Application of image data for geo steering horizontal wells for better productivity by maximizing reservoir contact – A case study from Mumbai High Field.

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Abstract

Mumbai High Field was discovered in 1974. It is located in the Western Offshore Basin about 165 km WNW of Mumbai. The field was put on production in 1976.

MH field contains light oil (38 - 42 °API) in numerous pools, some are with large gas cap, structurally trapped within gently dipping, tilted fault-blocks. The field is divided into two main structural compartments (Mumbai High North and South) by a major WNW – ESE trending graben containing impermeable shale. The main reservoir horizons in the field are Middle Miocene limestone and Lower Miocene sandstone and carbonate. The Lower Miocene carbonate formation has been named as L-III reservoir. It contains more than 90% of the total Mumbai High reserve and comprises low-energy carbonate bank made up of lagoonal limestone and shale.

The reservoir is highly heterogeneous with thin limestone pay zones with shale inter-beds having large areal extent but with different lateral and vertical poroperm characteristics. Permeability ranges from 50 - 500 md, with the higher values associated with vugs, channels and moulds developed due to severe leaching action.

Large number of wells have been drilled with horizontal drain holes in this field to exploit untapped oil pools, leading to incremental oil production and also as injectors for maintenance of pressure support by water injection. Most of these drain holes have been drilled with LWD technology. In this case, apart from basic suit of logs, the image data (density image) is critically interpreted to successfully steer and place the drain holes in relatively good reservoir facies, which leads to better productivity. Azimuthal Density Neutron (ADN) tool records density image data in 360 deg during rotation. Whenever a formation boundary is intersected, the tool records densities of the successive formations coming in contact. Hence the angular contact of the tool with the adjacent formations is recorded / displayed as a sine wave in the image form. The progress of the drain hole

within / across the formations is assessed by interpreting the resultant image data accordingly.

Three wells from a single platform located in MH South have been taken as a case study to demonstrate the application and utility of density image logs (ADN) in the placement of drain holes.

Introduction

Drain hole trajectory plan takes into account, the reservoir structural variations using updated model and seismic signature of the layer for the local startigraphy and structural aspects encountered along the path of the trajectory. L-III reservoir of Mumbai high field of Lower Miocene age is sub divided into number of oil/gas pools separated by carbonaceous and calcareous shale interbeds. These reservoirs are characterized by low gamma response and high resistivity with good poroperm values. These electro facies corresponding to geological lithofacies namely packstone, wackstone and mudstone etc.

During the drain hole drilling through the carbonate reservoir layers and tracking the best available facies, the objective is to maximize the reservoir contact with the sweet zone or oil window. Such target is achieved by vigilant observation of progressive real time log data and assessment of drain hole structural changes with respect to the desired electro lithofacies of the reservoir. However, there can be two types of variations affecting the process, one is technical difficulty to maintain the trajectory in desired orientation and second is the structural variation of the formation. LWD tool dynamics is assessed from the deviation information like bit inclination, vertical section and azimuth. Any variation in these technical inputs can be observed in the log signature of the drain hole and appropriate measures have to be taken to restore the drain hole in the sweet zone. In the second case where static structural variations are taking place, it requires advance information like ADN image data for the required task.

Arrival of LWD log information on real time transmission depends on the position of different tools in the array of LWD string. This tool configuration normally gives gamma ray information followed by the resistivity and density neutron logs. With typical LWD configuration, during real time monitoring of drain hole drilling, the first alarm rings from GR log, as a trend of rising GR count. Subsequently after further drilling, resistivity log may show up with boundary effect and later density & porosity logs or ADN image.

The Azimuthal Density Imaging

Measurements of the formation bulk density and neutron porosity are important for quantitative evaluation of reservoir properties, fluid typing, hydrocarbon saturation, and in some cases, producibility. With the help of ADN tool, bulk density, neutron porosity, photoelectric absorption factor (PEF) and ultrasonic caliper around the wellbore are measured.

During the drilling operation, density is measured azimuthally along with Pe and neutron porosity, as it is being rotated. The Density tool detector counts rates are binned into 16 sectors around the bore-hole defined by internal accelerometer and magnetometer. These sector density and Pe data are average in quadrants and labeled up, down, right and left for real time transmission and formation evaluation. The standoff in each of the quadrant is derived by means of an ultrasonic sensor, to estimate the differential hole size of the wellbore relative to the bit diameter.

One of the main problem faced by the density measurement in the LWD environment is the large mud standoff between the tool and the formation. With the use of full gauge stabilizers across the tool in $8^{1/2"}$ hole and 6” hole, the mud standoff is eliminated and high quality density measurement are obtained. With the 7” spacing of detectors, high strength of the gamma-ray source and the counting statistics of the tool, the depth of investigation is approximated with over 80% of the received gamma-ray flux coming from this region. The gamma ray from the formation are sampled at a high rate and density standoff correction applied using the conventional spine and ribs technique which allows accurate measurements to 1 inch of stand-off, when the tool is rotating or sliding. Using statistical analysis, density measurements are corrected for hole shapes and rugosity effects. With four-quadrant azimuthal density measurements from the tool, low-resolution images of the wellbore geometry are derived. Assigning graduated color scale to the range of density measurements generates the images. The images maybe displayed with respect to top of the wellbore, or oriented with respect to geographic north when processed on a workstation. Images can also be created from PEF data, which has a vertical resolution of 2 inches. The best image to use will depend upon environmental conditions and the dynamic range

Interpretation of density Image log

ADN is latest generation of density- neutron tool and combined with other LWD tool. ADN tool is configured to provide real time apparent neutron porosity, formation bulk density and photoelectric factor data to characterize formation porosity and lithology while drilling.

Prior to drilling a drain hole in the desired layer, pre-job study of the offset well data is required. The structural variations in the area can be understood using offset well log data and seismic data. Though, the seismic data gives structural orientation and inclination of the bed, but due to its limitation, the small but significant structural feature may be missed on seismic section, as the velocity contrast is too low. In such cases, the seismic information is insufficient to achieve an accurate structural description of the reservoir.

ADN tool during sliding and drilling of drain hole, comes in contact with the adjacent formations, the bed boundaries, and micro contrasts existing within a bed, simply the internal lamina of the formation. Density and Pe (Photo Electric Factor) data recorded in 360 deg direction and in the form of 16 sectors which is averaged into four quadrants and displayed on the log in the form of an indicative graduated color band.

Whenever a plane of bed boundary or laminae is intersected by the drain hole, its impression around the well bore forms a sine wave on image log (Figure 1), similar to the data seen on a plane formed by unfolding the cylindrical well bore. A straight line is seen when the hole is intersected by any vertical feature of the formation such as fracture etc. This is possible in case where the drain hole intersects a formation boundary, but in case of parallel contact of drain hole with the bed boundary, the image log will form parallel bands on the log.

The sign wave is divergent towards the direction of the drain hole trajectory when the drain hole is cutting into the underlying beds/layers. Similarly if the image is convergent towards the direction of the drain hole, when the drain hole is cutting into overlying beds/layers of the formation. Thus a bull’s eye is formed when the drain hole cuts in to underlying beds and then is restored back to its position. In some cases there will not be any image contrast if facies is homogeneous.

Amplitude of the sine wave is function of the angle of incidence between the well bore and the formation dip. Higher will be amplitude if the incidence angle is low and vice versa. The incident angle is calculated from the following formula

⇨ $\tan \alpha$ = (Bore hole diameter / Amplitude of the sine waveform)

⇨ $\alpha = \tan^{-1}$ (Bore hole diameter / Amplitude of the sine waveform)

Where α = Incidence angle between the borehole and the formation

Case study:

Case study of three wells from MHX platform

Platform MHX is located in northeastern side of MH South. The platform MHX is close to main eastern boundary fault, in the crestal part of the multilayered LIII reservoir. Being in crestal part of the Mumbai High anticline structure, the upper sub layers of LIII-A reservoirs are likely to be gas bearing with oil down to LIII-B or part of LIII-C layer, depending upon the structural position of the well. Further, being in the vicinity to the main fault, the area has been affected by many minor associated sub surface faults/ fractures. In view of the large gas cap, the seismic reflection events at L-III top exhibit chaotic nature and hence minor depth variation in marker layers are expected. The existing geological model shows much variation with respect to structure and facies in this part of the field. Gross thickness of LIII-B and LIII-C are of the order 7 and 6-10m, respectively. The layer LIII-B is having very good reservoir facies and has effective thickness and porosity in the range of 4-7m and 24-30% respectively. The area around the MHX platform is relatively flat, with slight undulation (Figure 2).

Case 1: MHX-IH

In well MHX-IH drain hole was drilled from 2617m to 3132m with average log parameters; gamma ray value 20-25^0 API, resistivity around 10 ohm.m and showing positive separation on density neutron with porosity around 25-30%.

The drain hole was drilled in good reservoir facies with gentle up dip angle, upto 2650m. Around 2630m, there was increase in bit inclination and as indicated by convergent sine wave on the image log (Figure 3), the drain hole was cutting into overlying tight formation.

Decision was taken to come down structurally by dropping bit angle. Drain hole was restored back to the desired level which was confirmed by the divergent sine wave on image log. While tracking further, good reservoir facies was encountered upto 2725m.When Density neutron log started showing intermittent positive separation, the bit angle was built up to track come up in structural level to enter into the good reservoir facies. However, the drain hole had entered into overlying tight facies around 2770m, as shown by the convergent sine wave on image log.

During the course of drilling, gamma ray log value was almost constant and there was no indication of any facies variations. Monitoring of the drain hole drilling was carried out on the basis of density neutron log / ADN image log.

Case 2: MHX-IIH

The drain hole was drilled in LIII-B reservoir from 2205m to 2730m, with gamma ray value 20-25API in the limestone formation showing positive separation on density neutron log with a porosity of 25-30% and resistivity in the range 10-20 Ohm-m.

Initially, the oil zone was tracked at a structural level of around 1334m TVDMSL. During the course of drain hole drilling, the image log (Figure 4) has shown dark patches developed on both the corner of the image log at 2535m, as upper quadrants of density tool were reading the overlying formation, also it has started to form a convergent sine wave. It was due to a denser formation being encountered as the tool/ bit was cutting into overlying bed.

Accordingly decision was taken to drop inclination at bit. However, the drain hole from 2550m to 2580m was drilled in tighter facies. The drain hole was restored back into the good reservoir facies from 2580m onwards. Later at the depth of 2610m, gamma ray value indicated entry into shaly formation. Bit inclination was built up to decrease the structural level of drain hole and hence to remain in the good facies. Subsequently from 2640m, the resistivity started to drop and showing the effect of shaly formation. It was decided to bring down structural level of the drain hole. A divergent image is seen as the bit angle was dropped and the drain hole tracked into structurally lower level, thus remained in good reservoir facies.

Case 3: MHX-IIIH

Drain hole of 500m was planned in LIII - B reservoir and it was to be drilled with 6" LWD. Thickness of LIII-B reservoir is around 7m and the sweet zone is around 2m. The sweet zone was started 2m below from LIII-B reservoir top. LIII-B is heterogeneous in this area with some tight / shaly bands.

Initially this well was landed with $8^{1/2"}$ section at LIII-B top at 1341m TVD-MSL. Due to excessive mud loss and subsequent stuck up, the well was re-drilled for landing at a shallow level within the overlying sub layer A2-VII bottom.

The drain hole drilling was carried out with 6" LWD tool and it was placed in good reservoir facies with an average gamma ray 25API^{o} , resistivity 10-20 Ohm-m and with porosity of around 24%. In the beginning part, the drain hole traversed through N shale, overlying the LIII-B reservoir from 1840m. Thickness of N shale encountered was 4m.Drain Hole entered into the target layer B at 1915m. The drain hole was steered with in the reservoir with gentle down dip as per plan.

The image log (figure 5) indicated tighter facies at the top of target layer upto 2025m. This was shown with darker color spectrum. Also the divergent sine wave images were seen through out the drain hole length, as drain hole was steered with a gentle down dip. This suggests that the target formation is almost horizontal. Gamma ray response indicated facies variation in tighter top 2m portion of LIII-B reservoir and relatively lesser afterwards. The resistivity log indicated boundary effect from 2075m onwards with a higher range of resistivity around 30 Ohm.m. It may be due to some facies variations near by with higher hydrocarbon saturation in the reservoir.

Conclusion:

The easy oil production is a history, and tapping the trapped oil from a complex layered matured carbonate reservoir, is a real challenge. With the advancement of LWD technology such as ADN tool, it enables to reduce the geological and geophysical uncertainty. Maximization of reservoir contact and hence better productivity is really apprehensible from the wells drilled from MHX platform of Mumbai High South field. With the help Azimuthal Density Image log, it was possible to exit from the maximum possible intercalated shale within L-III reservoir during the drain hole drilling and remain about 80-90% in the best possible sweet zone within the reservoir. Apart from this, it reduced the intricacies associated with the collapse of drain hole due to swelling of shale. The completion program in these three wells was planned smoothly and objective was achieved. It also helped to comprehend the structural element of the reservoir. The Azimuthal Density Image, in conjunction with Resistivity, Density, Thermal Neutron Porosity and Gamma ray logs, enabled real-time updates to the geological model of the reservoir, which helped in better understanding the petro - physical characteristics of the reservoir.

From this case study, following conclusions are drawn:

1. Structural dip can be effectively defined in 6” drain hole by Azimuthal Density Image log.

2. Redundancy in the geological risk and steering decision process was aided by the real-time LWD data modeling, which significantly reduced well positioning uncertainties.

3. Azimuthal LWD measurement is a powerful tool for confirming drain hole position and for establishing whether drilling up or down and keeping at sweet spot during drilling by ascertaining the formation dip.

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References

Al-Fawwaz ,A.:, *et al.*, 2004 "Increased Net to Gross Rario as the result of an Advanced Well Placement Process Utilising Real-Time Desity Images

Amer, A. *et al*., 2005"Geological Modeling Using Azimuthal Density Neutron Images: A Case study in Khamilah Field, Northwest Oman"

Ribeiro, M. *et al.*, 2005, "Real-Time Azimuthal Laterolog Image Interpretation for Successful Horizontal Drilling in a Carbonate Reservoir in the U.A.E". This paper was prepared for presentation at the SPE/IADC Middle East Drilling Technology Conference & Exhibition held in Dubai, U.A.E., 12–14 September 2005.

Tribe, I.R. *et al*., 2003 "Precise Well Placement With Rotary Steerable Systems and Logging-While-Drilling Measurements". Presented at the 2001 SPE Annual Technical Conference and Exhibition, New Orleans, 30 September-3 October.

Tribe, I.R. and Burns, L. 2001, "Precise Well Placement using Rotary Steerable Systems and LWD Measurements" This paper was prepared for presentation at the 2001 SPE Annual Technical Conference and Exhibition held in New Orleans, Louisiana, 30 September–3 October 2001.

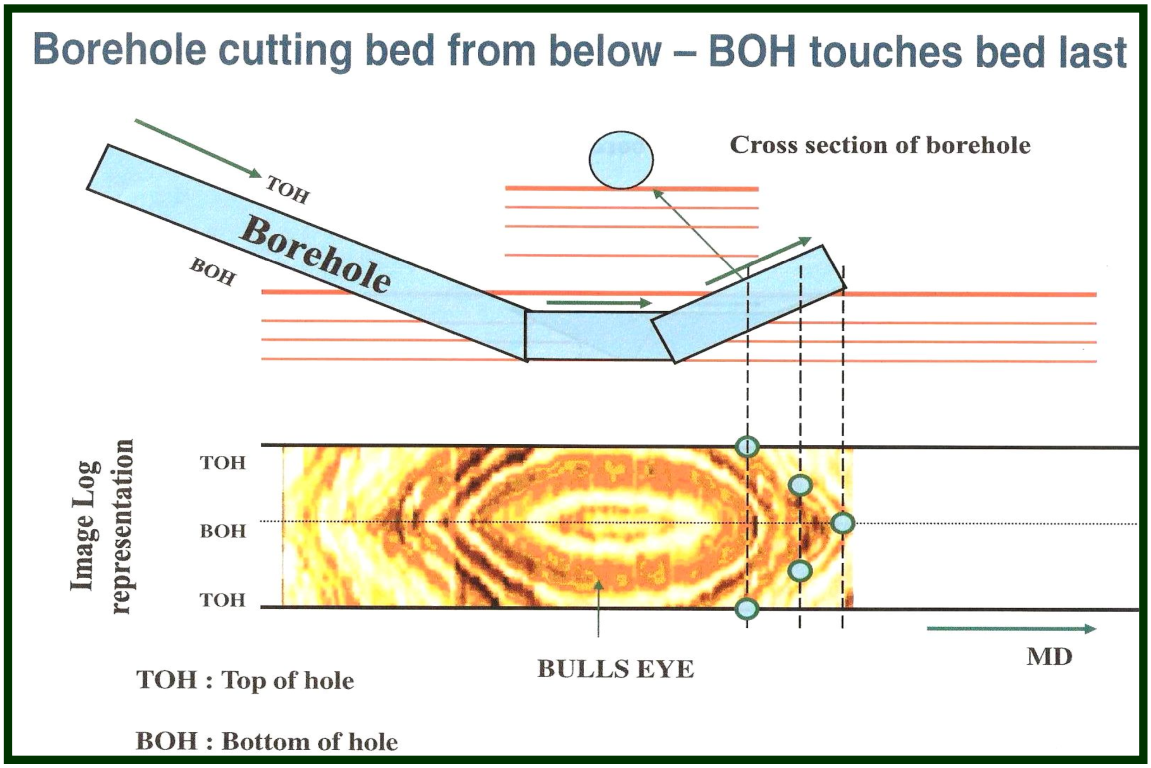

Figure 1: Showing Bull's eye formed by the convergent and divergent sine waves.

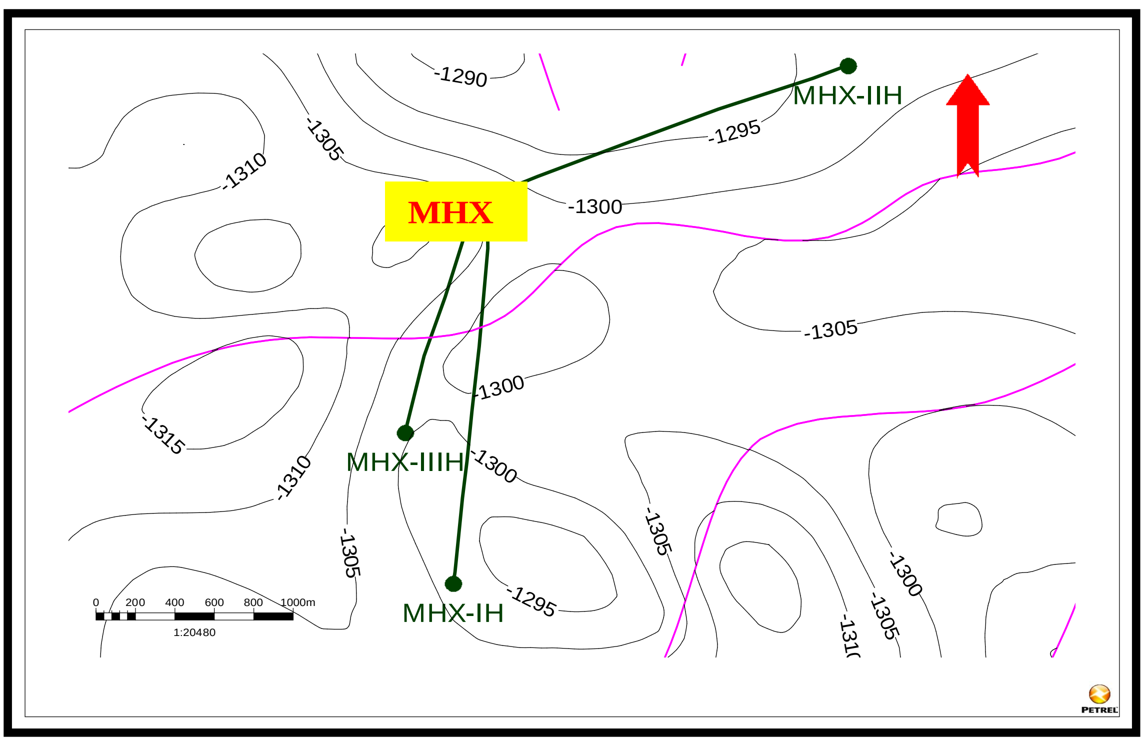

Figure 2: Location map at L-III top.

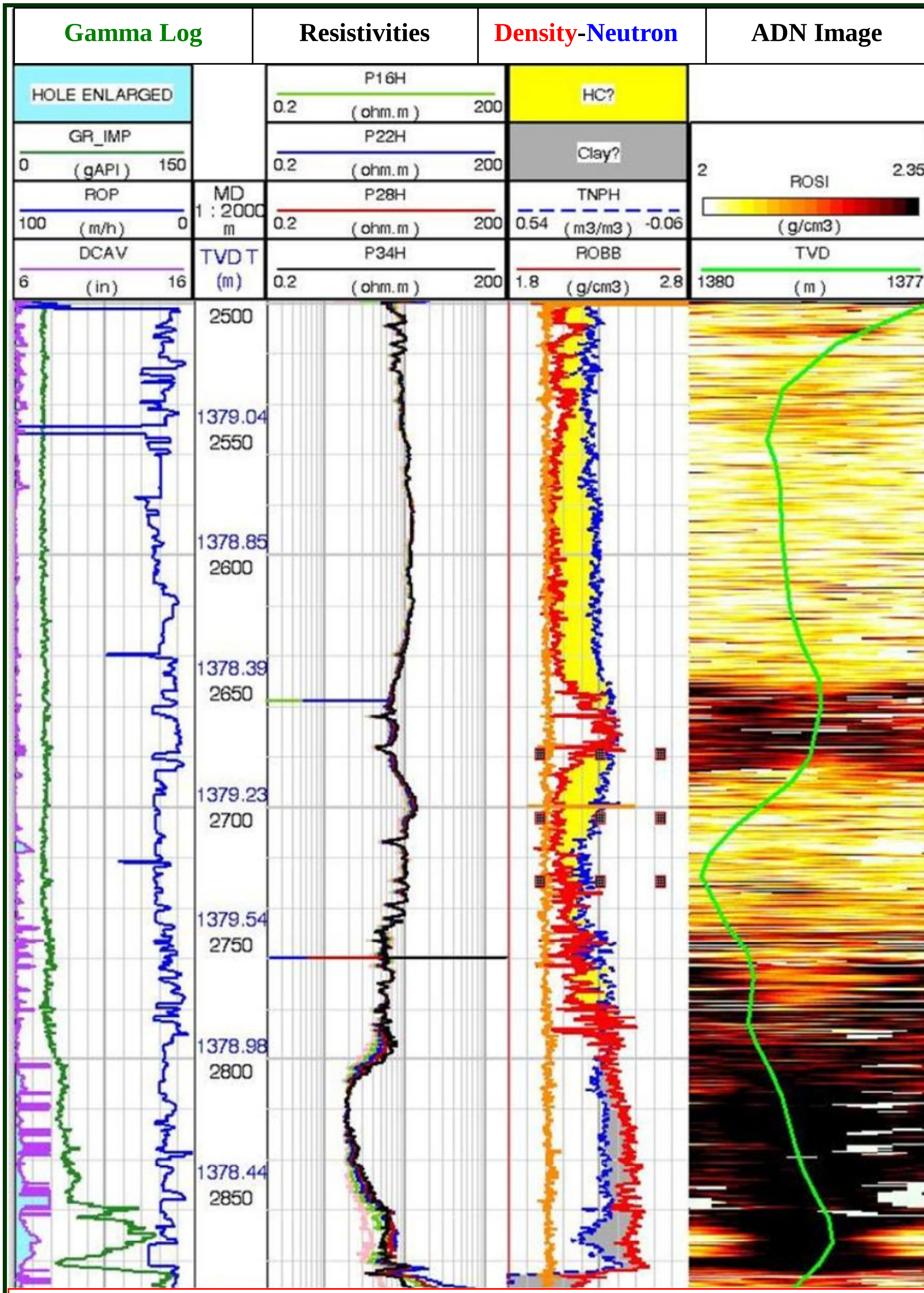

Figure3:MHX-IH drain hole section–ADN 16sector Density image

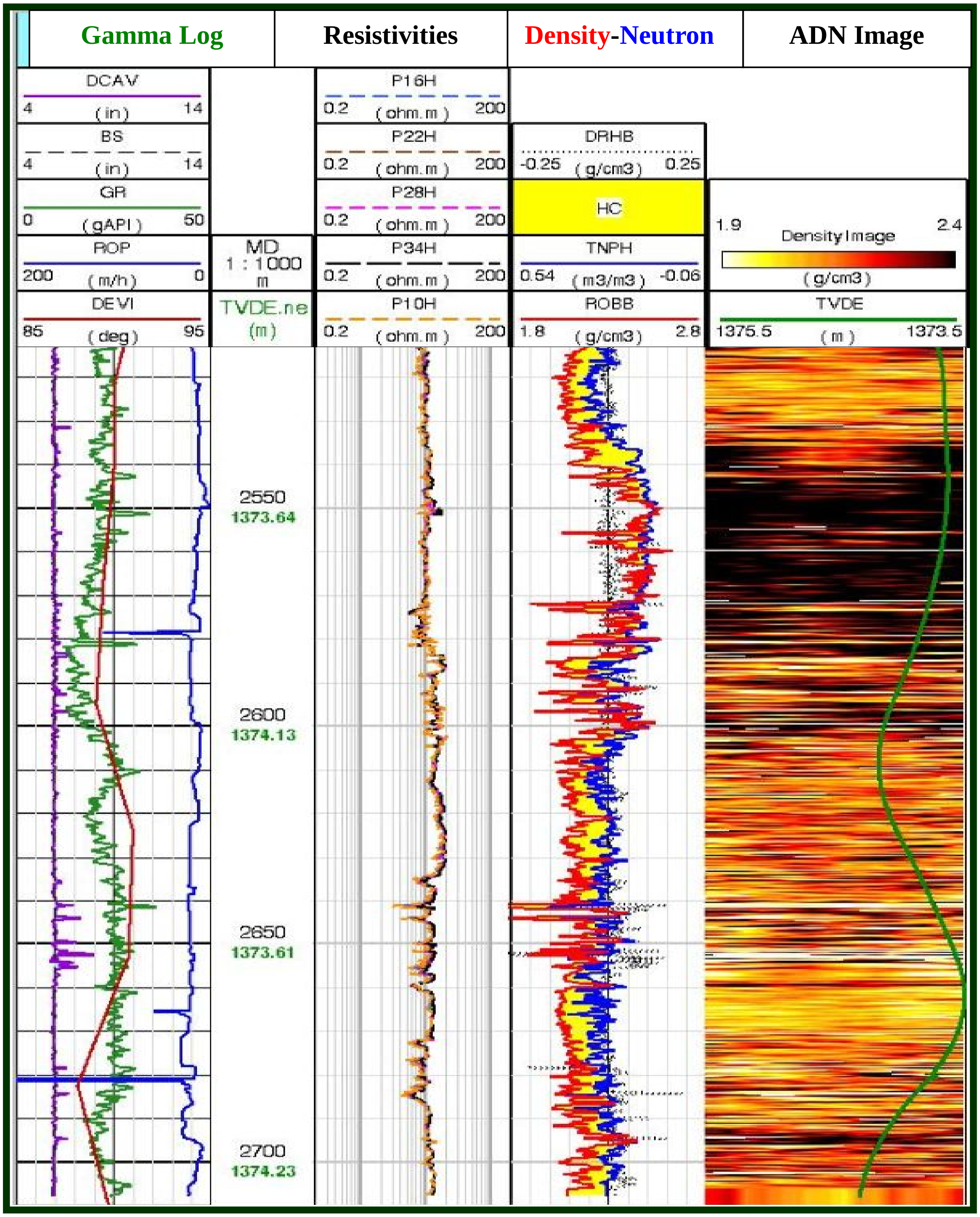

Figure 4: MHX-IIH drain hole section–ADN 16sector Density image

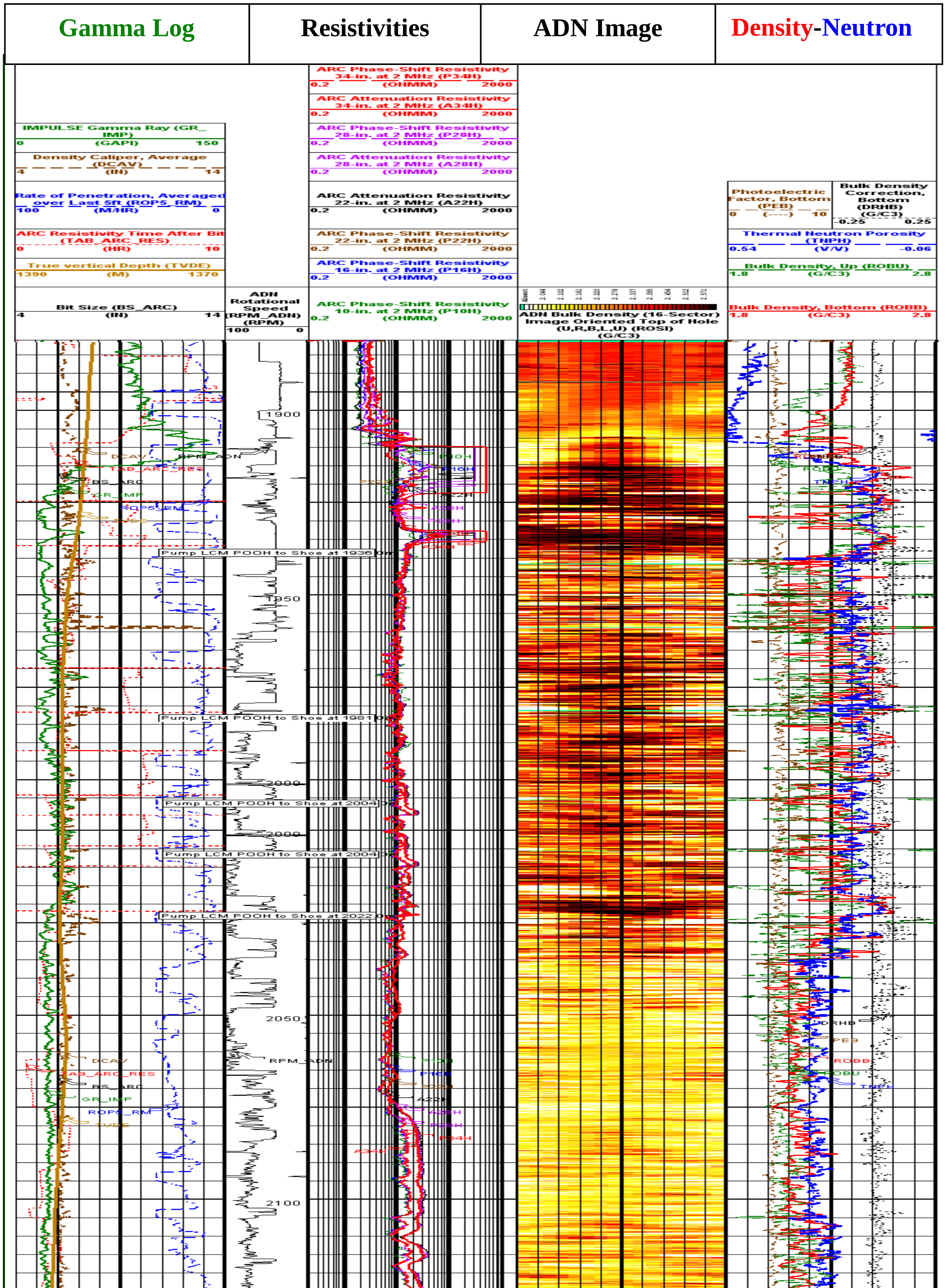

Figure 5:MHX-IIIH drain hole section–ADN 16sector Density image