SPWLA INDIA CHAPTER

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Quarterly Bulletin
Volume 2 Issue 4
January-March 2022

Value Addition through Enhanced Micro Resistivity Imaging in Oil Based Mud

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Enhanced Micro Resistivity Imaging tool was deployed in exploratory well XY#Z in KG Offshore to map the geological features through borehole images. The service was deployed in Dual configuration in low resistivity environment with Oil Based mud system. The service delivers high borehole coverage and vertical resolution which enables high confidence in identification of near-wellbore geological features and petrophysical evaluation.

The innovative design of the Enhanced Micro Resistivity Imaging service utilizes advanced electrical conductivity measurements with multiple frequencies. This design enables petrophysical and geological evaluation in low-contrast, low resistivity environments and enhanced vertical resolution in oil-based mud (OBM) systems. High-resolution pads with 10 sensors are mounted on six articulated arms, providing 60 micro-resistivity measurements with a vertical resolution of 0.2 in and 80% borehole coverage (in an 8-in borehole). The service delivers borehole coverage greater than 90% in a 12 1/4-in hole, in dual configuration. The exploratory well XY#Z was drilled to explore the hydrocarbon potential of Deeper Vadaparru sequence (Eocene). To resolve low resistivity (minimum 0.5 ohm-m) sands in this well, the Enhanced Micro Resistivity Imaging log was recorded in target sands.

- Fractures are clearly resolved on the Enhanced Micro Resistivity Imaging data, owing to its high vertical resolution with NE-SW average staking. (Fig:1&3)
- Thinly-bedded section observed on the Micro Resistivity Image data corroborates with the 3DEX anisotropy data. (Fig:2)
- Enhanced borehole coverage enables high confidence dip picking, with dip angle varying from 5-40 degrees. 9 zones with different orientation were also identified.(Fig:3)
- Bedding fractures are clearly resolved on the image data, and 3 different bedding azimuth were observed.

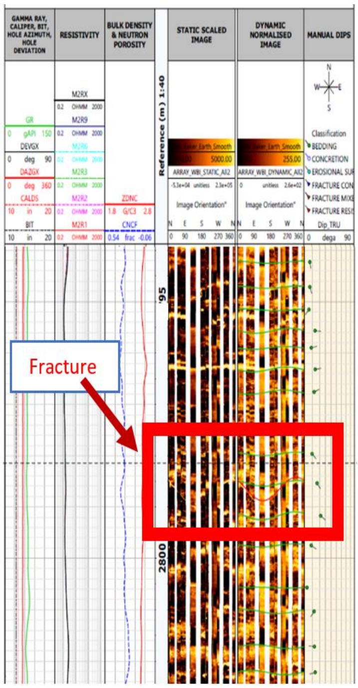

Fig: 1- Fractures

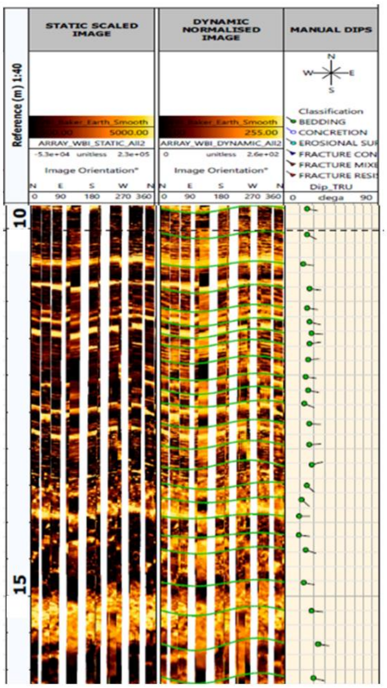

Fig: 2- Thin laminations

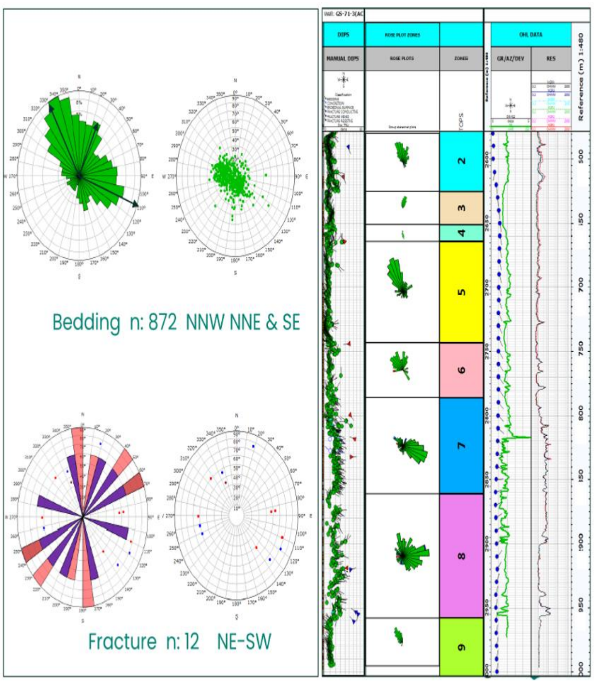

Fig: 3- Bedding and Fracture Orientation

Real time Fracture Characterization using LWD micro-resistivity imaging gives a fillip to devise optimal completion strategy using Inflow Control Devices (ICD) in horizontal drain holes

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Horizontal wells are drilled to increase the exposure of pay zones thereby achieving a more efficient drainage pattern leading to enhanced overall reserves recovery. Drilling horizontal drain holes also help reduce the number of wells that are required to develop a field substantially. However, the inherent challenges associated with horizontal well completions needs to be addressed during the development of a field to extend the well's lifetime. A horizontal well normally produces more oil at its heel section and wherever there are high permeability zones within the reservoir (Fig 1). The flow rate would be less in the low permeability zones and in the toe-section of the well pipe. The goal then would be to maximize oil recovery by creating a uniform flow pattern across the drainage area and effectively choking water and gas breakthrough downhole.

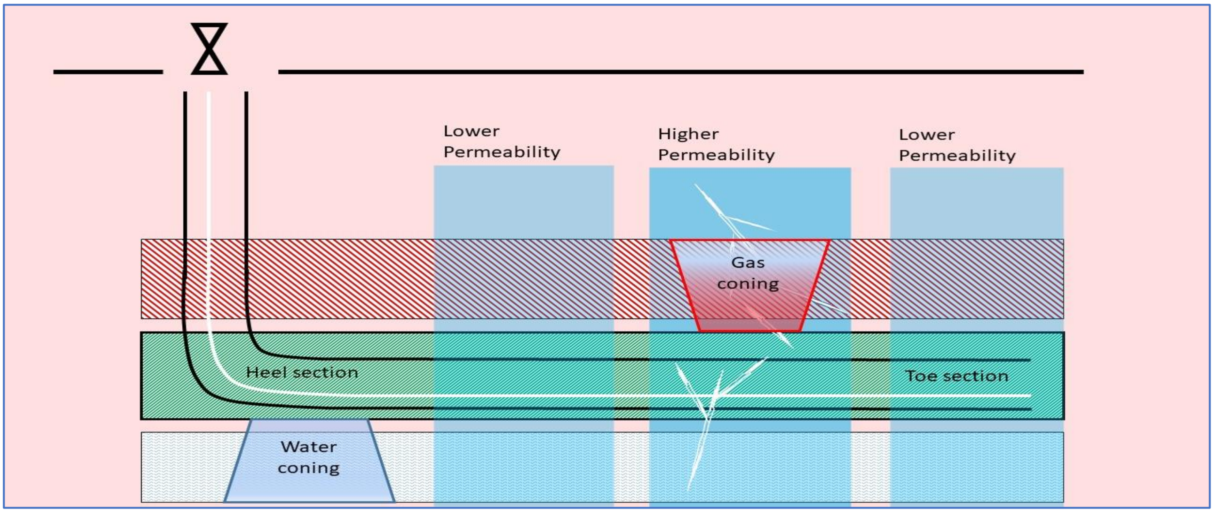


Fig 1: Representation of a horizontal drain hole in carbonate reservoir showing inherent heterogeneity

Inflow Control Devices (ICDs) are used to balance the initial non-uniform oil production in horizontal wells. This helps in draining oil at a slower pace in the higher flow rate zones, and thereby delaying water and gas coning in these areas. However, once water breakthrough has occurred, water production will dominate the flow for the remainder of the well's productive life. To mitigate this challenge, effective means of choking the unwanted fluids downhole itself within the reservoir, zone by zone, using appropriate number of ICDs with optimal Flow Resistance Ratings (FRR) are employed during completion.

In typical carbonate reservoirs like the Bassein pay of Neelam field in Mumbai High, the presence of natural fractures, vugs and solution channels add to the heterogeneity and it becomes all the more important to identify these zones for proper placement of ICDs. High resolution wireline resistivity imaging techniques have long been used for identifying natural fractures, their intensity and direction in both clastic as well as carbonate reservoirs. However in horizontal wells with long drain holes, the log data acquisition has evolved over the years from pipe conveyed logging to state of the art real time Logging While Drilling (LWD) methods which saves valuable rig time. Micro resistivity imaging logs were recorded on LWD in below mentioned wells for fracture characterization, compartmentalization of the drain hole and further completion using inflow control technology (ICT).

The three development locations XYZ-4H, XYZ-5H & XYZ-6H, released in Neelam field were planned for an ICT completion. The field has been on production for nearly more than 4 decades and is presently producing with high water cut at 90-91% W/C. By completing the wells with optimal number of ICDs after proper isolation of zones, it was envisaged to reduce the liquid rate compared to the field average so that water breakthrough is delayed as much as possible thereby improving both the daily production of oil and the ultimate oil recovery.

In the aforesaid wells, 6" drain hole was drilled from the 9 5/8" casing shoe and while drilling, besides the basic suite of LWD logs, LWD micro resistivity imaging logs were also recorded for detailed fracture and fault characterization. The acquired LWD micro resistivity image, upon processing, clearly showed the presence of fractures which could be later demarcated into different zones for final ICT completion depending upon the fracture density. In well XYZ-6H where fracture distribution was clearly brought out by LWD micro resistivity image (Fig 2), four zones were identified based on the fracture swarms viz., XX98-XX65m, XX65-XX02m, XX02-XX75m and XX75-XX15m.

These were isolated by placing swell packers in between. Optimal flow resistance rating (FRR) for the ICDs were chosen based on the heterogeneity, envisaged flow rates against each zone and other geological inputs. Best practices suggest that the compartment which is more susceptible to the water/gas inflow will require higher FRR. FRR is a term that underlines the strength of pressure drop achieved across the ICD and also the degree of choking imposed. As a rule of thumb, the average pressure drop across the ICD has to be equal or greater than the pressure drop within the formation. In well XYZ-6H, ICDs with higher FRRs were employed in the top three zones which had relatively higher density of fractures aiding greater permeability regimes (Fig 3).

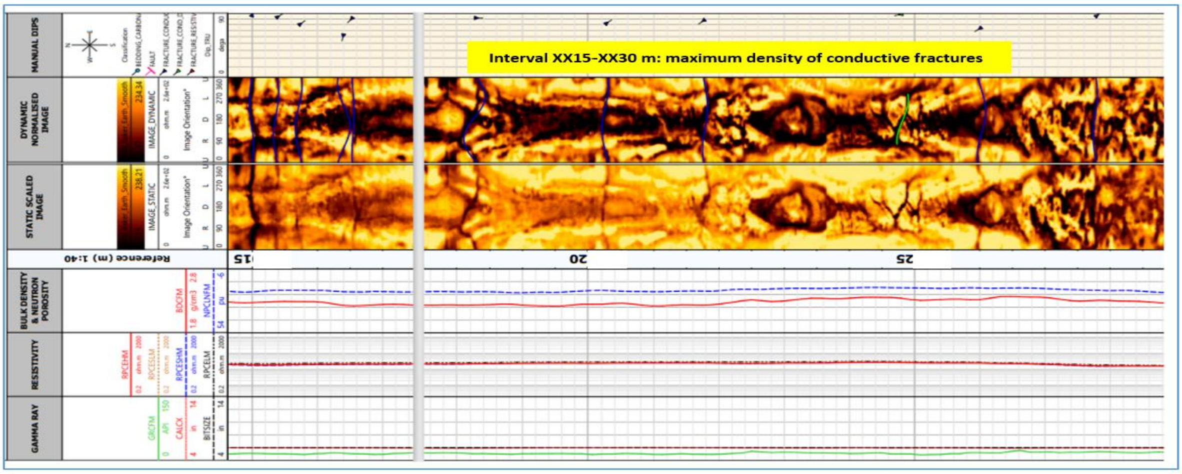


Fig 2: LWD Micro Resistivity image showing the presence of fractures in well XYZ-6H

The successful choking back on production at high permeability regions meant that the well initially produced 620 bopd oil with no water. The completion of the three wells with inflow control technology has resulted in initial cumulative oil production of **1422 bopd** from these three wells with substantially **low water cut.** In Comparison, nearby wells are producing with high water cut.

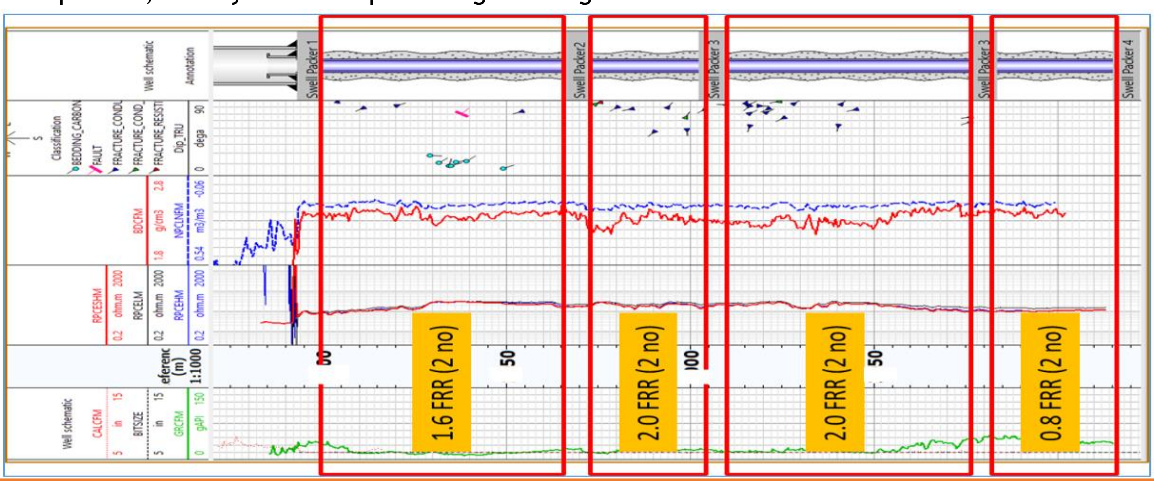
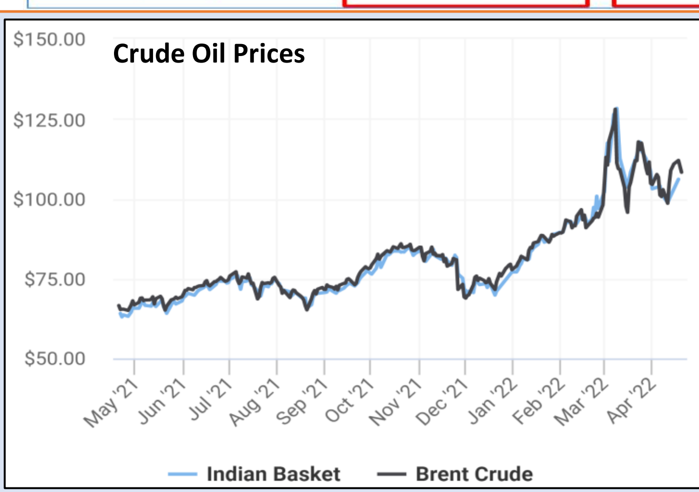
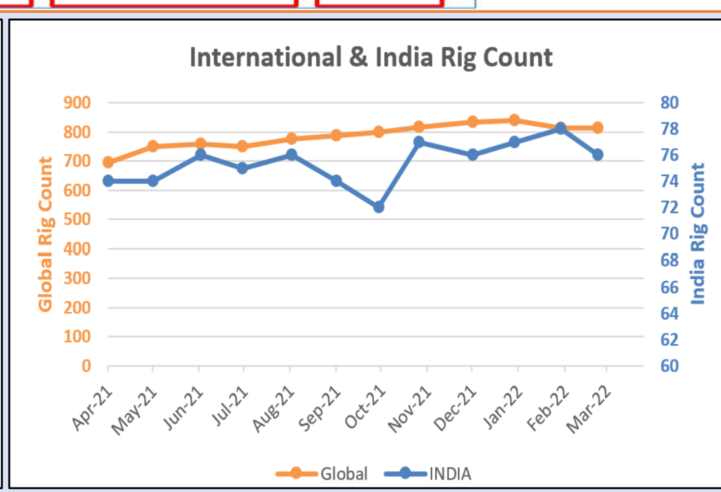


Fig 3: Completion plan of Well XYZ-6H showing the compartments isolated by swell packers and ICD configuration.





Quantifying uncertainty through AI-ML driven Advanced Lithology Interpretation

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Background: Advanced Lithology Interpretation is an integrated interpretation technique which uses supervised machine learning to predict lithology from log responses according to a trained model. Using trained lithology models, unseen wells with pertinent log curves can be processed and a predicted lithology provided, alongside confidence in that prediction, through prior and posterior probability calculations. Mapped features are classified into expected lithology categories, using the trained predictive model, and the resulting classification undergoes post-processing. This workflow is able to deliver rapid, detailed, and consistent lithology predictions for a well in less than five seconds.

Objective to deploy supervised machine learning: Lithology Interpretation plays an important role in a reservoir study as it provides primary input data for reservoir characterization of subsurface formations and evaluation of resources. Manual lithological interpretation of petrophysical well logs for large set of wells is a time-consuming process and it can also sometimes lead to inconsistencies between wells interpretation due to interpreter bias which ultimately attributes errors in subsurface models. Complete suite of logs are not always available throughout all sections of borehole. Therefore, to address these challenges, to reduce uncertainties and increase productivity a completely new AI-ML driven process has been devised.

Value Addition through Supervised machine learning: Trained lithological models built by data scientists are provided by default within the supervised machine learning technique to deliver rapid and consistent lithology interpretations. The models have been trained using supervised machine learning (ML) techniques, learning from a number of wireline or logging-while drilling (LWD) data. Algorithms are encoded with intelligence to recognize combined features in well log curves and quantitatively assess the likelihood that these represent a particular lithology, based on previous examples seen by the system.

Results: The proposed AI-ML solution not only address the above-mentioned challenges but also brings new way to quantifying estimation of uncertainties in lithology interpretation through probabilistic approach. This data derived automated supervised novel solution approach has the following elements/workflow sequences.