Logging While Drilling Aids Accurate Core Point Selection Providing Time Savings with Lower Risk*

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Abstract

The primary objective of drilling an exploratory well is to identify potential hydrocarbon-bearing zones. Wireline logging techniques acquire data after the formation has been drilled. Once zones of interest have been identified from wireline logs, a sidetrack is required to recover core from these zones. There are majors risks associated with the number of trips and sidetracks required to obtain the cores. Borehole instability, deep invasion and formation alteration may cause problems for both core retrieval and formation evaluation. Logging while drilling (LWD) measurements are acquired with the least borehole enlargement, invasion, and formation alteration possible, providing the lowest uncertainty on the true formation properties of interest and the lowest risk of data not being available due to borehole conditions. Another important benefit of running LWD is to acquire measurements as close to the drill bit as possible to assist in timely identification of zones of interest. Geostopping before the bit exits the layer provides considerable time savings and minimizes the risks associated with sidetracks and coring. This paper outlines techniques using LWD resistivity at bit measurements to identify the top of a target layer enabling coring to proceed with reduced risk and considerable time savings.

Introduction

Some of the challenges faced in drilling exploratory wells in complex environments include lack of geological control due to fewer wells drilled in the area being explored. Other complexities, such as the geological uncertainties and complex depositional systems, compound to the problem. Use of offset well logs which are a few kilometers away cause difficulties in correlation. In the past such exploratory wells were drilled using the minimal basic information such as the combination of monitoring the rate of penetration

(ROP) to identify drilling breaks associated with porous zones and cuttings analysis of these porous zones to take decisions depending on the objective of the well which could be either casing point or core point selection. The drawback of this technique is the relationship of drilling breaks with drilling parameters such as surface weight on bit (SWOB) and surface drill string rotation per minute (SRPM) to name a few. Other techniques involved drilling a pilot hole through the possible zone then pulling out of hole and running in with wireline logging tools to identify zones of interest. Then cement the section and sidetrack and drill a deviated hole up to the top of the target layer and then pullout to run in with the coring assembly. This technique involves many trips and sidetracks which increase the risks associated with these operations together with increase in cost of the well. Along with this there is uncertainty associated with complex depositional systems such as channel sand systems including the lateral extent of the sand bodies and whether the sand will be encountered at the same depth as identified from the vertical pilot hole. This paper will explain the techniques used to identify zones of interest in the pilot hole using LWD resistivity at bit measurements without fully penetrating them, enabling the ability to core the section with more certainty and reduced risks and costs associated with techniques outlined above.

The Technology

The LWD laterolog resistivity tool measures five resistivity values: bit, ring, and three button resistivity (azimuthal electrodes) as well as gamma ray (Figure 1).

Bit Resistivity

An alternating current is driven through a toroidal-coil transmitter, 1 ft [30 cm] from the bottom of the tool that induces a voltage in the collar below. Current flows through the collar, out through the bit and into the formation, returning to the collar far up the drillstring (Figure 2). Knowing the voltage and measuring the axial current through the bit determines resistivity at the bit. The resolution of the bit measurement depends on the distance between the transmitter and the bit face - the bit electrode length. When the tool is run on top of the bit, the resolution is about 2 ft [60 cm]. As the bit-resistivity measurement is not actively focused, the current patterns and volume of investigation are affected by nearby beds of contrasting resistivity. Bit resistivity relies on a good bit-to-formation electrical path. The path is always excellent in water-base mud and generally sufficient in oil-base mud. Applications for the bit-resistivity measurement include Geostopping to precisely stop at casing or coring point picks.

Focused Multidepth Resistivity

The tool with button sleeve provides four multidepth focused resistivity measurements. For an 8½ in bit, the ring electrode has a depth of investigation of about 7 in, and the three 1-in buttons have depths of investigation of approximately 1, 3, and 5 in [2.5, 7.6, and 12.7 cm] from the borehole wall into the formation. Button resistivity measurements are azimuthal and acquire resistivity profiles as the tool rotates in the borehole.

Data from the azimuthal scans are stored downhole and dumped from the tool between bit runs. In addition, the azimuthal data may be averaged by quadrant and transmitted to surface in real time along with the ring and bit resistivity, and gamma ray measurements. All four resistivity acquisitions use the same measurement principle: current from the upper transmitter flows down the collar and out into the formation, leaving the collar surface at 90°.

Bit Resistivity in WBM and OBM

In water-base mud, the tool uses the transmitter labeled T2 and the monitor coil M0 to make its measurements. The two coils must be somewhat far apart in order to avoid an area of high current density close to the transmitter coil caused by the current shorting through the mud (Figure 3).

In oil-base mud it is slightly different, since no current can leave from the body of the tool due to the insulating nature of the mud. In this case, the monitor coil M2 is used; it is very close to the transmitter but is not affected by high current density due to the lack of currents present in the mud. The current leaves the tool at the bit, since this is in intimate contact with the formation and returns at some touch point on the tool or BHA above. The M0 coil is not used because of the unpredictable nature of the touch points and the fact that most of the current returns to the near-bit stabilizer mounted on the tool just above M2.

Case Study

The exploratory well was to be drilled from a land location to a target below the sea. A water-base mud system was used. The initial part of the well was deviated until the horizontal drift was achieved and then dropped to drill and explore the zones of interest for coring. The nearest offset well was a kilometer away. The target is a laminated shaly sand channel system as seen from the offset well log in Figure 4.

It was expected that the use of the offset well data for correlation purposes would be quite difficult due to the complex geology of the target zone. Using the ROP as an indicator of formation tops would also be very difficult due to the reasons cited above. The LWD resistivity at bit tool was placed right above the bit to enable getting measurements as close to the bit as possible. The bottomhole assembly with the measurement offsets is shown in Figure 5. Below the Resistivity tool and above the bit a float sub is included for well control purposes and a crossover to accommodate the float sub. Because of this the entire section below the lower transmitter acts as the electrode and the midpoint of the measurement is 1.8 m from the bit face. This also causes a reduction in the resolution of the measurement.

The other measurements such as the gamma-ray, high resolution focused resistivity, and density and neutron porosity are much higher up. These measurements are run to acquire high quality data for enhanced formation evaluation purposes and for data assurance purposes in events when wireline based measurements cannot be run due to borehole problems. The correlation between the drilled well and the offset well as seen in Figure 6 is very difficult due to the reasons cited above. The bit resistivity in red (second track of the drilled well) was monitored continuously while drilling. As noticed the bit resistivity is slightly lazy as compared to the focused ring and button measurements in green, this is due to the reduction in resolution due to the placement of additional equipment between the bit and resistivity tool. Table 1 shows the comparison of the resolution between the different resistivity measurements.

The well was drilled with continuous monitoring of the logging data, drilling data and correlation with offset well logs. The combined techniques including the bit resistivity enabled picking the core point in time without drilling through the entire zone of interest. In doing so additional activities associated with conventional techniques were eliminated such as extra trips, sidetracks and hence reduced safety risks and operational costs.

Other points to note are that there are some borehole enlargements observed during the LWD time as seen by the shading in Track 1 of Figure 7. Most likely the borehole could deteriorate further with time and increase uncertainty on the post drilling logs such as the wireline based methods. This gives us a better assurance on data quality from the LWD measurements. Figure 8 shows LWD logs over the section cored.

Conclusion

LWD resistivity at bit measurements as close to the drill bit as possible assists in timely identification of zones of interest with measurement at 1.8 m from the bit. Geostopping before the bit exits the layer of interest provides considerable time savings and minimizes the risks associated with sidetracks and coring. High-resolution LWD images over the cored section give a good picture of what can be seen in the cores. Log data can also be calibrated with core data to improve interpretation.

Logging while drilling measurements are acquired with the least borehole enlargement, invasion, and formation alteration possible, providing the lowest uncertainty on the true formation properties of interest and the lowest risk of data not being available due to borehole conditions.

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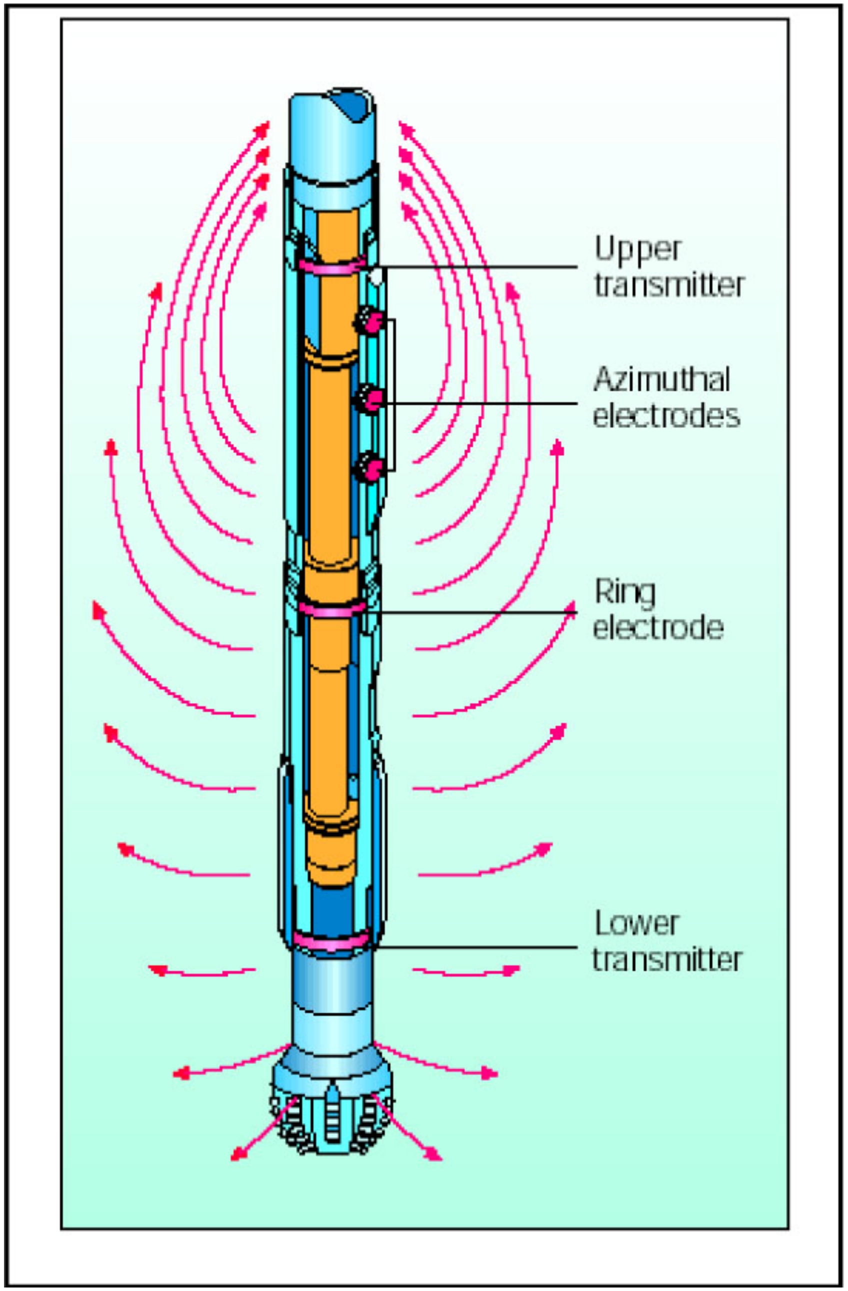

Figure 1. The LWD laterolog resistivity tool.

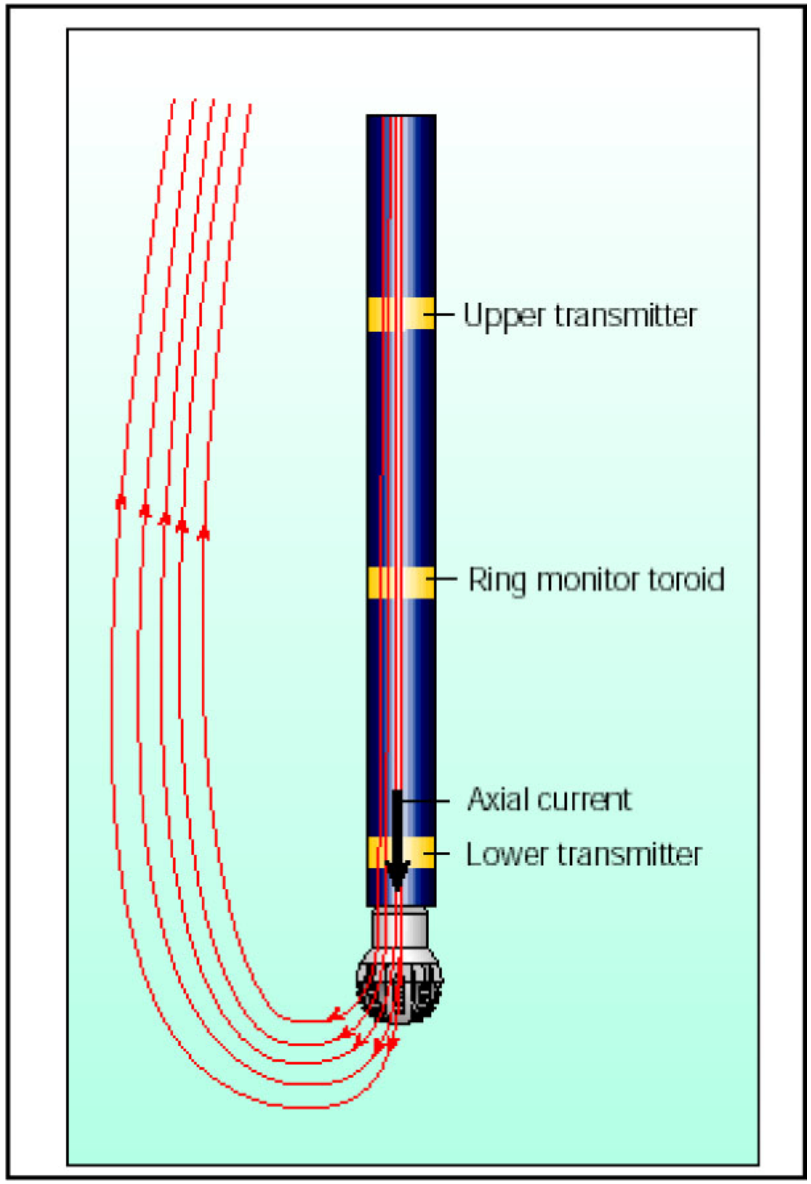

Figure 2. Bit resistivity measurement. The lower toroidal transmitter generates axial current that flows down the tool and out through the bit. The ring monitor toroid measures the axial current. Formation resistivity is given by Ohm's law once the upper transmitter drive voltage and the current are known. Corrections are made to compensate for tool geometry and transmitter frequency.

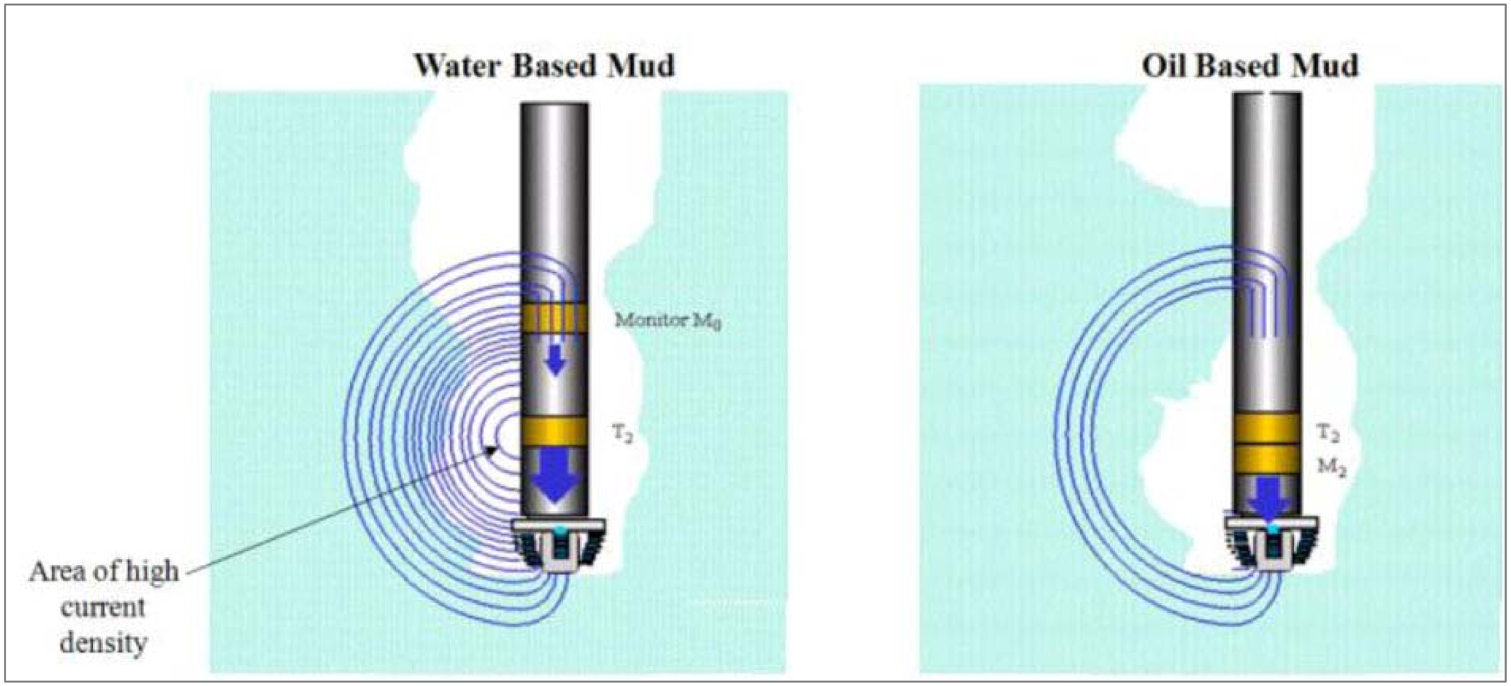

Figure 3. Bit resistivity in water- and oil-base mud.

In oil-base mud, it is slightly different. Since no current can leave from the body of the tool due to the insulating nature of the mud. In this case, the monitor coil M2 is used; it is very close to the transmitter but is not affected by high current density due to the lack of currents present in the mud. The current leaves the tool at the bit, since this is in intimate contact with the formation and returns at some touch point on the tool or BHA above. The M0 coil is not used because of the unpredictable nature of the touch points and the fact that most of the current returns to the near-bit stabilizer mounted on the tool just above M2.

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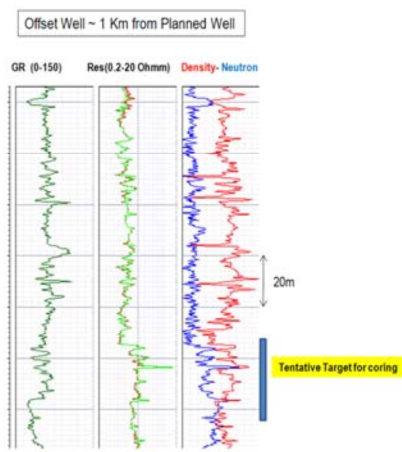

Figure 4: Offset well log showing the tentative zone that needs to be cored.

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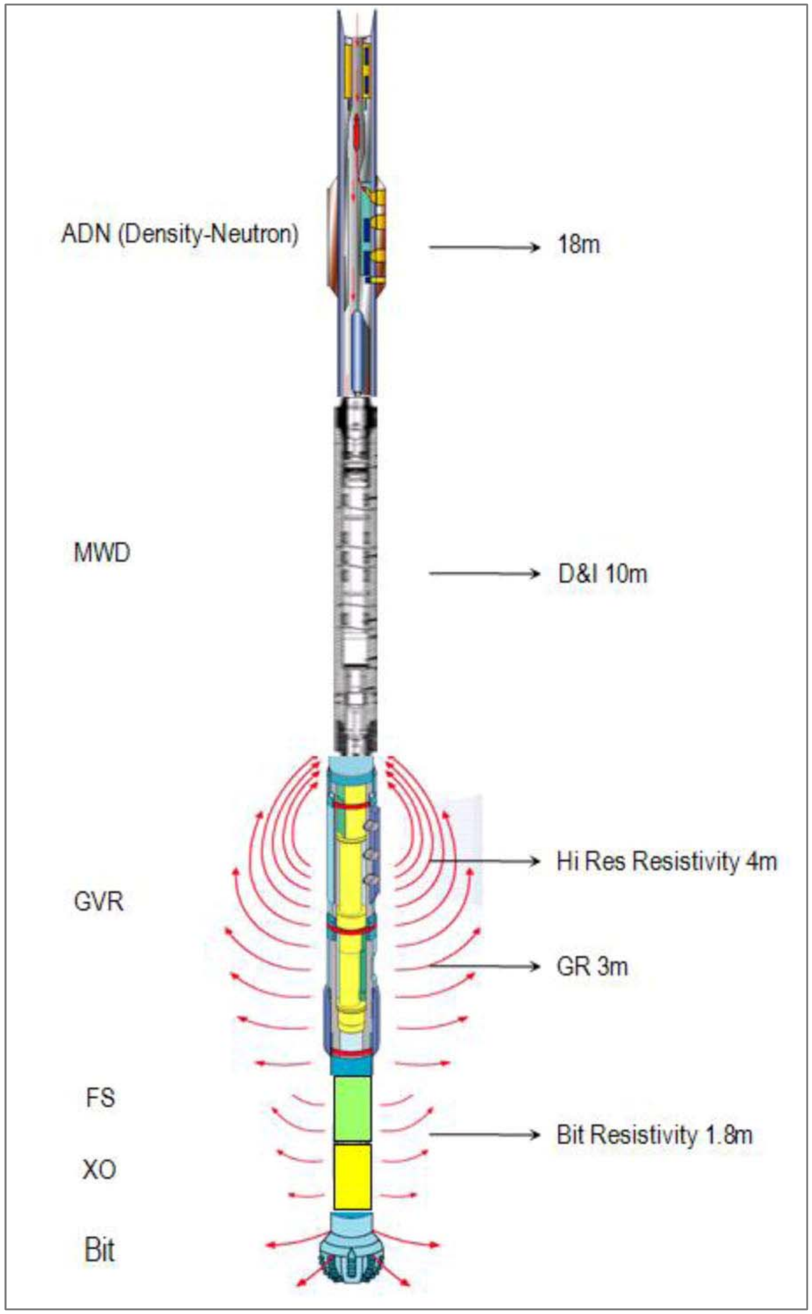

Figure 5. Bottomhole assembly depicting measurement offsets from the bit.

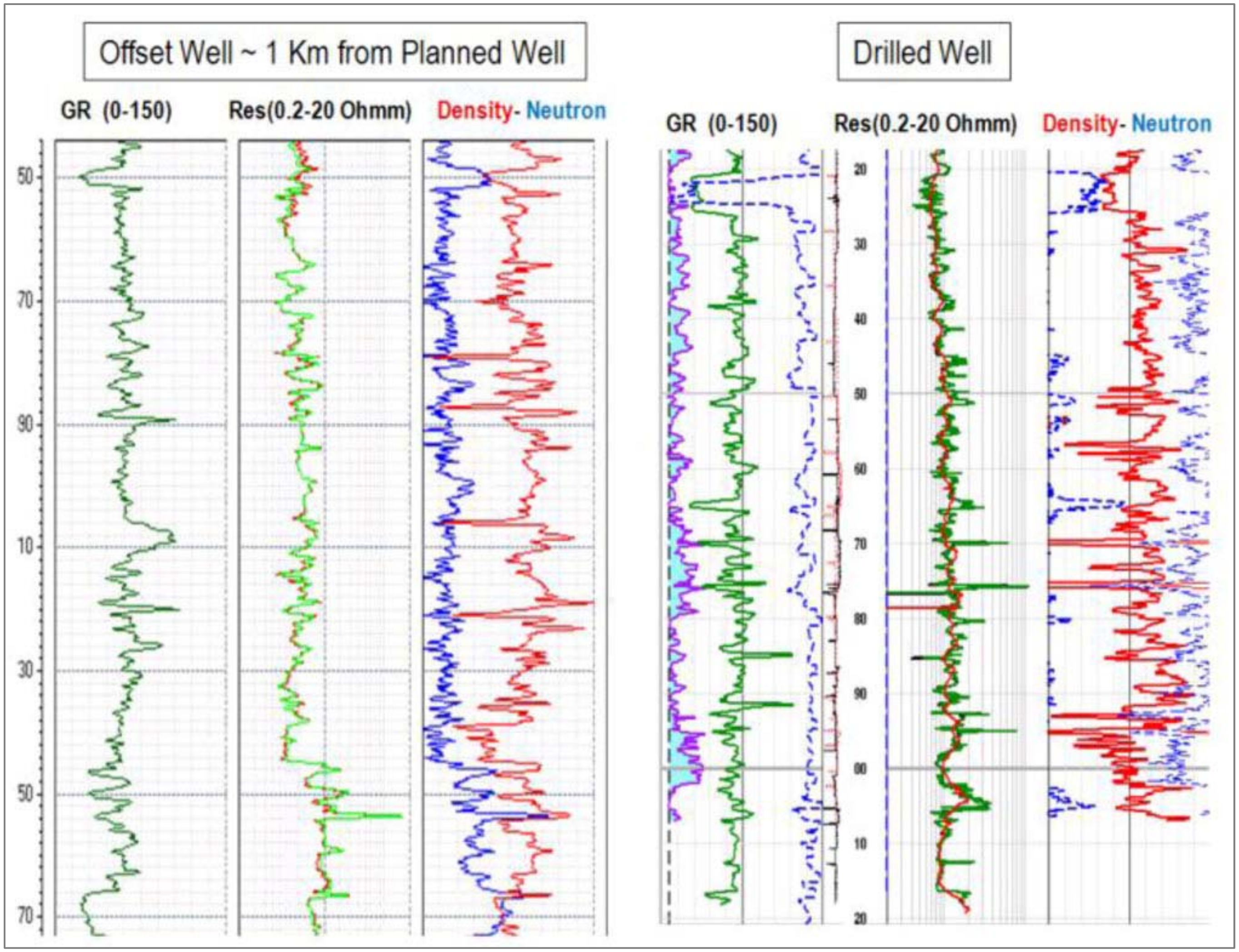

Figure 6. Correlation between the well is a challenge due to the complexity in geology and the fact that the wells are approximately a kilometer apart. The second track of the drilled well shows the resistivity measurements. The solid red curve is the bit resistivity which is 1.8 m from the bit and the green are the high resolution focused ring and button resistivity which are a little higher up.

	Vertical resolution (in.)
R_{BIT}	12 to 24
R_{RING}	3 to 4
R_{BD}	2 to 3
R_{BM}	2 to 3
R_{BS}	2 to 3

Table 1. Rbit is the resistivity at the bit. The vertical resolution with a bit screwed directly on the bottom of the LWD tool is about 24 in (2 ft). As the distance from the bit increases, the resolution decreases.

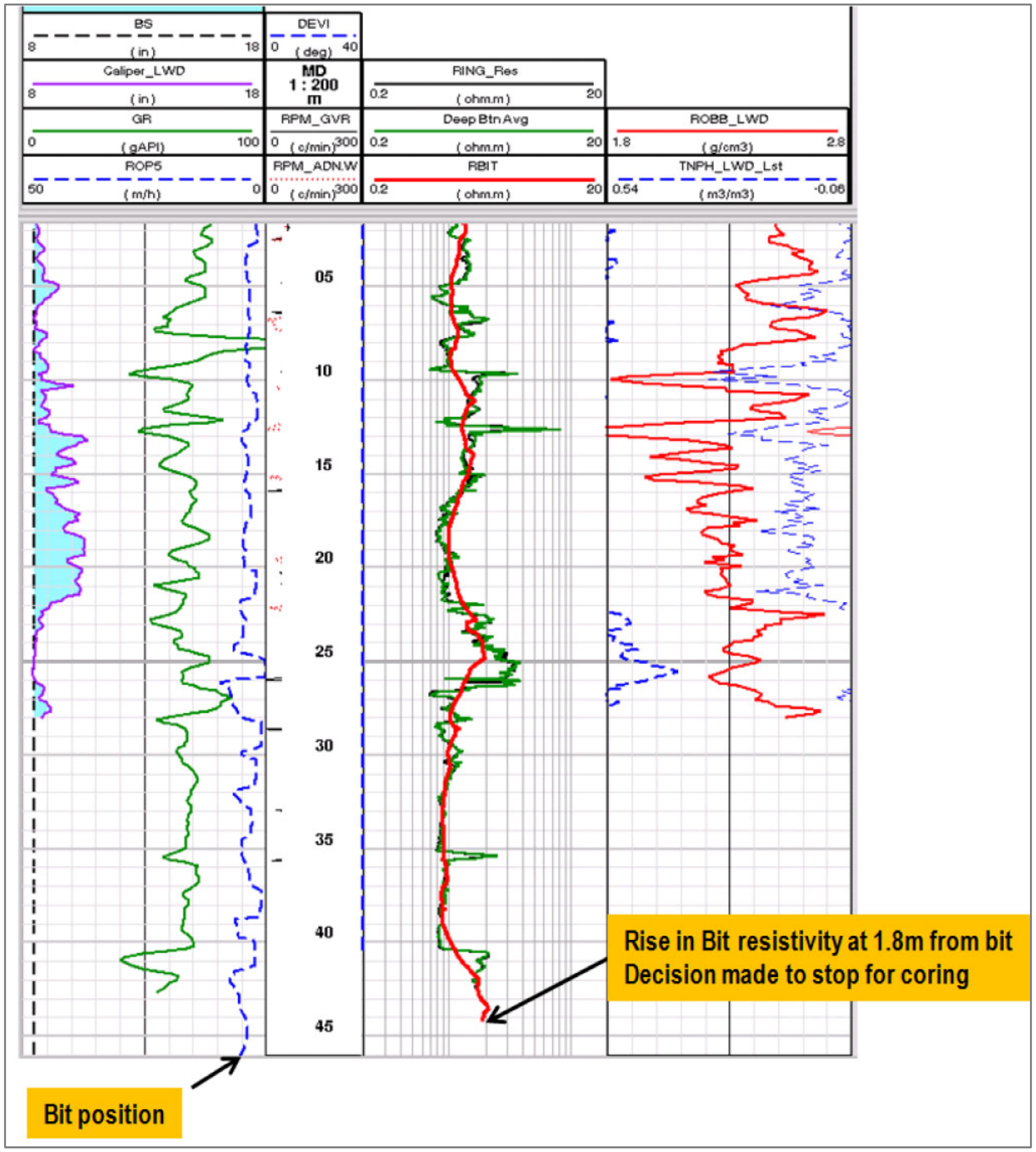

Figure 7. Notice the minor resistivity spikes associated with thin beds are picked up by the high resolution focused measurements. These are not seen by the bit resistivity due to reasons cited in Table 1. If the bit were screwed directly on the tool itself then the resolution would have improved. Also notice the ROP in blue dashed first track does not correlate with the other measurements. Increase in porosity shows a reduction in ROP.

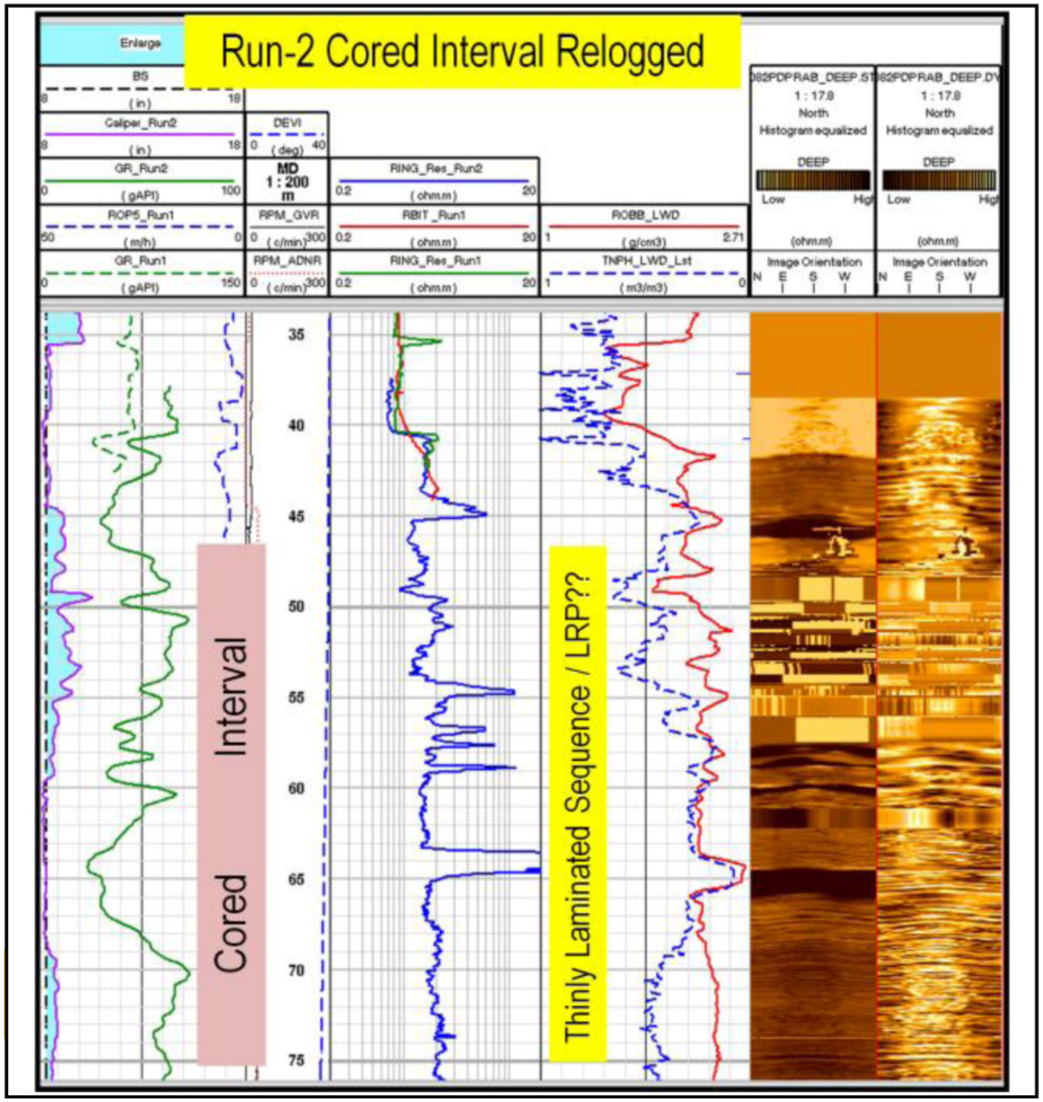

Figure 8. The cored interval consist of thinly laminated sequence as seen from the high-resolution LWD resistivity images.