Understanding the Anomalous Behaviour of Dual Induction Log Against Highly Conductive Thin Bed – A Case Study

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Summary

Field examples from Cambay Basin India demonstrate that the conventional Induction Log behaves anomalously at each interface of a high-conductivity contrast. The deep and medium induction curves show a very high value while crossing the bed and an unrealistic value in the form of “horns” appears which is not seen on the shallow latero log (LL3). It is observed that at high resistivity contrast with a thin (< 1.5 m) low resistivity layer, skin effect corrections do not give the true formation resistivity. In such cases three- point deconvolution for shoulder bed effect, also does not yield the desired result.

Such phenomenon has been studied by Duesterhoft[1] and observed that addition of the auxiliary coils in the Dual Induction Tool, having spacing less than the main-coil span to achieve better focusing results, can add anomalous character to the curve shape while crossing the interface of highly conductive bed. Dual Latero Log (DLL) and High Resolution Induction Log (HRI) were recorded after horns were observed on the Induction Log and the field examples presented in Figure-1&2 demonstrate the magnitude by which the resistivity measurement can vary.

The high resistivity horns appearing in Dual Induction Logs (DIL) against highly conductive thin formation has been relooked. Field examples exhibiting these phenomenons are studied. An attempt has been made to analyze the anomalous behaviour of induction log by comparing its response with other resistivity and porosity logs.

The study concludes that these horns are not representing the formation resistivity but are spurious and should not be misinterpreted. It is also concluded that DLL and HRI tools provide better results in such cases where “horn” effect is observed and the original raw data, prior to deconvolution, provides comparatively more realistic resistivity values.

Introduction

The anomalous behaviour of Induction log Deep and Medium response has been observed against a Babaguru formation in Santhal field of Cambay Basin of Western India. Cambay basin[2] is a narrow intracratonic rift graven elongated in the north-south direction. It is filled with tertiary detrital deposits which are mainly composed of sandstone, siltstone and shale with interbedded coals. The anomaly is found in the Babaguru formation at varying depths above 1000 m. This formation is mainly sandstone with alternating bands of shale and claystone belonging to Miocene age. Conventional Induction, Formation density, Neutron, Gamma, and Sonic log are generally recorded in this field to delineate hydrocarbon bearing reservoirs. The Induction log anomaly occurs against a thin bed and often put the logging engineers in a paradox. Resistivity logs like Lateros and High Resolution induction log give undistorted response against the similar formation. The objective of this study is to understand the anomalous behaviour of Induction log by analyzing probable reasons behind the anomaly and suggest remedial measures.

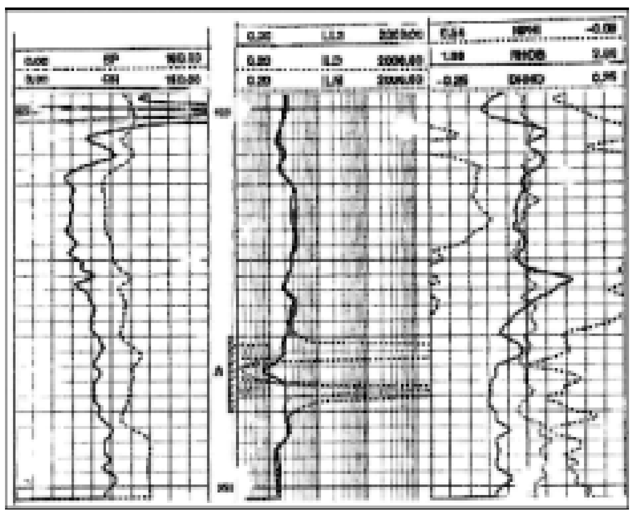

Fig-1: Anomalous behaviour of DIL

Methodology

Methodology adopted to understand the anomalous behaviour of Induction Log is

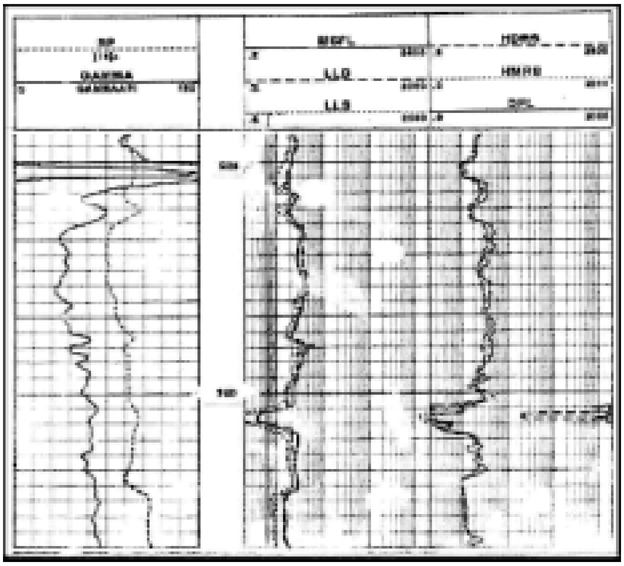

Fig-2: DLL & HRI log against the anomalous layer of DIL

a) Analysing the propagation effect phenomenon.
b) Studying the skin effect correction and three-point deconvolution effect.
c) Analysing the Induction Log tool design and tool physics.
d) Understanding the impact on curve shape due to coil design.
e) Comparing the DIL response with DLL and HRI response under similar condition

Skin or propagation effect

The conventional Induction Logging tool uses geometric factor concept which considers that "ground loops" are standing alone in free space and are mutually non interactive. In conductive medium the energy of electromagnetic wave generated by transmitter attenuates and experiences phase shift significantly as it propagates farther from transmitter. Thus the performance of induction tool could be different from that predicted by the simplified geometric concepts under specific formation condition. The signal reaching to the receiver has three components: -

i) **R- signal** which is 180° out of phase with the transmitter current and reflects formation conductivity,
ii) **Formation X-signal** or quadrature signal arising from mutual coupling of primary and secondary loops which is 270° out of phase with transmitter current and
iii) **Sonde X-signal** which is 90° out of phase with the transmitter current and produced due to mutual coupling of tool coils.

In Induction tool, **R-signal** is considered for measurement.As the conductivity of formation increases, the strength of induced eddy currents become progressively weaker in amplitude farther from transmitter and the phase angle of formation X-signal increases. Both these factors combine to reduce the R-signal received at the receiver. This reduction or loss of signal is referred as "**skin effect**". But the distribution of current in the formation, produced by the induction field, is the direct result of phenomena associated with the propagation of electromagnetic field through the formation. Hence, the authors suggest that appropriate description would be "**Propagation effect**". The propagation effect reduces the recorded apparent conductivity to a value lower than that obtained from geometric factor calculation. The effect is more pronounced for high conductivity and is nonlinear.

Skin effect correction and three point deconvolution

Induction log is corrected for skin effect for thick and moderate to low conductive bed. But these corrections do not suffice when the beds are highly conductive and deeply invaded, or too thin. In conventional Induction tool only R-signal is measured and the formation X-signal which is out of phase and destructive in nature, is not measured for skin correction. Designers of traditional induction devices have included skin effect boosting algorithms to increase the measured signal. There exist three such algorithms for Induction tool (6FF40). However, for conductivities greater than 2000 milli-mhos (resistivity < 0.5 ohm-m) corrected conductivities can vary significantly. The algorithms are inadequate when the measurement is in highly conductive medium. Thus in conductive formation the correction for skin effect does not yield the true resistivity of the formation and may give an anomalous result.

When the sonde is located in a thin resistive bed, the voltage is strongly influenced by eddy currents in the conducting shoulder beds, as eddy current in the resistive bed is relatively small. As a result, the conductivity of resistive bed detected by the sonde is greater than its actual value. The reverse phenomenon occurs when a thin conductive bed is located in more resistive shoulder beds. Doll[3] proposed an algorithm to make correction for this effect and to improve vertical resolution. This is done by processing raw data through following equation known as three-point deconvolution.

$$\sigma d(z) = (1+2a)\, \sigma a(z) - a\, [\, \sigma a\, (z+h) + \sigma a\, (z-h)\,]$$

where $\sigma d(z)$ is the processed conductivity at depth z, and $\sigma a(z)$, $\sigma a\ (z+h)$, $\sigma a\ (z-h)$ are the raw conductivity data obtained at depths z, z+h, and z-h, respectively. The terms "a" multiplied by the conductivities measured at "h" inches above and below the current sonde position represent the estimated contribution of the shoulder bed conductivities.

Figure –3 shows the effect of application of skin effect correction (SEC) and three point deconvolution (DC) process on a 6FF40 log. The thickness of center bed is 1 foot and the resistivity is 0.5 ohm-m. The resistivity of shoulder bed is 100 ohm-m. The three point deconvolution has produced the processed resistivity curve closer to the true resistivity at the center bed but it has resulted in producing two infinite resistivity streaks or "horns" at the bed boundary. When the resistivity contrast is small (10 versus 5 ohm-m), the effect of the three point deconvolution process is small. For moderate resistivity contrast (100 to 5 ohm-m), the three- point deconvolution process does produce a desirable effect of improving the resolution of the bed boundary.

Effect on curve shape by auxiliary coils

The conventional Induction tool makes two measurements ILD (6FF40) for deep investigation and ILM (7FF34) for medium investigation the main transmitter being common. Auxiliary coils, having spacing less than the main coil span, are added to the main coil pair to achieve better focusing and vertical resolution.

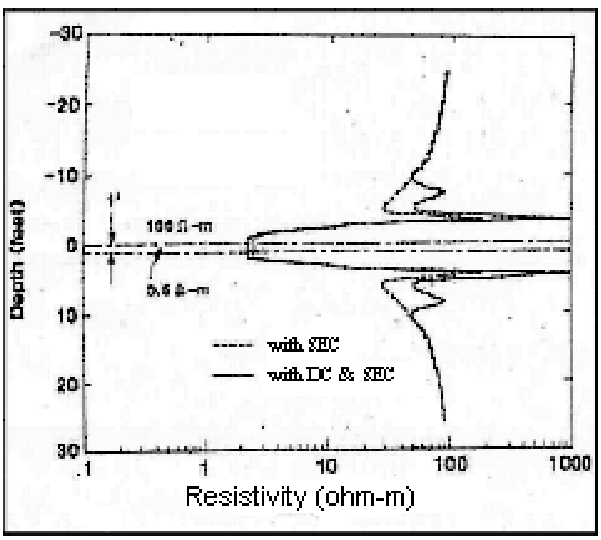

Fig-3: Effect of three point deconvolution process on the DIL (After Liang C. Shen – SPWLA, June- 1998, Vol-I)

Duesterhoeft[1], et al have calculated the response of a highly focused two-coil pair system (Figure – 4) while logging upward from a formation of conductivity 100 millimho/m into a formation of conductivity 1000 millimho/m as shown in Figure-5. The curves show that focusing, accomplished by adding the auxiliary coils, sharpens the response of the tool while crossing the conductivity interfaces. The steepest break in the conductivity curve of a coil pair is developed as the coils pass the interface.

As the sonde approaches the interface from bottom, this coil pair starts to sense the change in conductivity about 2.54m below the interface. A large change in signal occurs as the sonde passes from one bed to the other with the maximum rate of change taking place at the bed boundary.

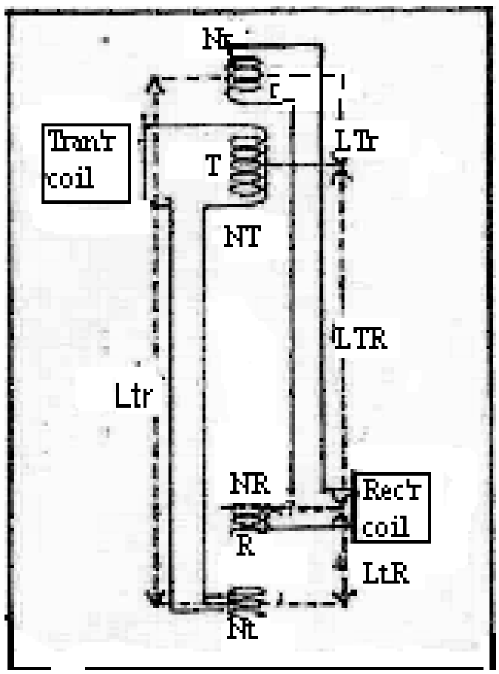

Fig 4: Coil arrangement for two coil –pair system (After Duesterhoeft et. al. J. Pet. Tech-Nov 1961, Vol. 13)

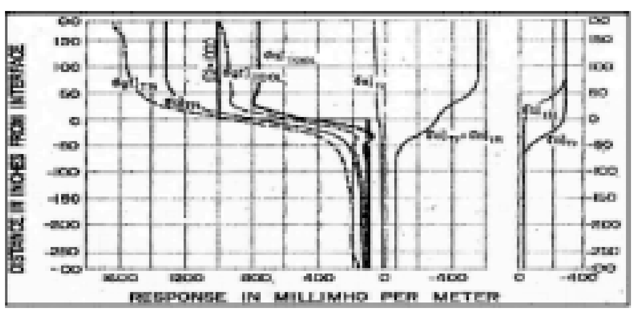

Fig 5: Effect on curve shape by auxiliary coils (After Duesterhoeft et. al. J. Pet. Tech-Nov 1961, Vol. 13)

The compensating action of the leading auxiliary coil is to diminish the effect of the approaching high conductivity formation. Around 1.27m to .5m below the interface the contribution of leading coil pair (**Tr**) starts increasing at a high rate which is greater than that of main-coil pair. As a result, the leading auxiliary coil pair subtracts signals at a high rate so that overall conductivity at this interval decreases as the tool moves towards the higher-conductivity formation. The reversal of direction of the conductivity curve over this short interval causes the peak developed approximately .9m below the interface.

Similarly, the signal developed by the trailing auxiliary coil (**tR**) supplies a negative signal above the interface, which increases more rapidly than the signal from the main coil pair decreases. This causes a reversal of the conductivity curve, which results in the conductivity peak developed at 0.9m above the interface.

Field example-1: Analysis of anomalous DIL

A field example of DIL anomaly has been shown in Figure-1 with SP and GR logs. Log was recorded in 21.6cm hole filled with water base mud using 3.81cm stand off. The anomaly is spread over an interval (940 – 945) m which is marked as "A" in the figure. Actual bed thickness is 1.5m ie (941.5 – 943) m as seen from LL3 log which is reading 0.7 ohm-m. ILD (Induction Log Deep) and ILM (Induction Log Medium) values show high resistivity (appr. 10K ohm-m) just 2m below and 2m above the bed symmetrically creating two high resistivity "horns"**.** The horns are mirror image of each other. SP log against the bed is positive and GR (Gamma Ray) is reading 60 API. Density and Neutron logs indicate that the bed is shaly and contains no heavy mineral. Both the Induction logs are reading 0.2ohm-m against the bed lying between the two high resistive horns.

The anomaly is attempted to be explained by propagation phenomenon in highly conductive formation, three point deconvolution process and coils effect on curve shape. The conductivity of the bed under study is appro. 20k millimho/m as read from HRI log and conductivity of shoulder bed is appro. 0.25k millimho/m. Because of this high contrast (1:80) of conductivity, when the induction tool moves upward, induction signals are reduced drastically at the interface. Such spurious peaks do not develop if the conductivity contrast between two formations is low or the lightly focused coil system is used in the sonde. Moreover, three- point deconvolution process applied to the raw data also tends to affect the curve shape resulting in accentuating the formation of horns.

A common example is produced from our field (Figure-6) when conventional induction tool enters the casing shoe. There is formation of single horn which is similar to the example of formation of two horns at each interface (Figure-7(i),7(ii),7(iii)), of a thin layer with high conductivity contrast.

Field example-2: Comparison with DLL

DLL log shown in Figure-2 recorded in the same well to study the Induction log anomaly. The curves do not show "horns" and are able to read low resistivity values. It is observed that DLL provides good bed definition (2ft) independent of neighbouring bed resistivities.

Field example-3: Comparison with HRI log

A HRI log has also been recorded for comparison, as shown in Figure-2, against the same layer of DIL anomaly but in different well. The log shows normal and stable response of all three curves. HDRS (deep resistivity) and HMRS (medium resistivity) are reading as low as 0.051

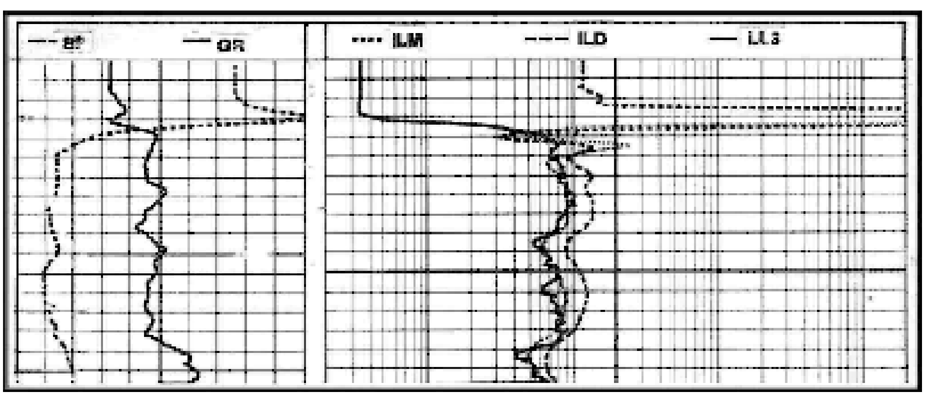

Fig-6: Casing shoe effect on DIL (Single horn)

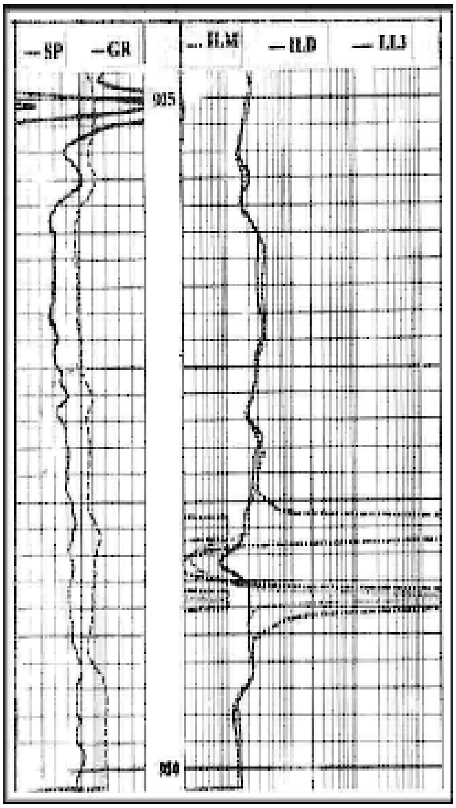

Fig-7(i): DIL Anomaly in Well # A

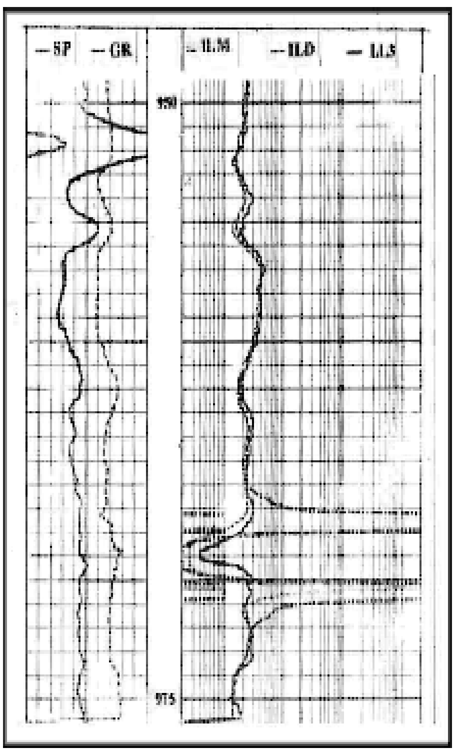

Fig-7(ii): DIL Anomaly in Well # B

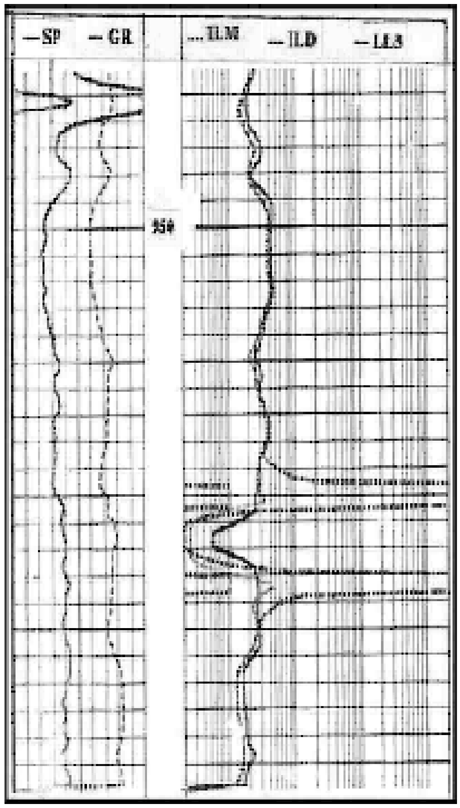

Fig-7(iii): DIL anomaly in Well # C

ohm-m and 0.054 ohm-m respectively as per digital values of deep and medium resistivities. The sonde X-signal in HRI is eliminated by winding its multiple coils in a precise manner and placing at specific locations in the sonde. In conductive bed, the formation X-signal (phase shifted), which reflects the formation conductivity and results due to propagation effect, is taken into account. Both formation X-signal (out of phase) and R-signal (in phase) are measured dynamically while logging and are digitized downhole. The phase shifted signals are measured for skin effect corrections to provide improved apparent conductivity values. The deconvolution filter used in HRI for shoulder bed effect correction maintains undisturbed curve shape. The bed conductivity is thus more accurately measured by HRI log than DIL.

Conclusions

After examining field examples and studying Induction tool physics it is concluded that: -

1) Due to abnormal resistivity contrast (more than 1:10) Dual Induction Log (DIL) shows very high resistivity

(horns) which are spurious. This effect is not significant when the resistivity contrast is low. Such effect occurs only in cases where there are interfaces with high resistivity contrast.

2) The horns appearing in Induction log are also due to tool design and data processing (three-point deconvolution).
3) The propagation effect is directly related to the frequency used by tool .DLL (280 Hz maximum) is less affected as compared to DIL which uses 20 KHz.
4) HRI tool is comparatively more suitable for highly conductive formation because of its improved tool design and measurement principle.
5) Latero and High Resolution Induction tools provide better results against high contrast thin bed interface and either DLL or HRI log is recommended in the logging suite instead of DIL, for accurate resistivity measurement.

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Views expressed in this paper are those of authors only and may not necessarily be of ONGC.

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