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# EMAT (Electromagnetic-Acoustic Transducers) Technology, a Solution for Cement Evaluation in Difficult Logging Environments

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## ABSTRACT

The interpretation of cement evaluation logs in difficult logging environments, such as lightweight foam cement, micro-annulus environment, extremely heavy mud, thick casing, large casing, air filled well, is a very challenging and critical task. Any misinterpretation may lead to well integrity issues and costly consequences. The conventional technologies, which use compressional acoustic wave measurements, have shown limitations in such difficult environments, because of the measurements dependency on the environment. The ElectroMagnetic–Acoustic Transducers (EMAT) technology, a new cement evaluation technology relatively unaffected by cement density, mud weight, casing size, and casing thickness, has shown a high performance in such difficult logging environments.

## EXTENDED ABSTRACT

Cement bond quality is crucial for well integrity and zonal isolation. Any misinterpretation of cement evaluation logs may lead to very costly consequences. Unfortunately the conventional sonic and ultrasonic cement evaluation tools have limitations in some challenging environments. In this document we introduce the ElectroMagnetic–Acoustic Transducers (EMAT) technology, the latest cement evaluation technology, and demonstrate with real log examples its strength in several difficult downhole environments.

### Present-day Cement Evaluation Challenges

Currently most of the oil and gas operators drill deeper and deviated wells with complex wellbore geometry and completion systems. Cementing these wells requires non-conventional cement systems, such as lightweight foam cement, to avoid or reduce any potential cement losses into the formations. Other challenging factors are the difficult logging environments encountered when evaluating cement behind casing, such as: extremely heavy mud, thick casing, large casing, and the presence of a micro-annulus. The deeper the well, the higher the formation pressure. Consequently, heavier muds and thicker casings are required. To maintain zonal isolation of the producing formations, a strong but light weight (low density) cement is needed, as the regular weight cement requires higher pumping pressures that may damage the formation. Large casing in surface or intermediate depths is usually needed to have the production liner or casing at the production formations with effective production size. Unlike the oil and gas production wells, the gas storage wells are drilled and completed with air or gas phase fluid instead of a liquid mud. Cement bond evaluation of such wells requires an adequate technology that can perform in non-liquid environments. The conventional cement bond evaluation technologies can not perfom in such environment, whereas the ElectroMagnetic–Acoustic Transducers (EMAT) technology can.

**EMAT Technology: Theory and Methodology**

EMAT transducers consist of a transmitter coil, a magnet and a conductive casing. The coil and the permanent magnet, coupled to the casing, generate acoustic waves in the conductive casing. As the casing is part of the transducer, the generation and measurement of acoustic waves directly in the casing eliminate the need for a coupling liquid. This makes also the measurements relatively unaffected by the mud weight, the casing size and the casing thickness. The transducer type and the arrangement of the different transducer components enable the generation of various guided wave modes, notably flexural and shear waves. The flexural modes particle displacement is normal to the casing surface, while the shear modes particle displacement is perpendicular to the fluxureal modes particle displacement, or paralel to the casing surface, as illustrated in Figure 1.

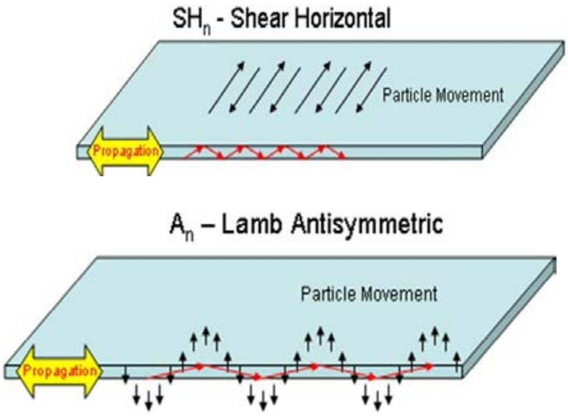


*Figure 1 – Shear and Flexural wave propagation in a plate.*

The shear modes are guided shear waves propagating inside the casing. The propagating waves exhibit signal leakage at the interface between casing and the surrounding medium. The measured propagating waves attenuation along the casing circumference is a function of the medium shear modulus, making the measurements unaffected by the weight of the medium behind casing. When this medium is a liquid, the attenuation is very low, approaching zero db/ft. When the medium is a solid material, the signal attenuation is high and proportional to the solid strength. This signal attenuation property allows indentifying the solids strength and also their mechanical properties such as Young’s modulus and Poisson’s ratio. Figure 2 shows that the shear waves attenuation varies uniformly across the range of cement velocity (direct correlation to cement shear modulus). SH0 is the shear low frequency mode wave and SH1 is the shear high frequency mode wave. SH1 attenuation is about three times higher than SH0 attenuation. Figure 2 also shows the varying response of flexural mode (A0) attenuation, which is more complex and occurs over a limited range of the cement shear modulus. A0 attenuation in slower cement (with its compressional and shear leakage) is fairly uniform, then rapidly changes in the proximity of the critical evanescense point, and quickly drops off in fast cement. The combination of shear and flexural mode measurements allows EMAT technology to detect the presence of any micro-annulus. The huge difference in sensitivity to a microannulus between the two types of measurements enables detection of microannuli in one single pass.

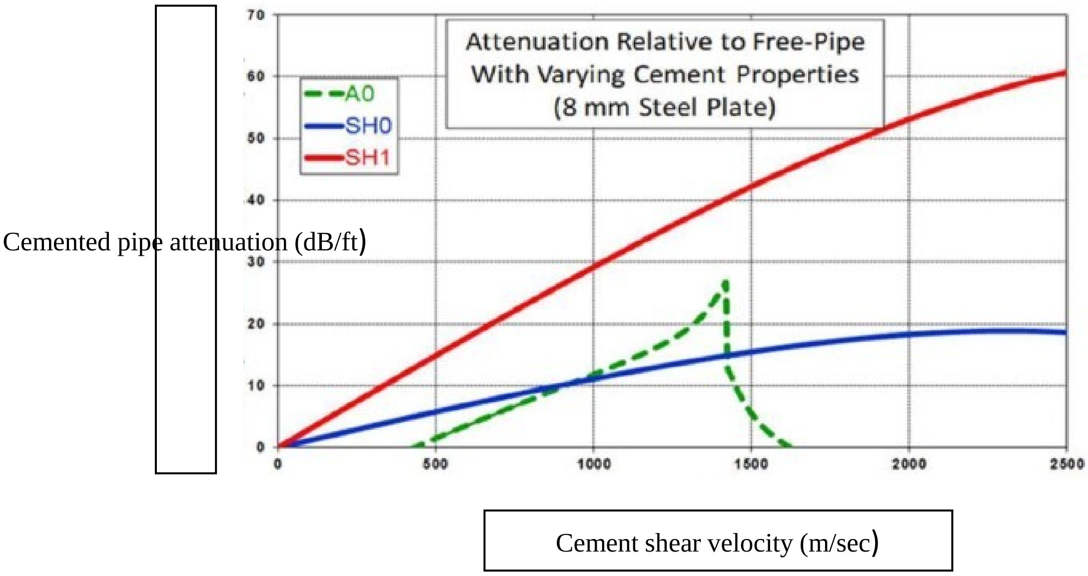


*Figure 2 – Relative attenuation (to free pipe) of different guided wave modes with varying cement velocity on an 8 mm thick steel plate. The cement has 1.8 g/cc density with 0.3 Poisson's ratio.*

## Log Examples

### 1. Light Cement Environment

As the EMAT measurements respond primarily to the shear modulus of the material behind casing, its measurement is unaffected by the low density cement. In other words, the EMAT technology based

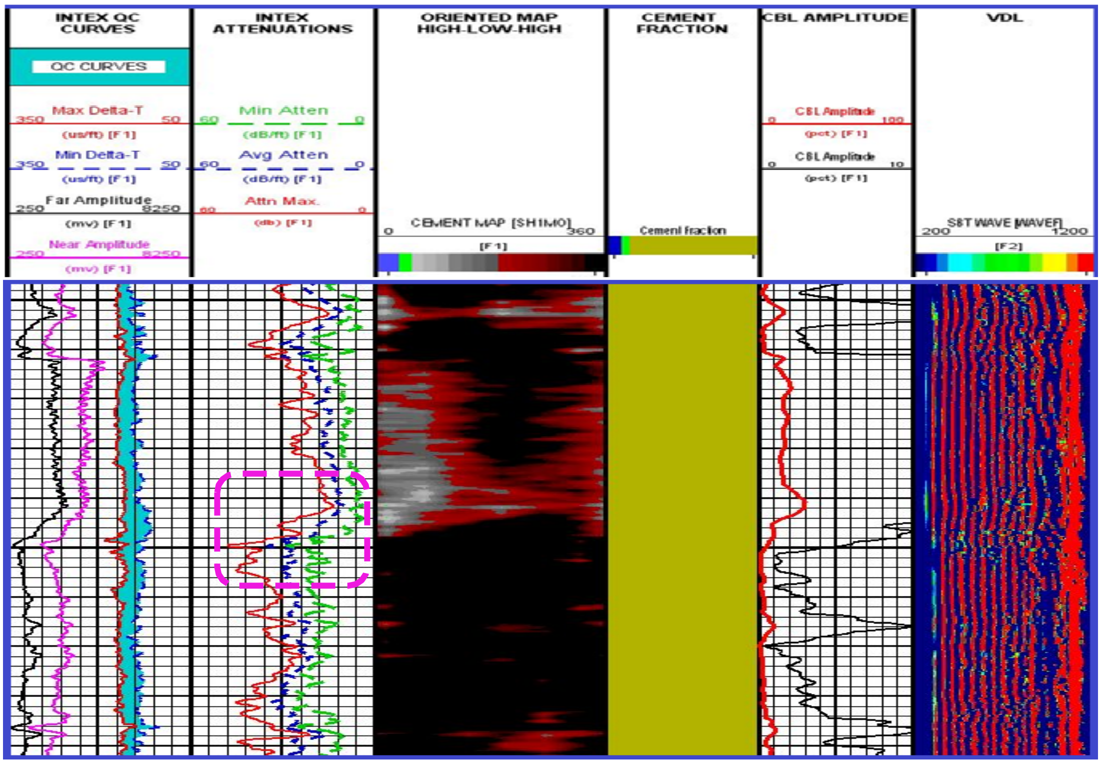


*Figure 3 – Example of EMAT based cement bond evaluation log of light weight cement. The contrast of the average attenuation is high, 16 dB/ft for 8.5 ppg cement.*

cement evaluation tools can easily distinguish between low density cements and liquids behind casing. Figure 3, shown above, contains a log example in low density cement environment (8.5 ppg cement). The log shows very high attenuation range, allowing easy and accurate interpretation of the data.

## 2. Heavy Mud and Large Casing Environments

Acoustic signals are significantly attenuated when traversing heavy muds toward casing wall. This attenuation gets worse in large casings. This is a very challenging environment for scanner types cement evaluation devices and conventional cement bond log (CBL) tools. EMAT cement bond evaluation tools have transducers in direct contact with the casing, making the measurements unaffected by any heavy mud and/or large casing environments. In Figure 4 below we see an example of EMAT tool response in extremely heavy mud (19.8 ppg). Figure 5 shows the log response in 13 3/8" casing. In both cases the logs show high dynamic range data.

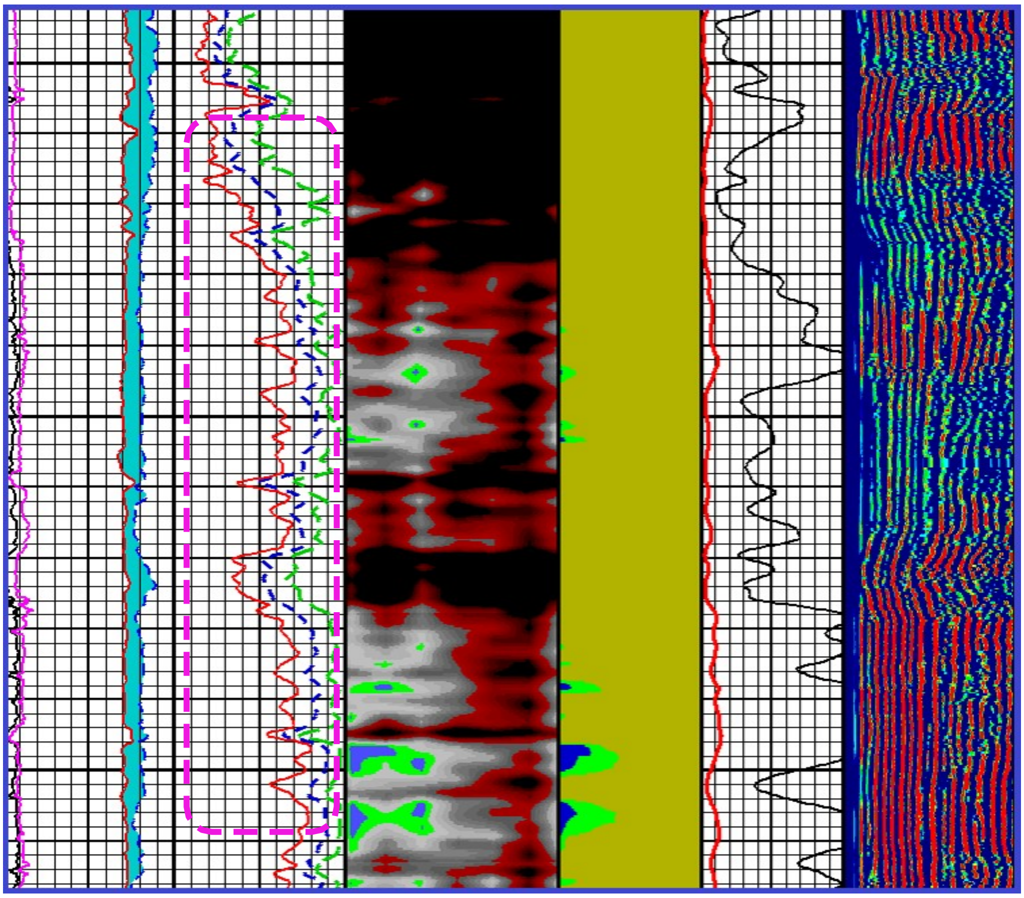

*Figure 4 – Example of EMAT based cement bond evaluation log in heavy weight 19.8 ppg mud environment. The contrast of the average attenuation is high, 30 dB/ft.*

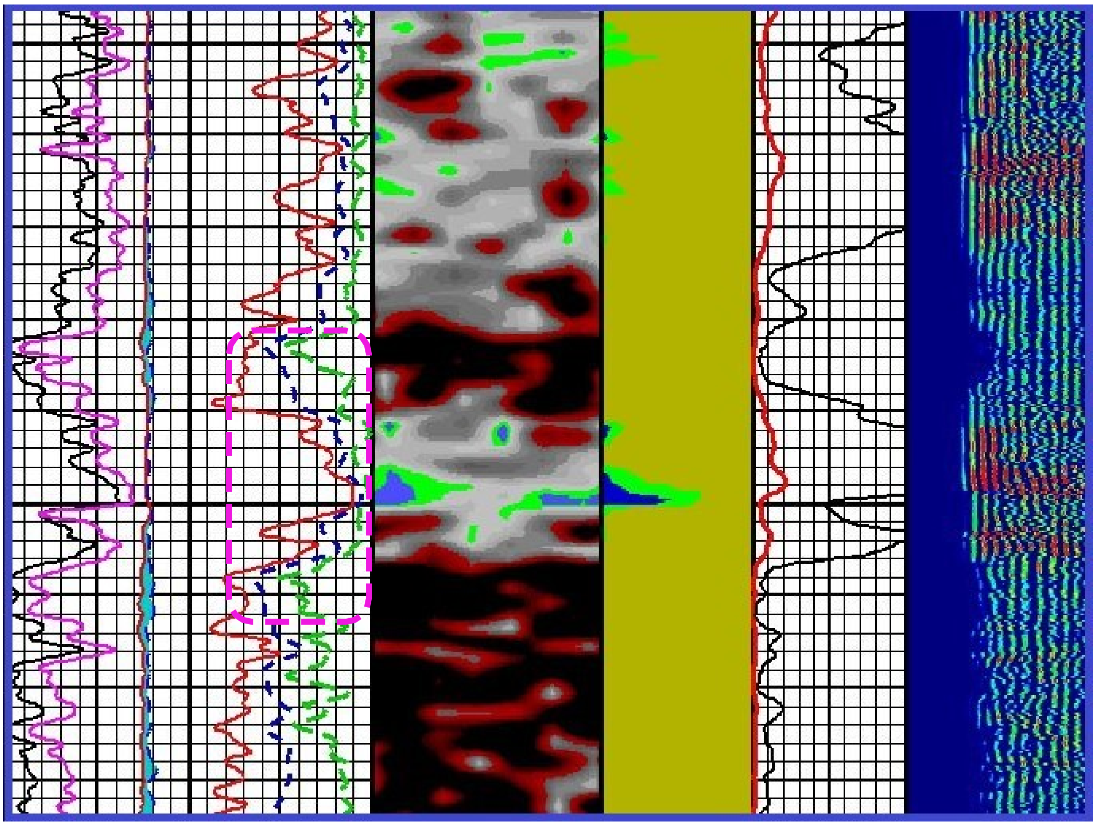

*Figure 5 – Example of EMAT based cement bond evaluation log in 13.375" OD casing. The contrast of the average attenuation is high, 18 dB/ft.*

## 3. Thick Casing Environment

Casing thickness reduces the measurements dynamic range, and therefore adding uncertainty to the interpretation. The operating frequencies and parameters of EMAT technology based cement evaluation tools are selected in such a way to optimize the measurements dynamic range within reasonable signal to noise ratio values. The log in Figure 6 is an example of EMAT tool response in 0.75" thick casing. A high attenuation contrast (18 db/ft) is observed between the well bonded cement and the poorly bonded cement.

## 4. Absence of Liquid Environment

Before the introduction of the EMAT transducers in the market, cement evaluation of air filled wells was not possible, unless the well is filled with liquid, which obviously increases the well cost. EMAT technology based tools are able to provide valid cement bond evaluation in air wells or wells partially filled with liquid. Figure 7 is a log example in such environment. Over the interval with no liquid, where the Variable Density Log (VDL) response disappeared, the EMAT tool response is not impacted by the absence of liquid.

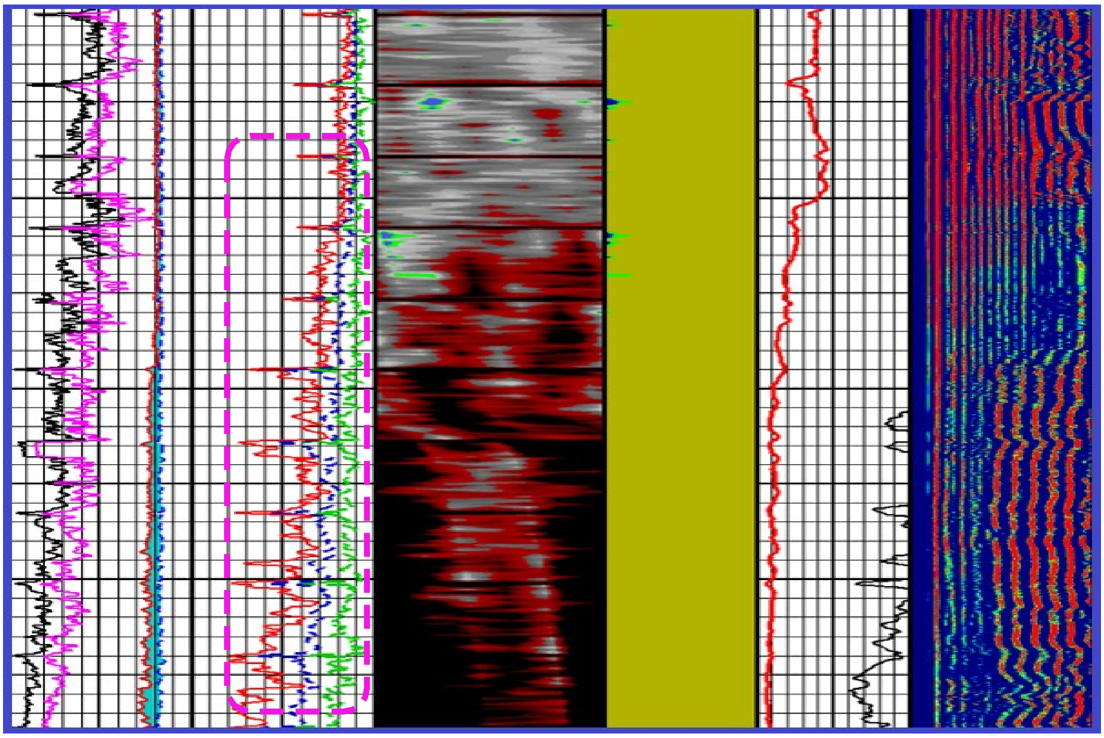

*Figure 6 – Example of EMAT based cement bond evaluation log in 0.75" thick casing. The contrast of the average attenuation is high, 18 dB/ft.*

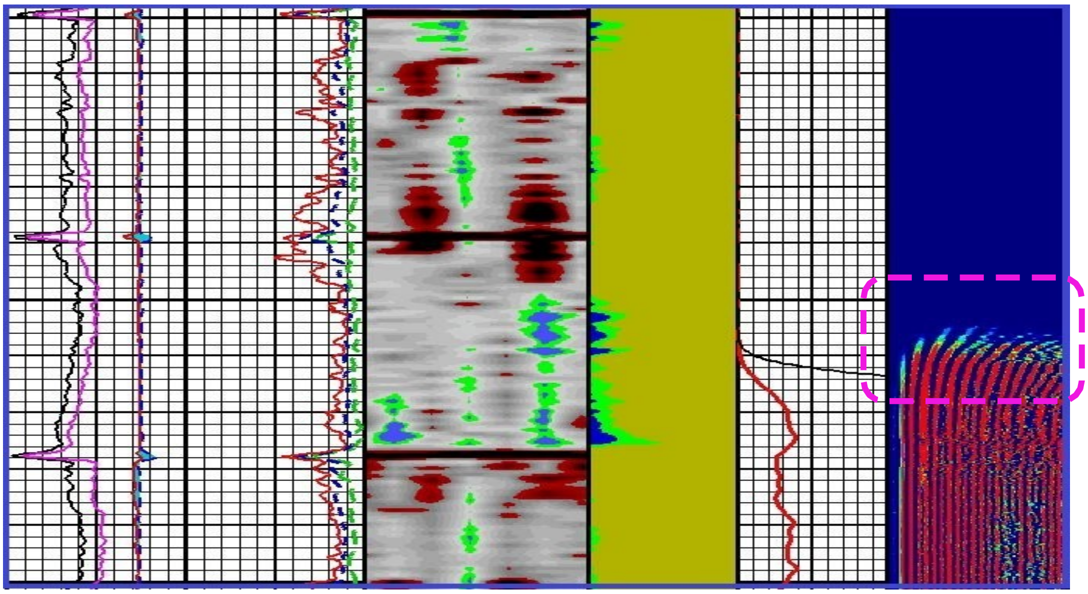

*Figure 7 – Example of EMAT based cement bond evaluation log in air-filled hole. The EMAT response is not affected by the absence of liquid but the VDL is affected. The VDL response indicates the liquid level in the hole.*

## 5. Micro-annulus Environment

The presence of a micro-gap between cement and casing and filled up with fluid (liquid or gas), commonly named a microannulus, is very common in the wells. This can be ca result of a drop in hydrostatic pressure in the well after it is cemented, or any mechanical or hydraulic operations downhole. This microannulus environment has a negative impact on the cement bond evaluation data quality because the microannulus behaves as a barrier and prevents the acoustic waves to travel to reach cement and formation. It is not easy to know if the drop in cement bond qualiy is due to the presence of a micro-annulus, or poor cement bond, or cement contamination. Obviously this would lead to wrong log interpretations and future well integrity issues. A practical commonly used solution is to acquire data in two passes, non pressurized pass and pressurized pass, to expand the casing and close the microannulus. This practice requires extra rig time and is not always possible, especially in deep wells where the allowed surface pressure would not be enough to close the microannulus. EMAT technology based tools are able to identify the presence of a microannulus without the need of a pressure pass. As stated early, the combination of both shear and flexural waves in the measurements allows to detect the presence or no of a micro-annulus. This important feature allows EMAT technology to differentiate between microannulus, poor cement bond and free pipe responses, thus removing any uncertainties in the interpretation, and also eliminating the need for extra pressure pass and rig time. Figure 8 is an example of EMAT based cement bond evaluation log showing the presence of a microannulus and its cicumferential position in the well.

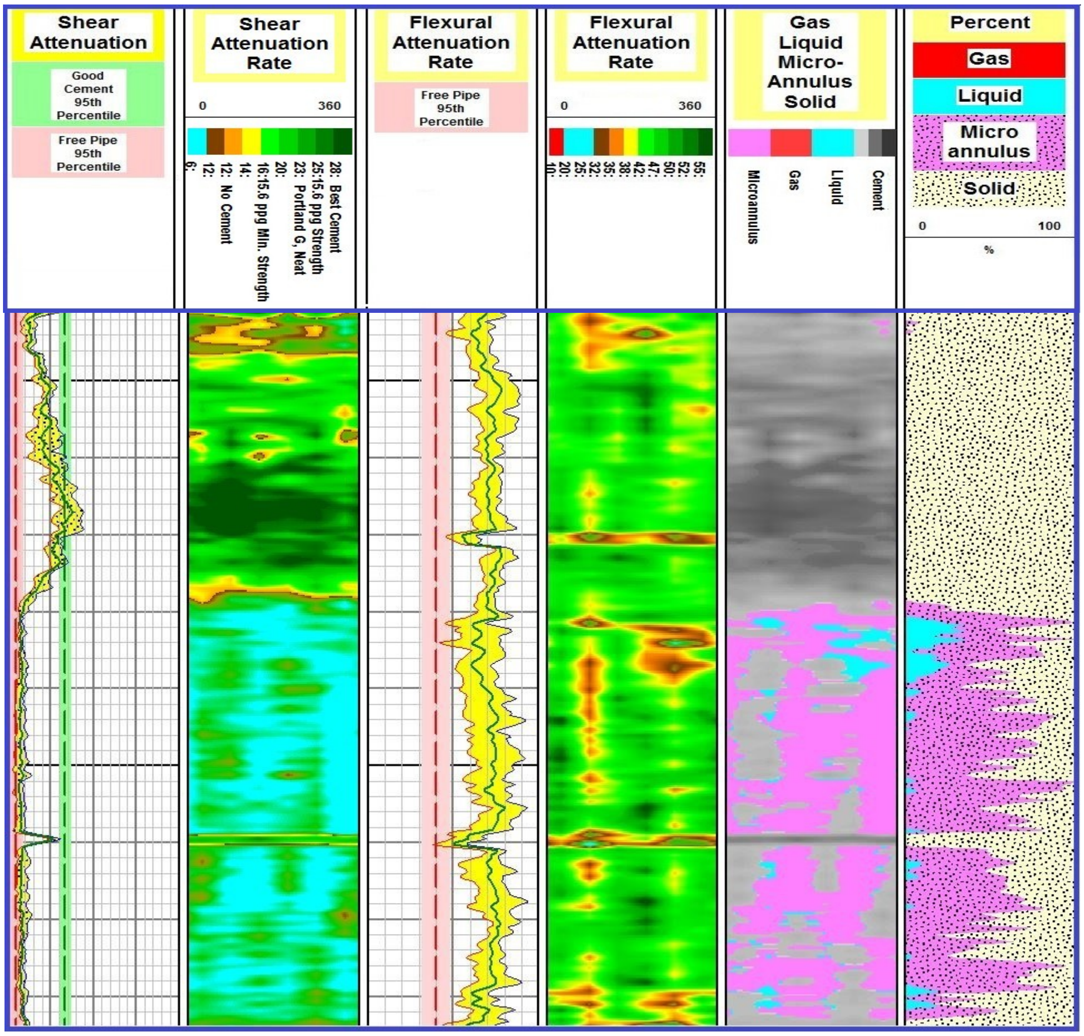


*Figure 8 – Example of EMAT based cement bond evaluation log showing a microannulus effect on the measurements. The shear attenuation drops to free pipe level when the microannulus is present, while the flexural attenuation drops slightly only, far above free pipe level.*

## Conclusions

Through actual log examples we have demonstrated that EMAT technology offer valid and effective way to evaluate cement bond in difficult environments, such as lightweight foam cement, micro-annulus environment, extremely heavy mud, thick casing, large casing, and air filled well. EMAT technology helps avoiding cement evaluation logs mis-interpretation that may lead to well integrity issues and, sometimes, to very costly consequences.