Detecting Top of Cement in Real-time using Acoustic Logging while Drilling, Offshore Nigeria

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ABSTRACT

Uncertainty in successful wireline cement bond log and cost of deploying a dedicated wireline run to determine the top of cement (TOC) in a highly deviated well offshore Nigeria to meet regulatory standards is a challenge to field development. This paper presents a successful approach to determine TOC while drilling in a highly deviated well in real-time, eliminating the need for a dedicated wireline logging, saving cost, and meeting regulatory requirements. The Logging while drilling (LWD) acoustic tool provides compressional correlogram and compressional slowness (DTC) transmitted in real-time. This tool was deployed as part of LWD tools in the study wells. Formation slowness and cement density were key to successful programming of the tool to differentiate formation arrivals from casing arrivals. LWD acoustic tool was programmed to transmit two delta-T values, two delta-T semblance and correlogram for the high frequency. The first delta-T corresponded to the free casing arrival while the second delta-T corresponded to formation slowness behind casing. Telemetry was optimized to transmit a high data density of correlogram and DTC data, allowing for similar results between the transmitted result in real-time and memory modes. In addition, this allows for cement evaluation during rotating and/or non-rotating activities. Eight different wells drilled in this field utilizing the same bottom hole assembly (BHA) with acoustic tool effectively determined the top of cement in real-time behind 9 5/8in casing. Based on the real-time TOC results, the drilling of the reservoir section was continued without any additional logging run on wireline. Real-time TOC evaluation was started 300ft above the theoretical top of cement and logging continued to casing shoe for cement bond index determination. This was done due to an uncertainty in the theoretical top of cement and to determine interval of free casing. The real-time data transmission was optimized to get best possible data density with the logging speed of 500-600m/hr. The real-time TOC was successfully completed and compared to memory. Real-time and memory correlation was confirmed at similar depths. The full recorded waveforms correlate closely with the correlogram transmitted in real-time establishing this as an acceptable method for TOC determination. Operationally, 48 hours rig time savings was achieved deploying LWD acoustic tool for real-time TOC determination. Reliable real-time DTC data transmitted matched the processed memory data and contributed to quick decision making while drilling. The fast resolving of the top of cement in real-time enabled drilling operation to continue without spending time to acquire the TOC depth using wireline options or other separate logging run.

Keynote: Acoustuc tools, Telemetry, Logging While Drilling (LWD), Correlogram, Top of Cement (TOC).

INTRODUCTION

Over the years, there has been a significant challenge in meeting regulatory demands with field development offshore Nigeria. The need to determine the presence and depth of cement required dedicated cement bond log (CBL) deployment on wireline. With the deepwater offshore environment, highly deviated wells posed a risk of unsuccessful CBL operation, costing money and operating time.

Bonga field deep offshore Nigeria presented a need to change the traditional approach as number of wells drilled surged over the years and desire to optimize operation grew with it. Acoustic logging while drilling technology was deployed along with other logging tools making up the BHA. This service was used in the 9 5/8” casing run in the 12.25in hole sections with deviation starting between 35 – 45 degrees, reaching 90 degrees towards the bottom of the section prior to 8.5in drain sections.

Eight wells in this field were evaluated with this approach

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prior to the 8.5in drain sections. Compressional slowness is attenuated by casing where cement is absent with no bond between the casing pipe and the formation, evidenced as free casing arrivals in the tool receivers. Cement bond provide coupling required to propagate acoustic signals into formation, and formation slowness in measured in such instance. In these study wells, top of cement were effectively determined in real-time in all the wells drilled as we could differentiate free casing arrivals from formation arrivals.

Compressional slowness (DTC) transmitted in real-time both in casing and in open hole reservoir sections were useful for real-time decisions and seen as best practice to develop these reservoirs and meet regulatory requirements.

GEOLOGICAL BACKGROUND

Bonga is the first deepwater oil field developed in the Gulf of Guinea. It is located 120km offshore Nigeria and lies in water more than 1,000 meters deep across an area of 60 square kilometers, on the continental slope of the Niger Delta.

The hydrocarbon reservoirs consist of middle to upper Miocene turbidites, characterized by mud-rich, unconsolidated amalgamated channel belts and canyon deposits, with depositional environments ranging from channel systems to turbidite lobate systems. These reservoirs were deposited along a mid-lower slope setting with a mix of channelized lobate and amalgamated channel belts.

The geology can be described as a complex interaction between syn-depositional faulting and turbidite deposition, leading to a series of stacked, hydrocarbon-bearing channels and lobes. The field is composed of distinct and vertically stacked turbidite reservoirs bound by structural-stratigraphic traps formed by the draping of turbidite sand fairways over shale-cored structures. In some cases, the traps trend in a particular direction and are dissected by en-echelon faults, creating fault blocks and relay ramps that may allow block-to-block communication, and could have a controlling effect on the deposition and subsequent compartmentalization of these reservoirs.

The light oil, characterized by API gravities ranging from 26° to 33°, within the Bonga reservoirs have favorable reservoir properties, allowing for relatively high production rates. Reservoir fluids exhibit low gas-oil ratios, and the reservoirs are normally pressured. The initial pressures in these reservoirs range from 3,000 to 5,000 psi. Reservoir porosities range from 27% to 33%, and permeability is reported between 1 to 3 Darcy.

Some uncertainties considered in this field include sand continuity and connectivity, reservoir compartmentalization, and fluid contact. These factors are critical due to the complex channel systems, structural discontinuities, and stratigraphic barriers that have potential for compartmentalization.

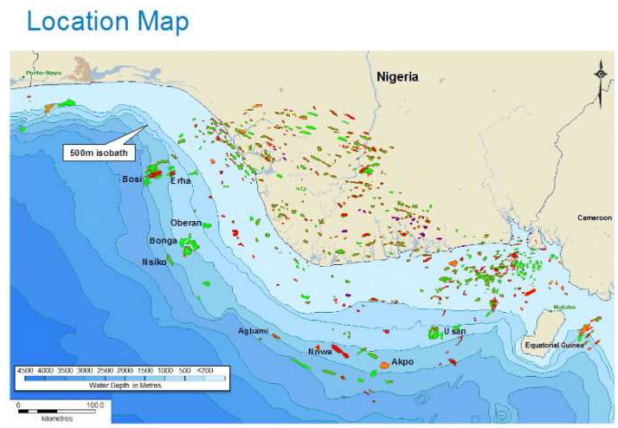

Figure 1: Bonga field Location.

METHODOLOGY AND WORKFLOW

LWD acoustic tool provides different programming options, and this offers flexibility to optimize acquisition to meet different objectives in real-time and memory modes. Multi-frequency excitation ensures high data quality in both fast and slow formations in different hole sizes. In the study wells, real-time TOC was the primary objective and this required programming the tool to transmit two delta-T values, two delta-T semblance and correlogram for the high frequency. Hence, real-time DTC and Cement bond index evaluation (CBE) was also performed as part of this project and results matched memory processed DTC.

Figure 2: Workflow

Monopole logging mode used to acquire two delta-T values, transmits compressional acoustic energy uniformly around the tool. The omnidirectional compressional wave travels through the mud, casing and cement towards the borehole wall and formation. (See Fig 3) On the borehole wall, the compressional waves are reflected along the formation through critical refraction as described in Snell's Law. The compressional waves travelling in the formation are constantly radiated back into the cement, casing, and mud also through critical refraction. This wave energy is recorded at the receivers as the compressional signal.

Logging While Drilling Acoustic Technology

LWD acoustic tool consists of transmitter, acoustic-isolator, receiver-array, and the tool electronics (fig. 4). The

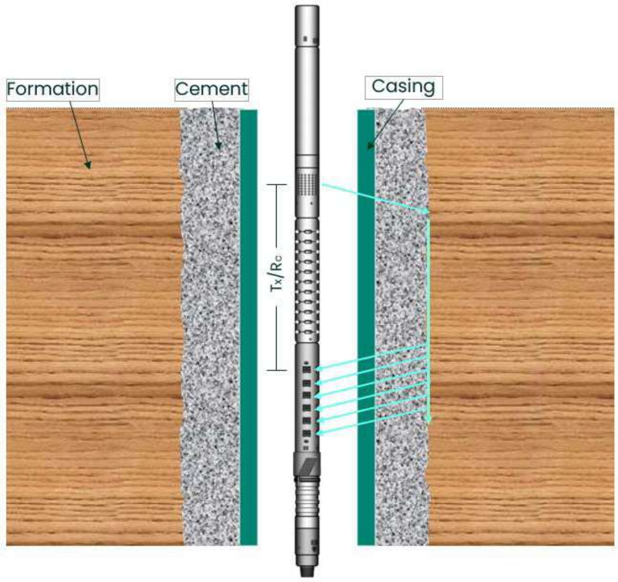

Figure 3: An illustration of how Compressional acoustic waves travelling through the mud, casing and cement, its further reflected along the cement/formation boundary, before reflected back through the cement, casing and the mud to the receivers.

acoustic isolator prevents direct acoustic signal coupling between the transmitter and the receiver-array. This technology uses multi-frequency excitation to derive high quality acoustic data in both fast and slow formations while drilling in different hole sizes. These acoustic properties have wide applications not limited to lithology identification, dynamic rock property measurement, primary and secondary porosity determination, seismic time-depth tie, pore pressure prediction, and borehole stability determination. Data availability in real-time ensures quick drilling optimization and various model updates.

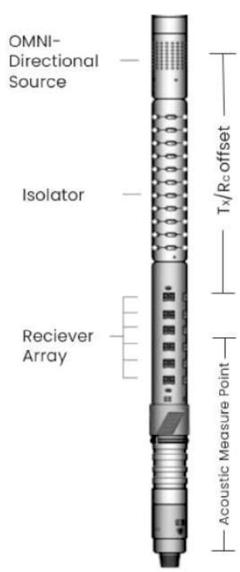

Figure 4: Basic illustration of acoustic tool components.

RESULTS DISCUSSION

Eight (8) wells in the study field were assessed to determine TOC in real-time. TOC determination was done at logging speed varying between 1640 ft/hr and 1968 ft/hr achieving good data quality in real-time and memory mode. Cement bond index evaluation (CBE) was also performed across these wells which complemented the TOC evaluation. Results showed good agreement between these two-analysis done using LWD acoustic tool. In real-time, tool was programmed to transmit two delta-T values, two delta-T semblance and correlogram for the high frequency. The first delta-T from monopole excitation mode corresponded to the free casing arrival while the second delta-T from monopole excitation mode corresponded to formation slowness behind casing. The formation slowness occurs where there is significant amount of cement bonding the casing and the formation. Hence, acoustic waves travel through the casing, into the formation and received by the acoustic receiver-array in the tool. Well XX in the study field showed free casing arrival at 57us/ft (fig. 5). This appears as a strong continuous signal coming from acoustic reflection at the casing pipe.

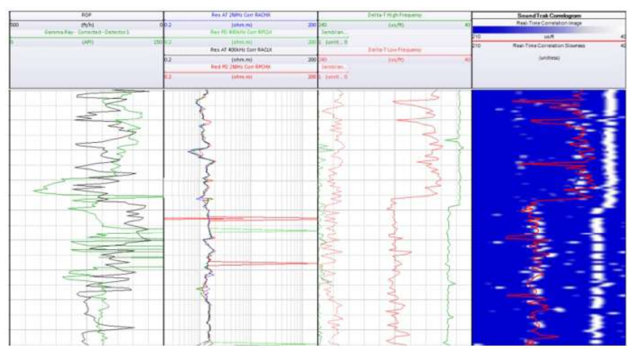

Figure 5: Real-time display of data transmission of LWD acoustics in well XX.

Track 1: Gamma Ray & ROP

Track 2: 2 MHz Phase resistivity & 400 KHz Attenuation resistivity

Track 3: Delta-T High Frequency, Delta-T Low Frequency, High Frequency Semblance and Low Frequency Semblance

Track 4: Real-time Correlation Image & Real-time correlation Slowness

Real-time transmitted data indicated TOC at depth Y900ft. This was subsequently affirmed by the memory processed data result showing TOC at the same depth indicated in real-time (fig. 6). This was marked by formation slowness arrival which can only be seen where there is cement bonding the casing and the formation. High RMS amplitude indicates high noise/ringing in the casing which reduces when cement interval is encountered. If the casing ring are not seen and there is a bond to the formation, the fast taper will pick on the tool mode at 67usec/ft.

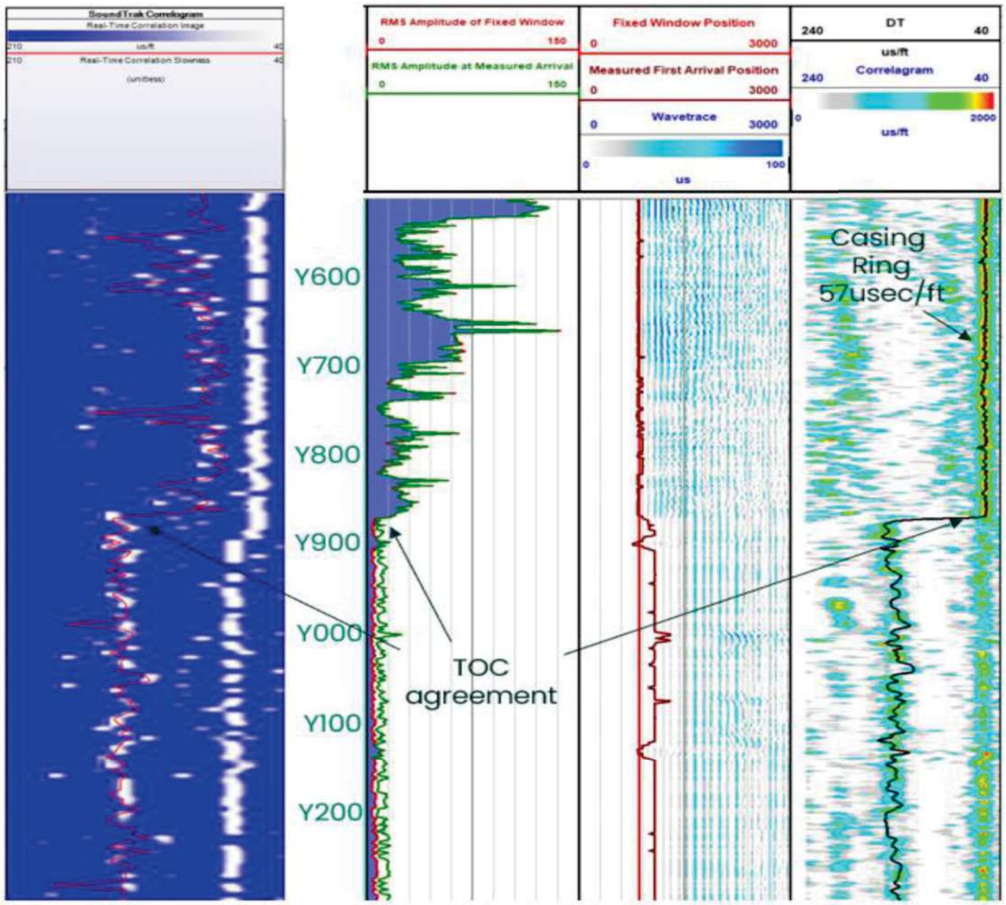

Figure 6: Real-time versus memory TOC of well XX.

Track 1: Real-time correlogram, real-time correlation slowness from high frequency and low frequency

Track 2: Depth

Track 3: RMS amplitude

Track 4: Wavetraces with travel time

Track 5: Compressional slowness and correlogram

Cement bond index evaluation which uses the principle of amplitude of acoustic waves to evaluate where there is good bonding of casing and formation with cement was also done to corroborate the results determined in real-time and memory processing of the acoustic waves slowness. There is a linear relationship between casing amplitude and bond index (fig. 7) illustrates.

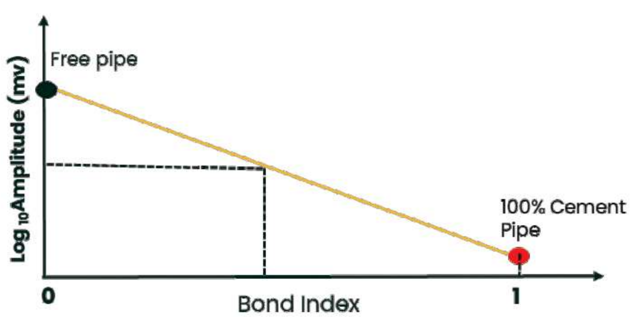

Figure 7: Linear relationship between casing amplitude and bond index.

Bond index (BI) is determined by the equation:

$$BI(z) = \frac{\log_{10} A(z) - \log_{10} A(FP)}{\log_{10} A(WB) - \log_{10} A(FP)}$$

Where A(z) is the casing amplitude at depth z, A(FP) is the amplitude at free pipe and A(WB) is the amplitude for 100 % bonded pipe. All measured at first receiver. Values greater than 80% BI are typically seen as "good" cement whereas values below 80% are typically seen as either "poor, contaminated or channeled" cement. To determine BI, we require to convert the casing amplitude using two reference points which are free casing and 100% bonded point.

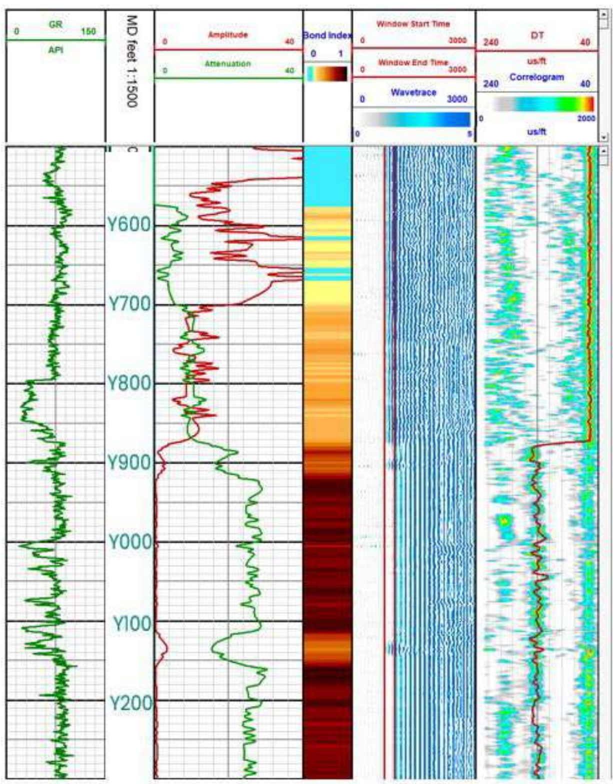

Figure 8: Cement Bond Evaluation of well XX.

In the study wells, the measurements were performed in an interval of free pipe and interval of 100% bond pipe and used as reference to determine the quality of cement bond. The bond index is color-coded sky blue to dark brown on a scale of 0 – 1 going from no bond to good bond with gradation between showing variations of bonding. The CBE presented the results as expected. It is either there is no bond, poor bond, or good bond to the formation (fig.8).

Track 1: Gamma ray and caliper
Track 2: Depth
Track 3: Amplitude and attenuation
Track 4: Bond index
Track 5: Wavetraces with window start and end time
Track 6: Compressional slowness and correlogram

CONCLUSION

Eight wells evaluated using LWD acoustic tool have proved the effectiveness in determining the TOC in real-time. This was demonstrated by the results obtained from full recorded waveforms as they closely matched the real-time data. Cement bond index also confirmed the obtained real-time TOC result, establishing this method as acceptable method for TOC determination in real-time. This approach resolved TOC in real-time and enabled drilling operation to continue without spending additional 48hours operation time to acquire the TOC depth using wireline options or other separate logging run. This approach also timely availed the regulatory requirements. The results show the reliability, cost effectiveness and operational efficiency of this technology.

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