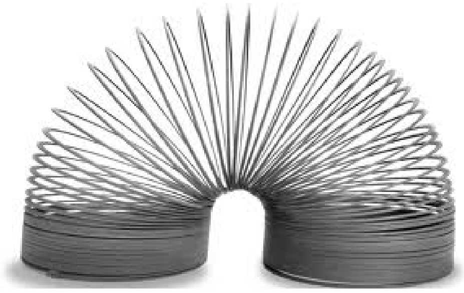
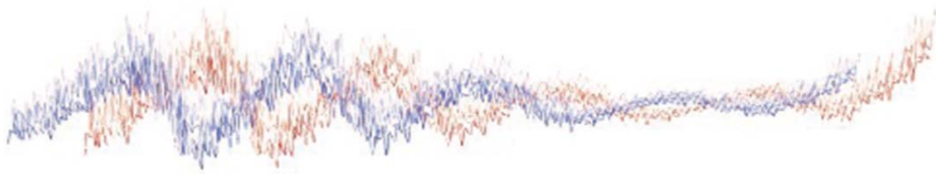
London Petrophysical Society presents

"Shear Magic":

The applications of full waveform acoustic logging

Wednesday 20th March
The Geological Society
Burlington House
London





With presentations from
Oil & Gas companies, Academia & Service companies

Case studies & presentations including:-

History & advances of sonic logging
Wellsite acquisition of sonic logs & QC of sonic data
Applications of modern sonic logging & choosing the right technology
Processing sonic waveform data
LWD Quadrupole sonic logging case study
Deep shear wave imaging away from the borehole
Fluid substitution & shaley sands
LWD sonics for cement bond logging

Registration open from 14th January:
£150 for delegates
(LPS is not VAT registered)
Students can register for free
Includes lunch and post-seminar wine and savouries. Doors open at 9am.

For more info or to register for this event please visit
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"Shear Magic" - The applications of full waveform sonic logging - 20th March 2013

Outline Agenda

Talk	Time	Name	Talk Title	Affiliation	Slide pack
	09:00 - 09:25	Registration			
	09:25 - 09:30	LPS	Welcome	LPS	
1	09:30 - 10:30	Jennifer Market	History of sonic logging & modern acoustic logging applications	Senergy	b
2	10:30 - 11:00	Adrian Leech	The practical aspects of wellsite QC	Gaia Earth	b
	11:00 - 11:30	Coffee break			
3	11:30 - 12:00	Iain Whyte	LWD Sonics for CBL logging	Tullow Oil	a
4	12:00 - 12:30	Erik Wielemaker	Anisotropy characterisation from sonic logs	Schlumberger	b
5	12:30 - 13:00	Marek Kozak	Quality control of dipole acoustic data	Supersonic	b
	13:00 - 14:00	Lunch			
6	14:00 - 14:30	Mike Lovell	From Sonic to Seismic: Basics of Petroacoustic Modelling	Leicester University	b
7	14:30 - 15:00	Ahmed Abdelkarim	Solving Shaly Sand Fluid Substitution Pitfalls Using An Adaptive Gassmann's Model	BG Group	b
8	15:00 - 15:30	Ian Pigram	Use of sonic data in pore pressure prediction	BP	c
	15:30 - 16:00	Tea break			
9	16:00 - 16:30	TBA	LWD Azimuthal Sonic Logging for Shear Wave Anisotropy Measurement and Borehole Imaging	Weatherford	a
10	16:30 - 17:00	Tom Bradley	Deep Shear Wave Imaging Away From the Borehole	Baker Hughes	b
11	17:00 - 17:30	Arthur Cheng & B.Langley	Stoneley Wave Integration with Shear Data	Halliburton	b

a) as seen.
b) with some edits and/or omissions
c) sorry but not all.

1) History of sonic logging & modern acoustic logging applications

Jennifer Market (Senergy)

History of Sonic Logging:

This presentation gives a succinct overview of the development of borehole sonic logging technology and the services available today. Included is a brief explanation of each generation and type of hardware and what they were designed for, as well as the limitations. Applications of borehole acoustic data will be reviewed, ranging from basic pore pressure prediction to seismic correlation through to 3D stress profiling. Finally, a glimpse of the future will round out the talk.

Modern Acoustic Logging Applications

The last decade has seen extensive advances in sonic logging technology. For example, not only have multipole LWD sonic tools become commonplace, but advances in azimuthal abilities in both wireline and LWD have opened up the possibilities of 3D sonic imaging for stress profiling , geosteering, and brittleness mapping in unconventional wells. This talk will review advanced applications possible with modern sonic logging technology along with considerations for choosing the right service and configuration for optimal data collection. It is also essential to consider that proper quality control of the data is critical with advanced applications and some examples of QC methods for advanced applications will be included as well.

About the Author:

Jennifer Market is the borehole acoustics manager for Senergy, an international software and consulting company. She has 15+years' experience in borehole acoustics, working in a service company to develop acoustics tools and applications. She frequently publishes articles for both SPWLA and SPE and was an SPWLA distinguished lecturer in 2008-2009 and 2011-2012.

2) The practical aspects of wellsite QC

Adrian Leech (Gaia Earth)

Modern Sonic Logging is one of the most data and processing intensive services available from the wireline contractors. With the large amount of data available real-time and many of the answer products relying on post wellsite processing how can we be sure that the data we are obtaining is of a good quality?

3) Anisotropy characterization from sonic logs

Erik Wielemaker (Schlumberger)

The typical sonic logging program objective is to obtain a compressional and a shear. Does one compressional and shear describe the rock, and will this be sufficient as input to the subsequent workflows? Most of the sedimentary rocks are Shales, which are known to be anisotropic with measurements that depend on direction. Besides bedding-related anisotropy, imbalanced stresses and fractures are also sources of elastic anisotropy. One P &S will be adequate to describe isotropic rocks yet will not correctly describe anisotropic rocks. It will be discussed how we can establish whether rocks are isotropic or anisotropic. Where rocks are anisotropic it will be shown how the source of anisotropy can be identified and how the anisotropy can be further quantified. Examples of the importance on subsequent workflows will also be shown.

4) Quality Control of Dipole Acoustic Data

Marek Kozak (SuperSonic)

Wave form data excited by an acoustic dipole source should only generate flexural waves. Unfortunately - other acoustic modes can also be created including Stoneley, compressional wave and ringing casing. These undesired modes depend on the tool position, well deviation, borehole size and the presence of casing. Unwanted wave forms might be additionally augmented by a poorly balanced dipole source or receivers. The classic semblance processing method will routinely deliver good looking values even when there are problems with one or more acoustic receivers and/or where the processing parameters are wrong. Therefore we propose to add complex wave form analysis as an additional quality control measure and cross check to the semblance method. We illustrate how to identify a mixed acoustic mode condition and eliminate biases in the shear slowness curves. We also show how to qualify cross dipole data needed to perform shear wave anisotropy analysis.

5) From Sonic to Seismic: Basics of Petroacoustic Modelling

Author: Sam Matthews (presented by Professor Mike Lovell), University of Leicester

Petroacoustic models (a combination of petrophysics and rock physics) enhance the ability to extract reservoir properties from seismic data, providing a connection between seismic data and fine-scale rock properties. These models take a variety of forms, from simplistic empirical relations to more complex theoretical models, such as Gassmann's (1951) equation for fluid substitution. Theoretical models describe the elasticity of the reservoir through various transforms, with some incorporating parameters to describe the reservoir sedimentology (for example pore shape, grain shape, grain size,and packing). The majority of these models are, however, limited in that they were developed for clean "idealised" sandstone reservoirs. Consequently erroneous results are often observed in more shaly reservoirs due to the unpredictable effects of clay minerals and clay-sized particles on geophysical properties, and in particular acoustic wave propagation. This is typically addressed using adaptive methodologies that vary with clay distribution. Clay distribution characterisation is often based on the Thomas – Stieber model (Thomas & Stieber, 1975), however, such an approach is inconsistent with current understanding of 'shaly sand' sedimentology and neglects properties such as grain sorting and grain size.

This presentation provides an overview of petroacoustic modelling techniques and discusses their implementation in 'shaly' sandstone reservoirs. In doing so the presentation reflects direct industrial experience where a pragmatic approach is often taken, and this is built upon using subsequent industry-sponsored research into the various modelling strategies available. Emphasis is placed on acknowledging and understanding the assumptions and limitations of petroacoustic models when applied to 'shaly' sandstone reservoirs. The successful improved characterisation can, however, help unlock more potential from these significant hydrocarbon resources.

6) Solving Shaly Sand Fluid Substitution Pitfalls Using an Adaptive Gassmann's Model

Ahmed Abdelkarim (BG Group)

Compressional (Vp) sonic, shear (Vs) sonic and density logs are vital for Geophysics modelling. Vp and Vs measured by the acoustic tools influence: elastic property calculations, seismic-to-well ties, wavelet extraction, fluid substitution and amplitude versus offset (AVO) modelling.

Gassmann (1951) and Biot (1956), predict how the rock modulus changes with a change of pore fluids by computing the elastic effect of fluid substitution. This often assumes statistical isotropy of the pore space and is performed for clean sand only. However, when shale constitutes part of the rock bulk volume, whether as laminated sand/shale sequences or shaly sand lithologies, the result of standard Gassmann modelling will be incorrect.

This presentation introduces an adaptive technique to fluid substitution that can be used to correct errors due to shale complexity. Improvements are demonstrated using a BG example well, in which realistic Vp modelling is achieved in a shaly sand sequence.

References used in this talk include more than seven papers discussing Gassmann modelling in sand shale sequences, a highlight of which is Rob Simm's practical Gassmann fluid substitution in sand shale sequences, First Break volume 25, December 2007.

7) Pore pressure estimation using sonic

Ian Pigram (BP)

The talk covers the basics of pore pressure estimation using logs (sonic log in particular). The log response due to under-compaction/overpressure is presented. The process for pore pressure estimation is illustrated by first establishing an overburden stress trend. Then the difference between a "normal" log trend and an actual log trend is developed to compute an estimated pore pressure "log" and finally a fracture gradient.

8) LWD Azimuthal Sonic Logging for Shear Wave Anisotropy Measurement and Borehole Imaging

TBC (Weatherford LWD)

An azimuthally focused LWD unipole sonic tool has been used to resolve shear wave anisotropy in fast formations, and provide borehole images of acoustic slowness. As the drillstring rotates, waveforms are recorded in 16 fixed-orientation azimuthal bins. The waveforms are processed to yield azimuthally focused compressional and refracted shear wave slowness values, which can then be displayed as borehole image logs and shear anisotropy images.

Field logs show sensitive response to stress-induced HTI anisotropy in vertical wells, and accurate resolution of intrinsic VTI anisotropy in horizontal shale reservoir wells, where anisotropic geomechanics information can enhance completion planning and production evaluation.

This new shear anisotropy measurement technique offers several advantages over dipole flexural wave logging, particularly in horizontal wells. Because the LWD transducers scan 360 degrees with each drillstring rotation, they make a direct measurement of shear wave velocity in the fast and slow directions without requiring additional processing such as Alford rotation. Measurement of the mud head wave from critically refracted formation shear waves provides a more direct measurement of shear slowness, without the need for dispersion corrections. Finally, there is no requirement to maintain tool centralization in horizontal wells, simplifying logging operations. The main limitations of the technique are the shallow depth of investigation compared to lower frequency dipole measurements, and the limitation of the shear measurement to fast formations where Vs > Vmud.

9) Deep Shear Wave Imaging Away from the Borehole

Tom Bradley, Baker Hughes Inc., Den Helder, Netherlands.

The goal of acoustic deep shear wave imaging analysis of cross dipole array waveform data is to map geologic structures and fractures away from the borehole. In addition to the direct dipole flexural arrivals commonly used for shear slowness determination, the dipole source also propagates shear body waves into the formation. When these waves encounter a shear impedance contrast energy is reflected back allowing it to be detected by the logging tool. This does not require special equipment, special acquisition or additional logging passes as it is done using the standard cross dipole system with standard acquisition. This standard data is then processed to isolate the reflected acoustic waves utilized for imaging the structures.

The reflection imaging processing utilizes the recently developed shear-wave imaging technique (Tang and Patterson, 2009) which expands considerably on Hornby's (1989) original work. Compared with conventional monopole imaging methods using compressional waves in the 10 kHz range, the deep shear wave imaging provides an advantage by its deeper depth of penetration due to the low-frequency nature of the shear body waves (2-3 kHz). Using this technique it is possible to image planar reflectors 20m or more from the borehole axis. This provides a measurement that fills the resolution gap between conventional borehole images measuring the immediate borehole environment and borehole seismic which measures from tens to hundreds of metres from the borehole.

There are many applications for this technique: Formation structures identified by conventional borehole images can be evaluated as they extend away from the borehole: A good example of this is with fractures, so enabling the identification of naturally fractured intervals and hence optimisation of stimulation jobs. This application being of particular interest for unconventional 'shale' and 'tight' formations where the understanding of natural fractures are so critical. The technique can also be applied post-stimulation to image the created fractures and assess the effectiveness and extent of stimulation jobs. As it is possible to image features that do not intersect with the borehole, in highly deviated and horizontal wells the technique has been applied to image the approach to and measure the distance of the wellbore from nearby formation boundaries.

In conclusion, the deep shear imaging technique is a valuable addition to the range of tools available to image the formation with many applications in both conventional and unconventional reservoirs.

Figure 1 shows an example of the images obtained where a non-borehole intersecting feature has been imaged.

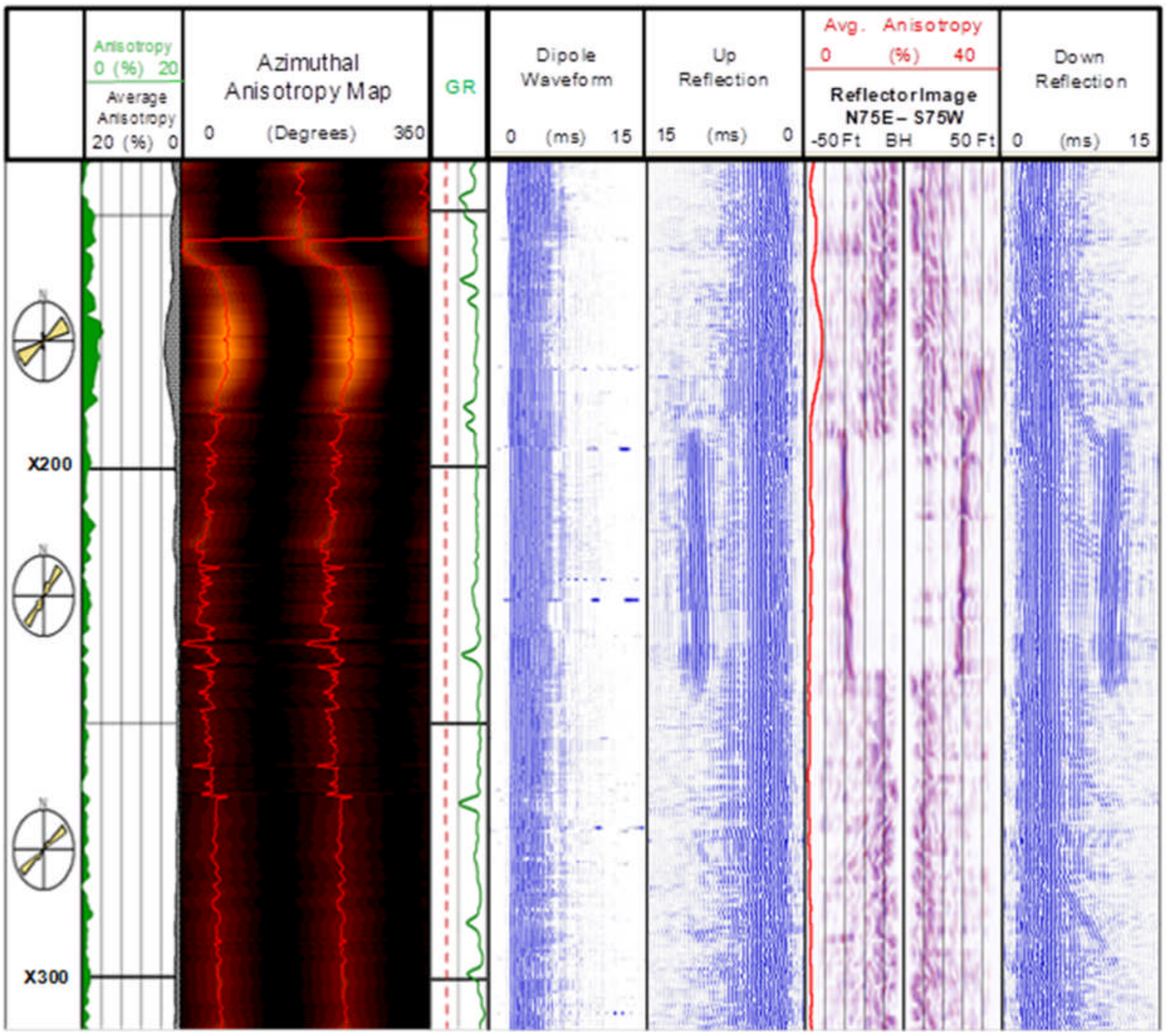

Figure 1 - Cross-dipole anisotropy results compared to the Deep Shear Wave Imaging looking out 50 ft from the borehole along the N75E-S75W azimuth; note the large vertical structure seen 30 ft away from the borehole over the interval from X195 to X240

References

- Hornby, B. 1989, Imaging of near-borehole structure using full waveform sonic data. Geophysics, 54(6).
- Tang, X.M., Zheng, Y. and Patterson, D.2007, Processing array acoustic logging data to image near-borehole geologic structures. Geophysics, 72(2), E87–E97.

- Bradley, T, Patterson, D, Tang, X, Applying a through-casing acoustic imaging technique to identify gas migration paths in a salt body. First Break volume 29, July 2011.
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Biography – Tom Bradley

After graduating in 1996 with a BSc honours degree in Geology with Engineering Geology from the Royal School of Mines, Imperial College London, Tom began his oil industry career with Baker Hughes (then Western Atlas) in 1997 as a wireline log data processor. In the following 16 years he has progressed through a variety of technical and supervisory geoscience roles in the UK, West Africa, the Middle East and Europe. Since 2005 he has been based in Den Helder, Netherlands and is currently a Geoscience Advisor for the Europe region geoscience team, specialising in open hole petrophysics and in particular acoustic data analysis and interpretation; He is one of the acoustic global subject matter experts for Baker Hughes.

10) Stoneley Wave Integration with Shear Data

Arthur Cheng & Bill Langley (Halliburton)

The cornerstone of correct rock physics or seismic correlation is the detection and measurement of the correct acoustic modes. The simultaneous solution of the Stoneley and Dipole modes optimizes the accuracy of the mode selection. In this brief presentation, dipole and Stoneley data from fast and slow formations in two test wells is characterized. We have a fast formation when the compressional and shear waves are refracted along the borehole boundary as head waves. We have a slow formation when the shear wave velocity is less than the borehole fluid velocity and there is no critically refracted shear wave.

It is necessary to distinguish the Stoneley from the Dipole mode prior to any analysis. The Stoneley mode is an interface wave guided by the borehole-formation boundary as an omnidirectional wave. The dipole transmitter source generates a directional flexural mode wave in the formation. The flexural mode is a dispersive waveform where the flexural mode slowness approaches shear wave slowness at lower frequencies. The flexural mode can measure shear velocities in both fast and slow formations. We will illustrate the distinguishing characteristics using wave form and frequency analysis utilizing datasets collected from two separate test wells.

Characterizing the dipole and Stoneley modes simultaneously using a two layer dispersion model with a known fluid velocity is useful to measure anisotropy properties. One anisotropy application that is increasingly important in slow formation is Vertical Transverse Isotropy (VTI). The Stoneley wave is the only borehole wave mode sensitive to VTI when the formation is acoustically slow compared to the borehole fluid. We invert the Stoneley and Shear Wave modes simultaneously to estimate the shear wave TI parameter c66. We utilize these results to estimate the Thomsen coefficient γ from c66 and c44 values by analogy to the vertical and horizontal shear slowness values.

The data being presented has been collected from two test wells with a range of acoustic response properties. The test wells are located in Texas, USA.

11) LWD Sonic Cement Logging: Benefits, Applicability, and Novel Uses for Assessing Well Integrity

Iain Whyte (Tullow Oil)

With the ongoing changes affecting the global drilling industry, well integrity has become an area of great engineering focus and development. Cement bond analysis is of key interest as the consequences of failed, or partially complete, cementing operations can, at best, be a costly delay in drilling operations and, at worst, an extremely hazardous safety issue. Traditionally, wireline acoustic tools have been used to analyze the quality of the cement bond between the casing and the formation. Wireline tools have been developed over many years to produce high-quality assessments of cement bond, which can then be confidently used to confirm well integrity. However, the conveyance method requires that the analysis be performed on the critical path and also that additional methods be used in high-angle wells. Logging-while-drilling (LWD) technology offers a potential alternative without these issues, provided the current limitations of the technology are understood and its applicability properly assessed as a fit-for-purpose solution. LWD Top Of Cement logging can be performed with no incremental rig time as it is acquired on trip in and trip out with no reduction to typical tripping speeds. As a minimum the LWD logging technique can provide a trigger as to whether more advanced and dedicated logging techniques must be deployed or can be avoided.

This paper explores the applicability of LWD sonic tools to the analysis of cement behind casing. It considers both the currently accepted deliverable of top of cement (TOC) analysis, along with examples of more advanced processing techniques and their comparison to wireline cement evaluation, providing case study examples in each case. The benefits and limitations of these methods will be discussed, along with operational considerations to aid in successful logging, including the use of repeat logging passes from trip in and trip out and on successive bit trips to indicate changes in cement quality with time. The use of LWD sonic tools to identify casing collar connections on driller’s depth, enabling the safe positioning of cased-hole whipstocks without the need for a separate wireline casing collar location run, is also be covered, demonstrating a novel and little-used application of LWD technology.