PaperID **AU284**

Author **TUSHAR KANTI MAHATO , ONGC , India**

Co-Authors **RBN Singh, RS Rarh, NK Punjrath**

Fracture characterization using different Acoustic based methods for optimal production: A case study in Vindhyan Basin

Abstract

In low porosity hard rock environment, open natural fractures provide conduit for gas. Fracture characterization plays a very significant role for well productivity and reservoir management. Borehole fractures can be either of natural in origin or induced by drilling process. Therefore a complete understanding of fracture attribute, aperture and permeability is required for well designing, cementing and reservoir modelling. Preferably electrical Image tools are being used for characterizing near well bore attributes in higher resolution. Acoustic based fracture detection method can be used both as complementary to image log and independently where image logs are not available. In cross dipole sonic tool different types of sonic waves (compressional, shear and stoneley) are recorded over different time interval and frequencies. Each wave interacts differently with fractures and have their individual constraints as well. Different acoustic methods are applied and analyzed on the logs acquired in wells drilled in Vindhyan Basin. Presence of gas in carbonate reservoirs coming from fractures has already been established. Therefore it becomes of utmost important to analyze these fractures in terms of acoustic based methods and compare it with non-acoustic methods. Also comparing all the fracture detection techniques, zones can be prioritized before taking up for testing.

Introduction

Understanding natural and drilling induced fractures is essential for well stability and maximizing production. Open fractures act as conduits for production, while closed fractures add complexity to stimulated fracture networks. Closed fractures may be critically stressed and likely to reopen by suitable well design and proper completion techniques. Drilling induced fractures help to understand what measures to taken for providing wellbore stability and to calibrate geomechanical models. In order to identify and characterize fractures, micro-image log is preferable, which can identify and locate near-wellbore fractures within few inches. Micro-image logs can differentiate between resistive and conductive fractures, as well as determine the dip, strike, azimuth, and aperture. Sonic methods lack the vertical resolution of micro-images but in the right environments, can identify and distinguish not only open fractures and closed fractures but also calculate stress concentrations that will likely fracture the formation when further stress is applied. Following acoustic methods are used for fracture characterization.

i. Stoneley reflection analysis
ii. Anisotropy analysis
iii. Common receiver and transmitter gather

Stoneley reflection Analysis

The Stoneley signal is strongly effected by any change along the borehole wall, such as fractures, borehole breakouts, bed-boundaries etc. Stoneley wave being of low frequency, is dispersive in nature as a result its energy decreases radially away from the borehole-formation interface. In the presence of open fractures intersecting the borehole, the Stoneley wave will attenuate and also generate a reflected wave from the discontinuity between the fracture and borehole wall. The Stoneley wave fracture response depends on the fracture being open and its extension in the formation. The move-out of reflected signal or secondary signal due to open fracture, borehole washouts or bed-boundary create “chevron patterns” (Figure-1).

To counter for the similar effect due to borehole washouts and bed-boundary, caliper and gamma ray log should be presented. In order derive fracture information from raw monopole data following processing steps are carried out and displayed in figure 1 & 2.

i. Low frequency filter applied to monopole data to extract Stoneley arrivals (Track-2)
ii. Extracted direct waves (Track-3) and secondary waves (Track-4) from total signal
iii. Located secondary source locations (Figure-2)
iv. Compared secondary source locations with borehole imagery to distinguish fractures from other sources (Track-5 & 6).

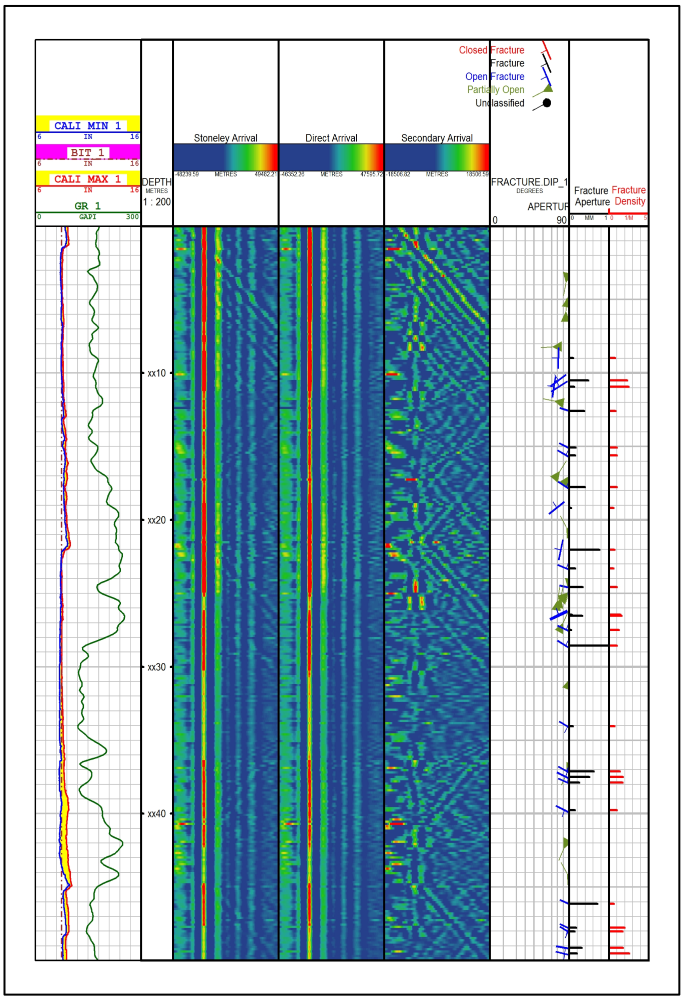

Figure 1. Direct and reflected waveform from stoneley waveform data) along with fractures picked from micro image log. Fracture density and aperture plotted in last track.

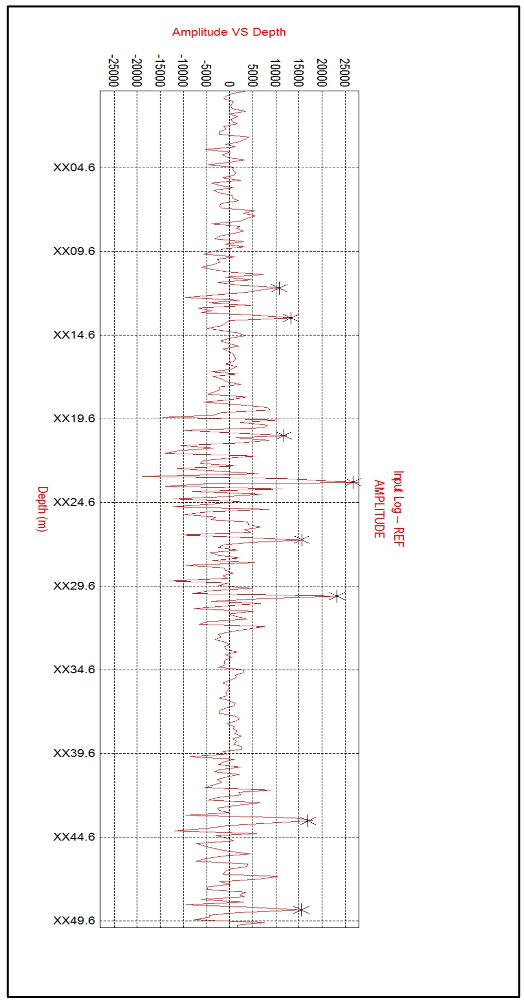

Figure 2 Stoneley amplitude curve showing good correlation with fractures

Example depicted in figure-1 partial and open fractures are visible at dips of 70-88 degrees. Also gamma ray log and caliper logs have been plotted to distinguish chevron patterns due to open fractures. Amplitude log of the reflected stoneley have been plotted in figure-2. The peaks in the amplitude log corresponds to fracture density and aperture. This amplitude log can be used as a good indicator for representation fracture opening.

Anisotropy analysis

Cross dipole acoustic tool carries out directional shear measurement by transmitting and receiving flexural waves along the borehole. The tool consists of two sets of dipole transmitter-receiver systems facing 90 degrees apart that measure azimuthal shear wave anisotropy in two vertical planes that are parallel to the borehole axis. A formation's anisotropy is assumed to have two orthogonal principal directions. The magnitude of the anisotropy is measured from the difference of fast and slow shear waves that travel along these principal directions. During cross dipole logging in anisotropic formation, the borehole flexural wave motion induced by a source transmitter split into fast and slow waves, which are received by in-line (XX-YY axis) and cross-line (XY-YX axis) receiver arrays on the tool which are processed to provide the azimuth and magnitude of the anisotropy.

In terms of fracture characterization, azimuthal shear anisotropy is most useful when the angle between the wellbore and fracture is low. In the presence of such fractures, shear waves split so that the fast shear is aligned with the maximum stress direction (fracture strike). If the anisotropy is due to unbalanced stresses, it is important to understand whether the anisotropy is responding to the natural (far-field) stress or to near-wellbore induced stress.

Borehole wall failures magnify near well bore anisotropy disturbing mechanical stresses in the region of failure. In figure-3 from the caliper log it can be seen that there is no enlargement of hole size, still considerable amount of anisotropy is visible. Combining this with fractures picked from image log it can easily be interpreted that the anisotropy is due to natural fractures. Whereas in figure-4 significant amount of anisotropy has developed due to borehole washouts which is evident from the caliper logs as well as breakouts picked from resistivity image log. Here SHmax orientation can be determined from fast shear azimuth data. In figure-4 SHmax is in NW-SE direction. From resistivity image log data it is seen breakouts are in NE-SW direction which is the orientation of Shmin.

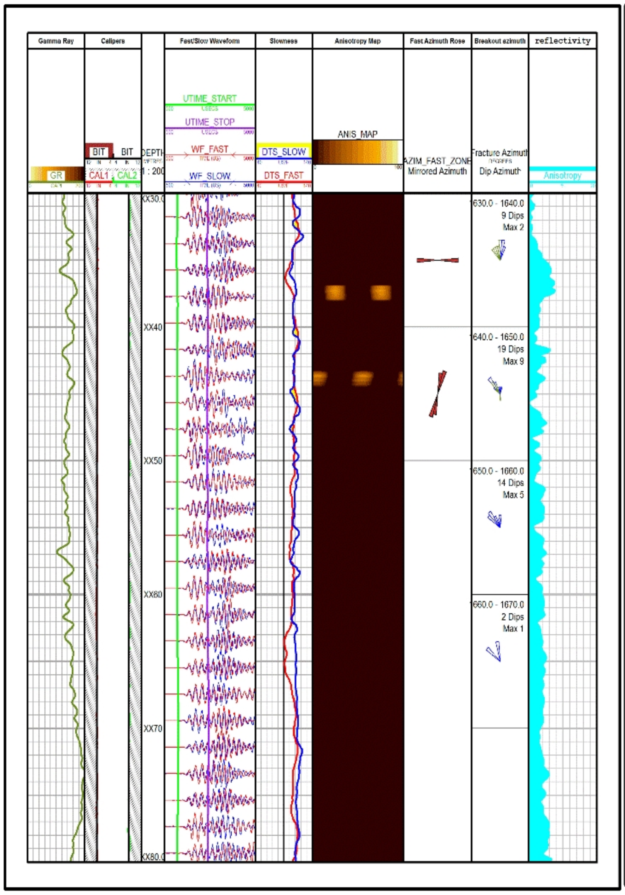

Figure 3 Anisotropy due to natural fractures

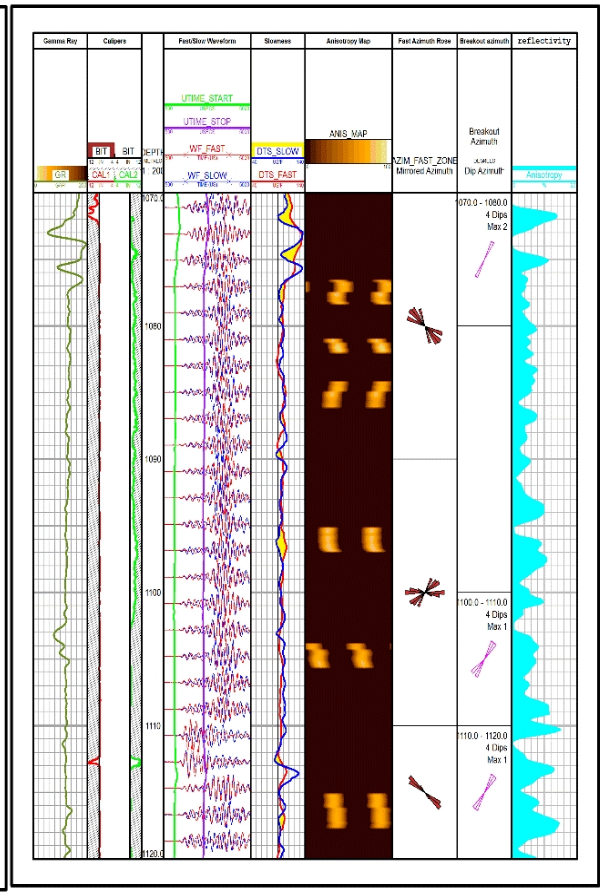

Figure 4 Anisotropy due to breakouts

Also slowness-frequency dispersion analysis provides a methodology to distinguish whether the anisotropy is due to intrinsic fracture or induced fracture. In case of induced fracture there is a cross over in the dispersion curves of slow and fast shear waveforms. This is due to reversal of horizontal stresses for near well bore and far well bore conditions. For natural fractures, both the dispersion curves stay parallel to each other. But for this analysis data should be recorded over full frequency range.

Common transmitter and receiver gather

Flexural waveform data can be processed for semblance analysis using both common transmitter and receiver gather. In presence of fractures, derived shear slowness from transmitter/ receiver array data show “S” pattern.

Interpretation of field data

Well A drilled in Vindhyan basin have been studied using the above mentioned acoustic methodologies. In figure-5 along with the conventional wireline logs in first three tracks, dynamic image log and fractures picked from it are plotted in track-5 and track-6. Reflected waveform from recorded Stoneley waveform data is plotted in track-7. Stoneley waveform data is filtered using low pass filter of 0-1 KHz and 1-2 KHz. For both the waveforms two different reflectivity curves are generated. The waveform filtered using lower frequency investigates deeper into the formation and generate stronger reflection. Therefore the difference of these two reflectivity curves is a good indicator of conductivity and mobility in the fractured interval. (Track-8). Along with this anisotropy data is plotted to aid the fracture interpretation. In track-9 shear slowness derived from semblance analysis of common receiver (brown) and common transmitter (blue) gather is shown. In track-10 gas shows during drilling from mud log data is plotted.

The interval shown in figure is a shale dominated part with thin limestone streaks in between which can be seen from the Multimin Analysis. In the processed dynamic image log number of open (blue) and partially open (green) fractures can be seen. From the resistivity image it can be seen there are mainly three fractured zones from XX22-XX36 m, XX41-XX48 m and XX54-XX60 m. Dip of the fractures varies from 60-88 degrees where dominant strike direction is NW-SE.

Between interval XX22-XX36m and XX41-XX48 m it can be seen the reflected waveform is showing stronger reflection. Also both the low and high frequency reflectivity curves showing higher values. Since no borehole breakouts is observed in the intervals, stoneley reflections can be correlated with the natural fractures. Also stronger reflections suggest fracture aperture in the interval is good. Also due to presence of fractures, anisotropy of around 8 percent can be seen. For shear slowness from common receiver and transmitter gather characteristic “S” pattern is visible. In both the intervals gas has been observed during drilling with TG max of 0.5 percent.

Whereas in the interval from XX54-XX60 m, number of open fractures can be seen but reflectivity data is showing weaker response. Although anisotropy of 5 percent can be seen, it can be concluded that fracture aperture is less compared to the shallower zones. Table 1 depicts how these acoustic based techniques complement resistivity based fracture detection methods. Also the three zones are prioritized based on the mentioned techniques.

Interval (m)	**Max fracture density from micro resistivity log (1/m)**	**Max fracture Aperture from micro resistivity log (mm)**	**Stoneley reflectivity (0-1 KHz)**	**Stoneley reflectivity (1-2 KHz)**	**Anisotropy in Percentage**	**Priority**
XX22-XX36	5	7	0.483	0.480	6.21	high
XX41-XX48	6	5.5	0.408	0.333	6.08	medium
XX54-XX60	5	0.18	0.205	0.127	4.8	low

Table 1. Prioritization of zones to be tested on basis of resistivity based micro image log and acoustic based fracture detection techniques

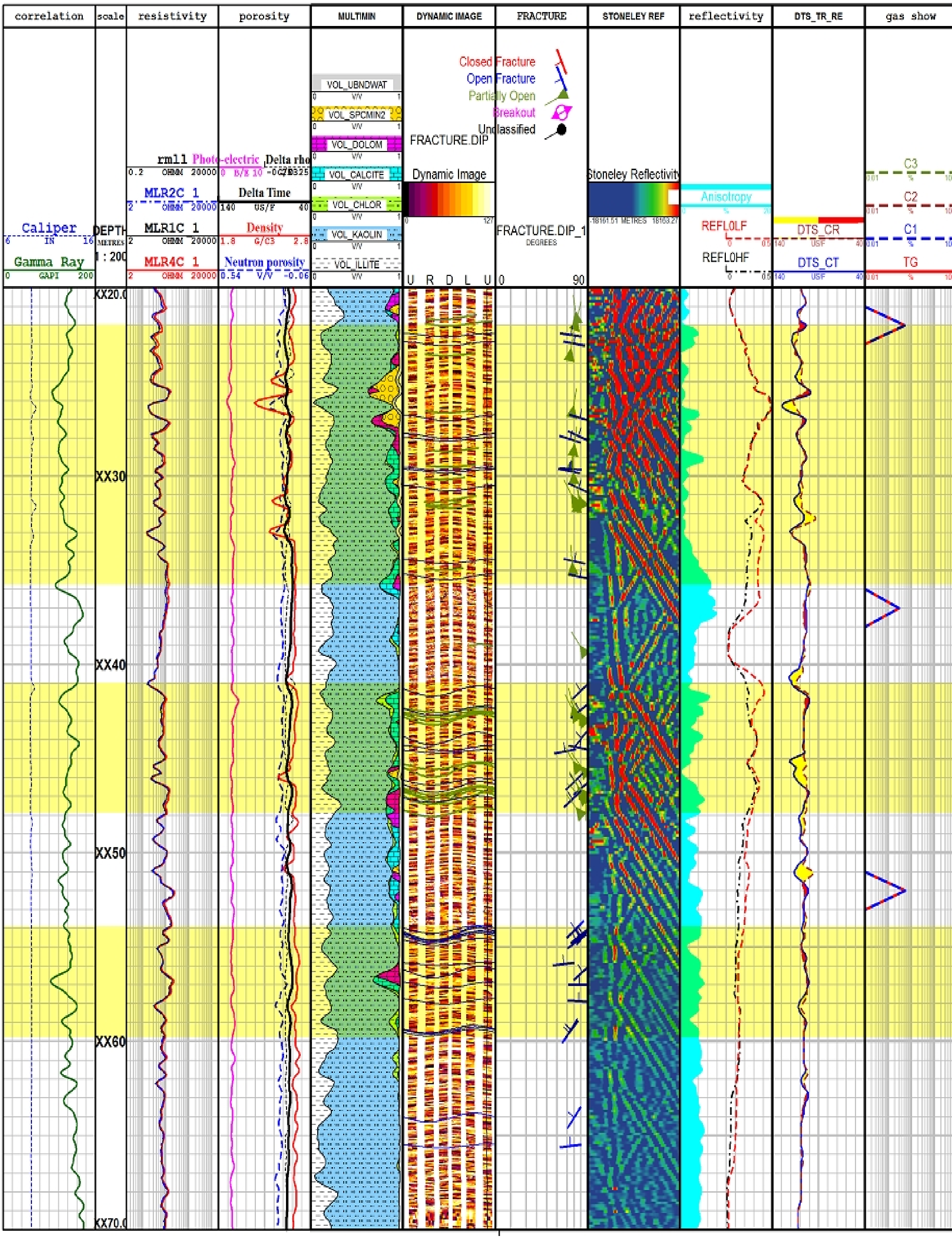

Figure 5 Acoustic processing results correlated to interpreted fractures from resistivity image log in Well A

Conclusions

Cross dipole acoustic data provides us different types of waveform data over varied frequency range. Acoustic data in amalgamation with resistivity image logs were used for proper fracture characterization. Each borehole acoustic methods has its own strengths and weaknesses. Although it cannot provide high resolution fracture interpretation like micro image log but it can read deeper depth of investigation. This study guides us for selection of suitable zones for testing. On the basis of above interpretation, the zones are prioritized, which will act as a guide to select best zones for optimal production. From stoneley reflectivity and attenuation data fracture conductivity can be calculated, which will provide us an estimation of productivity of the fractured reservoir. Also by recording shear wave data over long time interval, through deep shear imaging, interval up to 50 feet deep inside the formation can be visualized.

Acknowledgement

The authors sincerely acknowledge the data and facilities provided by ONGC Ltd. for the preparation of this paper. The views expressed in this paper are of the authors only, and not necessarily of the organization to which they belong.

References

Canady, W. and Market, J. 2008. Fracture Characterisation by Borehole Logging Methods. Presented at the 49th SPWLA Annual logging Symposium, Austin, Texas, USA, May 25-28. SPWLA-2008-AAA.

Hornby, B.E., Johnson, D.L., Winkler, K.W. et al. 1989. Fracture Evaluation using reflected Stoneley-wave arrivals, Geophysics 54 (10): 1274-1278.

Hornby, B.E. and Luthi, S., 1992, An integrated interpretation of fracture apertures computed from electrical borehole scans and reflected Stoneley arrivals. Geological Applications of Wireline Logs II, Geological Society Special Publication, No. 65, pp. 185-198.

Market, J., Ramos, L., Harris, N., Suarez, C. et al. Acoustic Fracture Characterisation – Intelligent Interpretation. Presented at 58th SPWLA Annual Logging Symposium, Oklahoma City, Oklahoma, USA, June 17-21, 2017

Patterson, D., Skjoong, G., and Wade, J.M., Horizontal Stress Orientation Analysis using the Cross-Dipole Acoustic log in the ELDFISK field. Presented at 40th SPWLA Annual Logging Symposium. May 30-June 3, 1999

Plona, T., Sinha, B., Kane, M.R., Shenoy, R., Bose, S., Walsh, J., Endo, T., Ikegami, T., and Skelton, O., 2002, Mechanical damage detection and anisotropy evaluation using dipole sonic dispersion analysis, Paper F, Proceedings of 43th SPWLA Symposium ’02.

Tamoto, H., Rossi, T., Fouraux, M. et al. Identification of Stresses on Near-Borehole field Using Cross-Dipole Sonic Tool and Image Logs: Case Study in Deepwater Carbonate. Presented in Offshore Technology Conference, Rio de Janerio, Brazil, 24-26th October 2017