SPE-199180-MS

Behind Casing Gas Identification Using Ultrasonic Wireline Logs: An Overview of Multiwell Field Plug and Abandonment Study, Offshore Malaysia

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This paper was prepared for presentation at the SPE Symposium: Decommissioning and Abandonment held in Kuala Lumpur, Malaysia, 3 - 4 December 2019.

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Abstract

During the plug and abandonment (P&A) of a gas field, offshore Malaysia, detailed cement evaluation logs were performed using a circumferential ultrasonic cement evaluation tool in combination with a traditional cement bond log (CBL) tool. The tools were combined in a single string and conveyed on wireline monocable. A total of eleven wells are included in a multiwell analysis across the field, which resulted in the successful identification of gas sources behind casing and the detection of buildups of migrated gas behind casing.

An ultrasonic scanning tool operating with a rotating transducer (which transmits high frequency acoustic waves) measures the acoustic impedance of the material behind the casing wall at more than 50 azimuthal points. In combination with a CBL tool, these are used to simultaneously evaluate the cement bond quality and integrity between the 7-in. production casing and the formation to help ensure adequate isolation to continue with abandonment plan. Analysis of this data revealed consistent low impedance gas anomalies across specific permeable formations. These formations were subsequently interpreted as possible gas sources contributing to sustained annulus pressure and were identified without the requirement to perform dedicated pulsed neutron logs.

Correlations were identified between sustained annulus pressure, historical petrophysical and diagnostic logs, and modern-day cement evaluation logs. Formation evaluation logs revealed parts of the identified formation were likely gas-bearing. Results from the ultrasonic data showed that the gas now occupied areas of the annular space behind the production casing, and the position of the gas within the annular space could have been affected by depletion. In several logs, it was observed that low impedance measurements continued to shallower depths above the major producing formation, signifying a gas migration pathway. In cases within the field, the shallowest hundred meters of the data were dominated by low impedance fluid measurements, correlating with sustained annulus pressure. The results were corroborated with separate acoustic-based diagnostic measurements in the same field, which also indicated a probable source of gas migration from the same identified formation into the cemented annulus.

This paper highlights a case study whereby ultrasonic cement evaluation logs run on monocable wireline were able to identify trapped gas within the 7- × 10 ¾-in. annulus, as well as pointing the probable source

of gas bearing formation contributing to gas migration into the annular space. This real-time additive information allowed the operator to help ensure proper planning for gas evacuation, zonal isolation, and cement remedial operations. By analyzing multiple offset wells, it also allows for predictions to be made for future wells in the field that suffer from sustained annulus pressure.

Introduction and H-Field History

The H-Field is located 260 km offshore Terengganu state, Malaysia, at a water depth of 77 m. H-field was first discovered by H-1 in August 1973 and was subsequently developed on August 1977, achieving first oil on March 1978. A total of 24 wells were drilled in H-A (1977), followed by three infill drilling in April 2000. H-field ceased production on March 2016 (Fig. 1).

Figure 1—The H Field location.

P&A is part of the late-life stage of an oil and gas field. An important aspect of the successful P&A of a well is mitigating and preventing flow to surface from both reservoir intervals and other shallow gas hazards. One of the many aspects of integrity is assessing the bond quality behind the production casing. Typically, this is achieved by deploying a traditional omnidirectional CBL tool in combination with an ultrasonic scanning tool.

The study was performed initially to assess the cement bond quality across multiple wells to help ensure adequate cement bond for P&A. However, suspicion grew that a specific permeable gas-bearing formation was flowing to the annulus zone, resulting in sustained annuls pressure. The result of this unwanted flow is gas migration to the surface with sustained casing pressure. Eventually, multiple wells have been logged and interpreted across the H-field. Subsequent correlation suggested the presence of trapped gas behind the casing. This interpretation was supported by increased pressure recorded in the annulus, in addition to openhole formation evaluation data and behind casing ultrasonic measurements. The results of this study are discussed.

P&A

P&A campaigns are inevitable in a mature field environment. The main P&A candidates are wells that are no longer economically viable to produce. In recent years, wherein the oil price has been adjusted to a new normal, attempts can to be made to keep a field producing effectively and economically. However, if a well is to undergo P&A, an integrated analysis of the well integrity must be conducted.

A study performed by Asia Outlook (2015) suggested that 50% of current offshore platforms, including wells, facilities, and subsea infrastructure, are operating at or beyond their designated life. Many, if left unchecked, can potentially damage the marine environment surrounding it (Asia Outlook 2015). According to Othman et al. (2018), the P&A process can be divided into four main phases: (1) securing the well, (2) cutting and retrieving tubing, (3) reservoir plugs, and (4) remediation of sustained casing pressure. P&A can easily contribute to 25% of the total cost of drilling an offshore well (Saasen et al. 2013).

Cement Bond Evaluation Tool

A CBL tool uses a transmitter to produce an omnidirectional acoustic wave (15 to 25 kHz) that travels through the borehole fluid, pipe, cement, and formations, to the receivers. Conventionally, the receivers are at a 3- and 5-ft spacing from the transmitter.

The first arrival amplitude that is captured at 3 ft is known as the pipe amplitude; this provides an indication of the cement to casing bond quality. In simplistic terms, in a free pipe section, this amplitude reading will be high because of the fluid filled space that makes the signal resonate. Typically, having a good cement bond provides a low amplitude reading caused by dampening of the acoustic signal from the cement.

The 5-ft receiver records the entire waveform. This waveform will be stacked and displayed as a microseismogram (MSG). In a simple configuration of pipe to formation cement bond, the response of this MSG reflects the cement bond quality of the interval, straight lines indicate a free pipe, and the variation of the MSG indicates a cement bond presence behind the casing. Furthermore, any variation within the MSG that corresponds with the gamma ray or another petrophysical curve is typically known as formation-arrivals and signifies coupling to the formation.

Fig. 2 shows the difference between a predominantly free pipe section at the top logged interval (left) and a good bond interval between casing and formation (right). As explained, the free pipe section has a high pipe amplitude reading compared to that in a good bond interval. The MSG shows a straight line response compared to a varied MSG from a better bonded interval.

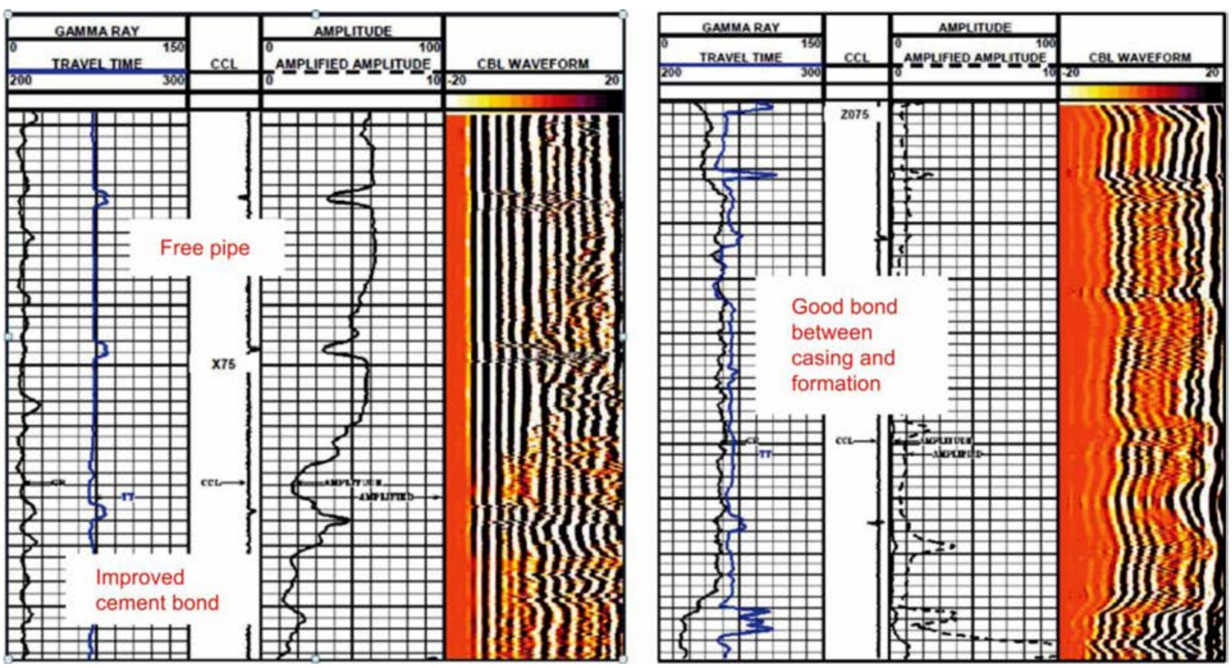

Figure 2—Cement bond log display from poor bond at top (left) and good cement bond (right).

The use of CBL tool alone to evaluate cement bond is limited when interpreting features, such as a microannulus, elastomeric cement, or light cement blends. Such interpretations require the combination of the CBL and an ultrasonic cement evaluation tool to fully understand the bond quality (Frisch and Mandal, 2001).

Ultrasonic Acoustic Scanning Tool (USAT)

A UAST for cement evaluation uses a high frequency (200 to 400 kHz) rotating transducer that is both the transmitter and the receiver. This transmits an acoustic wave that provides a circumferential cement coverage behind the casing at a far shallower depth of investigation than cement bond logging tool.

The peak amplitude from the first reflection is used to compose a detailed textural image of the internal casing wall. This internal casing dimensions can be determined from the first arrival travel time (Lavery and Imrie 2017). With the application of the correct transducer frequency, casing thickness can be obtained at multiple discrete azimuthal points (Frisch and Mandal 2001). The acoustic impedance of the material behind casing depends on the decay characteristics of the resonance window after the first arrival. When the ultrasonic signal reaches an interface, part of the signal is transmitted across the interface, while some is reflected back (Mandal and Quintero 2010). This difference of reflected and refracted energy defines the acoustic impedance contrast of materials at the interface (Fig. 3).

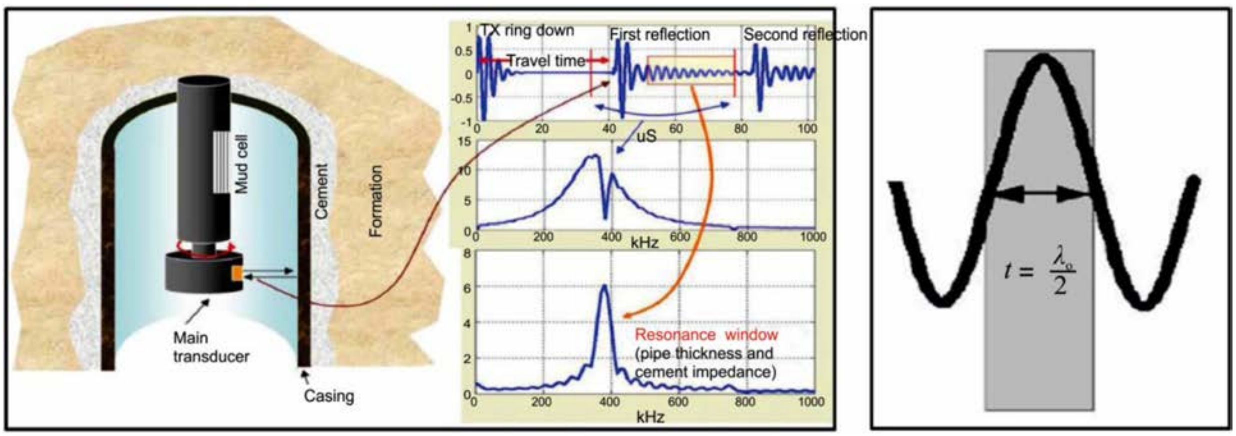

Figure 3—Basic processing of the received signal and casing thickness calculation (Mandal and Quintero 2010).

Contrary to the omnidirectional measurement from CBL, the UAST provides azimuthal measurements of acoustic impedance, providing the position and orientation of any channeling behind pipe. The measured acoustic impedance map is based on color coding shown in Fig. 4.

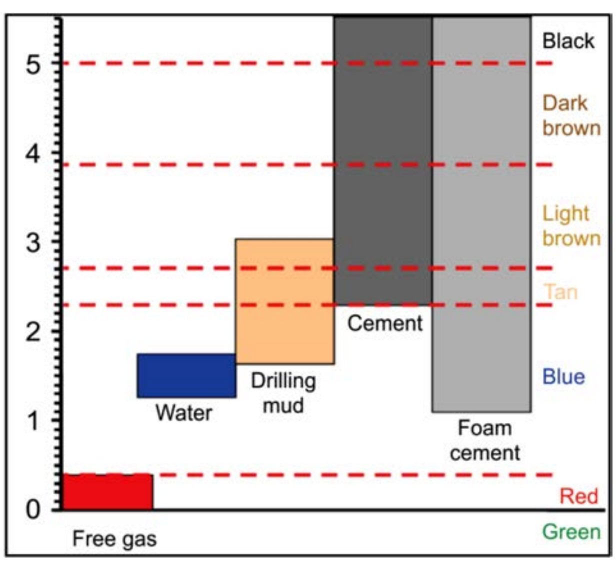

Figure 4—Acoustic impedance values for gas, water, and cement.

For identification of gas behind casing, the measurement window is typically between 0 and 0.38 MRayls (annotated in red, Fig. 4).

Log Quality Control

1. Before the ultrasonic data is processed and interpreted, quality control on the data is required. A QC plot, such as in Fig. 5, is generated to verify and check all the relevant curves and images.
2. Verification of the navigation data is compared to the deviation of the checkshot survey.
3. Radius and thickness should read correctly for the logged casing values. Eccentricity should always less than 0.20 in. The number of bad shots should be minimal.
4. All images (amplitude, impedance, and thickness) should be clear.
5. The impedance image should reflect cement present behind casing and the CBL readings should read the expected value.
6. Table 1 is an example of data quality control histograms for Well 04.

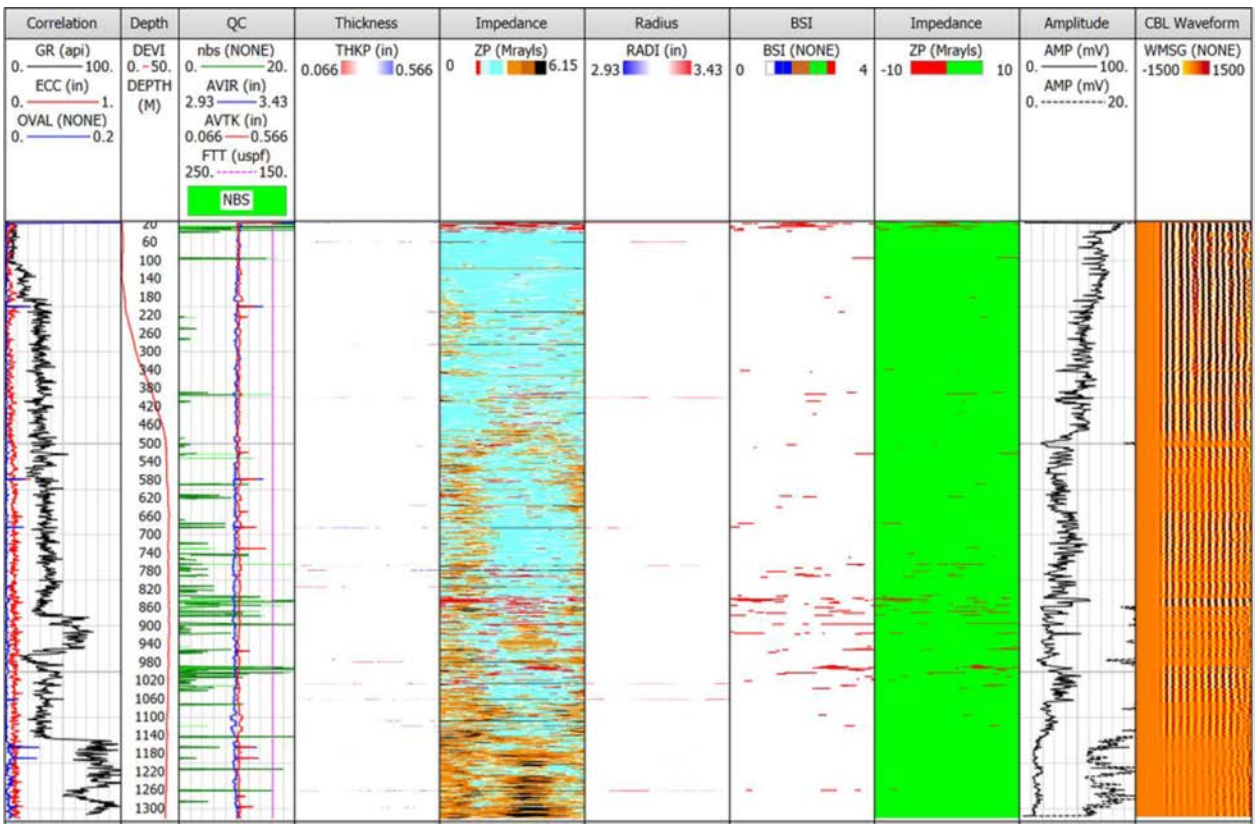

Figure 5—Quality control plot for ultrasonic data.

Table 1—Casing details of Well 04.

Casing OD	7 in.
Casing OD	23 ppf
Casing ID	6.366 in.

The eccentricity is low with average of 0.06 in., as indicated in Fig. 6.

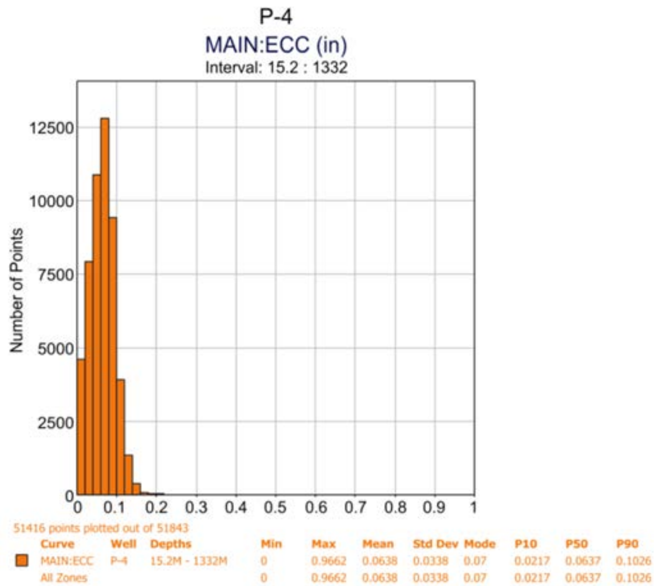

Figure 6—Histogram of eccentricity Well 04.

The average thickness is 0.325 in., which is close to nominal thickness of 0.317 in. The average radius reads 3.175 in., which is close to nominal radius of 3.183 in. These critical quality control metrics provide confidence in the acquired data and it is therefore suitable for processing and interpretation (Figs. 7 and 8).

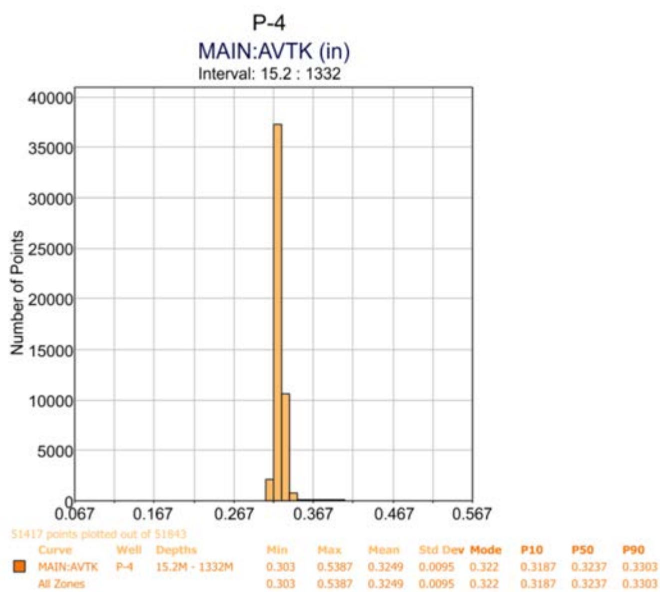

Figure 7—Histogram of average thickness Well 04.

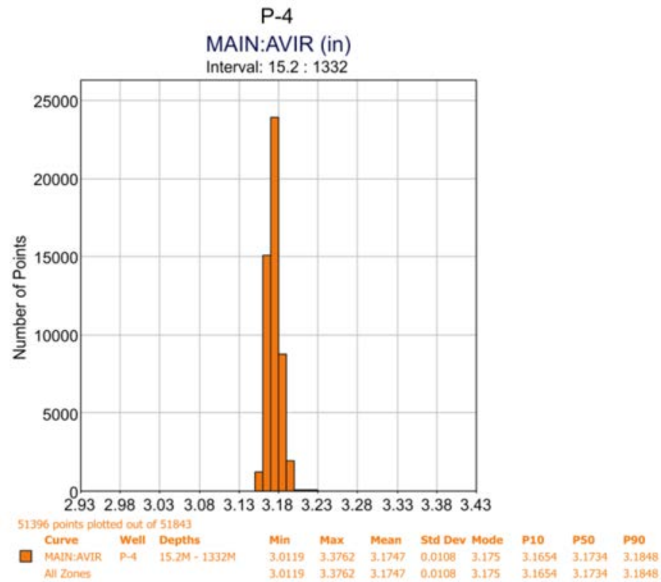

Figure 8—Histogram of average radius Well 04.

Well 17: No Sustained Annulus Pressure

Sand B sand starts at approximately 1160 mMD in Well 17. This sand is characterized by a typically low gamma ray, which indicates the sand or reservoir section. Based on well to well correlation, this sand is filled with gas in its upper section. Based on the CBL response, the 3 ft amplitude shows a better bond at the top section compared to the bottom section and the acoustic impedance (ZP) shows high impedance (brown color) to indicate solids behind. The bad shot index (BSI) map at this sand shows white; it is an indication good quality data is obtained in the gas section interval.

Approximately 100 mMD shallower than the Sand B lies Sand A. Based on well to well correlation from openhole log (Fig. 9), Sand A is likely gas bearing. In alignment with this formation, an indication of the presence of gas is recorded by way of low impedance measurements, obtained by the ultrasonic tool.

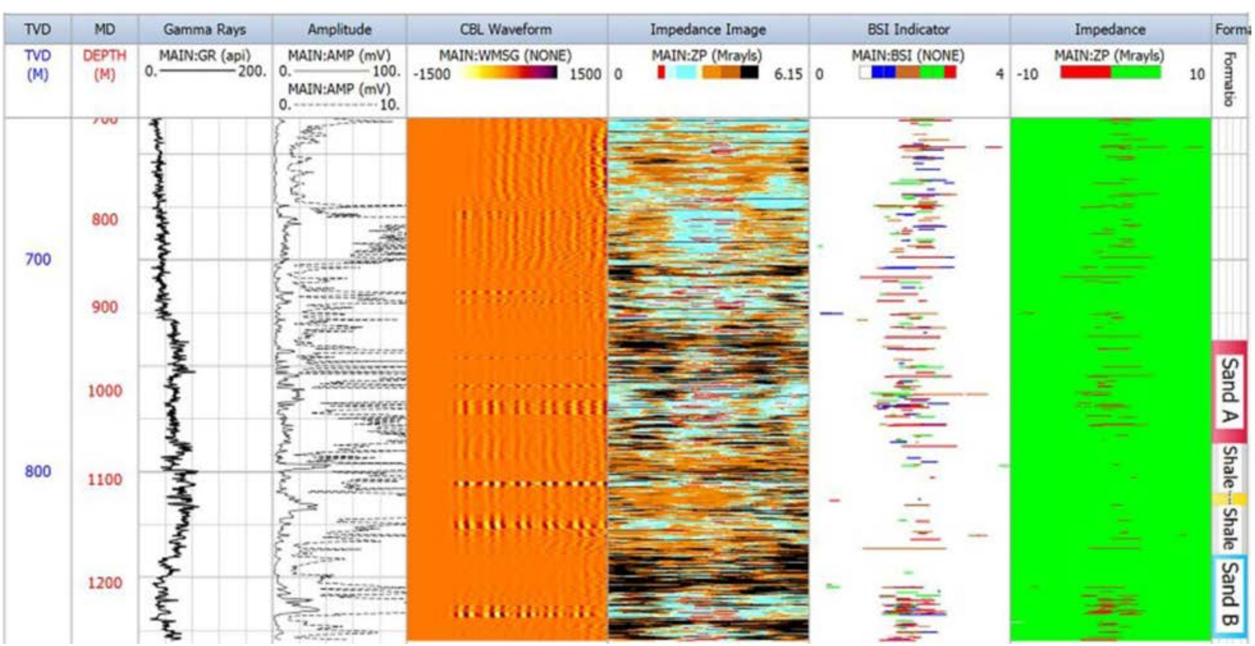

Figure 9—Well 17: Cement evaluation log.

Well 11: Sustained Annulus Pressure

Sand B begins at approximately 870 mMD in this well. Evaluating the available openhole resistivity, density and neutron data indicates the sand is filled by gas across its upper section. In terms of bond quality, the interval is largely poor with channeling. The ultrasonic data suggests that gas is present in the annulus behind the casing. The acoustic impedance data also reveals that depletion has occurred through the life-time of the well and the lower portion of the annulus, opposite Sand B, has a liquid interface at the pipe wall.

Above Sand B is Sand A. Further, because the bond quality is poor, the acoustic impedance data is dominated by measurements below 0.38 MRayls, which is indicative of the presence of gas (Figs. 10 and 11).

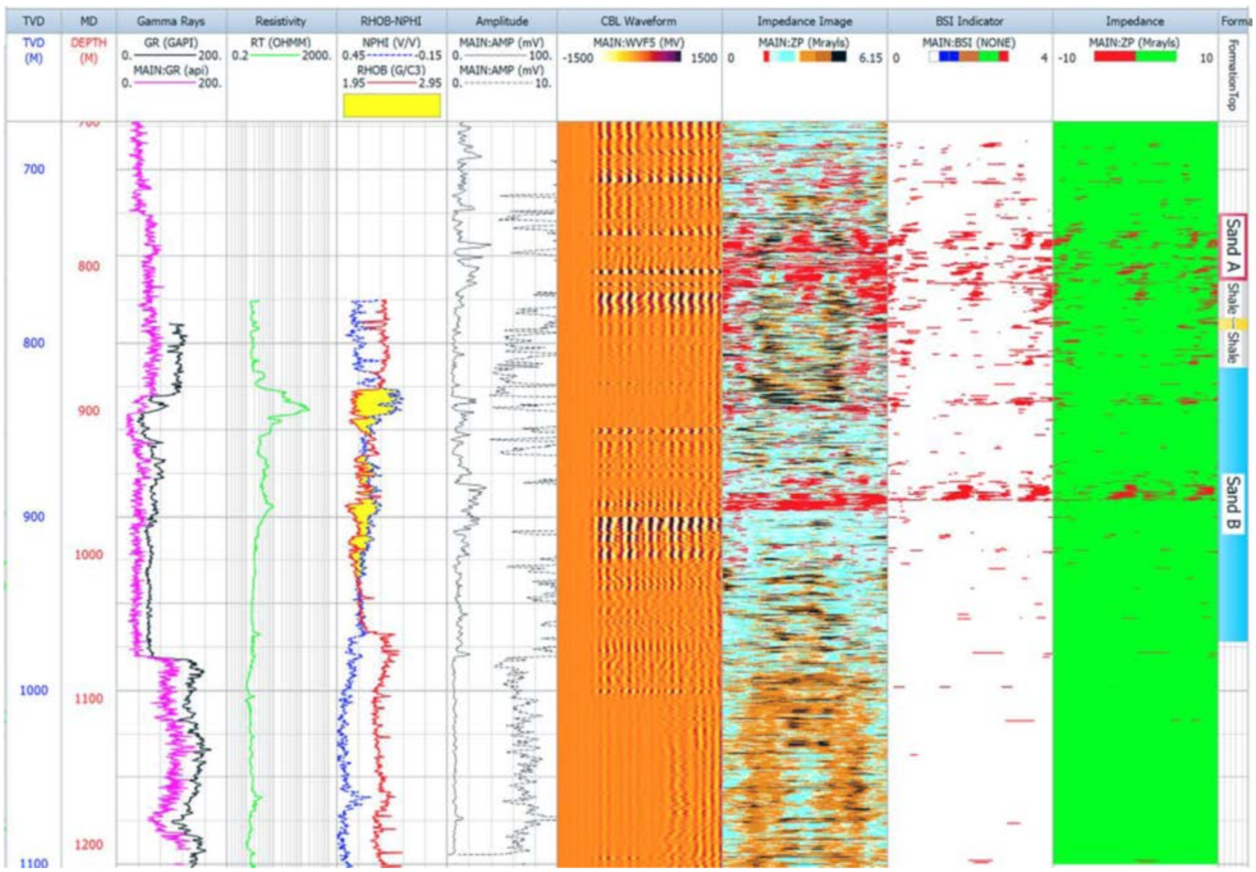

Figure 10—Well 11: cement evaluation log.

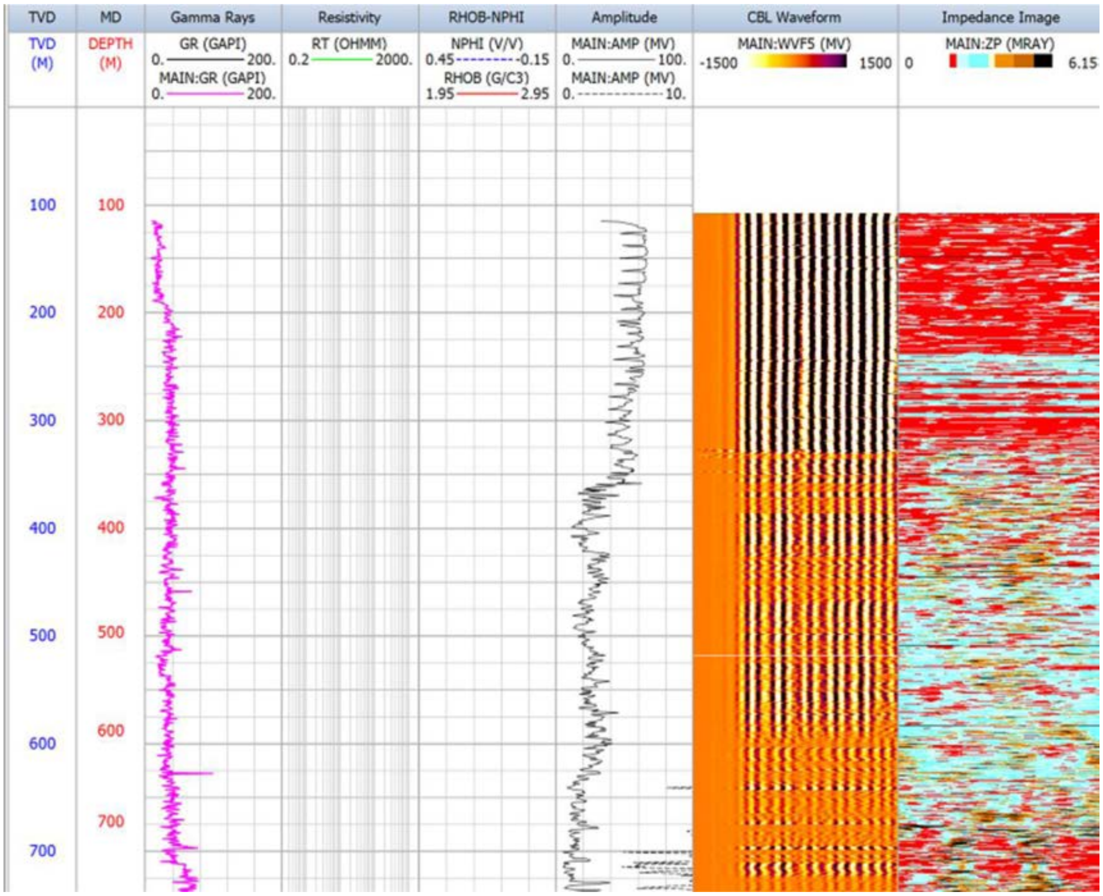

Figure 11—Well 11: cement evaluation log.

At the surface, Well 11 is shown to have sustained annulus pressure. The ultrasonic data shows a build-up beneath the casing hanger of low impedance measurements, which likely represents gas migrated from the Sand B and Sand A zones.

Well 04—Sustained Annulus Pressure

Similarly, in Well 04, the bond quality is poor across the interval above with obvious channeling along the low side. The openhole petrophysical data indicates that the Sand B is gas bearing. Both the shallower Sand A and Sand B feature low impedance gas measurements indicative of gas at the casing wall opposite these formation.

At the surface, Well 04 is shown to have sustained annulus pressure (Fig. 12).

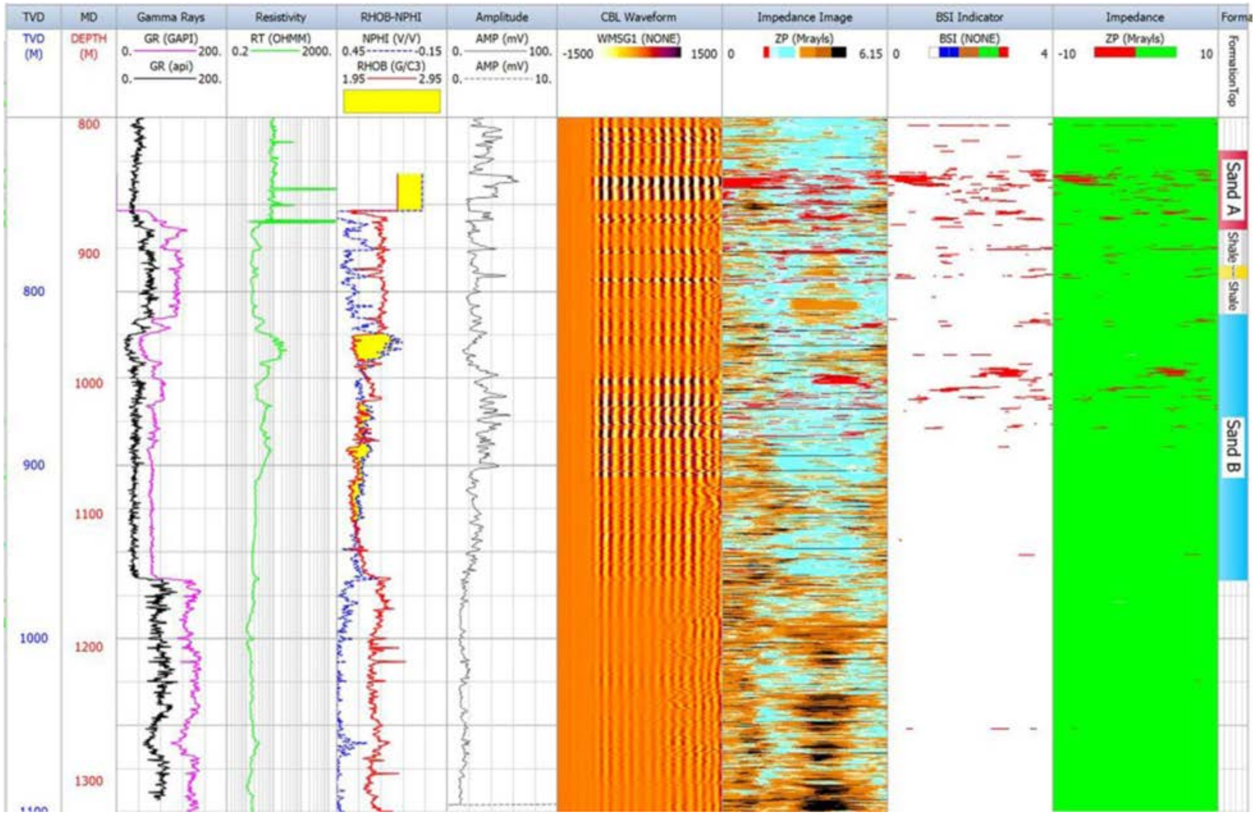

Figure 12—Well 04: cement evaluation.

Multiwell Correlation

It is clear from an individual analysis of the aforementioned Well 11 and Well 04 that a collection of low impedance measurements occurs close to the wellhead. To evaluate the source of the gas measurements, it is necessary to perform a multiwell correlation of the acquired data across the field.

Fig. 13 illustrates a correlation of six offset wells. Two sandstones of interest are Sand B (orange) and Sand A (red), highlighted. In addition to a common collection of low impedance measurements at shallower depths, it is apparent that these two formations consistently feature low acoustic impedance measurements, which are suggestive of gas at the casing-annulus interface. In cases visible in Fig. 13, the presence of gas can be traced to shallower depths, which is useful for verifying the existence of gas migration pathways that were suggested by sustained casing pressure at the surface.

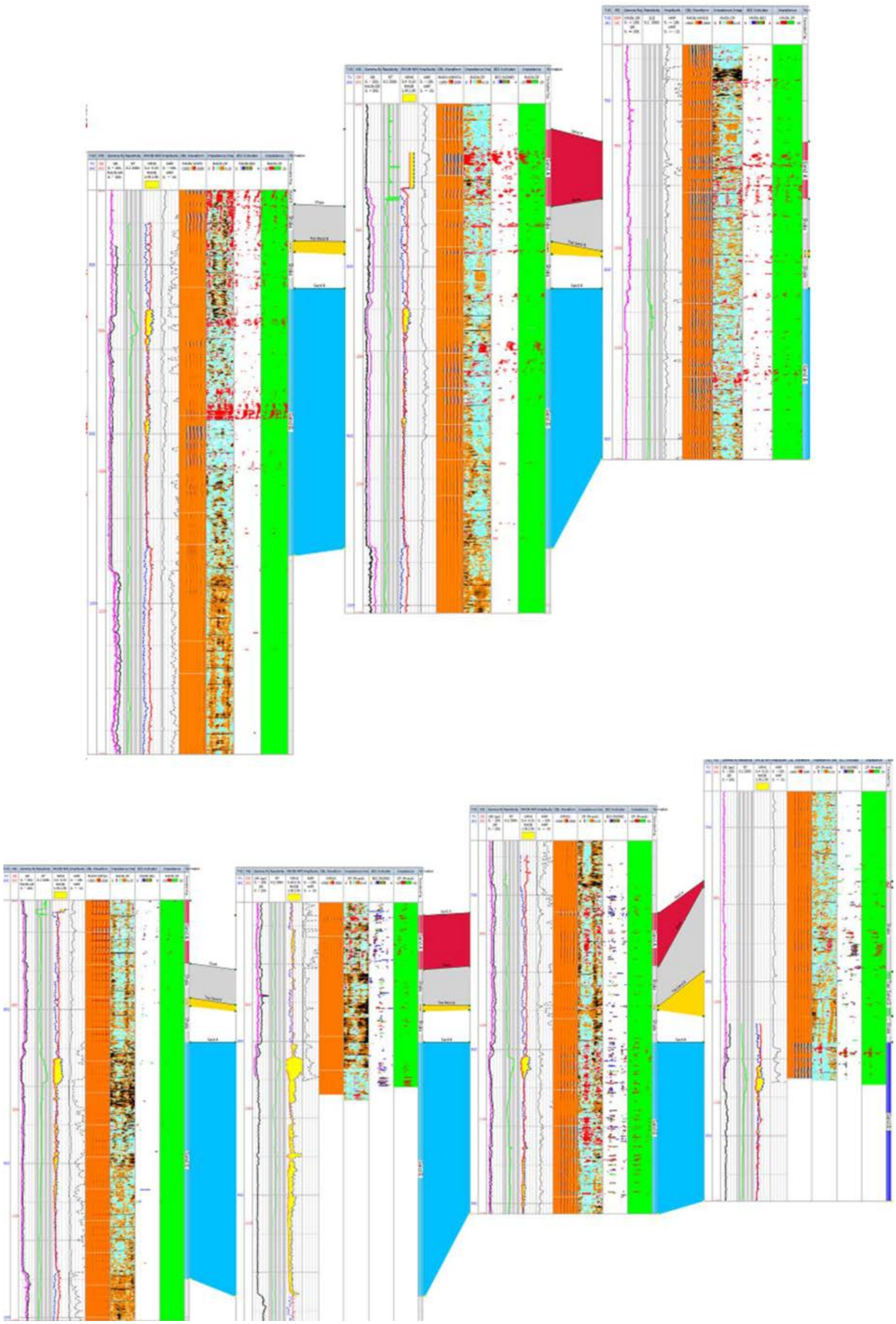

Figure 13—H Field multiwell correlation.

Conclusions

The source depth of a field-wide gas migration behind casing was successfully identified by integrating cased hole cement evaluation logs with historical petrophysical data. Parallel to Sand A and Sand B, consistent low acoustic impedance measurements were observed, commonly associated with gas. In cases across the field, these low acoustic impedance measurements could be traced to shallower depths, indicating gas migration pathways. This additive information allowed the operator to gain additional insight into the field as part of planning for the continued P&A of the H field.

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