Integrating Static and Dynamic Data to Derive Analytical Conclusions on Reservoir Performance of a Heavy Oil Carbonate Field in the Partitioned Zone, Saudi Arabia and Kuwait*

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Abstract

There are several variables that can affect fluid flow from any reservoir and some that are specific to carbonate reservoirs. This discussion seeks to shed light on less recognized variables that affect fluid flow such as well deliverability, historical operations, completions, facilities constraints and for carbonate reservoirs, the reactivity of the rock with injected fluids. All of these contribute to what is actually produced at the wellhead and many times it is hard to determine which has the most impact without a significant data set.

Discussion

This field study will show how over 50 years of production data can be integrated with a multitude of studies in order to generate analytical insights into the character of the reservoir and a detailed historical understanding of production (impact of operations and facilities). The following summarizes the detailed analyses that were completed as part of this study.

1) Production zone analysis – well deliverability

In the several decades that the reservoir has been on production, a majority of the completions have been comingled between several field production zones. These zones, named “A”, “B”, “C”, “D” and “E” are determined and picked by field personnel and do not represent any geological change within the reservoir. However, because these zones have been used historically for production and pressure data recording they are being used in this study to determine if deliverability can be discerned by zone and area from historical data. Because no production logs were ever taken in the reservoir, an analytical technique to determine zonal flow contribution was used. The method utilized a normalized deliverability equation based on total fluid produced per foot of completed interval. Examples of the results are plotted in Figure 1 and shows normalized deliverability by zone and its associated statistics. The results show that while the first look at the data indicate a difference in deliverability the calculation is perhaps being impacted by a small dataset and should be used with caution (data frequency is plotted in Figure 1).

2) Field wide trends

This study analyzed various data through time to determine if trends existed in an areal and/or vertical extent or if the historical data issues that are present in the field's history have affected fluid movement. In Figure 2, some examples are shown that demonstrate the variables that were mapped and studied.

3) Historical operations induced water movement

This study is one that addresses the water movement in the reservoir. Significant changes in produced water salinity have historically been attributed to poor casing cementing practices early in the field's life that lead to dump flooding of reservoir by an overlaying aquifer. In order to confirm this report and to evaluate if dump flooding is still occurring, all aspects of water movement were analyzed. This included a material balance study, water cut maps through time, salinity maps through time, analysis of a newly collected water chemistry dataset and a detailed review of the original oil water contact (OOWC) and the current oil water contact (OWC). Figure 3 shows the result of the combination of the full suite water chemistry analysis as displayed using colors that indicate sodium to calcium rich. The results indicate that the dump flood is indeed still occurring and will need to be remedied prior to steam flooding in the eastern part of the field.

4) Pressure mapping

This study integrated pressures from wireline formation tests and shut in bottom hole pressures through time in order to understand how pressure was changing horizontally and vertically. Cross sections and areal maps were generated from the analysis that can be utilized for comparison with the history matched simulation model. Results of this study show where the lowest predicted pressures are likely to occur in the field and will guide decisions on initial areas of steam flood because lower pressures are more attractive to initial steam flood developments due to facilities costs and operational complexities. Figure 4 shows a summary of the workflow utilized to generate the pressure maps.

5) Oil sampling and analysis

Due to the nature of the proposed EOR project (steam flooding) extensive efforts were made to collect a comprehensive wellhead sampling of the reservoir oil due to large uncertainties in the variability of the viscosity and API. These measurements were used to constrain the simulation model and ensure appropriate temperature dependant viscosity curves were used for forecasting. Additionally, these collected samples will serve as the baseline for oil API and viscosity prior to steam flooding and to help guide decisions on the strategy in which to develop the full field steam flood. Figure 5 shows the results of the API and viscosity value at 60°F and 95°F respectively.

6) Carbonate reactivity - scale and corrosion

Historical operational evidence exists in the field for minor scale and corrosion issues due to the sour nature of the crude and the reactivity of the rock with fluids used for flushing the wells. Additionally evidence of an increase in scale and corrosion have been seen at the steam flood pilots due to higher temperatures (anhydrite scale has an inverse relationship to temperature for precipitation and corrosion is accelerated). Understanding of the impact that scale and corrosion has had on the overall deliverability of not only the wellbore but the in situ reservoir deliverability, due to complex chemical reaction away from the wellbore due to hot and cold waters mixing, is important to understand and capture as part of the impact to fluid flow. These operational observations coupled with knowledge of the chemistry of the system are imperative to understand how fluid flow dynamics can change within a carbonate reservoir.

Summary

Results from the above studies were utilized to help aid in the simulation modeling and ensure an independent assessment of fluid flow was done prior to the detailed forecasting work. Efforts are currently underway to align the simulation results with the analytically derived maps and insights delivered by this study.

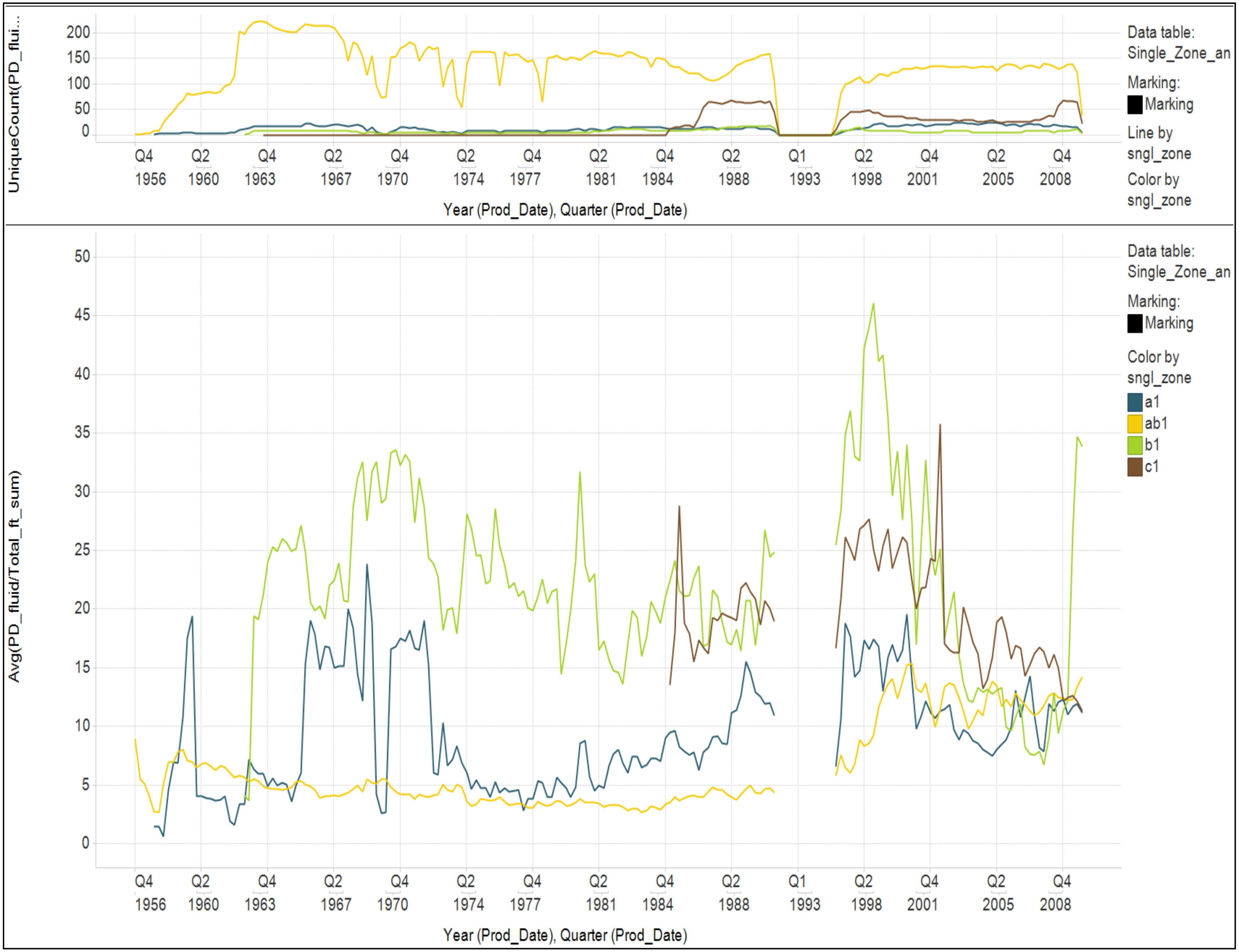

Figure 1. Normalized deliverability of single zone completions.

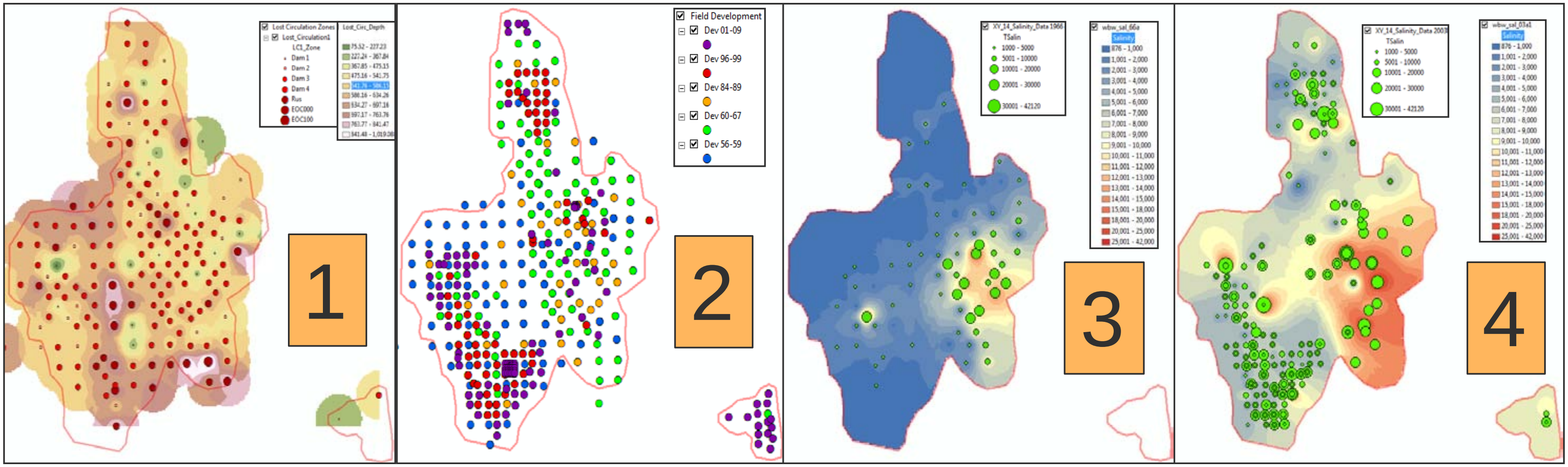

Figure 2. Examples of maps generated as part of the field wide trend study: 1) Lost circulation Zone Mapping, 2) Field Development through time, 3) NaCl 1996, 4) NaCl 2003.

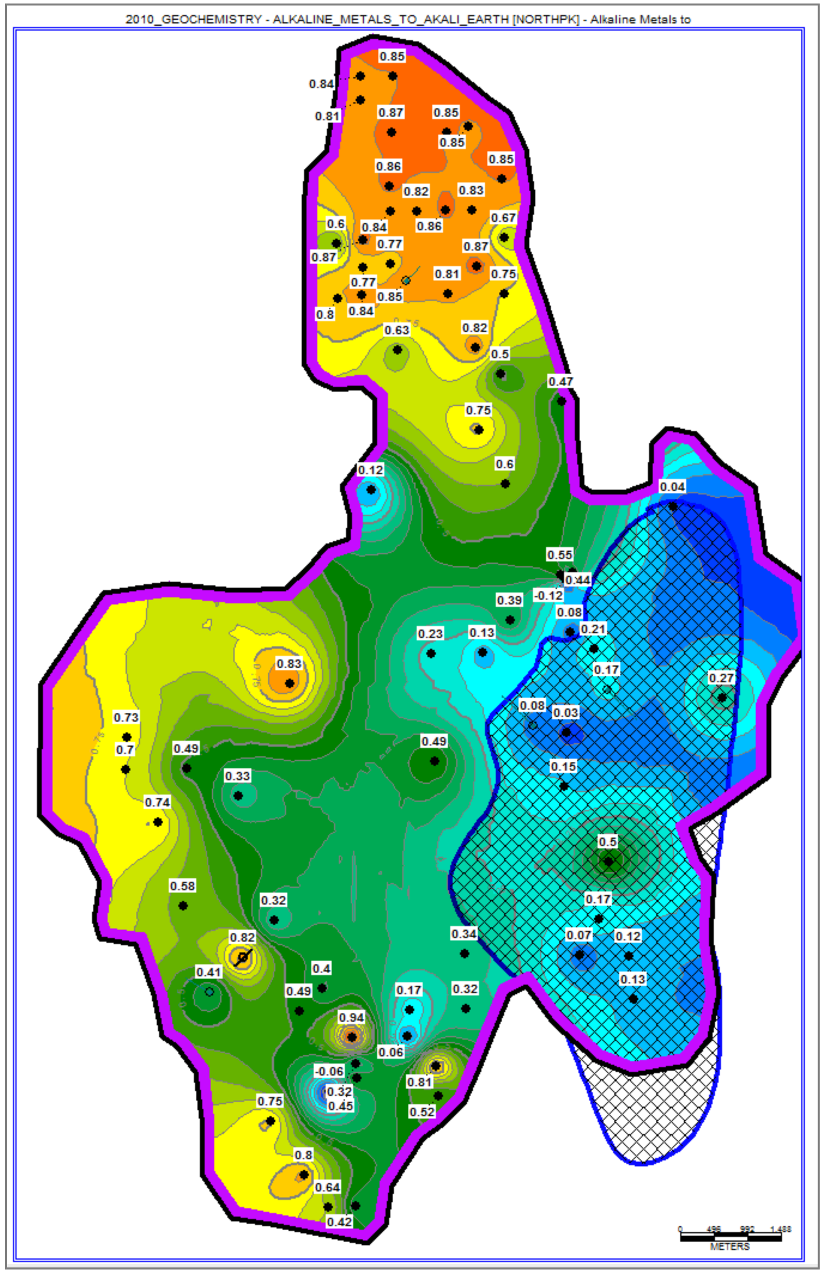

Figure 3. Map of alkali metal to alkaline earth elements expressed in Meq percentage using the equation $(Ca^{+2}+Mg^{2+})-(Na^{+}+K^{+})$. Sodium to Calcium rich waters appear as blue to red, respectively. Cross-hachured pattern indicates 1965 recognized Dammam dump flood area. Sample values posted next to well symbol.

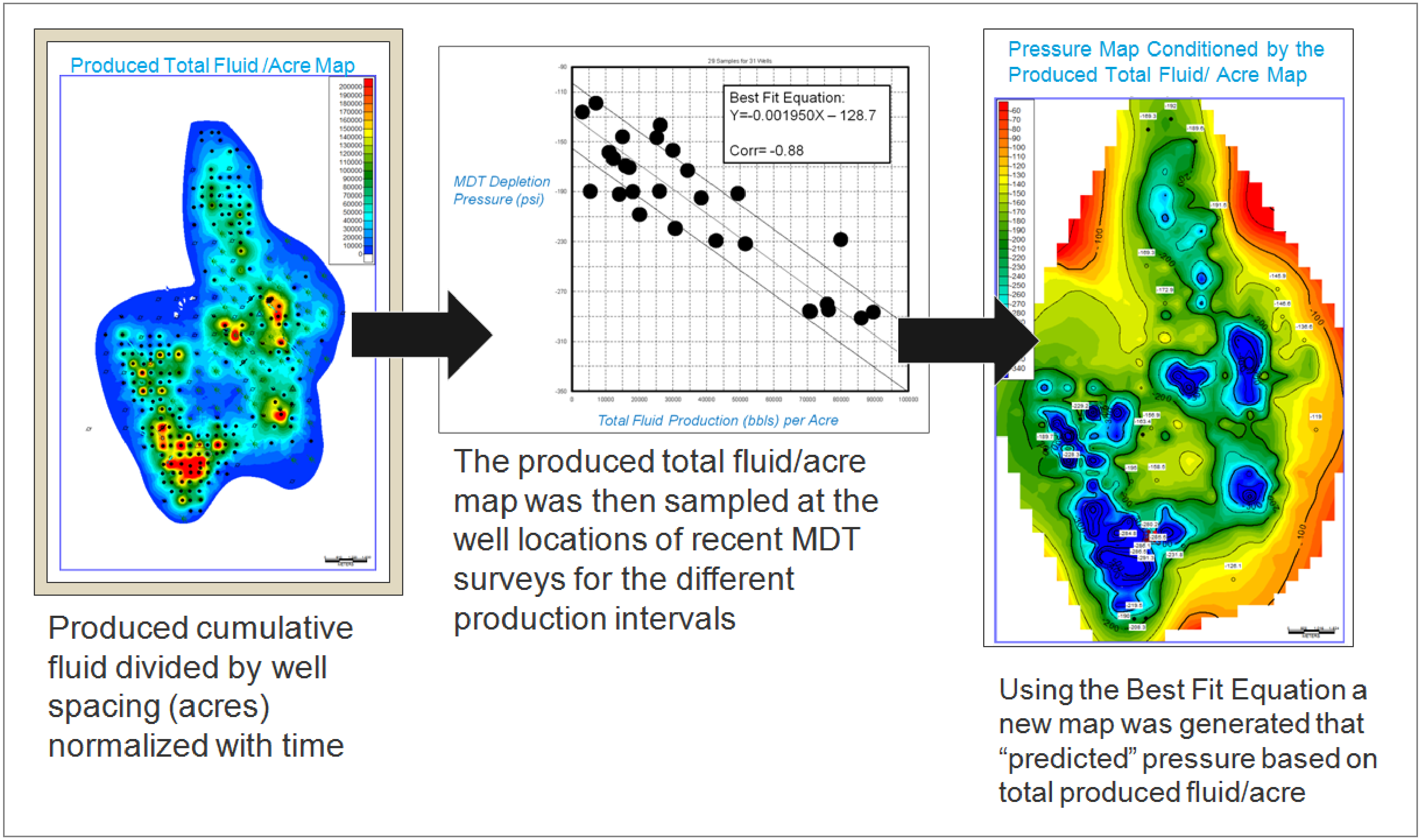

Figure 4. Final MDT pressure depletion map of the interval 130 ft. above the 1EOC610_ANHY marker using recently (2007-09) acquired data. This map has been conditioned using the cumulative total fluid per acre grid. The depletion values use a pressure gradient of 0.433 psi/ft corrected to a datum of 250 ft. above sea level.

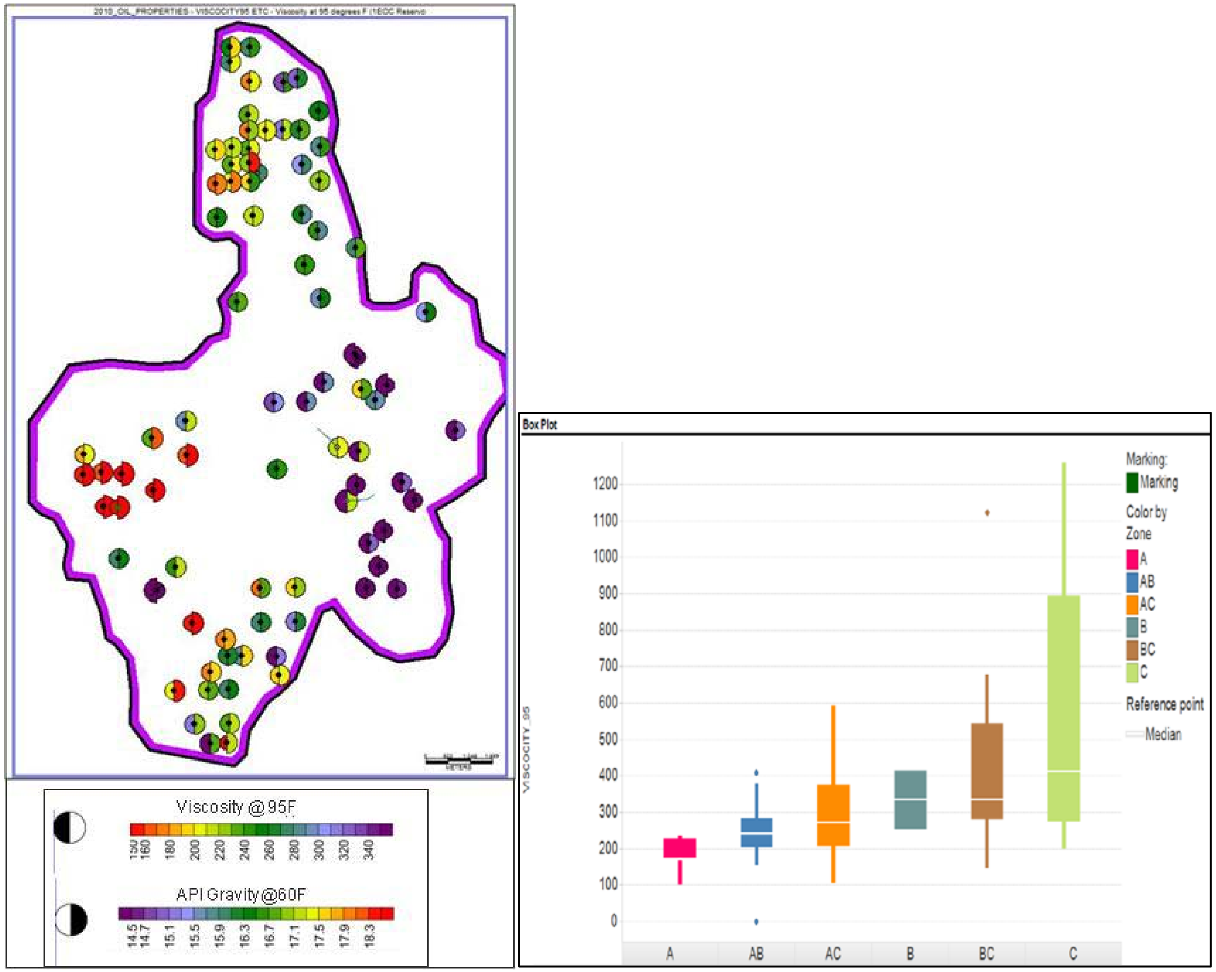

Figure 5. Map showing oil gravity and viscosity variation across the reservoir and box plot showing variability with depth.