ExxonMobil

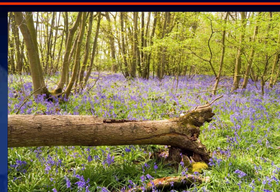
Challenges with Cement Evaluation

What We Know & What We Don't

SPE Webinar
July 11, 2012
Presented by David Stiles
ExxonMobil Development Co

Challenges with Cement Evaluation

If a tree falls in the forest and no one is there to hear it, does it still make a sound?



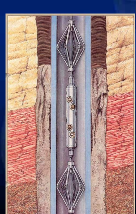


Image courtesy of Schlumberger

If an annulus is fully cemented but an acoustic bond log can't "hear" it, is the cement really there?

Decisions, Decisions, Decisions

What do we do with log data?

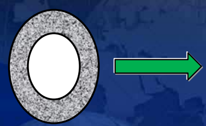
- Select completion intervals
- Verify isolation of fresh water, hydrocarbons & corrosive brines
- Decisions on remediation
- Continuous cementing improvement
- Decisions on abandonments
- Satisfy regulatory requirements

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

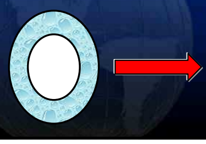
What Do We Really Need to Know?

- Is the material behind pipe solid?



Isolation

- Is the material behind the pipe liquid?



No Isolation

SONIC BOND LOGS

Polling Question #1

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

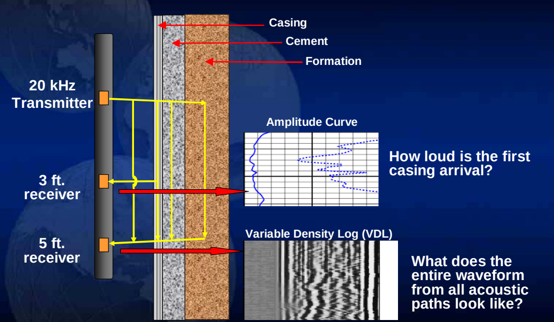
D.I look at bond logs routinely and feel pretty good about my interpretations

Sonic Bond Log Physics 101

- SPE-1512, Oct. 1960 - *A Sonic Method for Analyzing the Quality of Cementation of Borehole Casings*
  - M. Grosmangin; P.P. Kokesh; P. Majani, Schlumberger

"The amplitude of a sound signal after it has traveled in a firmly cemented pipe is only a fraction of that recorded by the same device in free pipe."

Conventional CBL



Polling Question #2

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

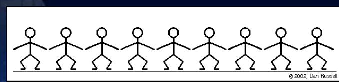
A. Mud, Casing, Cement, Formation

B. Formation, Cement, Casing, Mud

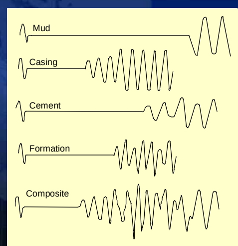
C. Casing, Formation, Cement, Mud

D. They all arrive at the same time

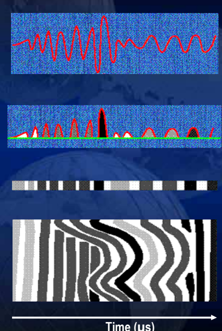
Sonic Wave Propagation



Animation courtesy of Dr. Dan Russell, Grad. Prog. Acoustics, Penn State



VDL (Waveform) Processing



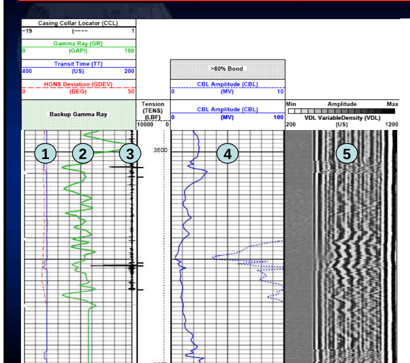
Raw Waveform

Half Wave Rectified and Shaded

Top View of Shaded Half Wave

Stacked Shading

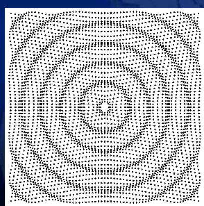
Typical CBL Presentation



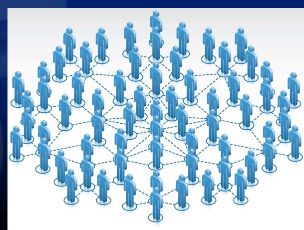
1. Transit time
2. Gamma ray
3. CCL
4. Amplitude
5. VDL

CBL Assumptions

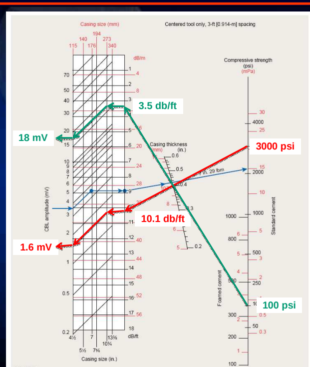
- The CBL sends out a monopole signal which measures the average circumferential amplitude
- The CBL assumes uniform cement behind the pipe



Animation courtesy of Dr. Dan Russell, Grad. Prog. Acoustics, Penn State



CBL Nomograph



Graphic Courtesy of Schlumberger

- Tool specific chart
- Converts compressive strength to amplitude or attenuation and vice-versa
- Function of casing size and thickness

Polling Question #3

What does >80% B.I. mean?

A. The acoustic impedance is >80% of what was anticipated

B. 80% of the data is “Bad Information”

C. The cement is good

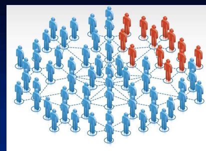
D. The cement is bad

Bond Index & Why is it Wrong?

- What is needed?
  - Expected cement amplitude ($E_{100\%}$)
  - Free pipe amplitude (E_{free})
  - Measured amplitude (E_{Meas})
- Bond index (BI):

$$\frac{\log_{10}(E_{meas}/E_{free})}{\log_{10}(E_{100\%}/E_{free})}$$

- Conventional thought
  - BI > 80% = “Good” cement
  - BI < 80% = “Bad” cement



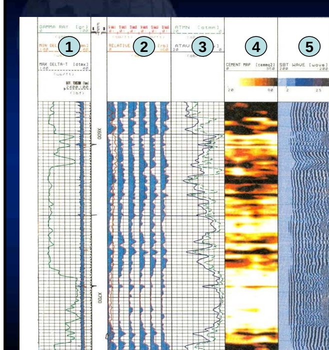
80% Channel = No Isolation

80% “Weaker” Cement = Isolation

Advanced Sonic Tools

- Advanced sonic tools have been developed that partially address some of the limitations of the standard CBL
- Compensated Bond Tool (CBT)
  - CBTs have two monopole transmitters and three monopole receivers
  - They measure a compensated signal attenuation independent of wellbore fluid or transmitter signal strength
- Sector Bond Logs (SBL)
  - Standard monopole transmitter with omnidirectional 3 and 5 ft receivers
  - Plus 6 or 8 additional focused transmitter and receiver arrays for 60 or 45 degree azimuthal average amplitude
- Segmented Bond Tool (SBT)
  - Actually an ultrasonic tool at ~100 kHz but physics are similar to sonic logs
  - Tool has six pads in direct contact with the casing, each with a transmitter and receiver that communicate with the adjacent pads
  - This tool has 60 degree azimuthal resolution but otherwise works on similar physics as the CBT

Typical SBT Presentation



1. Gamma ray

2. Amplitude of six sectors

3. Min & avg attenuation

4. Attenuation map

5. Standard VDL

Some Limits of Sonic Bond Logs

- Amplitude or attenuation readings only indicate what is directly acoustically coupled with the casing – it is not an indicator of isolation
- The VDL is only a qualitative indicator of the acoustic coupling at the cement/formation interface - it is not an indicator of isolation
- A microannulus or coated casing will cause acoustic decoupling
- Fast formations or cycle skip will cause misleading amplitude readings

More Limits of Sonic Bond Logs

- Logging tools must be centered within specifications
- Evaluating low compressive strength cement is difficult
- Evaluating gas cut or foamed cement is difficult
- Evaluating a thin cement sheath can cause problems
- Evaluation behind thick walled casing is difficult
- Interference in concentric casings can affect logging
- Channels cannot be identified with a standard CBL and even advanced sonic tools can't identify small channels

Q & A ON SONIC LOGS?

ULTRASONIC BOND LOGS

Polling Question #4

What parameters can an ultrasonic log (e.g. USIT, CAST-V) measure?

A.Azimuthal casing condition

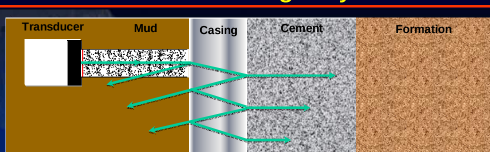
B.Azimuthal acoustic impedance of material behind pipe

C.Azimuthal casing internal radius

D.Azimuthal casing thickness

E.All of the above

Ultrasonic Bond Log Physics 101



Wave animation courtesy of Dr. Dan Russell, Grad. Prog. Acoustics, Penn State

- Rotating pulse-echo transducer operating at 200 – 700 kHz
- Ultrasonic echoes produce four measurements
  1. Pulse-echo amplitude ⇒ casing condition
  2. Pulse-echo transit time ⇒ casing internal radius
  3. Resonant frequency of casing ⇒ casing thickness
  4. **Decay of the resonance ⇒ acoustic impedance of material directly behind casing (MRayl = 10^6 kg.m^{-2}.s^{-1})**

Ultrasonic Bond Log Physics 101 (cont.)

- Tools take 36, 72 or 100 readings per revolution
- Wellbore fluid properties are measured
  - Fluid velocity (μs/in)
  - Fluid acoustic impedance in MRayl (10^6 kg.m^{-2}.s^{-1})
- Fluid density, velocity and impedance parameters are required inputs to measure the impedance of the material behind the casing
- Impedance readings are processed into a cement map that is color coded with the colors indicating the relative range of the acoustic impedance readings
- Many logs use an arbitrary cut off point for cement of ≥ 2.6 MRayl acoustic impedance

Acoustic Impedance of Various Materials

Material	Acoustic Impedance 10^6 kg.m^2 sec
Fresh Water	1.5
Free Gas	0.1
Steel (casing)	46.0
12 lb/gal Drilling Mud	2.16
15 lb/gal Drilling Mud	2.70
17 lb/gal Drilling Mud	3.06
9 lb/gal Foamed Class C (250 psi)	2.19
9 lb/gal Foamed Class C (1000 psi)	2.69
13 lb/gal Cement (500 psi)	3.37
13 lb/gal Cement (2000 psi)	4.42
16.5 lb/gal Cement (500 psi)	4.38
16.5 lb/gal Cement (2000 psi)	5.62

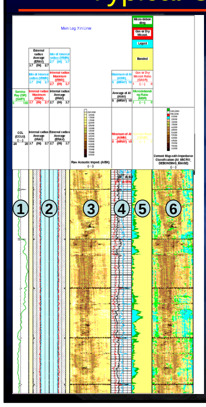
Tool accuracy is ± 0.5 MRayl

2.16 + 0.5 = 2.66

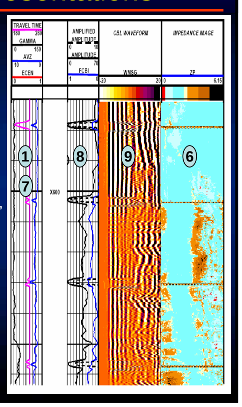
Δ = 0.21 MRayl

3.37 – 0.5 = 2.87

Typical Ultrasonic Presentations

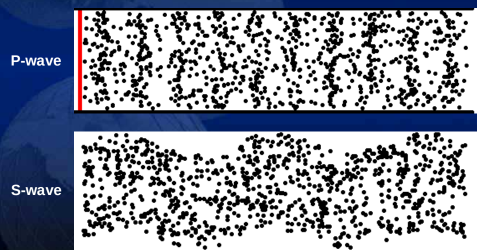


1. Gamma ray
2. Casing Inspection
3. Raw impedance data
4. Min, max & avg impedance
5. Percent bonded, liquid, gas and "micro-debonded"
6. Cement impedance map
7. Avg. impedance & tool eccentricity
8. Signal amplitude
9. VDL



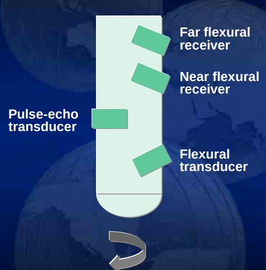
Advanced Ultrasonic Tool

- The newest generation ultrasonic tool compliments the existing pulse-echo (P-wave) measurements with flexural (S-wave) measurements



Animations courtesy of Dr. Dan Russell, Grad. Prog. Acoustics, Penn State

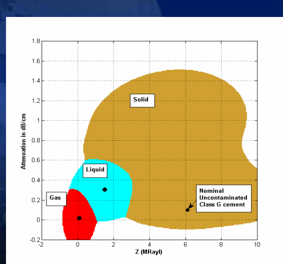
Advanced Ultrasonic Tool (cont.)



- The decay of the pulse-echo wave provides acoustic impedance of the material directly behind the casing (same as a standard ultrasonic log)
- Flexural waves propagate along the casing and generate shear and pressure body waves in the cement sheath
- Supported waves are dependent on the material in the annulus
  - Liquid supports only P-waves
  - “Fast” cement only supports an S-wave
  - “Slow” cement supports both S-waves & P-waves

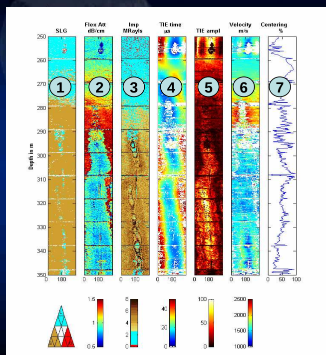
Advanced Ultrasonic Tool (cont.)

- The combination of pulse-echo resonance and flexural attenuation are used to discern between solid, liquid and gas directly behind the casing



Graphic Courtesy of Schlumberger

Typical Tracks on Advanced US Logs



Courtesy of Schlumberger

Always presented:

1. **Solid/Liquid/Gas Map**
2. **Flexural Attenuation**
3. **Acoustic Impedance**

Presented only if a Third Interface Echo (TIE) is detected:

4. **Signal Transit Time**
5. **Third Interface Echo Map**
6. **Velocity**
7. **Casing Eccentricity**

Some Limits of Ultrasonic Bond Logs

- Maximum mud weight is ~16.0 lb/gal – less in NAF
- Logging tools must be centered within specifications
- A minor error in input logging fluid properties has a major impact on measured impedance of the annular material
- Maximum casing thickness is ~0.75 inches
- Limits of tool resolution may make it hard to discern low density, low strength cement from mud
- Poor casing condition will incorrectly affect the cement map
- A wet microannulus or coated casing will affect the measurements, although less so than with sonic logs
- Depth of investigation is usually very small – no indication of cement to formation interface

Q & A ON ULTRASONIC LOGS?

IMPROVING BOND LOG INTERPRETATION

Polling Question #5

What is the first thing you should do when interpreting a bond log?

A.Look for dark colors on the cement map

B.Check to see if the Bond Index is >80%

C.Review the well history

D.Call an expert for help

So How Do We Improve Confidence?

You can't interpret a bond log in a vacuum

1.Determine what you <u>expect</u> the log to look like

- Know the objectives of the cement job
- Gather all pertinent data related to drilling and cementing of the well

2.Perform thorough quality assurance checks

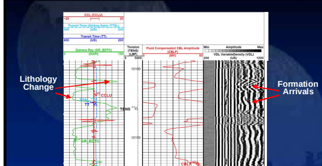
3.If the log is valid and it differs from what was expected or the response can't be explained…

- Use additional data processing or interpretation techniques
- Run additional logs as appropriate

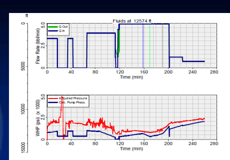
Does the Log Look as Expected?

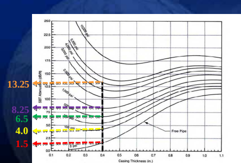
- What significant events occurred while drilling the section?
- What is the lithology?
- Was the job designed for good mud removal or was channeling expected?
- Was the job executed as per design?
- Did significant events occur during the job (e.g. losses, unplanned shut-downs, etc.)?
- Do actual job pressures match those predicted?
- What was the expected cement compressive strength at the time of logging?
- Did significant events occur after cementing but prior to logging?

Some Clues to Proper Interpretation



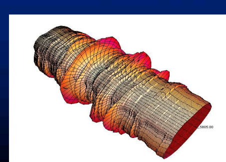
Lithology Change


Pressure Matching

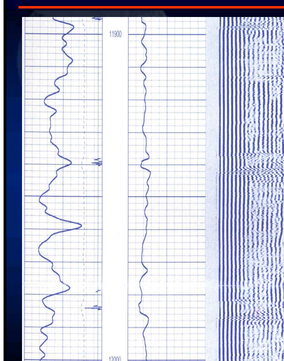


Compressive Strength

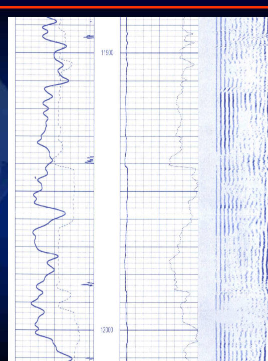
Courtesy of Baker


Borehole Quality

Pressure Pass to Confirm Microannulus



Zero Pressure Pass



1500 psi Pressure Pass

Log Quality Assurance – Is it Valid?

- Is the tool centered?
  - Transit time on a CBL should be no more than 4 to 10 μsec/ft faster than the time for a perfectly centered tool (only exception is fast formations)
  - For SBT, DTMN & DTMX curve separation should not exceed 4 to 5 μs /ft
- Does the repeat section match the main pass?
- If there is a free pipe section, is the amplitude within ± 10% of published specs?
- Were casing size & weight input correctly?
- Were mud velocity & impedance measured & used for ultrasonic logs?
- Are any amplitude, attenuation or impedance curves less than zero?
- For logs with a cement map is the solid/liquid threshold correctly set for expected cement and mud properties?
- For ultrasonic logs are there any processing error flags or bad checkshot indicators?

Polling Question #6

Solids have a more consistent acoustic response than liquids

A. True

B. False

C. It depends

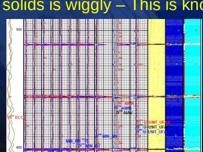
Different Presentation Improves Picture

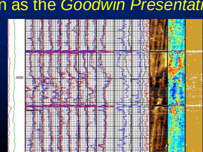
- Liquids are relatively homogenous while solids are heterogeneous

Image Courtesy of Fir0002/Flagstaffotos

Image Courtesy of the Portland Cement Assoc.

- The acoustic response to liquids is relatively flat while the response to solids is wiggly – This is known as the *Goodwin Presentation*





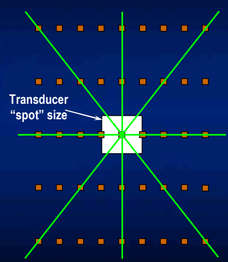
Computer Post-Processing of the Data

Schlumberger USIT Micro-debonding

If the following conditions are met:

1. All four standard deviations are higher than set thresholds
2. The cement impedance is low (in the gas or liquid classes)

Then the current pixel is considered to be of locally debonded set cement and is colored green

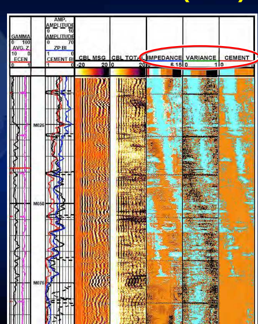


Graphic Courtesy of Schlumberger

Computer Post-Processing of the Data

Halliburton Advanced Cement Evaluation (ACE)

- A statistical variation process to discern solid crystalline structures, such as cements, from fluids
- Analyzes the vertical and horizontal rate of impedance change



Courtesy of Halliburton

Summary

- A multitude of high impact decisions are based upon cement bond logs
- Sonic logs work on the principal that the amplitude of a sonic signal as it travels through casing is relative to the degree of cementation of the casing
- Ultrasonic logs work by producing a resonant frequency in the casing, the decay of which can be used to determine the acoustic impedance of the material behind the pipe
- All bond logging tools have many limits that prevent complete certainty in their interpretation

Summary (cont.)

- Bond logs cannot be interpreted in a vacuum
- Log quality assurance checks are imperative
- Knowledge of the expected log response based on pertinent events associated with drilling and cementing the well is required before interpreting a bond log
- Looking at data variance through a Goodwin presentation or computer processing can decrease the degree of uncertainty

FINAL Q & A

Special thanks to Baker Hughes
for continued support and sponsorship of
SPE R&D Technical Section web events

BAKER HUGHES

SPE
R&D Technical Section

Nomenclature

DTMN: delta time minimum (for an SBT)

DTMX: delta time maximum (for an SBT)

GOR: gas-oil-ratio

MRayl: Mega Rayleigh

NAF: non-aqueous fluid

WOR: water-oil ratio