SPE-228597-MS

Revealing Hidden Pathways: Cement Evaluation Using Fluid Density Control to Apply Pressure for Reliable Well Abandonment

Johana Reyes and Aditya A. Wijaya, Halliburton, Aberdeen, Scotland, United Kingdon; Ana Licia Domingues and Jorge Manzanares, Shell, Assen, Netherlands; Maciej Kozlowski, Halliburton, Warsaw, Poland; Laura Martel, Halliburton, Aberdeen, Scotland, United Kingdon; Amit Awasthi, Shell, Assen, Netherlands

This paper was prepared for presentation at the SPE Symposium - Asia Pacific Decommissioning and Well P&A held in Perth, Australia on 11 – 12 November 2025.

Abstract

Ensuring long-term well integrity is a critical aspect of well abandonment, where effective zonal isolation plays a significant role in preventing fluid migration. One common challenge in cement evaluation is detecting micro-annuli, which can compromise the seal and lead to future issues.

Traditional cement evaluation methods performed without applied pressure often fail to capture these hidden flow pathways. This study explores the impact of applying pressure using fluid density control during cement integrity evaluations, highlighting its ability to reveal the presence of a micro-annulus. By comparing results from pressurized and non-pressurized methods, this work emphasizes the importance of advanced evaluation techniques in achieving reliable conditions for well abandonment purposes.

In 2024, a well in the late stage of its life cycle was logged to evaluate the cement bond quality for barrier assessment analysis. The first logging run was a radial cement bond log (RCBL) and an ultrasonic log with a completion fluid of 8.56 ppg - around 2700 psi of pressure during logging. Although the ultrasonic log indicates a good cement bond with high impedance and good azimuthal coverage, the RCBL still shows a partial bond at some intervals with presence of casing arrivals. A second run with increased pressure was proposed to address the possible presence of a micro-annulus.

The second logging run was performed in 2025, only RCBL, with an increased pressure in attempts to reduce the gap in the microannulus. A 14.1 ppg fluid was used during logging, which gives circa 4500 psi – a difference of 1800 psi of pressure between two passes. The results comparing two passes confirms the presence of the micro-annulus, as shown by a reduced amplitude, increased attenuated microseismogram, and better azimuthal coverage from the radial cement map – indicating an improvement of cement bond quality.

Based on the pressure differences between passes, a gap size of 38 micron is estimated across the target zones. Some intervals with less/ no significant changes are believed to be associated with bigger gaps (> 38 microns).

This case demonstrated that increasing mud density to apply pressure during cement evaluation can identify micro-annuli by comparing results with a non-pressurized cement logs. This approach provides

more accurate insights into cement integrity, highlighting the importance of pressure-applied evaluation methods for reliable well abandonment. Based on these results, the client decided to set a cement plug under high-density conditions to ensure an effective cement barrier.

Statement of Theory and Definitions

Plug and Abandonment (P&A)

When a well approaches the end of its productive life, it must be permanently plugged and abandoned (P&A) to ensure zonal isolation and prevent the leakage of subsurface fluids to the surface, which could lead to serious environmental issues. The specific Plug and Abandonment (P&A) method depends on the quality of the bond behind the casing (formation or cement).

If the bond quality is adequate, indicating a competent barrier, a cement plug can be placed inside the wellbore to isolate the relevant zones. However, if the bond quality is insufficient, additional remedial actions such as section milling or the Perforate-Wash-Cement (PWC) technique may be required to enhance the barrier quality. These methods aim to improve the cement integrity behind the casing but can significantly increase operational complexity and cost.

Figure 1 illustrates a simplified well schematic showing the well configuration before and after P&A operations, including a comparison between the use of a cement plug and the section milling approach (Vrålstad et al., 2019).

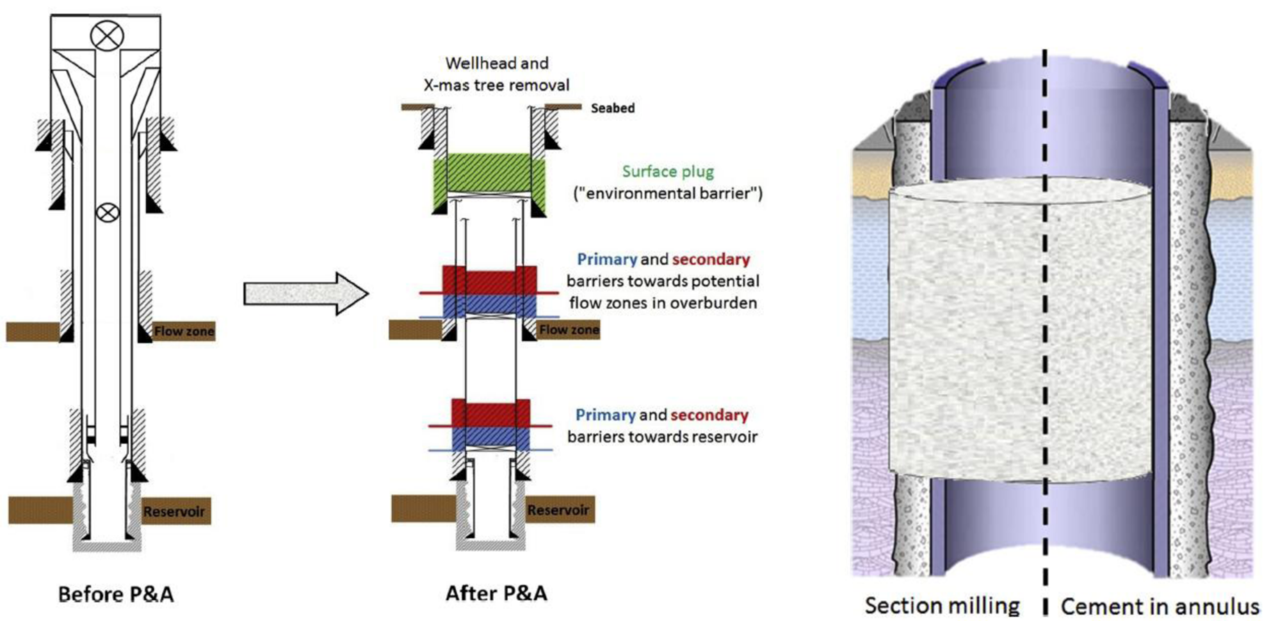

Figure 1—Simplified Well Schematic in P&A and Illustrated Section Milling vs Cement Plug (Vrålstad et al., 2019)

Cement Bond Evaluation Tool (CBL)

A CBL transmits omnidirectional acoustic wave with low frequency (sonic) of 15-25 kHz that travels through wellbore fluid, pipe/ casing, cement, and formations – then back to receivers (3ft and 5ft). The first arrival amplitude captured from 3ft receiver provides an indication of cement-casing bond quality, while the waveform from 5ft receiver reflects the cement bond quality from pipe-cement-formation. High 3ft amplitude, straight waveforms (low attenuation) indicate free-poor cement bond, whilst low 3ft amplitude and wiggled waveforms (highly attenuation) indicate good cement bond. A. Inrie, et all (2019)

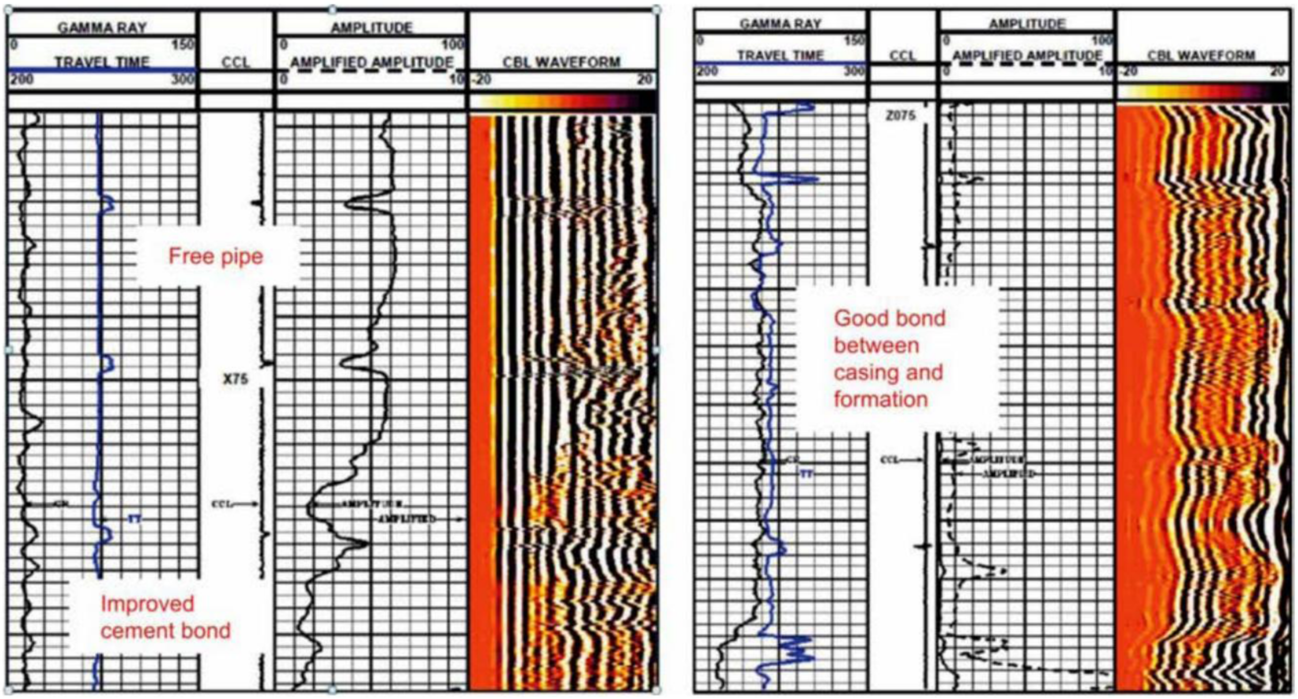

Figure 2—Cement Bond Log Display of Free-Poor (left) and Good (right)

Ultrasonic Acoustic Scanning Tool

Ultrasonic Acoustic tool transmits a high frequency (200-400 kHz) acoustic wave from rotating transducers that are both transmitter and receiver. The rotating transducers give the USAT an azimuthal reading which provides circumferential measurement of the pipe (360 degrees map), unlike the omnidirectional reading of the CBL. In cement evaluation, the Ultrasonic outputs the acoustic impedance measurement which reflects the density of material behind the pipe e.g., gas, liquid, and or cement. The acoustic impedance of the material behind casing depends on the difference of reflected and refracted energy defines the acoustic impedance contrast of materials at the interface (cement). The measured acoustic impedance map is color coded depending on the values as noted below. A. Inrie, et all (2019)

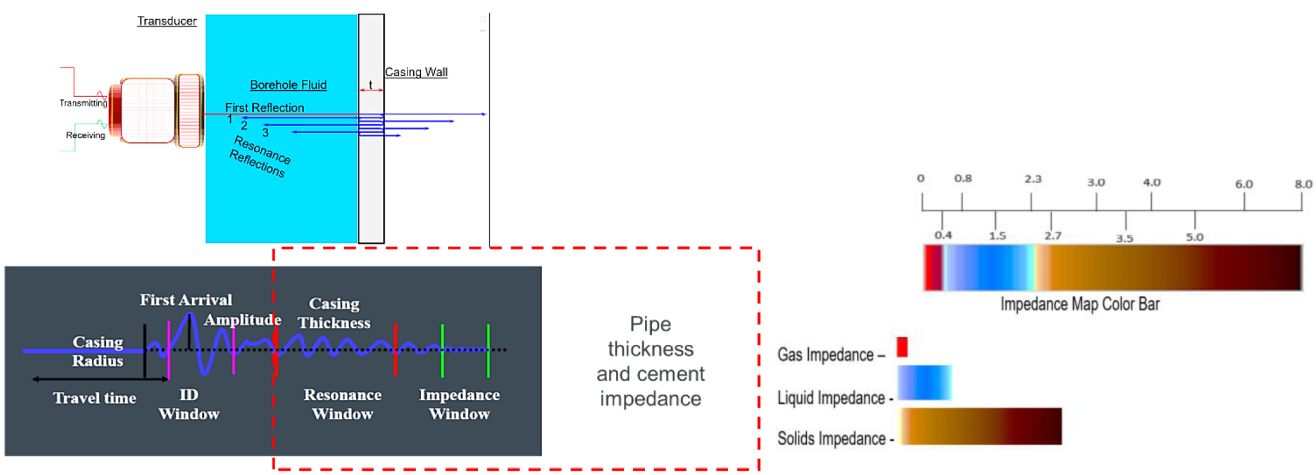

Figure 3—Ultrasonic acoustic Measurement and Color Code for Acoustic Impedance Map

The well under study has been completed with a 7-in. casing and is currently in the late stages of its life cycle. The final objective is to plug and abandon (P&A) the well in compliance with national regulatory requirements and industry best practices. A key component of the P&A process is to verify the presence of an effective, continuous cement barrier across critical zones to ensure long-term zonal isolation and prevent any future fluid migration between formations or to the surface.

Job Objectives

In accordance with applicable government regulations and abandonment standards, the operator is required to confirm a minimum of 50 meters of continuous, competent cement across the cap rock formation. This cement barrier must demonstrate good bonding to both the casing and the formation to qualify as an effective hydraulic seal.

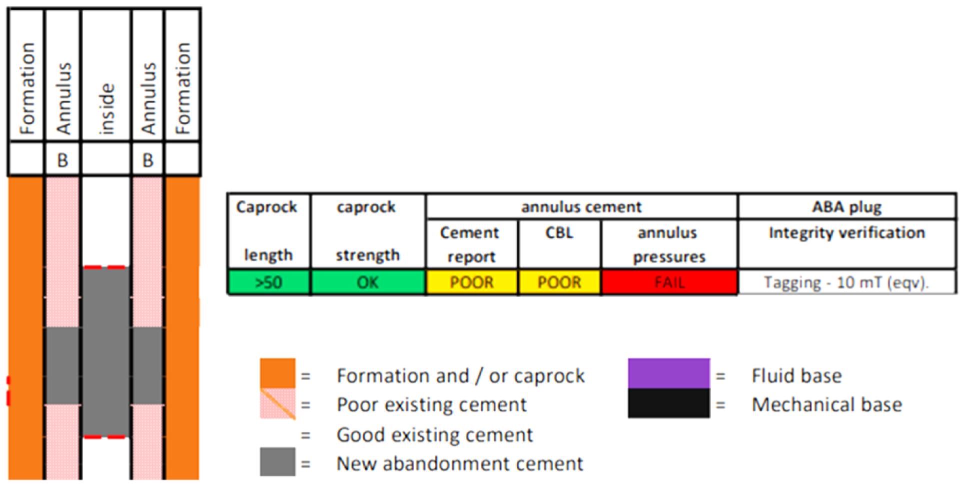

Figure 4—Job Planning and Criteria for P&A. Courtesy of Shell.

To validate the integrity of the cement sheath in this interval, a cement bond log (CBL) and ultrasonic evaluation must be performed.

In this successful case study, a radial CBL tool was employed based on the same principles of conventional CBL but with sectorized detection for improved spatial resolution. Additionally, incorporated ultrasonic cement evaluation, which relies on a single rotating transducer to generate high-resolution, azimuthal (circumferential) acoustic images offering enhanced detection of partial or non-uniform bonding compared to traditional CBL.

These tools provide essential information on the acoustic coupling between the casing, cement, and surrounding formation, helping to identify any defects that could compromise isolation. The assessment must consider several possible integrity issues, including:

- Microannuli: Thin, micrometer-scale gaps between the casing and the cement sheath. These often form after cementing due to thermal contraction, pressure cycling, or mechanical stress and can severely degrade acoustic coupling. Although small in size, microannuli can allow for fluid migration under differential pressure, making them critical to identify and assess.
- Channels: Larger, often vertically extensive voids within the cement column. Channels typically result from poor mud displacement, inadequate centralization, or incomplete slurry placement during the cementing operation. Channels can create preferential flow paths and significantly reduce the sealing efficiency of the cement barrier.

The presence of either of these conditions would indicate insufficient zonal isolation and would require remedial action before proceeding with permanent abandonment operations. Therefore, the primary objective of the job is to obtain high-resolution cement evaluation data across the cap rock interval to determine the presence, quality, and continuity of the cement sheath.

In cases where standard ambient pressure logging is inconclusive—especially due to microannuli that affect acoustic readings without visibly disrupting the cement body—a pressure-assisted cement evaluation may be deployed. This involves increasing the hydrostatic pressure in the wellbore (e.g., by using high-density mud) to temporarily close microannuli and improve acoustic coupling, thereby revealing the true bonding condition behind the casing.

Ultimately, the job aims to:

- Confirm the presence of at least 50 meters of well-bonded cement across the cap rock.
- Detect and characterize any microannuli, channels, or other bonding defects.
- Support the decision-making process for setting the final cement plug.
- Ensure full regulatory compliance and achieve long-term well integrity during and after abandonment.

Why a microannulus is "preferable" than a channel?

Although both are cement defects, their severity and implications differ:

A microannulus typically allows limited fluid or gas movement and often does not pose an immediate or catastrophic integrity risk, especially if not continuous. Risk Level is Lower than in channel presence because a microannulus does not always connect formation to surface and Leak Potential can be Low to moderate (may allow gas migration under pressure) with remediable intervention often manageable with casing expansion.

A channel, especially a vertically continuous channel, poses a serious risk to zonal isolation, allowing formation fluids to communicate or reach surface. Risk level is High, this can create direct fluid pathways between formations leading to zonal communication, pressure buildup, and losses. Channels require major remediation such as squeeze cementing, perforate wash and cement (PWC), or section milling and cement. It is important that the existence of a microannulus be recognized since it can be confused with a channel, resulting in attempted remedial squeezes. Attempts to repair a microannulus by squeezing cement jobs are historically futile.

Given this, if a defect is present, operators typically prefer a microannulus over a channel due to its lower risk profile and more manageable remediation.

Logs can be influenced by the presence of a microannulus in different ways:

CBL (Cement Bond Log) / VDL (Variable Density Log). *Effect:* A microannulus can mimic poor bonding, even when cement is present and zonal isolation is adequate.

Reason: The micro-gap permits casing signals to pass with little attenuation, falsely indicating poor bonding.

Note: VDL may still show some cement presence if the microannulus is small or discontinuous.

Ultrasonic Logs. *Effect:* More effective at identifying microannuli versus channels or free pipe.

Reason: These tools measure acoustic impedance and annular coverage and are less influenced by small gap widths.

Note: Better differentiation between defect types, providing a clearer assessment of cement integrity.

Data acquisition and results

First pass cement evaluation – Baseline

The initial cement evaluation was performed in 2024 (Figure 1) across the 7-in. casing using a combination of Radial Cement Bond Log (RCBL) and ultrasonic tools. The borehole was filled with a completion fluid (mud) of 8.56 ppg (1.03 g/cc), resulting in an approximate hydrostatic pressure of 2,700 psi. This relatively low-density fluid was selected to maintain a balanced well condition during logging operations while minimizing formation stress.

Figure 5 presents a composite log that summarizes the most relevant data obtained during this first logging run. The tracks are organized as follows: In the Track #1 are the correlation (GR, CCL) and QC curves (ECEN: eccentricity, OVAL: ovality, NBS: number of bad shots, TT3FT: acoustic transit time) Track #2 shows the well diagram, Track #3 shows the impedance curves, Track #4 shows the amplitude curve, Track #5 shows the waveform or VDL, Track #6 Total waveform with variance technique processing. This method analyzes the variance between vertical waveform samples to highlight subtle changes. Track #7 Pipe amplitude (PAMP), indicating internal casing condition, Track #8 radial map from radial bond log amplitude sectors, Track #9 ultrasonic impedance map and Track#10 shows the total cement computation from the ultrasonic data.

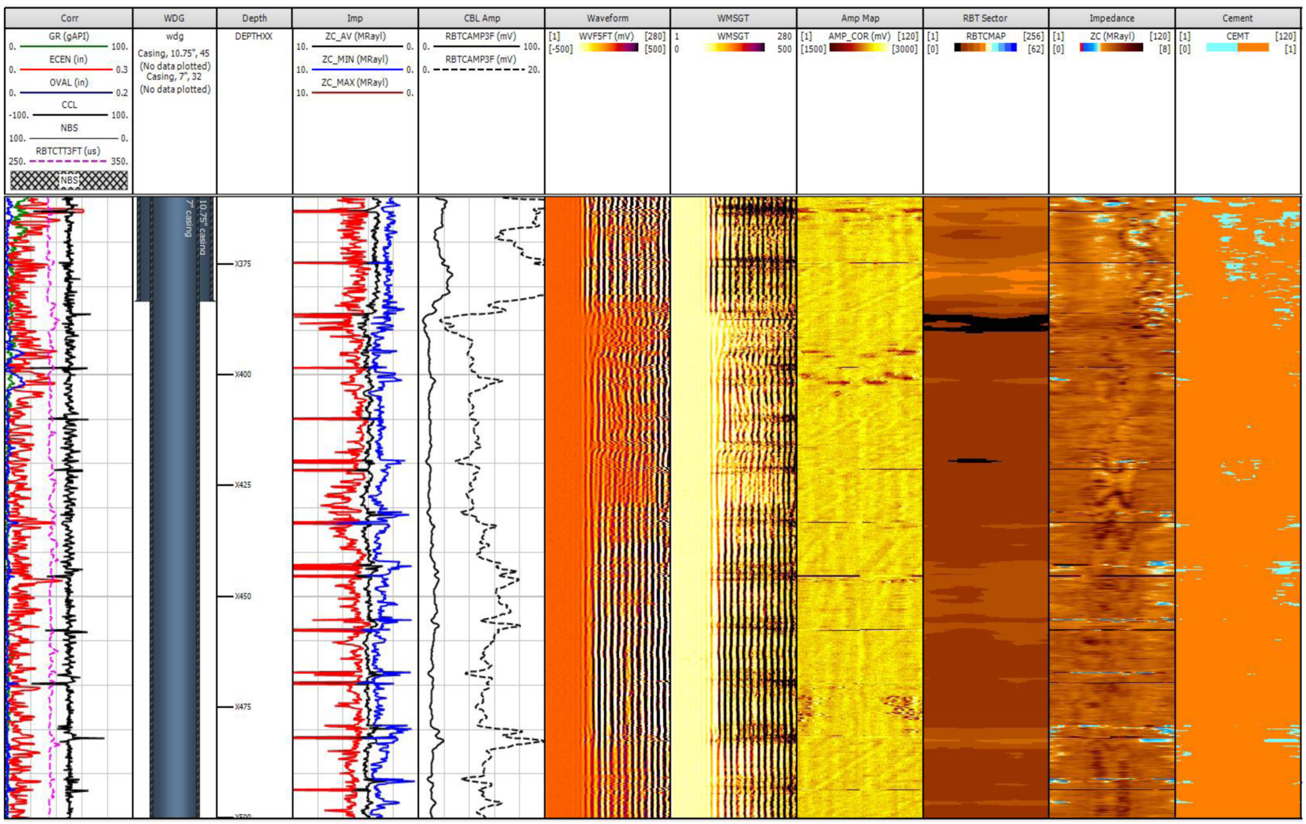

Figure 5—Cement bond log acquired in 2024 with 8.56 ppg (1.03 gr/cc) mud density.

From depth X380 to the bottom of the interval, the acoustic and ultrasonic data indicate strong cement bonding. Indicators include high impedance, solid azimuthal coverage on the radial maps, low to moderate amplitude levels, attenuated casing arrivals, and visible formation arrivals in the microseismogram. These results suggest a consistent cement sheath with good acoustic coupling, validated by both logging technologies.

Above X380, however, the RCBL log shows a notable increase in amplitude, reaching up to 35 mV, alongside strong casing arrivals and chevron casing collar waveform patterns—classical signs of poor cement bonding. In contrast, ultrasonic logs in the same interval continue to show high impedance values and good circumferential coverage, with only subtle anomalies. These inconsistencies suggest the presence of small, isolated fluid-filled gaps behind the casing.

The contrasting interpretation between the RCBL and ultrasonic data points to the likely presence of a microannulus—a thin gap between the casing and cement that can degrade acoustic coupling without necessarily displacing the cement sheath. The ultrasonic tool, which measures impedance directly through the casing wall, may not detect microannuli narrower than ~0.01 in (254 μm). Meanwhile, the RCBL tool is more sensitive to poor acoustic coupling, and thus more likely to register degraded responses even for smaller gaps. Based on the comparative responses, the microannulus in this case is estimated to be narrower than 0.01 in, likely below the ultrasonic detection threshold but still impacting amplitude-based measurements. However, due to a restriction it was decided to suspend the well and re-assess the way forward.

Second pass cement evaluation – Pressure-Assisted Cement Evaluation

Later, to further investigate the suspected microannulus and reduce its acoustic effects, a second cement evaluation was conducted in 2025 under pressure-assisted conditions. This logging run used only the RCBL tool, but under significantly increased borehole pressure. The mud weight was raised from 8.56 ppg (1.03 g/cc) to 14.10 ppg (1.69 g/cc), increasing hydrostatic pressure from approximately 2,700 psi to 4,500 psi—an increment of roughly 1,800 psi. This increase is sufficient to mechanically close microannuli as small as 0.001 in (38 μm) in a 7-in. casing, restoring the acoustic pathway between casing and cement.

Figure 6 presents the log for the second logging run. In the Track #1 are the correlation (GR, CCL) and QC curve (TT3FT: acoustic transit time) Track #2 shows the well diagram, Track #3 shows the amplitude curve, Track #4 shows the waveform or VDL, Track #5 radial map from amplitude sectors.

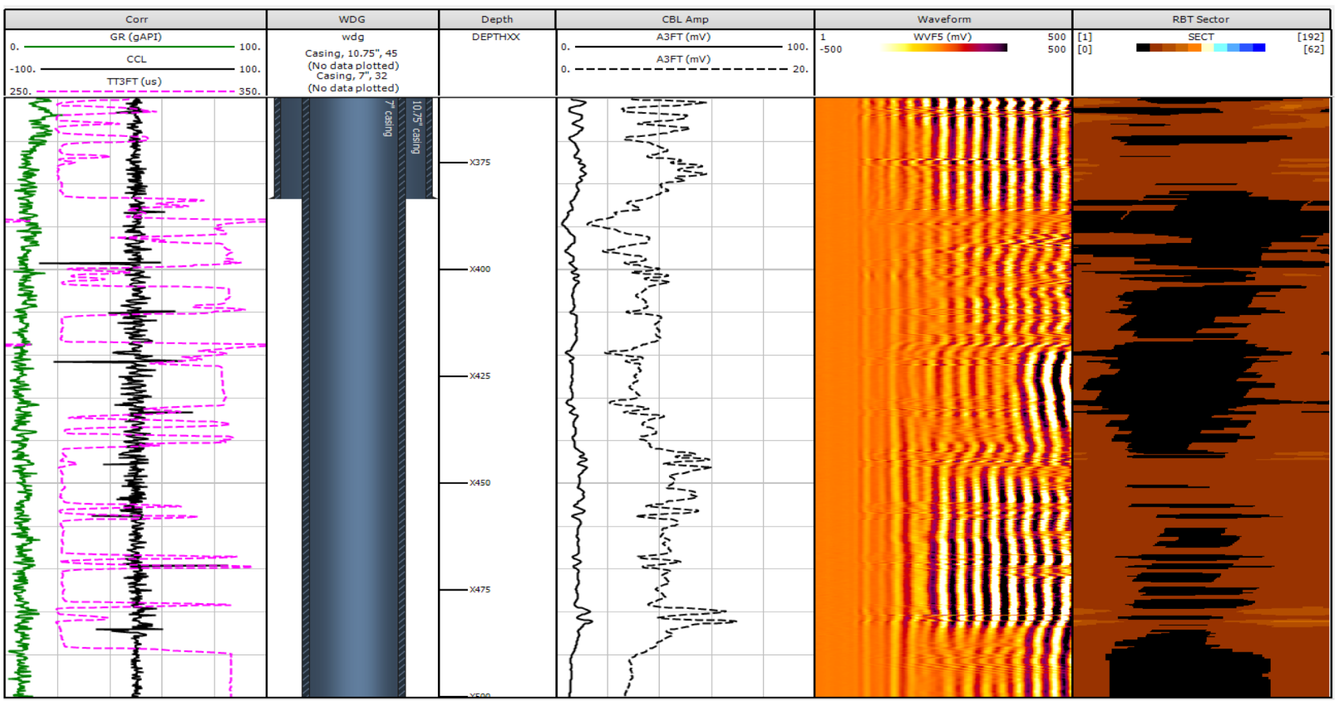

Figure 6—Cement bond log acquired in 2025 with 14.10 ppg (1.69 gr/cc) mud density.

The second pass shows amplitude values around 11mV in average with attenuated microseismogram signal, suggesting good bond.

Comparison of non-Pressure and Pressure Passes Cement Evaluation

Data Quality Assurance. The free pipe (figure 7) across the upper section clearly shows a strong presence of casing energy from CBL waveform, and high 3ft amplitude close to free pipe value (62mV) – both surveys show similar value and displays. The 3 ft travel time shows a difference in magnitude due to change in fluid density (in relation to applying additional pressure pass) – which was expected.

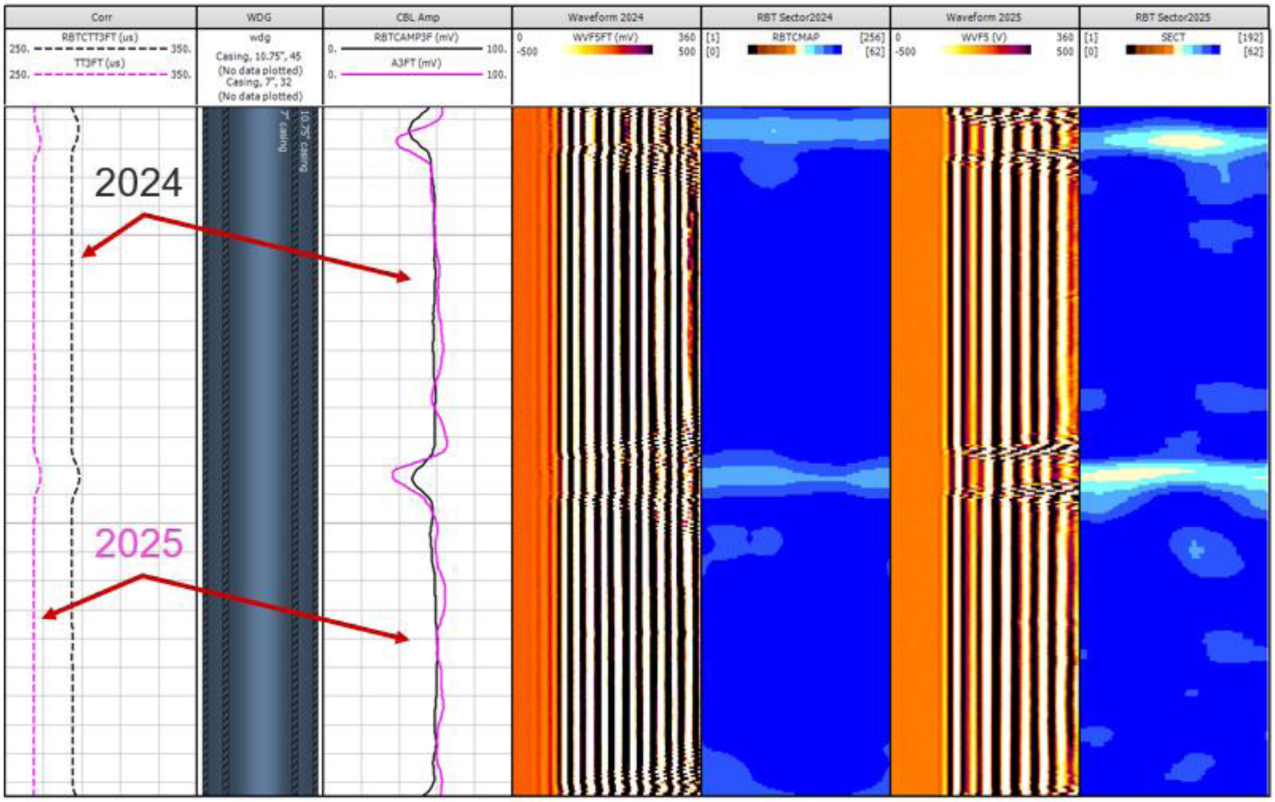

Figure 7—First and Second Survey (with additional pressure) Free Pipe section.

Figure 8 shows an integrated comparison between the baseline (2024) and pressurized (2025) logging runs, with the following track layout: In the Track #1 are the correlation (GR, CCL) and QC curve (TT3FT: acoustic transit time) Track #2 shows the well diagram, Track #3 shows the amplitude curve –blue for 2024, black for 2025 - Track #4 shows the waveform or VDL 2024, Track #5 shows the waveform or VDL 2025.

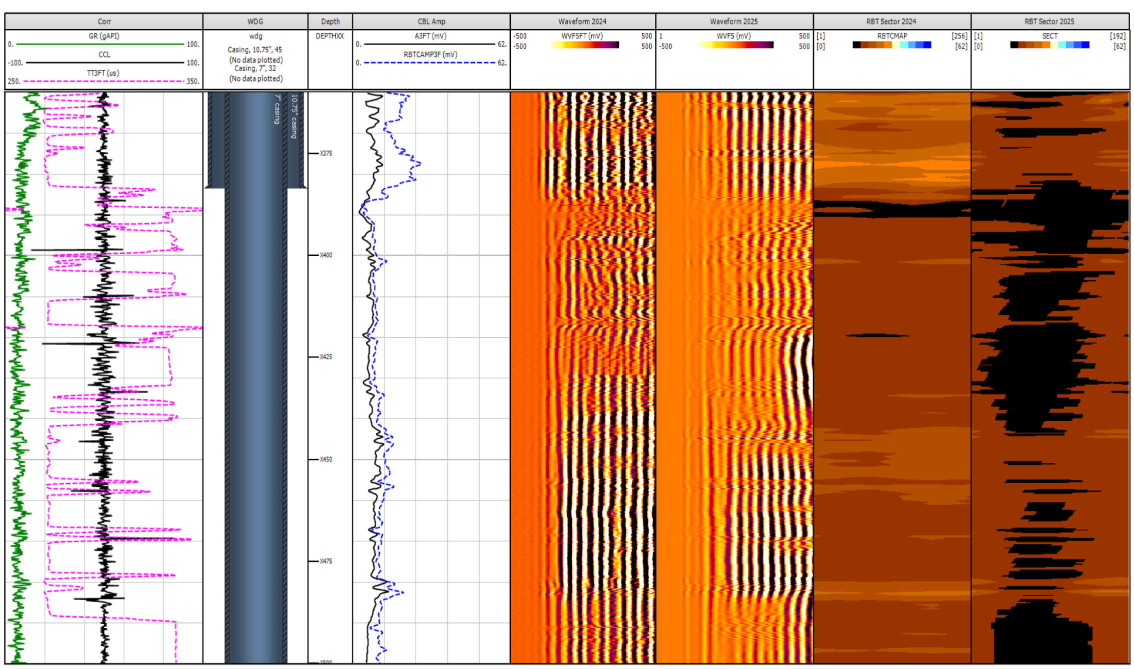

Figure 8—Comparison of cement bond logs acquired in 2024 and 2025.

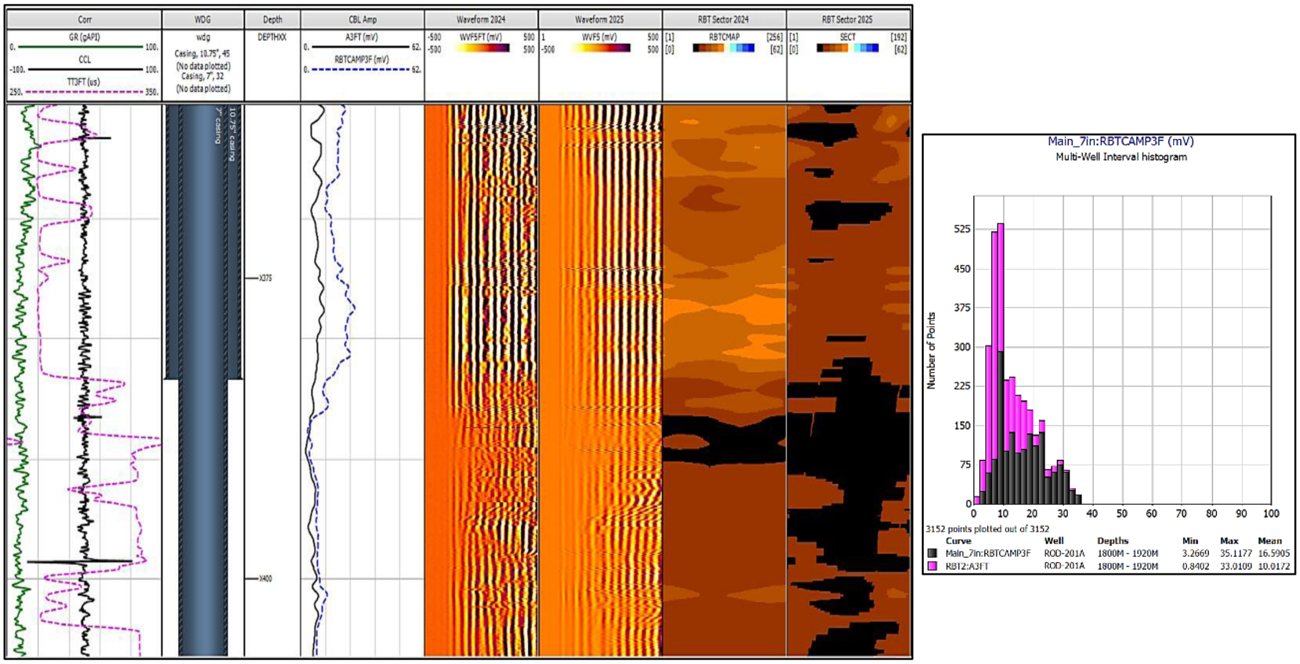

Figure 9—Comparison of cement bond log acquired in 2024 and 2025, expanded microannulus section.

The comparison shows a clear reduction in amplitude and improvement in waveform quality under elevated pressure, particularly in the upper section above X380 where the histogram in figure 6 shows a decrease in amplitude from an average of 16mV to 10 mV. These changes strongly support the presence of a microannulus that was temporarily closed by the additional hydrostatic pressure, restoring acoustic coupling and enhancing RCBL response. This result validates the interpretation from the first pass and demonstrates the effectiveness of pressure-assisted cement evaluation.

Conclusions

This case study demonstrates the value of using pressure-assisted cement evaluation as a diagnostic method to identify and characterize microannuli—narrow gaps in cement bonding that are often undetectable under ambient pressure conditions. By increasing the mud weight and performing a second logging run under elevated hydrostatic pressure, it was possible to suppress the acoustic effects of microannuli, enabling clearer interpretation of cement quality and validating the presence of these subtle defects.

The comparison between the baseline 2024 log and the pressure-assisted 2025 log provided a more accurate and complete picture of cement integrity along the 7-in. casing. Based on the improved bond indicators observed under higher pressure, the operator elected to set the final cement plug using high-density fluid, ensuring complete zonal isolation and long-term well integrity for abandonment purposes.

Importantly, this technique of hydrostatic pressure augmentation through increased mud weight is not only effective but also practical in scenarios where direct pressurization (e.g., via annular injection or surface pressure) is not operationally feasible. In cases where operational constraints, such as tool limitations or lack of access points, prevent direct pressure application, increasing the fluid column offers a controlled alternative. However, this approach must be carefully evaluated when there is a risk of formation breakdown, to ensure it remains within safe operational limits

This case underscores the strategic importance of pressure-assisted cement evaluation in achieving compliance with regulatory standards and ensuring robust, long-term well barrier performance.

Acknowledgments

The authors thank Shell for its ongoing dedication to advancing technology in pursuit of greater efficiency and sustainability within the oil sector. The company's strategic and logistical support played an essential role in bringing this project to fruition.

A particularly grateful to the technical team, whose skills, commitment, and professionalism were instrumental throughout the project's development, from initial design to data interpretation. This endeavor represents a truly collaborative and interdisciplinary effort. Its achievements are the result of the collective input and hard work of all those who participated.

Nomenclature

CBL, Cement Bond Log
CCL, Casing Collar Locator
ECEN, Eccentricity
GR, Gamma Ray
NBS, Number of Bad Shots
OVAL, Ovality
PAMP, Pipe Amplitude
P&A, Plug and Abandon
RCBL, Radial Cement Bond Log
TT3FT, Acoustic Transit Time
VDL, Variable Density Log

References

Torbjørn Vrålstad et al (2019). Plug & Abandonment Of Offshore Wells: Ensuring Long-Term Well Integrity And Cost-Efficiency. *Elsevier Jurnal Of Petroleum Science And Engineering*. https://doi.org/10.1016/j.petrol.2018.10.049

Andrew Imrie, Mohd Z. et al (2019) Behind Casing Gas Identification Using Ultrasonic Wireline Logs: An Overview of Multiwell Field Plug and Abandonment Study, *Offshore Malaysia*. SPE-199180-MS https://doi.org/10.2118/199180-MS

Gary Frisch, Larry Graham and James Griffith, (2000). A Novel and Economical Processing Technique Using Conventional Bond Logs and Ultrasonic Tools for Enhanced Cement Evaluation. *SPWLA 41st Annual Logging Symposium*, SPWLA-2000-EE Dallas, Texas.

Batakrishna Mandal and Alberto Quintero, (2010). A New Monocable Circumferential Acoustic Scanner Tool (CAST-M) for Cased-Hole and Openhole Applications. *SPWLA 51st Annual Logging Symposium*, SPWLA-2010-55460. Perth, Western Australia.

Singh K et al, 2023. Understanding Cement Gaps: A Blueprint for Microannulus Identification. *SPE/IATMI Asia Pacific Oil and Gas Conference*, Jakarta.

Huawen Gai et al, 1996. Zonal Isolation and Evaluation for Cemented Horizontal Liners. *SPE Drilling and Completion*.