MAXIMISE EXPLOITATION OF BROWNFIELDS USING OPTIMISED LWD TECHNIQUES FOR WELLPLACEMENT APPLICATION- CASE STUDIES FROM HEERA FIELD

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ABSTRACT

Hydrocarbon reservoirs in Brownfield are getting depleted with time and it is becoming challenging to exploit Hydrocarbon which is under exploitation over the years. Drilling wells in such areas is becoming a risky venture as the return on investment could take longer and sometimes even be negated. Sidetracking of wells helps in arresting production decline in a mature offshore field where significant oil exist as bypassed or locked in relatively tight reservoirs. The exploitation of this oil with new wells drilled through new platform may not satisfy the cost-effectiveness. The repositioning of wells with high angle and horizontal drilling in new areas from existing platform of the Brownfield is the need of hour.

A multi-disciplinary approach to monitor the reservoir, review of production and injection performance along with subsurface data led to identification of unexploited area in a matured field. Exploitation of this bypassed oil arrested the field decline and maintained the production rate. Drilling of high angle & horizontal wells in thin, dipping reservoirs and through fault zones could cause complexities such as total loss of well and the risks associated with them. The paper presents the methodology used to select the best measurement suite for the identification of faults in while drilling mode in horizontal wells and the application of new LWD technology in one of the wells, by which resistivity contrasting boundaries can be mapped and how the distance to boundary aids in maximizing the reservoir exposure with minimal exits drilled within a thin dipping reservoir.

INTRODUCTION

The Mumbai Offshore Basin, a pericratonic rift basin in the western continental shelf of India, is divided into six tectonic blocks (Tapti-Daman, Diu, Heera-Panna-Bassein, Mumbai high-Deep continental Shelf, Ratnagiri and Shelf Margin). Several large oil and gas fields have been discovered in this basin, and the presence of hydrocarbons has been established in the multiple pay zones. Heera field is one of them. The zones covered in this paper are the Mukta (early Oligocene), Bassein (middle Eocene) and Panna (Paleocene to early Eocene) reservoirs belonging to the Heera-Panna & Bassein block (Ref-1). The block is further divided into the North-Middle-South blocks. These blocks are separated by faults along the boundaries with no of smaller faults in between. Horizontal drilling through fault boundaries comes with their own challenges. Information about faults contributes to the reservoir and production studies. Faults could be conduits to water from below and if not identified and isolated could cause complications during the production phase, faults could also be associated with loss circulation which come with their own hazards. Horizontal drilling for targeting sweet porous layers which have been vertically displaced by faulting can also be quite challenging in terms of the well placement techniques adopted.

The following will cover examples on how the Logging While Drilling (LWD) technology was utilized in the horizontal wells to identify fault boundaries using various techniques including:

- Correlation of logs – repetition, missing zones.
- Electromagnetic (EM)-Propagation Resistivity curve separation interpretation.
- LWD images – cutting down, cutting up and layer parallel signatures.
- EM-Resistivity- “Deep Directional EM”.
This paper will begin with an example of how the DDDTB technology was utilized to proactively place a well successfully within the sweet zone of the Mukta layer. And later covers a topic related to fault identification mentioned above supported with suitable examples.

PROACTIVE WELL PLACEMENT USING “DEEP DIRECTIONAL EM” TECHNOLOGY

The “Deep Directional EM” tool is designed with a symmetrical transmitter-receiver configuration that optimizes the sensitivity to the desired formation parameters. While cancelling the influence of anisotropy and formation dip, adding the symmetrical directional measurements together maximizes the sensitivity to bed boundaries, which is optimal for Geosteering (Ref-2,3,4 and 5). The “Deep Directional EM” Tool offers directional Phase-shift and attenuation measurements at four different spacing (96, 84, 34 and 22 inch) and three different frequencies (100 KHz, 400 KHz and 2 MHz). The azimuthal orientation of the tool is provided by a magnetometer system. A key enabling technology for the directional measurements was the development of special antenna-protection shields, optimized to produce minimal attenuation and distortion of EM field figure-1. The tool design is optimized to maximize the depth of investigation and to allow symmetrization of the measurements.

The measurements are designed such that it is sensitive to the conductivity contrast between the formation bed the tool is drilling through and the approaching or adjacent beds. In stringers the conductivity contrast between the shale and oil bearing reservoirs is generally very good. Distance to approaching boundary and its orientation are the two key answers provided by this “Deep Directional EM” technology, and this information is routinely used by Geosteering teams for well trajectory adjustments.

Case Study-1 (Well-A)

The target layer of the horizontal well in question was assumed to be varying in thickness and overlain by thick shale. As per the offset wells, the good facies (sweet zone) was very close to the bottom of the layer. Thus the primary objective was to stay within the sweet zone without exiting through top or bottom . . The sweet zone of the target layer was expected to be underlain by another layer of poor reservoir quality (figure-2).

Some challenges associated with drilling the section within the sweet zone included variation of log responses due to lateral heterogeneity in facies of the target layer. This could lead to uncertainty in interpretation, attributed to the pinching nature of the layer. The formation is about 3° up-dip and the well is to be drilled in up-dip direction and structural dip variations also anticipated during the course of the well. In the pre-job planning stage various LWD log measurements were forward modeled in various geological scenarios. The “Deep Directional EM” technology deemed to be the best possible options to help achieve the objectives.
As seen in the figure-2, the map showing the planned trajectory due east. The well was planned to land close to the bottom of the layer and from there the drainhole section needed to be steered within the good facies. Meticulous planning was done to land the well in the desired target zone using real-time log correlation, image interpretation and by comparing modeled vs. actual logs. The 2-D Earth Model shows the layered earth structure at landing.

Figure 2: 2a – Structural contour map showing the planned trajectory and the offset wells; 2b – Intersection along the planned trajectory shows the position of the planned drainhole close to the bottom of the layer; 2c – landing section log correlation confirm that the well landed in the target layer after entering few meters into the layer; 2d - 2D Earth Model showing the planned trajectory cutting through the layers and landed in the target layer (red star) with an inclination of 85° towards 87.5° at 2167m MD. Red lines represent the dip sticks interpreted on the image and projected along the drilled trajectory to validate the layer earth model. The well successfully landed into the target layered with desired angle and azimuth.
As seen in figure-3, the final 2-D Inversion section showing the comparison between the planned trajectory versus the actual drilled trajectory through the Target layer. The “Deep Directional EM” service in this particular case enabled identifying the bottom boundary, marked by the first two red stars, and hence enabled in making well steering decisions to avoid exit and hence increase the exposure to the sweet zone of the target layer. The other LWD measurements along with the real-time images assisted in the decision making process as well. Towards the end of the well section a conductive boundary was detected proactively, this was completely unexpected and was assumed to be an internal clayey nodule and not the top shale layer. Decision was made to drill ahead and explore without changing the drilling trajectory drastically, as most of the objectives of the drainhole were already met. This also helped in confirming the ability of the tools boundary detection capability. Interlayers with minor resistivity variations along with clay nodules were mapped with sufficient accuracy, which helped to explore the sweet zone further and directly aided in the completion designing process. An overall net to gross of 97% was achieved with the highest oil production from the drainhole in Mukta pay and is the longest drainhole in Mukta field so far.

FAULT IDENTIFICATION TECHNIQUES

Identification of faults while drilling is very crucial and often plays a critical role in geosteering a well to meet objectives. It is important to have a thorough understanding of the measurement suite for the identification of faults in real-time. The following case studies indicate the importance of the fault while placing the drainhole in the desired target.
The technique includes interpretation of multiple images, propagation resistivity curve separation pattern, log response modeling and comparison with offset well data. Some of the newer measurements such as the thermal neutron capture cross section better known as Sigma and the neutron capture gamma ray spectroscopy responses can be quite valuable in interpreting faulting events in some instances. LWD images, even low resolution ones, can give a good indication of fault boundaries (Ref-5). In the given example, figure-4, the horizontal well trajectory entered the reservoir through a fault. This is clearly depicted by the images as well as other log measurements since the contrast on either side is very good. The post drilling wireline based high resolution resistivity image is confirming the same.

Faults could be sealed or opened, this information would be very crucial for completion designing and production planning. In case of sealing faults the seal material could be of varying mineralogy and could be sometimes picked by the elemental capture GR Spectroscopy (Ref-6) or PEF measurements (Ref-7). The high resolution resistivity images are also very useful to identify sealed faults as well as open conductive faults, again depending on the resistivity contrast present (Ref-6).

When faulting is present within a thick reservoir section with minimum heterogeneities, it becomes a challenge to identify the faults. It further becomes more difficult if the horizontal well is planned to be drilled at quite some distance from the top and bottom of the reservoir zone and any displacement occurring will be very discreetly represented by the log responses if not at all.

**Case Study-2 (Well-B)**

The horizontal well discussed in this case was to be drilled from one fault block to another fault block with known displacement (Figure-5; from southern block to the middle block of the field). The target layer is a thick limestone layer with some minor property variations. From field data it was know that the throw is roughly in the range of 7-10m and that the well will be drilled from the downthrown side into the up-thrown side. The structural dip is estimated at about 1.5°. Once the fault is encountered, decision would be to build inclination and get back into the good reservoir section which is toward the top of the layer. The fault is not evident on the vertical offset well log data since these wells have
not intersected the fault boundary. There is minimal heterogeneity in terms of resistivity and bulk density once inside the target formation. So identifying them using conventional log measurements would be challenging. The multifunction logging while drilling technology along with the Rotary Steerable Assembly (RSS) was used in this well to try and achieve the objectives.

MULTIFUNCTION LOGGING WHILE DRILLING TOOL

The multifunctional LWD acquisition platform provides integrated drilling and formation evaluation sensors in one compact collar figure-6 and 7. The tool provides conventional triple-combo measurements from a while-drilling service, along with key drilling measurements plus unique measurements such as elemental capture spectroscopy and sigma, which in a way is unique in the industry. Drilling and co-located formation evaluation sensors are integrated into one collar to increase efficiency and safety. The tool also improves well placement through improved imaging and by bringing measurements close to the bit. It is capable of providing multiple images including the Gamma ray (GR), density and PEF images (only one image in real-time due to transmission bandwidth limitations). The service also helps improve drilling performance with measurements of annular pressure, borehole diameter, and downhole shock etc. (Ref 8 and 9).

As seen in the figure-8, the final 2-D Earth model of the studied well, the initial part of the horizontal well was drilled with some minor changes in log properties. As seen in the middle portion of the logs there are some subtle variations observed. On enhancing the images and expanding the log scales, the GR image shows some low and high angle features (dips were picked and are projected on the curtain section along the drilled trajectory). With very close correlation with the nearest offset well it was interpreted that the well had cut through the fault with an approximate throw of about 13m and the layer dip was about $1^\circ$ up-dip. Subsequently the angle was built and section length was increased by 100m. The angle was not built fast enough due to other constraints and by the time the well got back into the sweet zone the well length objective was achieved and hence section TD was declared.

It was realized that an integrated approach by incorporating all the measurements together, sometimes even the least used property such as the GR image, can reveal a lot of useful information.
Figure 8: 2-D Earth model of the studied well. The initial part of the horizontal well was drilled without incidence. The multifunction LWD provides multiple images including the GR, density and Pef images. In this case some minor variations in the GR and density properties were expected with low contrast. As seen in the middle portion of the logs there are some subtle changes observed. The GR image shows a high angle feature (dips were picked and are plotted on the curtain section). With very close correlation with the nearest offset well it was interpreted that the well had cut through the fault with an approximate throw of about 13ms, the layer dip was about 1 deg. The angle was built and section length was increased by a further 100m, the well was not built fast enough due to other events and by the time the well got back into the sweet zone the well length objective was achieved and hence section was TDed.
Case Study-3 (Well-C)

The well is to be drilled from the central block of the Heera field to the northern block. The northern and central block is separated by a major graben in between. The well is to be terminated in graben (figure-9). The target layer is thick but top part is sweet zone, the trajectory is to remain in sweet zone. The amount of throw of the fault is not certain.

According to the existing structural map the fault assumed to be encountered close to the landing part. On resuming drilling, Mukta formation seemed to thicker 4-5m in TVD and the Bassien top was encountered at a deeper TVD (figure-10). The possible reason is due to faulting, Bassien formation was thrown to a deeper TVD. No confirmed signature of faulting was evident from the LWD logs or image as there was no lithological or property variation against the fault block along the trajectory (discussed previously in fault identification technique as well). In search of the target formation the well was steered deeper TVD and entered the target reservoir. After drilling about 100m the well exited through the top of the reservoir due to formation dip change. A geosteering decision was taken to drop inclination to get into the target layer again. After entering the reservoir again well inclination was maintained 90⁰ to stay longer in the layer by maintaining parallelism. However due to dip change the well again exited the reservoir and TD was declared as well objective was met. Due to appropriate placement of this drainhole in sweet zone, this well gave maximum production and is also producing presently at a very high rate.

Figure 9: Structural contour map on top of Mukta formation with the planned trajectory (red color) and offset wells.

Figure 10: A cartoon is created based on the actual LWD log and image response. The target layer appeared in a deeper TVD than expected and the layer above the target layer appeared to be thicker. The reason is fault with a throw of 4-5m which was expected as per the existing structural contour map at the reservoir top. After entering the reservoir the well was steered as per the log and image signatures obtained in real-time and significant portion of the drainhole was placed within the reservoir by maneuvering the drainhole.
SUMMARY

To achieve successful horizontal well placement within a thin sweet zone of a depleted Brownfield to target the pockets of bypassed oil, a thorough pre-job planning, to select the best possible measurements to aid in the geosteering process is needed. This has been demonstrated by a case study utilizing the “Deep Directional EM” service along with basic log data interpretation, including real-time images, monitored and decisions made in a timely manner.

Faults can be identified by various techniques in horizontal wells including images and other log measurement interpretation. The azimuthal and average measurements along with field knowledge can give an indication of the fault throw direction. The “Deep Directional EM” technique will give the fault throw direction quicker as long as there is enough resistivity contrast and the throw is within the measurement range. In thick homogeneous layers with subtle log property contrast, identification of faults need a thorough knowledge about the area as well as maximum utilization of available log measurements. Though it could be difficult to identify the fault, if the throw is small and there are no significant differences across the fault block w.r.t. to the trajectory. Local field knowledge comes handy in that respect. All the available data including multiple images (Density, PEF, GR, and Resistivity) along with conventional log responses need to be analyzed to get the optimum information for well placement process.

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