LWD sonic cement logging:
Benefits, applicability and novel uses for assessing well integrity (SPE-163461, SPE-159819 SPE-170886)
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Introduction

- Cement Evaluation from LWD Sonic can be opportunistic
  - Sonic may be inhole for seismic correlation or pore pressure – especially in deepwater environment

- Often LWD Sonic run in overburden section
  - Oft times no CBL planned but required to governmental legislation

- Acquisition can take place when Running In Hole, Pulling out of hole, bit trips etc
  - Allows time lapse data acquisition

- No “time cost” to running this service
  - Requires only downlink to change tool mode (fast/normal data acquisition)
  - For memory only TOC instantaneous trip speed of 900ft/hr max.
  - As a Petrophysicist you MUST exhaust your data source
  - Squeeze as much value out of each piece of data as you can
Polling Question

What level of experience do you have interpreting bond logs?

A. What’s a bond log?

B. Bond logs come across my desk once in a while but they’re just a bunch of squiggly lines to me

C. I have to look at a bond log once in a while but I don’t have much confidence in my interpretation

D. I look at bond logs routinely and feel pretty good about my interpretations
What do we do with log data?
- Select completion intervals
- Verify isolation of fresh water, hydrocarbons & corrosive brines
- Decisions on remediation
- Continuous cementing improvement
- Decisions on abandonments
- Satisfy regulatory requirements
- Total loss of a well

What are the implications?
- Bypassed pay & lost reserves
- Lost production
- High WOR or GOR
- Stimulating out-of-zone
- Unnecessary holes in casing
- Difficulty cutting & pulling casing
- Unnecessary section milling
- Total loss of a well
What are We Trying to Measure?

Most basic level: Top-of-cement analysis

Uses the free-pipe acoustic signature of casing to identify top of cement behind pipe

Gives only a simple Qualitative Indicator of Bond
LWD Sonic Top of Cement Evaluation

**What it is:** A method to confirm top of cement height behind casing

**What it is not:** A quantitative indicator of cement bond quality

**Benefits:**
- Acquired while tripping in or out with no additional rig time consumed.
- Requires no additional tools other than the standard sonic tool
- Available in both memory and real-time (depending upon the tool)

**Limitations:**
- Does not provide a thoroughly quantitative bond index or CBL measurement
- One string of casing only
Case Example of Value

- Deepwater exploration well in South America
- Governmental regulator required “evaluation of cement” over each and every casing/liner
- LWD Sonic planned in all overburden sections
  - Cement evaluation performed during trips in/out

- Consider cost of running exclusive wireline measurement?
  - 500 to 700 K USD?
  - Opportunity cost? Weather windows closing in – optimise efficiency

- LWD Sonic used to “guide the need” for more advanced evaluation
  - Saved 3 dedicated wireline runs = 2 MM USD PER WELL
Top-of-Cement Example

LWD

2500 ft

Full Receiver Amplitudes

Top of cement

LWD

300 ft

Wireline
Top-of-Cement Example

- Top of Cement identified by windowed casing amplitude
- Zero rig time acquisition – logged while the BHA is tripped.
- Can also give qualitative indications of relative bond quality.
- SPE-163461, SPE-159819
What are We Trying to Measure?

Casing plate extensional mode attenuation is a function of cement bonding.

Attenuates as the function of:
- Casing thickness
- Bond Index
- $Z_{CEMENT}$

* $Z_{CEMENT}$: acoustic impedance of cement = compressional velocity $\times$ density
Wave velocity and first arrivals

In what order do the acoustic signals arrive at the 5 foot receiver?

A. Mud, Casing, Cement, Formation

B. Formation, Cement, Casing, Mud

C. Casing, Formation, Cement, Mud

D. They all arrive at the same time
Sonic Wave Propagation

Animation courtesy of Dr. Dan Russell, Grad. Prog. Acoustics, Penn State
Casing Mode and Other Arrivals?

Expected slowness values:

- Casing plate mode \( \sim 57 \text{ ms/ft} \)
- Formation \( > 70 \text{ ms/ft} \)
- Fluid \( > 175 \text{ ms/ft} \)
Cement Bond Log Measurement Model

Conventional CBL measurement

\[ CBL = G \cdot \alpha \cdot P \cdot S \cdot 10^{-ATT \cdot D} \]

- **G**: Free-pipe normalization gain
- **\( \alpha \)**: Coupling, Tx/Rx & casing mode
- **P**: Transmitter (Tx) strength
- **S**: Receiver (Rx) sensitivity
- **ATT**: Casing mode attenuation rate
- **D**: Signal path length in casing

**Requires**

- Environmental corrections (fluid types, pressure & temperature)
- Tool normalization
Bond Index Basics

We measure CBL and from there we compute BI. There is one CBL input that can provide two BI outputs depending upon the cement used.
LWD Sonic Data
Field Calibration to USIT Bond Index

Qualitative Indicator of Bond QIB

<table>
<thead>
<tr>
<th>Amplitude</th>
<th>QIB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>200</td>
<td>0</td>
</tr>
</tbody>
</table>

\[ \text{QIB} = -0.4346 \times \log_{10}(\text{Amplitude}) + 1 \]
Applying the Calibration

\[ QIB = -0.4346 \times \log_{10}(\text{Amplitude}) + 1 \]
Free-Pipe Zone Example
Partial to Good Bond Example

AMPDT57_FILE AMPDT57_FILE
0.1

MD
1: 240 ft

USBI USBI@USI IS SONIC 0
1 ( )

BI. SVISION BI@DataFunction
1 ( )

USIT Cement Map

GASR MDR
Converting to an Attenuation Rate Based Bond Index

Further more recent developments of Bond Index Determination

- The apparent attenuation is a good match at high bonding but a poor match at low bonding (right track).

- The opposite is seen in the original amplitude based bond index approach (left track).

- Attenuation Rate Based Bond Index offers several advantages over 1st peak amplitude (such as removing the need to have a free pipe normalization and the temperature/pressure effects).

- Unfortunately it is not yet possible to expand the attenuation rate method to the full range of bonding due to the complicated response induced by the collar arrival.

Paper SPE #170886
Expanding to Full Range Bond Index

The proposed solution is a hybrid approach of the two methods.

- LWD Amplitude-Based bond index is shown in the left hand track
- LWD Attenuation-Based bond index is shown in the middle track
- LWD Hybrid Bond Index is shown in the right hand track

Paper SPE #170886
The Big Picture

Amplitude Waveform Within Window Over Casing Arrival

Casing Signal

Formation Signal

London Petrophysical Society – 23rd June 2016
Excerpt from Cement Evaluation Report

Figure 2: Zones of poor to good cement.

Figure 3: Zones of good to no cement.
SonicScope825 RT Top of Cement Example

Real Time Data
Obtained while drilling out the casing shoe

Memory Data
Obtained after pulling out of hole

14in Casing

Salt

XX150

XX200

XX250
Pre and Post cement squeeze of 18” casing shoe

Before cement squeeze

- 18” Shoe at 3127m
- Very poor cement bond
- Fairly good cement bond

After cement squeeze

- Post Squeeze all cement above shoe appears of good quality
- 18” Shoe at 3127m
Using LWD Sonic for Repeat Passes

Utilizes the fact that the sonic tool may pass over the same casing string multiple times in the drilling process.

These repeat passes can be processed to look at changes in cement over time.
Using LWD Sonic to Set Whipstocks

Utilizes the sonic to identify the connections between joints of casing.

Relies on the fact that sonic amplitudes and coherence drop off across a connection.

Once the joints have been identified then the spacing between connections gives joint length allowing drillers depth to be matched to casing depth.

Can be done during casing clean out.
LWD Sonic for Cement Logging:

The Top of Cement Service is a well established method of confirming the presence of absence of cement behind pipe. It can be acquired with zero additional rig time and is valid even in very large casing sizes providing its limitations are understood.

Deriving a bond index measurement from LWD sonic tools is complicated by the presence of collar arrival.

Quantitative Bond Index offers a method to deliver a full bond index measurement from LWD tools within its applicable ranges.
Questions?