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Enhancing the productivity of horizontal wells through real-time LWD measurements: case studies from north-east India

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Abstract

Field A is a major oil producing brown field in north-eastern region of India. The field was discovered in the year 1963 and since then the field is producing oil from multiple pay-zones. The sand-1 & sand-2 have been the major producing sands of the field and both have strong aquifer support. Due to prolonged production for more than five decades, these pay sands are facing production challenges viz. high water cut & water coning due to substantive upshift of OWC, depletion in hydrocarbon saturation causing problem in liquid lifting, bypassed oil and isolated hydrocarbon pockets due to reservoir heterogeneity. Such hurdles are resulting in decline in production and decrease in recovery.

In such scenario, conventional wells do not seem to be good option for hydrocarbon production due to reduced thickness of hydrocarbon column, lesser exposure of the well-bore to the reservoir, high drawdown pressure and close water contacts. Drilling horizontal wells in this mature brown field reservoir has proved to be preferred option to produce remaining oil and thus improve recovery through better exposure to reservoir with higher productivity index. Taking a step towards redevelopment of these brown field reservoirs, to enhance the overall field recovery and produce oil with minimum water, recently, four horizontal wells have been drilled with RSS-LWD. In these wells, prior to landing, pilot-holes were drilled to ascertain available pay thickness and prevailing OWC. The LWD technology has been extensively used in pilot-hole, landing section and drain-hole section. Continuous monitoring of LWD data in real time has helped a lot in successful landing of these horizontal wells as well as in drain-hole placement. RSS improved drilling efficiency and LWD deployment has not only helped in well placement, but also saved the valuable rig-time required for logging in such tough conditions. The results of horizontal wells have been very encouraging and more horizontal wells are being planned for this pay sand as well as for other pay-sands.

In the initial wells, drain-holes were placed in clean hydrocarbon bearing section with good vertical permeability. In view of early water breakthrough in these wells, the drain-holes have been placed in top silty part in later wells with the help of bed boundary detecting tool and are giving sustained production with lesser water cut. The paper brings out some case studies of deployment of latest LWD tools for successful drain-hole placement in the horizontal wells drilled in the mature brown field.

Introduction

Field ‘A’ is a brown field located in north eastern part of India. Since its discovery in year 1963, the field is continuously producing oil and gas from multiple pay-zones for more than five decades and is one of the major brown fields in the region. Some of these pay-zones have strong aquifer support whereas some are solution gas driven reservoirs. The present study involves pay-zones ‘X’ and ‘Y’, which are active aquifer driven sandstone reservoirs. These clastic reservoirs are fining upward sequences and the top part of these reservoirs is silty with comparatively lower porosity and permeability than the bottom clean part. Both these pay-sands are highly faulted complex structural reservoirs. In aquifer supported reservoirs, the undesired production of water along with oil has been a major challenge for the oil companies. In both the active water driven reservoirs ‘X’ and ‘Y’, the protracted production over the years has resulted in substantive upshift in oil water contact thus leaving only thin pay-zone in top part of the reservoir. Exploitation of this thin pay-zone has been tough task in a complex reservoir with high level of uncertainties. Lateral and vertical heterogeneities in the reservoir have caused bypassed oil and isolated hydrocarbon pockets. This brown field reservoir is facing many production challenges such as water coning, high water-cut, depletion in hydrocarbon saturation and liquid lifting problem which have resulted in production decline. Under the circumstances, when only thin pay-zones are available, the conventional wells do not seem to be a feasible option. It has been observed that the vertical and low angle wells start cutting water almost right from the date of completion and are producing with very high water cut. To overcome these challenges, horizontal wells were proposed to produce the attic oil with minimum water cut and thus improving the recovery factor.

Earlier Horizontal wells in the reference pay-sands

These horizontal wells were to be drilled in two different phases. Initially in first phase, 3 horizontal wells X1, X2 and X3 were drilled for the pay-sand ‘X’ and one in pay-sand ‘Y’. The wells drilled for the reservoir ‘X’ were drilled with the help of MWD and were completed successfully. However, during drilling of the well Y1, the target zone was encountered much shallower than expected and hence the well was completed as high angle well in pay-sand ‘Y’. These wells were logged with drill pipe conveyed logging techniques after completion of drilling. The flow rates of these horizontal wells were relatively better compared to the conventional wells in the area. However, the open-hole logs recorded after drain-hole drilling in these wells indicated that considerable part of the drain-hole penetrated into the non-reservoir section. One of these horizontal wells produced oil with more than 50% water cut from initial testing itself which indicated that the well was placed a little deep into the reservoir. In view of these lessons learnt from the earlier campaign of horizontal wells, the need was felt to introduce geo-steering technology so that the drain-hole placement and well productivity could be improved sustainability.

Horizontal wells drilled in the second phase

In continuation to the earlier campaign of horizontal wells, 6 more horizontal wells were drilled in the second phase. Out of these 6 wells, 5 wells X4, X5, X6, X7 and X8 were drilled for the pay-sand ‘X’ and one well Y2 for the pay-sand ‘Y’. In the second phase also, initial two wells X4 & X5 were drilled with MWD and were logged by using well shuttle services. In view of less productivity and involved complications in these two wells, rest of the wells were drilled with RSS and LWD. LWD technology was deployed during landing and drain-hole drilling which contributed a lot in proper drain-hole placement thus increasing productivity of these wells and also saving valuable rig-time. In the horizontal well Y2 which was drilled for the pay-sand ‘Y’, first time in north-eastern region, bed boundary detection tool was deployed which helped in placing the drain-hole in topmost part of the reservoir by detecting the overlying shale. The brief of wells drilled in the second phase are discussed below:

Well X4: The well X4 was drilled to exploit hydrocarbon from pay-sand ‘X’ by placing 6” horizontal drain-hole. LWD was not deployed in this well. The landing section (8 ½” section) was drilled to 2874m and was logged by well shuttle services. The 6” drain-hole was drilled up to 3035m (drain-hole length of 160m). Logs were not acquired in the drain-hole, however the drill cutting data indicated that significant part of the drain-hole was placed in the section of reservoir having poor facies. The drain-hole was completed with 3 ½” perforated tubing and after repeated activations it produced meager amount of oil.

Well X5: Objective of the well X5 was to exploit oil from reservoir ‘X’ by placing a horizontal drain-hole. To estimate the prevailing OWC and available pay thickness for drain-hole placement, 8 ½” pilot-hole was drilled into the target pay-sand. The open-hole logs of pilot-hole (recorded using well shuttle services) indicated that the sufficient pay-thickness was available. In view of available pay thickness, the well was landed and a horizontal drain-hole of 300m was drilled. The well was completed with 3 ½" perforated tubing in the drain-hole section and on activation, it flowed oil at flow rate as follows: Q_L=15m^3/d, Q_O=13m^3/d, W/C=12% and Q_G=6752m^3/d.

Well X6: The well X6 was drilled to exploit the pay-sand 'X' with a 6" drain-hole section of around 250m. To evaluate the pay thickness and present OWC, pilot-hole (8 ½") was drilled with RSS-LWD. Based on pilot-hole LWD logs (Figure-1), pay thickness of around 10m was observed and accordingly, landing section and drain-hole trajectory was planned. With the help of real-time monitoring of LWD logs, the 6" drain hole had been geo-steered within four meters of TVD keeping the well as much as possible within the sweet zone and maintaining sufficient offset from Free Water Level for sustained and prolonged production. From the logs of drain-hole section (Figure-1), it was observed that the initial 120m of the drain-hole was placed in the top silty part and rest of the section was placed in lower cleaner part. On activation, well flowed oil at a flow rate of Q_o=35m^3/d with almost nil water. Presently, the well is producing oil at a flow rate of 29m^3/d with a water cut of 17%. The sustained production from this well indicates that it is better to place the horizontal drain-holes in the top silty part of the reservoir.

Well X7: The strategy of pilot-hole was adopted in this well X7 also which was drilled to exploit the pay–sand 'X' through a drain-hole of the length 300m. The pilot-hole LWD data (Figure-2) indicated a pay thickness of about 8m. In light of the structurally favorable position at the top of the objective sand, the landing section was drilled with RSS-LWD and 306m drain-hole was drilled consuming about 5m in TVD. With LWD deployed, for enhanced production, the drain-hole was adequately steered in clean and potential part of the reservoir. On activation, the well flowed oil with initial reported rate of 29m^3/d with 0.7% water cut. Presently, this well is producing oil at flow rate Q_L=32m^3/d, Q_o=2m^3/d with 95% water cut. The production profile of this well suggests that though the drain-hole placement in clean part initially gives high flow rates, early water break-through occurs and water cut rises steeply. This can be attributed to the high vertical permeability in the cleaner part of the reservoir.

Well X8: The horizontal well X8 was targeted to exploit oil from the pay-sand 'X'. For proper drain-hole placement, the 8 ½" pilot-hole was drilled and open-hole logs were acquired through TLC. Withan effective pay thickness of about 8m, the well was successfully landed with RSS-LWD and the drain-hole placement was carried out in 3-4m of TVD. Initially the drain-hole drilling was carried out with MWD but the planned trajectory could not be maintained and the drain-hole penetrated into non-reservoir section. Later LWD was deployed and with suitable course correction, the drain-hole was steered back into the reservoir section (see Figure-3) and the target of 300m of drain-hole length was achieved. On activation it produced oil at a flow rate of Q_l: 20.8m^3/d, Q_g: 2050m^3/d with a W/C of around 0.7%.

Well Y2: The well Y2 was drilled with objective of exploiting oil from pay-sand 'Y' in the field 'A'. The landing section was drilled with RSS-LWD and was landed successfully at the top silty part of the reservoir with a maximum deviation of 86.6^0. In 6" drain-hole section, along with RSS-LWD, bed boundary detection tool Periscope* was deployed for proper geo-steering of the drain-hole. With the help of Periscope inversion chart (Figure-4) the drain-hole was drilled grazing the overlying shale. During drain-hole drilling, hydrocarbon shows were not observed and it was decided to drill another drain-hole at a deeper TVD by open-hole side-tracking. However during drilling of second drain-hole also the hydrocarbon shows were not observed and it was decided to terminate the drilling. For testing, the completion string was lowered for the second drain-hole however while running in, the completion string got held-up twice at a depth equal to the drilled depth of 1st drain-hole. Considering the entry of string into old drain-hole, the completion string was revised and was lowered. On activation, it produced oil with following flow rates: Q_L= 10m^3/d, Q_o=9 m^3/d and W/C= 10% with a GOR of 186.

Performance analysis of horizontal wells drilled in second phase

The horizontal wells have better productivity than the conventional wells due to their comparatively manifold more exposure to the reservoir and due to less drawdown pressure they suppress water production. The horizontal wells X4 and X5 produced oil at good flow rate with water cut less than 15% whereas at the same time nearby conventional wells had been producing with more than 95% water cut.

Although the horizontal wells completed with MWD had given better flow rates compared to conventional wells, these wells faced many problems like high water cut from the very beginning (Well X1), early water breakthrough (Well X5) and drain-hole entry into non-reservoir sections (Well X4). LWD was deployed as an attempt to overcome these problems. The testing results of the wells completed with LWD shows almost water free oil (Well X6: W/C-Nil, Well X7: W/C-0.7, Well X8: W/C - 1.4% and Well Y2: W/C – 8%) from these horizontal wells and have produced with minimum water-cut for a longer time spans.

It has been observed that the drain-holes placed in the top silty part of the reservoir, with poor vertical permeability have given more sustained production (Wells X4, X6 and Y2) compared to the drain-holes placed in lower cleaner part. The drain-holes placed in the clean part of the reservoir suffered from early water cut problems. Due to high vertical permeability, the water from the underlying aquifers enters into the drain-hole very soon and water cut increases abruptly.

For better drain-hole placement and further minimizing the water-cut, bed boundary detection tool was used during drain-hole drilling in the well Y2. Depending upon the resistivity contrast between adjacent beds, most of the time the tool could detect the overlying shale; Accordingly, the drain-hole could successfully be placed in potential part of the reservoir sufficiently above the prevailing OWC.

Conclusions

1. Horizontal wells have given better productivity compared to conventional vertical and low angle inclined wells.
2. The real-time LWD data provided a good control in landing and drain-hole placement. Horizontal wells drilled with LWD have better drain-hole placement and higher productivity compared to those drilled with MWD.
3. LWD played a vital role during drain-hole drilling and it helped in making course correction. Thus LWD has proved to be an effective geo-steering technique increasing the productivity of horizontal wells. This will help in further improving the overall field recovery factor also.
4. In pay-zones where effective hydrocarbon thickness is very less, it is better to place the drain-hole in silty part of the reservoir with low vertical permeability. In such cases, though the flow rates are less in comparison to those placed in clean part, the wells have more sustained production. Over a longer period of time, the effect of sustained production profile is reflected in higher cumulative production. In reservoirs with high level of heterogeneities the drain-hole lengths may be optimized for sustained production and longer life of the well.

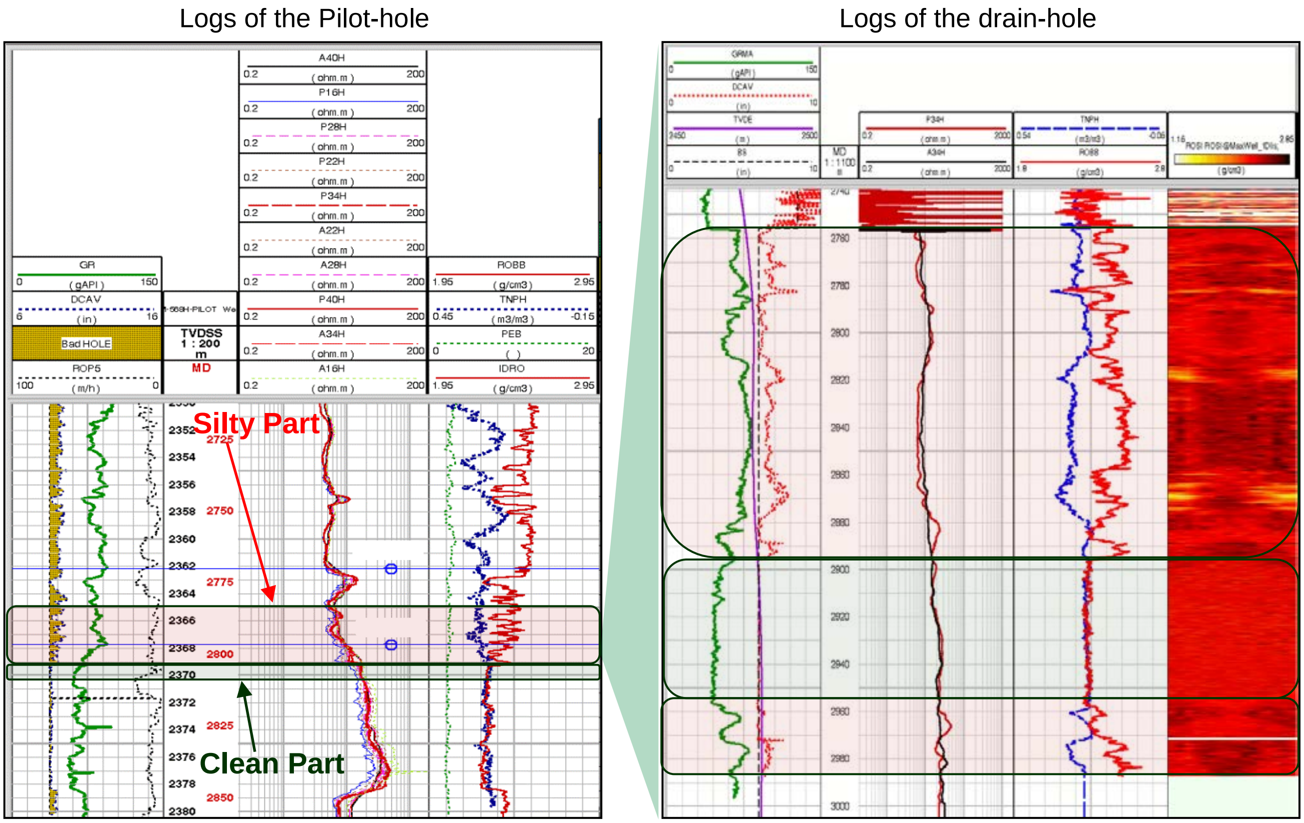

Figure-1: LWD logs of pilot hole and drain-hole of the well X6
The figure depicts that major part of the drain-hole was placed in top silty part of the reservoir

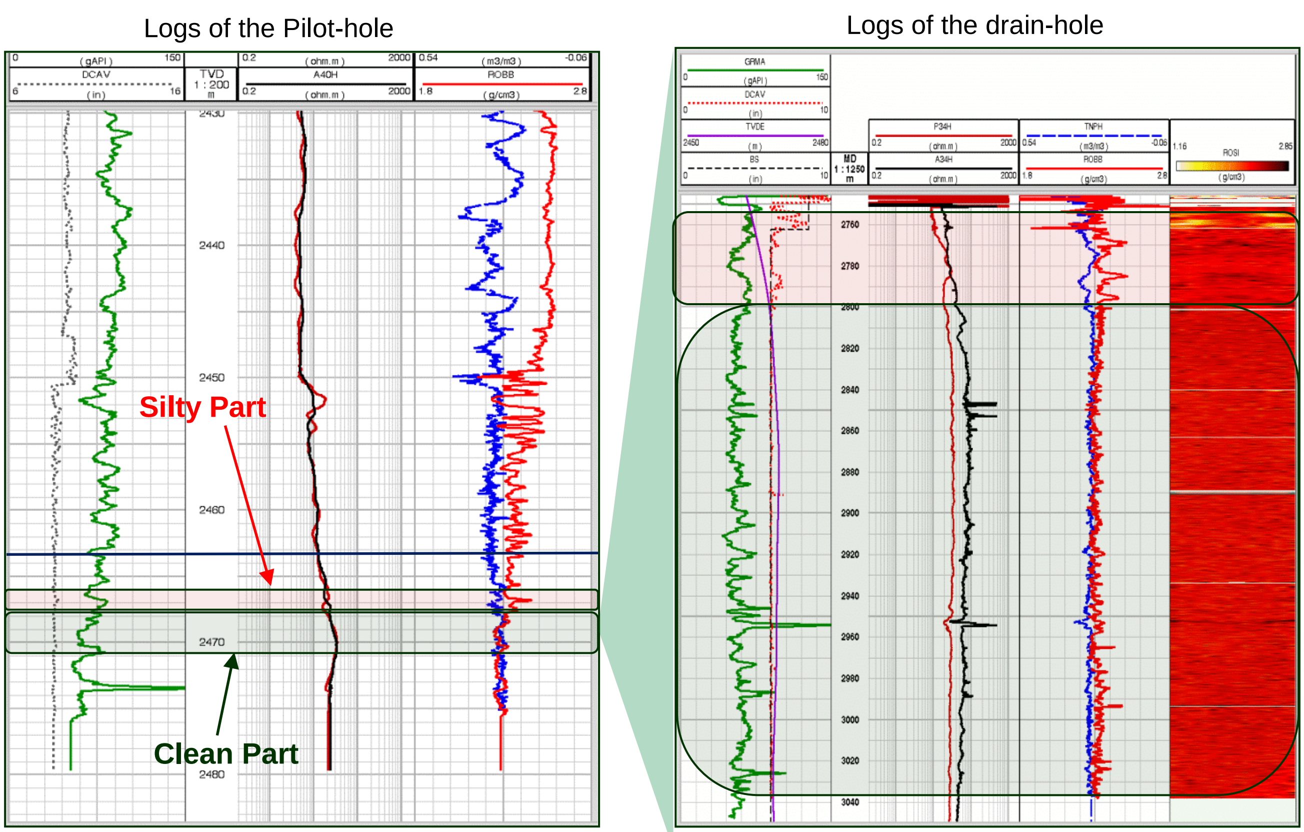

Figure-2: LWD logs of pilot hole and drain-hole of the well X7
The figure depicts that major part of the drain-hole was placed in clean part of the reservoir

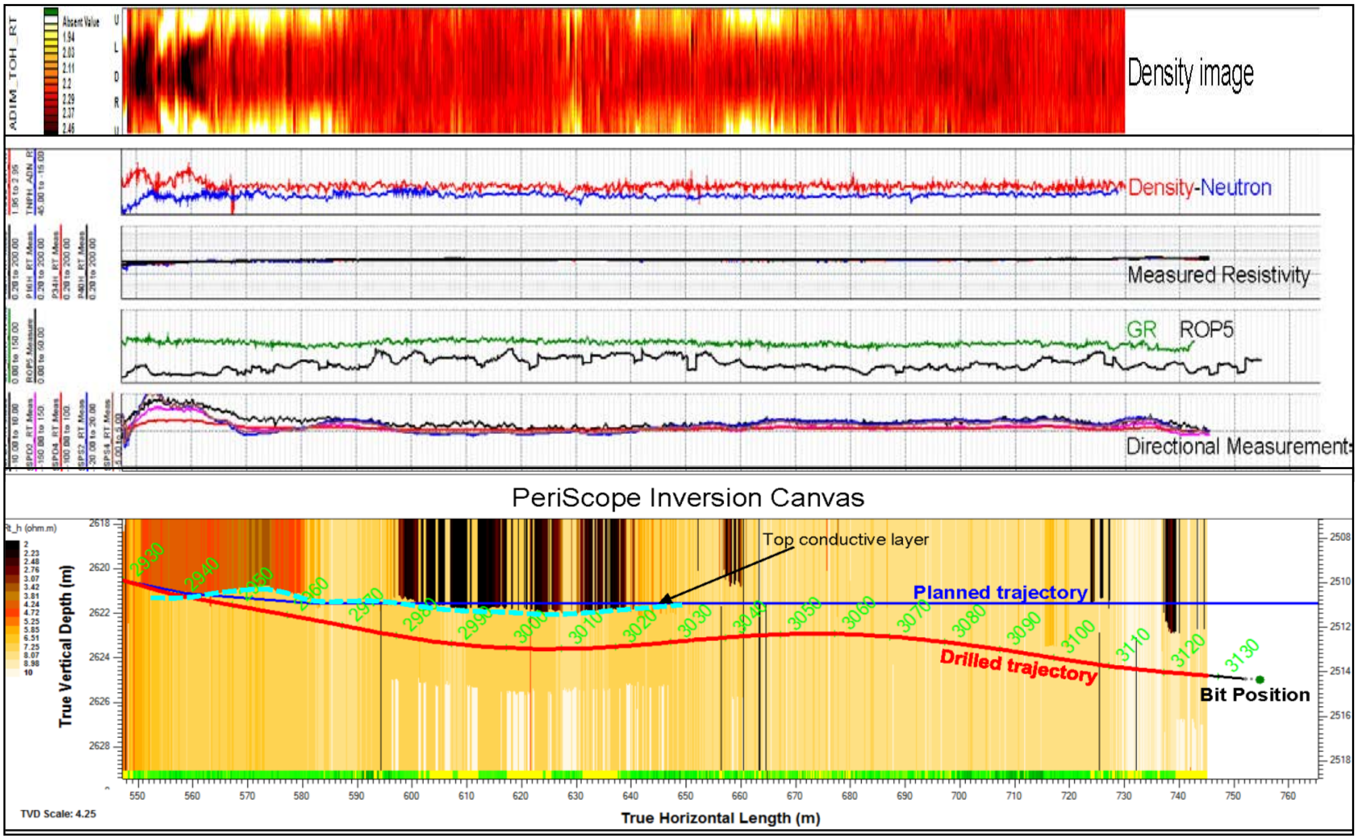

Figure-3 LWD logs and Periscope inversion canvas of the first drain-hole of the well Y2

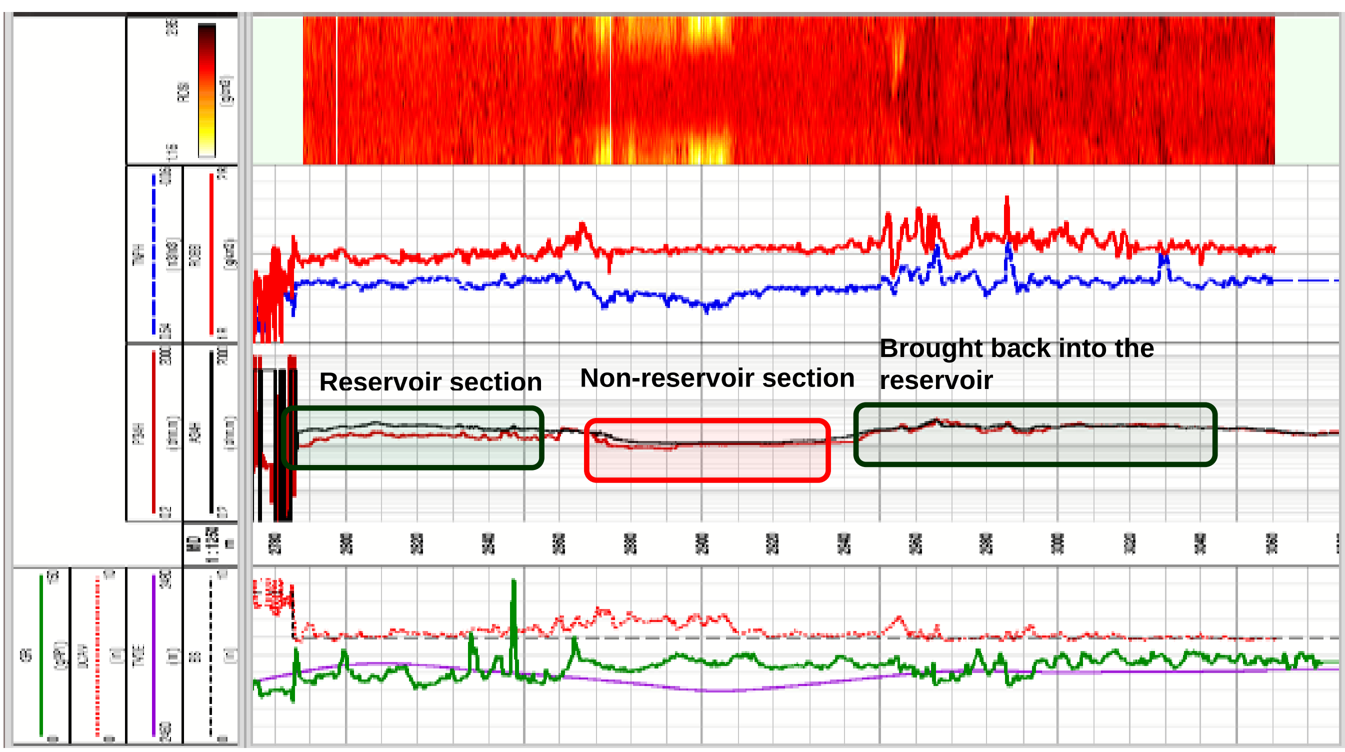

Figure-4: LWD logs of the drain-hole in the well X8
Later recorded LWD logs showed that after getting landed on top of the target reservoir, when drain-hole was drilled with MWD, it went into the non-reservoir section. Later with the help of LWD it was brought back into the reservoir section.