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Challenges of evaluating LRLC reservoirs in a brownfield: A case study from Changmaigaon Field, Assam

Abstract

Resistivity log has remained at the base of identification of Hydrocarbon zones from logs and Estimation of Hydrocarbon saturation. The conventional approach, however, yield impractical outcomes in case of Low Resistivity-Low Contrast reservoirs. The subject has got much attention in the last decade and the understanding of these reservoirs improved tremendously. Many workflows have evolved to first understand the primary reasons for the LRLC and then develop/ adopt available methodologies used globally to tackle and develop the reservoir.

Brownfields pose a different problem in regard to older reservoirs having LRLC character. Due to adept practices (e.g. mud logging, correlations with nearby conventional reservoir) LRLC reservoirs were identified and put to production for many years. However difficulty in establishing fluid contacts and as a corollary the areal extent ends into uncertainty in geological model. This has a direct and serious impact on reserve estimates and the field development program. The depleted nature of reservoirs and impact of secondary recovery techniques viz. water injection programs render difficulties in adopting established methodologies for evaluating LRLC reservoirs in drilled wells. Another challenge in depleted brownfield LRLC reservoirs is to find a cost effective methodology.

In Changmaigaon Field of Assam Asset, Tipam reservoir TS-5A, the main oil producer is typical example of Low Resistivity-Low Contrast/ Reverse Contrast reservoirs. The field has been put to production since 1991. The reservoir shows signs of depletion despite initiation of water injection scheme since 2010.There have been hiccups in execution of the initial field development plan.

A combination of fresh formation water and grain coating with smectite clay are considered to be the main reasons for the LRLC nature of these reservoirs. Reverse contrast is observed in resistivity in few wells. The paper discusses the challenges in evaluation through case study of a well CMXX wherein a number of hitech logs were recorded in addition to conventional suite of logging to better understand this type of reservoirs. Also massive coring was done to calibrate the log response.

1. Introduction

Changmaigaon field was discovered in 1984 and put on production in 1991.Tipam reservoir TS-5A, the main oil producer in Block-1, is typical example of Low Resistivity-Low Contrast/Reverse Contrast reservoirs.

A typical log response is given in Fig 1. With formation water salinity in the range 3.5 – 4.5 gpl, conventional processing of the producing intervals (Rt~5-6 ohm-m and Φ~18 to 21%) yield 100 % Sw

Core studies carried out (Ref-2) presence of authigenic smectite clay coating sand grains with honeycomb morphology along with framboidal pyrite nodules, metamorphic rock fragments and altered mica as main reasons for LRLC in study area.

Traditional qualitative methods based on analysing the SP trends, Rxo/RT vs SP overlay were used to good effects to identify HC bearing zones. However quantification of Sw was a big concern.

Pradeep Kumar et. al. (Ref-5) provided a methodology to quantify Sw from SP which worked particularly well in wells drilled with KCL muds.

In order to fine tune development model in study area, hi-tech suite of logs (CMR/FMI/ECS/MDT) were recorded in development well CMXX. Conventional cores were cut in all relevant sands to calibrate log responses. While detailed core studies are in progress a preliminary understanding based on conventional and hi-tech logs was carried out. The paper discusses how the results converge and discusses the problems of interpretation of hi-tech logs in respect of analysis of LRLC reservoirs in depleted brownfields.

2. Reasons for Low Resistivity Low Contrast in TS-5A of Changmaigaon Field

Paul F. Worthington in his 1997 paper (Ref-1) brought out a comprehensive discussion on different reasons for LRLC, how to recognise and develop them. Amongst many reasons discussed in this paper, two most relevant reasons for LRLC nature of Tipams in Changmaigaon field are

a. Low Formation water salinity making prevailing shaly sand models unsuitable for carrying out the quantification and

b. Superficial micro-porosity caused by smectite clay minerals coating quartz matrix. The problem here is two-fold. First the evaluation of water saturation and second the apportionment of this water between immobile and free –fluid regions.

The combination of fresh water and superficial micro-porosities in Changmaigaon makes the evaluation all the more difficult.

3. Workflow/ Methodology :

a. Conventional

b. SP Method

c. Based on Hitech Logs

A broad workflow exists to identify the nature of LRLC reservoirs based on hitech log suites:

- Texture analysis on micro resistivity image and NMR log helps us to identify/ rule out whether Laminated shale sand sequence is behind the LRLC in a reservoir.
- Identification of micro-porosity present as capillary bound water in the NMR.
- Use Formation Tester to establish fluid contacts, fluid typing and take fluid samples.
- Use a combination of CMR and MDT for evaluating Sw using Pseudo Capillary Curves.

4. Log Analysis and Formation Evaluation

All conventional and hitech log based techniques were applied to analyse the well. The outcomes are discussed below:

4.1 Establishing the OWC:

In well CMXX, it is difficult to identify HC bearing zone using Rt values and establish Oil Water Contact in TS-5A sand. To overcome this problem, a composite of Rxo/RT-SP overlay, Rxo-DT overlay, MSFL logs and MDT formation pretest gradient plot (Fig 2) was analysed. While making overlays the two curves used e.g Rt/Rxo and SP are overlain over each other in known/ assumed water bearing zone. Any variance/ separation between curves are interpreted in terms of presence of hydrocarbon. In this case the Rxo log and Rt/Rxo vs SP overlay seems to identify the OWC at X80 m. The primary reasons for success of these two is that the use of KCL mud increases the water salinity in the flushed zone creating a little contrast between the HC bearing and water bearing zone in Rxo log. The uninvaded zone on the other hand is still having fresh water and shows similar resistivity (no contrast) between HC bearing and water bearing zones. This leads to increase in Rxo/Rt in Hydrocarbon Bearing zone. The SP also decreases in the HC bearing zone on account of the increase in Qv_{eff} thereby creating a further separation in Rxo/Rt vs SP overlay.

The DT vs Rxo also seem to support the OWC at X80 m.

Extensive MDT program was executed in this well to get some help to establish/ confirm OWC and Fluid type. As seen in Fig 1 MDT points were of limited help. The data reveals a depleted/ sub hydrostatic reservoir and at best be defined as showing signs of differential depletion. Measured mobilities were found to be less than 10 md/cp. LFA attempted at few points showed mud filtrate even after prolonged pumping 2-2.30 hrs.

The late arrivals on T2 distribution on NMR log response in top parts of the TS-5A sand were interpreted to be confirming presence of Oil.

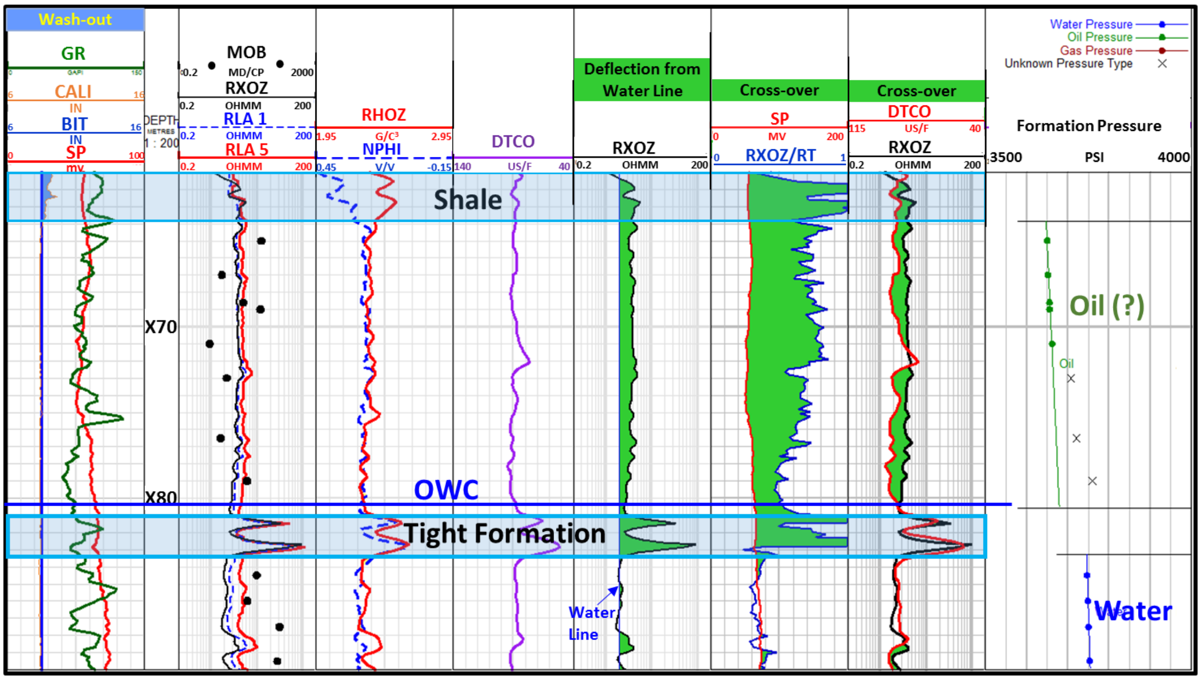

Fig 2: Determination of OWC for Well CMXX using Rxo/RT-SP overlay, Rxo-DT overlay, MSFL logs and MDT formation pretest gradient plot

4.2 Petrophysical Evaluation:

a) Conventional Method

The Petrophysical parameters were first evaluated in present well using conventional shaly sand method. A cross plot of Thorium Vs Potassium and Thorium Potassium ratio Vs PEFZ is used for mineralogical inputs. Minerals taken in the model are Quartz, montmorillonite and mixed clay. While good estimates of mineralogy and porosities could be made, using conventional parameters HC saturation was found to be nil.

b) SP-Method

SP-Method is based on the fact that principal contribution in SP amplitude recorded in high salinity KCl mud against fresh water formations is contributed by shale membrane potential as liquid junction potential is negligibly small due to almost equal mobility of K+ and Cl- ions and practically no streaming potential due to very low mud filtrate resistivity. Consequently, the SP log under such conditions can be treated as a membrane potential log, which has a strong correlation with cation exchange capacity (Qv) and hydrocarbon saturation in shaly sands.

As an input for SP-method, clay volume computed without using SP in ELANPlus (Vcl) and water saturation (Sw) are used. SP log is normalised using equation (1), which removes the volume weighted clay effect and comprises the effect of hydrocarbons on Qv.

$$PSPN = \frac{PSP}{1-V_{cl}} \quad \text{...} (1)$$

Where, PSP= SP amplitude obtained after making shale base line zero

The SP based water saturation is calculated using the equation:

$$[Sw]_e = Sw \left(\frac{\Delta U_\infty - \Delta U_{Sw}}{\Delta U_\infty - \Delta U_{Sw=1}} \right)^{\frac{1}{n^*}} \quad \text{...} (2)$$

$$\Delta U_{\infty} = -(56+0.12T)\log_{10}\frac{R_{mfe}}{R_{we}}$$

Where;Membrar

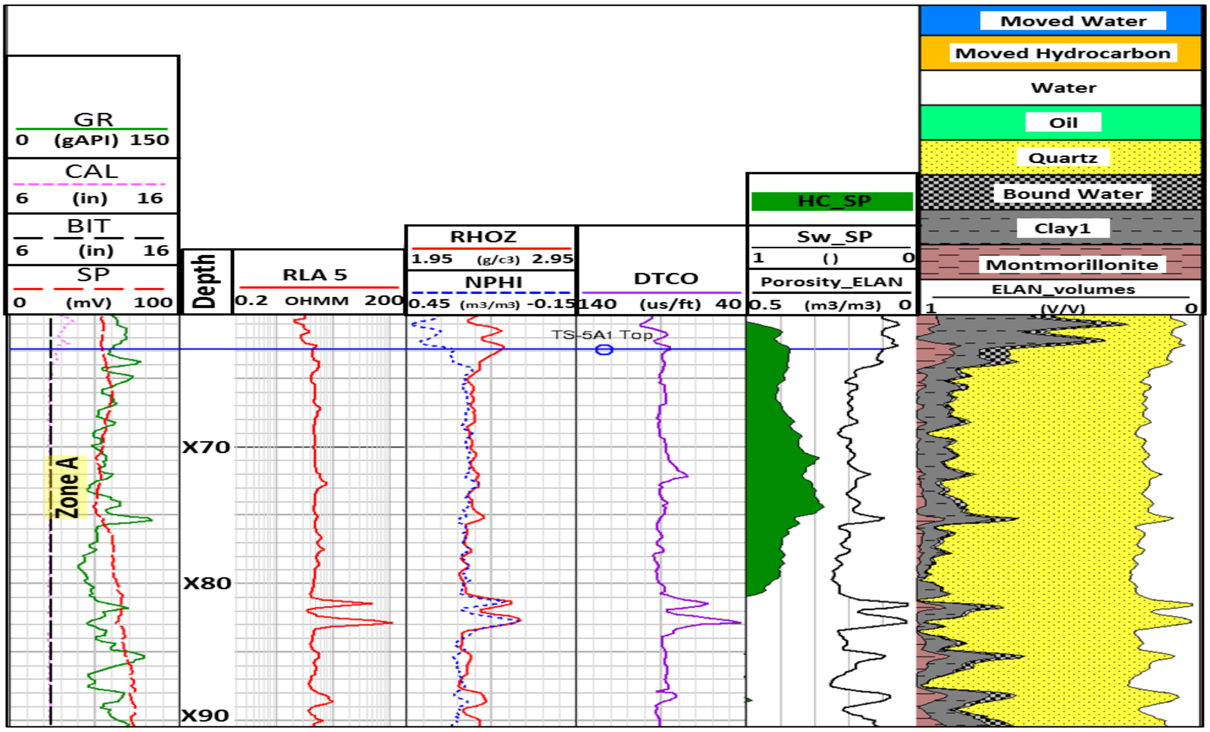

Fig 3: Hydrocarbon saturation using SP Method alongwith ELAN porosity (6th track). The last track present the ELAN output based on conventional shaly sand model (SW= 100%)

Membrane potential of 100% water bearing zone, $\Delta U_{Sw=1}$ is calculated from normalised SP amplitude PSPN log derived in equation (1)

ΔU_{Sw} is membrane potential throughout the log calculated in equation (1).

The application of the SP-based Sw in the present case study gave hydrocarbon saturation over the LR-LC sand compared to conventional resistivity based model (Fig 3). But, Sw is quite high as compared to other older producing wells in the area. This may again indicate depletion. Further, this method is limited by the low or erratic SP anomaly present in the reservoir zone (Zone A) reasons for which are still to be ascertained.

5. Discussions on special logs

FMI log was used in conjunction with CMR data to determine MDT points. FMI images reveal presence of blocky sands (4b) as well as laminations of shale and sand layers (4a). Presence of calcareous streaks also revealed. Against the interesting interval towards the top of the TS-5A, however, data got affected by mud smearing on the flaps. Not much analysis could be carried out.

The breakout analysis of FMI logs indicates possible direction of minimum horizontal stress as East-West. Being orthogonal to each other, the maximum horizontal stress is expected to be North-South which is confirmed by the direction of fast shear azimuth obtained from anisotropy analysis processing of sonic scanner data (Fig 5).

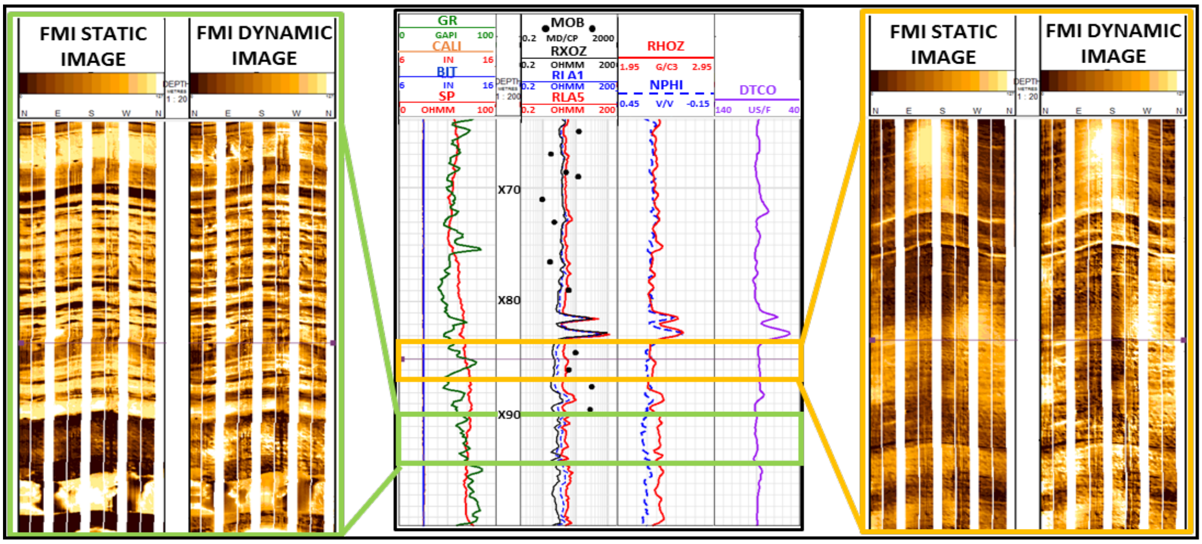

Fig 4: Depositional sequences (Left-4a) Laminations of shale and sand layers with resistive calcareous streaks (Right-4b) blocky sands

Anisotropy analysis of Sonic Scanner data in studied well showed very low level of anisotropy (0-8%) throughout the well (Fig 6).

In the well a total of 59 valid pre-tests, 8 LFA data and 2 samples were collected. Definite oil gradient was not observed in sand TS-5A, however two distinct pressure gradients were apparent across tight peaks observed in the interval X81-X83m. The pretest indicate formation pressures to be sub hydrostatic. The mobilities are observed to be less than 10 md/cp. A valid fluid density could not be calculated from the pretest formation pressure gradient in top part of TS-5A, as certain points went haywire and the formation pretest pressure gradient against Top part (X64-X73 m), was deflected from the trend line in bottom part (X73-X81 m)(Fig 7). Differential depletion seems to be the reason for the pattern observed.

CMR log reveals presence of high capillary bound porosity and very less clay bound porosity. Late arrivals on T2 distribution are also prominent in top part of TS-5A which could be indicating presence of light hydrocarbons (Fig 7). The NMR studies on core plugs cut against these intervals will help us establish the T2 cutoffs which will further fine tune the CMR results.

In case of virgin reservoirs, the saturation evaluation against interval above transition zone can be evaluated as a ratio of free fluid to total porosity. In view of depleted nature of the reservoir, this technique could not be applied here. Whether a combination of MDT and Pseudo capillary curves from CMR can be used for evaluating Sw in this case is being explored.

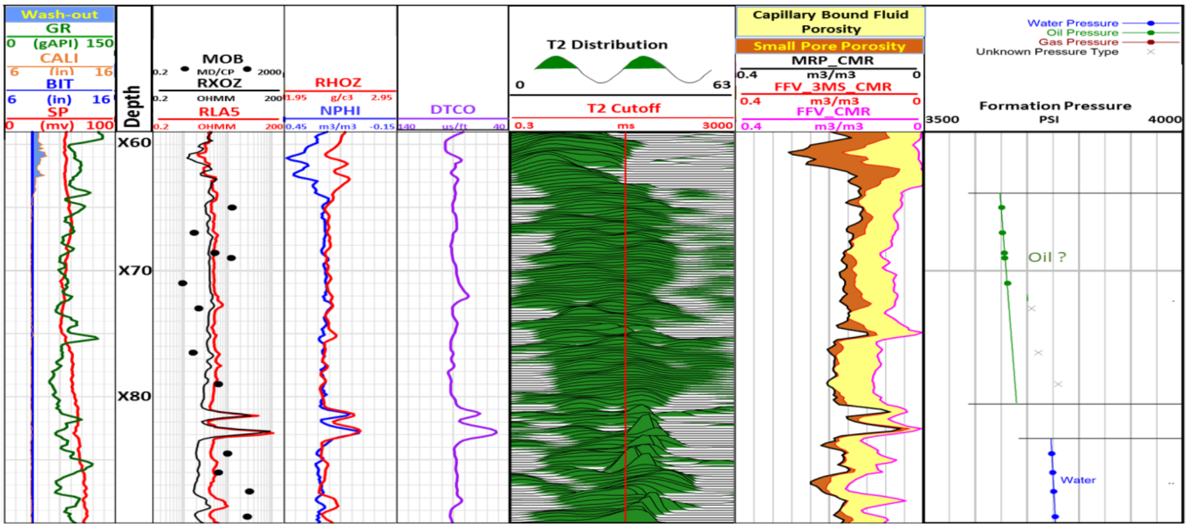

Fig 7: CMR log T2 distribution, CMR porosities and MDT Pretest pressure gradients plot

6. Conclusions:

- Evaluating LRLC reservoirs is a challenge. Broad methodology have been developed and are being used with varying degree of success. Applying the same in depleted brownfield reservoirs comes with further limitations.
- Determination of OWC was complicated here and various overlay techniques have served as a resort. KCL-PHPA mud system aids in application of all these overlay techniques.
- Hydrocarbon saturation estimation using the conventional shaly sand methods yields underestimation in low resistivity reservoirs and is more intricate when having reverse contrast.
- The calculated water saturation from SP-method limited by undulations present in log are still the most robust Sw estimates for this area.
- While hitech logs have provided a much needed insight to understand reservoir character. Various quantitative techniques developed using hitech logs were found to have limited applications due to depleted nature of reservoirs.
- The results of the various core studies planned will help in further reservoir characterisation and formation of a robust technique for quantification.

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