geochemistry-based process: 1) Yes, quantitative drainage information allows for data driven decisions on well placement, it shows Formations C and E can be co-developed; 2) Well 1 and Well 2 have contributing P80 drainage frac heights of ~75' (P80 drainage frac height represents 80% of the consistently producing interval), drainage frac height is typically less than stimulated frac height; and 3) Yes, lower targeted Well 1 receives contribution from Formation C, on average ~20%. Time-lapse Production Allocation also provides useful information on how drainage changes through time.

Case Study 2

Understanding key drivers of Drainage Rock Volume (DRV) is critical in optimizing full field development. All operators use significant resources to understand reservoir properties and find the perfect completion for their wells. While many tools can provide essential information, a key question all operators are left with is: What zones are actually contributing? The geochemically calculated DRV is able to answer this question at no risk to operations. The P80 drainage frac height represents 80% of the producing rock interval, providing a more fine-tuned answer than stimulated frac height and also allowing for a time-lapse, dynamic analysis. In the case of Anadarko Basin, 80 oil samples were collected from 76 wells and the P80 drainage frac height was calculated based on the production allocation (Figure 2(a)). The P80 drainage frac height for all wells in the area ranges from 120' to 250', averaging about 200' (Figure 2(b)).



(a) (b)

Figure 2: (a) The locations of 76 wells (red area) in Anadarko Basin. (b) The histogram of P80 Drainage Frac Height for all 76 wells in Anadarko Basin

By integrating P80 Drainage Frac Heights with rock properties, landing zone, well completion design, production results, and production allocation one can effectively find the most efficient drilling targets and completion design for optimal, full-field development.

Case Study 3

In Case Study 3, the operator had the goal of answering three questions: 1) Are we targeting stacked pay so there is minimal drainage overlap in stacked wells; 2) Does Well 2 effectively drain Formation D; and 3) How long, and at what magnitude, do infill operations impact the parent wells?

When PA is combined with spacing and TVD targeting information, we can clearly see a vertical drainage pattern for each horizontal well. In this case from Midland Basin (Figures 3(a) and 3(b)), Well 1 and Well 2 demonstrate a smaller P80 drainage frac height at ~135' and ~150' respectively; drainage frac heights look specifically at the contributing frac height through time, not the instantaneous frac height created by the well completion. P80 drainage frac heights are noticeably larger in Well 3 and Well 4, at ~415' and ~270' respectively; the significantly larger P80 drainage frac heights are possibly due to overlapping SRV. Both Well 1 and 2 saw strong drainage from Unit C and limited downward drainage. Well 3 showed less upward and stronger downward drainage frac growth; though the drainage frac height is more balanced than Well 1 and 2. Well 4 showed symmetrical drainage, both upward and downward.

The drainage frac height, as revealed by the production allocation result, is the result of many factors. Reservoir properties such as matrix porosity, permeability, oil saturation, etc. typically play the most significant role in driving the drainage frac height. Completion job size and style is seen as a secondary control. Other dynamic factors such as adjacent operational events of nearby wells, shut-ins, frac jobs, and well to well pressure communication, can also often be observed playing a role in the abundance each zone is contributing. To understand what zones are contributing to production, industry standard has been to measure or calculate stimulated frac height. However, not all stimulated rock will contribute to production as production contribution is dependent on the reservoir properties of each zone. Understanding the frac height that is draining is crucial to effective and efficient field development, having major implications on well spacing and stacking. Time-lapse production allocation can answer what zones are draining and how drainage changes through time. Therefore, it is also able to answer how long and how severe infill operations effect parent wells, and all at no risk to the wellbore.

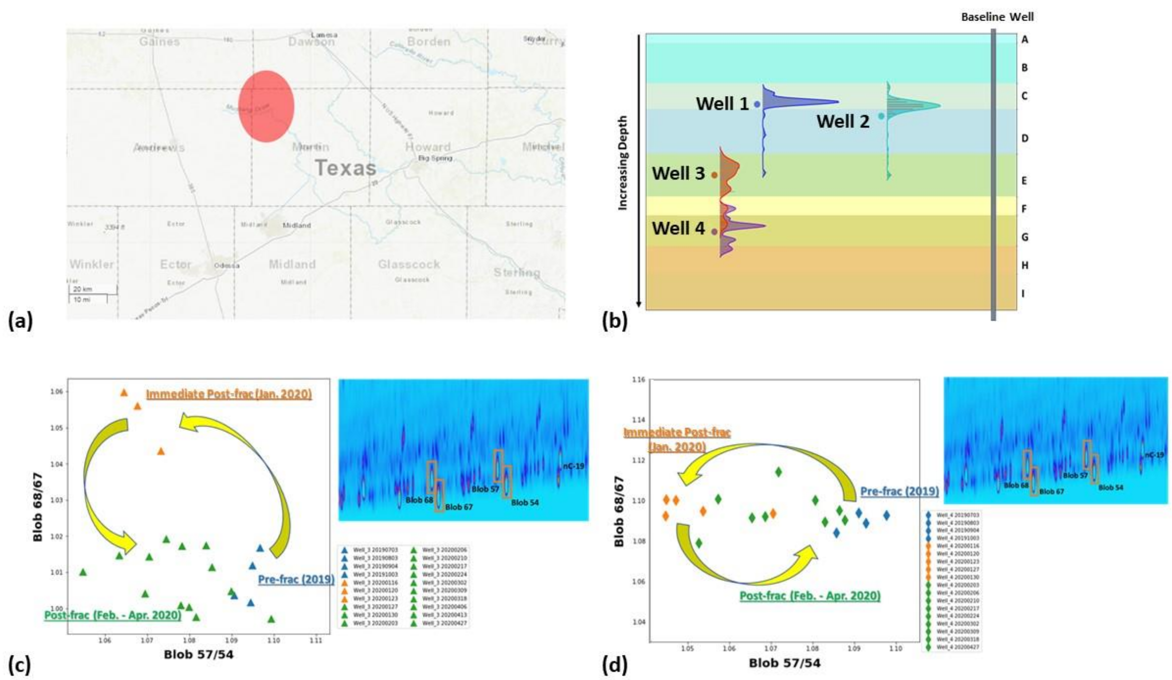


Figure 3: (a) The location of Case 3 in Midland basin. (b) Fitted curves of production allocation results plotted on the gun barrel section of the latest oil samples from each well (collected on 04/13/2020 in Well 1, and 04/27/2020 in Well 2,3, and 4). (c) Comparison of geochemical fingerprints change in the produced oil samples before infill drilling and after of Well 3. Upper-right: GCXGC chromatogram showing the illustrated blobs. (d) Comparison of geochemical fingerprints change in the produced oil samples before infill drilling and after of Well 4. Upper-right: GCXGC chromatogram showing the illustrated blobs.

Both Well 3 and Well 4 were parent wells that were drilled more than one year before the adjacent infill wells. Produced oil samples from Well 3 and 4 were collected monthly for 4 months before the infill drilling to establish the production allocation of the parent wells before having any impacts from infill operations. The samples predating the infill fracs are represented in blue markers in Figure 3(c) of Well 3 and Figure 3(d) of Well 4. Immediately after the infill drilling and completion jobs, the parent wells were brought back online, and oil samples were collected within the first few weeks as presented by the orange markers in Figure 3(c) of Well 3 and Figure 3(d) of Well 4. Noticeable changes are observed in geochemical signatures in the produced oil samples pre-frac and immediate post-frac in January 2020. However, the parent wells continued to be monitored and we found that approximately four months after infill well completions the geochemical signatures moved back, becoming similar to the pre-infill frac produced oil; illustrated by the green markers in Figures 3(c) and 3(d). When correlating the parent wells (Well 3 and 4) produced oil time lapse data with the production allocation results we were able to quantify the impact of the frac hit on the production allocation. The parent wells had about 10% change in production allocation immediately after the frac hit that steadily returned to similar pre-infill frac production allocation in approximately four months.

The three questions asked by the operator are comprehensively answered by this integrated methodology: 1) Well 3 and 4 share 20-25% of the producing intervals, it was recommended to adjust targeting and perhaps completion size or style for these targets; 2) Well 2 does not effectively drain Formation D, Well 1 and Well 2 have very similar Production Allocation even though targeted differently; and 3) Infill operations noticeably affected the parent wells, showing about 10% change in production allocation immediately after the frac hit, production allocation returned to pre-infill frac drainage in approximately four months.

Conclusions

High-resolution geochemical data can help provide important answers regarding reservoir quality, well targeting, well stacking, production contribution by zone through time, draining frac height, and impact of offset operations to producing wells. Thus, we can make the following conclusions:

- Reservoir Characterization Indices (RCI) derived from geochemical data of core or cuttings samples are a fast and effective way in providing essential information for reservoir evaluation and target selection. When combined with time-lapse production allocation, we gain an understanding of how targeting and reservoir properties effect zonal contribution through the life of the well.
- Production Allocation based on high-resolution GCXGC data provides quantitative zonal contribution information and identifies how much shared contribution stacked wells have, aiding in proper targeting and stacking.
- Geochemistry-based reservoir monitoring is a powerful and practical tool that can aide in optimal full field development; it provides quantitative zonal contribution and vertical frac height data through time to aid in data-driven decision with finer granularity and less operational risk than other tools.
- Wells in different landing zones have different vertical drainage patterns. By incorporating landing zone into fitted curves of production allocation, we can easily determine when a target is not draining the intended zone.
- The impact of frac hits to parent wells can be quantified using time-lapse production allocation; frac hit impacts can cause significant change and last for several weeks to months.

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