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Unconventional Approach for the Conventional Problems: A Curious Case of *m & n*

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Introduction

To assess a possible hydrocarbon reservoir, hydrocarbon saturation needs to be determined with good accuracy. In 1942 Archie published a formula to estimate water saturation in reservoirs. In case of carbonates, the saturation computed by the formula is not always correct. The factors complicating the role of the formula are known as Archie exponents: the porosity exponent (*m*, also known as the cementation factor) and saturation exponent (*n*). Both exponents tend to vary quite often in carbonate reservoirs. With the exception of cores, no reliable and well established techniques exist today that can give a good estimate of these exponents. Hence, deriving these components from logs has remained a challenge and new probes and techniques are required for a better understanding of these Archie parameters.

In particular with reefal carbonates where the extent of vertical heterogeneity and spatial distribution is enormous, this conventional assumption of constant values for the cementation exponent (*m*) & saturation exponent (*n*) does not exhibit the true picture of saturation (Fig. 1). Hence, improving the estimation of ‘*m*’ & ‘*n*’ from the well log was the main objective of this project. The technique is based on the assumption that the amount and pattern of cementation, caused by diagenesis, in carbonates is one of the factors controlling the value of ‘*m*’. Therefore in order to estimate it for carbonates, the cementation in them should be quantified. It was achieved through integration of electrical borehole images and petrophysical logs with the core. High resolution variable-*m* (*Vm*) thus obtained from image logs was used in Dielectric dispersion results to back calculate variable-*n* (*Vn*).

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Geological Overview of D1 Structure of DCS Field

Giant carbonate fields in offshore Mumbai are expected to be the dominant source of hydrocarbon production in the country. Hence, understanding carbonate reservoirs and producing them effectively have become industry priorities.

The D1 structure of Mumbai block is NW-SE trending doubly plunging anticline along the edge of the Paleogene shelf slope break, located at a distance of 200 km off the mumbai coast (Fig. 2). This western flank of the S-Mumbai depression within the Western Offshore basin has average water depth of 85 to 90m. Production has established the middle and upper pays of this structure as proven reservoir quality. However, the lower pay, with all its potential reservoir quality, has yet to be assessed properly.

The low-resistivity pays abnormal flow units and large extent of lateral and vertical heterogeneities further add to the complexities (Fig. 3 and 4).

Workflow

The technique addressed in this project (Fig: 5) is based on the assumption that the amount and pattern of cementation, caused by diagenesis, in carbonates is one of the factors controlling the value of '*m*'. Therefore in order to estimate it for carbonates, the cementation in them should be quantified (Fig: 6). It was achieved through integration of electrical borehole images and petrophysical logs with the core. The high-resolution *Vm* thus obtained from image logs was used in dielectric dispersion results to back calculate *Vn*. The di-electric dispersion also provides a value of cementation exponent which is close to the cementation exponent in the water bearing layers. This is used as a calibration factor for the cementation exponent from formation micro-imaging (FMI).

This project aimed at improving the saturation computation using *Vm and Vn* values obtained from characterizing the vertical and lateral textural details on high-resolution micro resistivity image and dielectric dispersion results, taking into consideration the type of lithology, compaction effect and the presence of secondary features like vugs and fractures. This study also led to characterization of each of 9 individual sub pays which are identified in the Lower Pay of the D1 structure of DCS field by considering all available static and dynamic data set.

Results and Discussions

As discussed earlier, accurate computation of water and/or hydrocarbon saturations has a large effect on the reserves estimation for a particular reservoir, and cementation exponent *m* and saturation exponent *n* are important parameters that are critical for that purpose. This is the challenge that was faced in the D1 structure of DCS field.

Well 'A'

The conventional elemental log analysis (ELAN) saturation using a constant value for *m* suggested ~60% oil in a zone of 2-m interval. However, production testing results showed that only water is being produced from this interval. With the introduction of variable *m* the oil saturation (*So*) came down to only 20 %, which well explained the water production from this zone (Fig. 7).

Well 'B'

Station 1: The conventional ELAN saturation indicated ~50% oil in upper zone which was in sync with the dynamic tester results. With *Vm and Vn*, the *So* did not deviate much in the upper zone, but in lower zone, the increase in oil saturation was a significant of 30%. This zone could have been considered for perforation had the saturation been determined with *Vm* and *Vn* (Fig.8).

Station 2: Conventional ELAN saturation indicated ~40% oil for this zone. However, only water was being produced and dynamic tester results also suggested the same. With *Vm* and *Vn,* oil saturation (*So*) dropped down to only 10%, which better explained the water production from this zone (Fig. 9).

Conclusions

This study established that introduction of variable-*m* and-*n* (*Vm* and *Vn*) leads to more realistic saturation computation. The cementation factor/ porosity exponent & saturation exponent across the entire length of the reservoir can be estimated from a curve indicating its variation with depth, which would ensure better control on perforation interval. The neural network-based high-resolution electrofacies thus generated helped in layer-by-layer, detailed characterization of the extremely heterogeneous D1 structure of DCS field. The results from the study provided pivotal inputs for accurate reserves estimation, informed decision making, better reservoir management that will be used in updating static facies and property models.

References

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2. Abdelaal, A.F. 2013. Integration of Dielectric Dispersion & 3D NMR Characterizes the Texture & Wettability of a Cretaceous Carbonate Reservoir. SPE 164150
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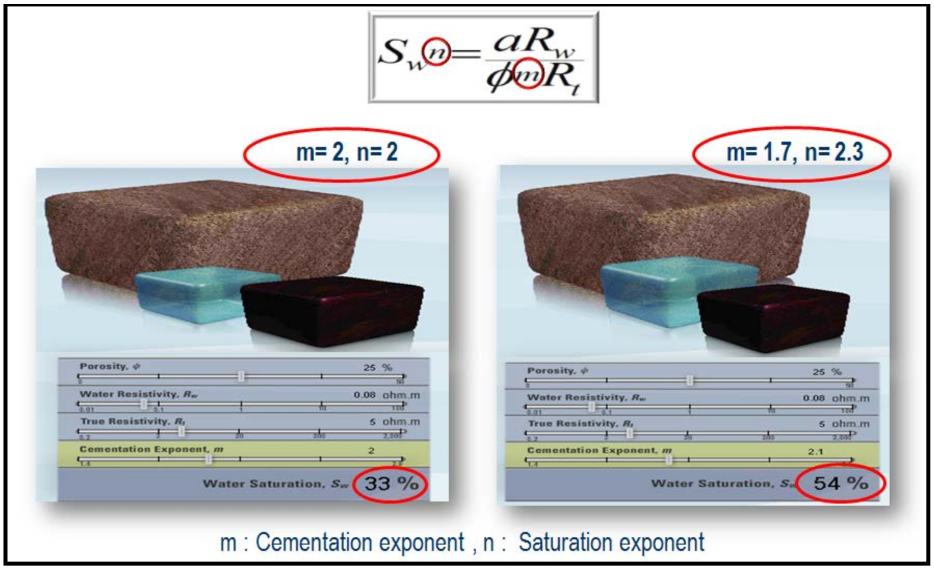


Fig 1: The conventional assumption of constant values for *m* and *n* does not exhibit the true picture of water saturation

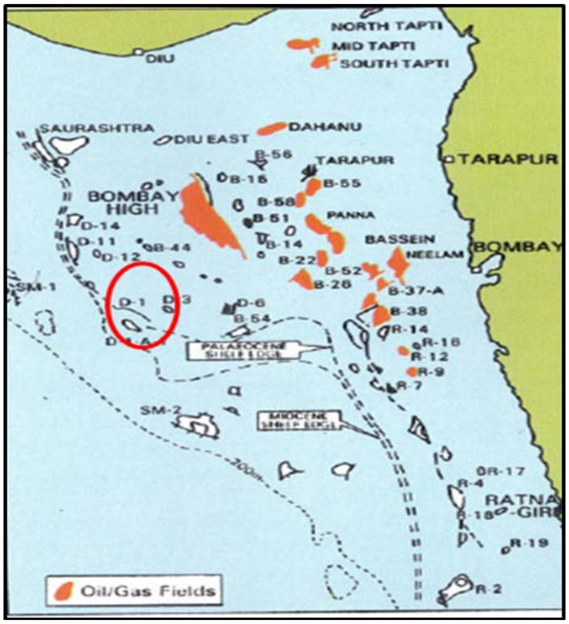


Fig 2: Structural map of the study area

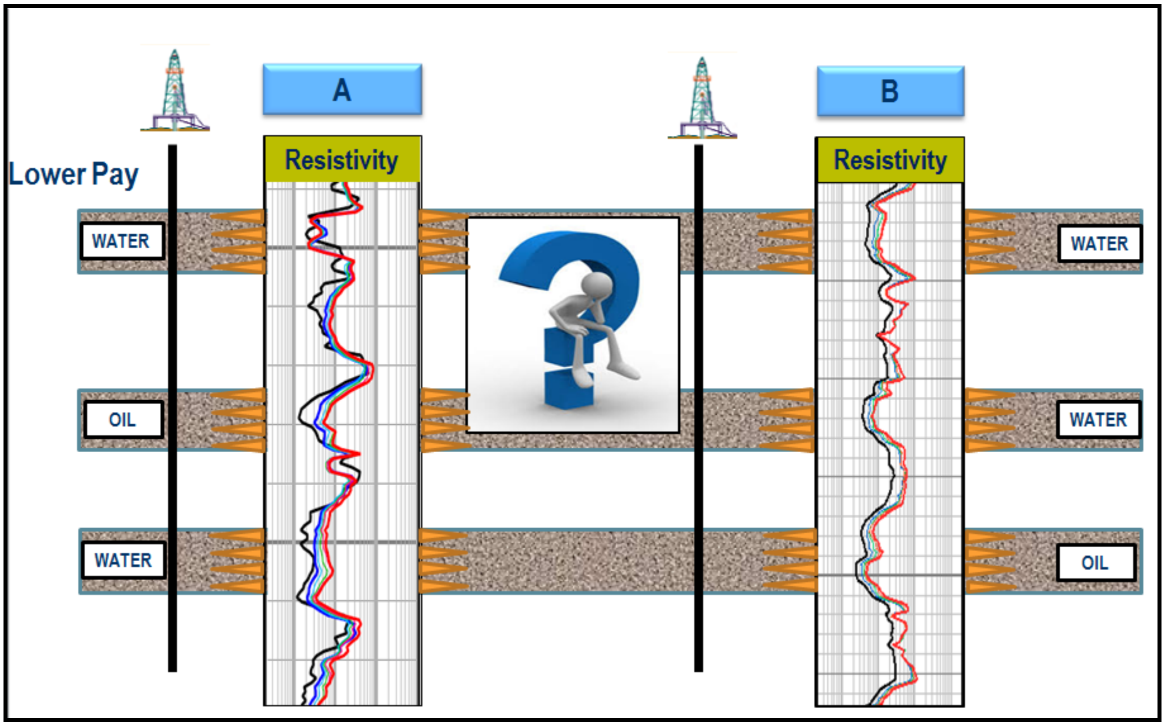
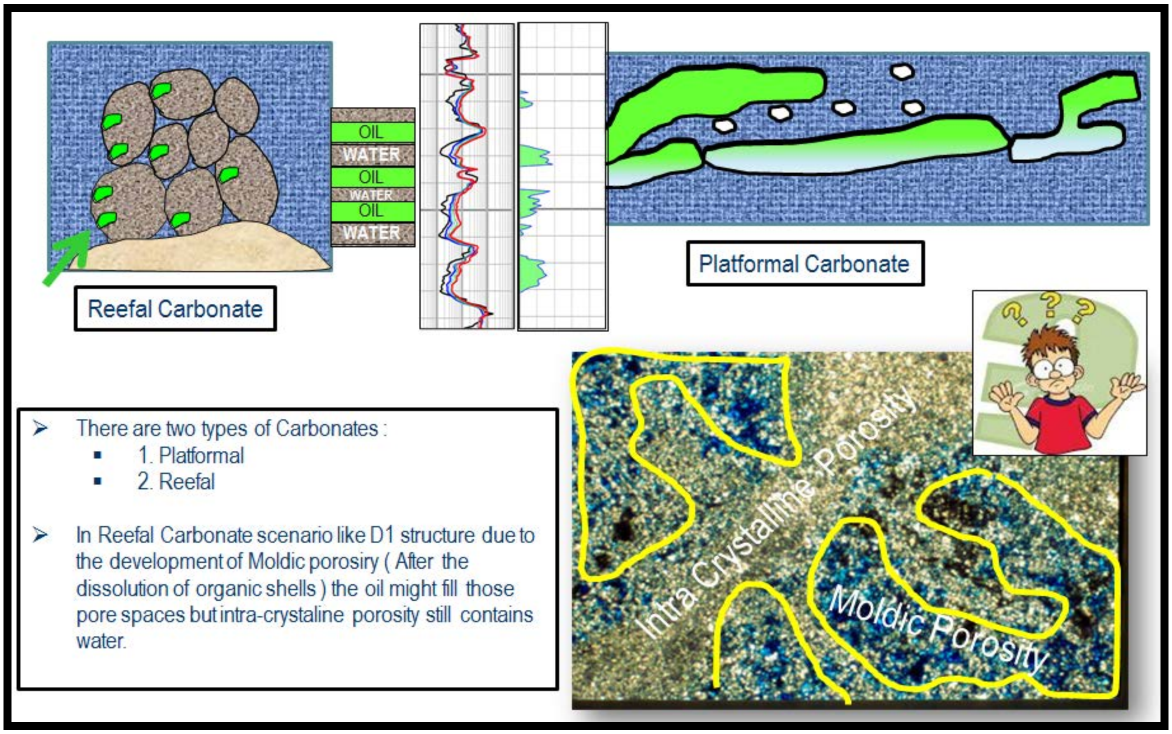


Fig 3: Low-resistivity pays. Pay zones are not correlatable due to the large extent of temporal and spatial variation



- There are two types of Carbonates :
  - 1. Platformal
  - 2. Reefal
- In Reefal Carbonate scenario like D1 structure due to the development of Moldic porosiry (After the dissolution of organic shells) the oil might fill those pore spaces but intra-crystaline porosity still contains water.

Fig 4: Reefal carbonate and associated complexities

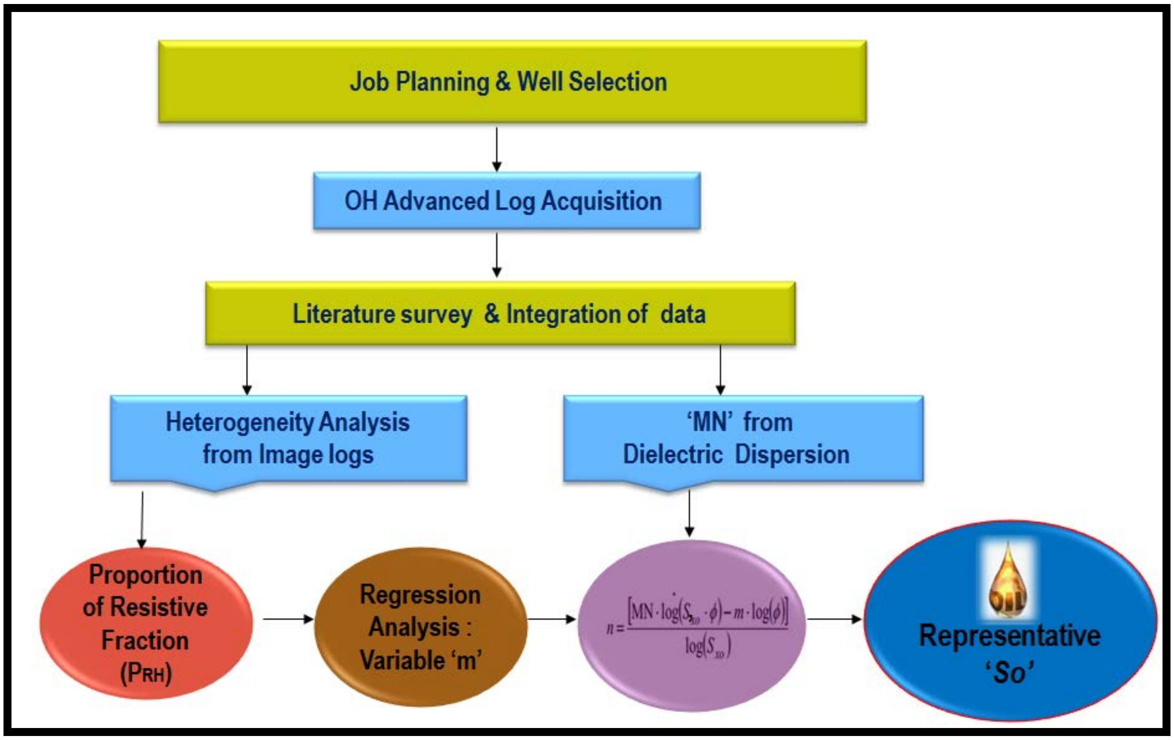
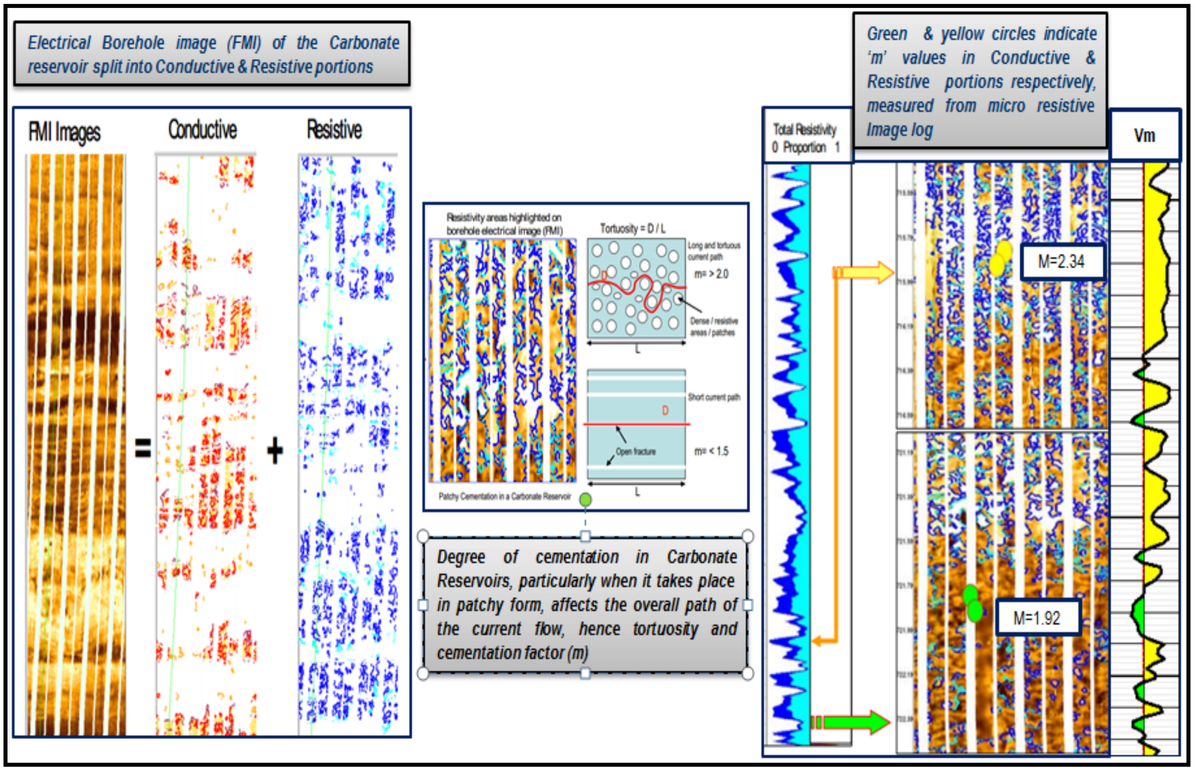


Fig 5: Workflow to get the realistic *So*

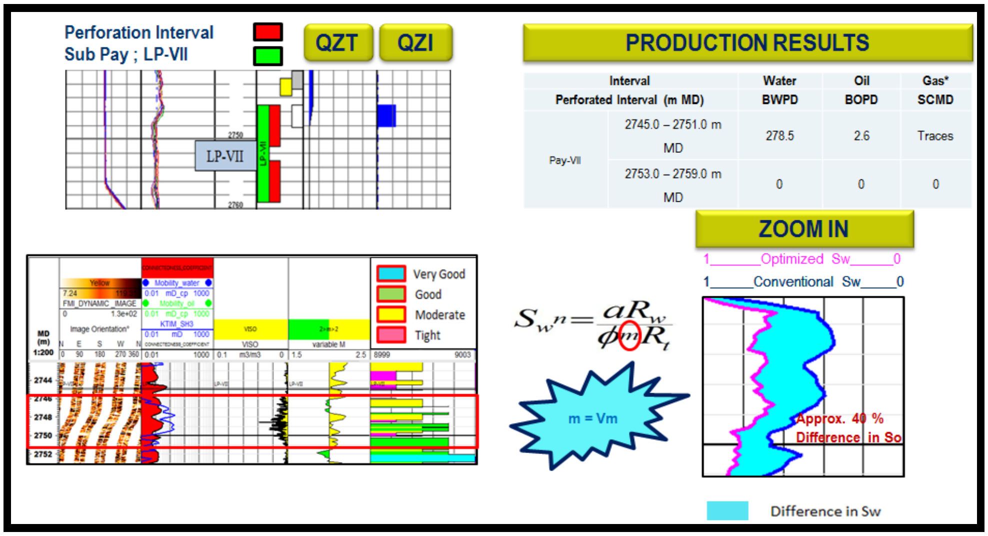


Electrical Borehole image (FMI) of the Carbonate reservoir split into Conductive & Resistive portions

Degree of cementation in Carbonate Reservoirs, particularly when it takes place in patchy form, affects the overall path of the current flow, hence tortuosity and cementation factor (m)

Green & yellow circles indicate 'm' values in Conductive & Resistive portions respectively, measured from micro resistive Image log

Fig 6: Methodology to get variable-*m* (*Vm*)



PRODUCTION RESULTS

	Interval Perforated Interval (m MD)	Water BWPD	Oil BOPD	Gas* SCMD
Pay-VII	2745.0 – 2751.0 m MD	278.5	2.6	Traces
	2753.0 – 2759.0 m MD	0	0	0

Fig 7: Well A. Realistic *So* captured through *Vm*

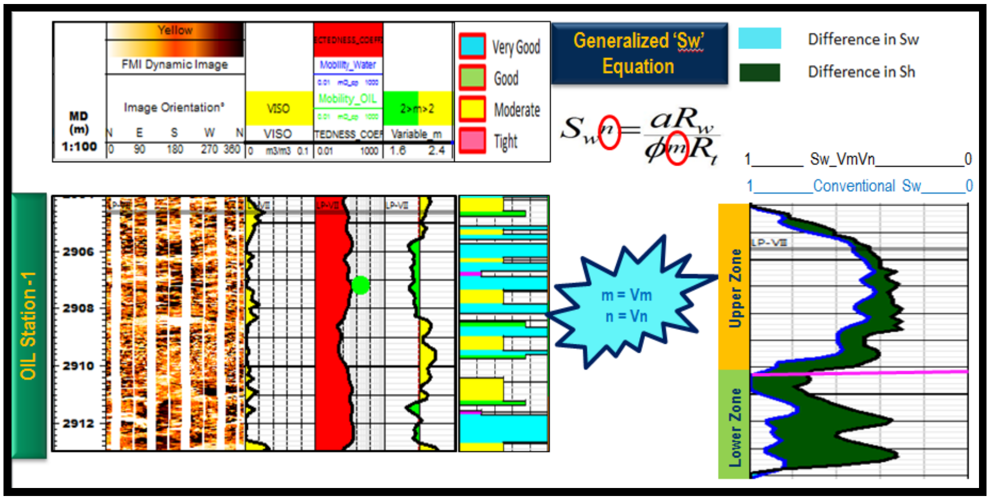


Fig 8: Well: B (Oil Station). Realistic *So* captured through *Vm* and *Vn*

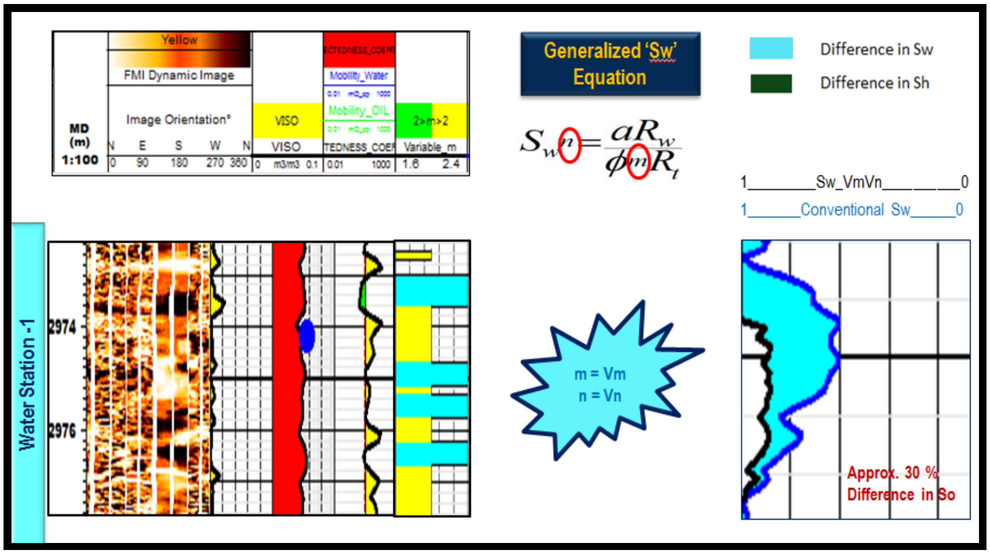


Fig 9: Well: B (Water Station). Realistic *So* captured through *Vm* and *Vn*