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Field Validation of Intervention-Less Acoustic Top of Cement Verification During Well Abandonment Operations

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Abstract

Verification of cement barrier placement is a critical activity during plug and abandonment (P&A) operations because uncertainty in top-of-cement (TOC) location can lead to unnecessary remedial work, additional rig time, and increased personnel exposure. Top of cement verification also critical to ensure the cement length is meet the requirement as per Governance Standard (GS) by Local Authority. Conventional TOC-location verification methods by tagging and cement bond logging are effective, but they require intervention, equipment mobilization, and additional operational steps. In mature offshore assets, TOC uncertainty also affects workover and sidetrack planning, particularly where historical cement records are limited to theoretical TOC which rely on pumped volumes

This paper presents a field application of an interventionless acoustic method for TOC determination in an offshore mature-field P&A well utilising specialized hardware. The method uses a surface-generated precise pressure pulse from an Advanced Gas Gun System (allowing strict control of dP pressure and removing human discrepancy in valve opening) introduced through the annulus side outlet valve and records reflected acoustic responses at surface utilising an advanced sonogram signal processor coupled with a customized digital microphone array with specific noise filtration capabilities.

The recorded acoustic sonogram data is interpreted using specialized software that allows dual analysis using conventional time-domain analysis and Advanced Frequency Analysis (AFA) processing. Advanced Frequency Analysis (AFA), incorporating customized wavelet-based time-frequency processing; provides a time-frequency representation of the acoustic response, improving the visibility of weak or attenuated reflections from downhole impedance contrasts such as cement interfaces, packers, bridge plugs, and annular fluid boundaries. Wavelet choice is chosen to most closely match the parameters of the AGG pulse generation.

Acoustic velocity was calibrated using known downhole reference points. A production packer provided a calibrated acoustic velocity of 1375 m/s, and a surface bridge plug provided a calibrated acoustic velocity of 1379 m/s. During the wait-on-cement period for the deep cement plug, the acoustic interpretation identified the TOC with an estimated uncertainty of +/- 10 m. Subsequent mechanical drill tagging confirmed the

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top of cement. For the surface cement plug, the acoustic method identified the TOC with an estimated uncertainty of +/- 10 m.

Four P&A wells was selected to run the equipment for TOC verification. The results demonstrate that AFA-assisted acoustic reflectometry can provide a reliable interventionless TOC-location determination when calibrated against known downhole markers and interpreted with operational context. Where accepted by the operator and regulator, the method may replace selected conventional TOC-location verification activities; however, it does not directly measure cement compressive strength or prove plug mechanical integrity. Beyond real-time P&A verification, the method has value as a pre-screening tool for P&A, workover, and sidetrack planning by improving confidence in existing annular cement depths before rig-intensive operations are committed.

Introduction

Offshore plug and abandonment activity is increasing as mature oil and gas fields approach the end of economic production. A key requirement in these operations is the placement and verification of permanent barriers that provide long-term zonal isolation and reduce future environmental and well-integrity risk. Cement remains a primary permanent barrier material, but the operational value of a cement plug depends not only on slurry placement but also on confirming the final location of the cement boundary relative to the planned barrier envelope.

Top-of-cement uncertainty has direct operational consequences. If the cement top is shallower or deeper than expected, the operator may require additional drilling, tagging, logging, squeeze cementing, or abandonment-plan changes. In P&A activities; where a rig is present at site; waiting on cement hardening to perform manual drill stem tagging can increase rig rental costs and raise the P&A costs; thus alternative methods of cement tagging have been explored that would allow the rig to continue work on other wells instead of waiting on cement prior to physical tagging.

In older wells, annular cement depths are often inferred from cementing reports, pumped volumes, and displacement calculations. These records can carry significant uncertainty because they depend on assumptions about hole geometry, losses, returns, slurry contamination, casing eccentricity, and displacement efficiency. As a result, more reliable interventionless TOC determination can improve P&A planning, workover risk assessment, and sidetrack-depth selection before rig time is committed.

This paper evaluates a surface acoustic reflectometry workflow supported by Customized Hardware deployment in conjunction with novel AFA processing. The technique does not attempt to replace cement-strength testing; instead, it focuses on determining the location of acoustic impedance contrasts associated with downhole cement boundaries and other known wellbore markers. The field case demonstrates how specialized hardware and domain specific software focusing on calibrated acoustic velocity, time-domain waveform review, and AFA-based time-frequency interpretation can be combined to determine TOC without deploying downhole logging tools or mechanical tagging equipment for selected verification steps.

Background

The well was completed in April 1990 as a single-string gas lift oil producer from the J Zone. As part of the Plug and Abandonment (P&A) program, Caprock restoration method is picked by placing cement across the existing caprock with good cement behind the casing. Caprock restorations were established through a series of abandonment activities. The operation commenced with a tubing cut and pull out of hole (POOH) up to TRSV section prior make up the remaining tubing in the well to drillpipe with Bottomhole Knockoff Assembly (BHKA) in between drillpipe and existing tubing. This assembly is used as cement stinger to perform cement placement at the calculated depth. Once cement is reach min 500psi minimum compressive strength as per lab design and surface sample, top of cement will be verified by tagging the TOC 5kips

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with cement stinger. Once confirm the TOC is acceptable, BHKA dart will be pump down to disconnect the tubing below BHKA and leaving the lower section of the tubing inside the well.

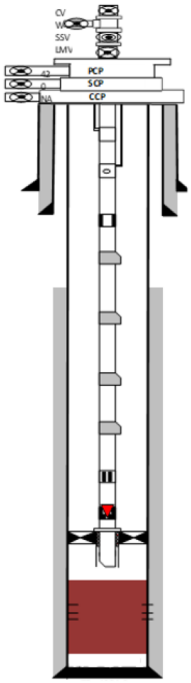


Figure 1—Well Schematic (before Plug & Abandonment)

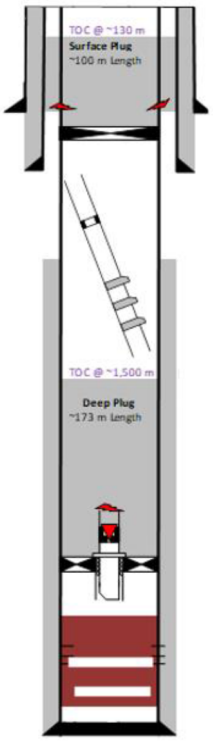


Figure 2—Well Schematic (after Plug & Abandonment Schematic)

The well provided multiple known downhole reference points suitable for acoustic velocity calibration and validation, including the existing packer depth, the installed bridge plug depth, and the subsequent drill-tag confirmation depth. These reference points enabled direct comparison between acoustic survey

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interpretations and conventional verification methods, providing an opportunity to evaluate the accuracy and reliability of acoustic-based Top of Cement (TOC) determination during P&A operations.

Technology

Conventional TOC-location verification

In offshore plug and abandonment operations, TOC is commonly verified by intervention-based methods such as by tagging via drillpipe or wireline, cement bond logging (CBL), or other downhole evaluation techniques. These methods remain important for barrier assurance, but the rig will be put on standy while wait on cement. In mature wells, the same uncertainty can also affect workover and sidetrack planning, particularly where historical annular cement records are limited to pumped volumes and calculated placement rather than direct measurements.

Acoustic reflectometry concept

The acoustic method evaluated in this field application uses a surface-deployed Advanced Gas Gun (AGG) connected to the annulus side outlet valve (SOV). The AGG chamber is charged with high-pressure nitrogen and triggered to introduce a controlled pressure pulse into a liquid-filled annulus. The Advanced Gas Gun is an advanced pressure pulse generator that is automatically computer controlled and allows precise control over the dP of the pulse generation and ensures consistent firing patterns vs a human operated pulse generator; thus, allowing precise repetitive pulses to be generated.

The resulting compressive acoustic wave travels through the annular fluid column, reflects from downhole impedance contrasts, and returns to surface where it is recorded by a high-sensitivity customised digital microphone array with advanced noise filtration; that is integrated with the customized acoustic acquisition system. No downhole logging tool or tagging assembly is required for the acoustic survey because the measurement is performed from surface. Reflection events occur where the travelling wave encounters a change in acoustic impedance, geometry, or boundary condition. For example; in annular surveys these events can include gas-lift mandrels or side-pocket mandrels, casing collars or restrictions, packers, bridge plugs, fluid interfaces, and cement interfaces. The physical depth of a reflector is estimated from the two-way travel time (TWT) and the acoustic velocity in the propagation path using Depth = AV × TWT / 2. The accuracy of the depth estimate therefore depends on the quality of the reflection signal and the reliability of the acoustic velocity used for time to depth conversions.

Time-domain and frequency-domain limitations

In conventional time-domain interpretation, the recorded pressure response is plotted as amplitude versus time. Strong reflectors may appear as clear kicks, inflection points, or repeated multiples. However, in deep, liquid-filled, or attenuative wellbores, target reflections can be masked by background noise, reverberation, casing-related responses, or lower-amplitude arrivals from other wellbore features. A standard Fourier Transform can identify the overall frequency content of a signal, but it does not preserve the arrival time of those frequency components. For TOC determination, the arrival time is essential because it is the basis for depth conversion.

AFA processing

AFA processing addresses this limitation by representing the signal jointly in time and frequency, or equivalently in time and scale/period. The method compares the measured acoustic waveform with scaled and shifted versions of a selected mother wavelet. The resulting scalogram shows localized signal energy, allowing the interpreter to identify when specific low-frequency or high-frequency components arrive. This is particularly useful when the TOC response is weak in the raw time trace but forms a coherent energy band in the AFA display.

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In the processing workflow used for this case study, the horizontal axis of the frequency diagram is converted from arrival time to depth using the selected acoustic velocity. The vertical axis is displayed as period in milliseconds, which can be related to equivalent frequency, and the color scale represents relative signal magnitude or energy. For this reason, the output is more accurately described as a time-frequency or depth-period representation rather than a simple frequency-domain plot.

Acoustic response of cement interfaces

The acoustic TOC response is generated by the impedance contrast between the annular fluid column and the cement boundary. The response may be expressed as a change in amplitude, phase, dominant period, or repeated multiples. Interpretation does not rely on a single visual feature; confidence increases when the candidate TOC response is repeatable across multiple shots, is consistent with the time-domain waveform, aligns with expected multiples, and is compatible with known or modelled acoustic velocity.

The method determines the location of an acoustic boundary. It does not directly measure cement compressive strength, cement sheath bond quality, or long-term plug integrity; those acceptance criteria remain subject to operator and regulatory requirements.

Methodology

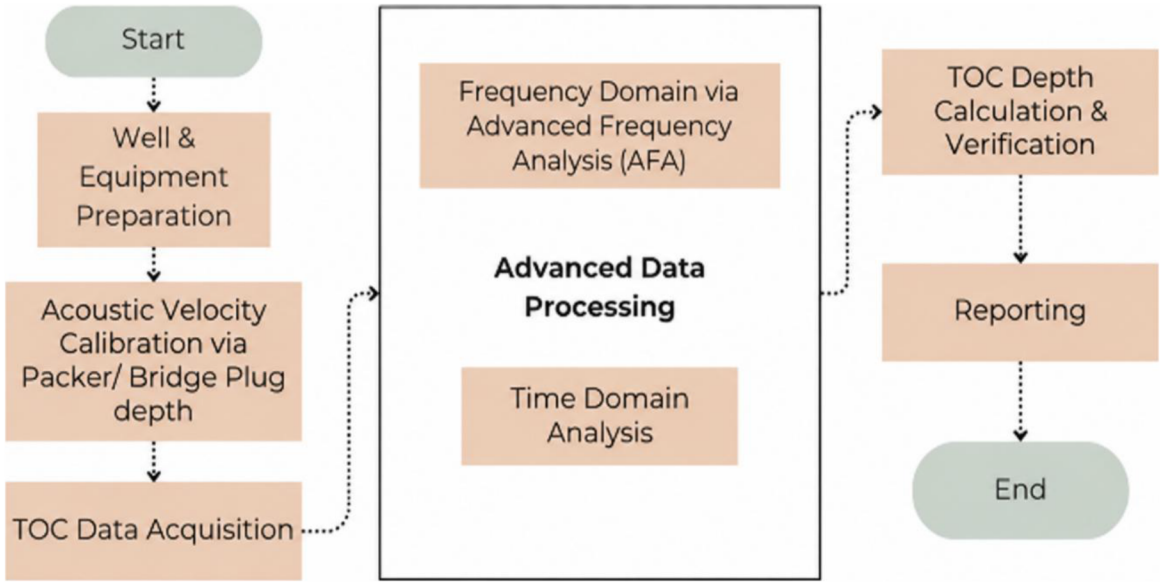


Figure 3—TOC Methodology

Well and equipment preparation

The field workflow required a continuous acoustic path from surface to the target interval. Before each survey phase, the annulus connection was prepared at the Annulus-A casing head and the annulus was filled or maintained with water to provide a continuous liquid column. This liquid path improves acoustic coupling and reduces uncertainty caused by gas pockets or discontinuous fluid columns. The AGG was connected to the Annulus-A SOV, charged with nitrogen, and operated in high-energy explosion mode where greater downhole attenuation was expected. Various shot dP were trialled to best determine the correct balance of energy transference to overcome background noise; whilst trying to minimise well bore resonance.

The workflow was applied during two operational phases of the P&A sequence. The first phase covered the deep cement plug above the existing production packer. The second phase followed the tubing drop operation and bridge plug installation, after which the surface cement plug was placed and monitored. The

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same surface-based measurement principle was used in both phases, with acoustic velocity recalibrated when a new known reflector was available.

Acoustic velocity calibration and modelling

Depth conversion requires an acoustic velocity (AV) representative of the actual propagation path. Although the unbounded sound speed in water is commonly in the range of approximately 1400 to 1500 m/s depending on temperature and fluid properties, pressure waves travelling inside casing are affected by pipe-fluid interaction. Elastic expansion of the casing wall reduces the effective propagation velocity. This reduction can be estimated using known correlations along with the physical properties of the piping material.

For the case-study well, the theoretical modelled acoustic velocity was estimated at 1389 m/s. Empirical calibration was then performed using known downhole markers because actual velocity can also be influenced by temperature, fluid compressibility, casing geometry, trapped or entrained gas, and local wellbore conditions. Thus where possible; downhole reference markers are always preferable.

The production packer at 1670.2 m MD RKB provided a calibrated AV of 1375 m/s. Later, the bridge plug at 230.0 m MD RKB provided a calibrated AV of 1379 m/s. The close agreement between modelled and calibrated velocities increased confidence in subsequent TOC depth conversion.

Where no suitable calibration marker exists, the same velocity modelling approach can be used as a pre-job estimate by combining expected fluid or gas properties, pressure and temperature conditions, and pipe-fluid interaction effects. In such cases, uncertainty should be carried explicitly in the TOC interpretation, and calibration should be performed whenever a known reflector becomes available.

Data acquisition

After cement placement, repeated acoustic shots were acquired during the WOC period. As the Surface Conditions of the well were essentially at ambient pressure and the well is open to atmosphere; large energy transference is required. The AGG was operated at 1000 psi explosion mode, injecting a short pressure pulse through the Annulus-A SOV. The acoustic response was recorded at surface by the digital microphone array and Sonogram Scada System at a sampling rate of 1706 Hz, corresponding to a time resolution of approximately 0.586 ms. Multiple shots were recorded at each survey condition using the automatic firing option to avoid discrepancy in valve openings and the most repeatable responses were retained for interpretation.

For the deep cement plug, surveys were acquired at 15-minute intervals during WOC and again after mechanical drill tag during the cement pressure test. This delay between shots is critical to ensure any resonance in the well has fully depleted prior to acquiring the next shot.

For the surface plug, surveys were acquired after surface cement placement using the bridge-plug-calibrated velocity. The repeated-shot approach allowed interpretation to focus on coherent, repeatable responses rather than isolated noise events.

Time-domain analysis

The first interpretation step reviewed the raw acoustic response in the time domain. Candidate reflectors were identified from repeatable amplitude changes, inflection points, or kicks in the waveform. A reflector depth was calculated from the two-way travel time using Depth = AV × TWT / 2. Time-domain analysis was useful for large, discrete reflectors such as the packer and bridge plug, but it was less definitive for weaker TOC responses where attenuation and background noise reduced visual clarity.

AFA processing and parameter selection

The same acoustic shots were then processed using the AMS Frequency Diagram utility with AFA-based time-frequency analysis. Processing used the 1706 Hz acquisition sample rate. The shot window was selected to isolate the region containing the expected reflection. The period range was chosen to include

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low-frequency acoustic energy associated with deeper, attenuated reflections, with period limits typically spanning approximately 1 ms to 100-150 ms depending on the target and display window. Gain and color-scaling thresholds were adjusted to improve visibility of weak responses without saturating strong near-surface energy. Low-pass filtering was applied where required to suppress high-frequency operational noise and casing-related responses.

The time-domain waveform and AFA scalogram were interpreted together. A candidate TOC pick required consistency across repeated shots, alignment between time-domain and AFA indicators, compatibility with expected acoustic multiples, and agreement with the calibrated or modelled velocity. This combined workflow reduced dependence on a single peak-picking decision and improved confidence where the raw waveform alone was ambiguous.

TOC verification and uncertainty

The final TOC estimate was reported as a measured depth relative to RKB and was reported prior to physical Tagging to ensure the blind nature of the test; with uncertainty reflecting the combined effects of sample interval, velocity uncertainty, pick uncertainty, and repeatability between shots. For the deep plug, the acoustic TOC pick was later compared with mechanical drill-tag depth.

An identical approach was conducted and validated for the surface plug, the acoustic result provided an interventionless TOC-location estimate that could support acceptance were aligned with operator and regulator criteria.

A secondary objective was to investigate whether the acoustic response changed during cement hydration. In this field application, no repeatable relationship was established between WOC acoustic signatures and cement hardening state.

Reporting

The diagnostic report consolidated the sequence of events, well configuration, acquisition conditions, acoustic velocity calibration, time-domain plots, AFA scalograms, interpreted depths, uncertainty estimates, and comparison with available conventional references. This evidence package is intended to support engineering review and, where accepted, operator and regulator decision-making for TOC-location verification.

Results

The field trial results are presented in the order acquired: packer acoustic-velocity calibration, deep-plug TOC determination during WOC, post-tag acoustic confirmation, bridge-plug acoustic-velocity calibration, and surface-plug TOC determination. Table 1 summarizes the key calibration and TOC-location results. All depths are reported as MD RKB unless stated otherwise.

Table 1—Summary of acoustic calibration and TOC interpretation results.

Survey step	Key acquisition / calibration data	Interpreted result	Validation or use
Packer AV calibration	Known production packer at 1670.2 m MD RKB; repeatable reflection at 2421 ms TWT; Theoretical modelled AV of 1389 m/s.	Calibrated AV = 1375 m/s.	Used for deep-plug time-to-depth conversion; AFA output showed the first packer reflection and an expected multiple.
Deep TOC during WOC	Five repeatable shots acquired between 21:00 and 22:00; reflection time of 2196 ms; AV = 1375 m/s.	Deep TOC = 1515 m MD RKB, with estimated uncertainty of +/-10 m.	Mechanical drill tag later reported 1519 m MD RKB; difference from acoustic pick was 4 m.
Deep TOC post-tag / pressure-test survey	Post-tag acoustic survey at 02:37 during the deep cement pressure test; reflection time remained 2196 ms.	Deep TOC again interpreted at 1515 m MD RKB.	Repeat response under a different pressure condition supported reflector stability; AFA output showed clear multiples.

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Survey step	Key acquisition / calibration data	Interpreted result	Validation or use
Bridge-plug AV calibration	Known bridge plug at 230.0 m MD RKB; four repeatable shots; reflection time of 326 ms.	Calibrated AV = 1379 m/s.	Provided the velocity basis for surface-plug TOC conversion and confirmed close agreement with the earlier packer-derived AV.
Surface TOC determination	Four repeatable surface-plug shots from 00:50 to 01:35; reflection time of 194 ms; AV = 1379 m/s.	Surface TOC = 139 m MD RKB, with estimated uncertainty of +/-10 m.	Provided TOC-location evidence for the surface plug; acoustic response does not directly measure cement compressive strength.

Packer acoustic-velocity calibration

The first survey established the acoustic velocity for the deep annular path. Three repeatable shots were acquired through the Annulus-A SOV into the liquid column and interpreted against the known production packer at 1670.2 m MD RKB. The dominant two-way reflection time was 2421 ms, yielding a calibrated acoustic velocity of 1375 m/s using the two-way travel-time depth relationship. In the time-domain response, the packer is visible as a major inflection, although the presence of other wellbore features means the time-domain pick alone is not the most reliable basis for interpretation (Figure 4).

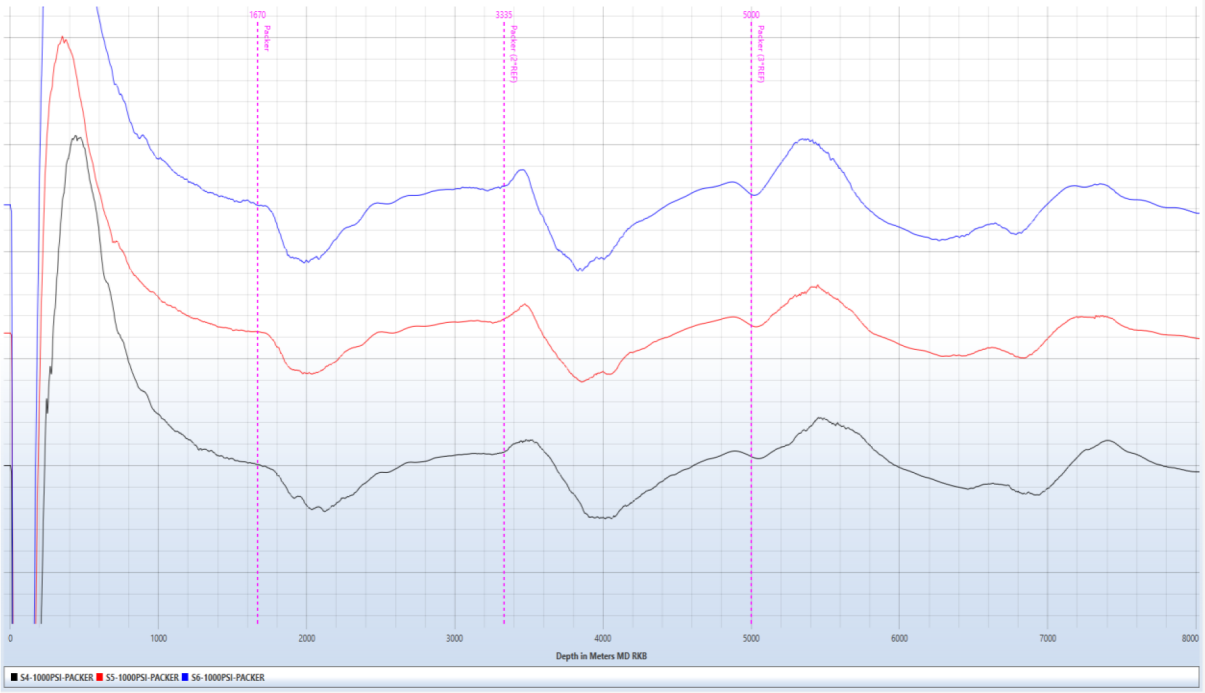


Figure 4—Packer AV calibration: time-domain response

The calibrated velocity is consistent with the Theoretical modelled AV value of 1389 m/s for a casing-constrained fluid column. The measured field value is expected to be slightly lower than the theoretical model because of temperature effects, fluid compressibility, casing nonuniformity, and small amounts of entrained gas.

AFA frequency-diagram processing confirmed the packer reflection at the known depth and showed the expected multiple response (Figure 5). This calibration provided the velocity basis for the subsequent deep-cement TOC interpretation.

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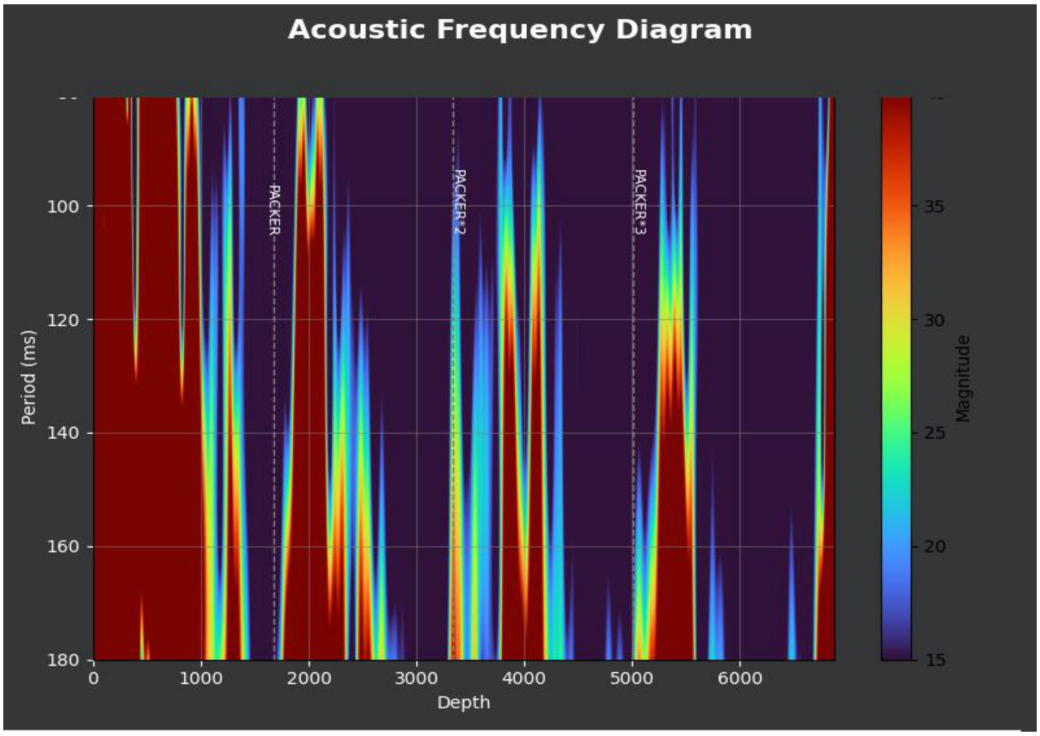


Figure 5—Packer AV calibration: AFA frequency diagram

Deep cement-plug TOC during WOC

During the WOC period for the deep cement plug, acoustic surveys were acquired at 15-minute intervals using the same AGG configuration and AFA processing parameters. Five repeatable shots acquired between 21:00 and 22:00 showed a candidate TOC reflection at 2196 ms TWT. Using the packer-calibrated acoustic velocity of 1375 m/s, this corresponds to a deep TOC of 1515 m MD RKB with an estimated uncertainty of +/- 10 m.

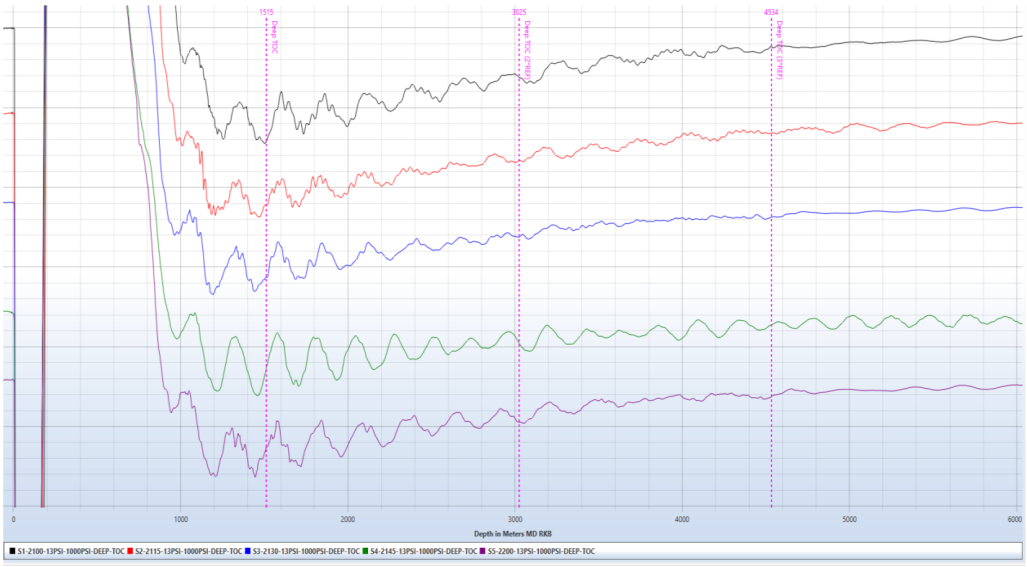


Figure 6—Deep TOC during WOC: time-domain response

The time-domain response showed an attenuated but repeatable candidate event at the interpreted TOC depth. AFA processing improved pick confidence by concentrating the reflected signal energy in the depth-

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period representation and by showing the associated multiple response expected from the cement boundary. The acoustic pick was later compared with the mechanical drill-tag result, which reported the cement top at 1519 m MD RKB; the 4 m difference was within the reported acoustic uncertainty (Figure 7).

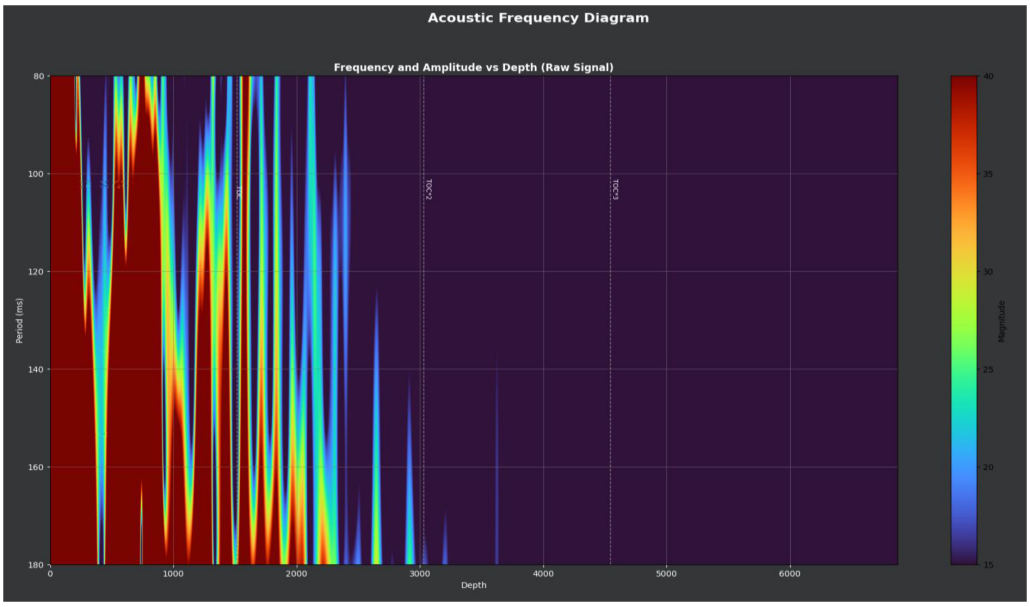


Figure 7—Deep TOC during WOC: AFA frequency diagram

Post-tag acoustic confirmation

A post-tag survey was acquired at 02:37 during the deep cement pressure test. The same reflection time of 2196 ms was observed, and the TOC was again interpreted at 1515 m MD RKB using the calibrated velocity of 1375 m/s. The repeatability of the response under a different operational pressure condition supports the stability of the reflector interpretation (Figures 8 and 9).

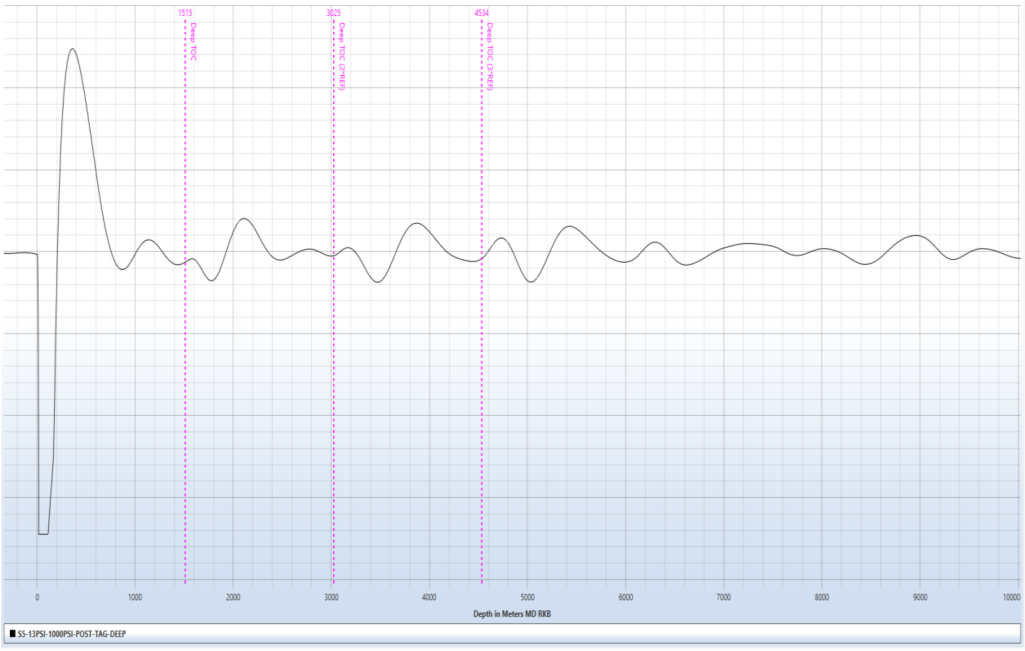


Figure 8—Deep TOC post-tag / pressure-test survey: time-domain response

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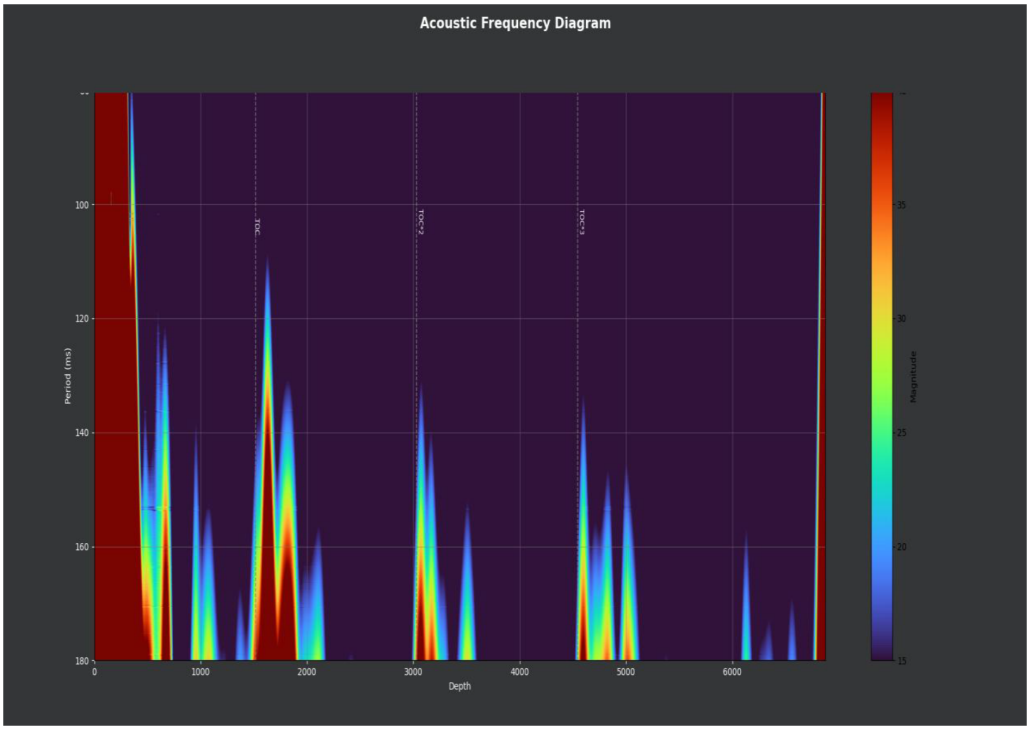


Figure 9—Deep TOC post-tag / pressure-test survey: AFA frequency diagram

Bridge-plug acoustic-velocity calibration

After the existing old completion tubing was dropped post deep cement plug operation, during surface bridge plug installation, a second velocity calibration was performed using the known bridge plug at 230.0 m MD RKB. Four repeatable shots were acquired, and the primary bridge-plug reflection was identified at 326 ms TWT. This produced a calibrated acoustic velocity of 1379 m/s, closely matching the earlier packer-derived calibration and confirming that the surface-plug interval could be converted to depth using a similar casing-constrained fluid velocity (Figure 10).

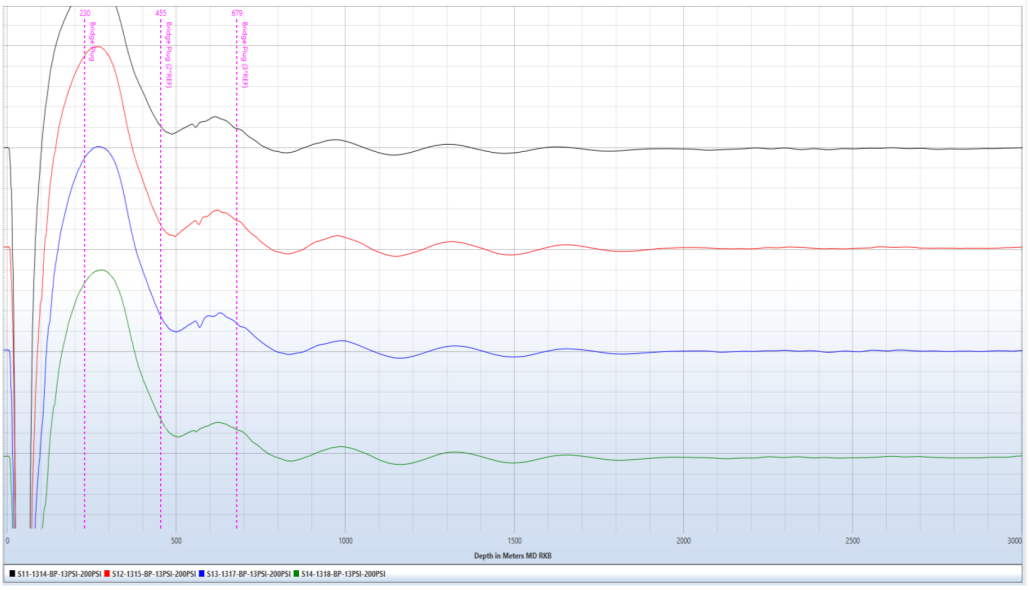


Figure 10—Bridge-plug AV calibration: time-domain response

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AFA processing confirmed the first bridge-plug reflection and the expected second multiple (Figure 11). This result provided the acoustic-velocity basis for the surface-plug TOC interpretation.

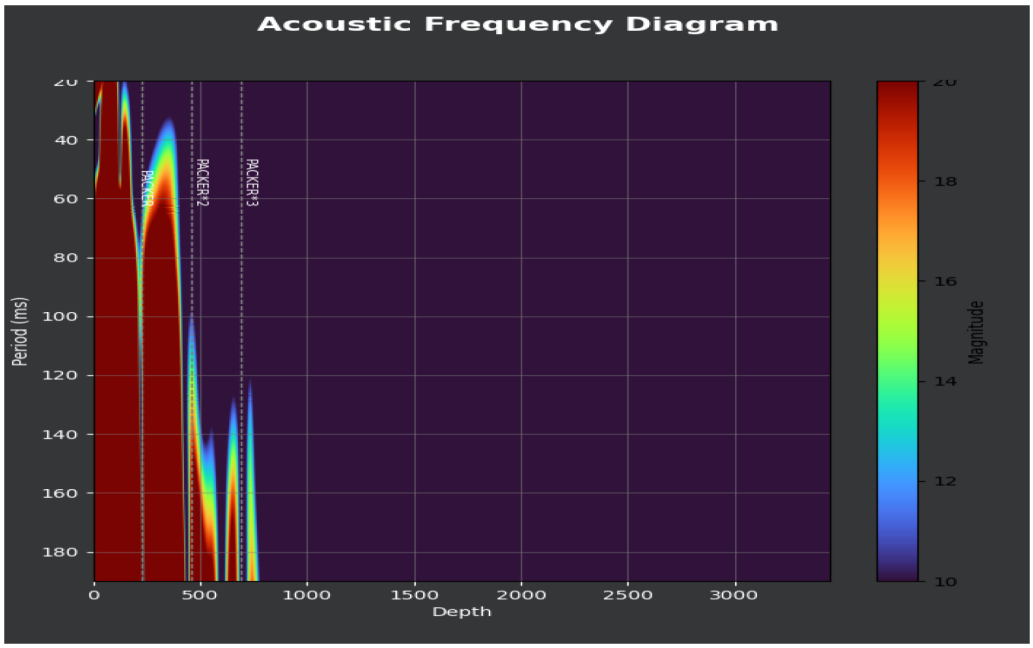


Figure 11—Bridge-plug AV calibration: AFA frequency diagram

Surface cement-plug TOC determination

Following surface cement plug placement, surveys were acquired at 15-minute intervals and interpreted using the bridge-plug-calibrated velocity of 1379 m/s. Four repeatable shots acquired between 00:50 and 01:35 showed a reflection time of 194 ms. This corresponds to a surface TOC of 139 m MD RKB, with an estimated uncertainty of +/- 10 m (Figure 12).

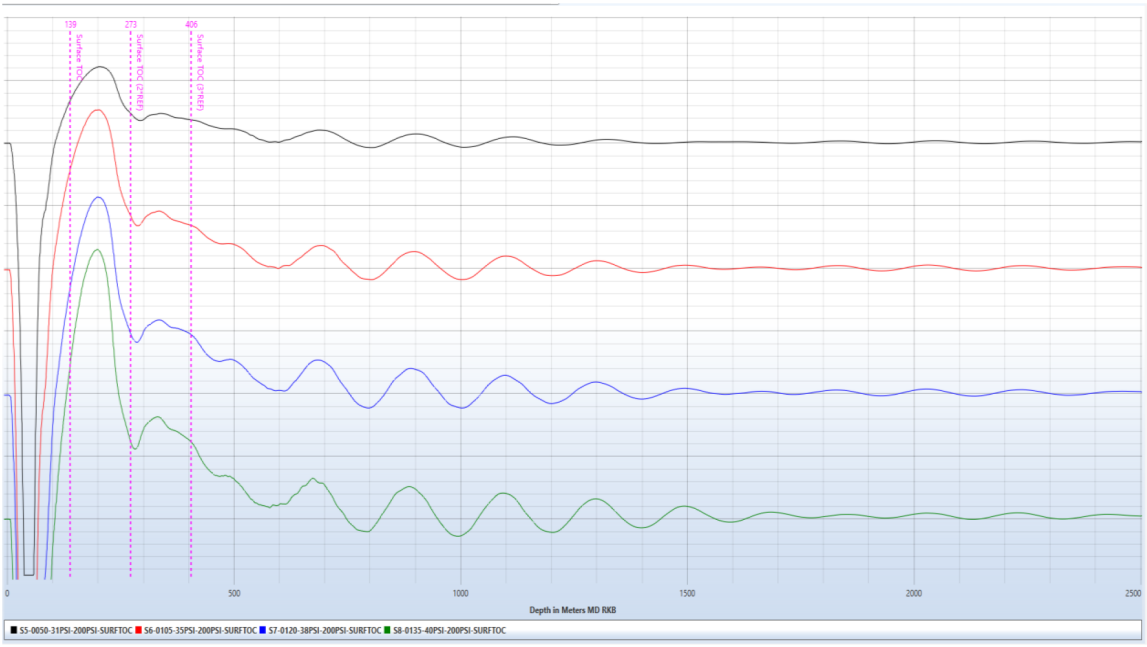


Figure 12—Surface TOC determination: time-domain response

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In the AFA frequency diagram, the surface-plug TOC response was observed as a repeatable localized energy feature, with associated multiples that supported the interpretation (Figure 13). As the first incident of reflection from the surface plug is partially masked by the pressure pulse itself, the 2nd and 3rd reflections of the same interface can be used for confirmation of response time.

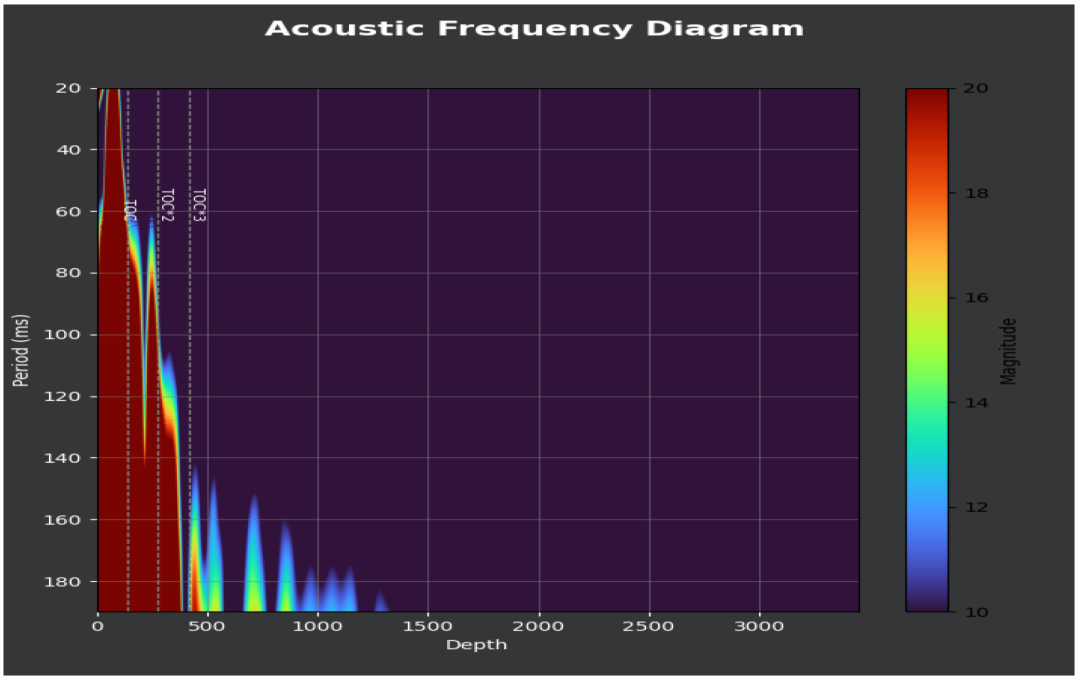


Figure 13—Surface TOC determination: AFA frequency diagram

Discussion

Validation of AFA-assisted TOC determination

The primary validation result from this case is the agreement between the acoustically interpreted deep TOC and the mechanical drill tag. The acoustic pick of 1515 m MD RKB differed from the reported tag depth of 1519 m MD RKB by 4 m, which is well within the stated +/- 10 m acoustic uncertainty. This comparison demonstrates that calibrated AFA-assisted acoustic reflectometry when combined with automated and controlled pulse generation and a customised digital microphone array; can provide a robust TOC-location measurement in a liquid-filled annular path when the response is repeatable and supported by expected multiples.

The AFA output did not replace engineering judgement; rather, it improved the quality of the evidence available to the interpreter. Time-domain analysis identified candidate inflection points, but the AFA depth-period representation improved event visibility, especially where attenuation, background noise, and multiple wellbore reflectors reduced the clarity of the raw waveform. The strongest interpretations were those where the time-domain response, AFA response, expected reflector depth, and multiple patterns were mutually consistent.

Importance of acoustic velocity calibration and modelling

The packer and bridge-plug calibrations produced closely aligned acoustic velocities of 1375 m/s and 1379 m/s, respectively. The agreement between these two independent direct calibrations increased confidence that the velocity model was representative of the casing-constrained fluid column. Where a suitable downhole calibration marker is not available, acoustic velocity can still be modelled from fluid or gas properties, pressure, temperature, pipe dimensions, and pipe-fluid interaction effects. Such modelled

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velocities can support pre-job planning and feasibility screening, although a calibrated marker remains preferable for final TOC-location verification where operationally available.

Applications for P&A, workover, sidetrack, and rigless operations

The value of the method extends beyond immediate WOC monitoring. Mature wells often have incomplete annular cement records, with historical TOC estimates based mainly on pumped volumes, theoretical capacity, returns, and assumed displacement efficiency. These estimates can be materially inaccurate because of losses, washout, eccentricity, channeling, contamination, or unrecorded operational events. Surface acoustic pre-screening can improve understanding of existing annular cement depths before a rig or workover package is mobilized.

For P&A campaigns, improved knowledge of existing annular cement height can reduce uncertainty in barrier design, contingency planning, and cement remediation scope. For workovers and sidetracks, improved annular-cement mapping can support selection of feasible kickoff depths and reduce unnecessary drilling or milling time. For rigless P&A, where mechanical tagging or downhole logging may not be practical, an accepted acoustic TOC-location measurement can provide important barrier-location evidence without deploying downhole tools.

Regulatory use, barrier assurance, and limitations

Acoustic TOC determination should be framed as a cement-boundary location measurement. It does not directly measure cement compressive strength, cement bond quality, permeability, or long-term hydraulic isolation. Therefore, use as a replacement for selected conventional TOC-location verification activities should depend on operator standards, regulator acceptance, well-specific risk assessment, and integration with other barrier evidence such as cement job records, pressure tests, slurry design, volumes, and well schematics.

A secondary objective of this field trial was to determine whether acoustic response changes during WOC could be correlated with cement hydration or hardening. No repeatable acoustic signature was established for cement hardening in either the time-domain or AFA-domain data.

Conclusions

1. The field application demonstrated that surface acoustic reflectometry utilising specialized automated pulse generation and advanced digital microphone arrays; coupled with specialized signal processing hardware when processed with AFA time-frequency analysis, can provide a practical interventionless TOC-location determination during offshore P&A operations when the annulus provides a continuous acoustic path and processing is calibrated or modelled appropriately. Further field deployments are recommended to ascertain limitations of the application.
2. Calibration against known downhole markers was essential. The production packer and bridge plug calibrations produced acoustic velocities of 1375 m/s and 1379 m/s, respectively, consistent with the Theoretical-modelled casing-constrained velocity of 1389 m/s.
3. The deep cement-plug TOC was interpreted at 1515 m MD RKB +/- 10 m and was subsequently mechanically tagged at 1519 m MD RKB, a 4 m difference. The surface cement-plug TOC was interpreted at 139 m MD RKB +/- 10 m using the bridge-plug-calibrated acoustic velocity.
4. Acoustic TOC determination is a cement-boundary location measurement. It does not directly measure cement compressive strength, cement bond quality, permeability, or plug mechanical integrity; therefore, use as a replacement for selected conventional TOC-location verification steps depends on operator and regulator acceptance criteria while cement compressive strength can be directly refer to sample since reputation on surface sample is well established.

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5. Beyond WOC monitoring, the method can reduce uncertainty in P&A, workover, sidetrack, and rigless planning by pre-screening existing annular cement heights, particularly where historical records are based primarily on pumped volumes and theoretical placement calculations.
6. No repeatable acoustic signature for cement hydration or hardening was established in this field trial.

Nomenclature

AGG = Advanced Gas Gun
AMS = Acoustic Metering Software
AFA = Advanced Frequency Analysis
Ann-A = Annulus-A
AV = Acoustic velocity
BP = Bridge plug
CBL = Cement bond log
CHP = Casing head pressure
CHT = Casing head temperature
FT = Fourier Transform
HSE = Health, safety, and environment
MD = Measured depth
MD RKB = Measured depth referenced to rotary kelly bushing
NPT = Non-productive time
P&A = Plug and abandonment
RKB = Rotary kelly bushing
SCP = Sustained casing pressure
SOV = Side outlet valve
TOC = Top of cement
TWT = Two-way travel time
VDL = Variable density log
WHP = Wellhead pressure
WOC = Wait on cement

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