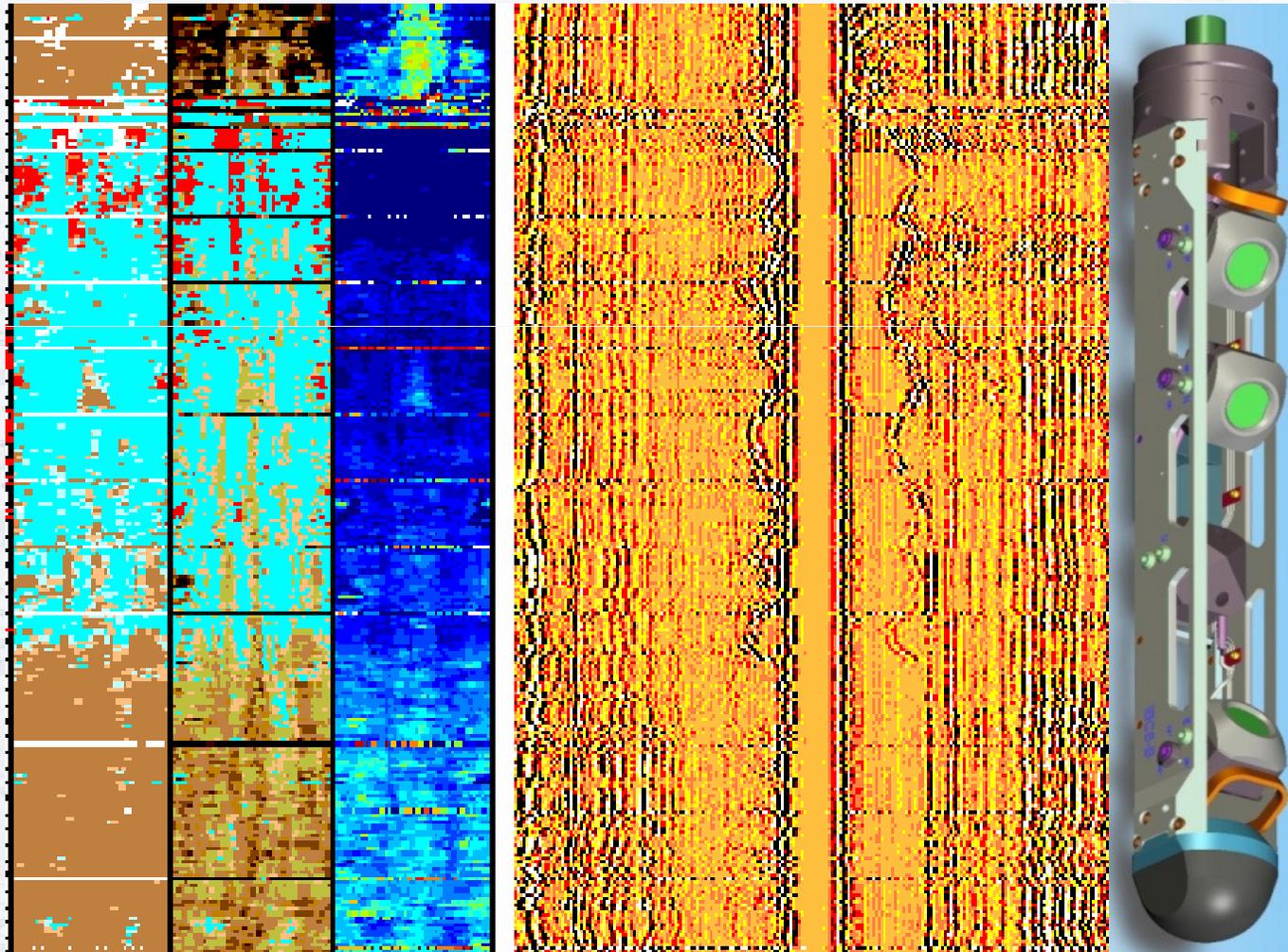


Vertical and Horizontal Cement Evaluation

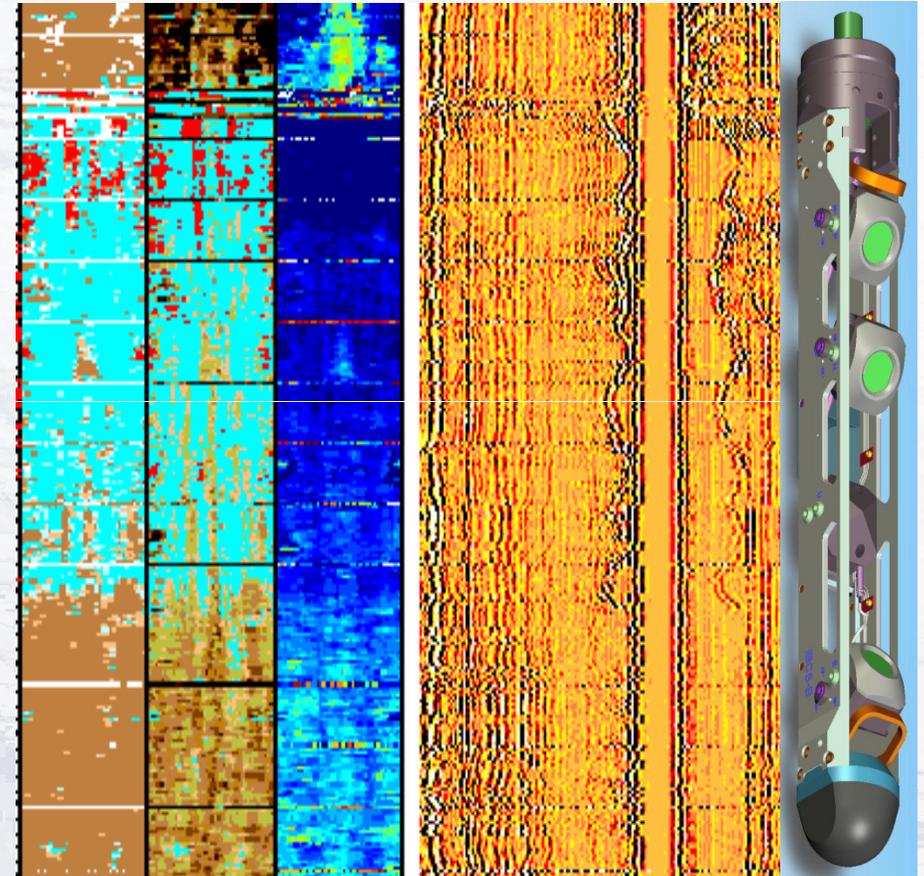
Overview of Basic & Advanced Cement Evaluation



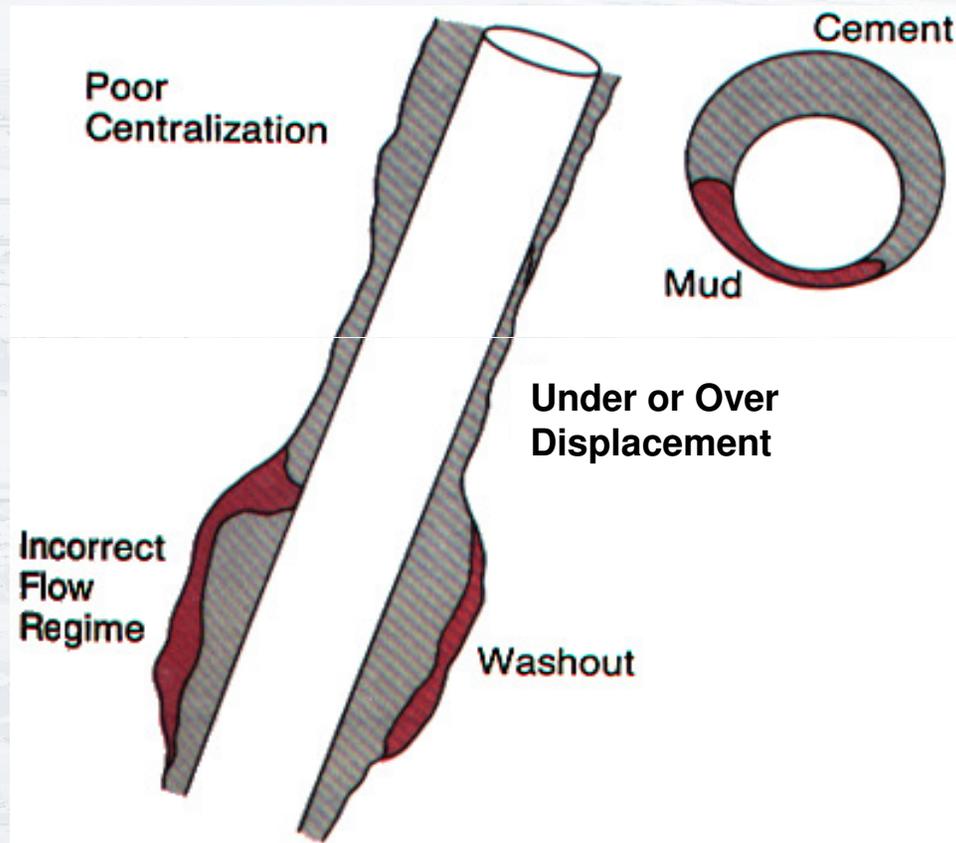
Stray Gas
Workshop
Pittsburgh, PA
11/6/2009

Overview

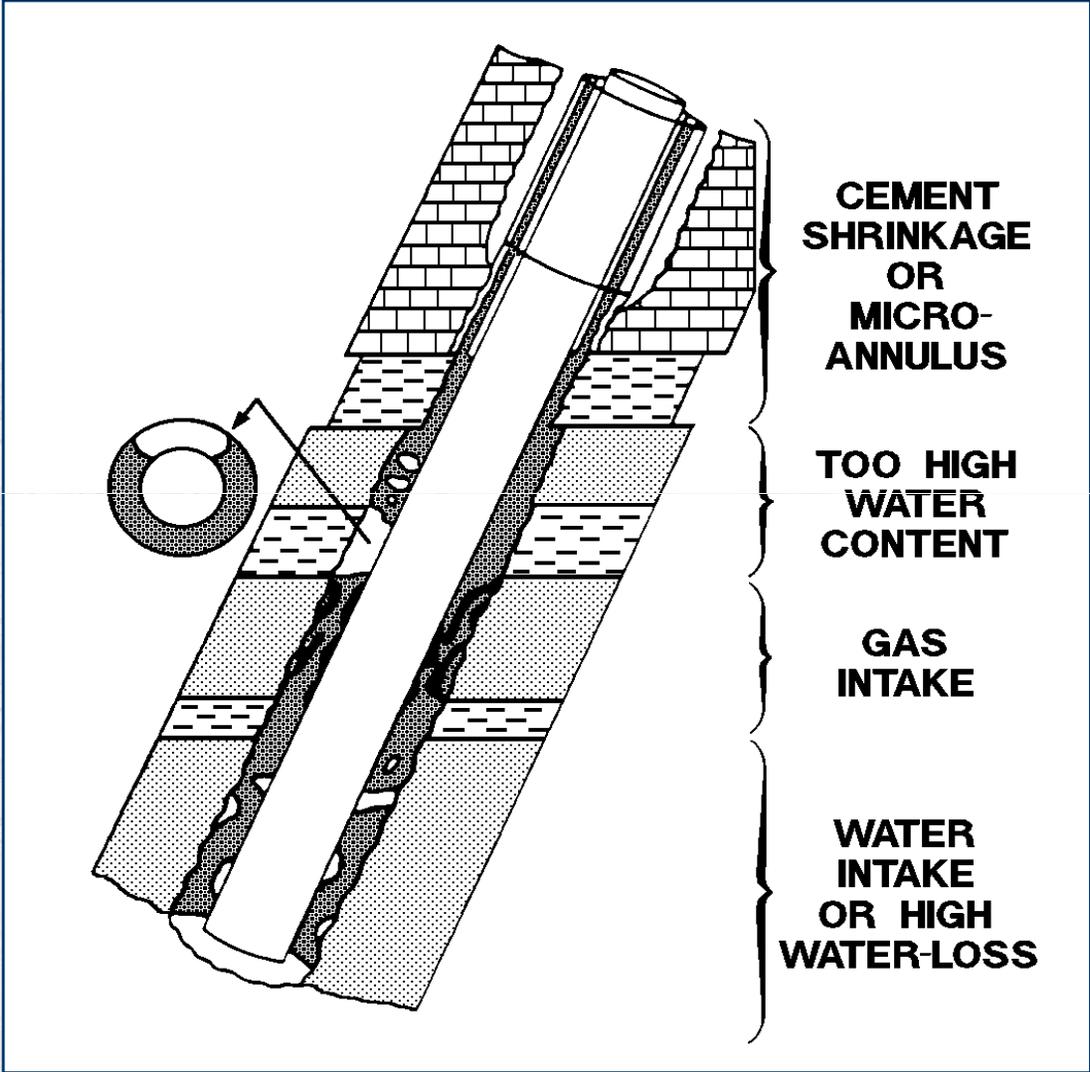
- Cementing Variables
- Cement Evaluation Today
 - Vertical and Horizontal Considerations
 - Traditional Tool Summary
 - CBL-VDL (Cement Bond Variable Density Log)
 - SCMT (Slim Cement Mapping Tool)
 - USIT* Ultrasonic Imager Tool
- Isolation Scanner*
 - Principle of measurement
 - Light-density cement evaluation
 - Third Interface imaging



Poor Slurry Installation

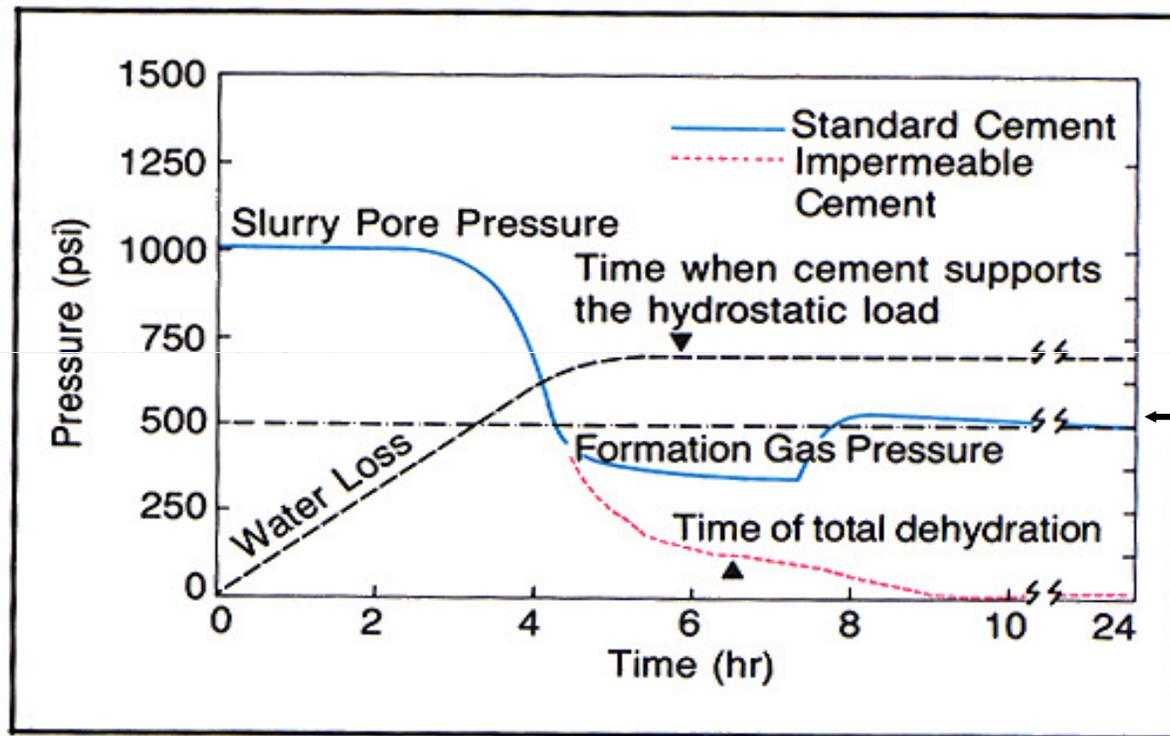


Poorly Adapted Slurry System



4 SLB
Figure A2

Pressure Drop in Cement Setting

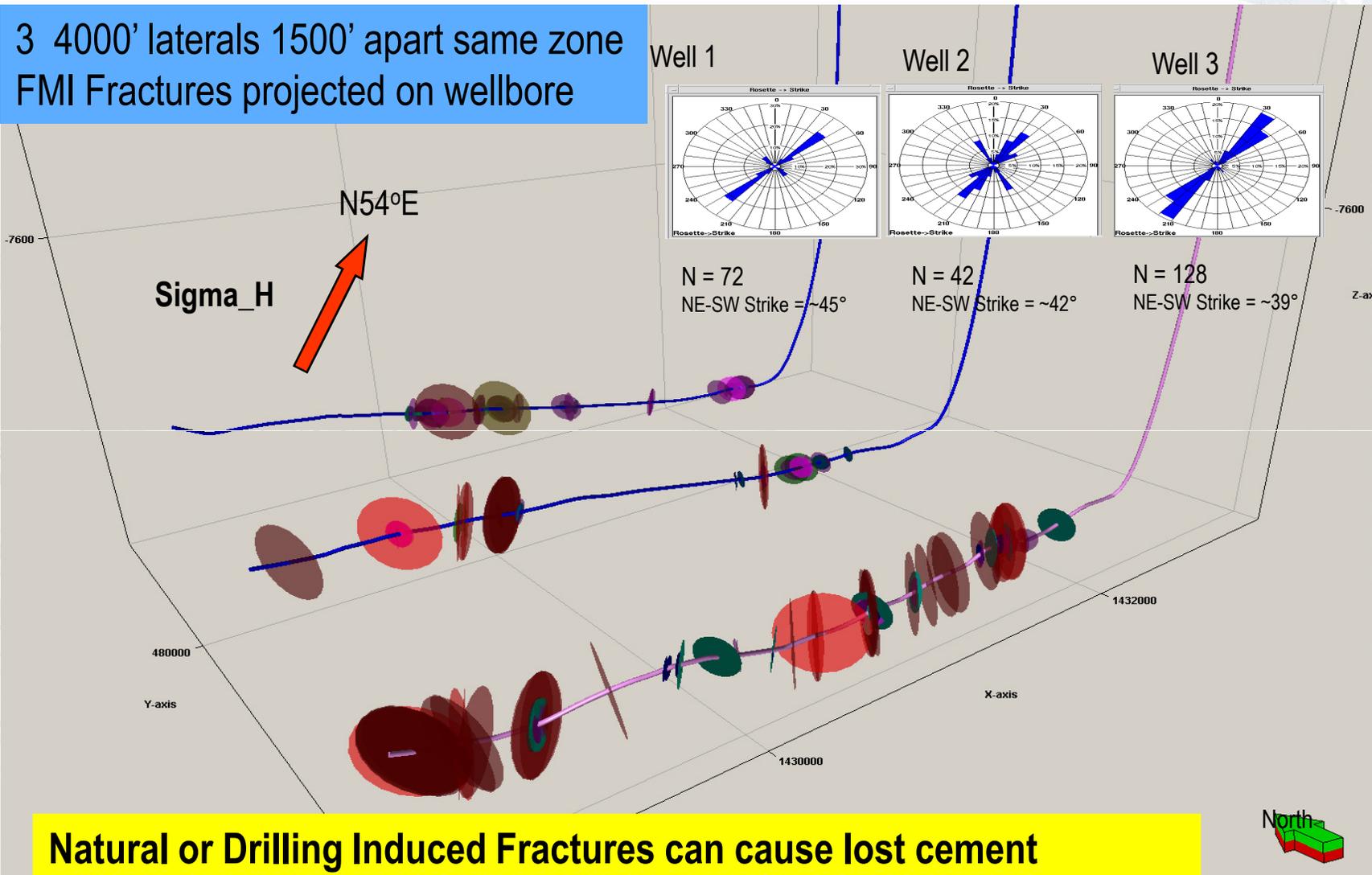


Loss of Compressive Strength & Possible Channeling if Slurry Pore $P <$ Formation P

Natural Fracture Considerations

GR

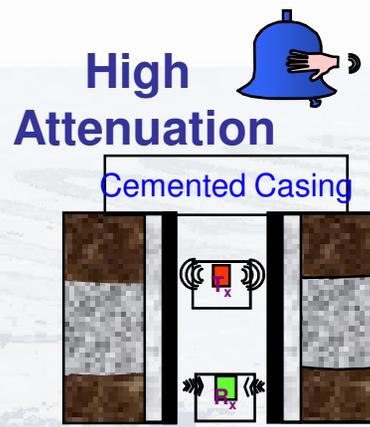
3 4000' laterals 1500' apart same zone
FMI Fractures projected on wellbore



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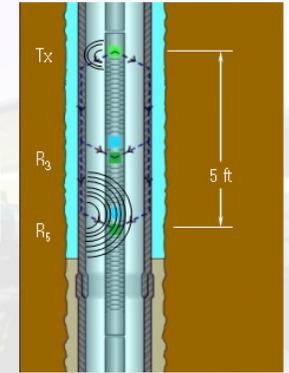
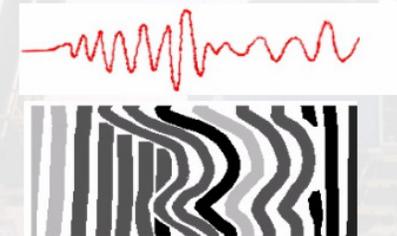
Natural or Drilling Induced Fractures can cause lost cement circulation &/or premature fluid loss, promoting channeling, lower compressive strength, deeper cement top

Sonic Measurement – Traditional CBL



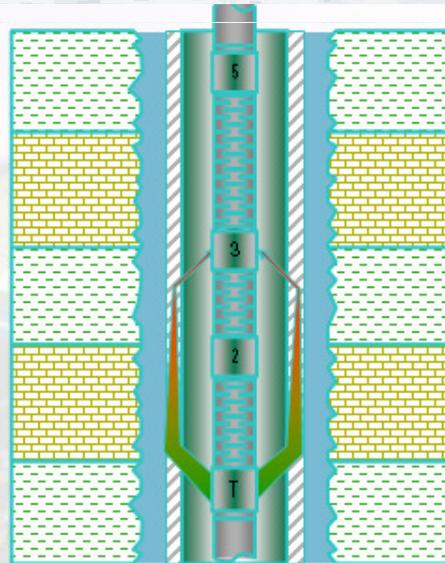
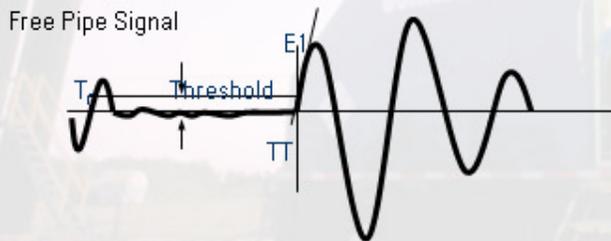
Variable density log

- 5 ft Receiver for VDL Analysis
- Allows differentiation between casing and formation arrivals



Basic interpretation

- Free pipe
 - No cement to casing bond
 - No attenuation of the signal

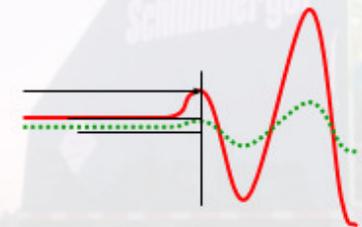


Good cement to casing bond

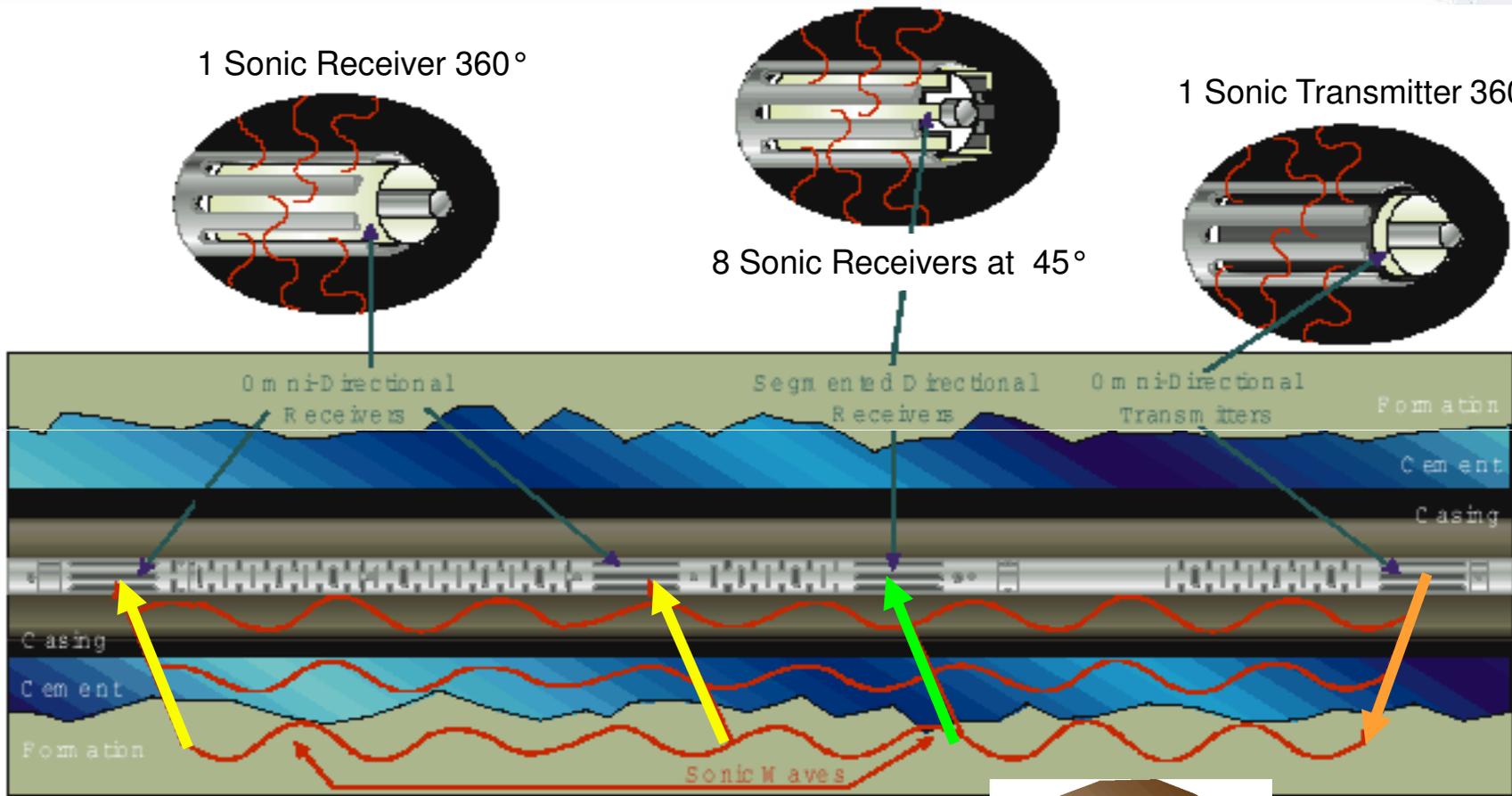
- If casing is well bonded, sound wave will be attenuated.
- The received CBL amplitude will be low.

CBL: Free Pipe

CBL: Good Bond



Slim Cement Mapping Tool (SCMT)

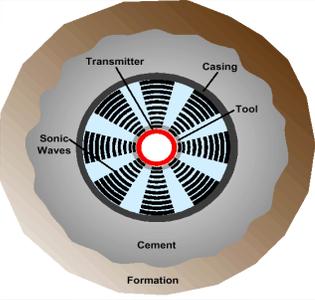


5' VDL

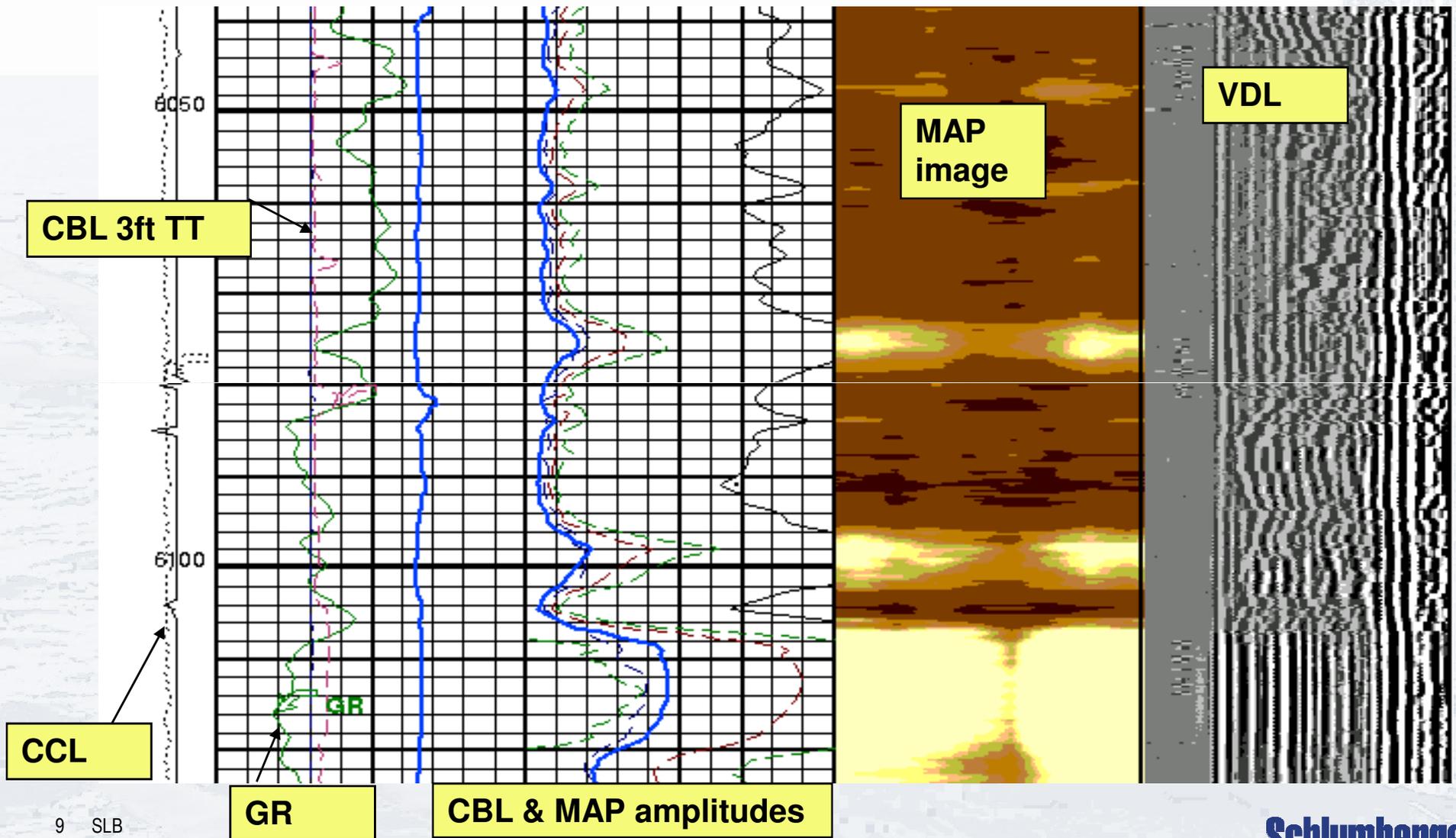
3' CBL

2' MAPs

Xmitter



Slim Cement Mapping Tool (SCMT) Log example



CCL

CBL 3ft TT

GR

CBL & MAP amplitudes

MAP image

VDL

Darker Image = Higher CS

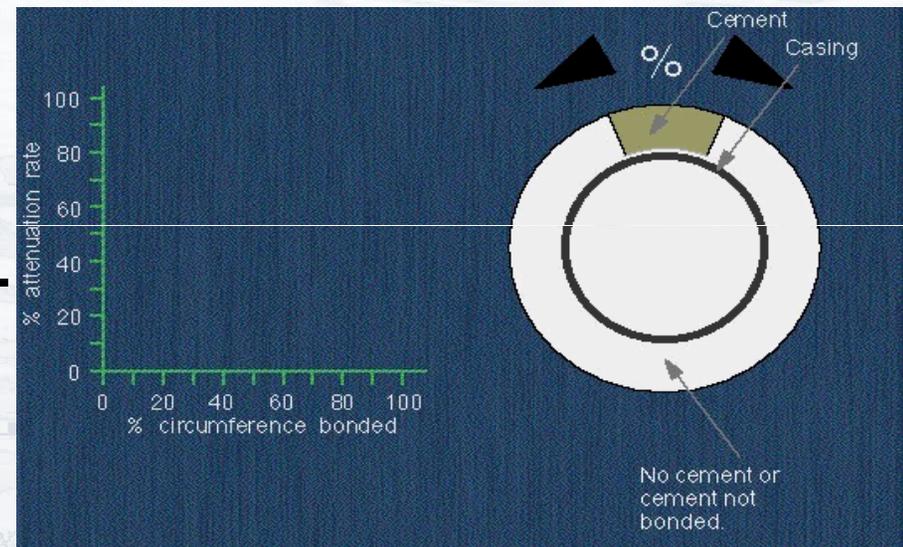
CBL Quantitative Interpretation

ATTENUATION

- Logarithm of E1 amplitude [first peak of CBL waveform]

BOND INDEX

$$BI = \frac{\text{Attenuation in zone of interest [dB/ft]}}{\text{Attenuation in best Cemented Section [dB/ft]}}$$



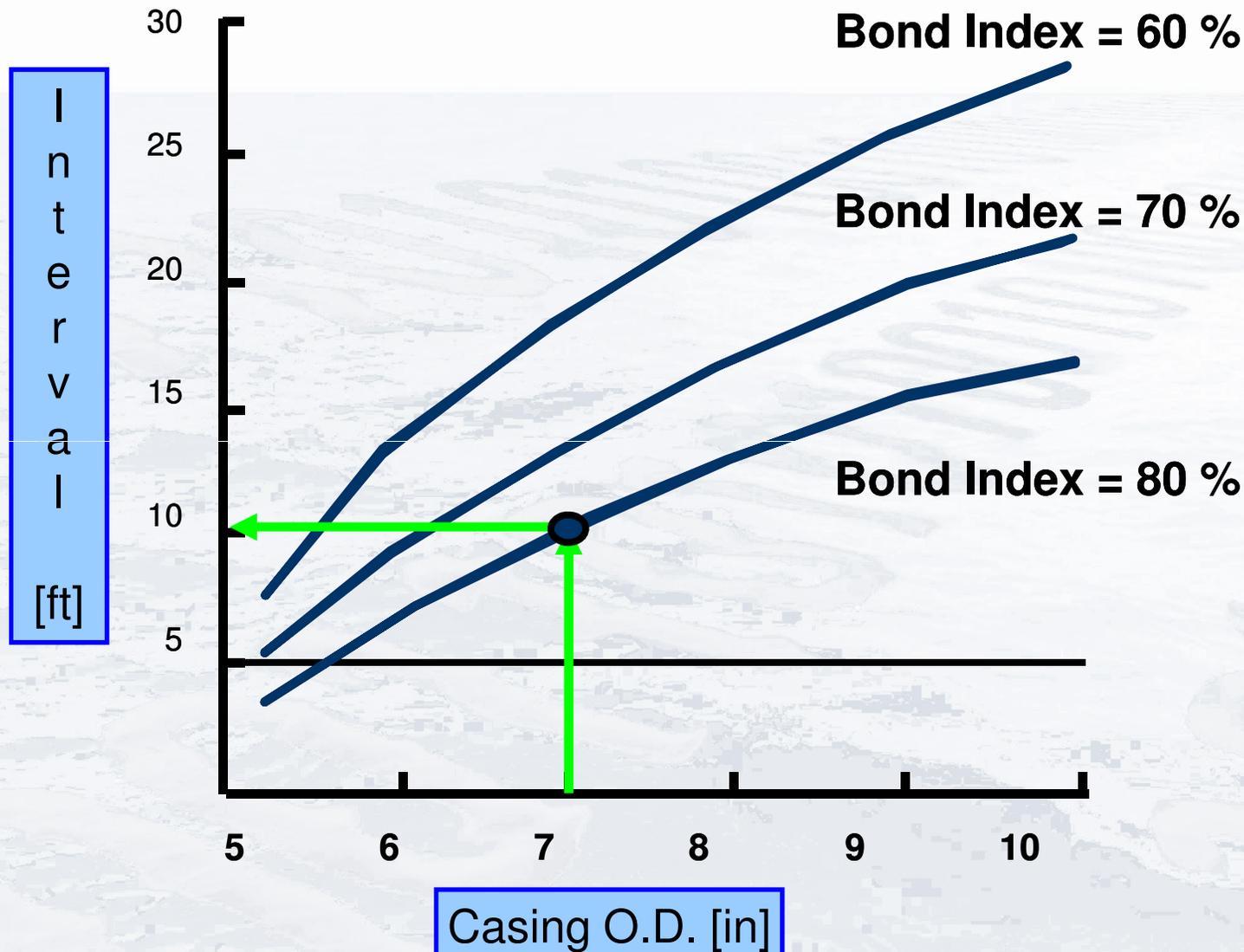
**Bond Index does not tell us if partially bonded intervals provide isolation or if channels exist –
360 Degree Average !**

11/16/2009

Amplitude and BI do not have a linear relationship

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Zone Isolation Based on Bond Index with CBL



Assumption is that un-bonded interval is not vertically connected - i.e. Channel

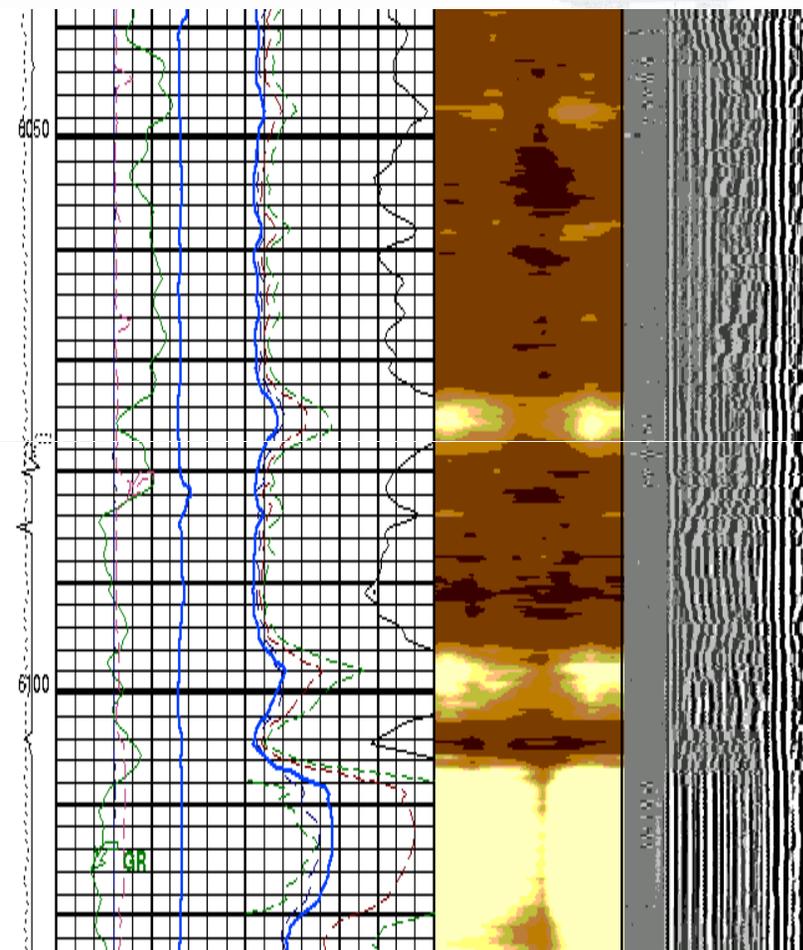
Amplitude Measurements

Strengths

- Respond to cmt. density (shear coupling)
- Work well in most well fluids, tolerates corrosion
- Qualitative cement-formation bond from VDL
- Mapping tools indicate broad channels

Weaknesses

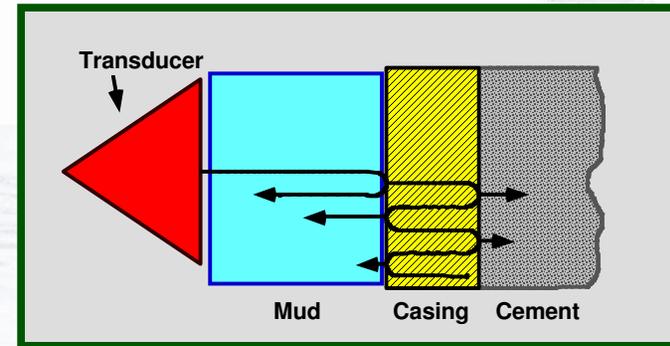
- **High CBL amplitude can be ambiguous**
 - Liquid microannulus (shear coupling lost)
 - Channels of contaminated cement and/or light cement
 - Not always related to poor hydraulic



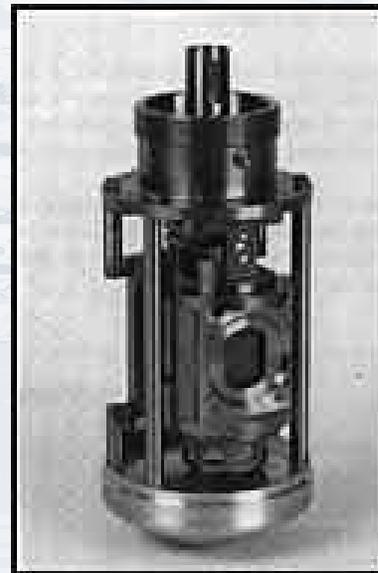
UltraSonic Imager (USIT)

Objective: Map Channels, evaluate Casing

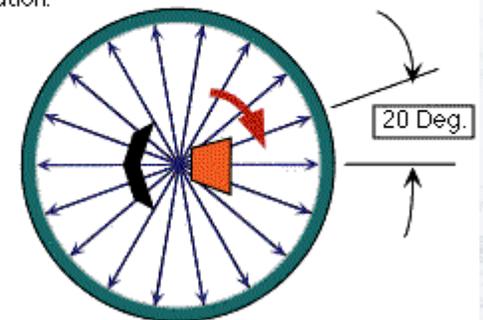
- ✓ Operates between 200 and 700 kHz
- ✓ Rotating Transducer provides full casing coverage – programmable resolution
- ✓ **Each firing measures radius, thickness and Acoustic Impedance of annular material for cement evaluation**
- ✓ Measurements Provide
 - ✓ Cement evaluation
 - ✓ Casing corrosion and wear



The transducer rotates at approximately 7.5 revs per second sampling 18-36 times per revolution every 5 or 10 degrees as needed/programmed

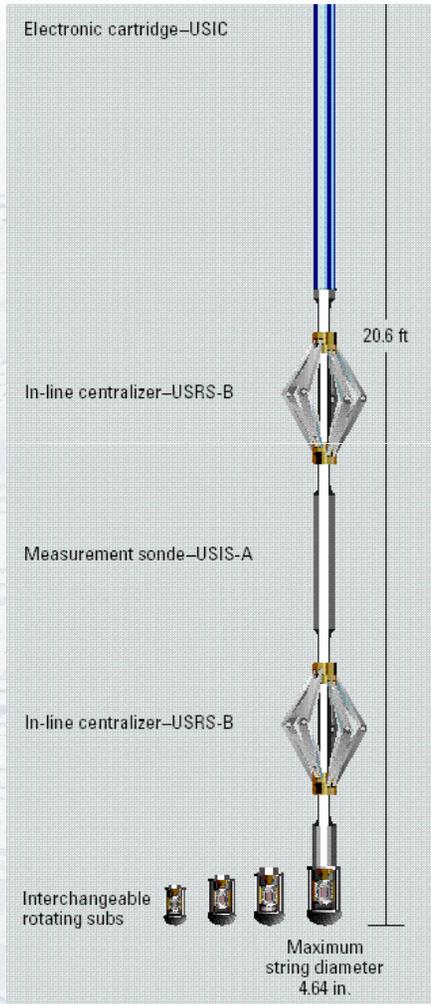


The transducer rotates at approximately 7.5 rps and is fired 18 times (every 20 degrees) per revolution.

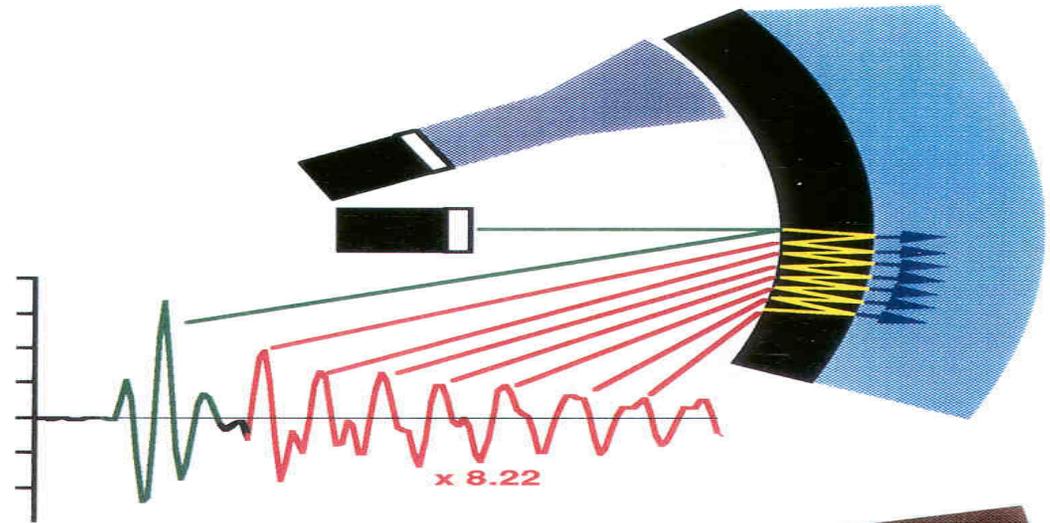


Schlumberger

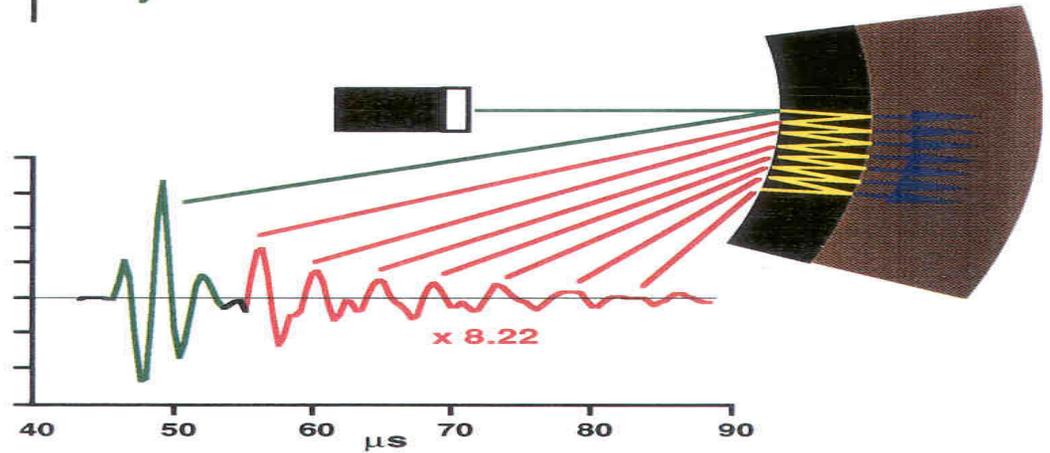
Principle : The resonance technique



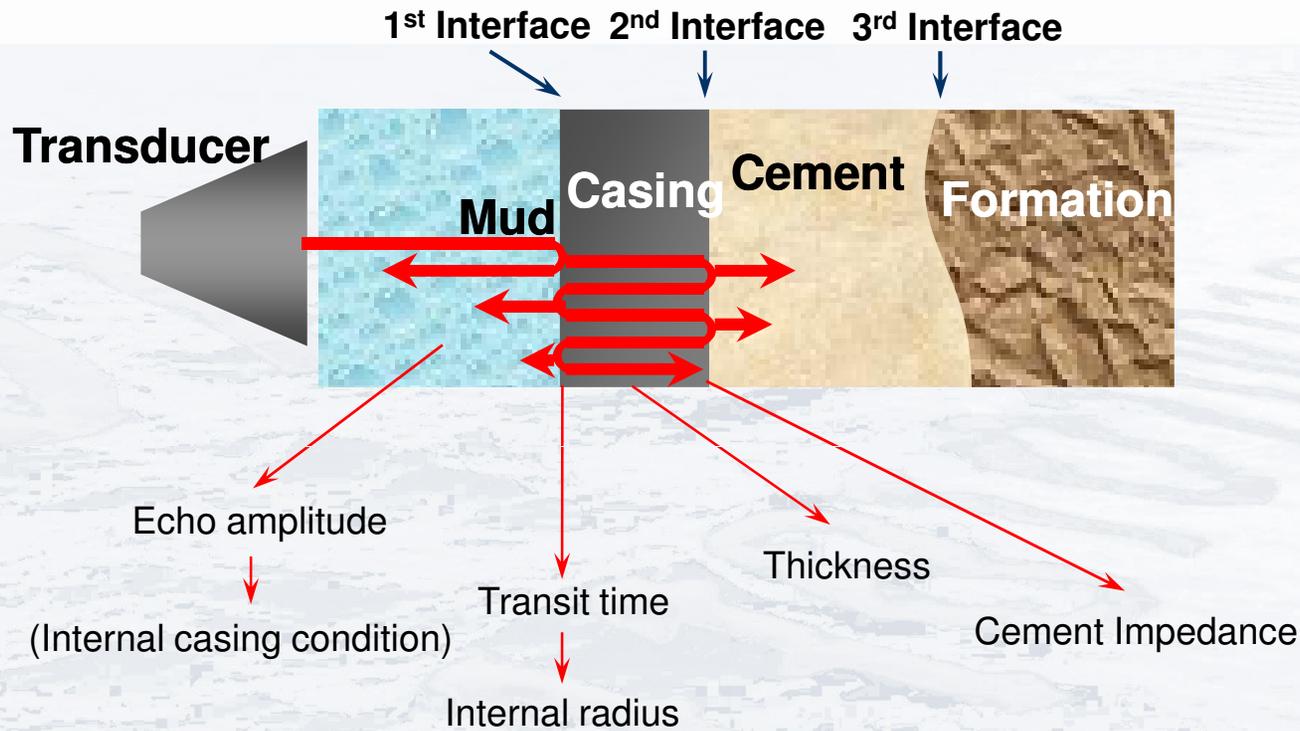
Free pipe



Good cement

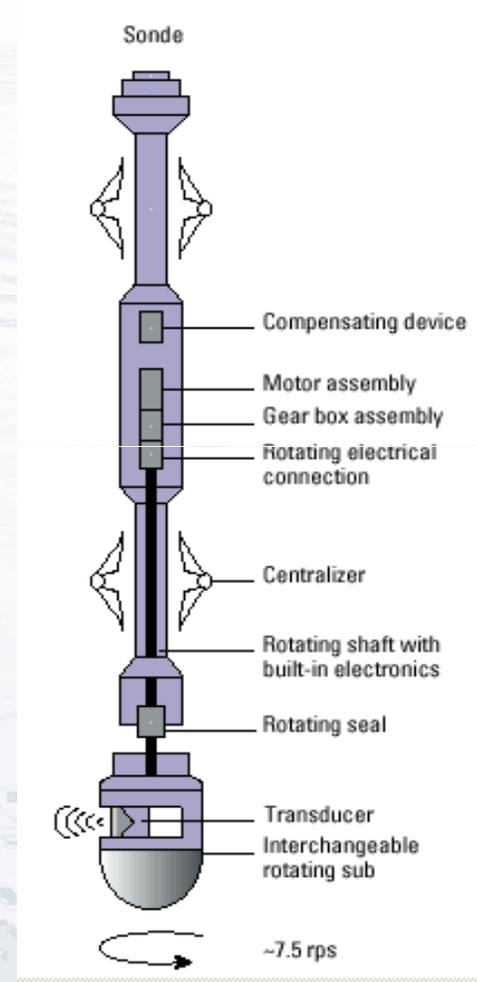


USIT Measurements



- Each Firing provides a Internal Amplitude, Radius, Thickness, and Annular Impedance Measurement at that point
- Sub rotates firing 18-36 times per rotation and spins at ~7.5 RPS
- Results Mapped providing much more complete information than CBL

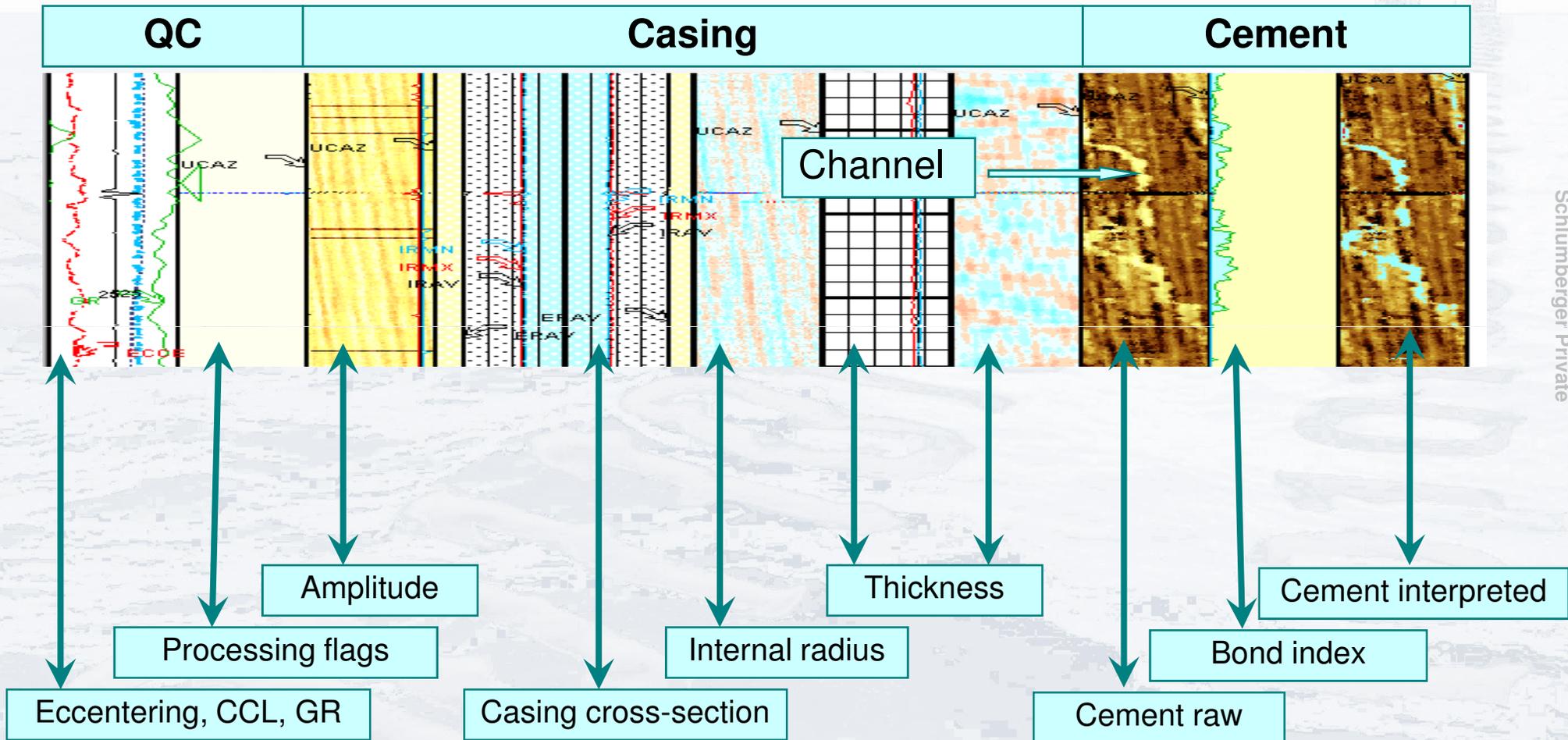
15 SLB
11/16/2009



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USI Log Display



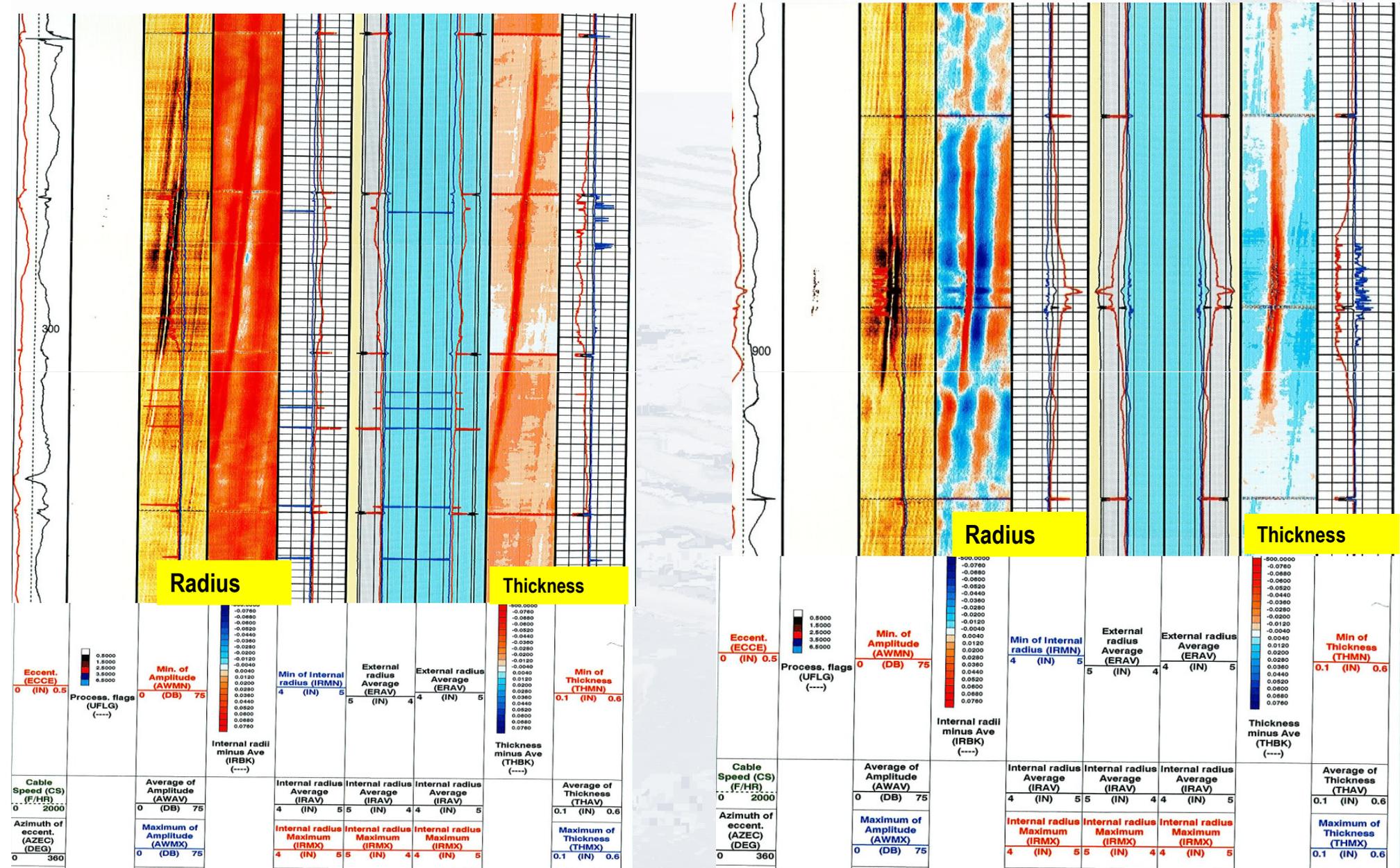
Schlumberger Private

16 SLB
11/16/2009

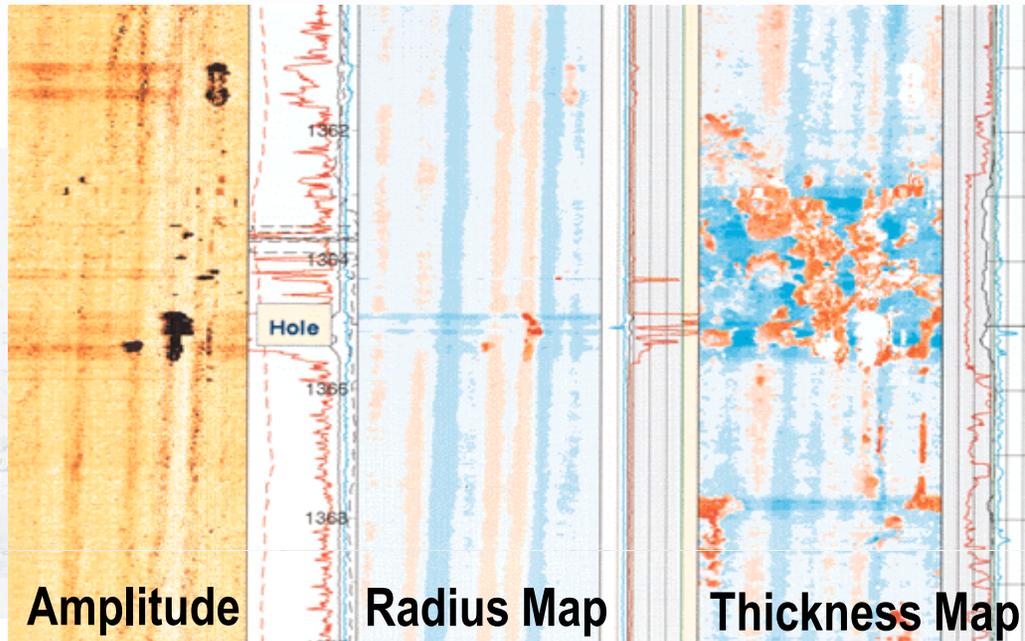
Now you have Bond Index and can visualize Channels

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Drilling Wear Example – USI Radius and Thickness Mapping



UltraSonic Corrosion Imager (UCI)



Same USI tool with UCI Sub

- ✓ Provides smaller “spot” size
- ✓ Higher Resolution
- ✓ Corrosion Mode Only
- ✓ Needs clean fluid for logging
- ✓ 3D products available

Internal Radius Specs

- ✓ Accuracy = 0.04”
- ✓ Resolution = 0.004”
- ✓ Beam Width = 0.11”

Thickness	
Range	0.18 to 0.6 in. [4.5 to 15.2 mm]
Accuracy	±4%
Resolution	0.015 in. [0.4 mm]
Sampling	
Azimuthal	2°
Vertical	0.2 or 1.5 in. [5.1 to 38.1 mm]
Logging speed	425 or 3000 ft/hr (dependent on sample rate)

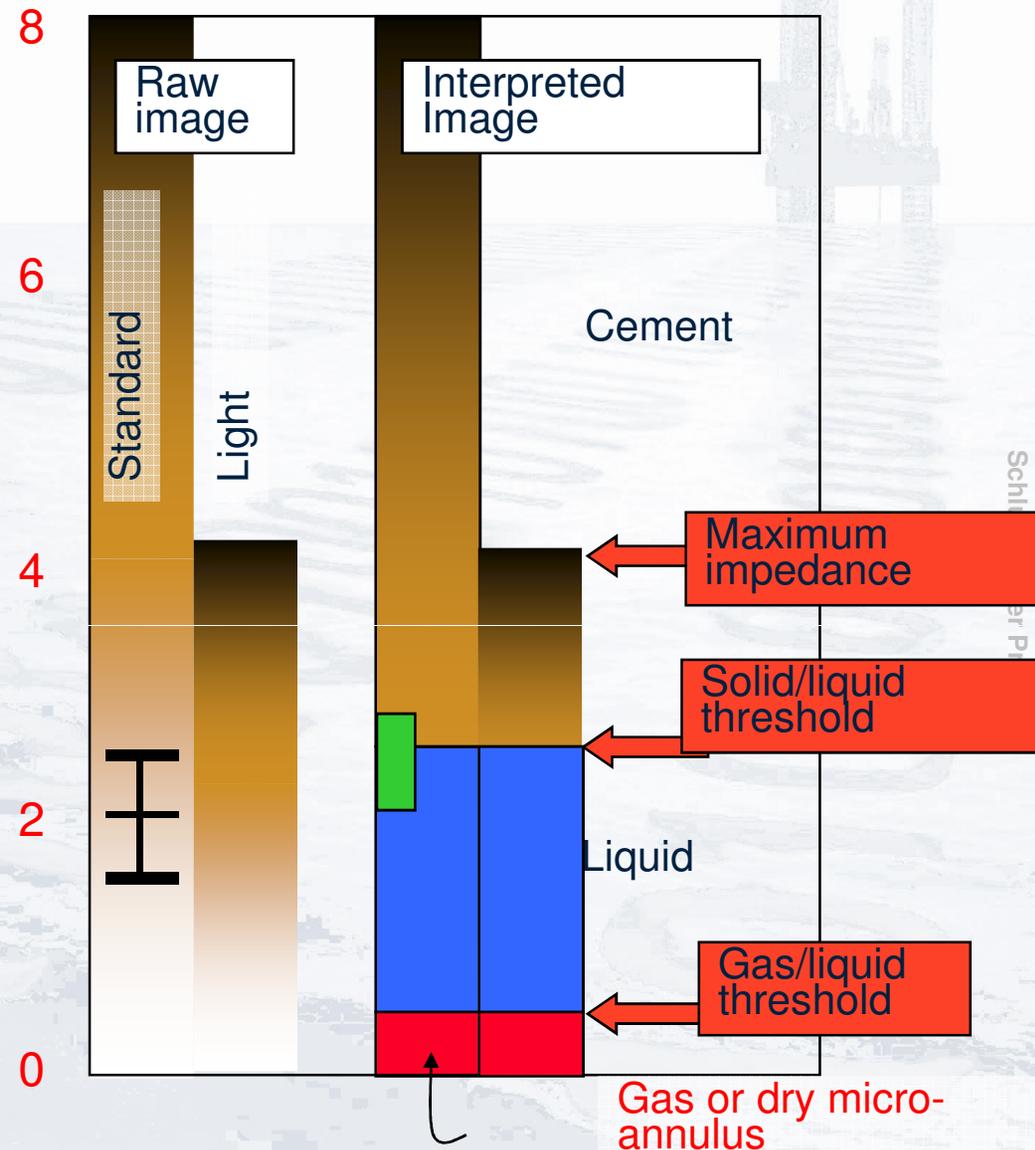
USI Tool Thresholds Setting

Z MRayl

The USI discriminates between solid, liquid and gas/dry microannulus using acoustic impedance thresholds.

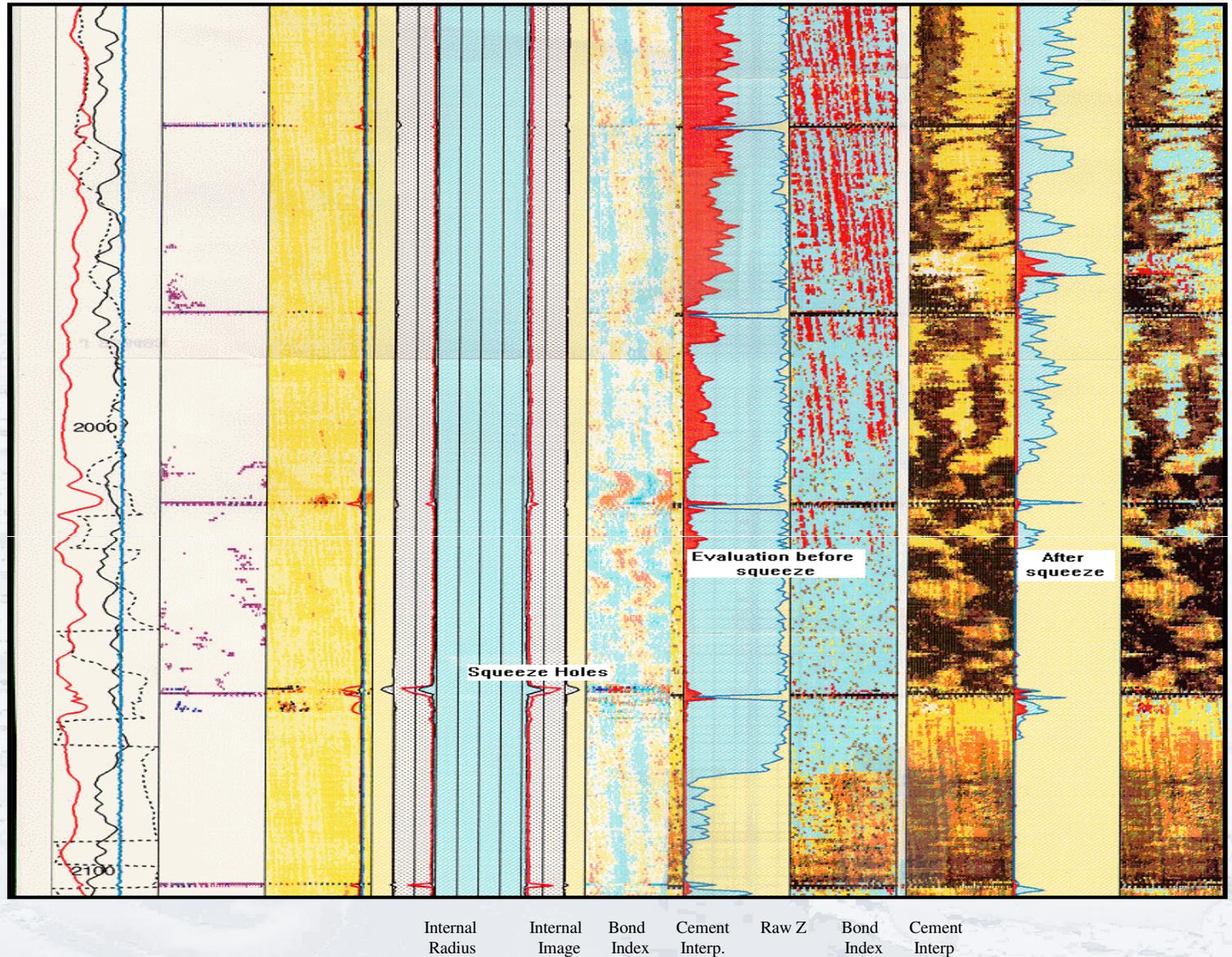
Works very well in uncontaminated cements above 11 ppg

When new "Light" Cement Acoustic Impedance approaches liquid impedance by design or by contamination – customize parameter selection



UltraSonic Imager

USI Log illustrates cement evaluation before and after squeeze. Gas was creating problems in the annulus prior to squeeze and is indicated by red shading.



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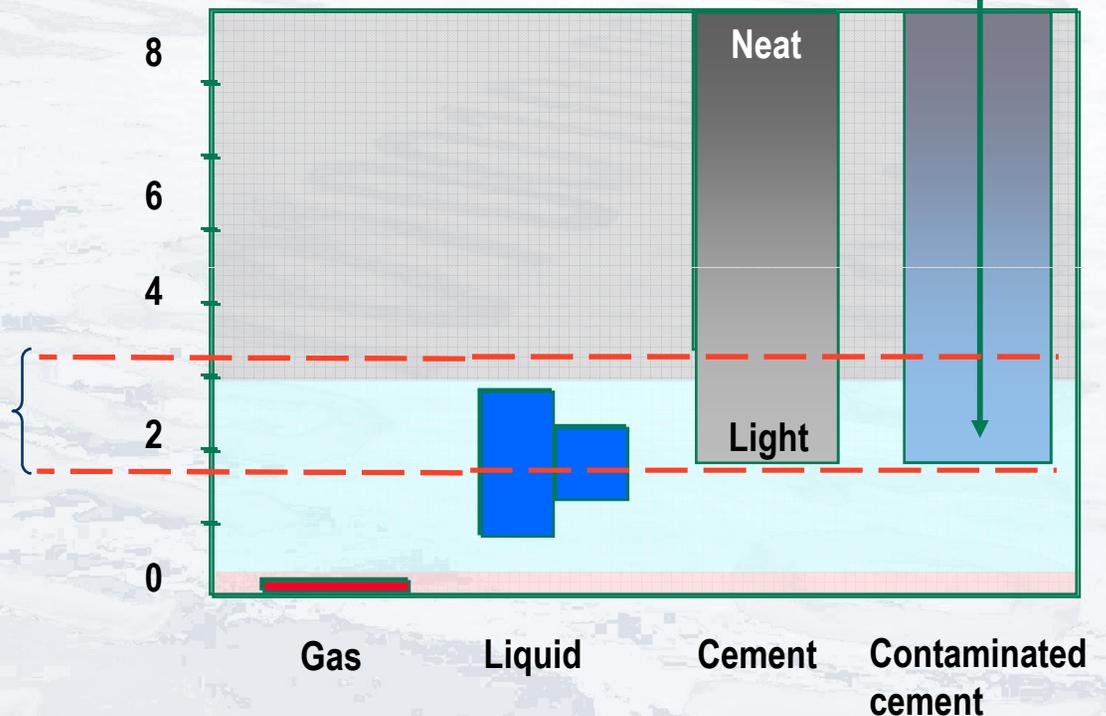
Sonic and Traditional Ultrasonic Limitations

- Heavy mud, thick casing limitations
- **Shallow depth of investigation**
- Dependant on logging fluid properties
- **Low-density cement evaluation**
- **Contaminated Cement Interpretation**

Difficult to diagnose with acoustic impedance or CBL-VDL measurements alone

Acoustic impedance

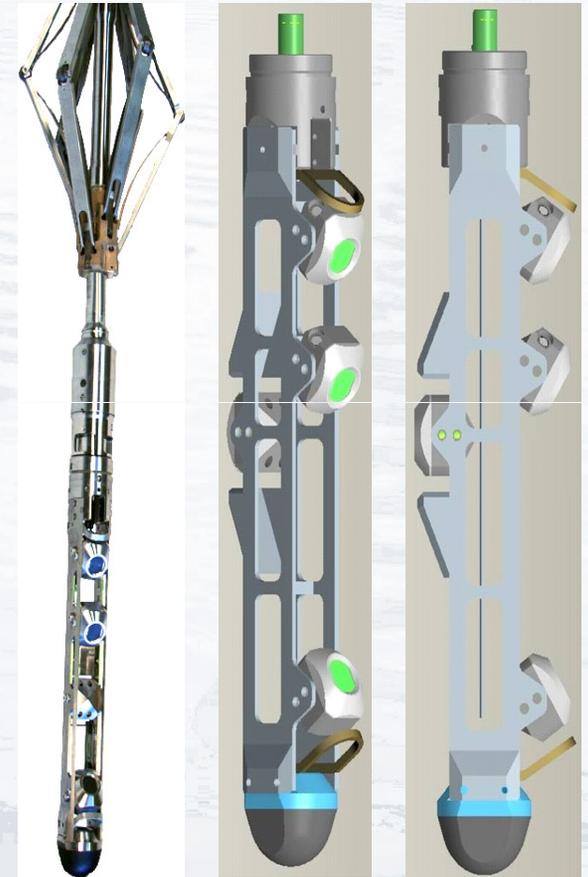
Increasing contamination



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Isolation Scanner* Introduction

- Service built on USI* UltraSonic Imager hardware
 - New Sub design and cartridge modifications
- Combines USI* measurement with a second measurement of *flexural attenuation*
 - Improved evaluation of lightweight and contaminated cements
 - Cement evaluation up to 20-mm [0.79-in] casing thickness
- Enhancement
 - Circumferential imaging, up to formation or second casing



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Isolation Scanner Principle

Combine USI (ultra sonic imager) measurement:

- Excitation of **thickness mode** of the casing
- Single transducer (Tx/Rx) configuration measuring resonance and decay of thickness mode
- Inversion for the acoustic impedance immediately behind the casing

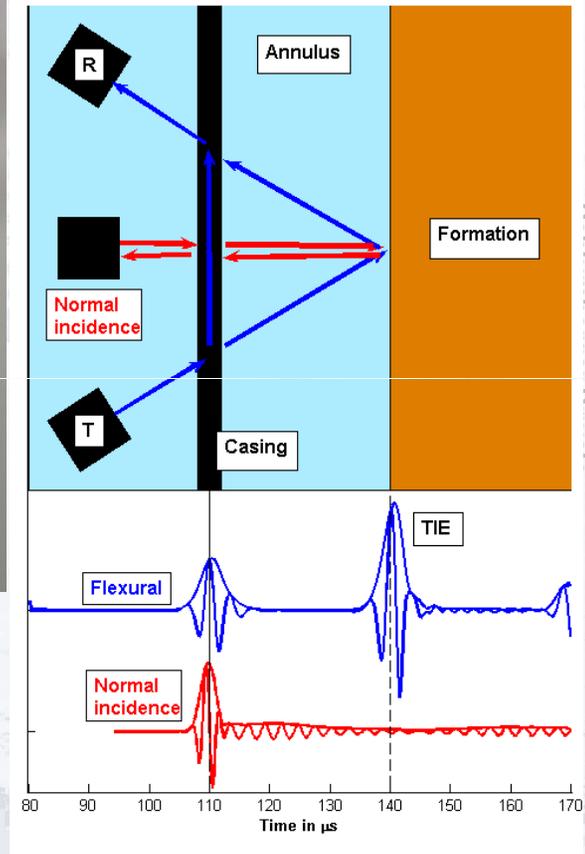
with FWI (flexural wave imager) measurement:

- Excitation of **flexural mode** of the casing
- Pitch-catch configuration (one Tx, two Rx) measuring flexural attenuation

to evaluate cement

$$\alpha = \frac{20}{\Delta x(cm)} * \text{Log}_{10} \left[\frac{\text{AmplitudeNear}}{\text{AmplitudeFar}} \right] \text{ dB / cm}$$

Imaging also possible (conditionally) up to third interface (formation/double string) due to flexural energy leakage

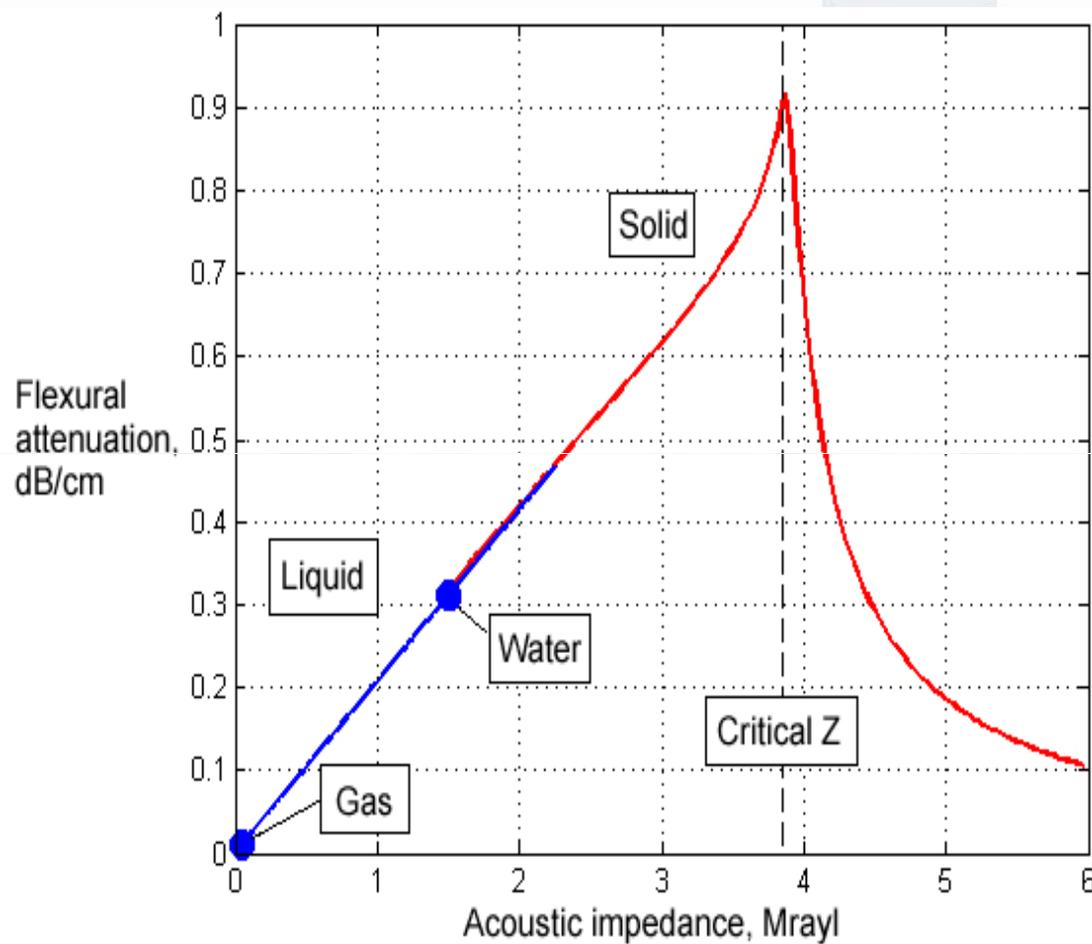


Acoustic Impedance and Flexural Attenuation

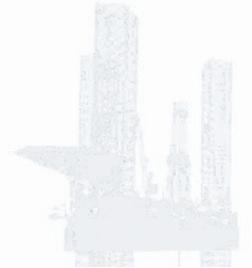
The behavior of Z and of the flexural attenuation are independent. This allows for identification of the material in the annulus with greater confidence.

To determine fluid properties in real time, the two independent measurements are combined, which eliminates the need for a separate logging pass or calculation.

Flexural Attenuation provides increased sensitivity to low impedance cements and is less affected by borehole fluid affects.



Material Identification in the Annulus

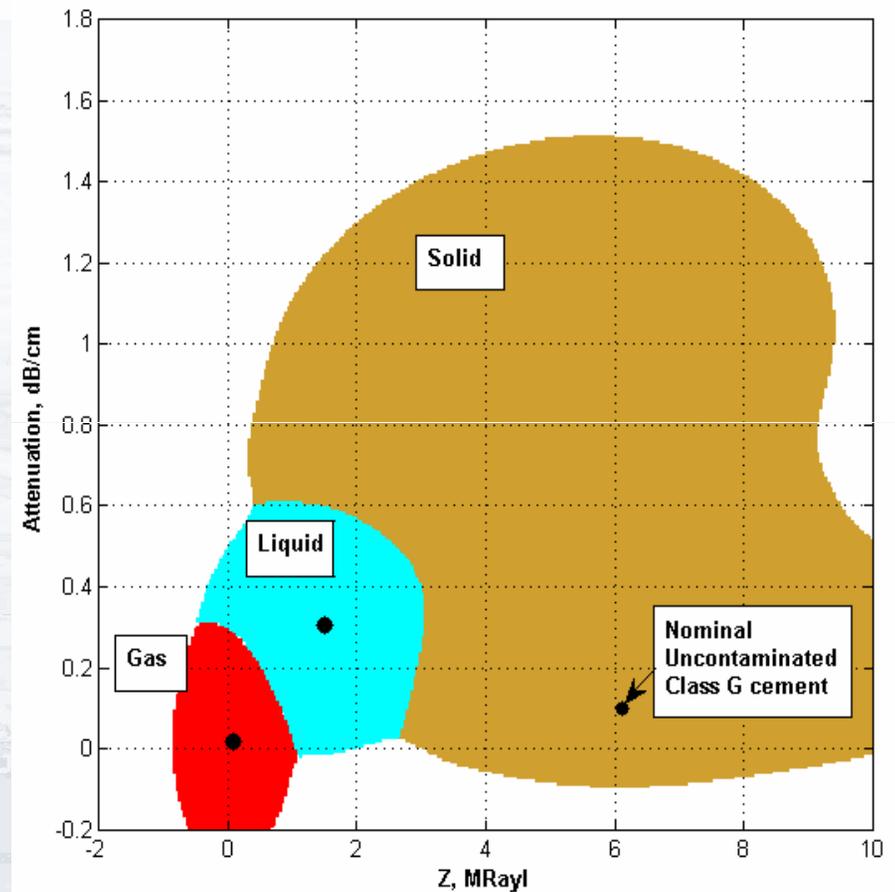


Traditional ultrasonic methods

- Determine acoustic impedance and set **thresholds** to discriminate between solid, liquid, and gas (SLG)

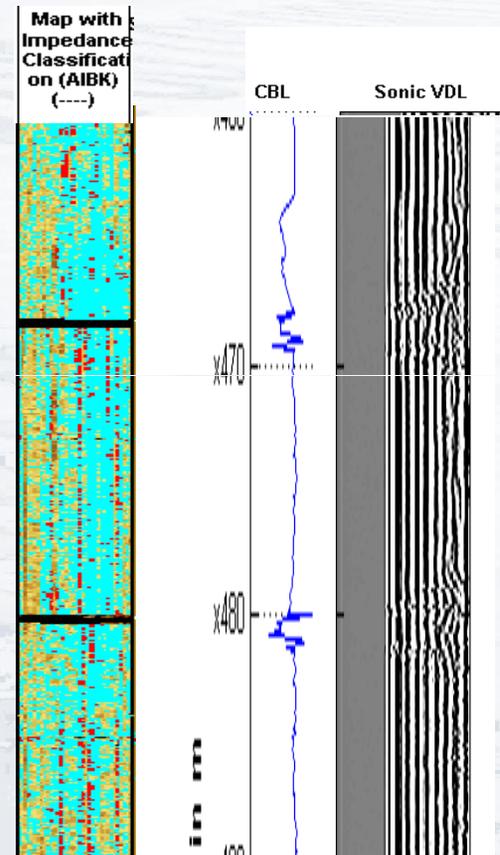
Isolation Scanner* service

- **Map** independent measurements to define annulus material in 1 of 3 SLG states, limiting reliance on thresholds
- Determining key fluid properties through combination of 2 independent measurements



Cement Evaluation: Existing Measurements

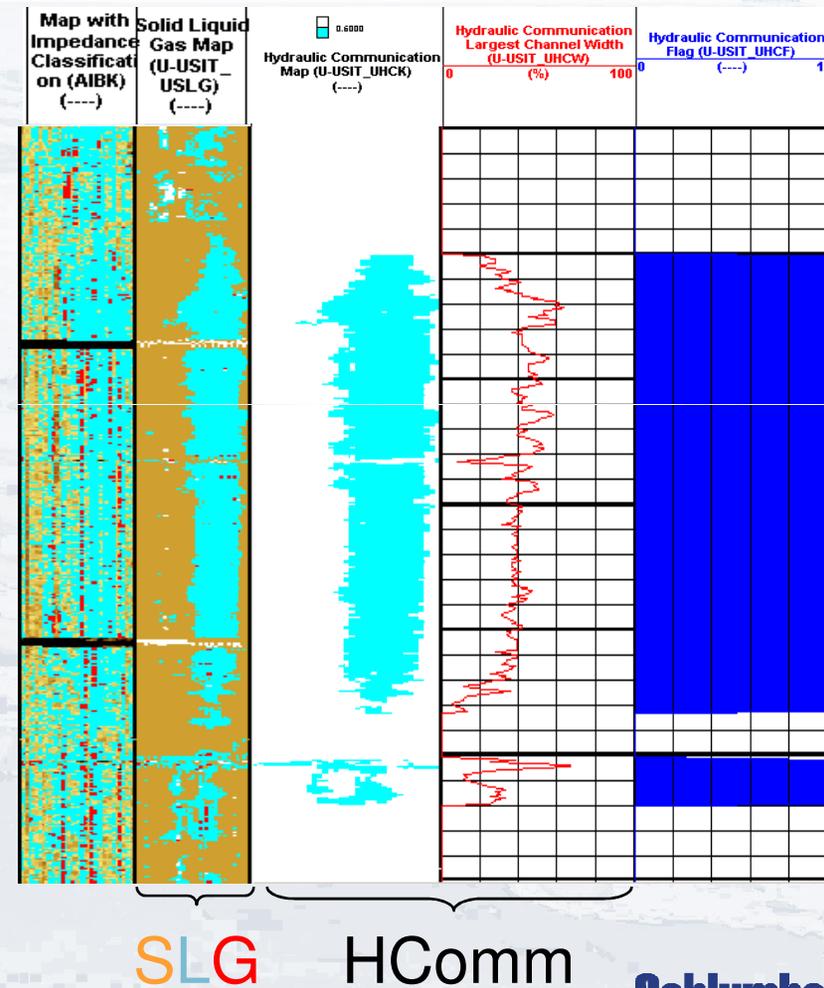
- 9 ppg LiteCRETE Cement
- Acoustic Impedance & CBL Only



Cement Evaluation: SLG & Hydraulic Communication

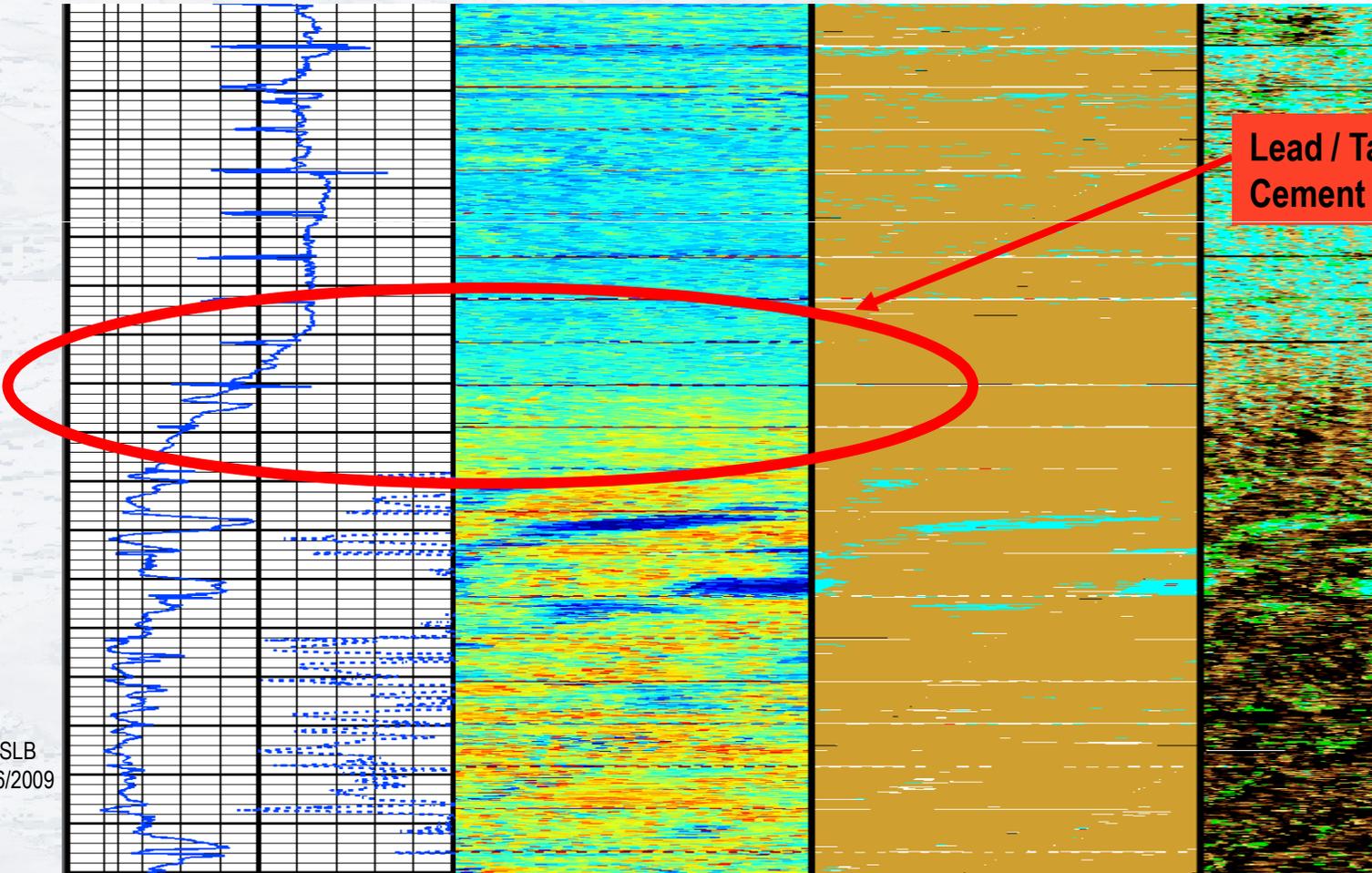
Flexural Attenuation Added

- Simplified picture via SLG Map
- Identifies significant channels in Hydraulic Communication Map
- Displays measured channel width



CBL vs SLG with Light Cement

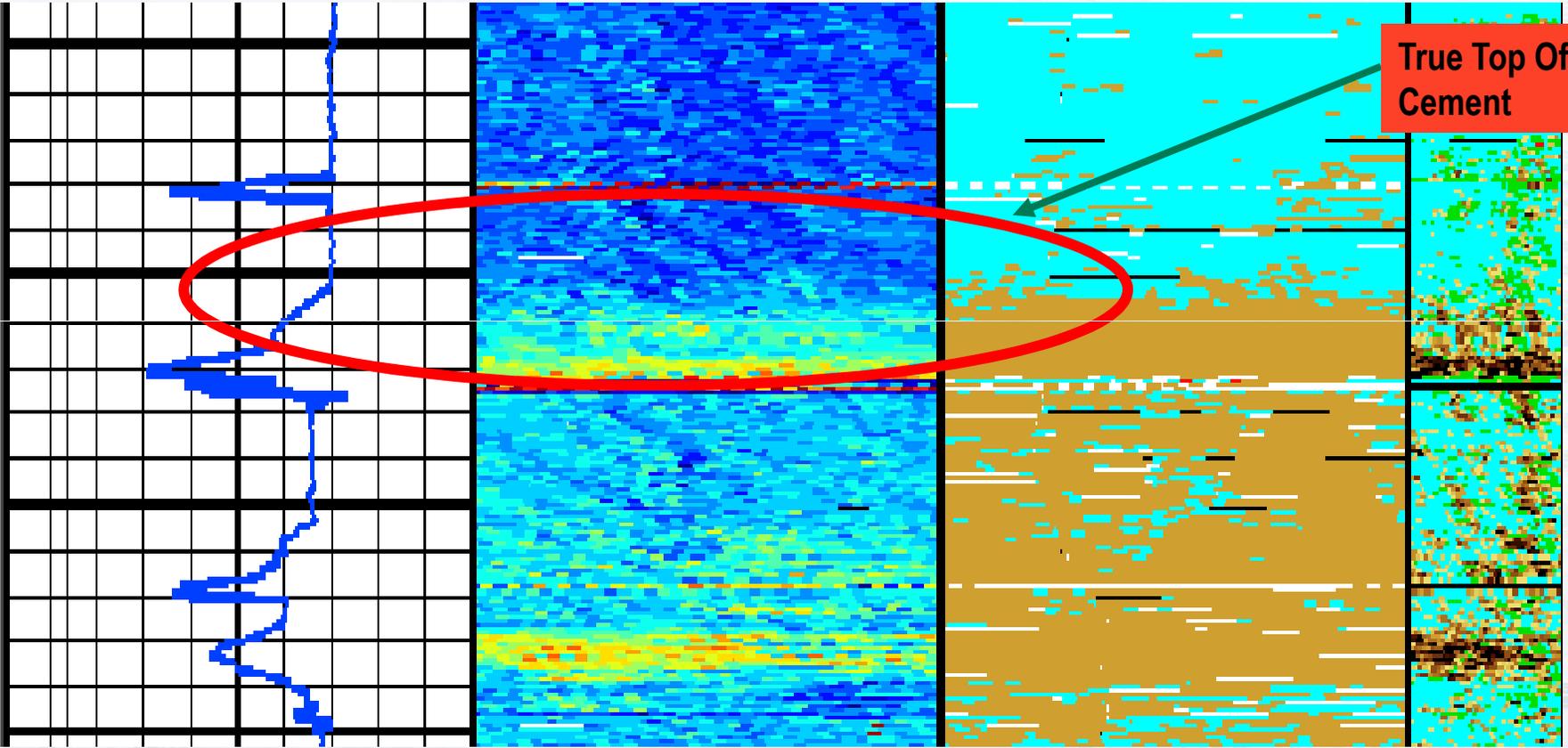
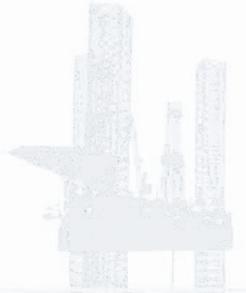
CBL Flexural Attenuation SLG Map Cement Map



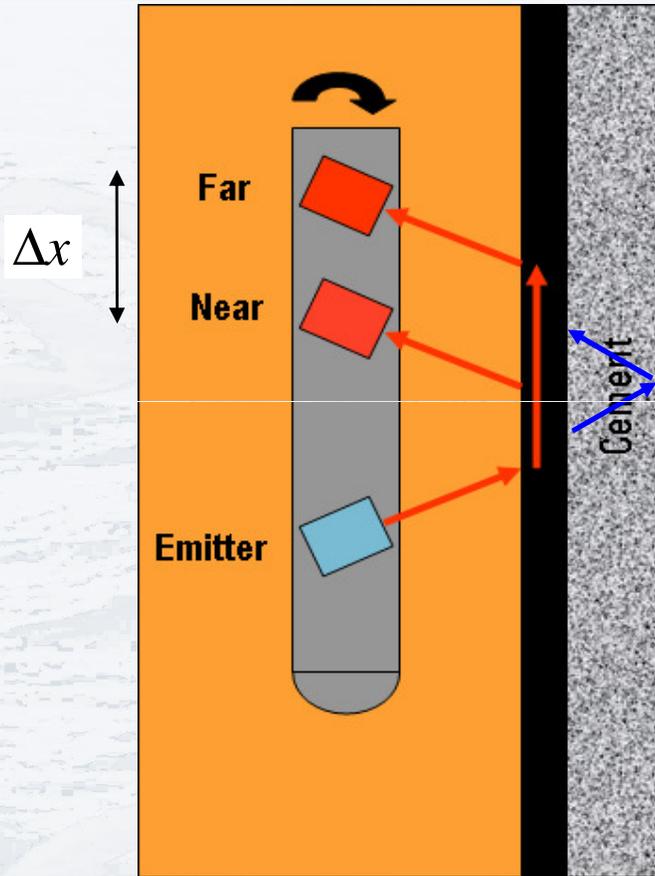
Lead / Tail contact ! - Not Cement Top !

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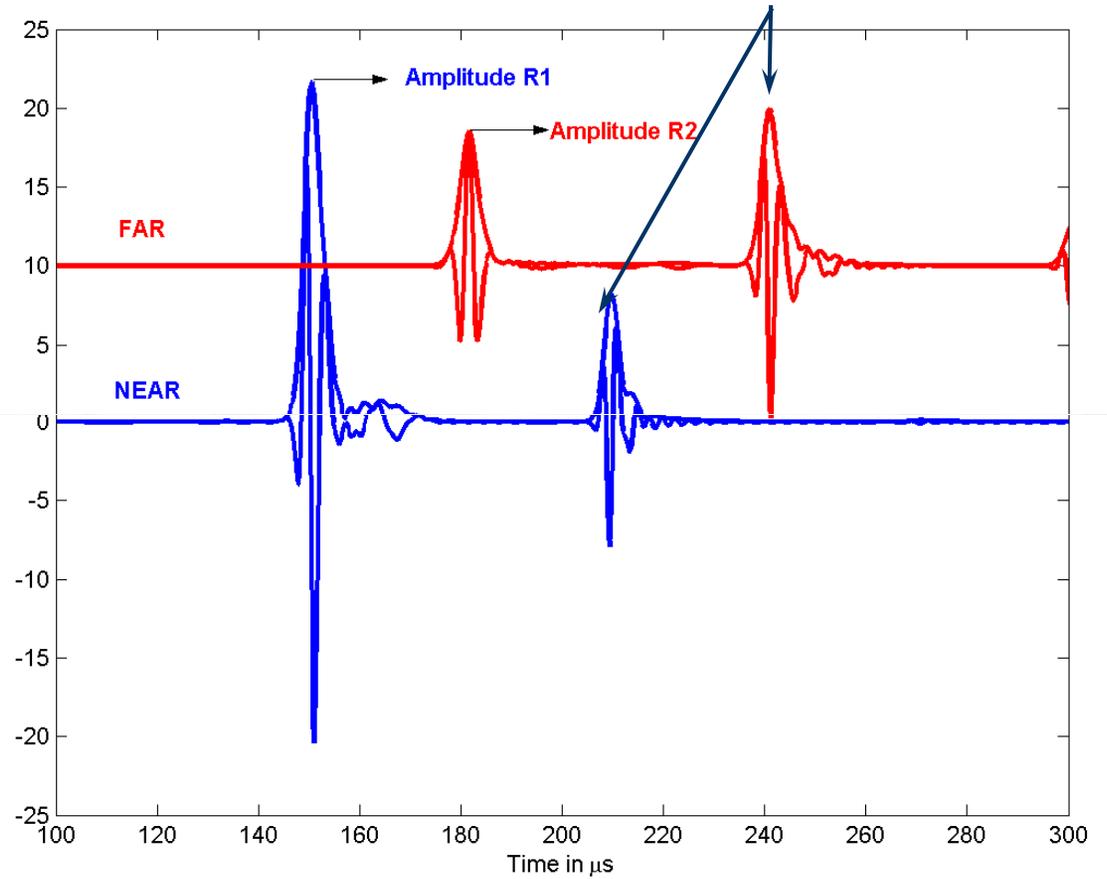
CBL vs SLG with Light Cement

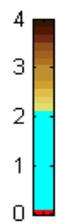
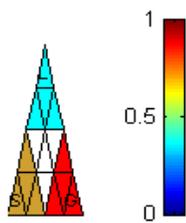
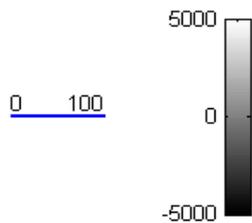
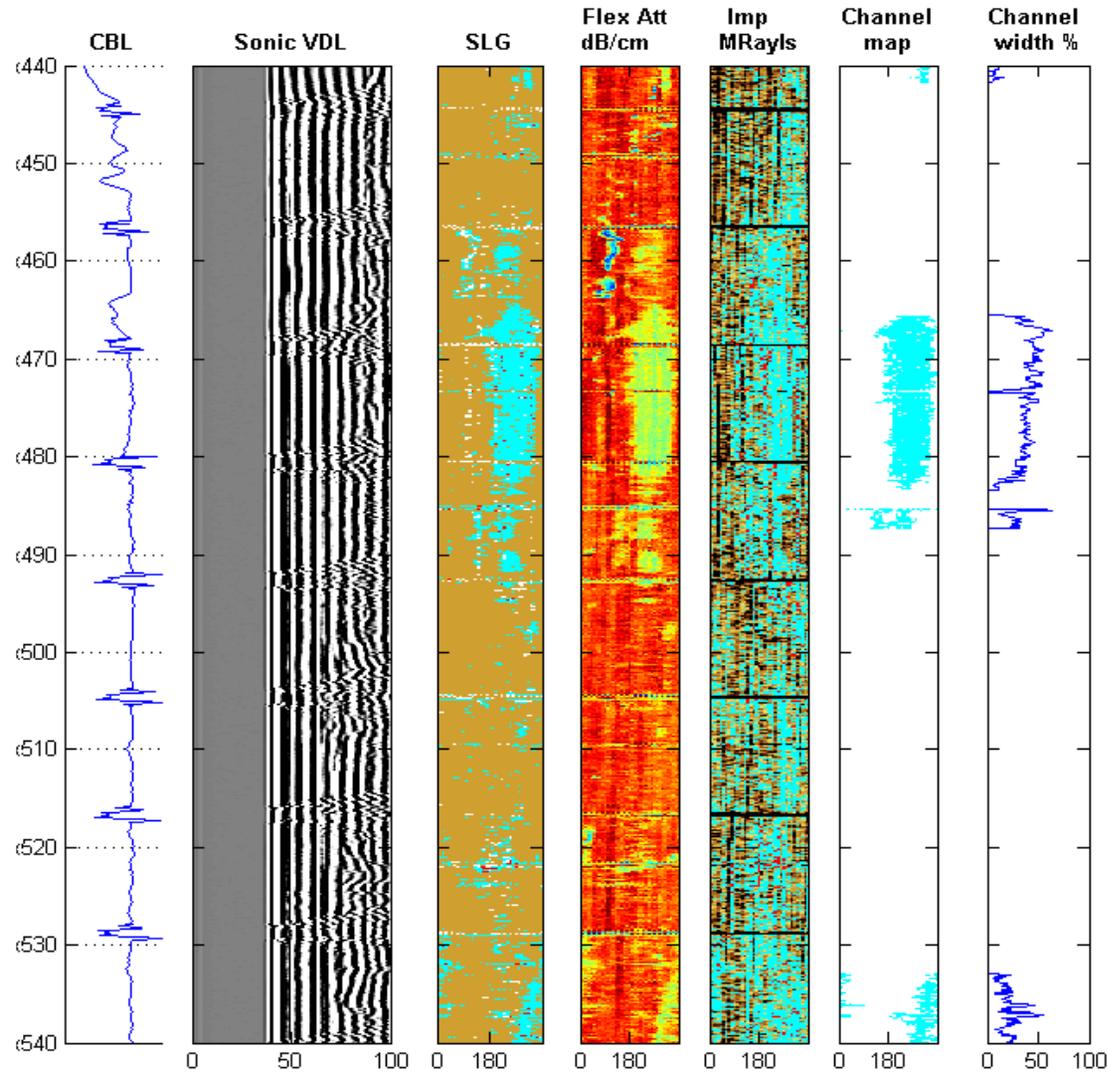


Third Interface Echo Response



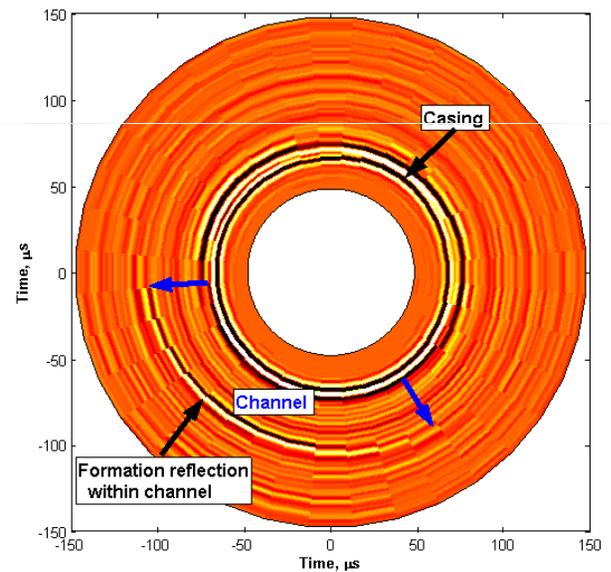
3rd Interface Echo Signals





Log Example: LiteCRETE

9 ppg (1050 kg/m³)



Third Interface Echo (TIE) Evaluation

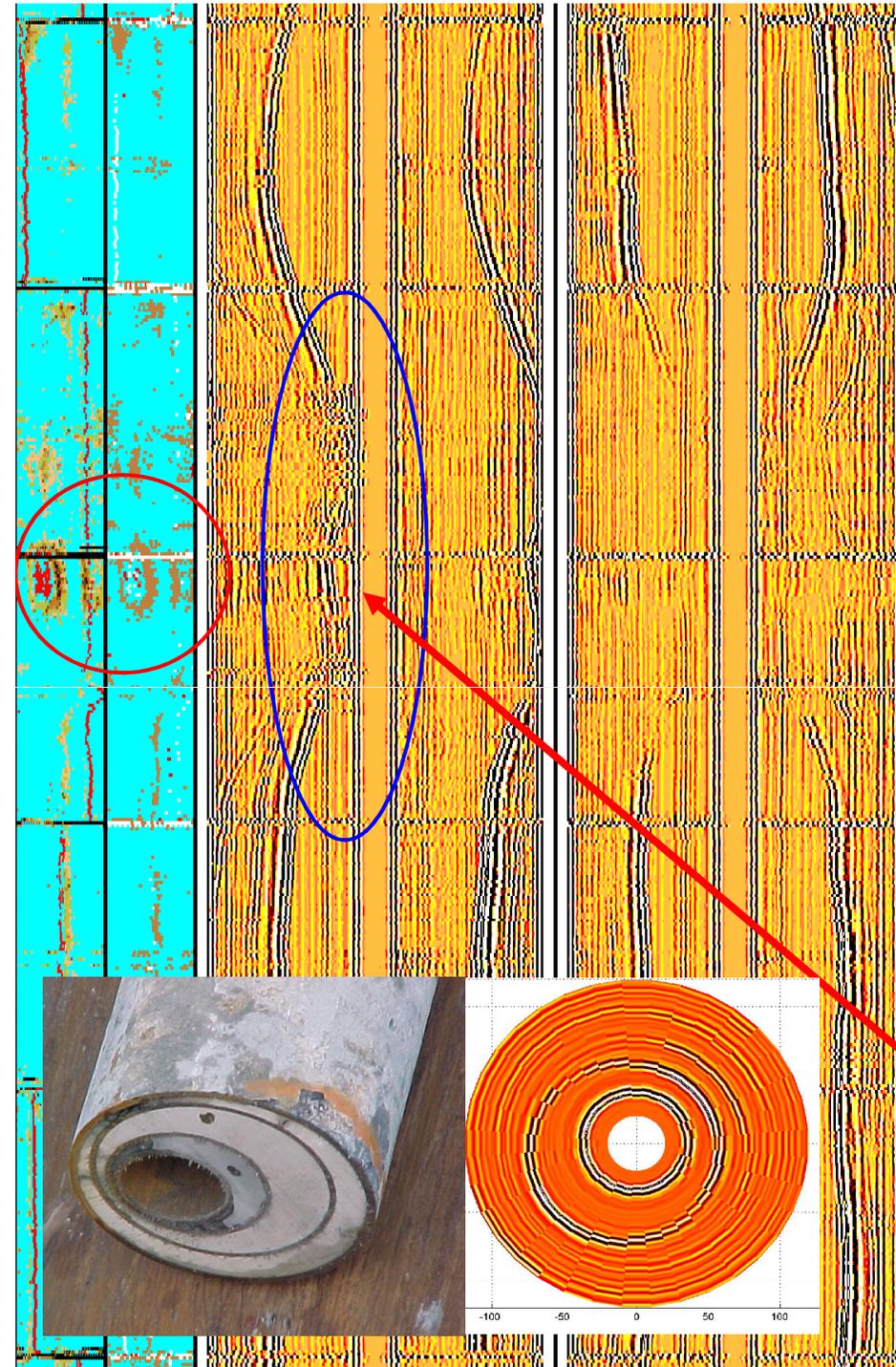
- Views reflections in impedance contrasts away from casing
- Can Image Surface casing location
- Eccentering Evaluation for improving next well design
- Channel Elimination – Hydraulic Isolation for frac containment
- Excellent tool for systematic cement improvement



**Casing touching BH
wall**

**Seen on the map as
rings**

Schlumberger



Best tool to run?

Depends on Objective of evaluation

- **Simple TOC only** - Amplitude type measurement
 - CBL
 - SCMT – 8 Segment Cement Map for Channel ID
- **Channel & Gas ID for Zonal Isolation in Neat >13 #/gal Cements**
 - USI
- **Contaminated (Gas) Neat Cements or Lighter Slurries**
 - USI or Isolation Scanner
- **Lightweight cement evaluation (<11 ppg) or eccentricing evaluations**
 - Isolation Scanner

Conveyance by Tractor, eCoil (heptacable) or with TLC on Tubing/DP