Resolving Carbonate Complexity with Respect to Fluid Movements in Brown Fields*

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Abstract

Carbonate rocks, unlike sandstones, have complex pore systems. These pore systems may have bi- or tri-modal pore size distributions. Pore sizes may range from a less than an inch to feet. The pore geometry of carbonate rocks is very heterogeneous and variable. The texture and structure of carbonate rocks are further rendered more complex by the digenesis caused by chemical dissolution, precipitation, dolomitization, leaching, and fracturing. Due to these reasons, petrophysical models comparable in terms of simplicity to the Archie equation have not been developed for carbonate rocks. In some petro physical analyses, the Archie equation is used to calculate water saturation in carbonate rocks. This approach could lead to significant errors.

This paper discusses the uncertainties and complexities involved in evaluation of carbonate reservoir. This paper describes the alternative approach, which based on calculation of water saturation of carbonate rocks on data from Nuclear Magnetic Resonance (NMR) logs. The saturations calculated from the NMR logs are lithology independent. Brown fields usually are under water injection, which makes even more difficult to predict the moveable fluid. The secondary and tertiary porosity features such as vugs, dissolution channels and fractures complicate relative permeability relationships as well as contribute to problems with respect to the movable fluid. It is difficult to differentiate between zones with higher connate water saturation and those with injection water breakthrough or with extensive WBM invasion. Because of these conditions water production in new drain holes is sometimes higher than anticipated. To address the problem of optimum drain hole placement a successful methodology was adopted in which Down Hole Fluid Analysis (DFA) and permeability profiling have been added to the conventional Wire line Formation Tester (WFT) pressure survey. This paper presents a case study that shows how completions done by acquiring the NMR logs and by mapping the fluid and permeability profiles throughout the target interval has resulted in far higher oil production than nearby wells placed solely on the basis of saturation estimation from open hole logs.

Reference

Griffiths, R., A. Carnegie, A. Gyllensten, M.T. Ribeiro, A. Prasodjo, and Y. Sallam, 2006, Evaluation of Low Resisivity Pay in Carbonates – A Breakthrough: Transactions of the SPWLA 47th Annual Logging Symposium, Veracruz, Mexico, Paper E.

Selected Website

Directorate General of Hydrocarbons: Ministry of Petroleum & Natural Gas, Government of India. Web accessed 1 August 2012.
http://www.dghindia.org/

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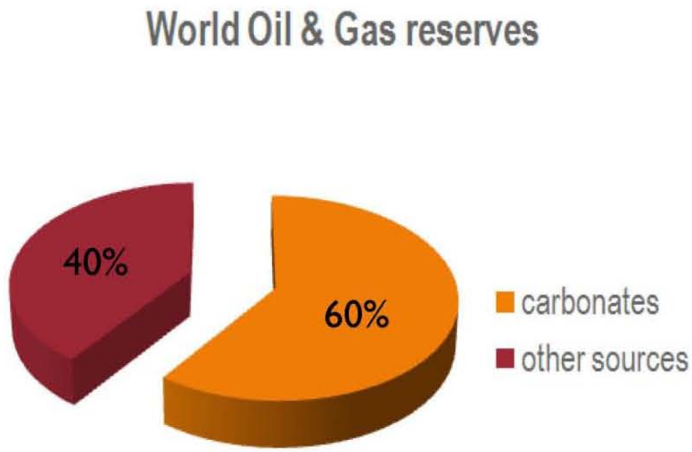
Agenda

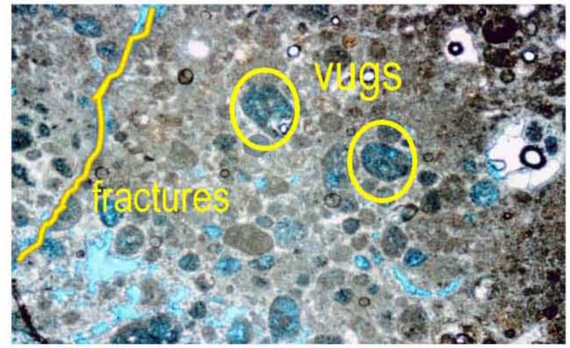
- Introduction
- Problem Statement
- Analysis and Impact of Uncertainties in Carbonates
- Proposed Solution
- Case Study
- Summary & Conclusion

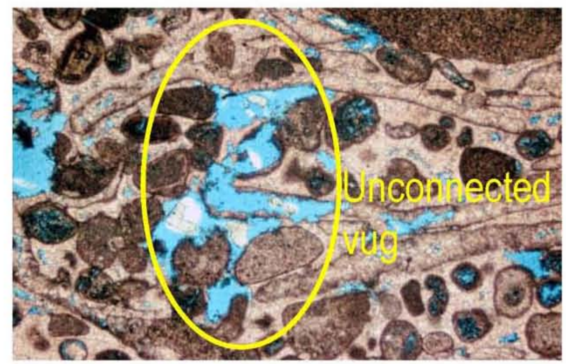
Introduction

- ✓ What makes **Carbonates** distinct ?



Source: Oilfield reviews, summer 2010

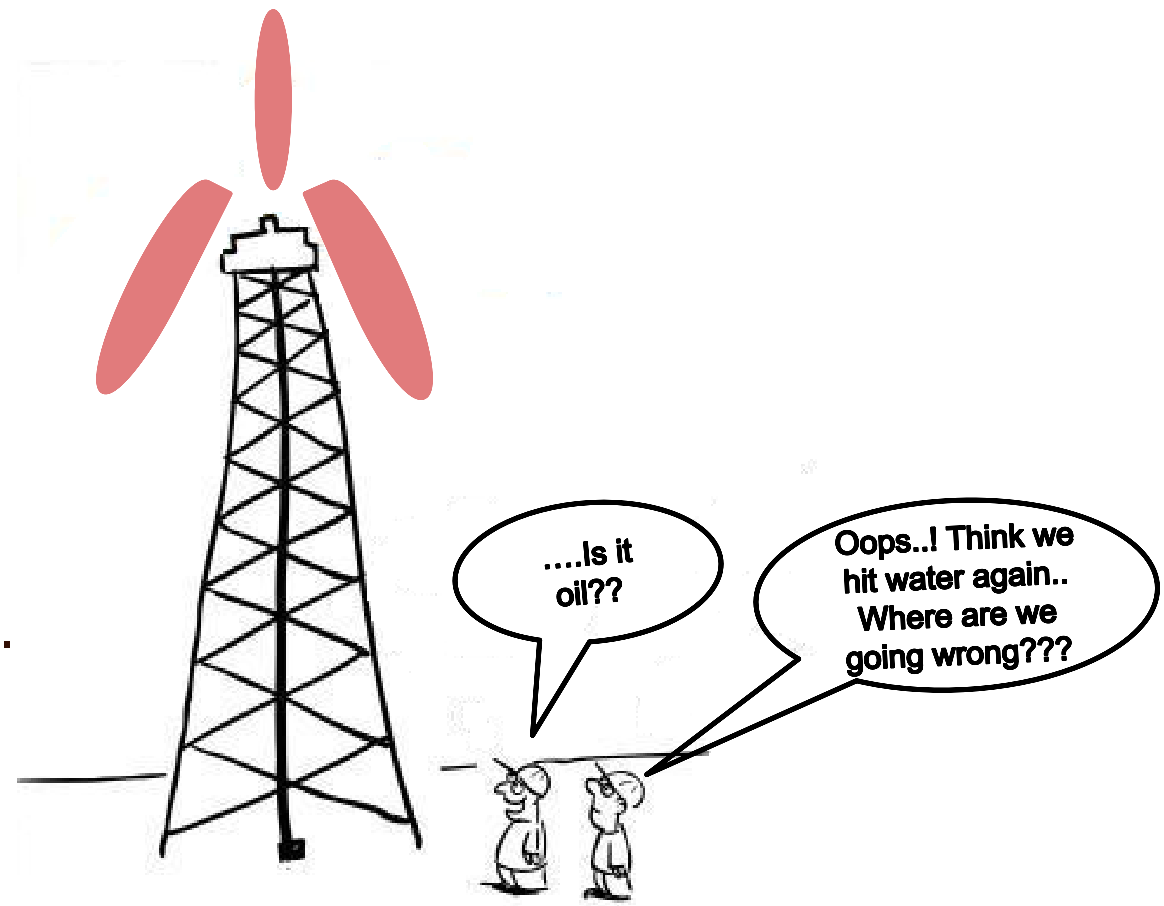




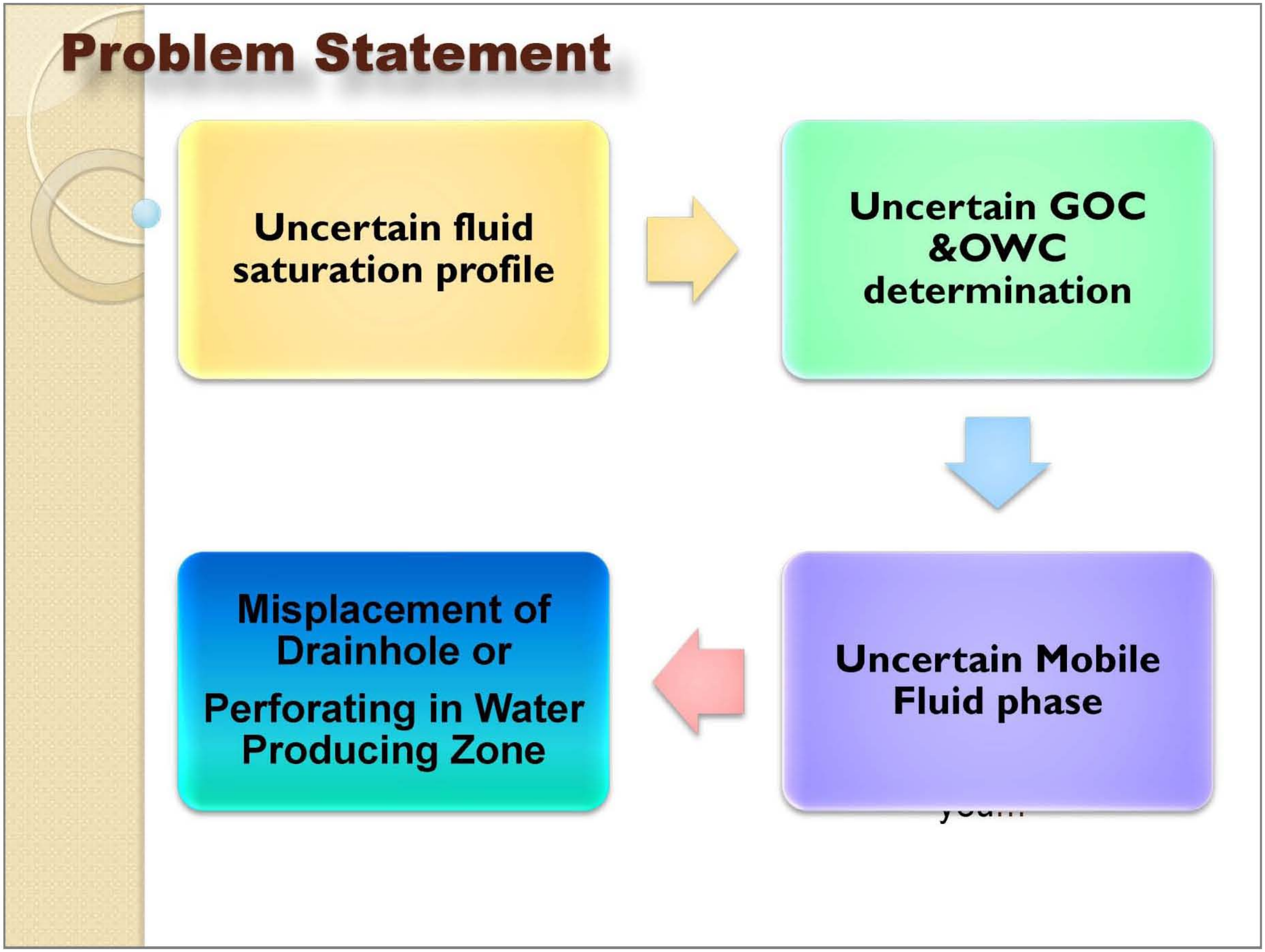
Presenter's Notes: It is estimated that nearly 60% of the world's oil as well as vast quantities of natural gas reside in carbonate reservoirs. Carbonate systems typically tend to be complex due to a highly varied pore size distribution. Pore geometries within carbonates exhibit a larger degree of modalities, size ranges and anisotropies when compared to clastics. Diagenetic processes such as chemical dissolution, precipitation, dolomitization, etc, result in structural and textural variations, which make it difficult to fully characterize the properties of such reservoirs in terms of porosities, fluid saturations and flow characteristics.

Problem Statement

What if …



this happens to you…



Presenter's Notes: Due to these inherent complexities, enhancing brown field production thru well placement can become a hit-or-miss game despite extensive petrophysical evaluations. Traditional interpretation approaches for determining porosity, permeability and saturation that work well for clastics may yield inaccurate results in carbonates. The implication of these inaccuracies is that there is always a doubt concerning fluid saturation profiles, which are required for determining contacts and mobile fluid phases. These unresolved doubts can result in the misplacement of a drainhole or perforating an interval with water as the dominant movable phase.

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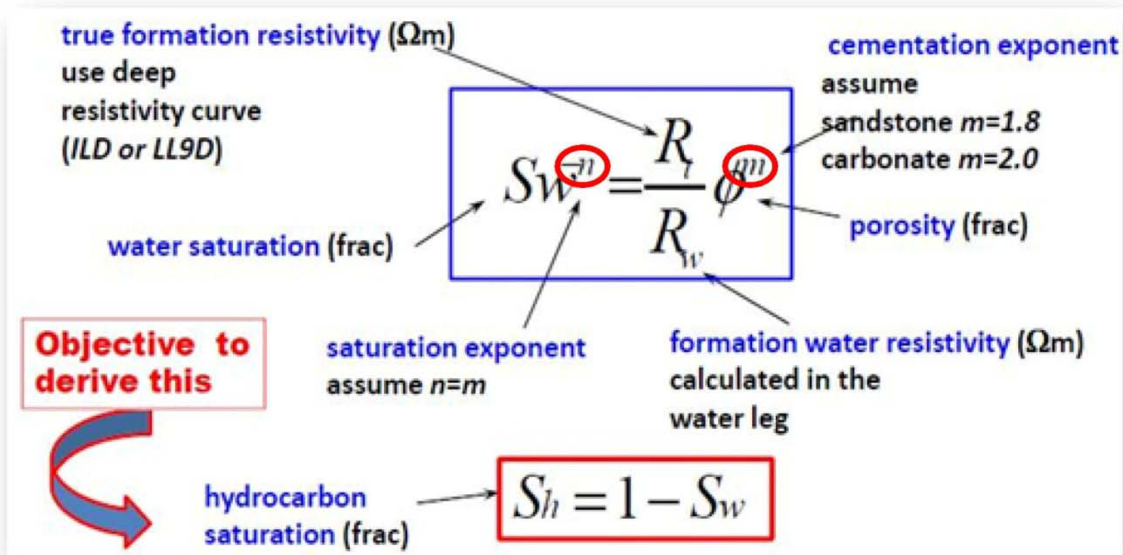
Uncertainty Analysis

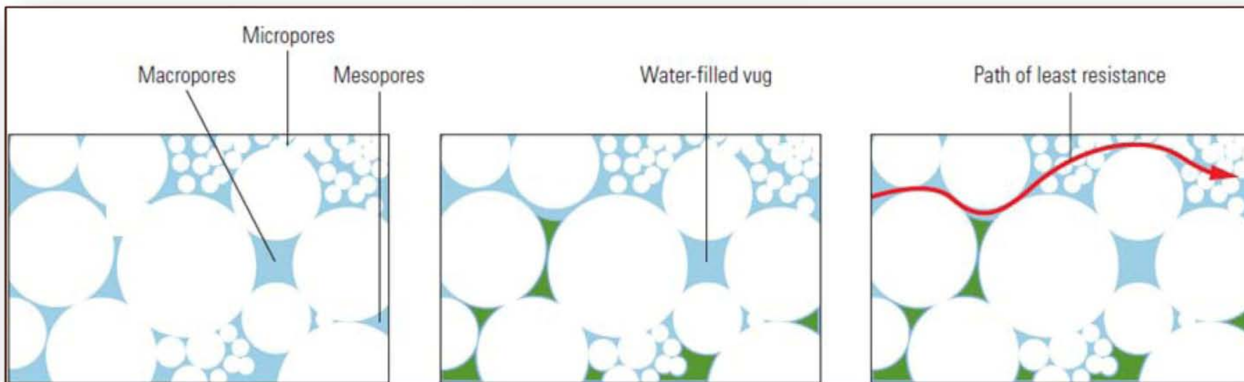
- *Archie's Equation:-* *Widely Used correlation linking formation resistivity, water resistivity & porosity with Water saturation.*



Presenter's Notes: Let us visit the source of these uncertainties and their potential impact. In addition, to do this, we shall start with our old friend Gus Archie. The Archie's equation is the most common method used for determination of saturations based on petrophysical parameters such as porosity, formation resistivity and water resistivity. Now, although most saturation calculation methods are based on variations of the classical equation, it is generally accepted that there are problems when it is applied to carbonate systems. Where do these problems come from? Let us start with the exponents m (cementation exponent) and n (saturation exponent). Certain assumptions are made for these exponents based on empirical relations in order to simplify the equation (as seen here). But in reality, due to the complex nature of carbonates determination of these variables becomes difficult, as they tend to change rapidly throughout the reservoir.

R_t and R_w Computation

$$R_t = \frac{a}{\phi^m}\frac{R_w}{S_w^n}$$



Source: Griffiths R, et.al: “Evaluation of Low Resistivity Pay in Carbonates-A Breakthrough”, Oilfield Review, Summer 2010

Presenter’s Notes: Rt: is usually derived through resistivity log measurements, involving current based sensors. Rt measurements can be difficult to measure as currents tend to follow the path of least resistance; this may work in uni-modal pore size systems. In the case of bi- or tri-modal distributions and mixed fluid distributions, the path of least resistance may yield lower resistivities than the actual value. This is sometimes referred to as low resistivity pay and can be overlooked leading to bypassed hydrocarbons.

Rw: is estimated using downhole salinity or directly measured from produced formation water and assumes a relatively simple and uniform fluid distribution within the matrix. Filtrate invasion and/or injected water incursion (as is common in brown fields) can lead to a more complex fluid distribution, which deviates, from the original model.

Porosity(Φ) Computation

$$\Phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$$

Uncertainty in Lithology Identification (ρ_{ma})

Limestone
- Measured bulk density = 2.539 g/cm^3

Porosity is 10%

Dolomite
- Measured bulk density = 2.539 g/cm^3

Porosity is 17%

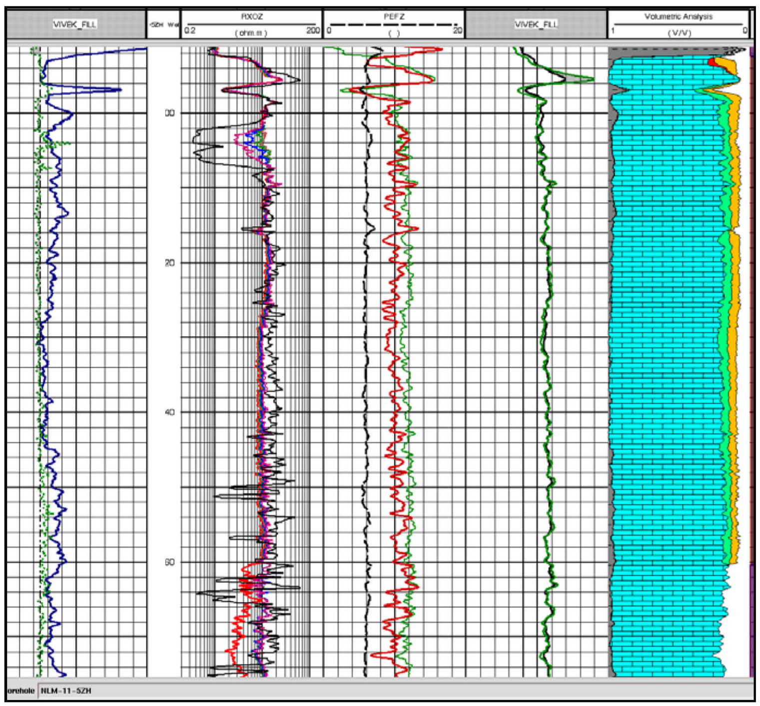
Error = 70%

Presenter's Notes: Phi: Porosity computations from bulk density tools react to both fluid and matrix properties and thus require knowledge of lithology to help establish matrix density. As can be seen here that an incorrect assumption for the lithology can lead to significant errors in the porosity calculation. Usually, this is not considered a major factor in brown fields as the lithology is more or less known throughout the field but this highlights the effect of an incorrect assumption on the porosity determination.

Impact of Uncertainty

$$S_w = \sqrt[n]{\frac{a}{\phi^m}\frac{R_w}{R_t}}$$

Cumulative uncertainties can lead to erroneously calculated saturations

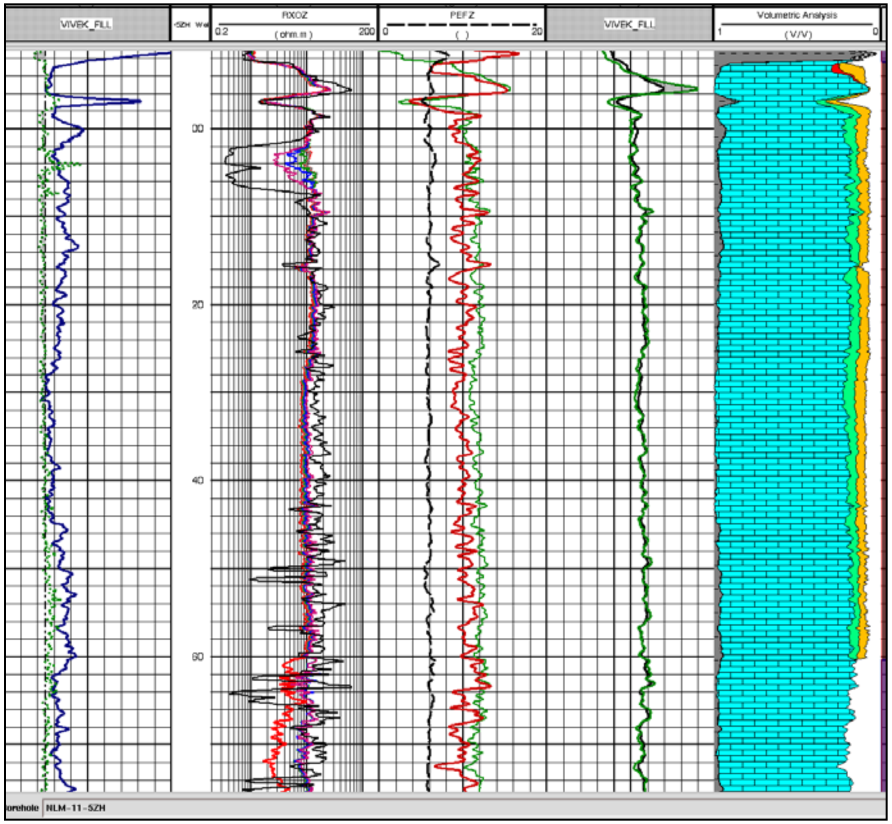


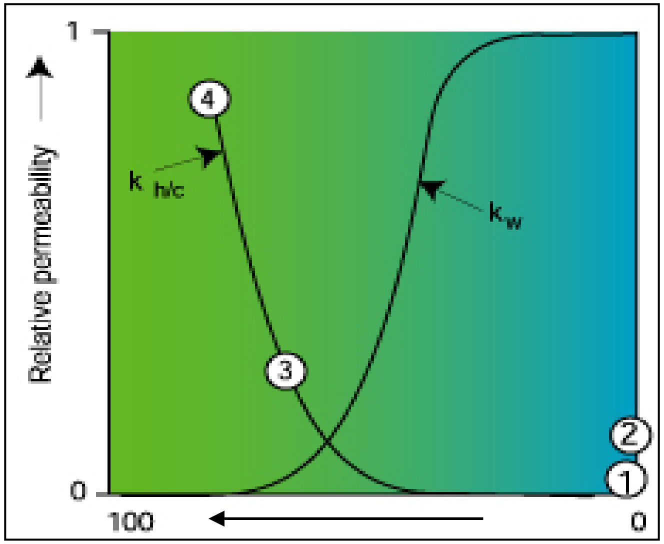
Presenter's Notes: As discussed in the previous slides, all the uncertainties combined can give rise to an erroneous saturation. The resultant error in fluid saturations will affect where we fall on the relative permeability curve and what fluid phase can be expected to move. This will ultimately affect the determination of fluid contacts and based on the error introduced; this can make the difference in a drainhole producing oil vs. a well watering out after being put on production. Thus, we come back to our initial question: Where should I place my drainhole or perforate?

Impact of Uncertainty

$$S_w = \sqrt[n]{\frac{a}{\phi^m} \frac{R_w}{R_t}}$$

Cumulative uncertainties can lead to erroneously calculated saturations



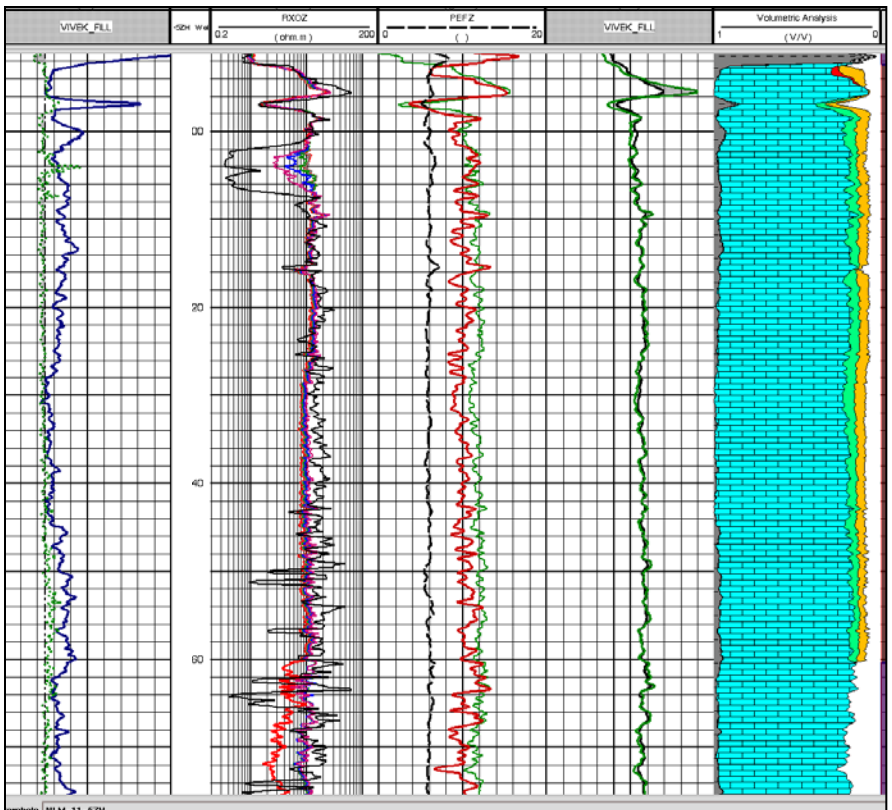


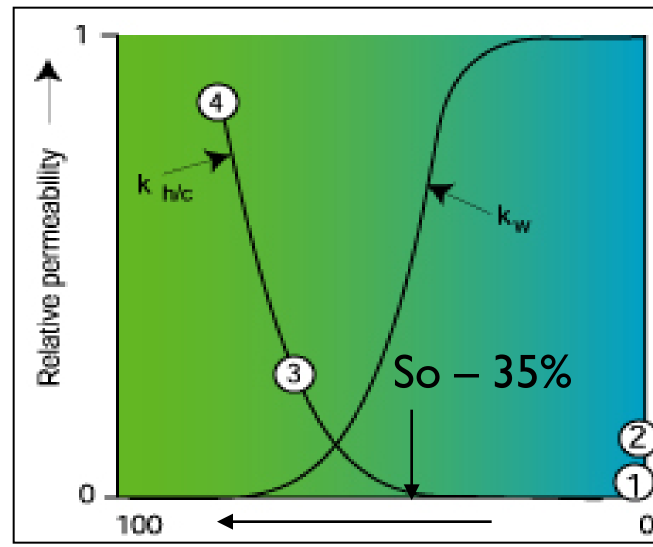
Hc Saturation

Impact of Uncertainty

$$S_w = \sqrt[n]{\frac{a}{\phi^m}\frac{R_w}{R_t}}$$

Cumulative uncertainties can lead to erroneously calculated saturations





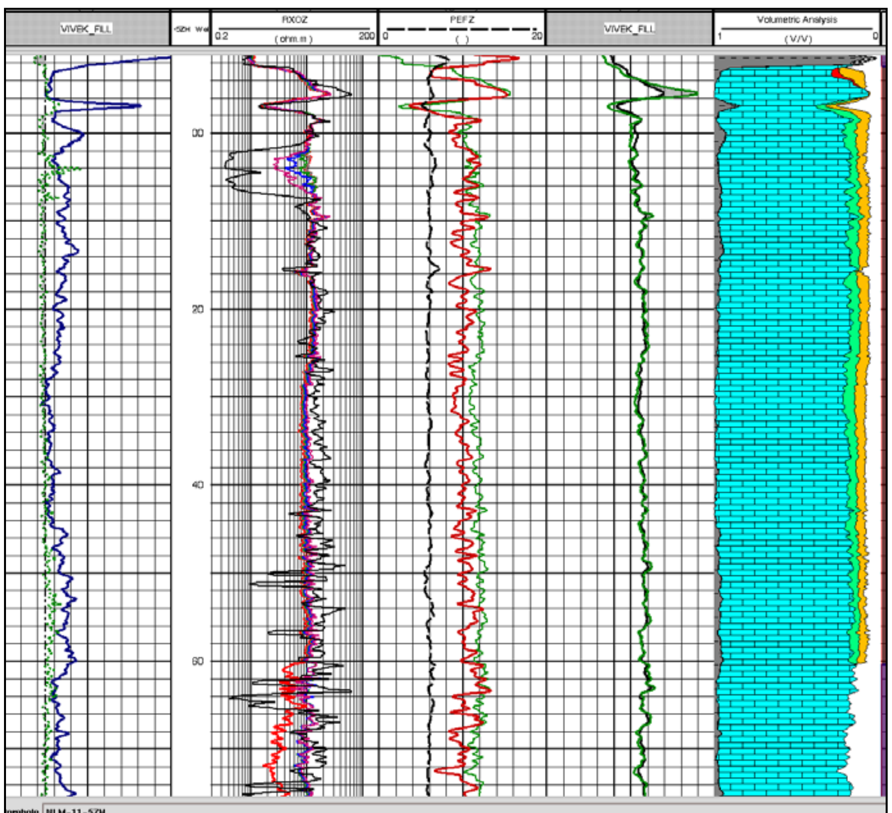
Hc Saturation

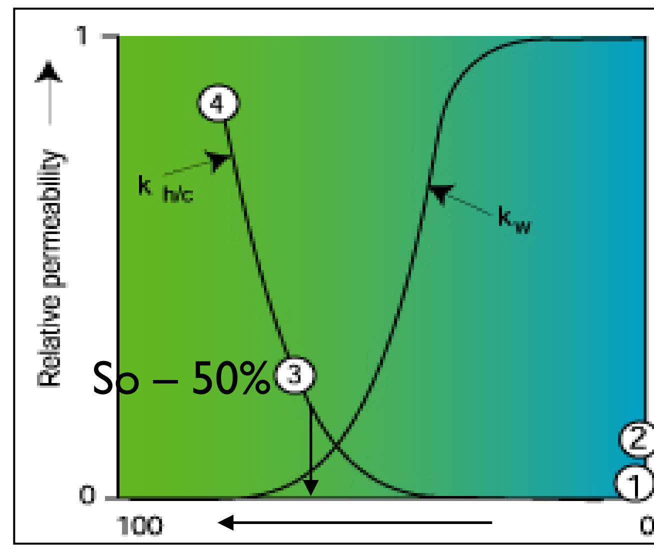
Oil will not flow

Impact of Uncertainty

$$S_w = \sqrt[n]{\frac{a}{\phi^m}\frac{R_w}{R_t}}$$

Cumulative uncertainties can lead to erroneously calculated saturations





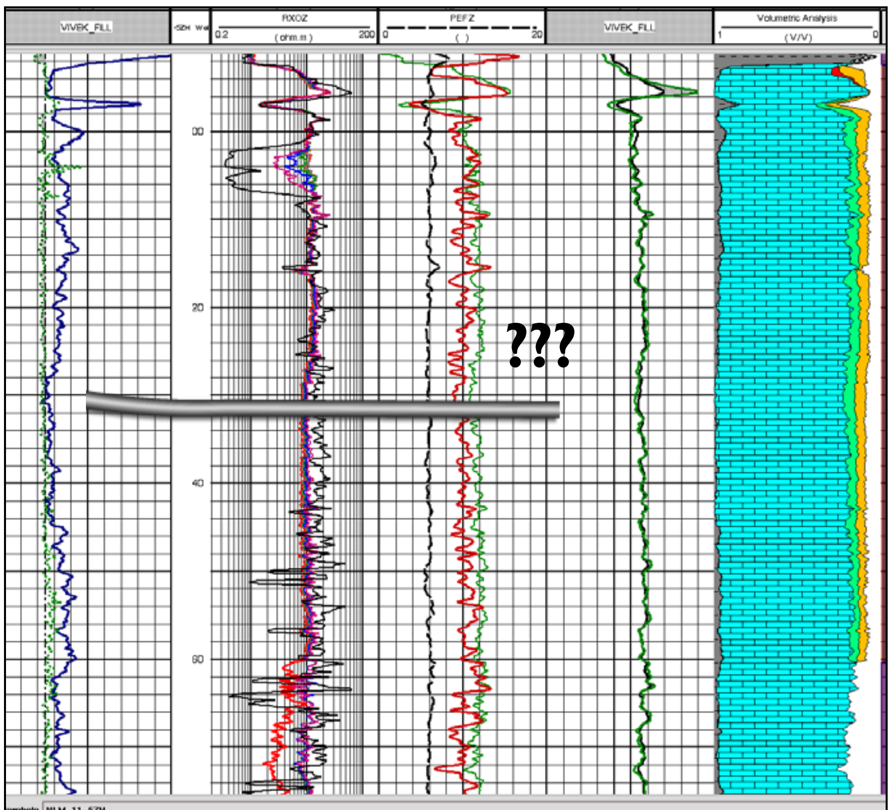
Hc Saturation

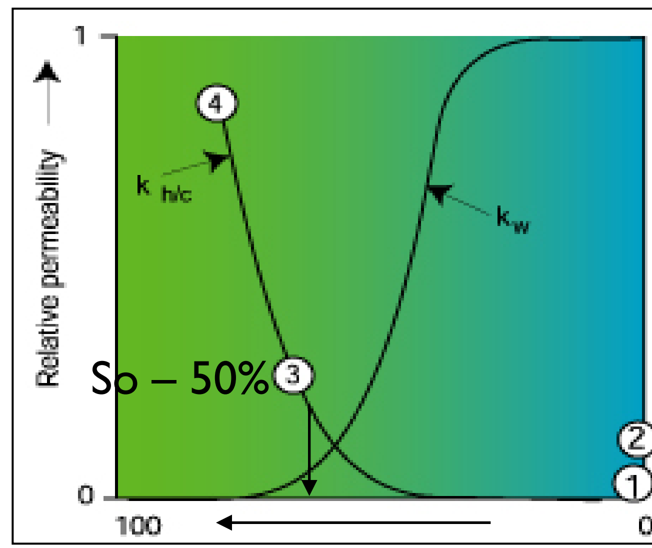
Oil will flow

Impact of Uncertainty

$$S_w = \sqrt[n]{\frac{a}{\phi^m} \frac{R_w}{R_t}}$$

Cumulative uncertainties can lead to erroneously calculated saturations





Hc Saturation

Oil will flow

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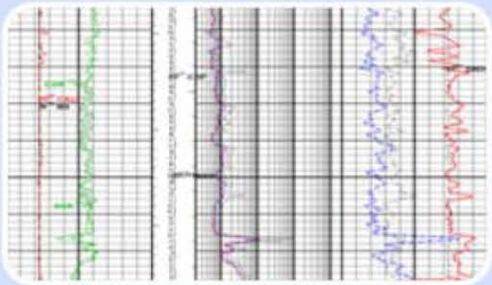
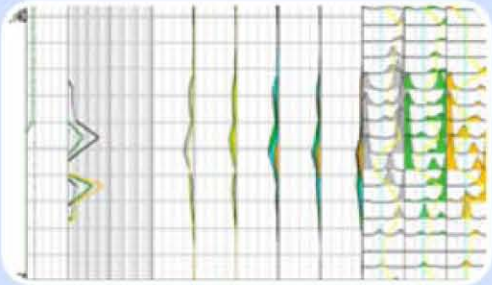
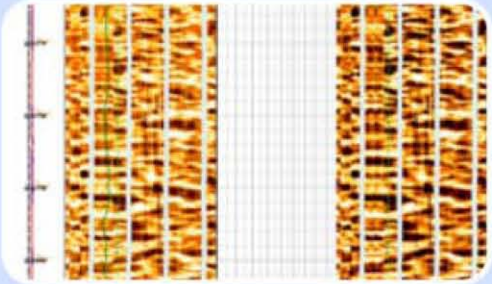
Proposed Solution



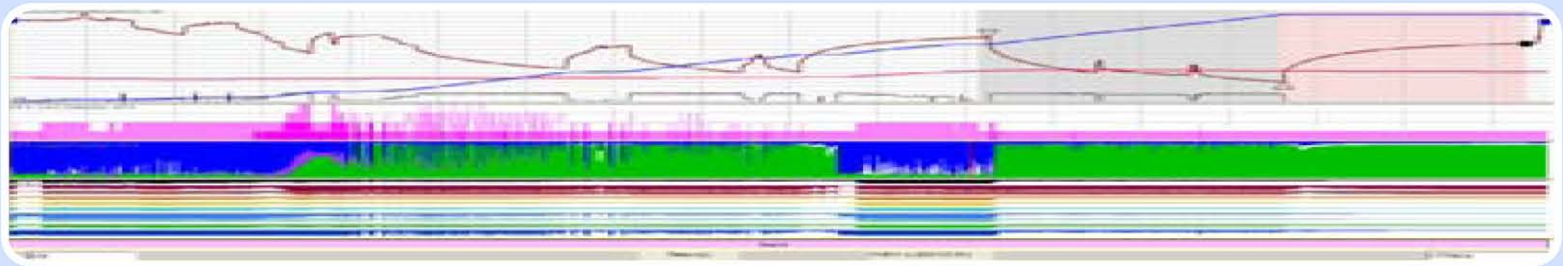
GR, Density-Porosity, Resistivity



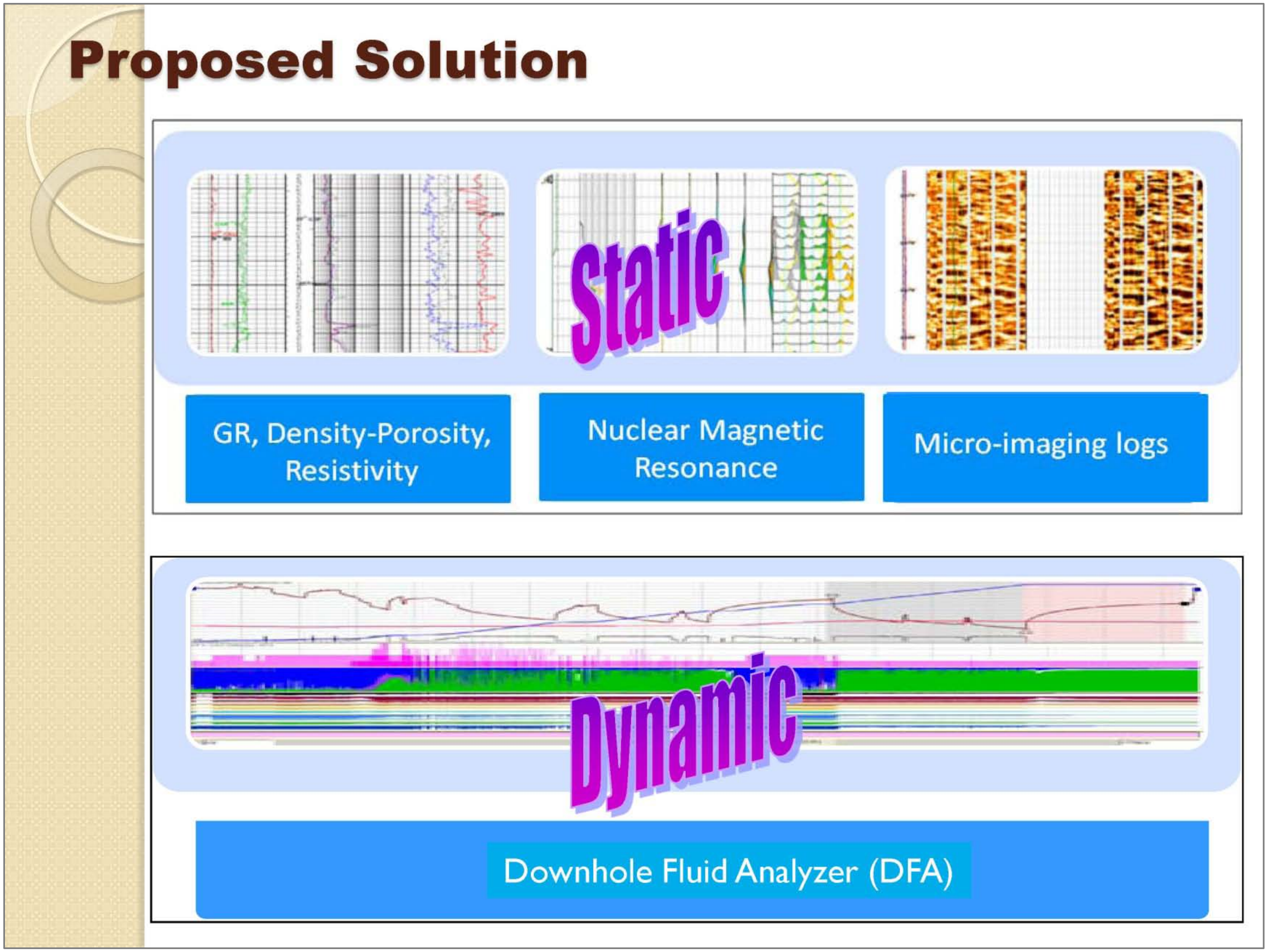
Nuclear Magnetic Resonance



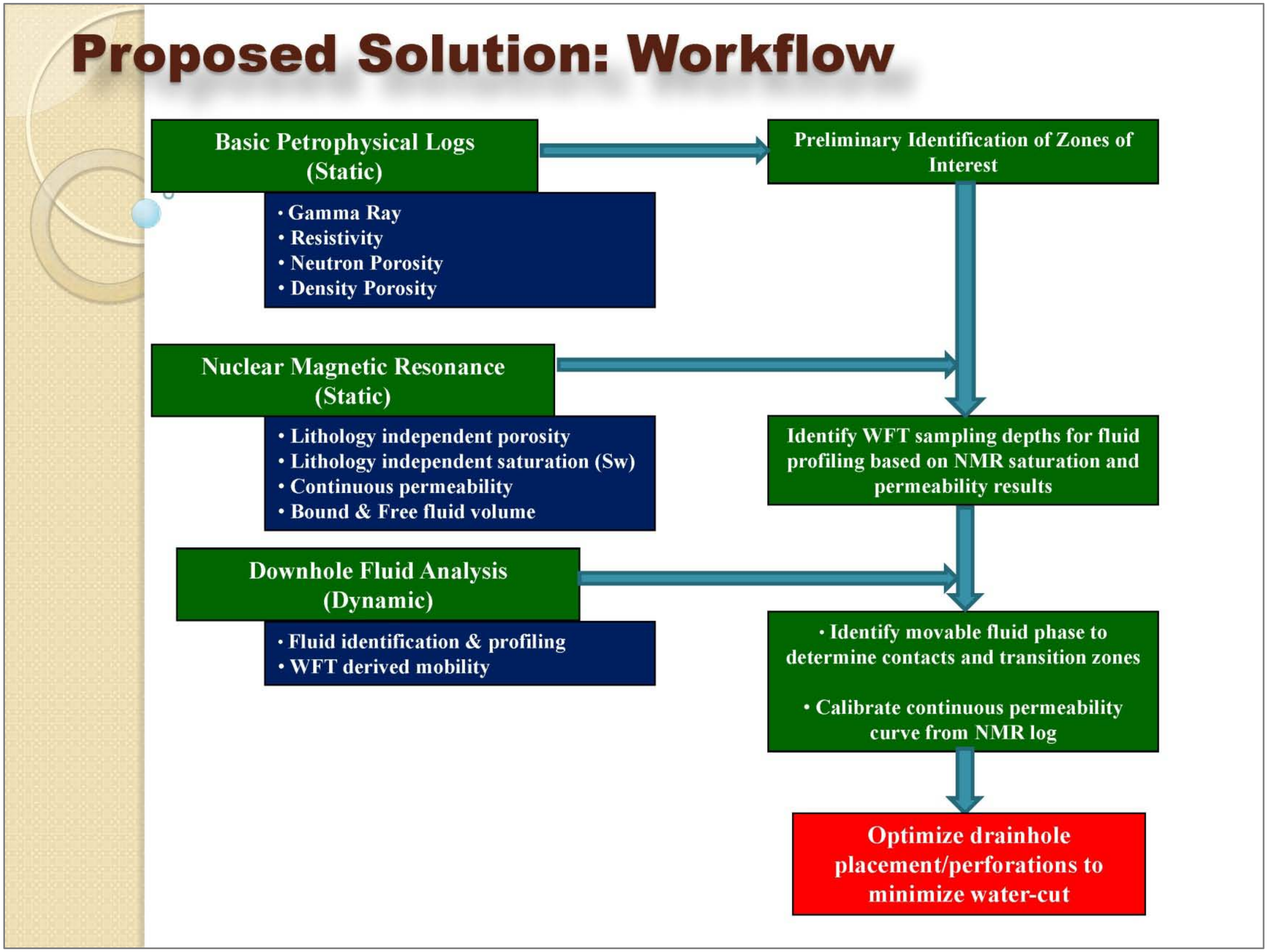
Micro-imaging logs



Downhole Fluid Analyzer (DFA)



Presenter's Notes: The solution to this problem can be provided by the use of current logging technologies using a combination of static and dynamic measurements. Static measurements are usually defined as logs that are acquired under conditions, which are mostly free of any changes in fluids or petrophysical parameters. This includes basic openhole logs such as density-porosity, resistivity and GR as well as advanced logs comprising of acoustic, nuclear magnetic resonance and micro-imaging logs. Dynamic measurements comprise of techniques such as in-situ fluid analysis where reservoir fluid is produced using a WFT downhole pumping unit and the pumped fluid is analyzed in-situ using DFAs or Downhole Fluid Analyzers. The results from both of these static and dynamic wellbore measurements can be combined using tools such as ELAN to get a more comprehensive picture of the formation and its inherent complexities.



Presenter's Notes: In this slide, a workflow is proposed where basic petrophysical logs are used for preliminary identification of potential zones of interest. As discussed previously, using these basic logs and Archie's eqn. can lead to erroneous Sw calculation. Therefore, to mitigate this, we acquire NMR measurements such as lithology independent porosity and saturations along with permeability and Free Fluid Volumes to identify WFT sampling depths for fluid profiling. The next step is to use the DFA to directly identify the movable fluid phase at the selected depths in order to estimate contacts. The final objective of this workflow is to use both static and dynamic measurements to optimize drainhole placement/perforations rather than solely relying on the Archie's equation.

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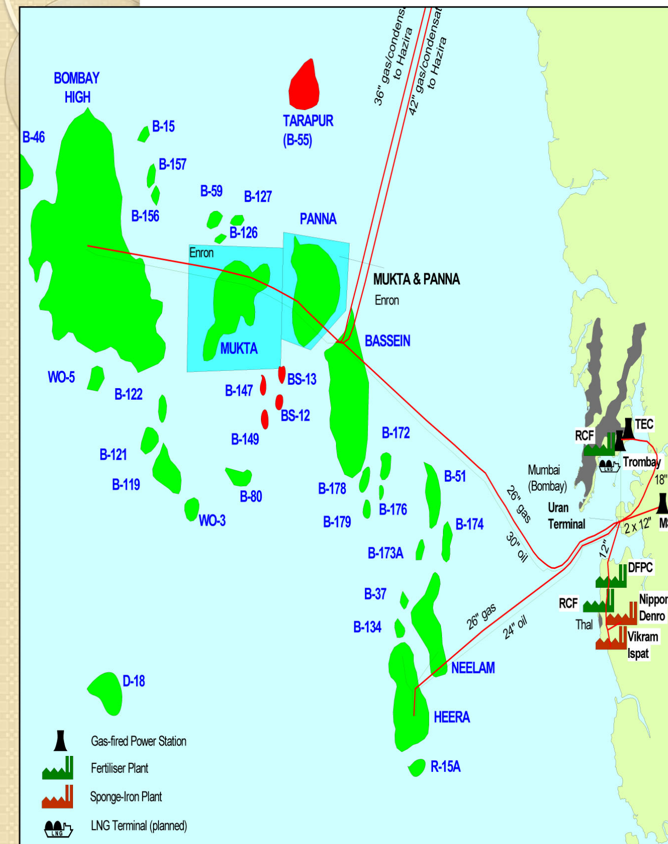
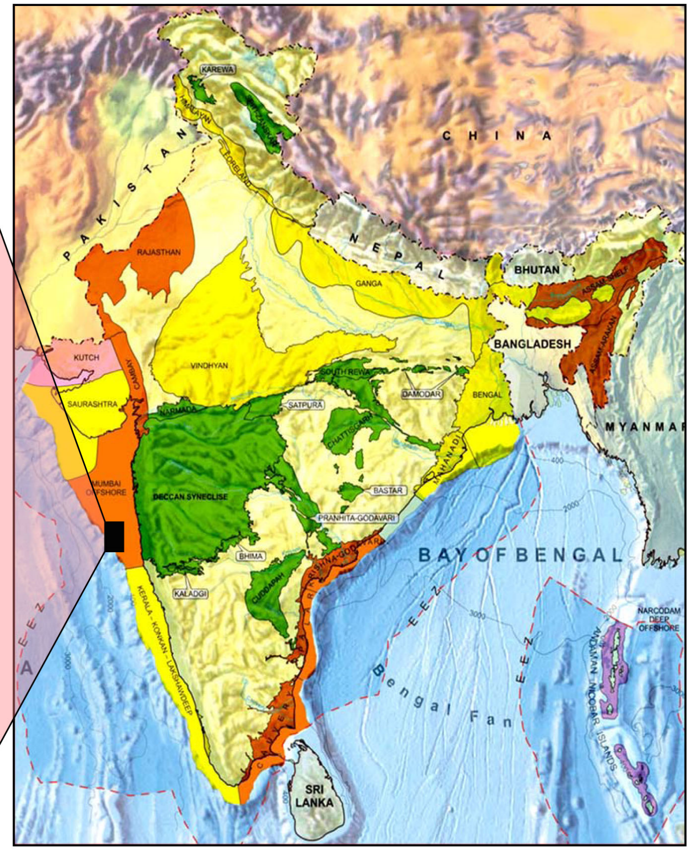
Case Study: Field Introduction

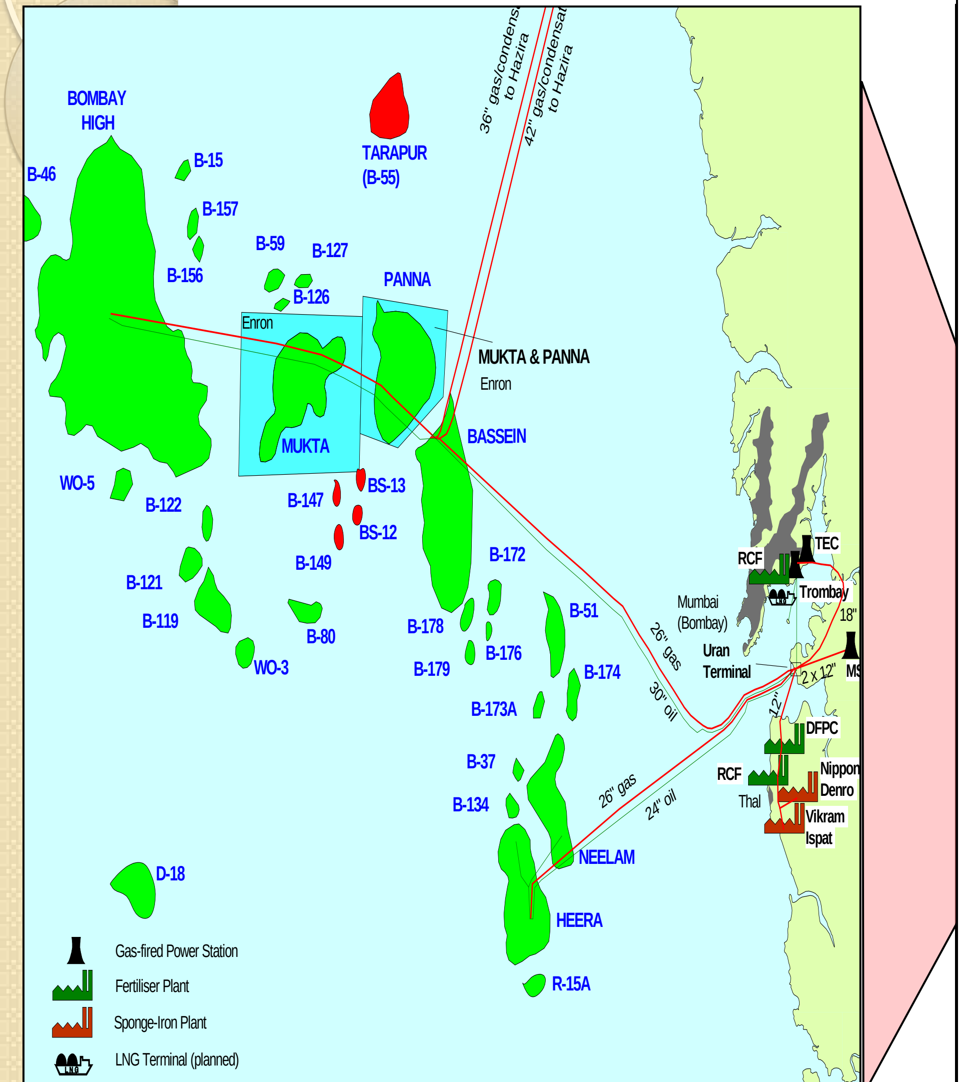




Reference: Directorate General of Hydrocarbons (India) official website

Presenter's Notes: Let us begin with a quick introduction of the field. The Arabian Sea off the western coast of India consists of a number of fields that are currently under production. Our case study concerns one of the fields located off the coast of Mumbai. The field was discovered in the 1980s and has been on production for a couple of decades. Lithology-wise, the brown field in question is a complex heterogeneous limestone with two major producing layers and has been facing a problem of declining production. The completion policy for this formation usually involved placing drainholes between the top of the transition zone and 6 m TVD-SS below the estimated Gas Oil Contact. However, drainholes placed using this approach showed a tendency of increasing water cuts almost immediately after being put on production until the hydrocarbon production would decrease to almost negligible levels.

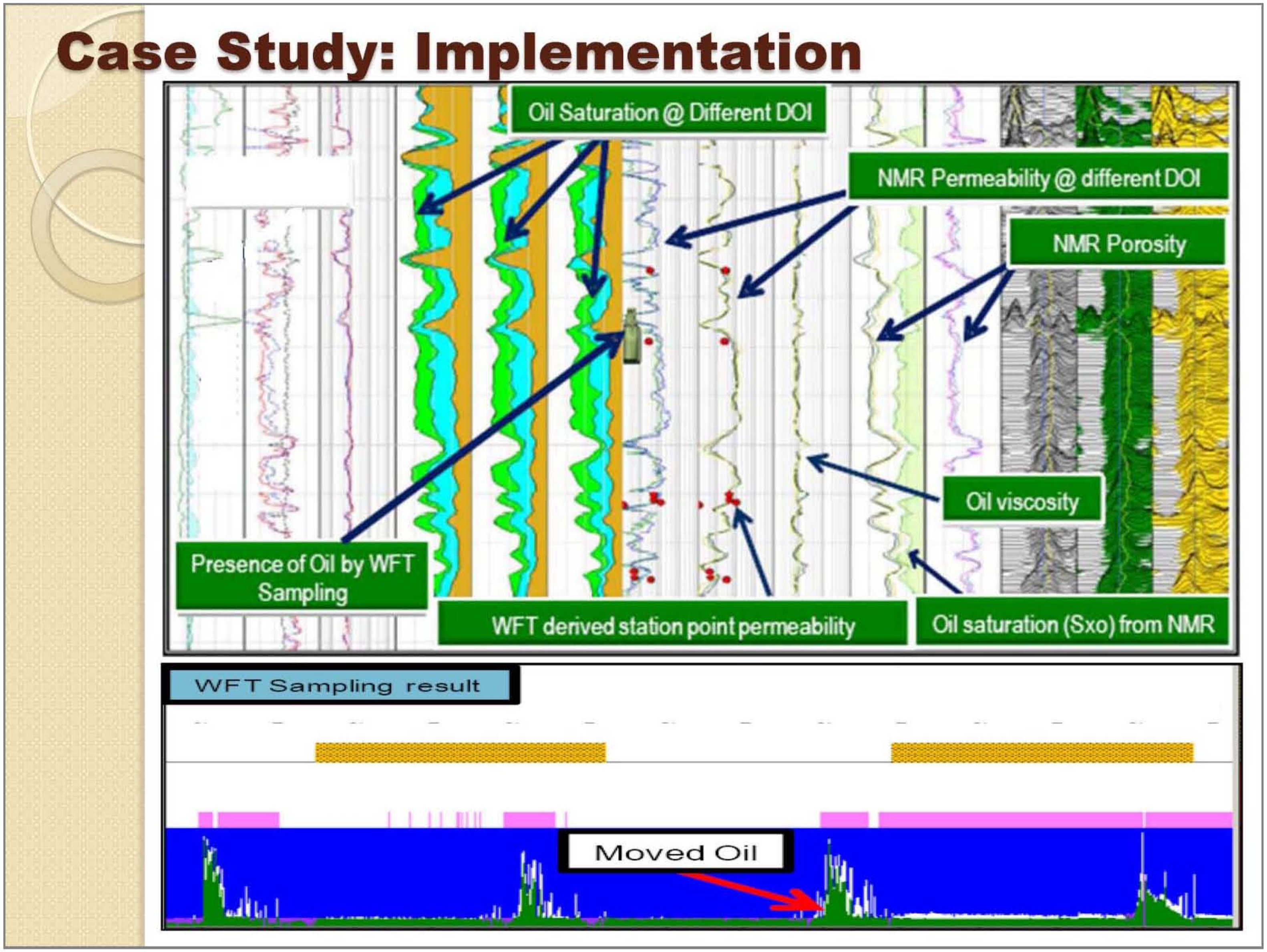
Case Study: Field Introduction



Reference: Directorate General of Hydrocarbons (India) official website

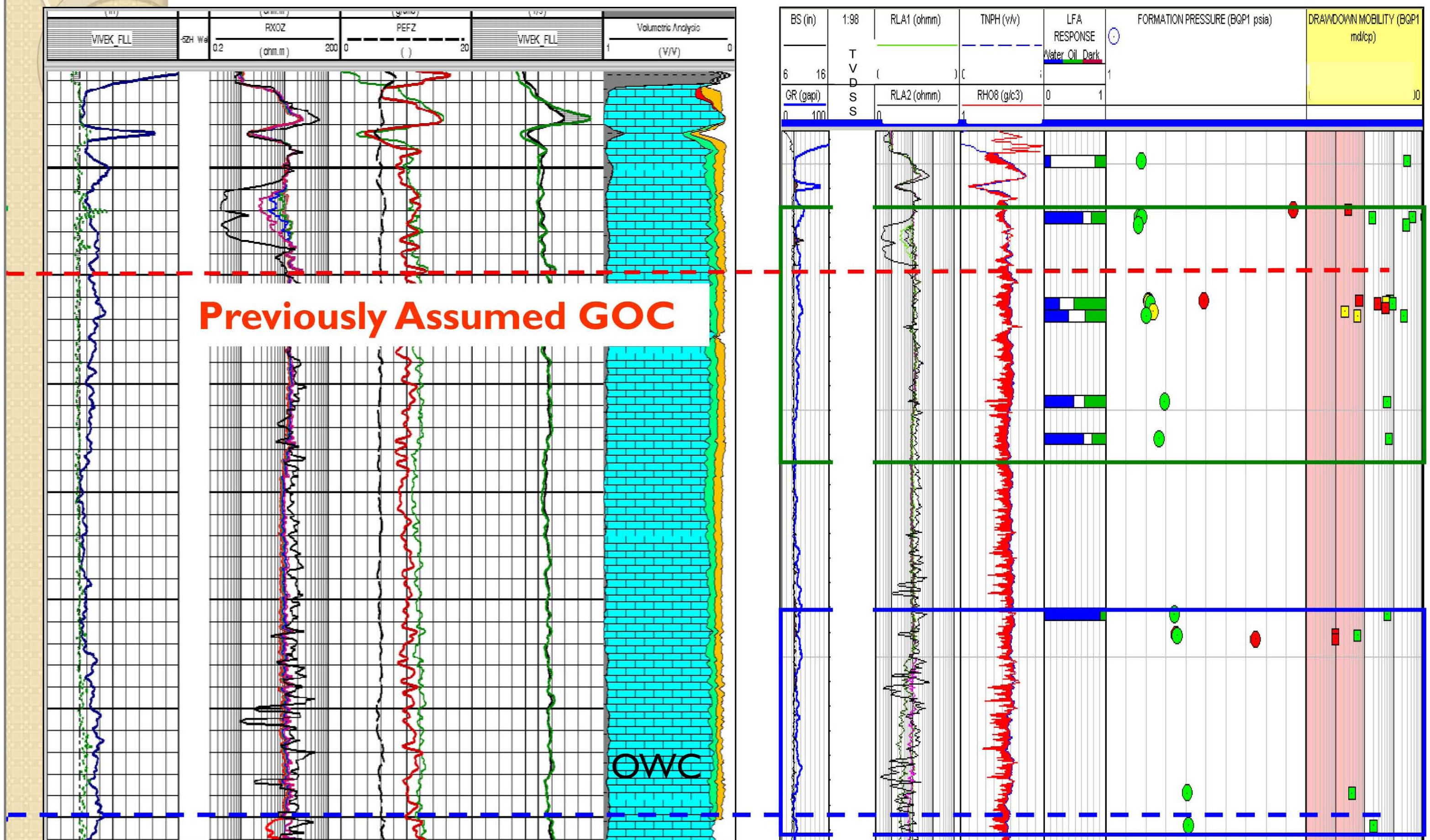
Salient points for Field

- Lithology: Complex Heterogeneous Limestone
- Producing since ~1990
- Typical completion strategy is to place new drainholes between ~6m TVD-SS below GOC to top of the transition zone
- New drainholes showing tendency to water out quickly



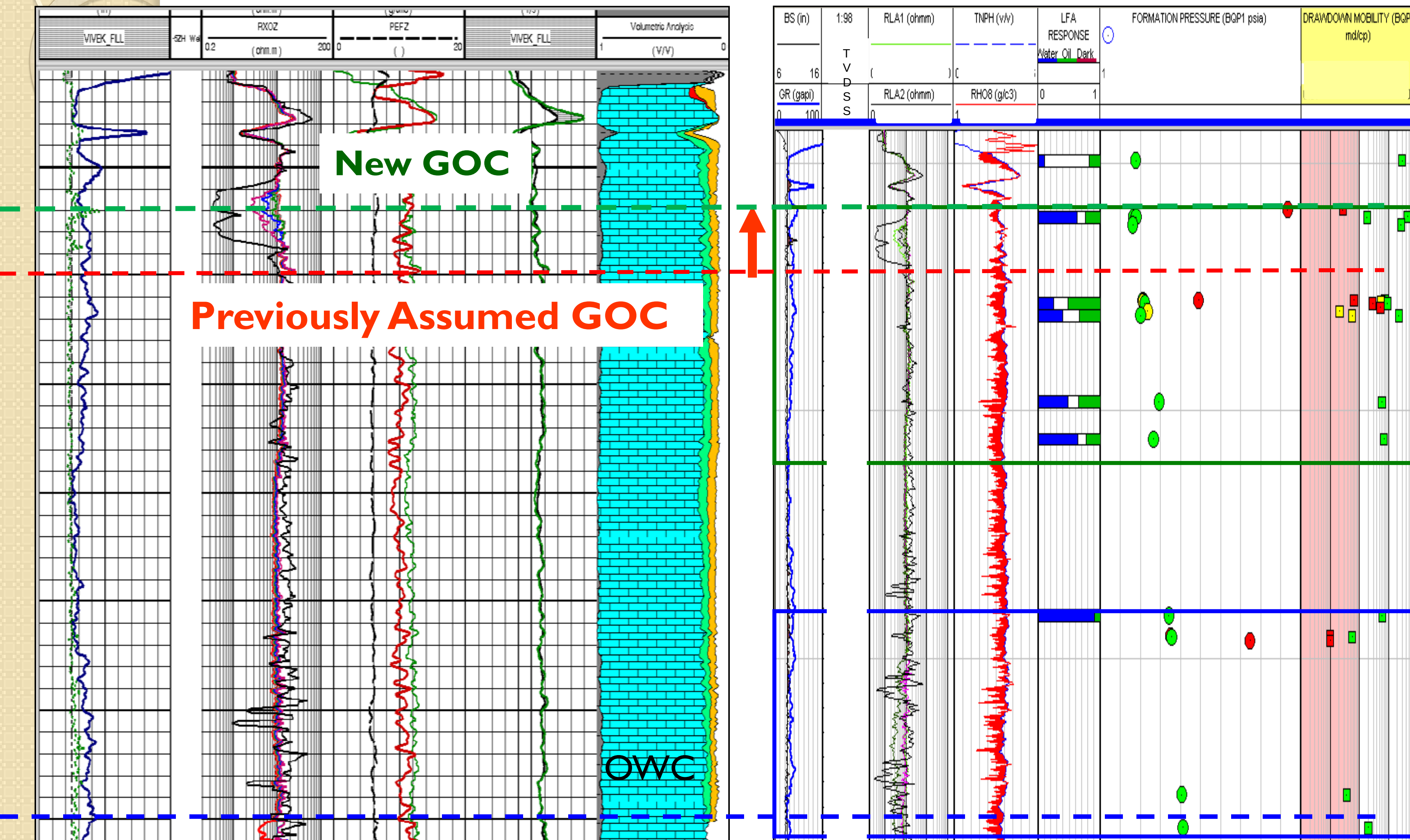
Presenter's Notes: In order to solve this problem, NMR fluid characterization was carried out as a resistivity independent analysis, which provided a continuous fluid characterization result at different depths of investigations. A high-resolution lithology-independent porosity and permeability were also determined as continuous measurements, which were used to optimize sampling station depths for the wireline formation tester run by avoiding potential tight points. The mobility derived from the WFT run was used for calibration of the continuous NMR permeability measurements and the fluid sampling data obtained from WFT at various stations re-confirmed the fluid characterization results derived by NMR analysis.

Case Study: Results

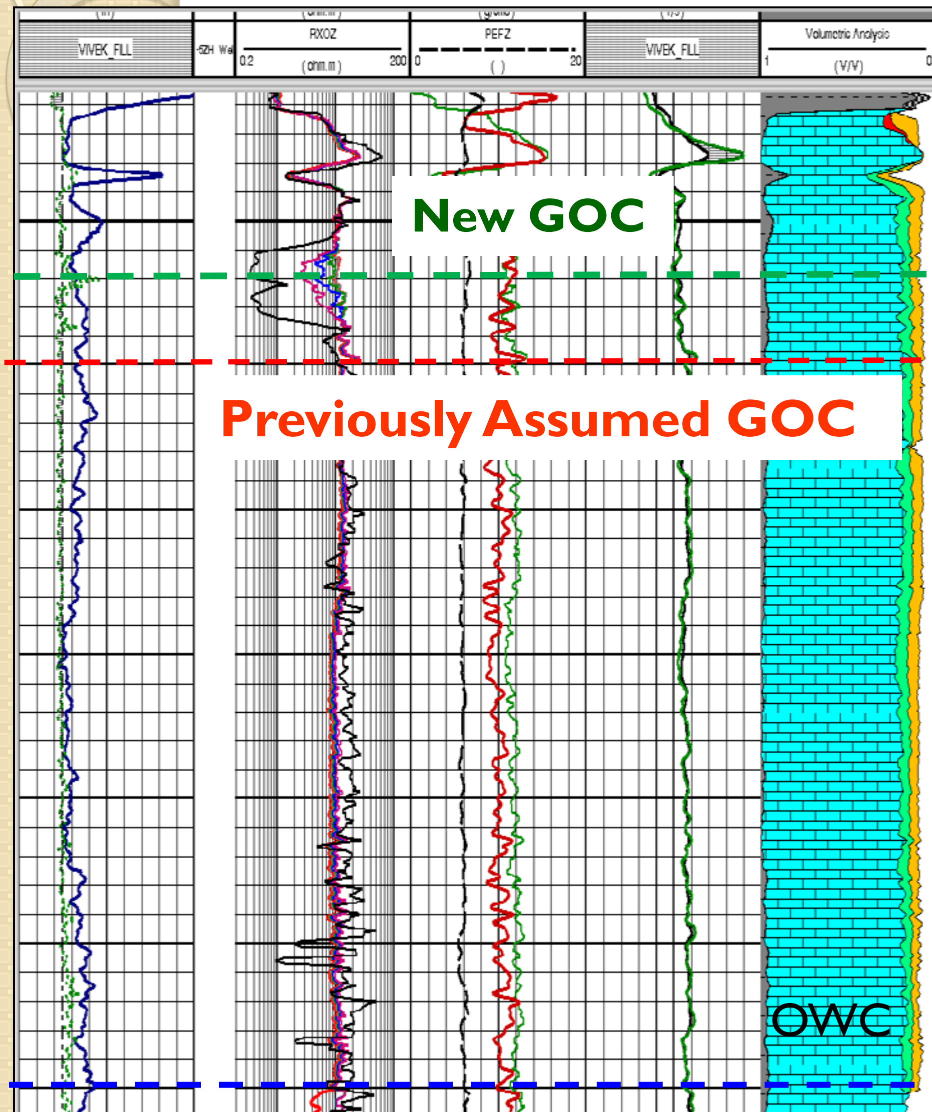


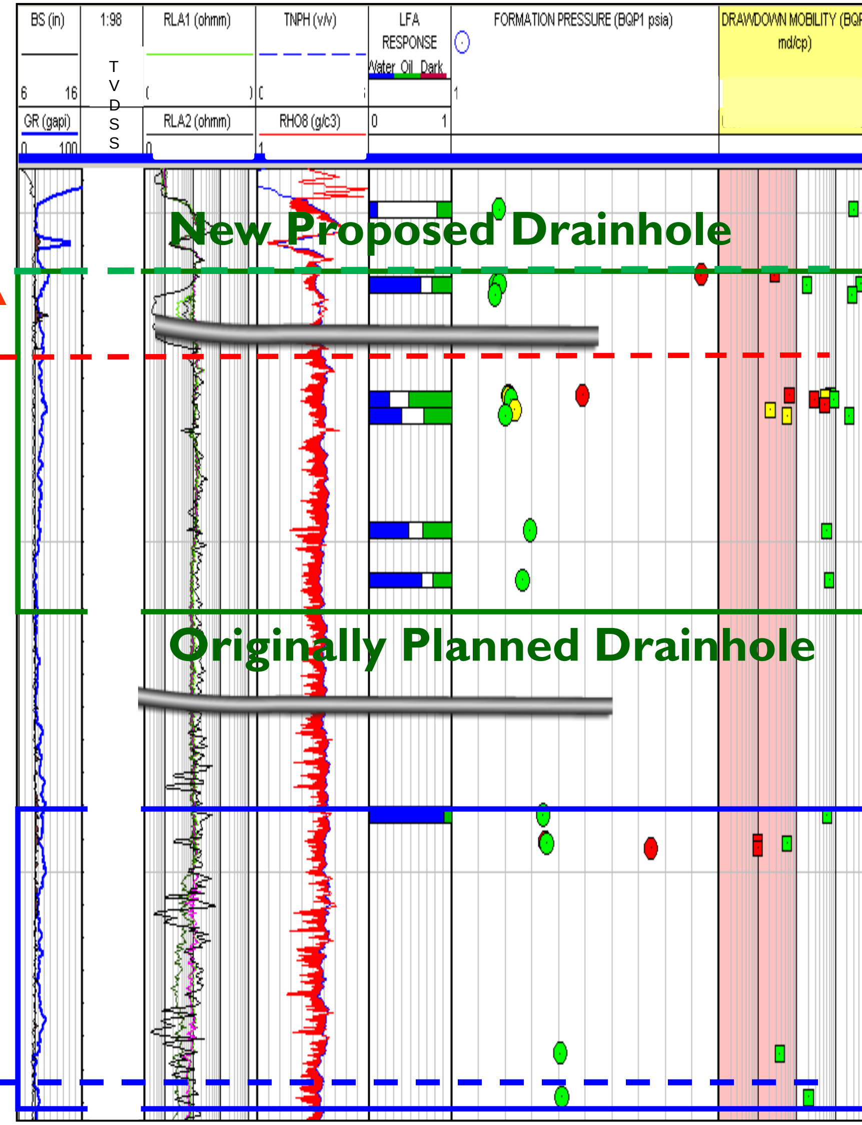
Presenter's Notes: As mentioned in the previous slide, based on the workflow, sampling was carried out using a wireline formation tester-pumping module coupled with a downhole fluid analyzer. By sampling at multiple depths, a fluid profile was generated. On analyzing the integrated NMR and fluid profiling results, it was inferred that the actual GOC had shifted and was in fact shallower than previously assumed and that the formation had a higher potential of oil production than previously perceived based on conventional analysis of basic open-hole log data. Based on this analysis, a new depth was proposed for drainhole placement that was in line with the updated GOC.

Case Study: Results

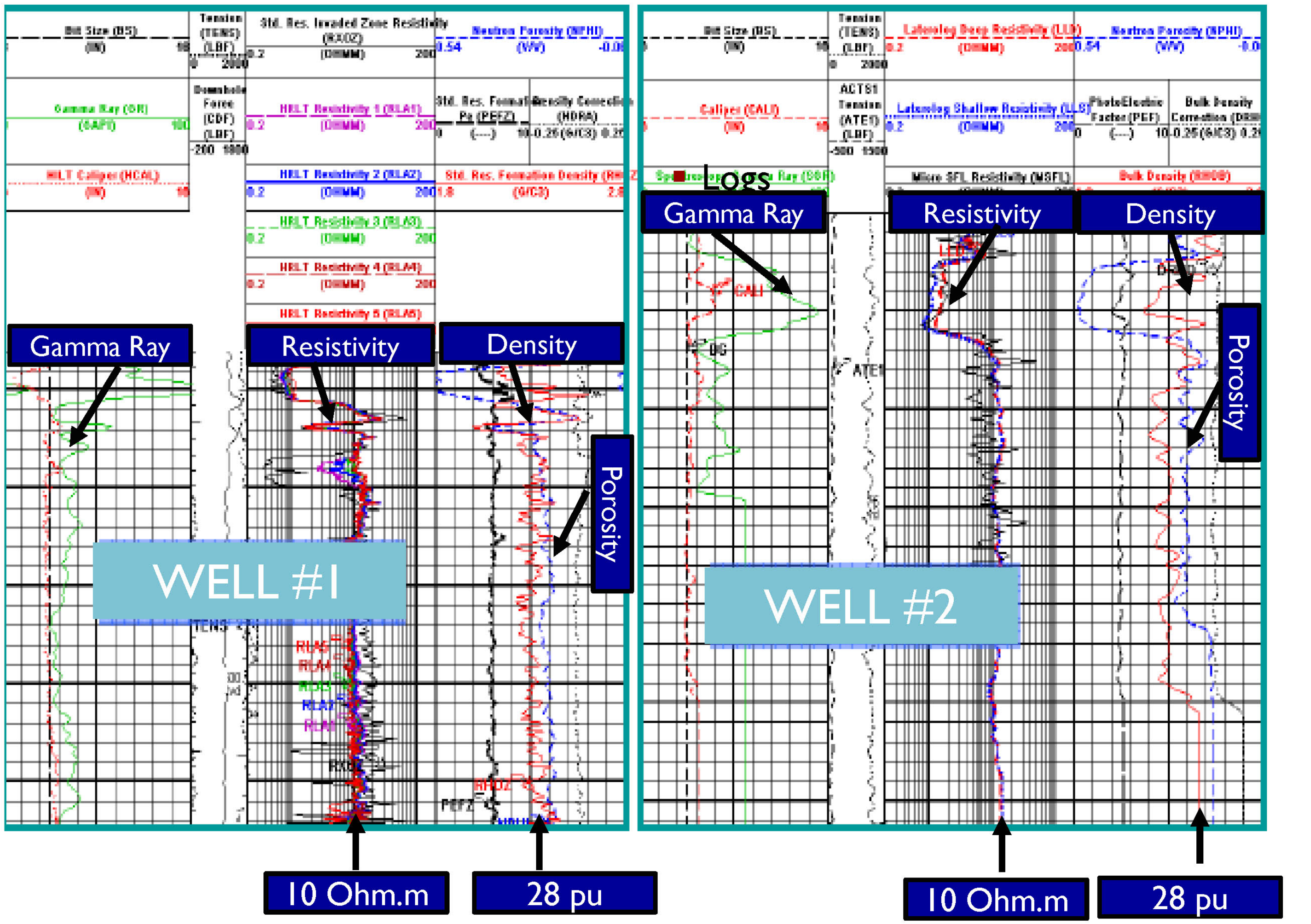


Case Study: Results



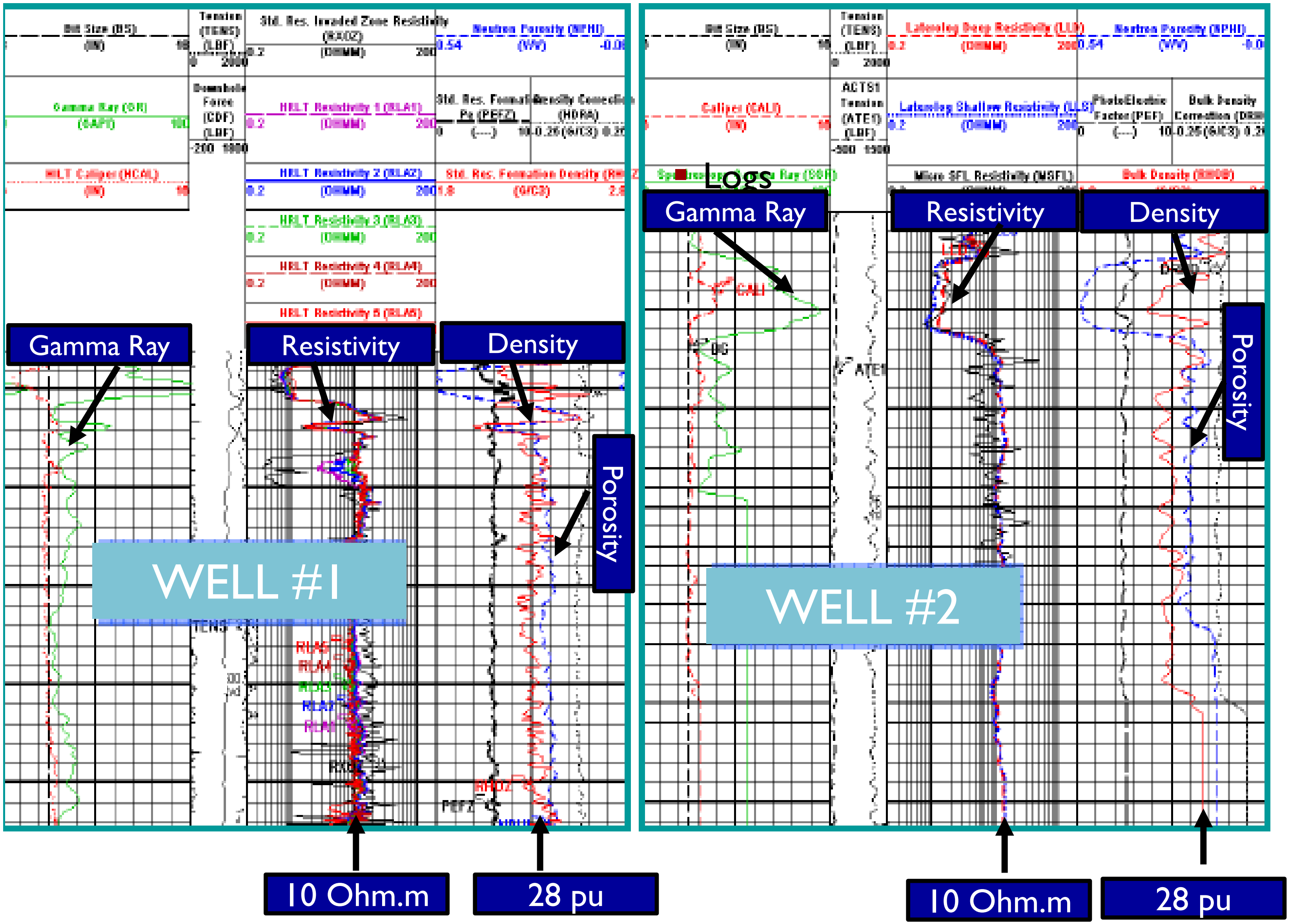


Case Study: Results

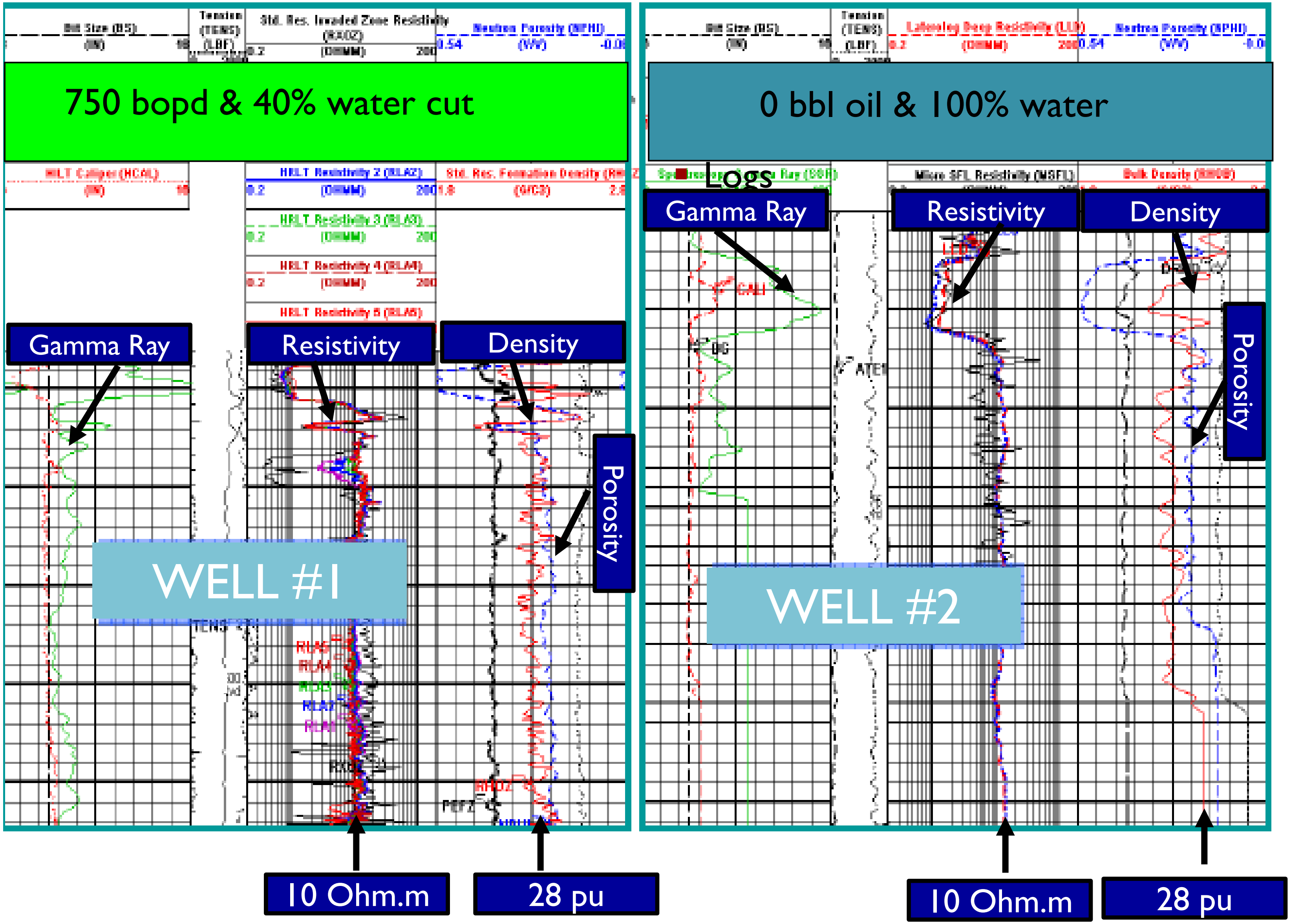


Presenter's Notes: Post implementation, a comparison was made between the performances of the drainhole placed with the aid of the proposed workflow and another recent drainhole that had been placed based on the previous completion strategy. It was observed that the optimally placed drainhole was producing almost 750 bopd oil with a marked decrease in the water cut, despite the fact that the petrophysical logs for both the wells exhibited similar formation properties.

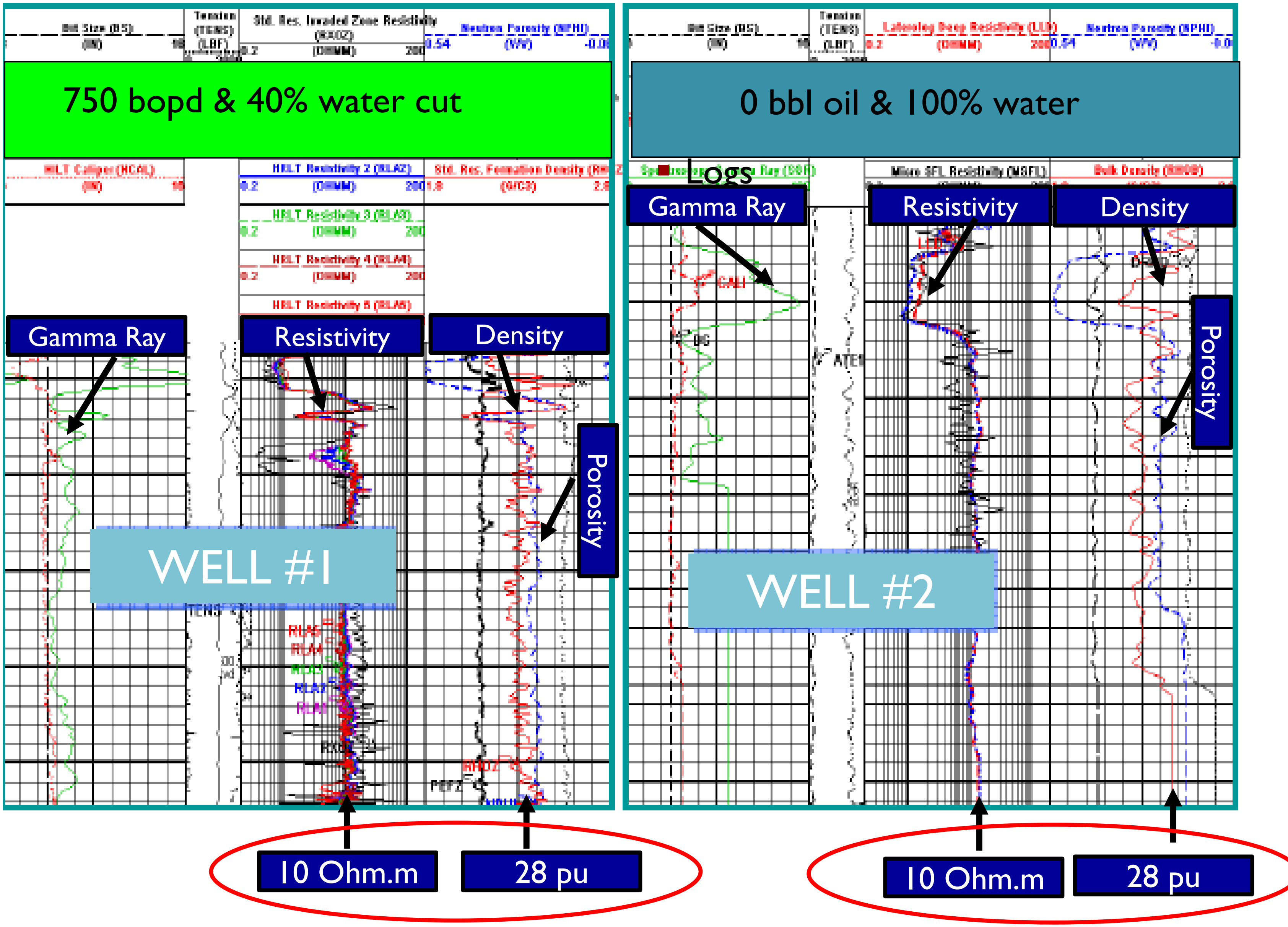
Case Study: Results



Case Study: Results



Case Study: Results



Summary and Conclusion

- Deriving saturations in complex carbonate systems based solely on Archie's equation can lead to erroneous results due to uncertainty in the input parameters.

- An integrated approach consisting of both static and dynamic data can help in mitigating the uncertainties with respect to fluid movement.

- A workflow was developed using NMR (static) data and WFT sampling coupled with downhole fluid analysis (dynamic) in order to better enable drainhole placement and perforations in a brown field.

- Implemented the workflow to facilitate optimal drainhole placement in order to boost oil production while mitigating rapid water breakthrough.

Thank you !