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New Age Formation Testing and Fluid Characterization Techniques for Evaluation of Marginal Fields in Offshore India

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Abstract

The giant Mumbai High structure, offshore the western coast of India is already in its late development phase. To address the falling production from this field, the focus of the operator has now shifted to more complex marginal cluster pools flanking the main structure.

These untapped reservoirs are widely different from the known field, and pay zone identification from even the most advanced petrophysical measurements is challenging. Another major concern here is elevated level of corrosion in production facilities. Pre- completion quantification of corrosive components, suspected to be carbon dioxide, is very critical for proper material selection and installation.

Traditionally, downhole formation fluid analysis has been a precursor to well completion. Evolution of formation tester probes and spectroscopy has addressed this task successfully in conventional environments, but here the unique challenges called for a brand new solution. Rigorous simulations for different probes were run to find best suited answer for region specific issues. The results indicated towards a new fluid inlet module with circumferential openings and much larger flow area: the 3-D Radial Probe, as a solution. For the first time in India, the new probe technology was used to successfully delineate the hydrocarbon bearing layers in mobilities as low as 0.07 mD/cp. Coupled with latest fluid analyzer capable of insitu CO_2 characterization, the combination quantified multiple levels of carbon dioxide (ranging from 1-20%) in different wells and provided critical inputs to designing of production facilities.

In this paper, several case studies from these marginal fields would be discussed highlighting the game changing revolution in the world of downhole fluid identification brought by the new radial probe and fluid analyzer combination. This would serve as an example for petroleum community worldwide, facing challenges with tighter and tougher reservoirs.

Introduction

Cluster fields satellite to mammoth Mumbai High field are mainly faulted carbonate structures with varied development of different limestone layers, basal clastics and basements. (Fig 1) Different degrees of development of vug connectedness in carbonate layers and complex mineralogy of the unconventional basal clastics make it difficult to conclude reservoir fluid type or establish reservoir connectivity with even the most state-of-the-art static petrophysical measurements. Fluid type in this region across different pays is different in different fault blocks and needs to be ascertained before going ahead with completion or testing.

Fluid composition and pore pressure measurements have been instrumental in making accurate reserve estimates and create representative reservoir models. In the past most formation fluid samples were captured after they reached the surface during Drillstem tests and production well tests and were separated into gas, oil and water components. These samples were then transported to offsite laboratories for analysis. But characterizing fluids from surface samples can be problematic due to many reasons such as contamination of sample while trying to attempt recombination; inducing pressure losses while transportation, recreating in-situ conditions. This is why formation tester tools lowered on wireline logging cable to multiple zones of interest, were introduced to address these and other sampling difficulties, since the 1950s.

Wireline Formation Testers (WFTs) have typically provided valuable information with respect to fluid characteristics using two basic configurations: either a single probe device or an inflatable straddle packer device. The choice of configuration is basically a trade-off between an easy to deploy probe with a small area of contact- typically a few square centimetres, or a difficult to deploy but very large surface area straddle packer. Formation fluids are analysed downhole for contamination and are flowed or pumped into the tool for capture and retrieval to surface, while pressure and temperature is measured using downhole gauges. Analysing fluids for purity before being directed to sample chambers allows contaminated fluids like the mud filtrate to be removed before samples are captured in bottles. These bottles are capable of maintaining fluids at formation pressure to avoid phase changes while the samples are being retrieved to surface for transport to a laboratory for analysis.

While pumping with WFT downhole, flow from the reservoir streams in a conical volume toward the probe and draws contaminants from the near wellbore invasion zone as well as some vertical distance along the wellbore. The outer edge of this flow stream may contain significant amount of non-reservoir fluids which may then require extended periods of time to be pumped away. Innovations in WFT designs have done much to overcome these limitations, especially shortening clean-up time. Several probes such as the focussed probe technology have over the years, ensured purity of samples and shortened time on station, which aggregates to significant savings in operating expenses. However, factors such as low permeability rock, high invasion environment and complex mineralogy still impact sampling success.

To be able to choose the most suitable probe type for downhole sampling in the wells from marginal fields in our case, a robust near well bore in-house simulation model was created with rock and fluid property inputs from existing field data. Further, detailed flow modelling based analysis was carried out, to be able to compare and contrast filtrate clean up performance in case of immiscible contamination model (hydrocarbon flow in water based mud filtrate scenario) for all possible probe type technology available. Sensitivity analyses were carried out for a wide range of formation properties and operating conditions. (Fig 2)

Comparison of the clean-up performance pointed towards the fact that in the face of numerous problems like very low intrinsic permeability, best available probe technologies were of limited use for high confidence fluid characterization. The simulation results indicated that a recently commercialized new 3D Radial Probe module is 10 to 20 times faster than the single-probe tools when sampling in tight formations. This new fluid inlet module is an in-between probe and packer type technology. This probe module attempts to combine the easy deployment and small dead volume characteristics of single probe tools with the larger flow area and full wellbore coverage of inflatable straddle packer. The 3D radial probe consists of four elliptically shaped probes mounted at 90 degree intervals around the circumference of the tool; each of the probes has a surface area of $20 in^2$ which compares favourably with $6 in^2$ of the largest single probe available (Fig 3). An inner bladder helps probes press against borehole wall. It is notable that the new module seals with less than half the inflation volume as compared to traditional packer inlet. The packer used in this probe seals more reliably against a rugose borehole than single probe WFT packers do and inflates and deflates more quickly than the dual straddle packers while completely eliminating sump volume, which further hastens clean-up process.

Putting Theory to Test: Case Studies

The Mumbai high cluster fields are predominantly carbonate reservoirs overlaying basal clastic and basement formations. The carbonate reservoir in this region has its own set of characterization challenges. Formation pressures cannot be used to construct gradients here due to rock tightness. Due to high invasion volumes, fluid sampling exercise tends to exceed desired station times than the times advised by sticking risk analysis. OWC levels and fluid type identification becomes ambiguous in low resistivity zones on the openhole logs. The decision on traditional zone saturations and their producibility can often be very challenging.

Well A was drilled in the marginal structure across carbonate and basal clastic formations which were objective targets. A formation testing solution using a combination of a fast measurement pressure while logging tool and modular wireline formation tester equipped with the innovative 3D Radial probe design was proposed to enable successful downhole fluid identification in minimal rig time. A total of 17 pretests using pressure while logging tool across the well section indicated maximum mobility expected would not be more than 4mD/cP indicated by one pretest, with all other mobilities reading lower than 1mD/cP. Based on the result of this run, the sampling toolstring was proactively designed, keeping in mind expected formation characteristics and relevant risk assessment: (Fig 4(a))

Fluid Analyzers: The string was equipped with two fluid analysers, above and below the Radial probe inlet. Above the pump was latest generation fluid analyzer with full composition measurements (Raghuraman, 2007) and below the pump was a fluid analyser for basic composition and fluid identification.

Pumps: There were two MRPO pump modules in the string. The lower pump was used to inflate the probe elements and for initial clean-up, to preserve the main upper pump to be used for final clean-up and sample acquisition. Furthermore, the upper pump was configured with a 385cc high pressure displacement unit allowing lower flow rates to control drawdown while sampling.

Fluid flow was successfully established in very tight formation across multiple pays, with near wellbore mobility measured in the order of 0.04mD/cP (Fig 5). Formation pressure measurements indicated flow regimes that were well established in pressure derivative- time plots (Fig 4(b)). Rates as high as 54 litres/hour were achieved in low mobility scenario. Hydrocarbon breakthrough was identified on the analyser at soon as 15 minutes, even in the face of flow line differential pressures of the order of 3500psi. In the toughest basal clastic formation, oil slugs were conclusively identified, marking additional reserves, for later exploitation using stimulation

In well B, in the same structure, new 3D Radial Probe was run with the latest generation fluid analyzer with full composition measurements, and the capacity to measure downhole CO_2 content. (Raghuraman, 2007). Carbon dioxide occurrence in this region was a major corrosion concern affecting capital and operational expenditures, causing corrosion failures, apart from being a Health Safety and Environment (HSE) risk. Optimizing the fluid sampling program with inclusion of latest generation fluid analyser was imperative here for in situ quantitative contamination to match existing fluid complexities.

In addition to achieving very high flow rates (50L/hour as compared to 20L/hour single probe run in similar environment), very high amounts of CO_2 were found in one of the three prolific limestone layers using fluid analyser based on near infra-red spectroscopy technique. Also, for the first time in the field the new inlet probe was identified as a viscous fluid flow enabler, as it identified downhole the flow of thick waxy crude, later confirmed on surface, leading the client to make informed completion decisions. (Fig 7(b)). The samples were obtained in least contamination state, and were sent for further lab analysis. The surface appearance of the sample indicated clearly towards the importance of fluid analysis in the region for flow assurance purposes. Sample analysis was recommended extremely critical for asphaltene analysis, resin analysis, and wax appearance temperature estimation.

Capturing CO_2 samples under wide range of environmental ambient pressures and temperatures of the geologic hydrocarbon reservoir for quantification in a laboratory is usually compromised by reactive nature of the gas, whose concentrations usually change before reaching analysis facility. Also, it is problematic usually to require numerous samples and perform large number of lab analyses, especially in case of a multiple layered reservoir such as in our case. However, quantification of CO_2 presence was critical for the client for ensuring appropriate design of completion and production facilities and optimal planning of reservoir production strategies. The state of the art formation testing toolstring comprising the fluid analyzer was run in multiple wells in the cluster field, and extensive in-situ quantification of CO_2 was done against multiple layers across the field. A significantly wide aerial variation of CO_2 was mapped in the area against multiple layers along the cluster field, which was not only a critical input for further equipment design and production strategy, but also helped provided a keen insight into the areal variation in physical and chemical properties of the hydrocarbon fluid in the field.

The first time 3D radial probe deployment in Indian oilfields proved that it is a powerful enabler to test low and ultra-low perm formations as well as highly viscous crudes. The impact of this technological innovation was realized in the first well where this combination proved a tight basal clastic reservoir to be oil bearing - an increment in reserves as much as 20m of pay zone thickness, contrary to the expectation of the operator. Based on the downhole oil flow establishment in these unconventional reservoirs, the operator also modified their individual well completion decisions by incorporating plans for stimulation before putting the wells on production.

In-situ downhole fluid analysis with NIR is another advanced fluid characterization technique that has proved to be a viable real time quantification method to quantify CO_2 content in the reservoir. Employing these technologies early at the time of openhole logging allows swift decisions and increases confidence in facility design selection.

References

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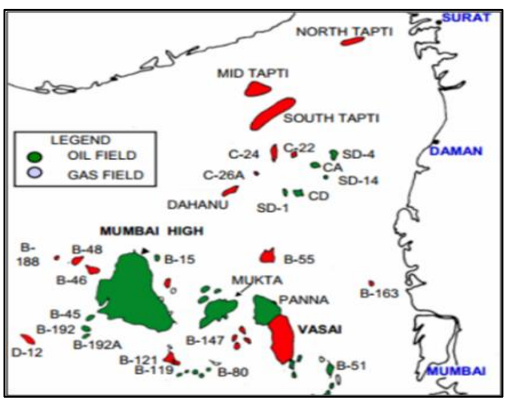

Fig 1: Map showing location of marginal cluster fields flanking the mail Mumbai High Structure

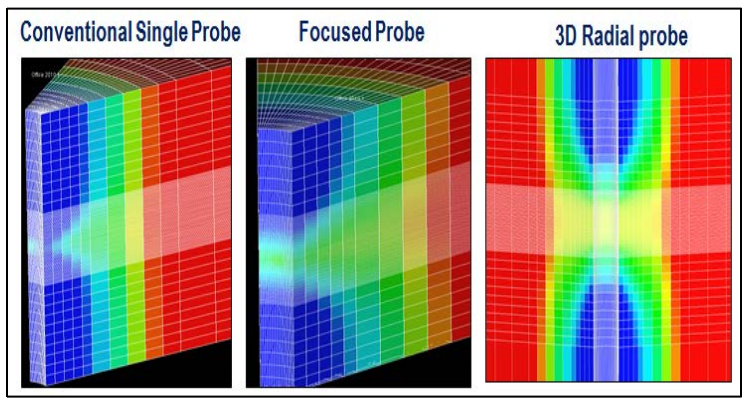

Fig 2: In house near wellbore fluid flow simulation for various probe types. Blue indicates maximum filtrate contamination whereas red indicates virgin formation fluid. Least filtrate contamination is observed on the sand face for 3D Radial Probe for similar reservoir setting, and same pumping rates for fluid flow

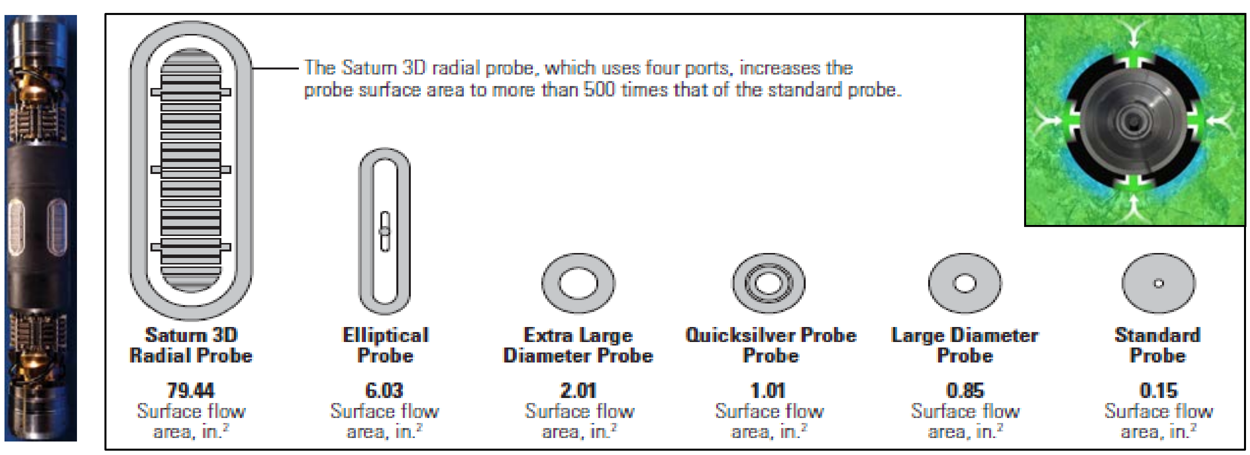

Fig 3: The 3D Radial Probe. The probe captures reservoir samples through four large ports spaced evenly on the tool's circumference. The ports are pressed against the borehole when the packer inflates and creates a seal separating reservoir fluids from wellbore fluids. The tool geometry provides a radial flow pattern (corner-right) for reservoir fluids (green) and faster removal of contaminated fluids (blue). The 3D Radial Probe has flow area many times larger than of traditional probes.

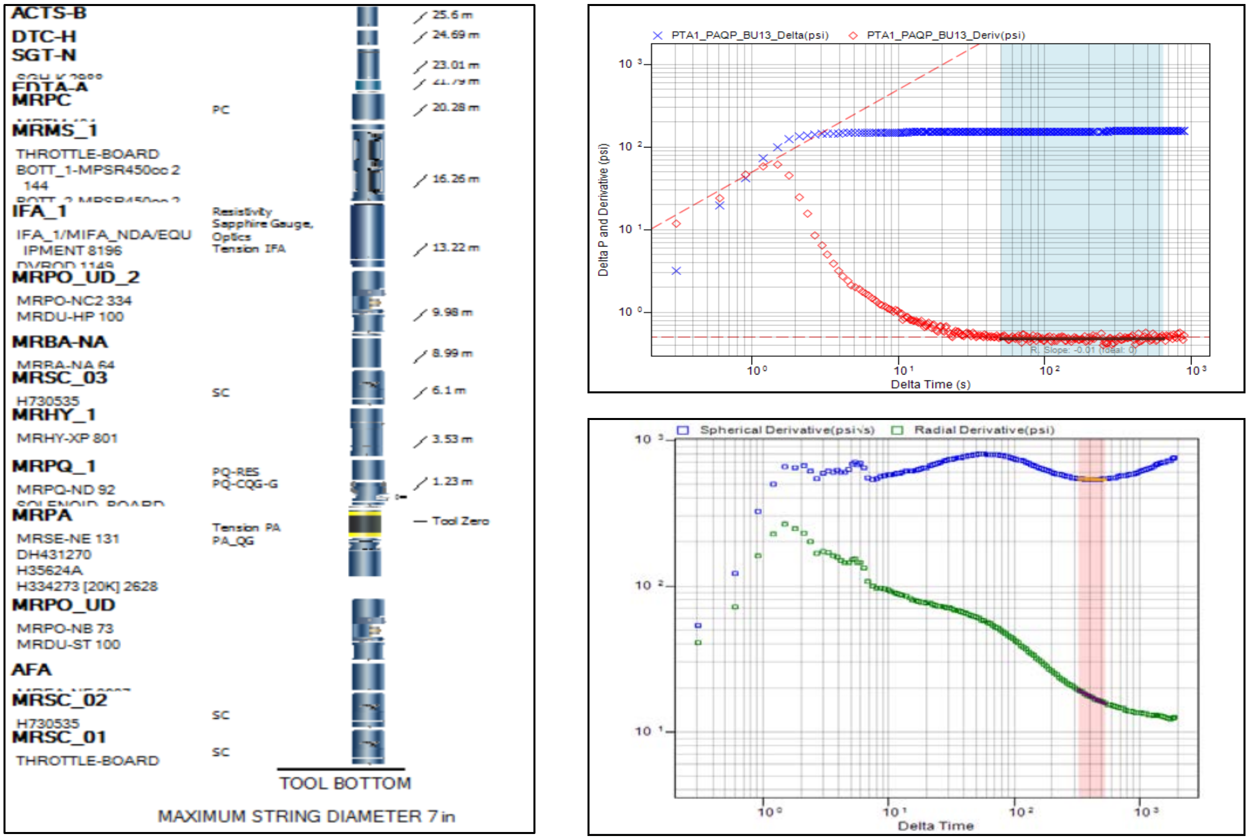

Fig 4(a) Left: WFT Toolstring utilized for sampling operation in well A; 4(b)Top Right: Flow regimes for a long buildup pressure acquired in basal clastic layer after sampling; Bottom Right: Flow regime for pressure derivative-time plots for pretest buildup. Well established radial/spherical flow regimes seen on all derivative plots.

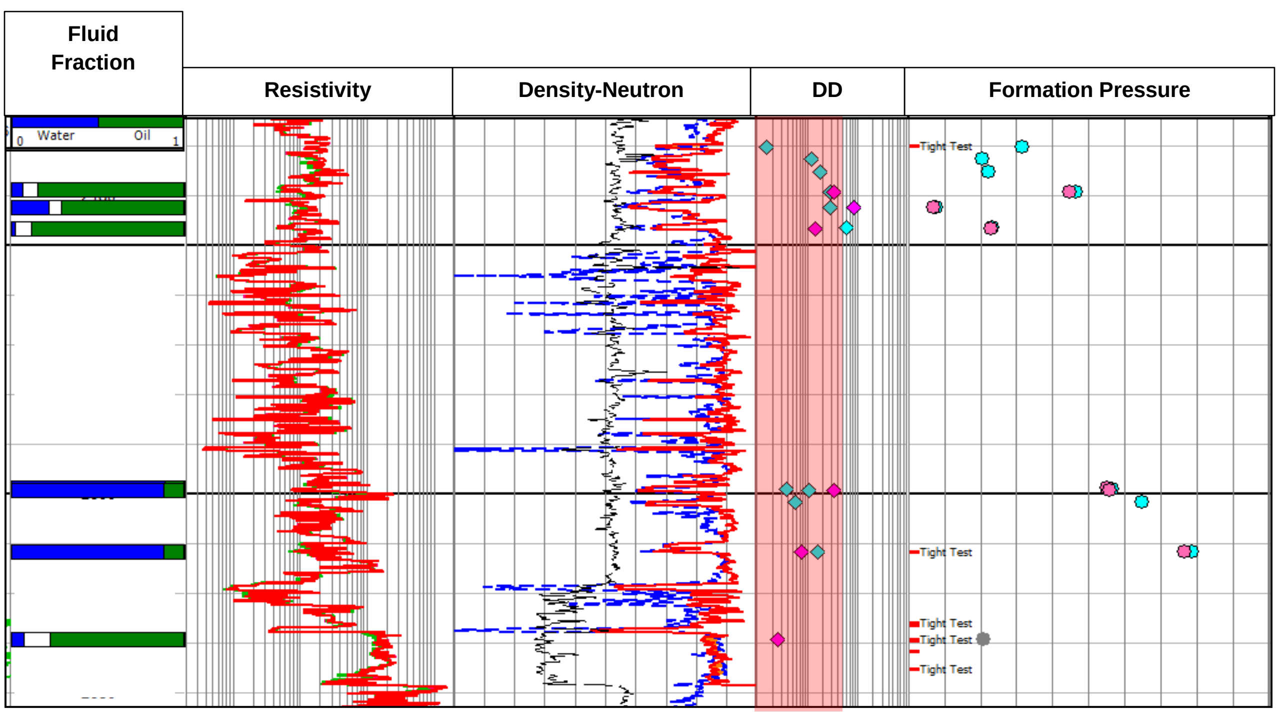

Fig 5: Fluid identification across multiple pay zones in well A was made possible with the novel 3D Radial probe. Note the mobility scale on the fifth track, ranging mainly between 0.02mD/cP to 0.08mD/cP.

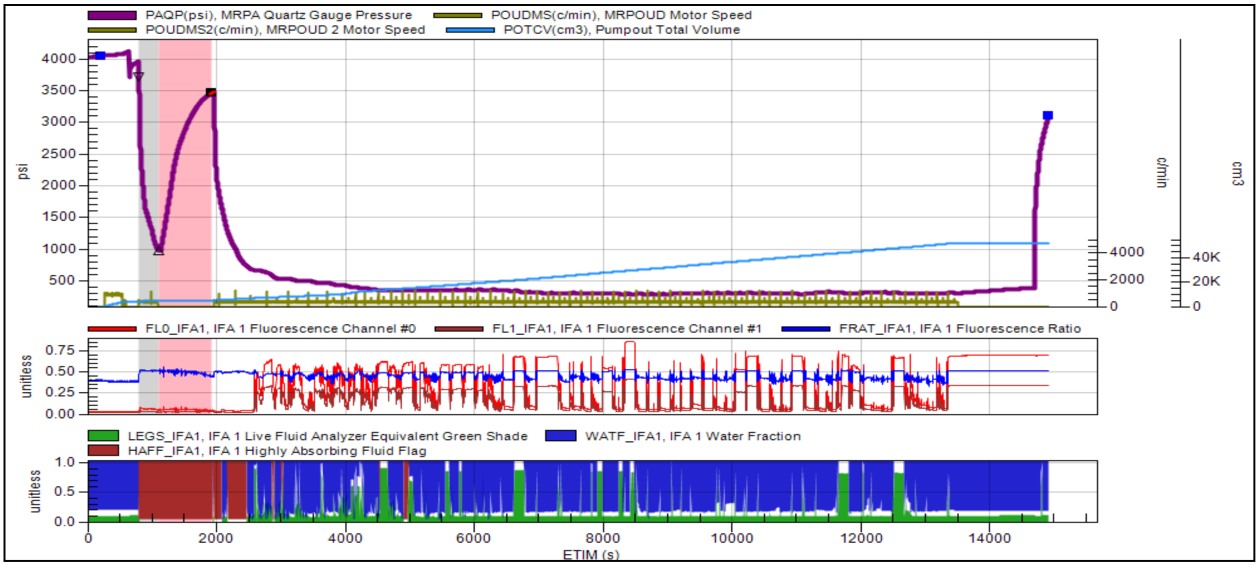

Fig6: Well A: Flow established in basal clastic layer in less than 0.1mD/cP mobility. Presence of moveable oil by Insitu fluid analyzer confirmed reserves within basal clastics. Green fraction represents absorption on the hydrocarbon channel, and blue fraction indicates water based mud filtrate.

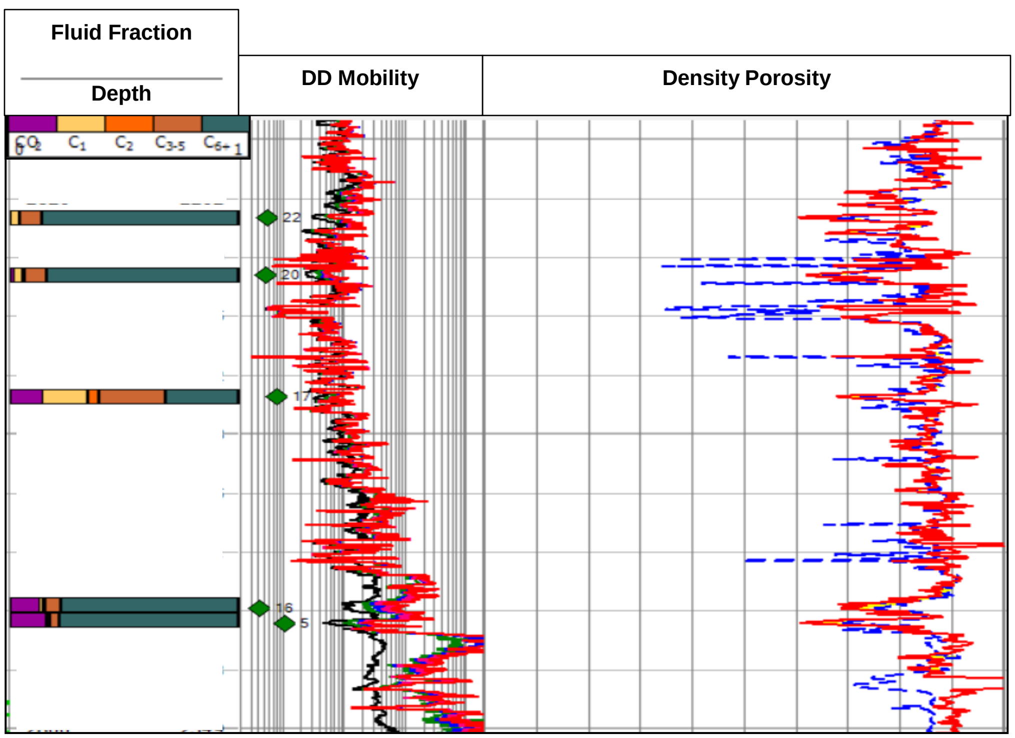

Fig 7(a) Top Left: Well B: CO_2 variation (magenta fraction) mapped across depth. Wide variation in CO_2 percentages were observed across different layers in the same well section.

7(b): Same is also graphically displayed on the graph (bottom right). Bottom Left: Waxy Crude observed on the surface after sampling using 3D Radial probe in well B. This proved that the large inlet flow area offered by the radial probe is also an enabler for flowing highly viscous crudes.

The sampling results in well B revealed critical information that served as input for planning flow assurance methods in this region.