Well Integrity Diagnostics and Reservoir Monitoring in Aging Completions to Arrest Decline in Gas Production: Experience from Dandewala Gas Field, Rajasthan, India

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ABSTRACT

Dandewala gas field is situated 50 kms from temple town of Tanot in Jaisalmer district of Rajasthan at India-Pakistan border. The field was discovered in the year 1990 by Oil India Ltd with gas finding in the very first well. The wells are drilled as vertical and completed mostly with 5-½" production casing with 2-$^{7}/_{8}$" tubing. The field has been on regular production since 1996 when commercial production was started. The produced natural gas from the field contains about 30% of CO_2 which is highly corrosive in nature and place serious threat to well integrity on exposure. Since majority of the wells are old & field is ageing, a workover campaign was started recently in the gas fields. Well intervention is prioritized in view of (1) water production increasing gradually with decline in gas production rate (2) annular pressure buildup and (3) well integrity issue in some of the aging wellbores. It was essential to assess cement and casing integrity to find out reasons for annular pressure buildup and complete the wells higher up after plugging back the existing perforations.

A well integrity and reservoir monitoring logging suite was recently run to evaluate cement and casing conditions, saturation changes and movement in fluid contact. Sonic and Ultrasonic combination in tool string is an efficient and good solution to successfully characterize cement and pipe conditions in aging wellbores prior to run reservoir monitoring tool. High-resolution cement and casing evaluation images are obtained from Ultrasonic tool oriented with respect to high side-low side of the wellbore, enabling identification of both internal and external casing wear, erosion, corrosion, or any other mechanical damage. The image also provides accurate measure of casing properties, and helps determine bonding and image channels in the cement sheath directly outside the casing. The cement evaluation is complete by using sonic (cement-bond log) providing cement quality inferred from the degree of acoustic coupling of the cement to the casing and to the formation. The measurements are omnidirectional and thereby cannot detect the channels which are being identified through Ultrasonic. The reservoir monitoring survey was performed in both Sigma and Carbon-Oxygen (CO) mode. Formation water is highly saline (100k ppm as NaCl equivalent) and Sigma log is well suited for gas evaluation. The CO log which is independent of water salinity is also recorded in casing for saturation monitoring.

Tubing strings were pulled out during work-over operations in Example A. The tubing strings were found heavily corroded. Ultrasonic log shows major damage in the casing at most of the places in the logged interval due to corrosion. Many factors can negatively affect the integrity of a well's casing. Here the most likely culprit is carbon dioxide (CO_2), which is highly corrosive and erosive element like flowing water. The well was abandoned after placing a proper plug. Example B shows minor damage in the production casing. Sonic and Ultrasonic log indicate good cement bond with zonal isolation across the reservoir. Reservoir monitoring survey confirms the lower most completed sand as watered out. The well was completed higher up after plugging back the existing perforations. The well is flowing gas and brought back on production. The production casing in Example C is damaged at few places, being suspected for gas leak causing annular pressure buildup between 5-½" and 9-$^{5}/_{8}$" casings. The well had been kept shut-in since initial completion. After carrying out multiple cement squeeze jobs behind production casing, the well was recompleted & brought on production.

The examples presented in paper suggests that over time, casing/tubing strings can begin to deteriorate especially in harsh environments, affecting the production and safety of the well. Keeping a close eye on

the integrity of casing strings is important. The log results acquired by the logging suite comprising well integrity and reservoir monitoring suite helped the reservoir and well engineering personnel to take decision for zone transfer, remedial measures to arrest annular pressure buildup and abandoning one wellbore.

INTRODUCTION

Oil India Limited (OIL) has its presence in Western India in the state of Rajasthan where it is engaged in exploration and production of hydrocarbons from Jaisalmer Basin and Bikaner-Nagaur basin. The Jaisalmer-sub Basin contains gas fields which include Bagitibba, Dandewala and Tanot Fields. Figure 1 shows the location of Jaisalmer PML situated along the international boundary with Pakistan. The Mesozoic/Tertiary basin system is filled with Permian to Plio-Pleistocene sediments which generally thicken north-westwards into the fold/thrust belts.

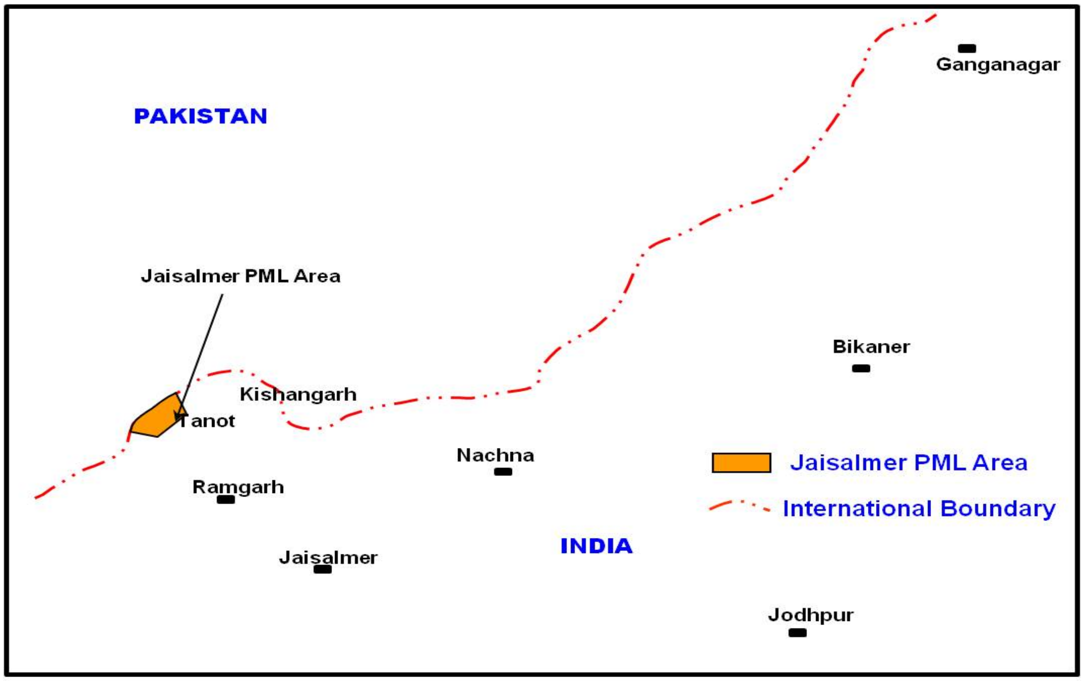

Figure 2. Location of Gas Fields of Jaisalmer PML

OIL established natural gas reserves in the Tanot structure in 1988. Subsequently, commercial quantities of natural gas reserves were established in Dandewala (1990) and Bagitibba (1991) fields in the same basin. The main gas reservoirs are Cretaceous sandstone (Pariwar sandstone, Lower Goru sandstone, and Upper Goru sandstone), Paleocene sandstone (Sanu) and Eocene carbonate/sandstone (Khuiala). Out of the three, Dandewala gas field is the main producing field with Pariwar reservoir as the major contributor.

Commercial gas production from the fields started in 1996. The produced natural gas from the field contains about 30% of CO_2 which is highly corrosive in nature and place serious threat to well integrity on exposure. Gas produced from Pariwar Sand is most corrosive with presence of CO_2 of as high concentration as 35%. Figure 2 shows the images of the tubing pulled out recently during workover operations in one of the well of Dandewala gas field which was producing from Pariwar Sand. Another issue is to maintain the gas production as water production is increasing gradually with decline in gas production rate. There is need to identify the true condition of pipe and then monitor current gas saturation helping reservoir team to take appropriate remedial actions.

Solution was sought by running first a well integrity logging suite. This consists of sonic and ultrasonic combination in tool string evaluating cement and pipe conditions. In case of a well in good condition, reservoir monitoring surveys were carried out to see saturation changes and movement in fluid contact. This helped to discern true well conditions to determine which wells were capable of extended service from those requiring abandonment. Well examples are presented in the paper describing the results obtained through evaluation of well integrity and reservoir monitoring surveys and subsequently net gas gain through remedial measures.

Figure 2. Snapshots of tubing pulled out during workover operations carried out recently in well A of Dandewala gas field.

APPROACH

A. Well Integrity Diagnostics

An ultrasonic scanner in combination with CBL-VDL is an ideal combination to evaluate the cement behind pipe and inspect the casing integrity. Very high horizontal and vertical sampling rates permit simultaneous cement evaluation and casing inspection. Data such as acoustic impedance, cement compressive strength, casing thickness, casing outer diameter and/or radius, casing ovality, tool eccentricity, and 40 to 100 calipers are recorded in real time and two and three-dimensional images are produced after processing. These images are useful in locating fractures, identifying borehole breakout, delineating bed boundaries, studying formation textural features along the borehole wall, and evaluating casing integrity by revealing distortion, wear, holes, parting, and other anomalies on the inner wall of the casing. The full circumferential map acoustic impedance generated from the measurements is used to clearly distinguish between cement and fluids in the annular space behind casing. The cement evaluation is complete by using sonic (cement-bond log) providing cement quality inferred from the degree of acoustic coupling of the cement to the casing and to the formation. The CBL-VDL measurement is omnidirectional and thereby cannot detect the channels which are being identified through ultrasonic.

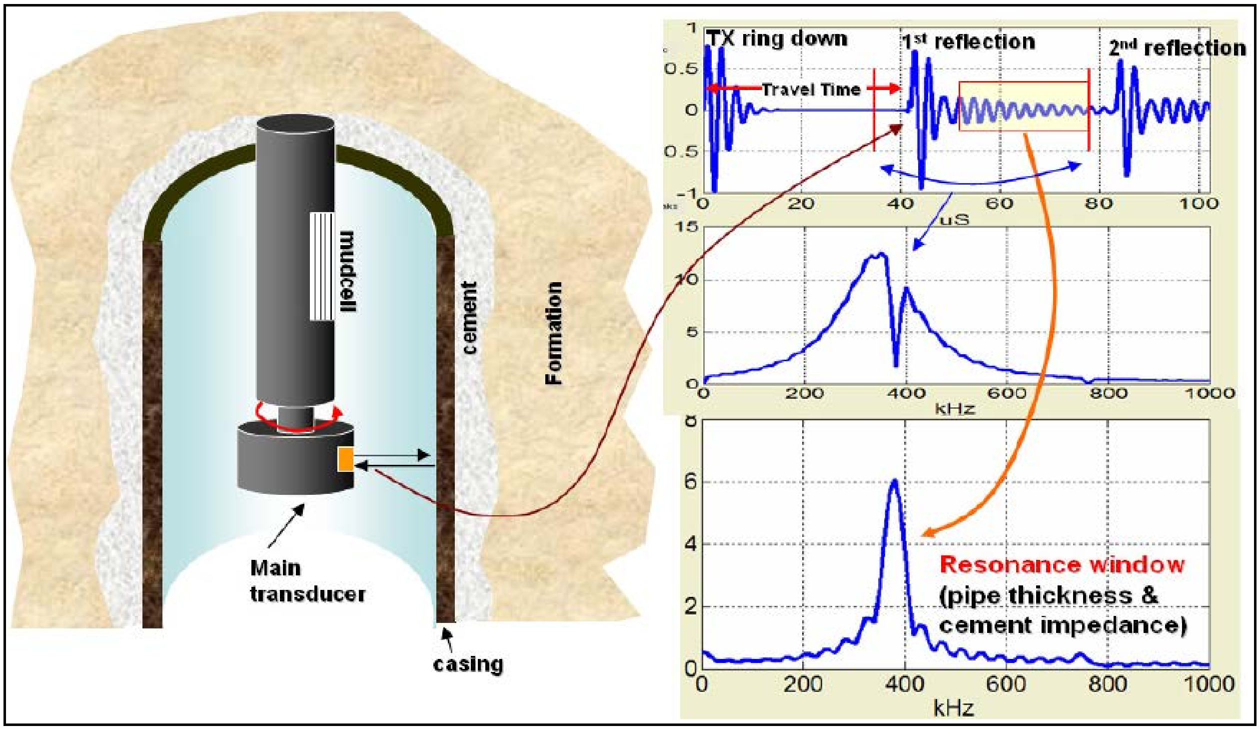

Figure 3. Basic Principle of Ultrasonic Measurement.

The basic principle of an ultrasonic tool is shown in Figure 3. An ultrasonic transducer acting as both transmitter and receiver located in the rotating head and positioned at a fixed distance from the bore hole wall, fires an ultrasonic signal that strike the wall of the borehole (casing or borehole wall). A complete rotation of the scanner head represents a scan. The number of shots per scan and vertical scans per foot can be programmed by the engineer to optimize the performance of the tool for any given condition. The tool sends a complete waveform of the main and mud cell transducers to the surface for recording and processing. The sample interval of the waveform and the length are also programmable. The peak amplitude of the first arrival waveform (first reflection) at the transducer is determined (amplitude), and the two-way travel time (TA) for the ultrasonic signal to travel from the transducer to the wall and back is determined as well. The peak amplitude measurement is used to form an acoustic image of the borehole wall, giving detailed textural characteristics of the wall. The travel time information is used to compute the diameter (acoustic caliper) and, hence, the shape of the borehole. In cased hole, the amplitude map is used to find minute deformations, perforating holes and other anomalies in the casing. The pipe inspection application uses the characteristics of the resonance window (amplitude sum) to evaluate the cement impedance directly related to the bonding of the pipe to the casing and borehole wall.

The only calibration required for the tool is the travel time calibration which is performed down hole to determine the velocity of the ultrasonic sound wave in the fluid medium. The tool must be run perfectly centralized with eccentricity <0.25 in order to obtain accurate log data. Failure to have the tool centralized can result in erroneous time and amplitude data which can affect impedance, thickness, and radius calculations as well. Another challenge is by heavy mud weight as the solids in the mud can seriously attenuate the ultrasonic signal such that the reflected waveform amplitude becomes very small. This problem is more pronounced in oil base mud. As such the upper limit for tool operation is 18 ppg for water based mud and 14 ppg for oil base mud.

B. Reservoir Monitoring Surveys

The reservoir monitoring surveys provide robust technique for reservoir surveillance to maximize and manage production from existing old fields. For several decades, Pulsed neutron tools are in use to estimate water saturation during well lifecycle. Two classic interpretation techniques are Sigma saturation analysis and Carbon/Oxygen saturation analysis. In Sigma mode, the tool measures the decay rate of capture gamma rays and this is quantified as a property known as “Sigma” which has a dimension of length-1. Thermal neutrons (low energies) are very susceptible to capture by chlorine. If there is a lot of chlorine present the neutron population is rapidly absorbed and the gamma activity rapidly decays. For low chlorine concentrations it takes longer for the neutrons to be absorbed and the gamma activity decays more slowly. In very saline formation water environments, the sigma measurement discriminates between water, oil, and gas as shown in Figure 4 (left). In C/O mode, the tool measures Carbon and Oxygen with water and hydrocarbons by directly looking for the Carbon in oil and Oxygen in water. The ratio of Carbon to Oxygen represents the amounts of water and oil, independent of water salinity. When the formation water salinity is low or varies as a result of flooding the C/O measurement leads to reservoir saturation analysis, especially for reservoirs with medium to high porosity. Higher C/O ratio signifies higher oil saturation Figure 4 (right).

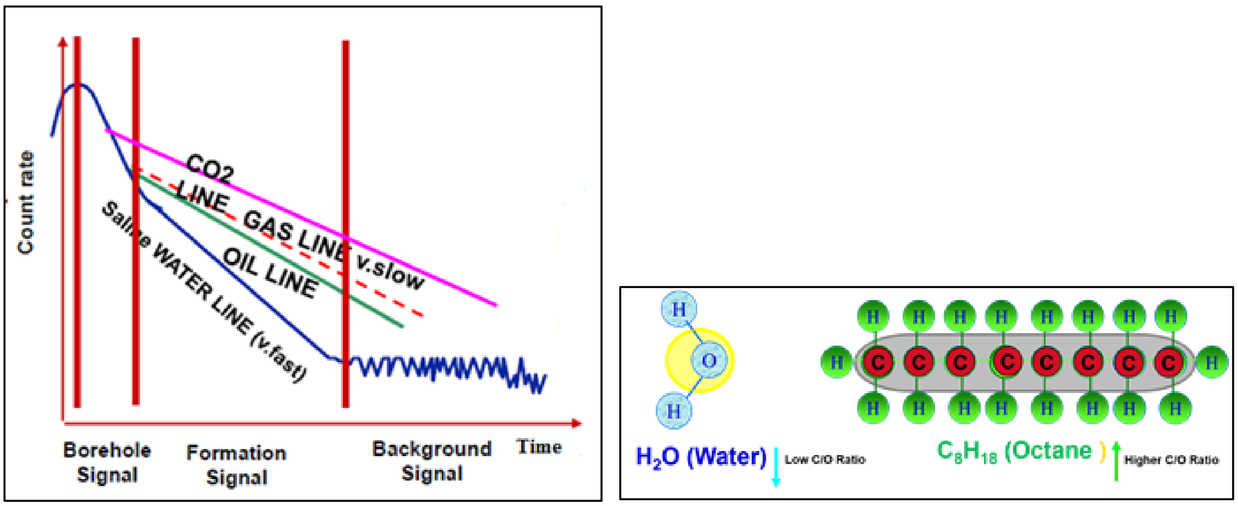

Figure 4: Decay curves in the Sigma mode (left), Carbon and Oxygen in C/O mode (right).

WELL EXAMPLE — A

In view of pressure buildup observed in annulus, the ultrasonic scanner in conjunction with CBL has been used for evaluating cement bond and pipe inspection in the well. The tool was run in 5.5-in. production casing. The casing is cemented with conventional cement and cement slurry density is 16-lb/gal. The cement-evaluation presentation includes casing ovality and tool eccentricity in Track 1. A gamma ray curve and a collar locator.is also presented in Track 1. Casing inner and outer radius is plotted in the 2rd track and casing minimum and maximum radius is represented in 3th track to study the pipe inspection (Figure 5). Major damage due to heavy corrosion is seen in the casing at most of the places in the logged interval. An increase in casing maximum radius (up to 2.7”) is observed along with dark color in amplitude vector image against the damaged casing which is presented in 4th track. Overall, casing is in very poor condition in this well due to heavy corrosion. The Snapshots of tubing pulled out during workover operations clearly shows the heavy damage due to corrosion (Figure 2).

In view of poor casing integrity which makes further testing and completion difficult and risky, the well was abandoned after placing a proper plug.

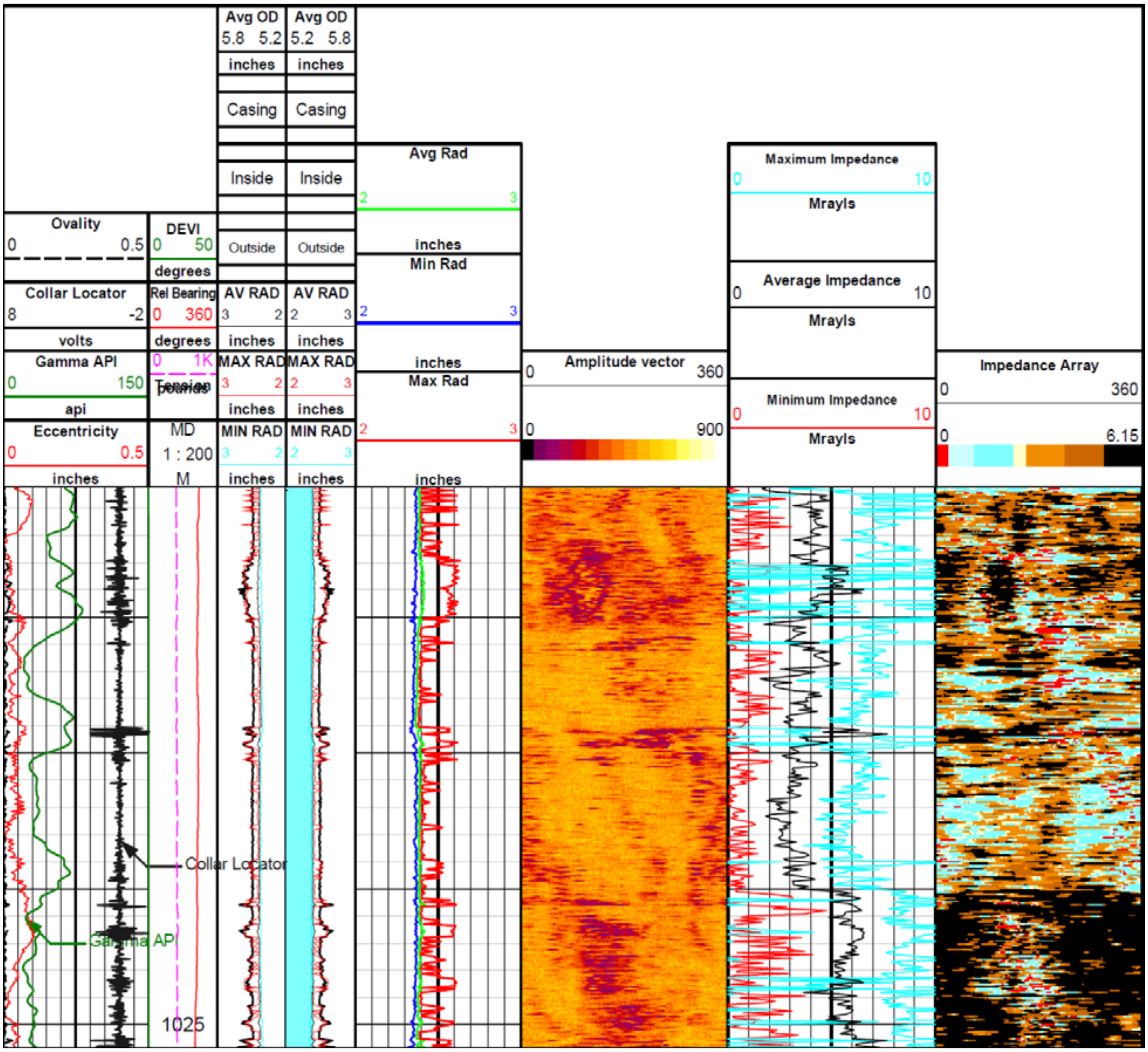

Figure. 5 Ultrasonic scanner log showing casing damage due to corrosion.

WELL EXAMPLE – B

The ultrasonic scanner has been used for evaluating cement bond and casing inspection. A typical log run in 7-in. production casing is shown in Figure 6. The casing integrity was found perfectly OK with good cement bond providing isolation between zone of interests.

The reservoir monitoring survey was carried out in well B in both C/O and Sigma mode spanning a wet sand. The clean water bearing sand in has been used for calibration purpose. The integrated analysis of Sigma, and Carbon/oxygen ratio data shows that present completion is watered out and sands above this completion are gas bearing (Figure 7 and 8). Zone transfer was carried out and well was brought back on production.

WELL EXAMPLE – C

The Well C was completed in Pariwar sand in the year 2007. On testing well produced gas @ 64,000 m3/d through 5 mm bean with FTHP-2300 psi and STHP-2400 psi. Gas leak was observed in 9- 5/8” and 5- ½” casing annulus with pressure buildup to 1700 psi. A number of workover jobs were carried out to repair the well, but due to annulus pressure build up again, the well was not brought into production and was killed. Recently, it was decided to assess the reasons for annulus pressure buildup and take necessary remedial actions accordingly.

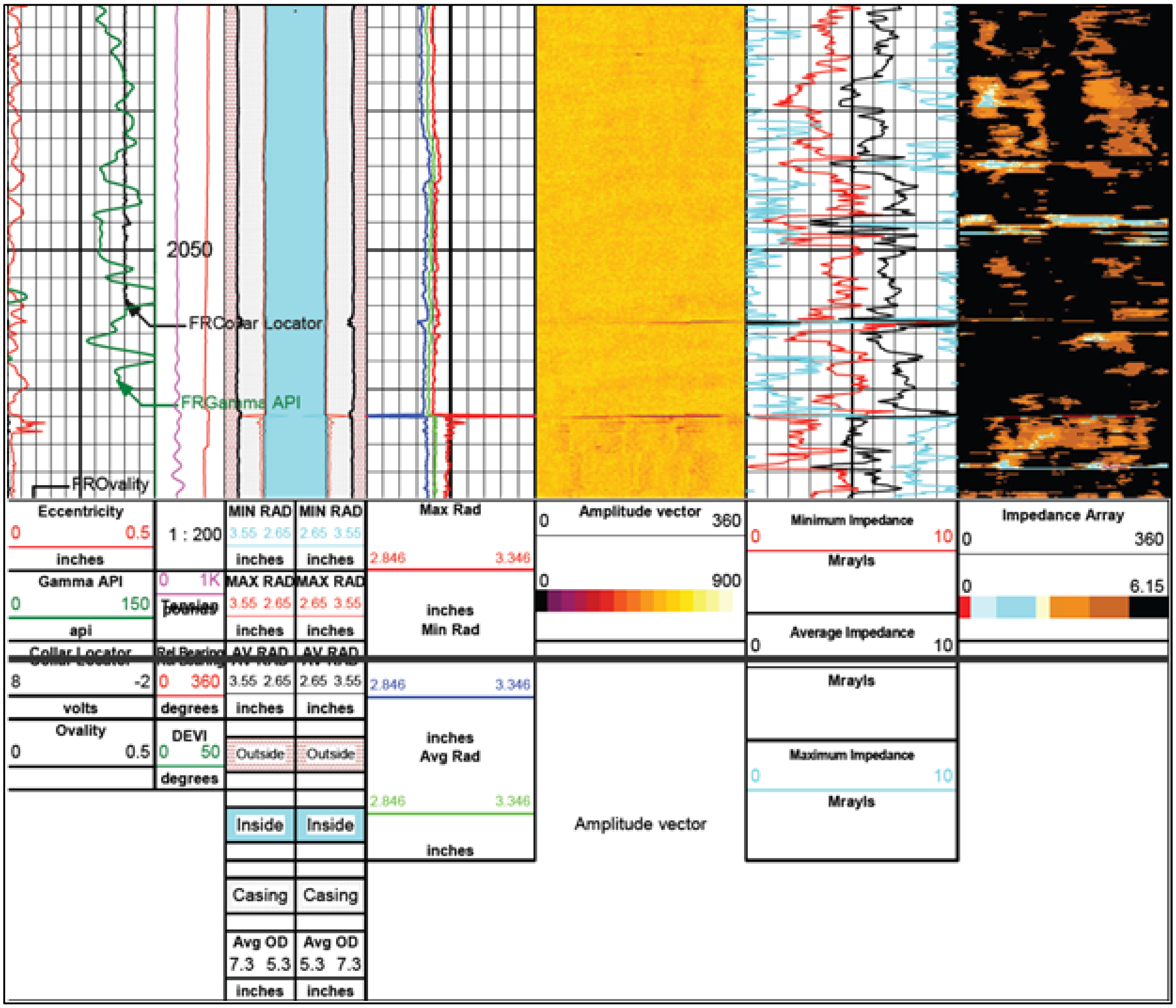

Figure. 6 Ultrasonic scanner log showing production casing and cement bond in good condition (Well B).

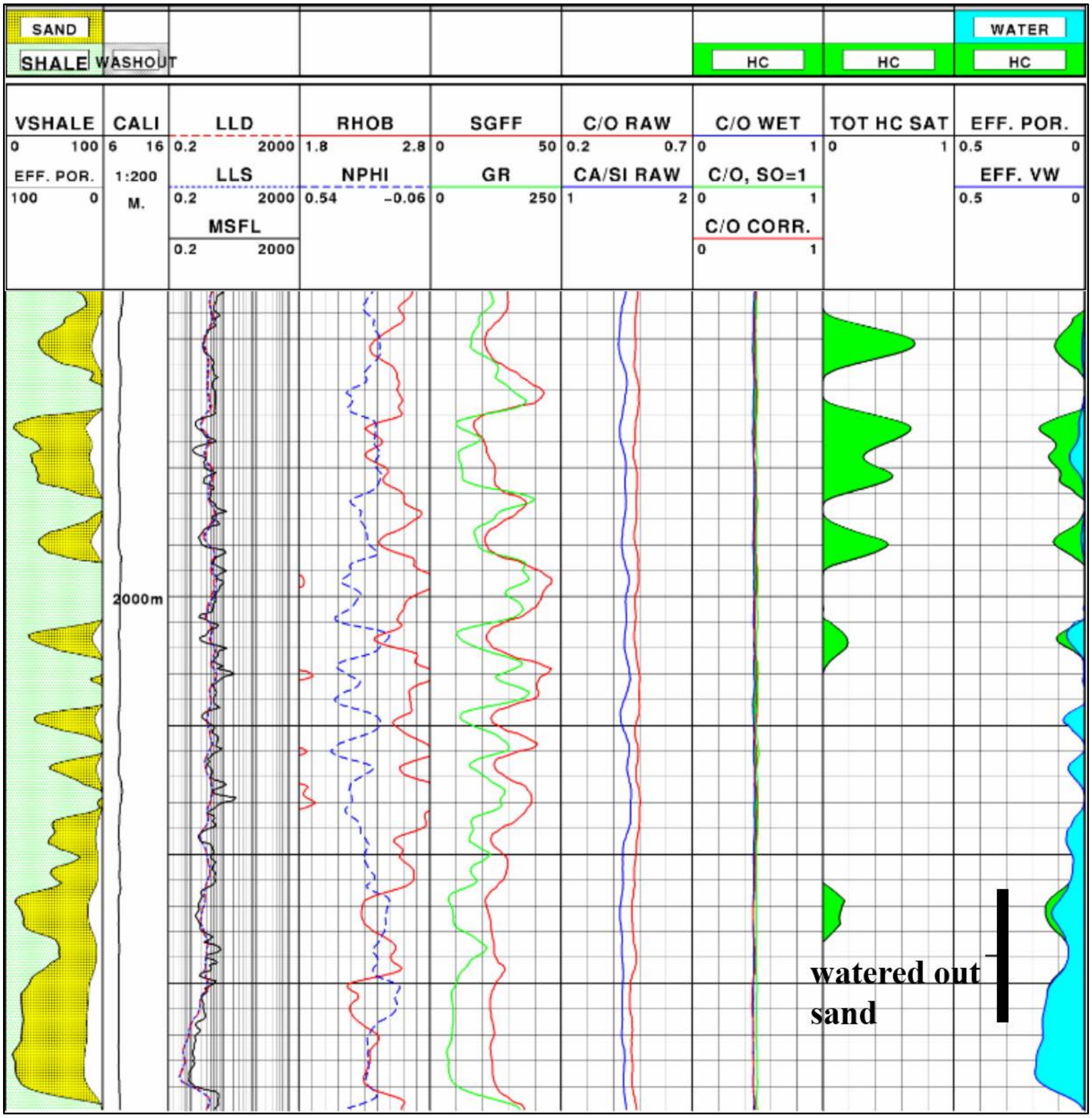

Figure 7. C/O mode in Well B showing lower most completed sand as watered out.

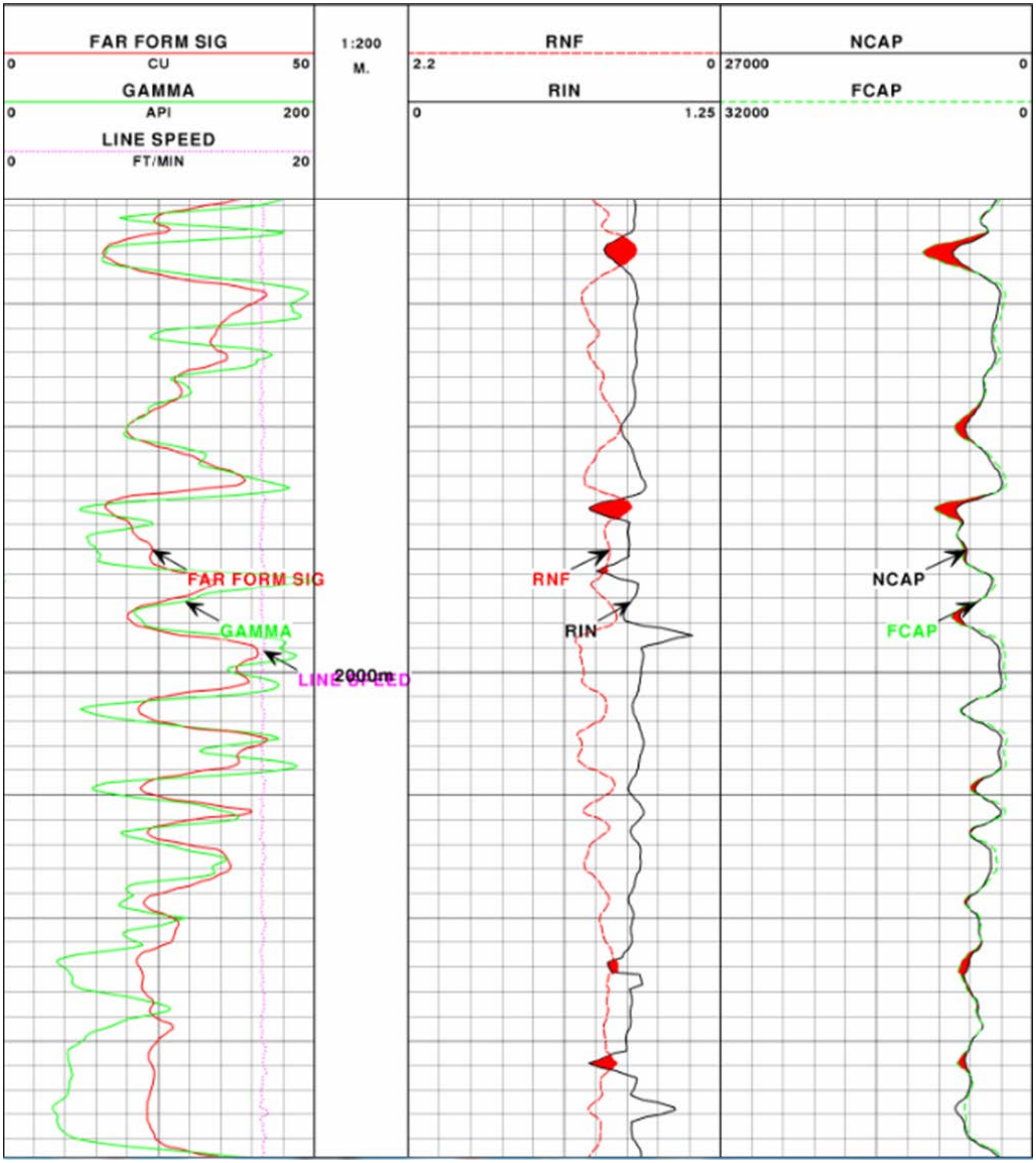

Figure 8. Sigma mode in Well B showing lower most completed sand as watered out.

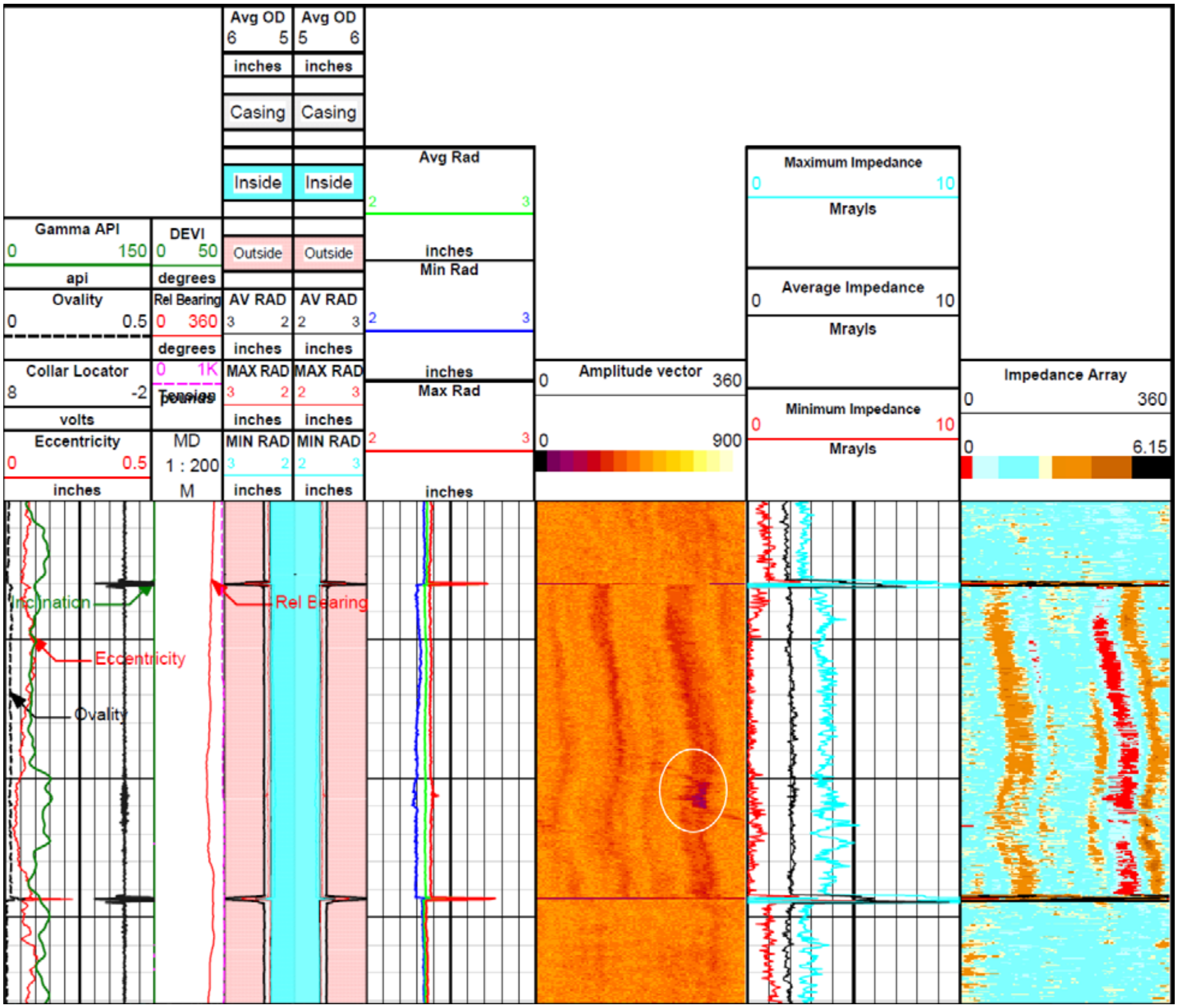

Figure. 9 Ultrasonic scanner log showing minor casing damage (white circle) and very poor cement bond with casing in well C.

The ultrasonic scanner has been used for evaluating cement bond and production casing. The casing is cemented with conventional cement and cement slurry density of 16.7-lb/gal. Casing Inspection log shows variation in inner diameter of casing at places. It is likely that different types of 5.5" casing have been used. There is casing damage seen at few places (Figure 9), being suspected for gas leak causing annular pressure buildup between 5-½" and 9-$^{5}/_{8}$" casings. The following remedial actions were taken:

- The casing head housing was tested up to 2000 psi and observed leakage. Ensured all safety precautions and welded the leaky casing head housing with 9.5/8" casing. Tested the same up to 2500 psi - no leakage observed.
- Lowered tubing and put hi-viscosity pills followed by a cement plug in selected depth intervals and squeezed cement slurry at around 1500-1700 psi.
- R/down WF Spool and replaced rubber seal of SSA, ring joint gasket and secondary seal of WF Spool.

Finally, 5-1/2" casing integrity was found OK with pressure testing. The well got activated and flowing through 6 mm bin at the rate of 65,000 SCMD with FTHP = 132 kg/cm2.

CONCLUSIONS

The log results acquired by the CBL/Ultrasonic scanner and reservoir monitoring tools helped the OIL well engineering and reservoir personnel to identify the damage in production casing, evaluation of cement job and current gas saturation respectively. Accordingly wells were completed by zone transfer isolating watered out sands. Successful workover jobs were carried out to mitigate the annulus pressure and subsequently bring back the wells on production. One well was abandoned based on the damage seen on production casing.

Aged well intervention and post-production well abandonment will greatly benefit from using combination of this well integrity diagnostics and reservoir monitoring services, enhancing capability to inspect casing and gas saturation behind pipe.

ACKNOWLEDGMENT

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