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# Integrating NMR and Borehole Image for characterizing Carbonate Permeability Behavior

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## Abstract

Characterization of carbonates based on their petrophysical properties have always been challenging due to their heterogeneous nature. These heterogeneities are due to a combination of different factors driven by complex pore systems, variable porosity-permeability relationships and the pore network, which are overlooked when interpreted using conventional tools and techniques. This complexity has an impact on the fluid flow characteristics and, hence, the permeability of the reservoir, so understanding these poro-perm systems along with the depositional system in carbonates is very crucial.

## Introduction

Our study focuses on the Kutch-Saurashtra Field, located in the offshore western coast, India. It is peri-cratonic rift basin, with the regional slope towards WSW. The stratigraphy of the area is mostly an intercalation of periodic clastic dominated shore-face to delta deposits and carbonate dominated platform-shelf deposit. Though the platformal carbonate is quite homogeneous in nature, due to sea-level changes their texture varies from highly porous heterogenous carbonates to layered carbonate-marl intercalation. In this field, the exploration methodology comprises of conventional logs along with NMR, borehole image, sonic and downhole sampling runs. Finding sweet spots for reservoir sampling is challenging as the permeability cannot be clearly understood using conventional log and NMR log. This study reveals the link between the textural aspect of a rock to its petrophysical properties using high resolution resistivity Image log, basic open hole logs and NMR which can improve the prediction of permeability to qualify the sweet spots for reservoir sampling.

## Workflow

The heterogeneity in the Nakhtarna carbonate of Paleocene age, has been characterized using P3A* methodology that integrates, high resolution resistivity Image log, NMR along with basic logs. From high-resolution resistivity image a core like picture of the sub-surface formations can be visualized, and the texture of image logs help to delineate different facies of carbonate. Using external shallow resistivity curve, image is calibrated and transformed into a quantitative image. Applying Porospect* and Porotex* methodology brings out the representative proportion of macro pores in the image, along with that, using multiple resistivity cut-off image can segregate the proportions of matrix, resistive nodules and isolated & connected pores in the formation. The macro porosity is also calculated independently from NMR T2 distribution. The average of the macro porosity proportions (VISO) from Image log and NMR is used as the final macro porosity in the formation. Porosity Partitioning and Permeability Analysis (P3A*) partitions the porosity into Micro (< 0.5micron), Meso (0.5 to 5micron) and Macro (>5micron) components. A carbonate permeability is then calculated using the partitioned porosity in carbonates (Figure 1). In absence of core results, macro-porosity (KMACRO) has been calibrated with the water-bearing carbonate zones in Well 1. Along with the P3A* analysis, Connectedness analysis from image log is also carried out. The connectedness analysis gives an idea of the flow property and pore structure of the rock in terms of connected pores and isolated pores. Combining the carbonate permeability and connectedness analysis from high-resolution resistivity image and NMR along with conventional logs helps in identifying the sweet spots for reservoir sampling/ perforations. Traditionally P3A* analysis is done in the later phase of a well when the complete reservoir characterization is required.

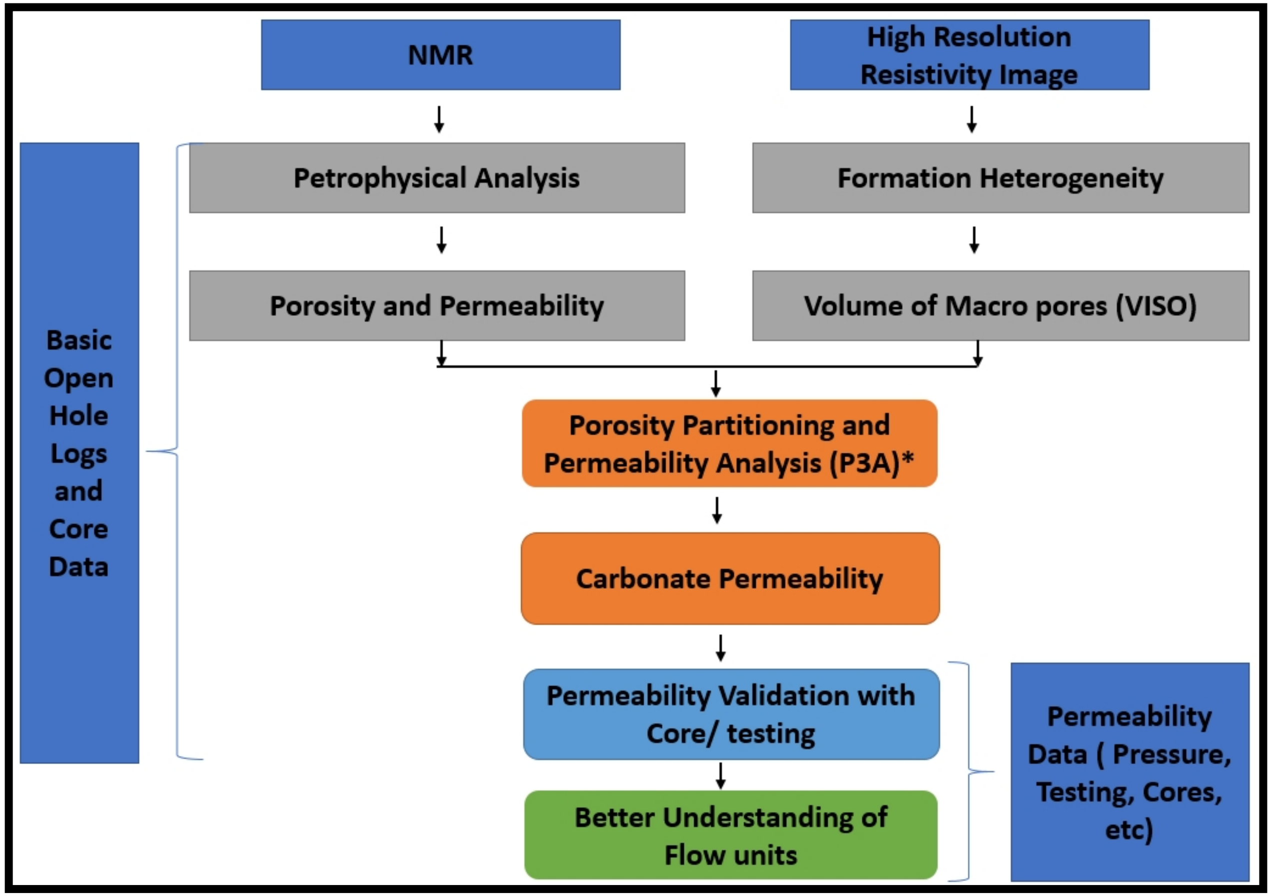
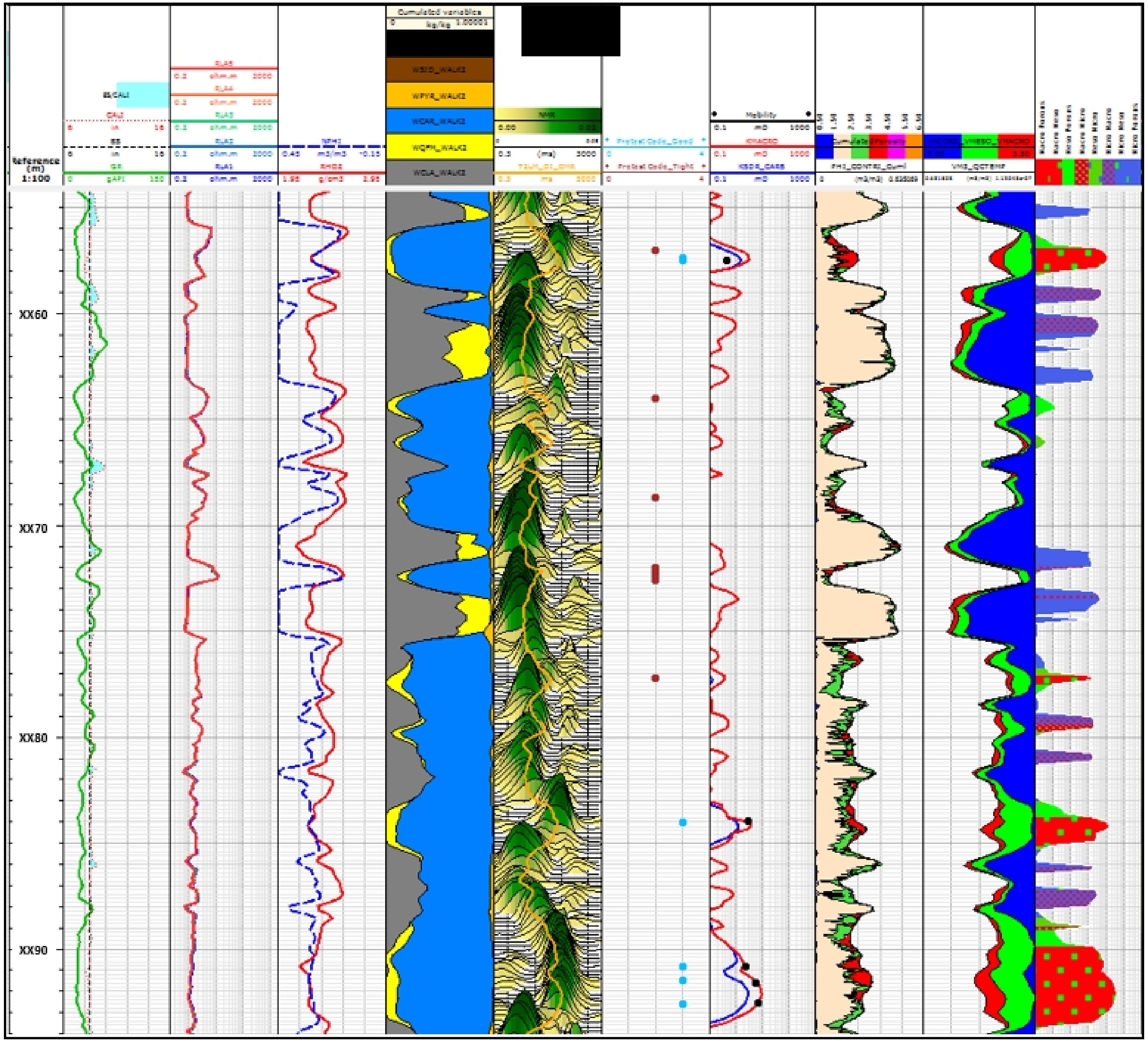



**Figure 1:** Workflow for performing the flow characterization in carbonates

## Analysis Overview

The general convention is to optimize the sampling points based on the log responses of the basic logs along with the NMR porosity, permeability and T2 distribution. In the Nakhtarna carbonates, despite having high free fluid indication from NMR T2 distribution, many pressure sampling points turn out to be 'tight'. For a detailed analysis of these formation, connectedness analysis and P3A* analysis was carried using NMR and high-resolution Image log. We observed that the zones that have high macro porosity, but the pores are not connected to each other. This can be identified by running the P3A* first and identifying the zones contributing to the macro porosity. Against the similar zones, it is observed that some of the macro porous zones are connected (as indicated by the red colour from the Porosity Contributed Cumulative curve- Track 9) while others are isolated connected (as indicated by the red colour from the Porosity Contributed Cumulative curve - Track 9). These can be clearly seen from the Figures 2, 3 and 4. The 7th track from left (Figure 2, 3 and 4) represents the sampling results. Brown colour indicates 'tight' points whereas Blue colour indicates 'good' points. As can be seen from these figures, the blue point corresponds to the depth that have good macro porosity (as indicated by the red colour in the 10th track), as well as good connected pores (as indicated by the red colour from the 9th track). On contrary, brown point corresponds to the depth that have good macro porosity (as indicated by the red colour in the 10th track), but isolated pores (as indicated by the green colour from the 9th track).

In this study, we have tried to propose a workflow, where we can optimize zones for sampling in the sweet spots by integrating the P3A* rock-typing along with FMI* Porotex* and Porospect* technique.




**Track 1: Depth track**

**Track 2: Bit Size, Caliper and GR**

**Track 3: Resistivity**

**Track 4: Neutron-Density**

**Track 5: Spectrolith log**

**Track 6: NMR T2 distribution**

**Track 7: Sampling points (**Brown colour indicates TIGHT points whereas Blue colour indicates GOOD points**)**

**Track 8: Permeability logs derived from P3A* (**Black dots indicates mobility of the sampling points**)**

**Track 9: Porosity Contribution Cumulate curve from high-resolution image log (**Applying Porospect* and Porotex***)**

**Track 10: Porosity distribution from NMR log (**derived from P3A*)

**Track 11: Rock typing from NMR log (**derived from P3A*)

**Figure 2:** Composite Plot for Well

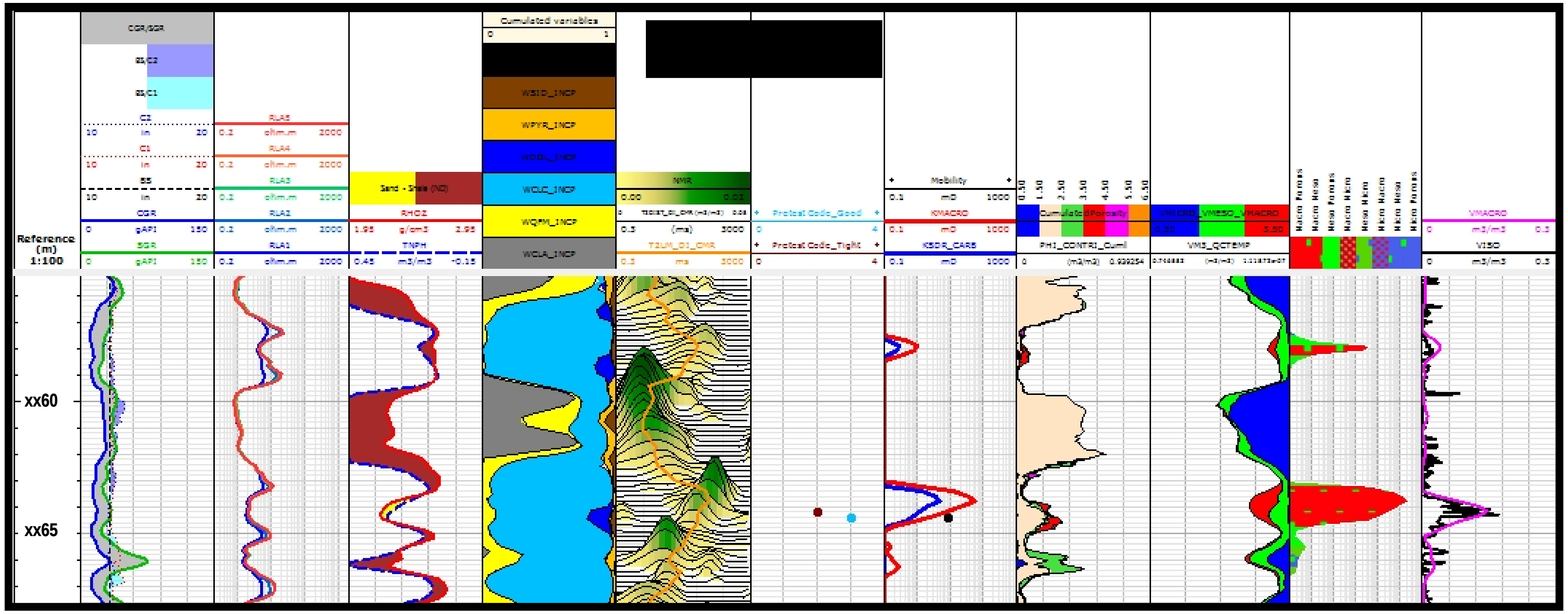



**Figure 3:** Composite Plot for Well B, Zone 1. (Track description same as Figure 2)

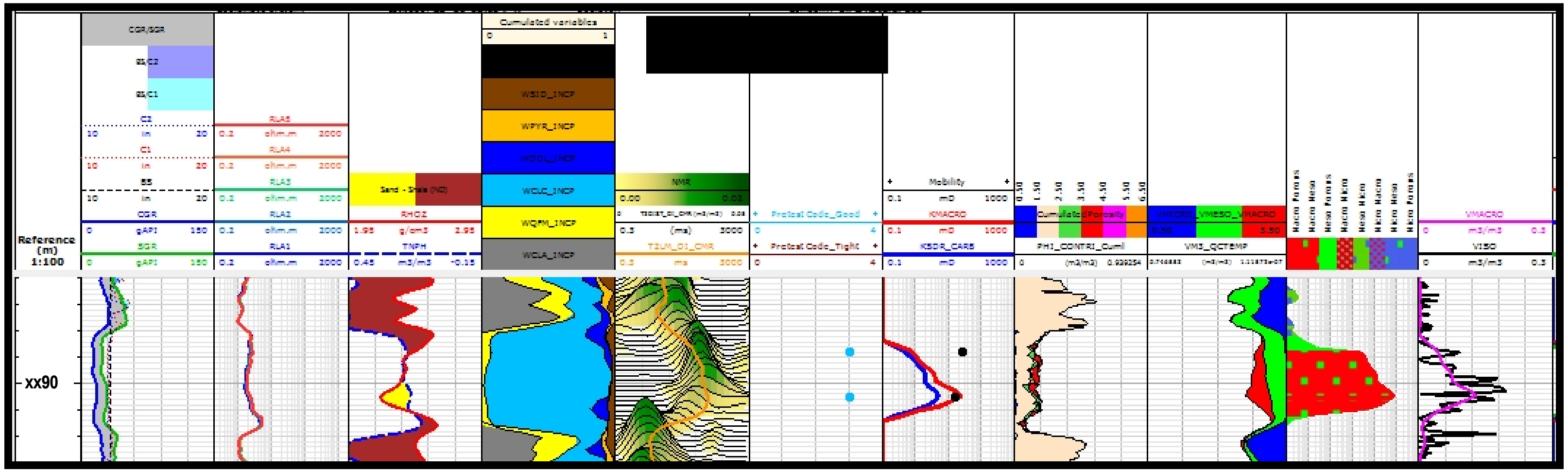



**Figure 4:** Composite Plot for Well B, Zone 2. (Track description same as Figure 2)

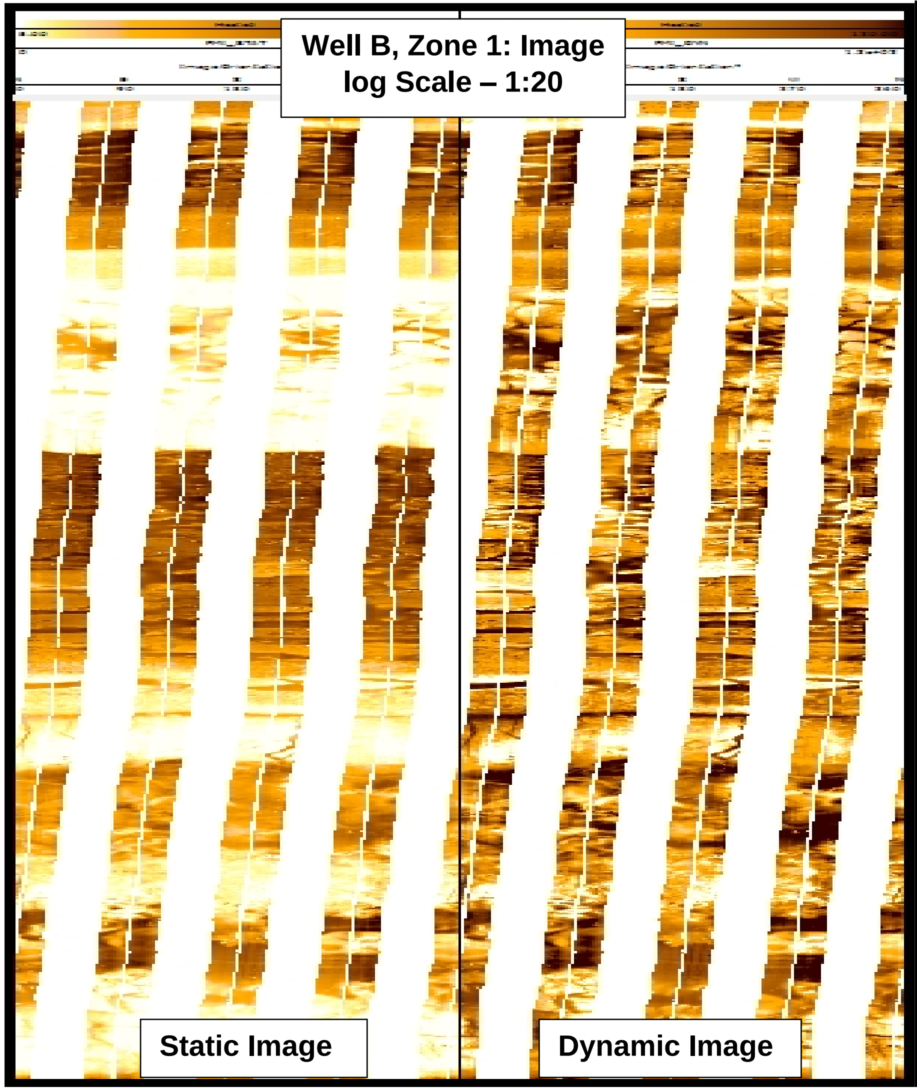



**Figure 5:** In the above image a prominent stratified carbonate is present, where an alteration of tight carbonate and marl section is visible. These high resistive carbonates probably indicate to a high density low porosity carbonates. Due to the carbonate cementation the pores get filled and the resistivity increases. Marl section is mostly argillaceous carbonate.

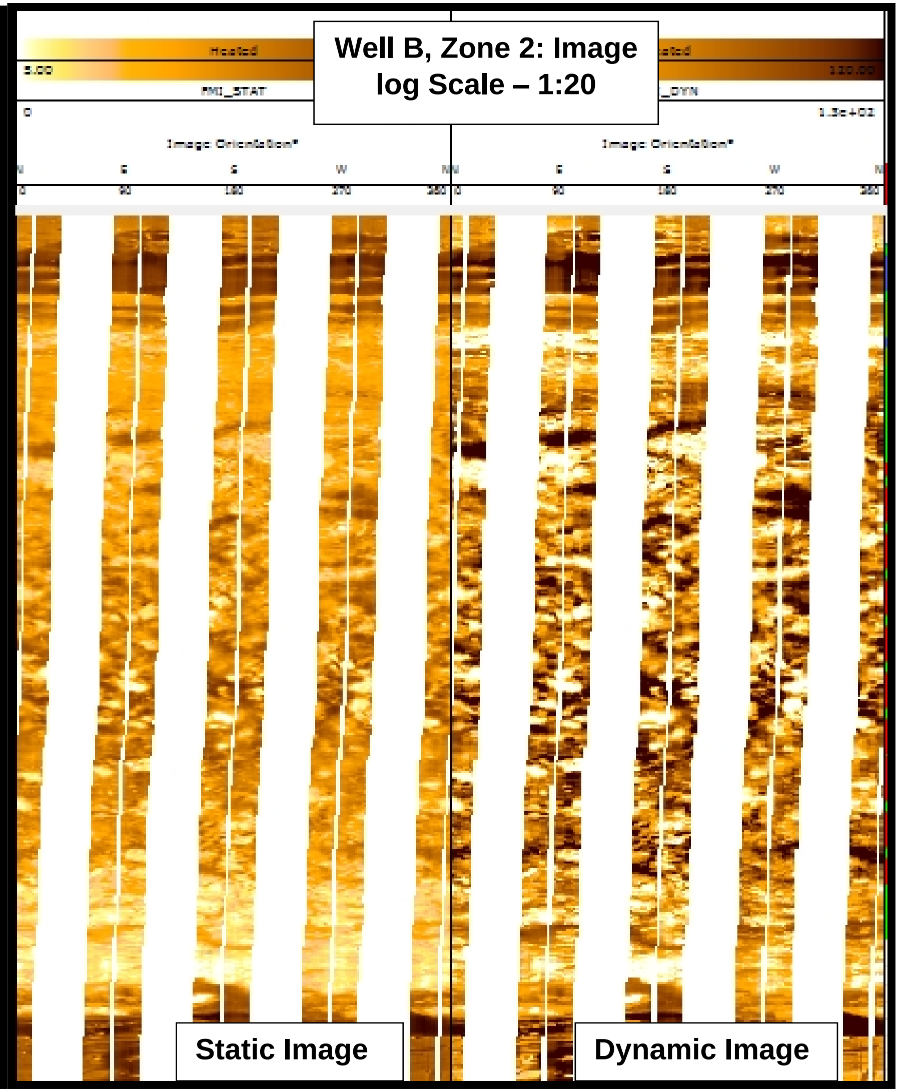



**Figure 6:** In this image some porous and highly heterogeneous carbonate facies is prominent. The Image is suggestive of a potentially good carbonate reservoir facies in carbonate with possibility of well-developed pore to pore connections.

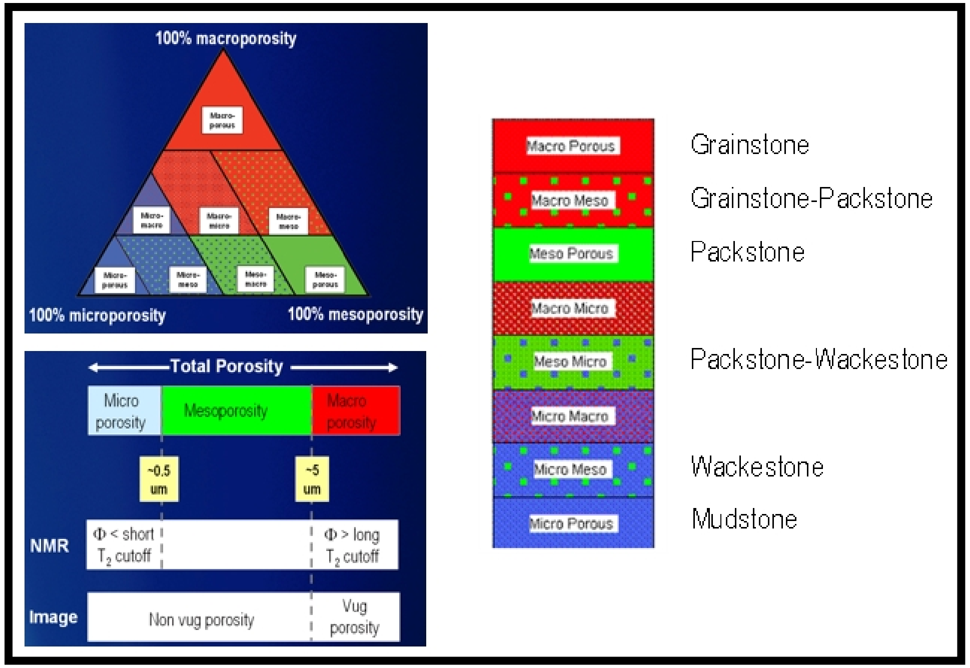



**Figure 7:** Ternary diagram specifying 8 rock classes based on relative proportions of micro-, meso- and macroporosity (Ref 4 and Ref 7)

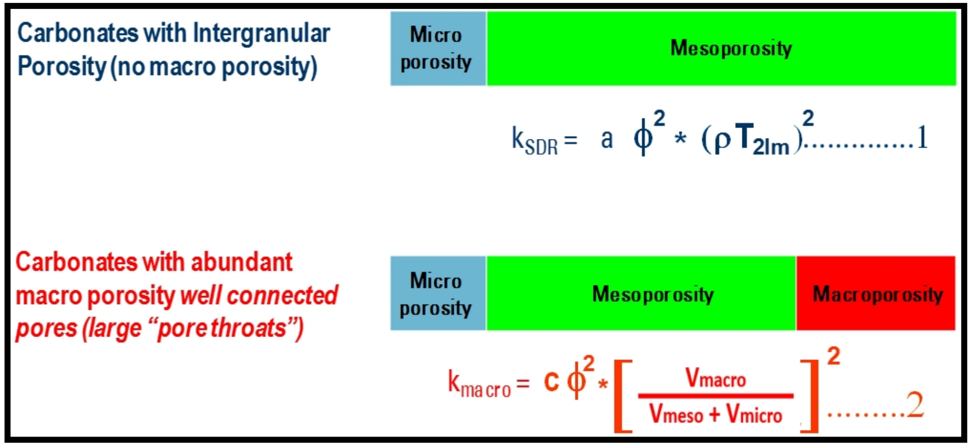



**Figure 8:** At each log depth interval, one of two simple permeability equations is chosen, based on the amount of macro porosity measured by the log data.

In carbonates containing predominantly micro and meso porosity, the permeability is controlled by the porosity and grain size. In these rocks, the preferred equation is the SDR carbonate equation (eq. 1) where phi is the total porosity fraction, rho is T2 surface relaxivity and T2LM is the T2 logarithmic mean from the NMR log.

In carbonates containing abundant connected macro-porosity, the permeability is controlled by porosity and the volume of macro-porosity. In these rocks, the preferred equation is the K Macro porosity equation (eq. 2) where c is a constant adjusted to the specific formation, phi is the total porosity fraction and Vmacro is the macro porosity fraction based on borehole electrical image log analysis or NMR log analysis. (Ref 8)

## Findings & Conclusions

- The carbonates in this field have a varied porosity distribution which proves to be quite challenging while interpretation with basic open-hole logs.
- Improved understanding of rock heterogeneity for better reservoir management
- Porosity Spectrum Analysis gives understanding of the dual porosity system in carbonate reservoirs.
- Established Porosity-Permeability transformation relation for the studied wells.
- This methodology identifies different permeable unit in such types of complex heterogeneous carbonate reservoir by different porosity distribution and pore partitioning.

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