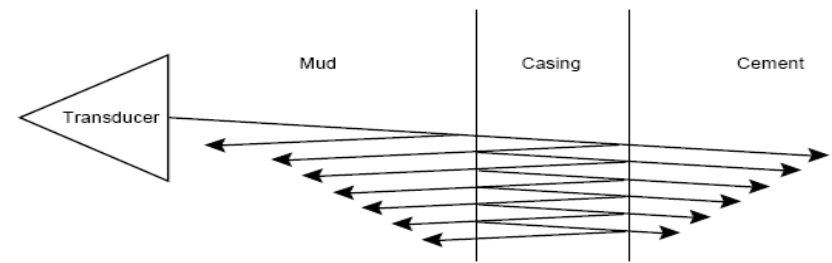
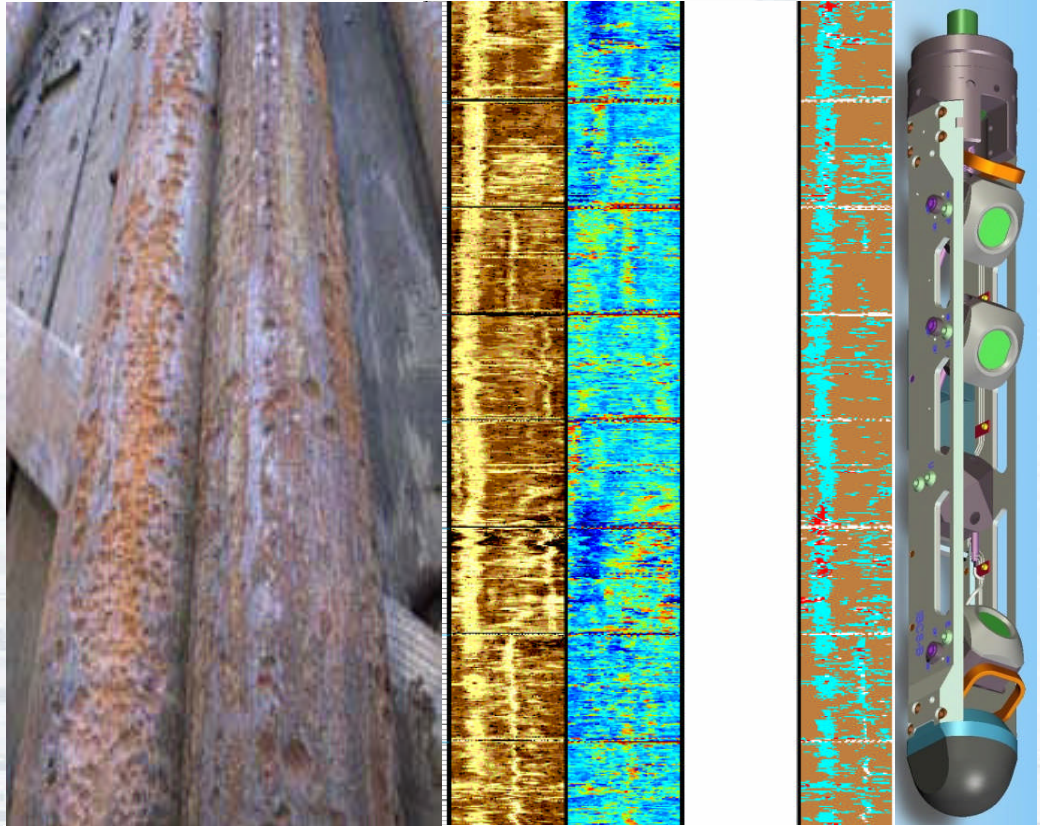


# Basic Cement Evaluation

- Cement Bond Log
- UltraSonic Cement Evaluation
  - UltraSonic Imager (USI)
  - Isolation Scanner
    - Flexural Attenuation
    - Third Interface Echo applications



**Dirk Valstar**

NAL Well Integrity Domain Champion

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valstar1@slb.com

**Schlumberger**

# Why Cement Evaluation ????

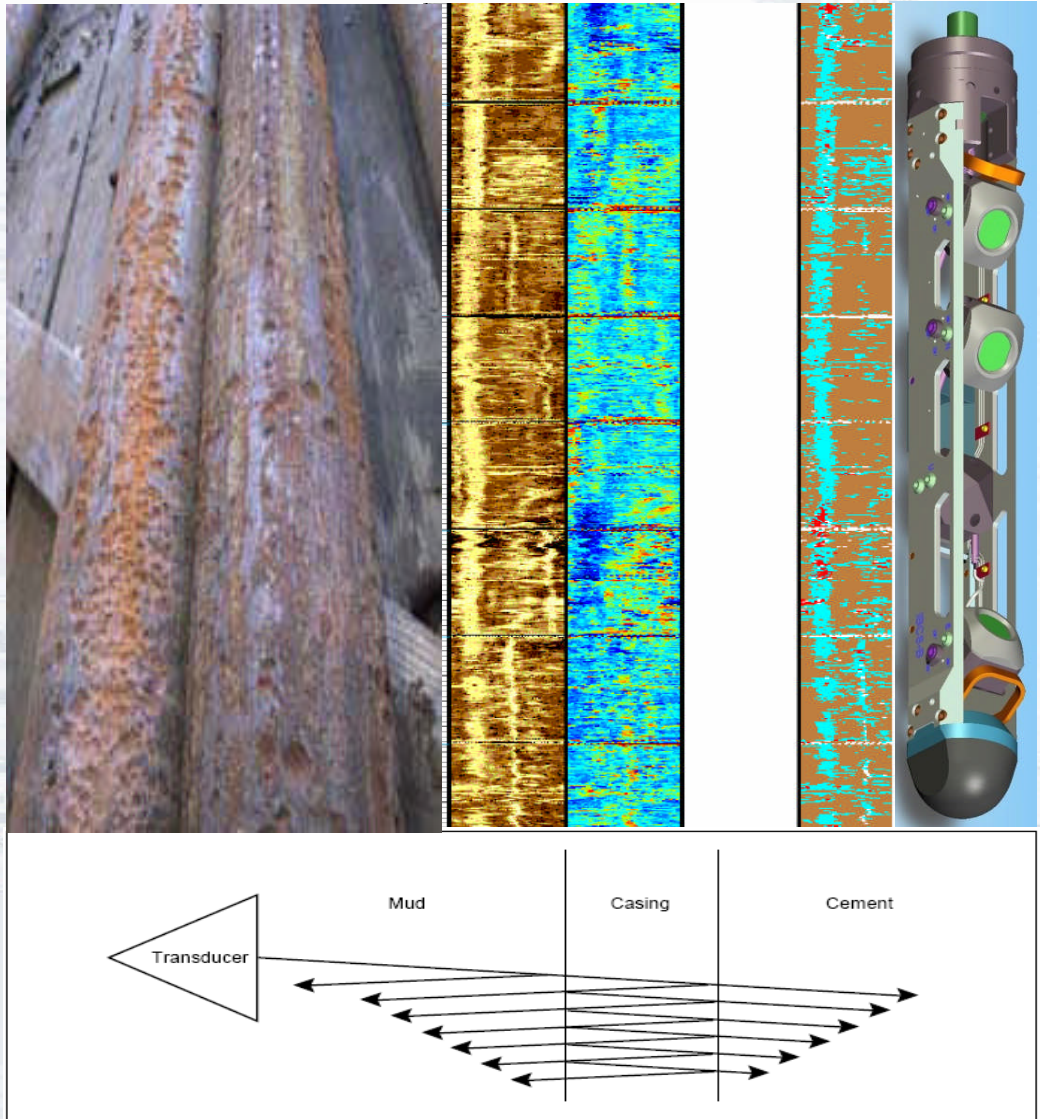
- Isolate water from hydrocarbon zones
- Environmental – Isolate Aquifers and prevent HC to surface
- Completion Design – Hydraulic Isolation for fracturing
- Protect Casing from Corrosion

## SLB - Cement Evaluation Tools

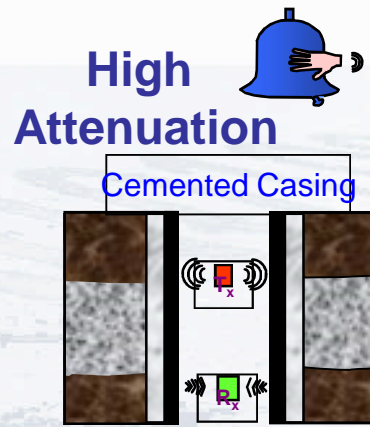
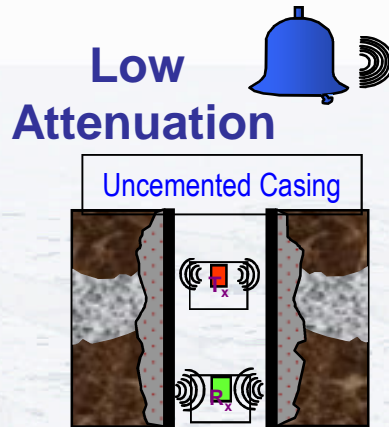
- Cement Bond Logs - CBL, SCMT, SSLT, Sonic Scanner
- Ultra Sonic Measurement – USI, Isolation Scanner
- Ultra Sonic & Flexural Attenuation Measurement – Isolation Scanner
  - Provides Improved Cement Analysis in Low Impedance cements
  - LiteCretes, Ultralite Cretes, Contaminated Cements, Foam Cements

# Agenda

- **Cement Bond Log**
- **UltraSonic Cement Evaluation**
  - UltraSonic Imager (USI)
  - Isolation Scanner
    - Flexural Attenuation
    - Third Interface Echo applications

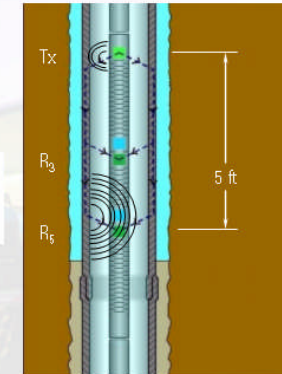
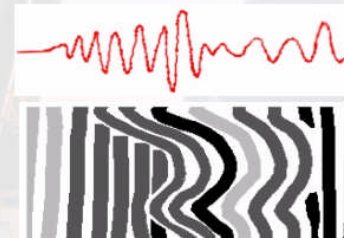


# CBL Sonic Measurement



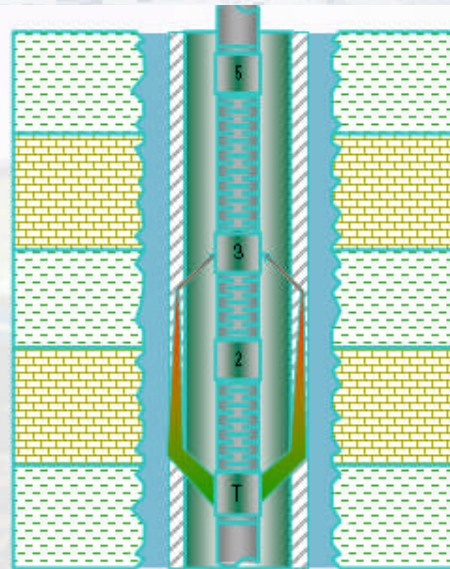
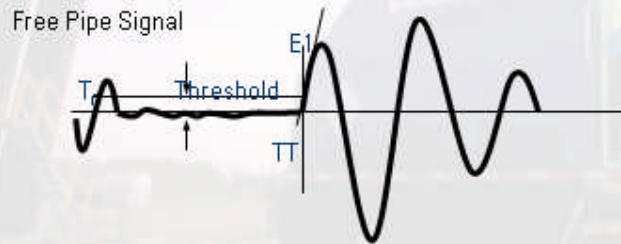
## Variable density log

- 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

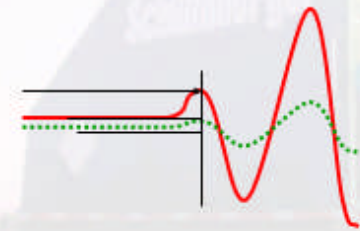


## Good cement to casing bond

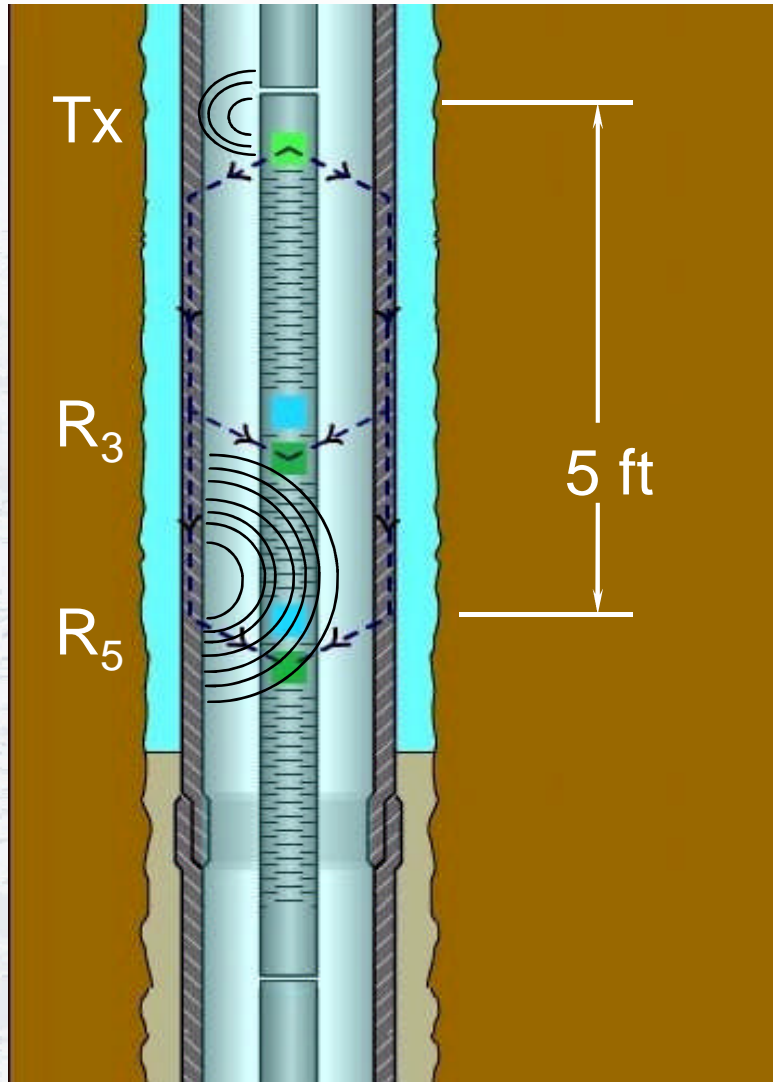
- If casing is well bonded, sound wave will be attenuated.
- The received CBL amplitude will be low.

CBL: Free Pipe

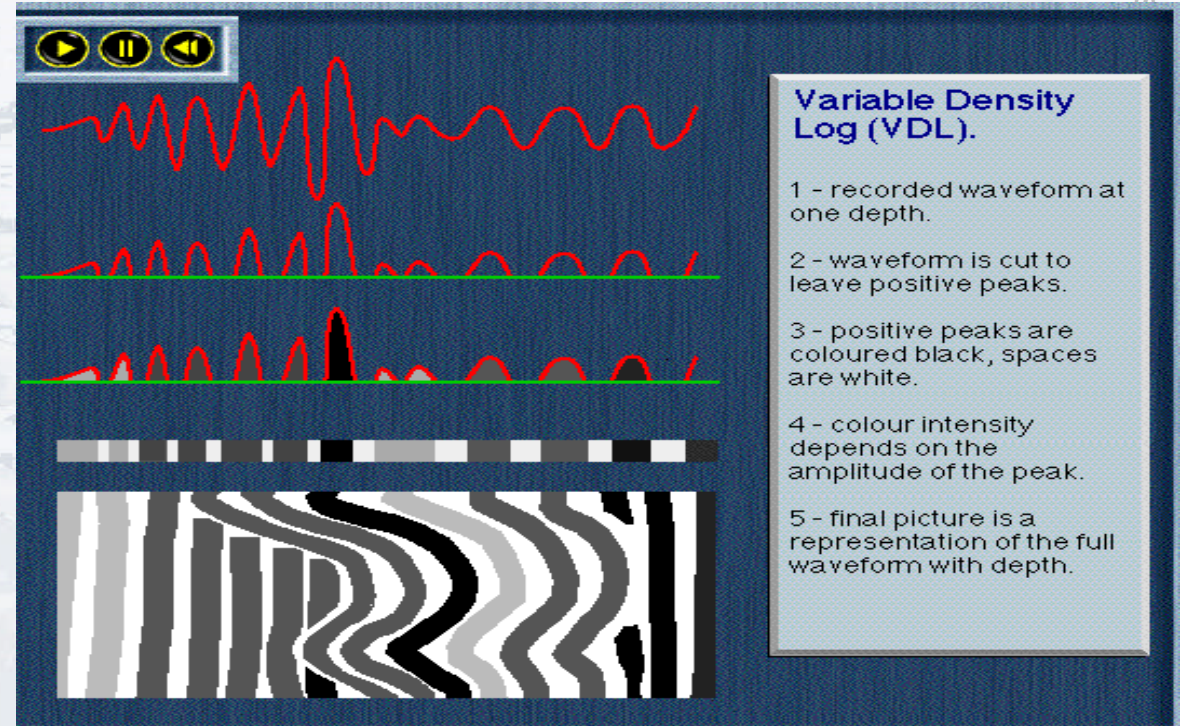
CBL: Good Bond



# Sonic Fundamentals - VDL Signal



VDL: VARIABLE DENSITY LOG  
5 ft Receiver for VDL Analysis  
Allows easy differentiation between casing and formation arrivals

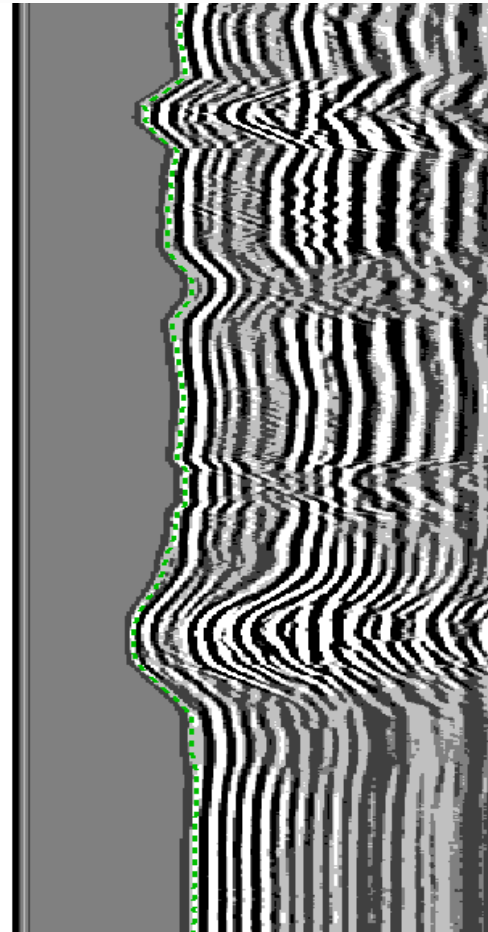


# Open-Hole VDL's (Before Casing)

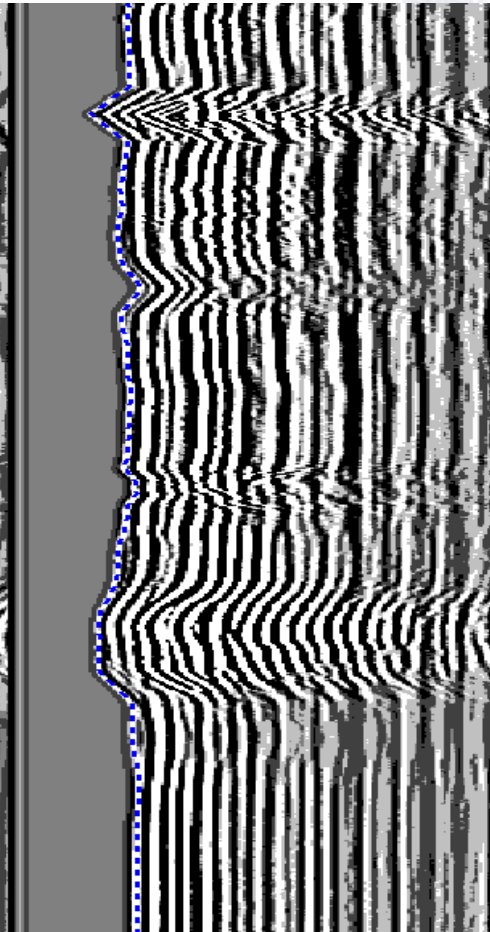


GR

700



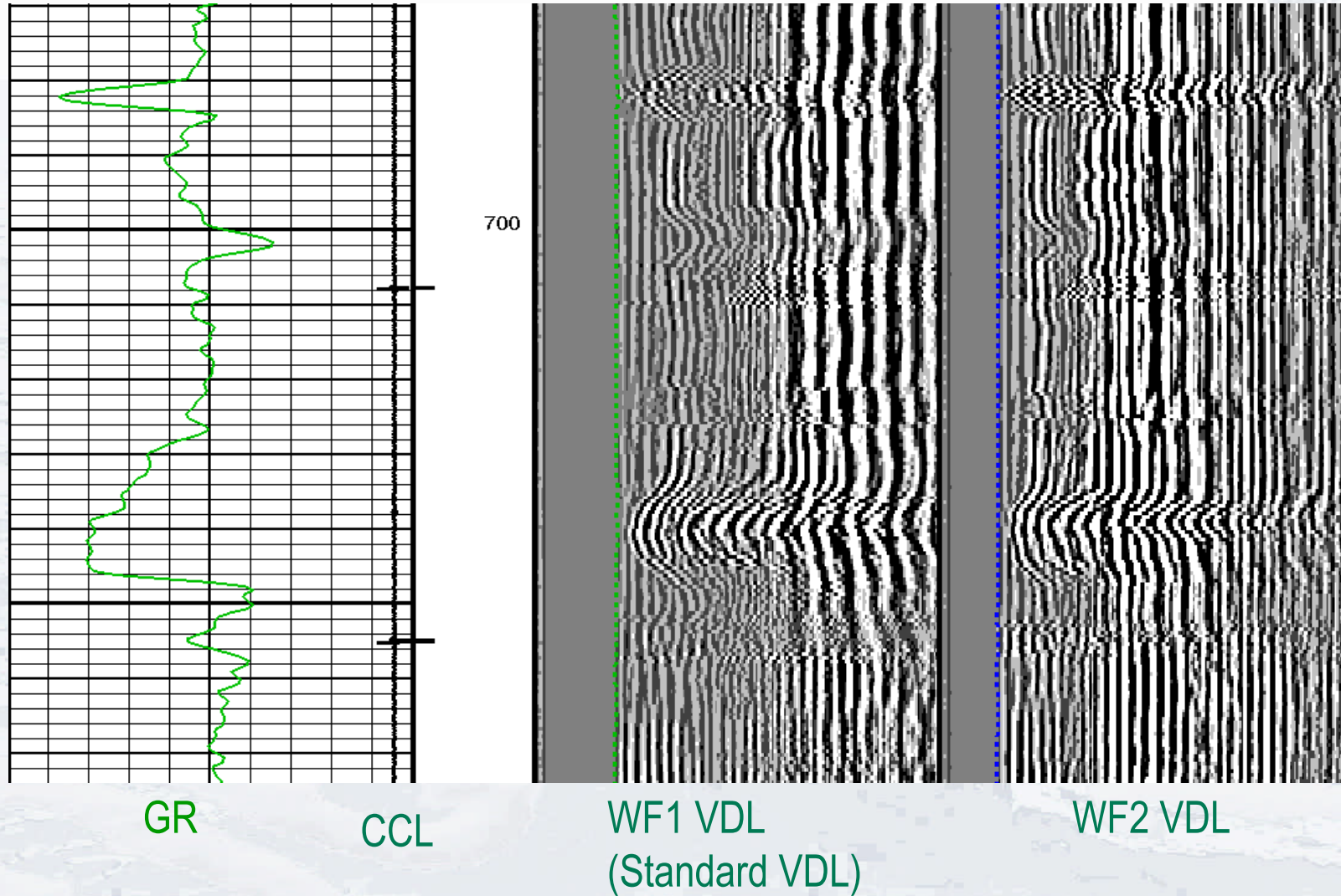
WF1 VDL  
(Standard VDL)



WF2 VDL

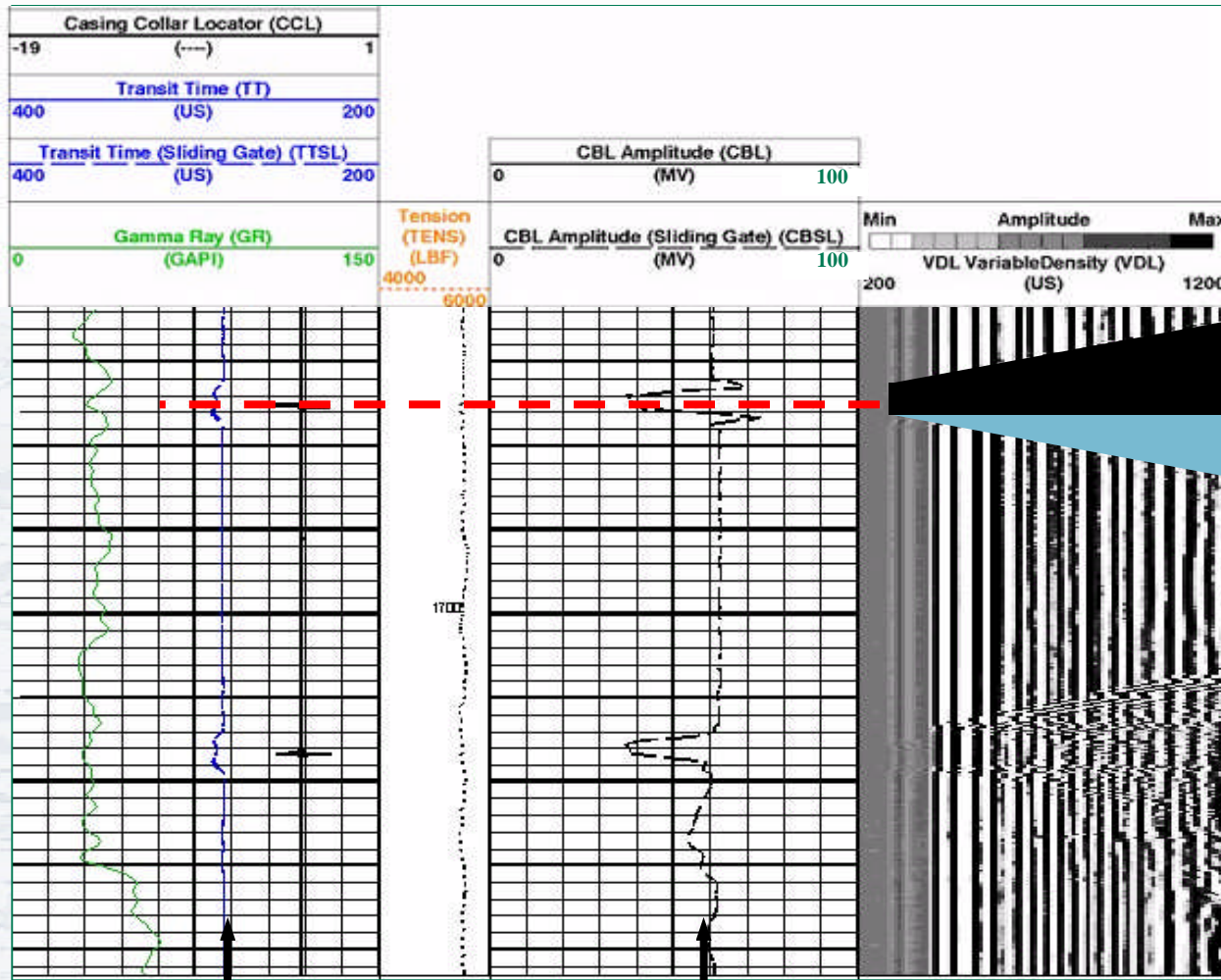
Schlumberger Private

# Cased-Hole VDL's (After Casing)



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# FREE PIPE CHECK



TT and CBL Amplitude  
as expected according to Casing Size

CBL

Interpretation

Chevron Patterns

Chevron Patterns

Schlumberger Private

Table 4-10: CBL free-pipe reference

Casing size (in)	Weight (lb/ft)	Estimated transit time (us)		Expected free-pipe amplitude (mV)
		SLS-E/W	SLS-D/C	
5	15.0	245	238	77
	18.0	243	236	
	21.0	241	234	
5.5	15.5	254	248	71
	17.0	253	247	
	20.0	251	245	
	23.0	250	243	
7	23.0	278	271	61
	26.0	276	270	
	29.0	275	268	
	32.0	273	267	
	35.0	272	265	
	38.0	271	264	
	40.0	269	262	
7.625	26.4	288	282	59
	29.7	287	280	
	33.7	285	278	
	39.0	283	276	
9.625	40.0	320	313	52
	43.5	318	312	
	47.0	317	310	
	53.5	315	308	
10.75	40.5	340	333	50
	45.5	339	332	
	48.0	338	331	
	51.0	337	330	
	54.0	336	329	
	55.5	335	328	
13.375	48.0	385	378	47
	68.0	380	373	

# Slim Cement Mapping Tool

Standard CBL measurements:

- 3-ft CBL
- 5-ft VDL

8 High-resolution transducers (2-ft):

CBL azimuthal variations image : Map image (MAP)

Relative Bearing

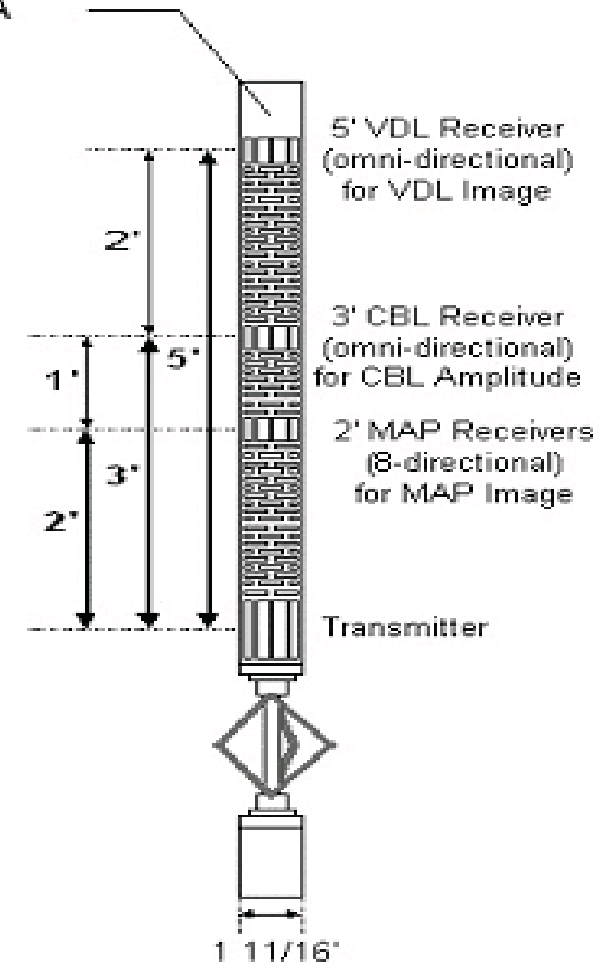
**Through-tubing operations**

2-7/8" to 7-5/8" casing

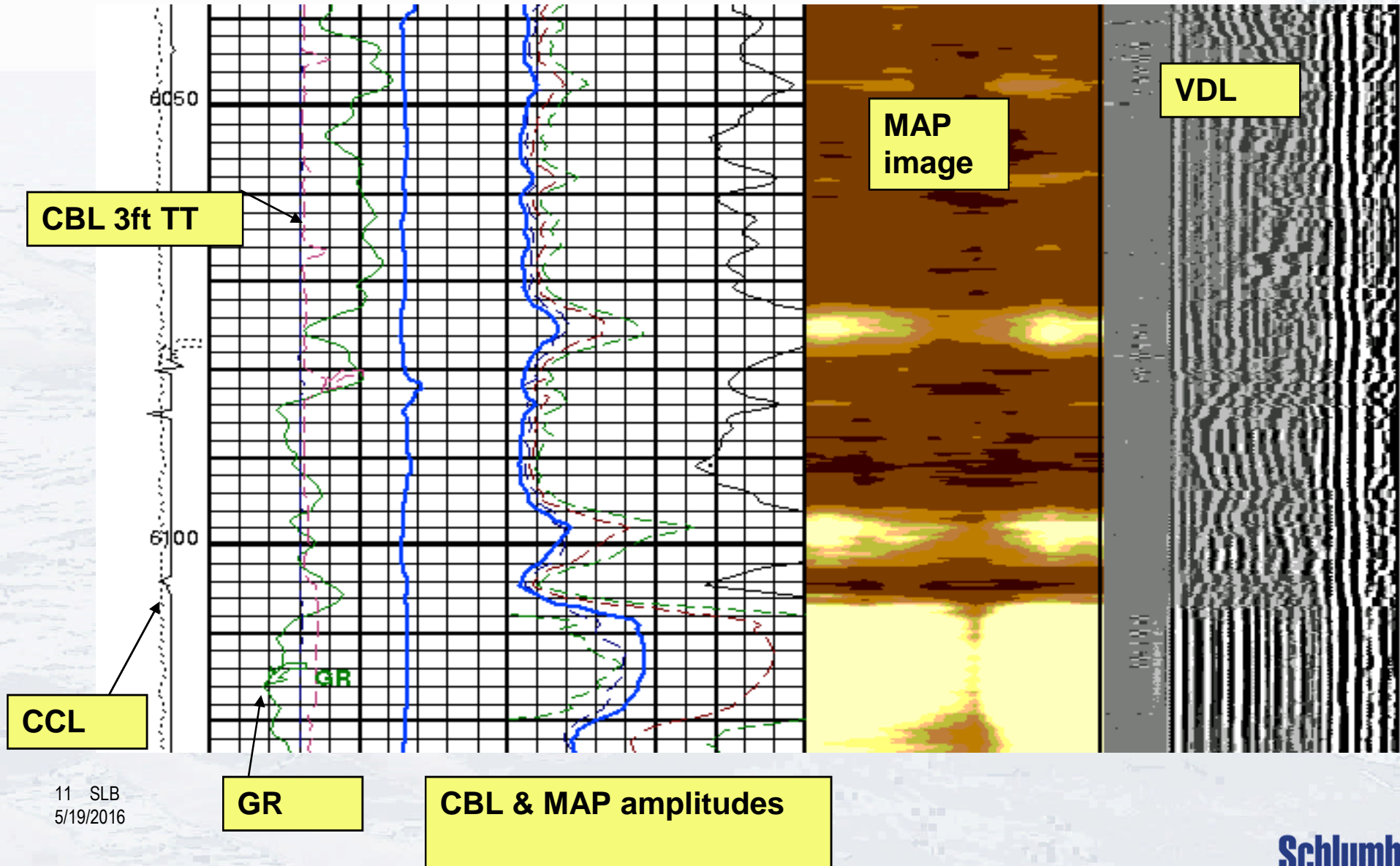
PSP combinable (MTS)

- Runs on Mono, Coax and Heptacable

SCMS-BB/BC  
SCMS-CA  
(Sonde)



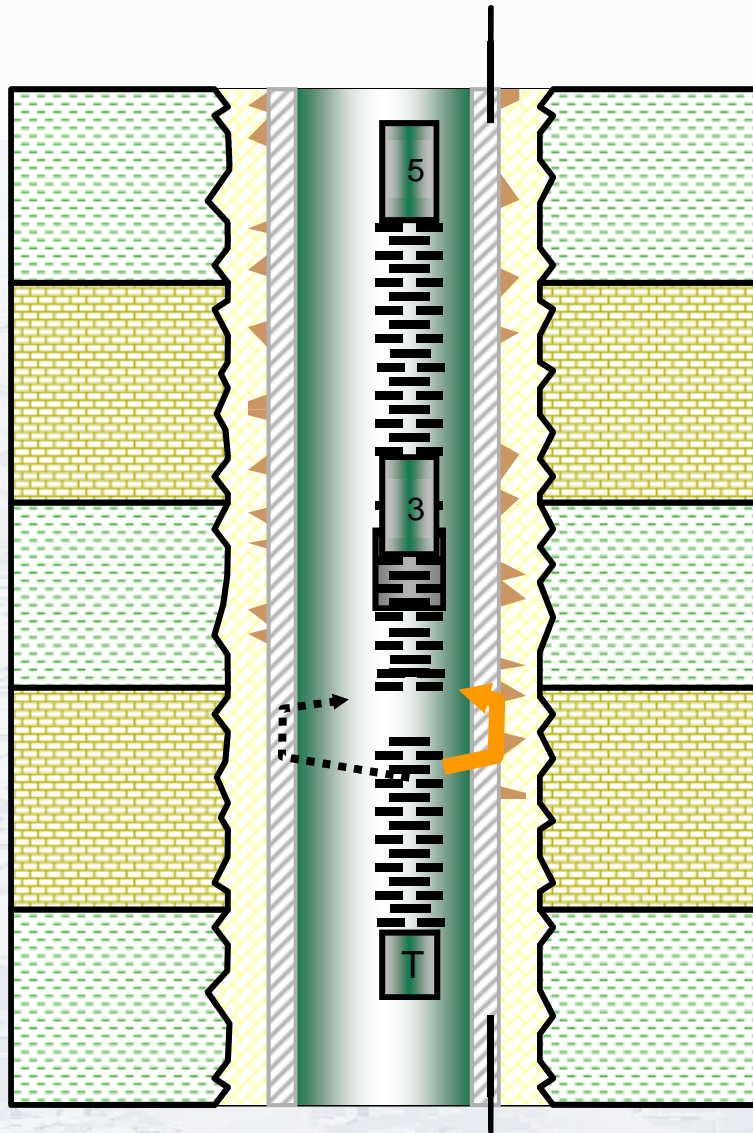
# SCMT Log example





# Factors affecting CBL-VDL

# Tool Eccentering



## Causes for Eccentralization

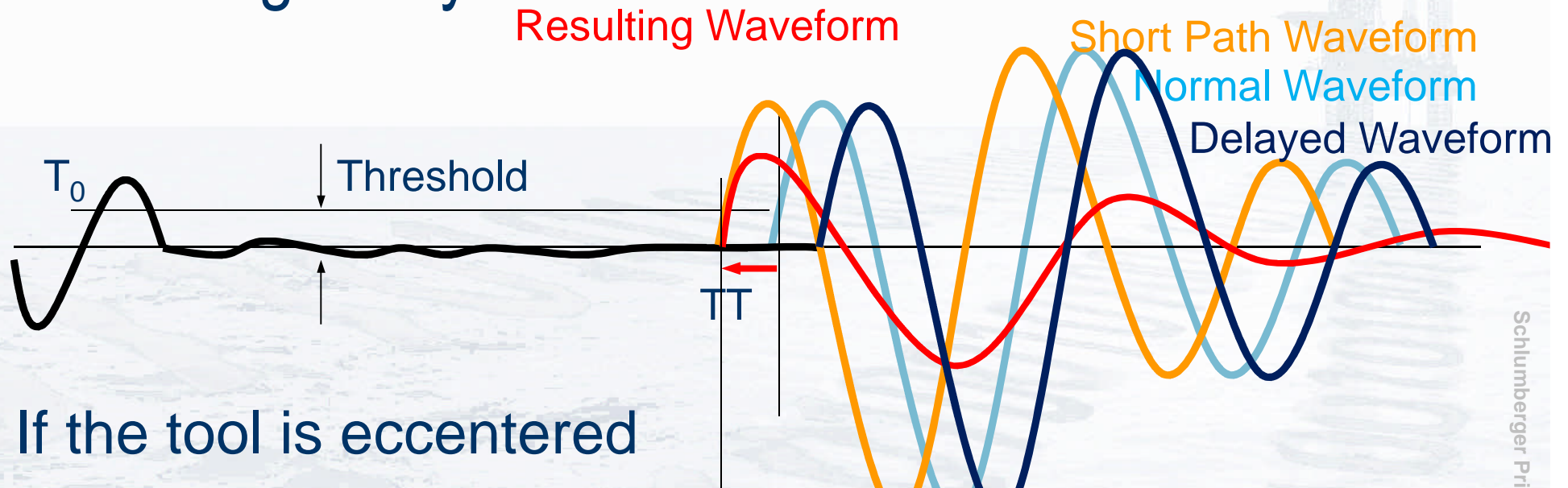
- Improper Equipment selection  
[ Centralizers ] for Casing Size
- Missing or Broken Centralizer(s)
- Weak Centralizers in deviated wells
- Tool Damaged and/or bent
- Damaged or rugose Casing

## Consequences

- Unbalanced sound paths
- Resulting waveform is meaningless

QC log is important prior to making decision

# Eccentering Analysis



If the tool is ecentered

There will be destructive interference from different sound paths

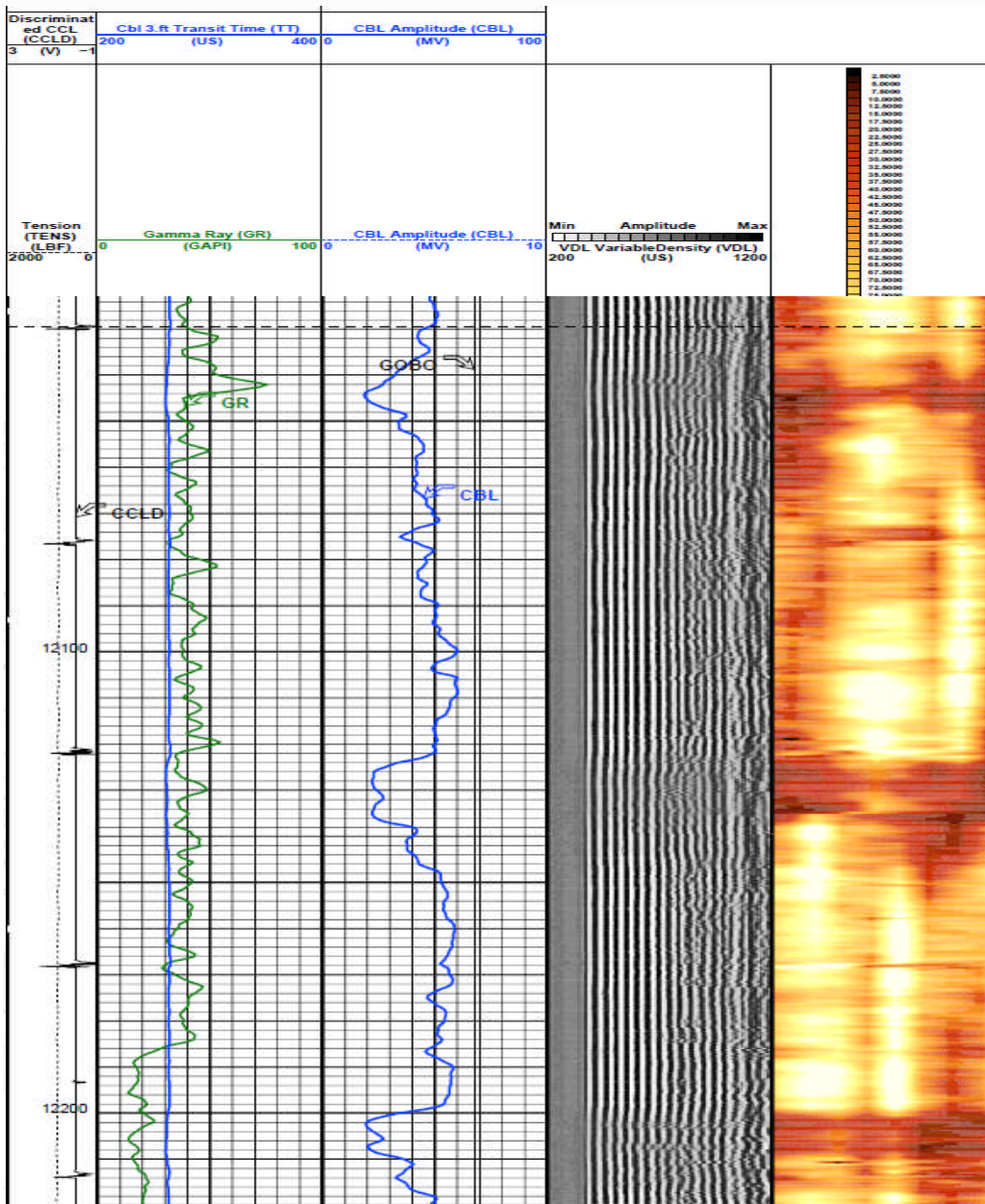
Waveform from close tool side to casing

Waveform from far tool side to casing

Resulting waveform has Dramatic lower amplitude

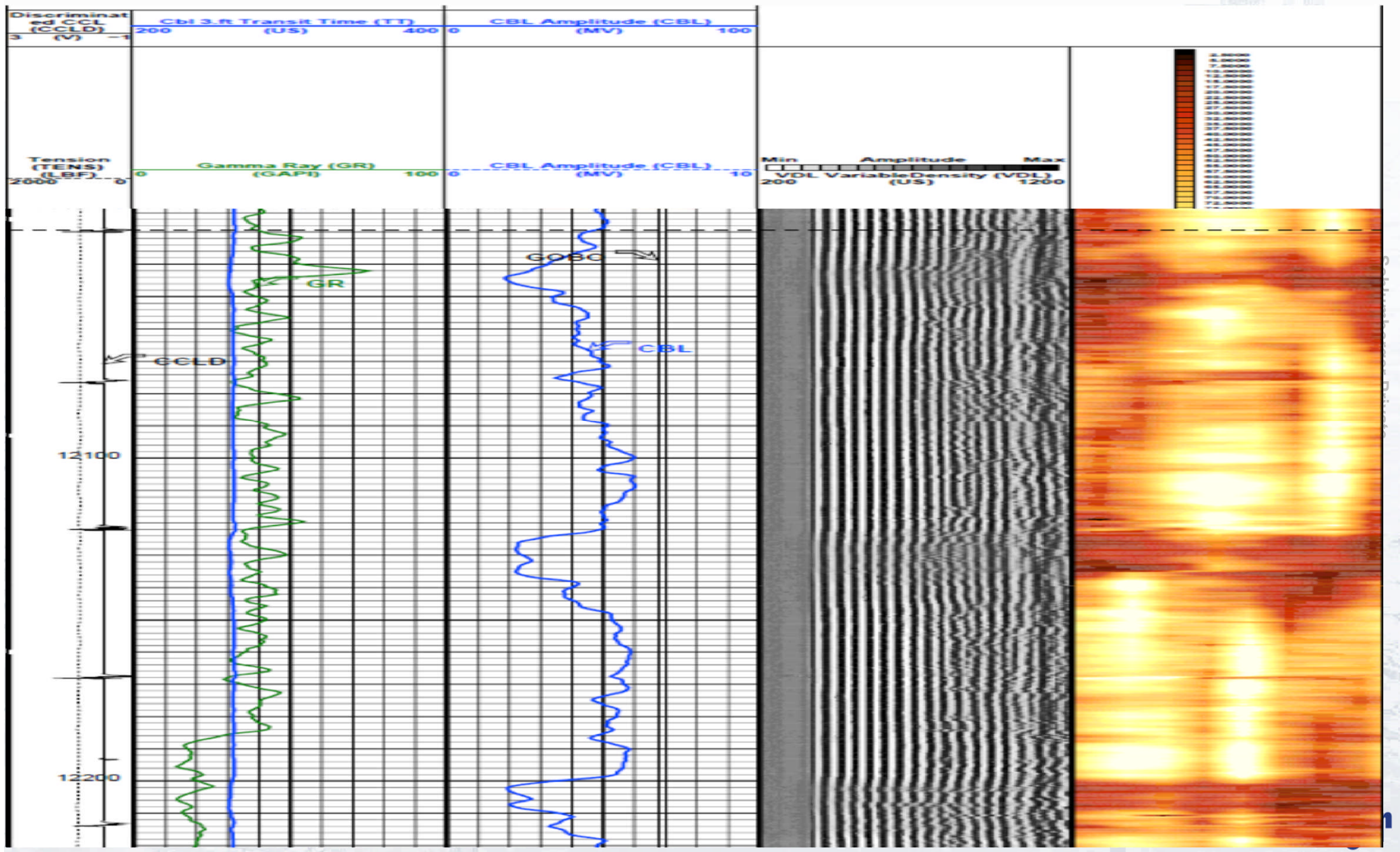
Resembling a zone of Good Cement but with shorter Transit Time [ $\approx 4 \mu\text{s}$  less]

# Eccentering Effect

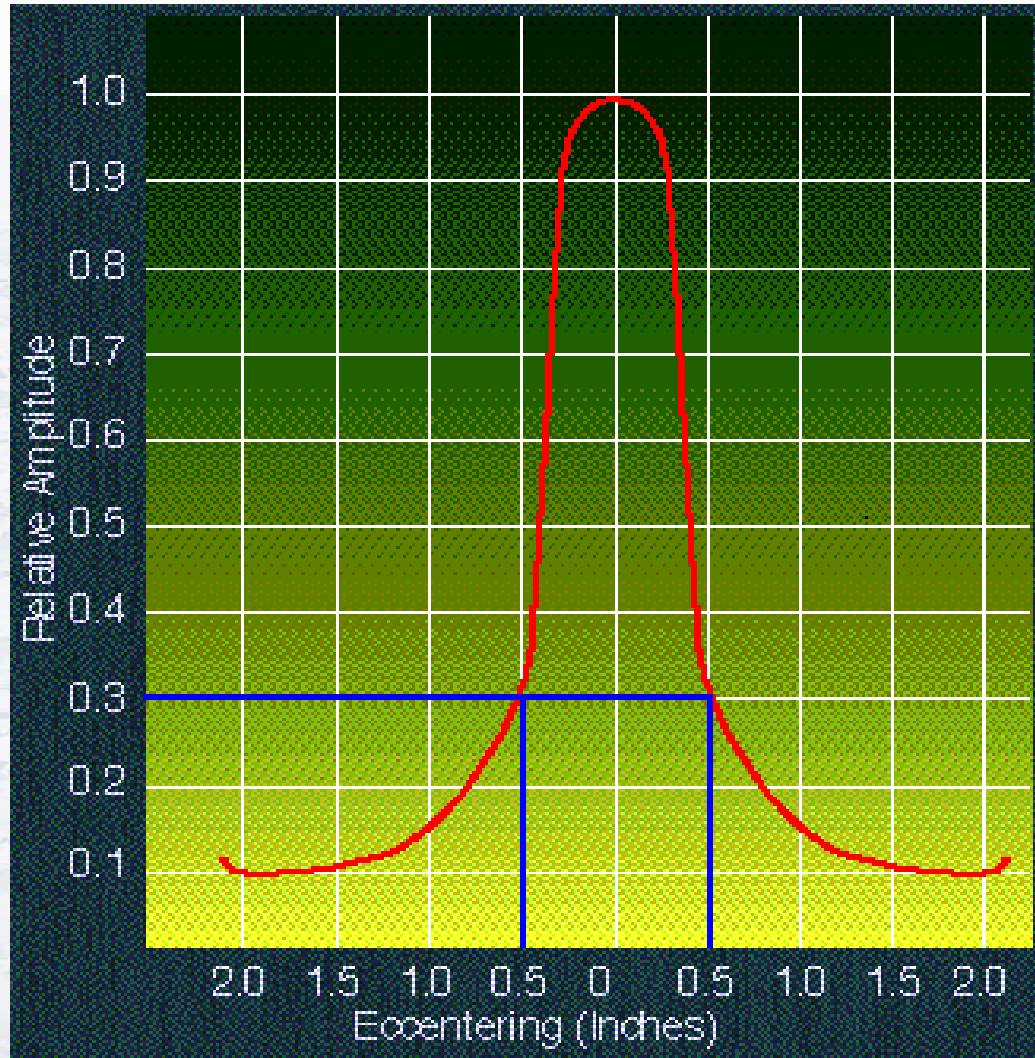


- Incorrect indication of zonal isolation due to eccentricity of the logging tool

# Eccentering Effect



# CBL Amplitude Vs Tool Eccentering



13-Nov-2008

# Basic Sonic Theory: Fast Formation

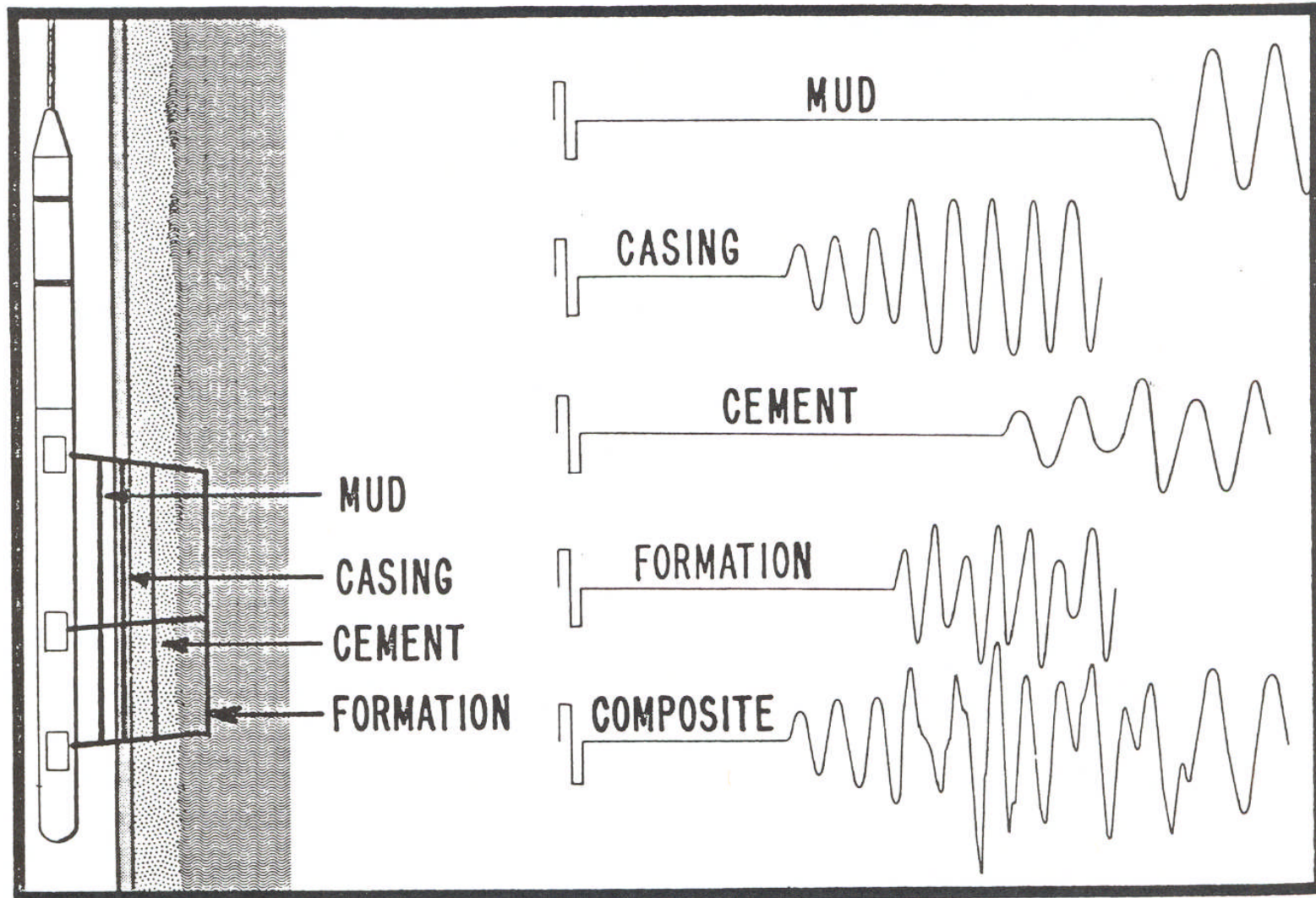
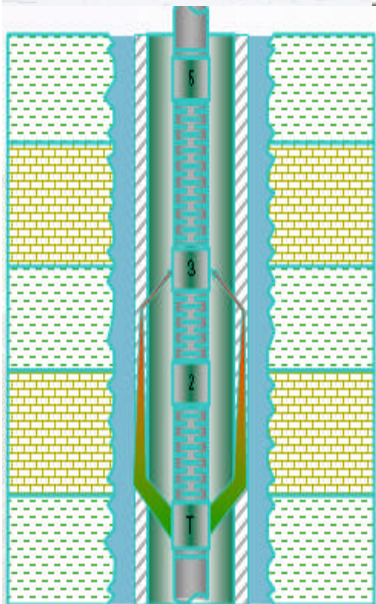


Fig. 3 SONIC WAVE PATHS

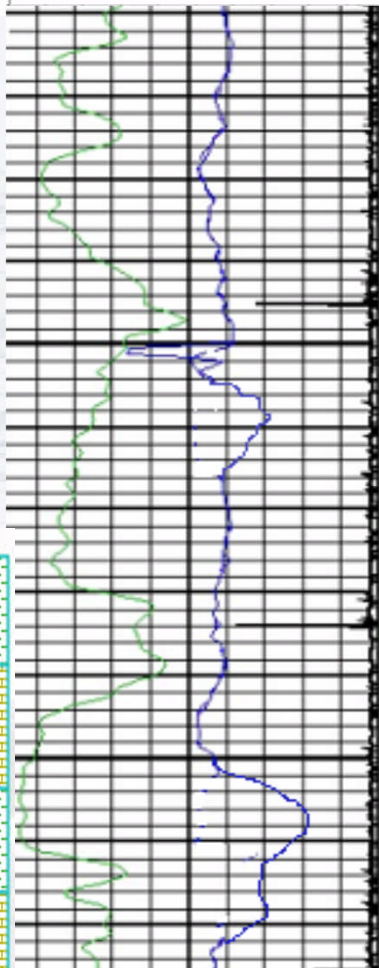
May-16

# FAST FORMATION

Transit Time  
Shorter than  
Casing arrivals



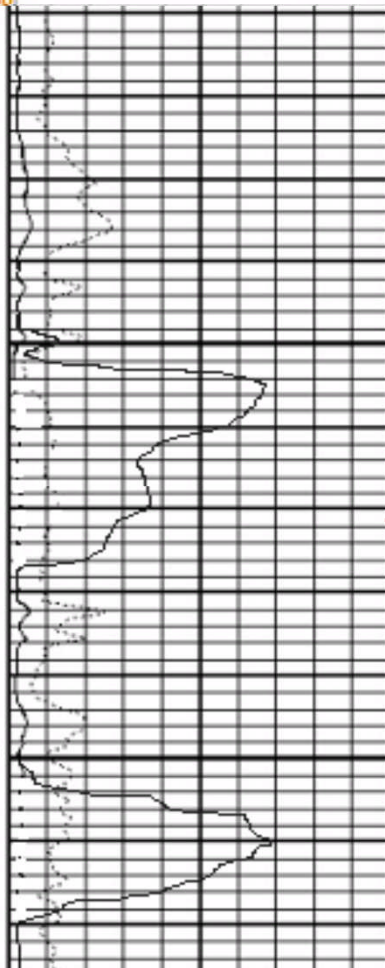
Casing Collar Locator (CCL)		
-19	(---)	1
Transit Time (TT)		
400	(US)	200
Transit Time (Sliding Gate) (TTSL)		
400	(US)	200
Gamma Ray (GR)		
0	(GAPI)	150



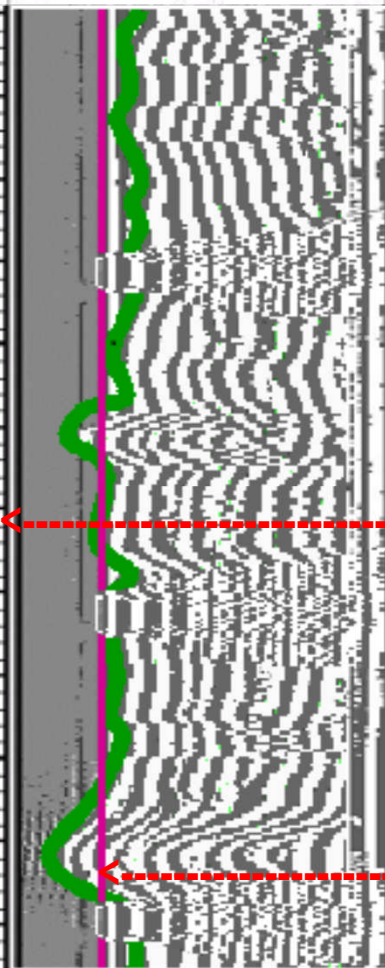
Tension  
(TENS)  
(LBF)



CBL Amplitude (CBL)		
0	(MV)	50
CBL Amplitude (Sliding Gate) (CBSL)		
0	(MV)	50



VDL VariableDensity (VDL)		
Min	Amplitude	Max
200	(US)	1200



CBL  
Interpretation

High

CBL Amplitude

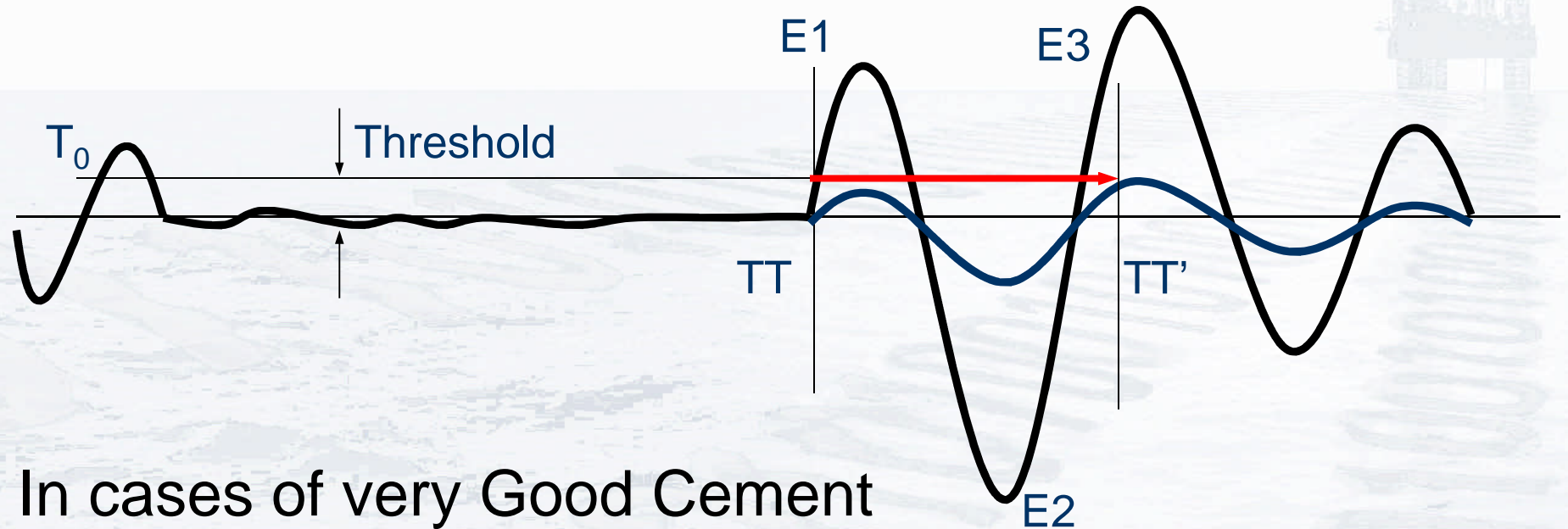
on areas of

fast formation

arrivals

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# TT Cycle Skipping



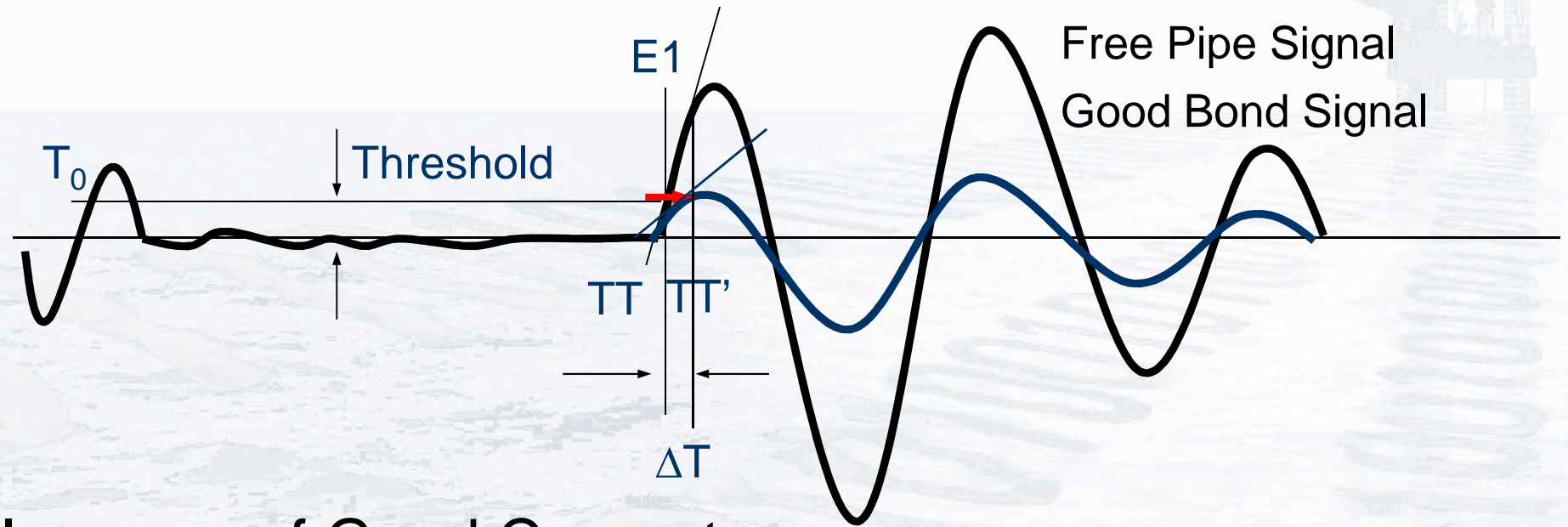
In cases of very Good Cement

E1 could not reach Detection Threshold Level

TT skips to 3<sup>rd</sup> Peak [E<sub>3</sub>]......this is known as **CYCLE SKIPPING**

If TT goes higher value = longer in time where amplitude on VDL is very low it is likely cycle skipping

# Stretching

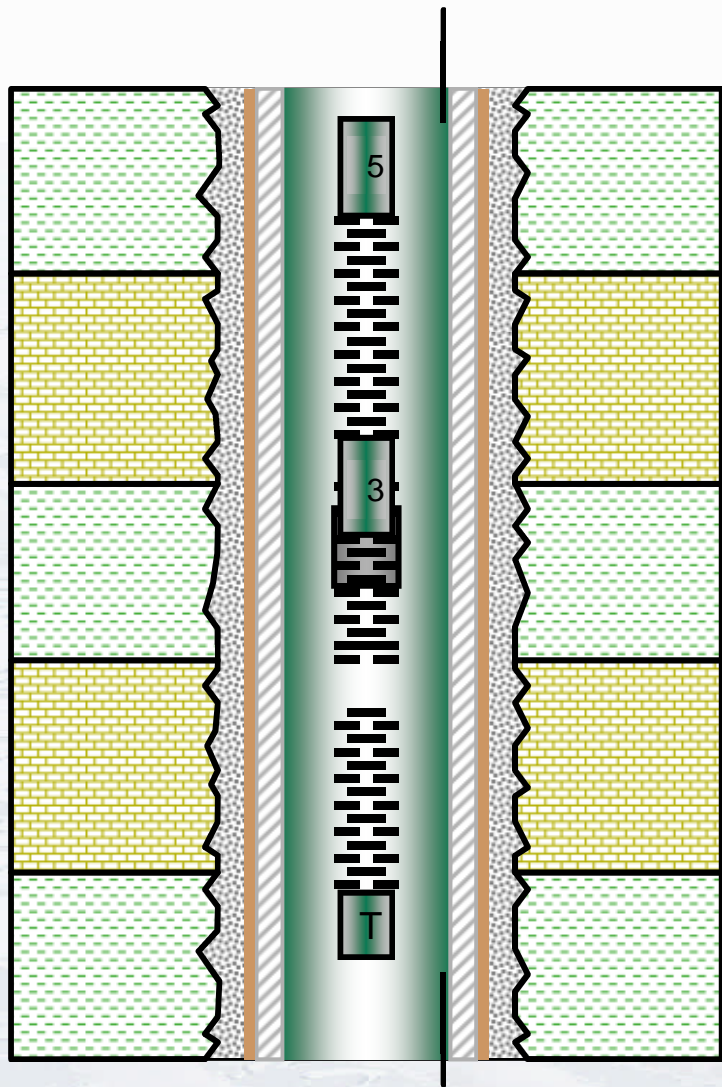


In cases of Good Cement

E1 decreases and TT is detected on a non linear portion of E1

$\Delta T$  STRETCHING is the TT increase from its value in free pipe

# Micro Annulus



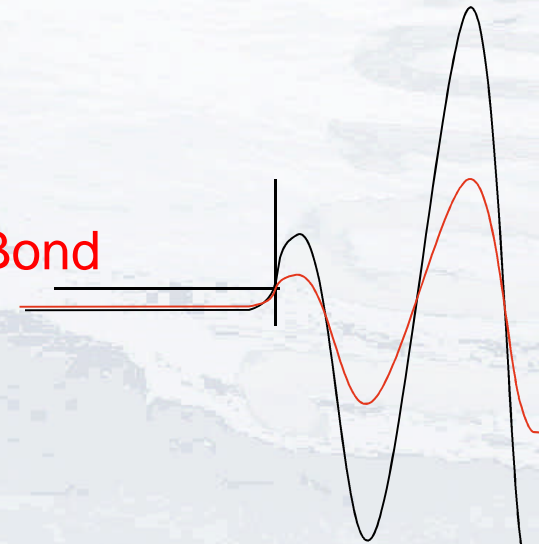
Gap between Casing and Cement

Can be caused by contraction of casing after cement sets if Casing Fluid is changed

E1 amplitude resembles a poorer bond than actual

Only a pressure pass can be done to eliminate the micro annulus

CBL: Poor Bond



# Causes of Microannulus

- **Changes in casing state of stress from curing time until log time**
  - Pressure testing casing while cement set – Hydraulic stimulation cycles
  - Floats not holding – holding pressure on casing while cement cures
  - Swapping of heavy displacement fluid to lighter completion fluid
  - Relaxation of tension held on casing by drilling rig during cement curing
  - Thermal stress – cooling of a hot well
- **Coatings which affect the ability to bond cement to casing**
  - Insufficient removal of OBM/SOBM
  - Heavy mill varnish
  - Engineered coatings for corrosion prevention
- **Low confining stress of formation or insufficient mud cake removal**
  - Cement should have lower Young's Modulus than surrounding rock
- **Bulk volume changes – shrinkage of cement slurries**
  - Chemical shrinkage – volume of reaction products of hydration is less than that of cement at 100% hydration – can lead to loss of internal pressure in cement
  - Bulk Shrinkage – external volume reduction seen due to contraction. Largest affects when cement is cured without access to excess water
    - Curing in multistring or other impermeable no source of water environments

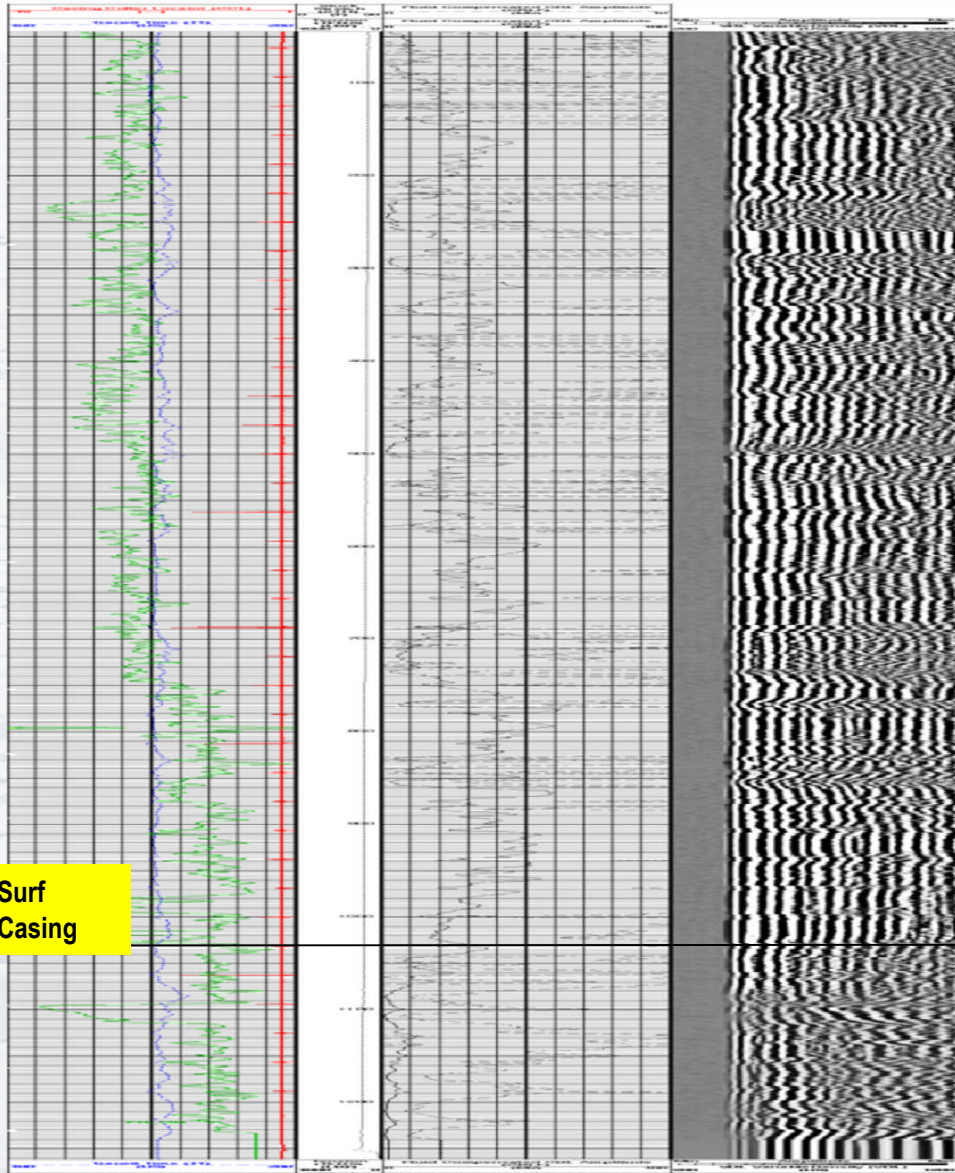
# Cement shrinkage

As part of an initial study to elucidate the mechanism of gas intrusion into the cementing material, the external and total chemical shrinkages of API class G cement slurries were measured during the first 48 h of curing. While the external chemical shrinkage expresses the volume change of the slurry leading to a possible micro-annulus between the slurry and the casing, the total chemical shrinkage is the sum of external chemical shrinkage and the volume of empty contraction pores of the slurry at all stages. The formation of empty contraction pores dominates when the built-up network between the particles in the matrix becomes strong enough to resist the forces created by the total shrinkage (i.e. the difference in volume between reactants and products). Contraction pores contribute to the continuity of the porosity in a set cement slurry, which influences the permeability.

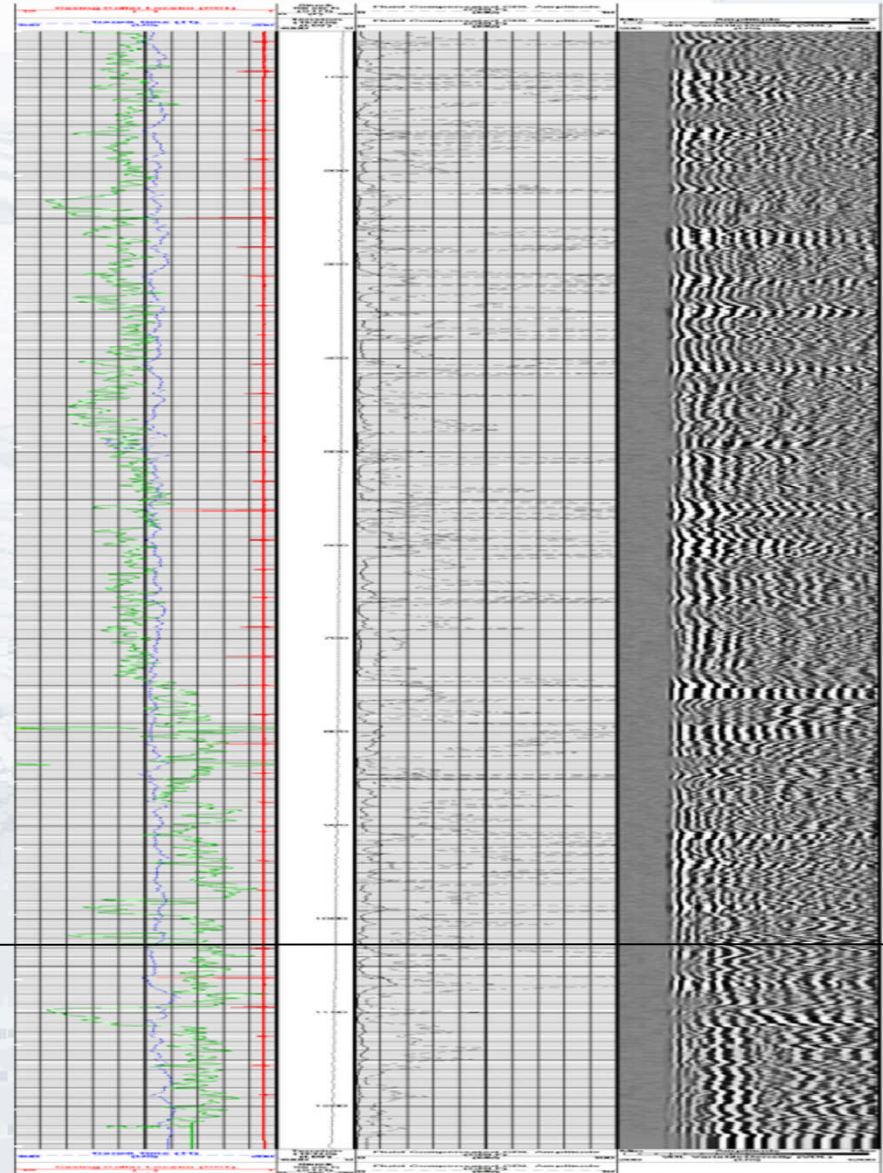
The present investigation is the second in a series of three to elucidate fundamental aspects of the phenomenon of gas migration during oil well cementing: porosity,<sup>4</sup> chemical shrinkage and dissolved gas.<sup>5</sup>

# Effect of Micro Annulus – CBL vs Surface Casing

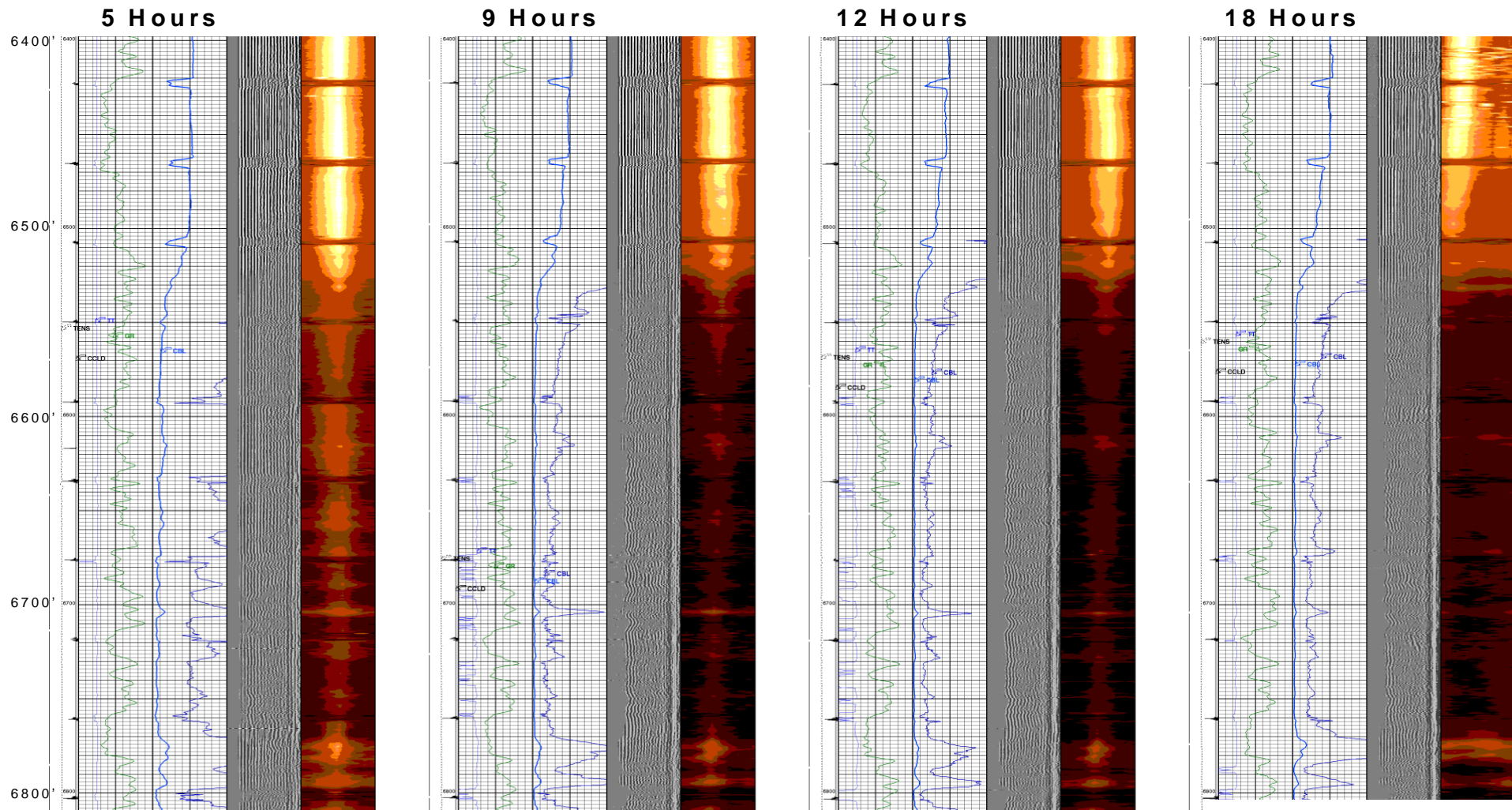
CBL 0 PSI



CBL 700 PSI



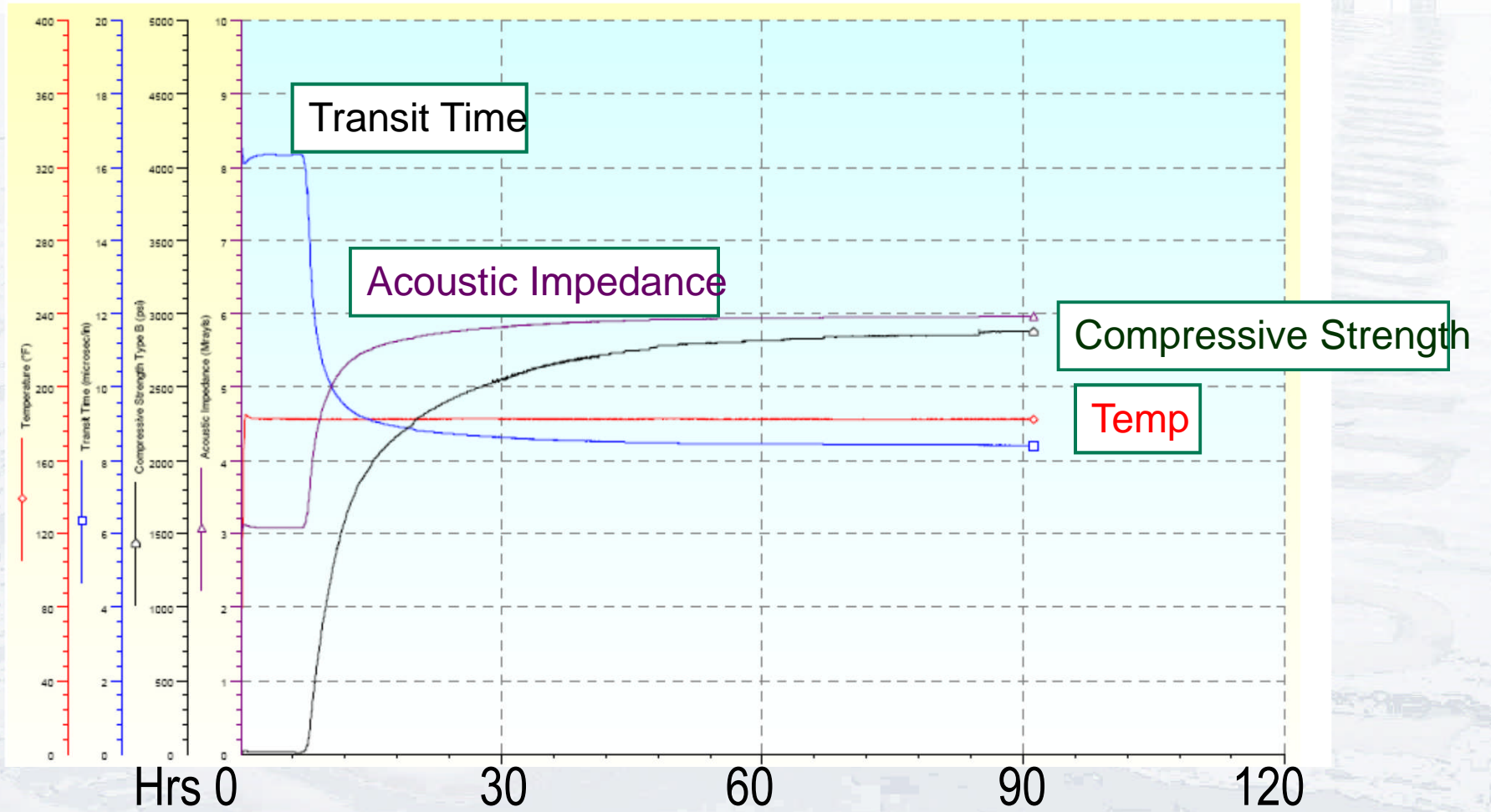
# Effect of Time on Cement Bond Readings



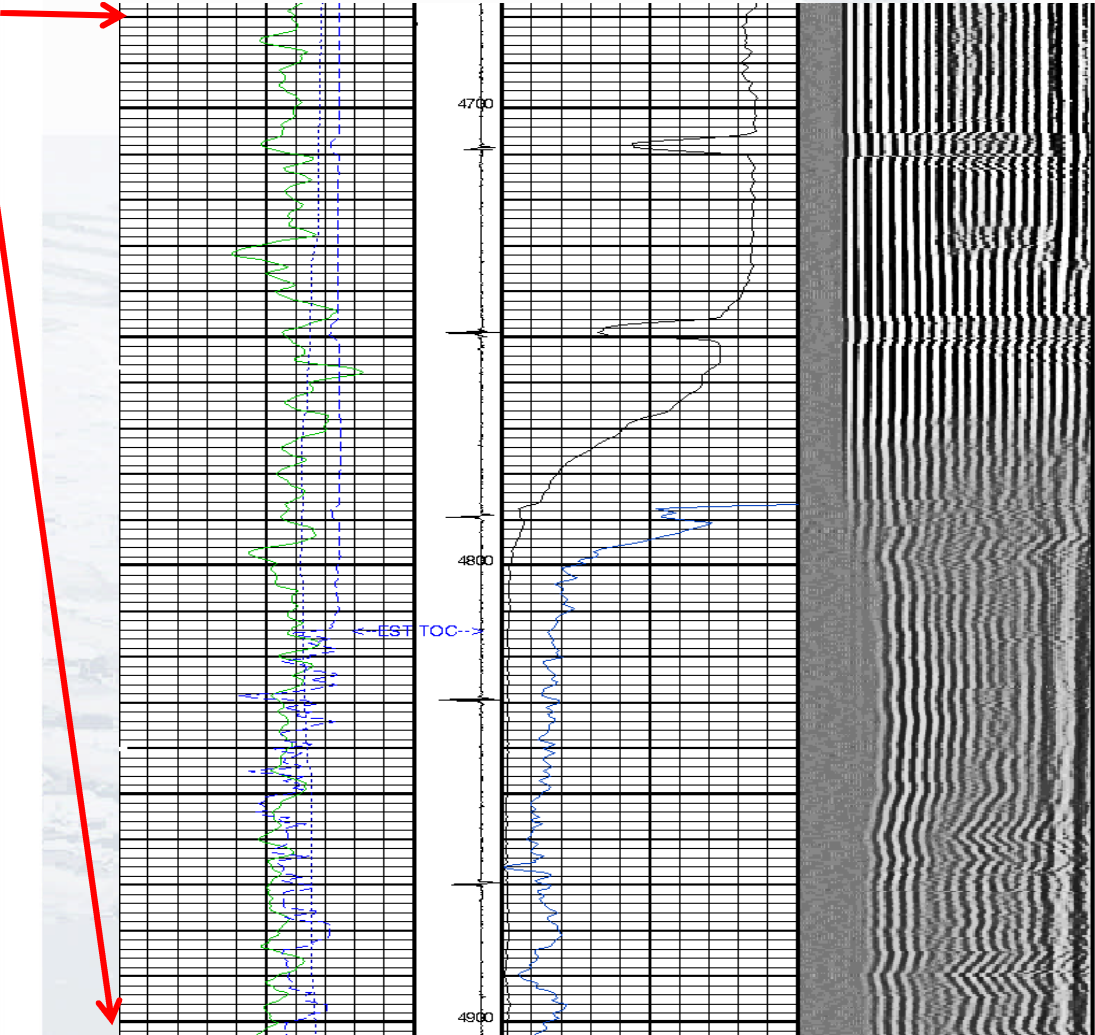
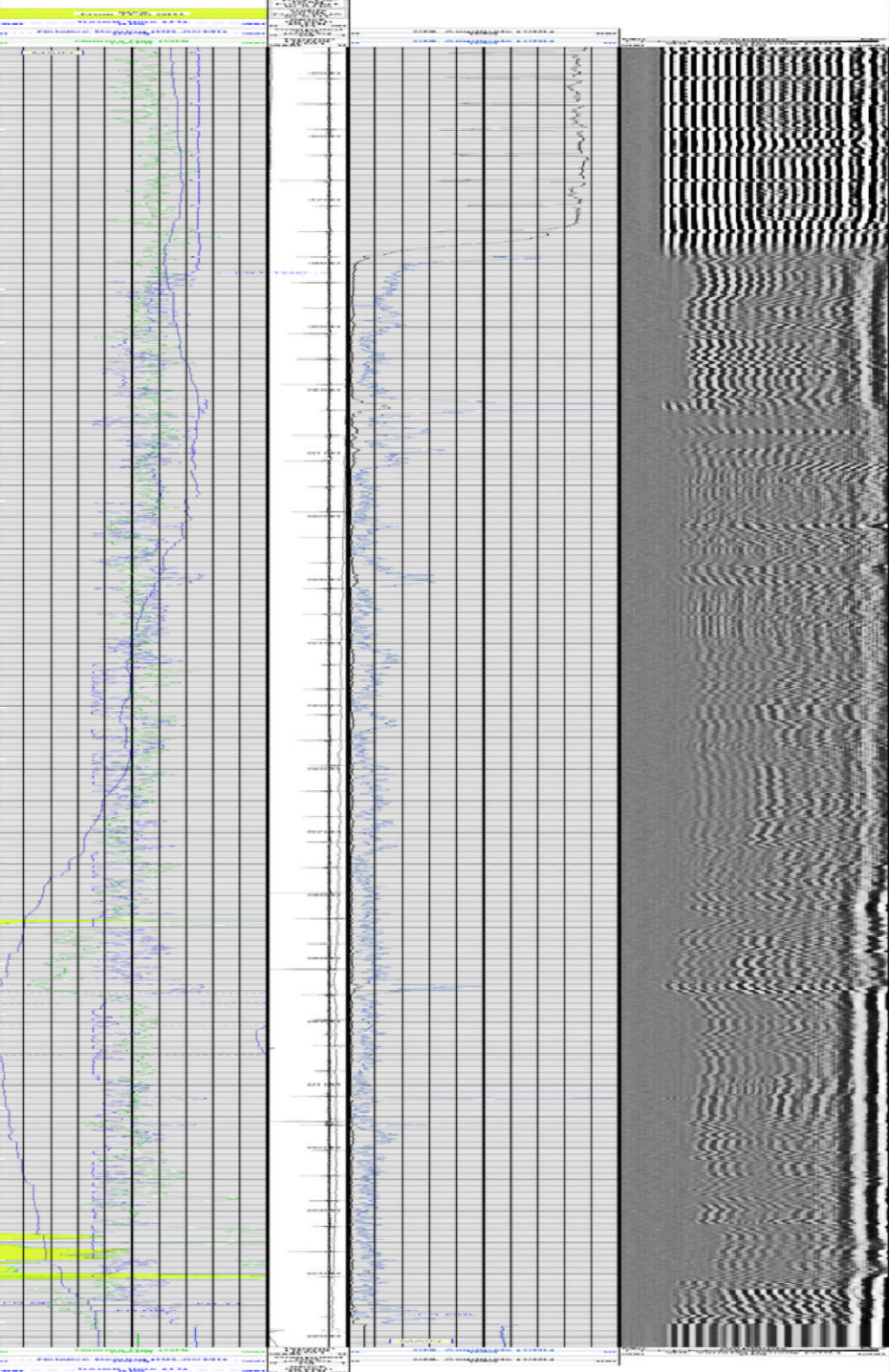
Dependent on slurry type

# Effect of Curing Time

## Class H Cement UCA

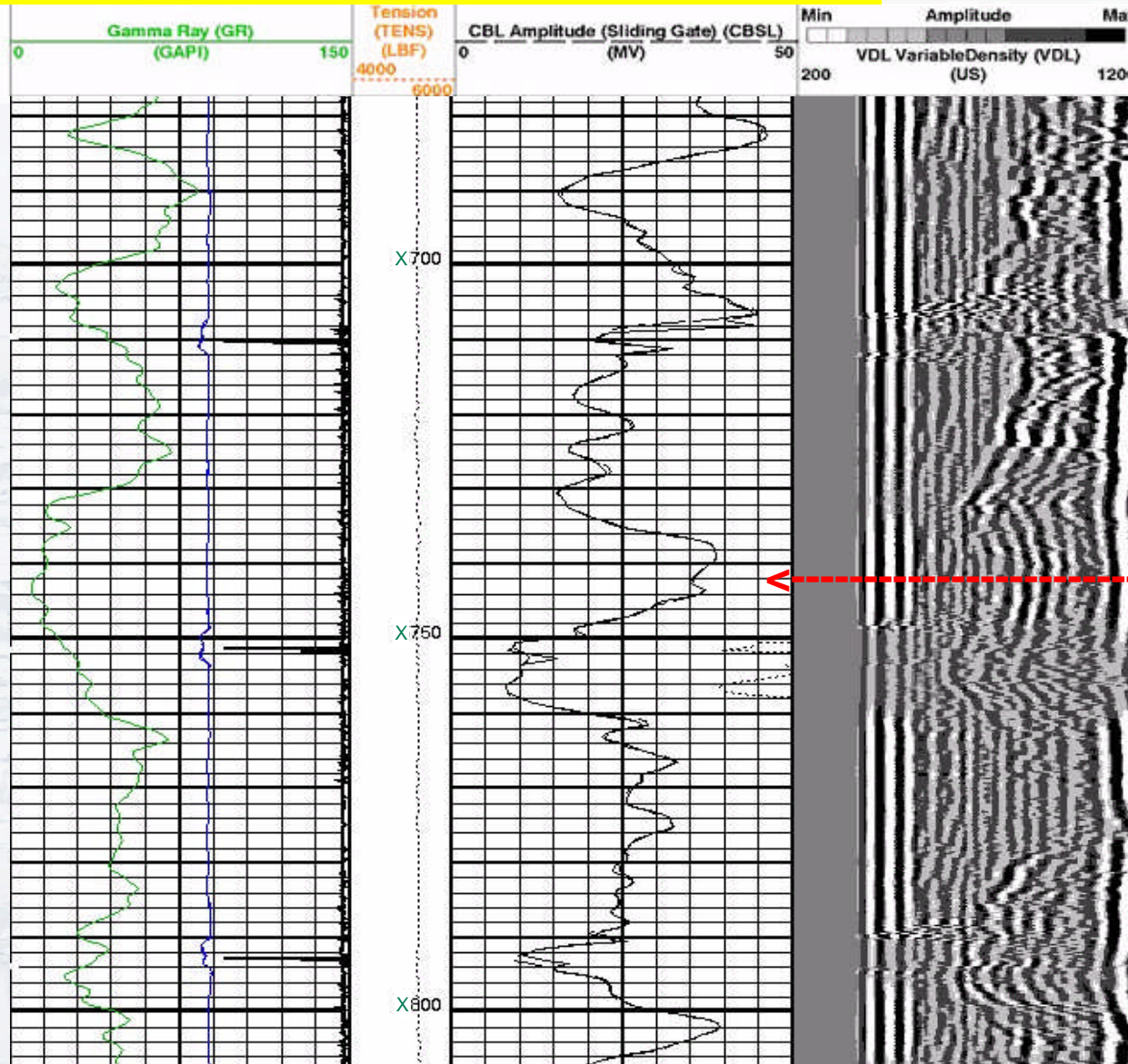


# CBL – What we want to see



Clear TOC heavy cement  
No pipe ring – low amplitude  
Good bond

# WHAT WE SOMETIMES GET: POOR BOND TO CASING



Why is bond poor?

Voids ?  
Channel?  
Contamination?  
Microannulus?

**Highly Variable**

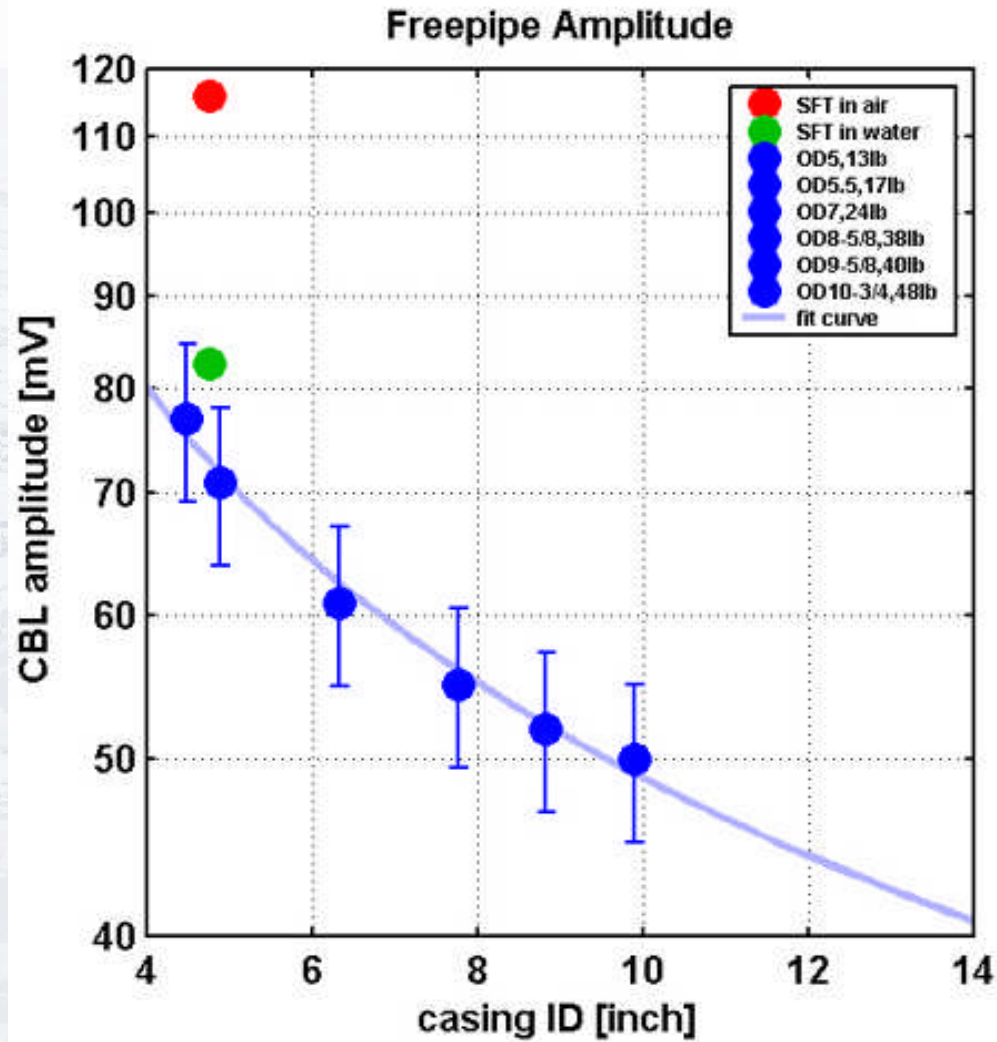
**CBL Amplitude**

What do we fix?

What to change in  
design for next  
well?

# Effect of Casing Size on Cement Bond Curve

- Tool is master calibrated in tube in shop.
- Should read predictable values in freepipe with water on both sides



13-Nov-2008

30

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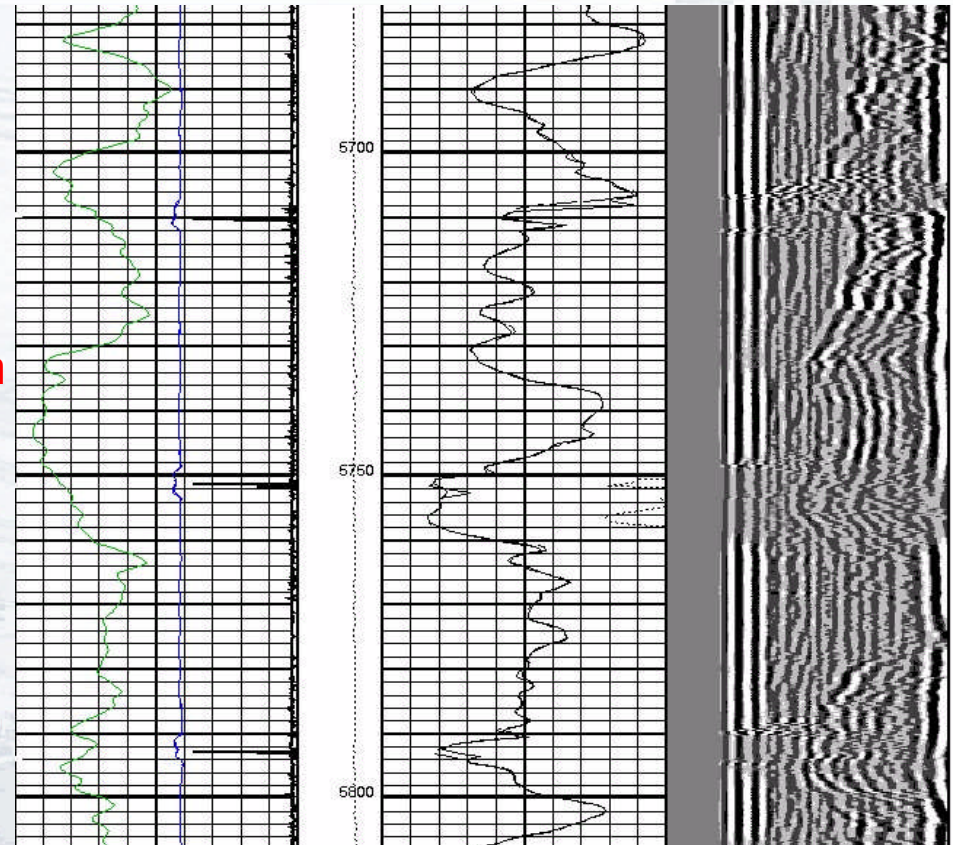
# Amplitude Measurements

## Strengths

- Respond to solidity (shear coupling)
- Work well in most well fluids, tolerate corrosion
- Qualitative cement-formation bond from VDL
- Good TOC indicator with (heavy) cements

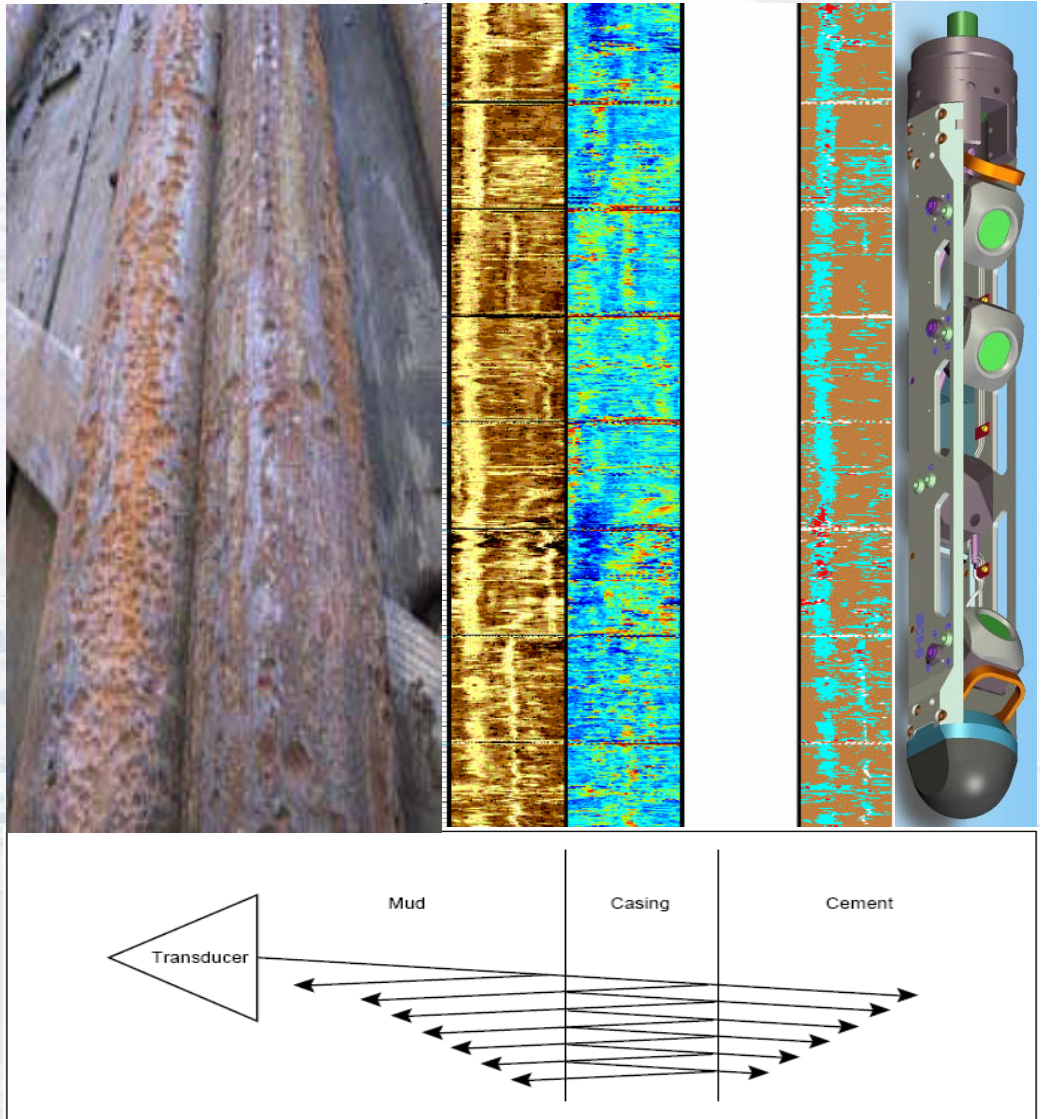
## Weaknesses

- **Amplitude and VDL each based on one waveform**
- **High CBL amplitude can be ambiguous**
  - Liquid microannulus (shear coupling lost)
  - Channels
  - Contaminated cement and/or light cement
- **Sensitive to fast formation**
- **Extremely sensitive to eccentricity**
- **Ability to predict hydraulic isolation limited**

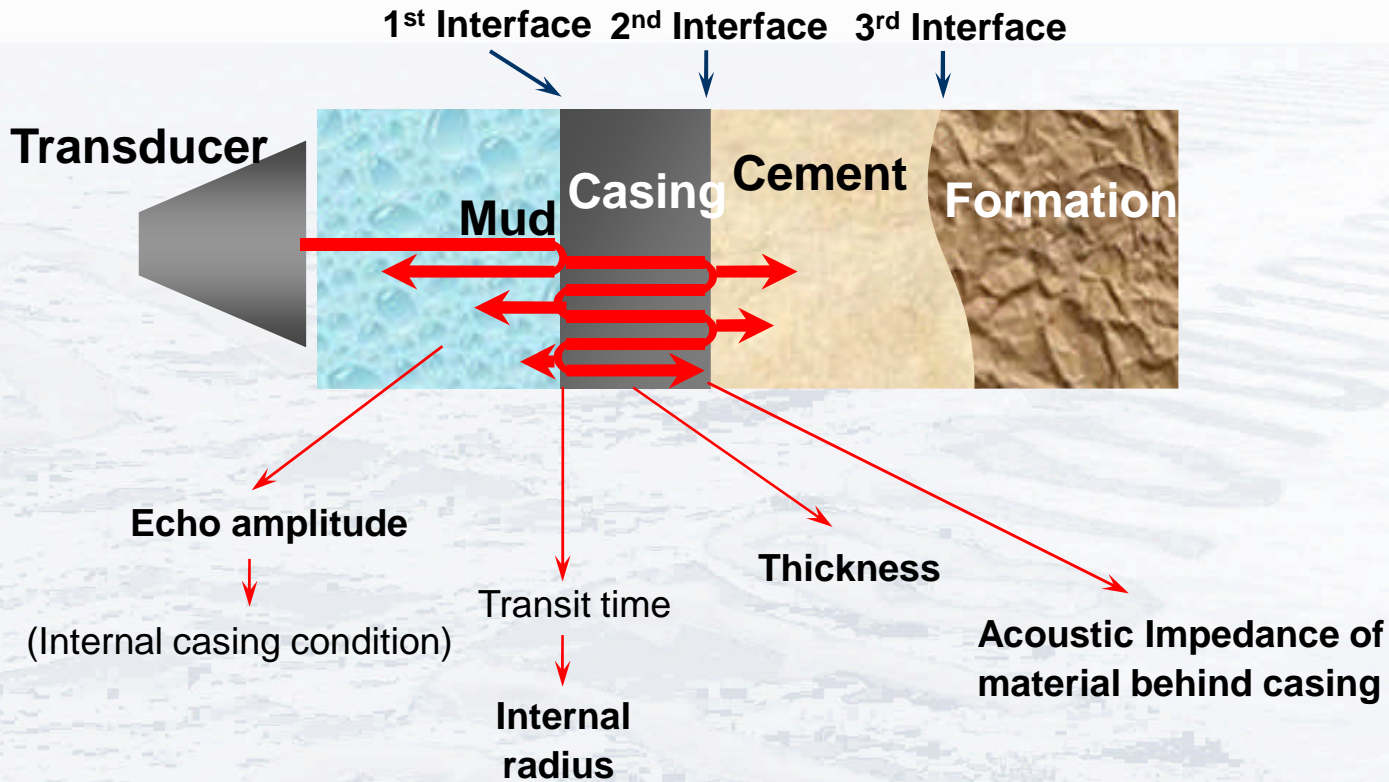


# Agenda

- Cement Bond Log
- **UltraSonic Cement Evaluation**
  - UltraSonic Imager (USI)
  - Isolation Scanner
    - Flexural Attenuation
    - Third Interface Echo applications

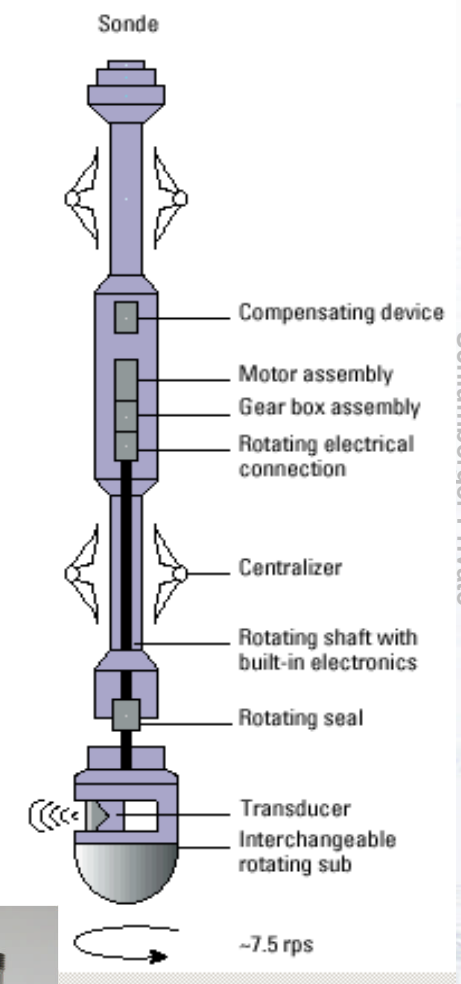


# UltraSonic Imager (USI) Measurements



Fires at 200-700 kHz far different from CBL Physics  
 270 firings per second – 4 radial answers/firing

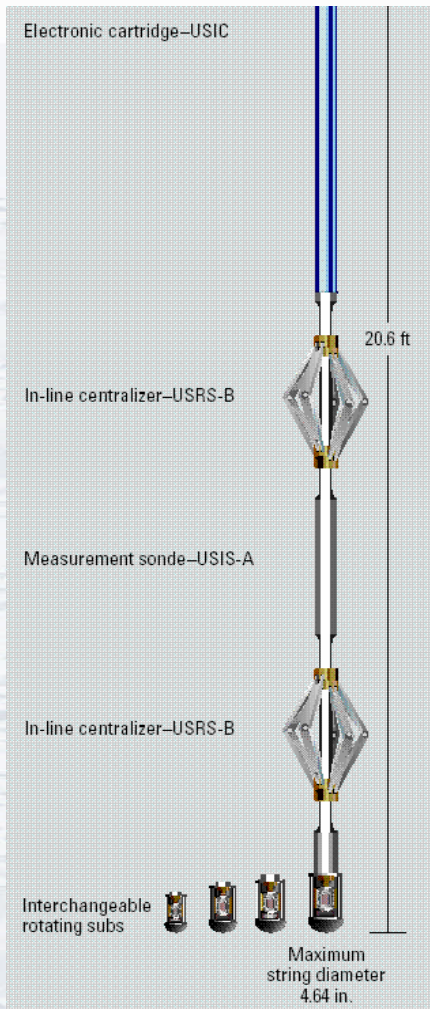
Casing Range: 4.5" to 13 3/8" (20")



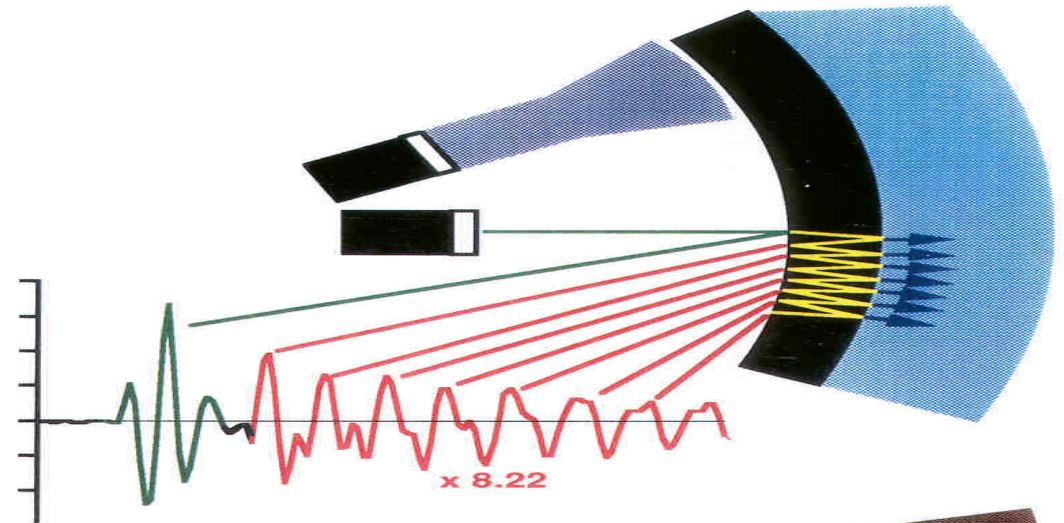
Schlumberger Private



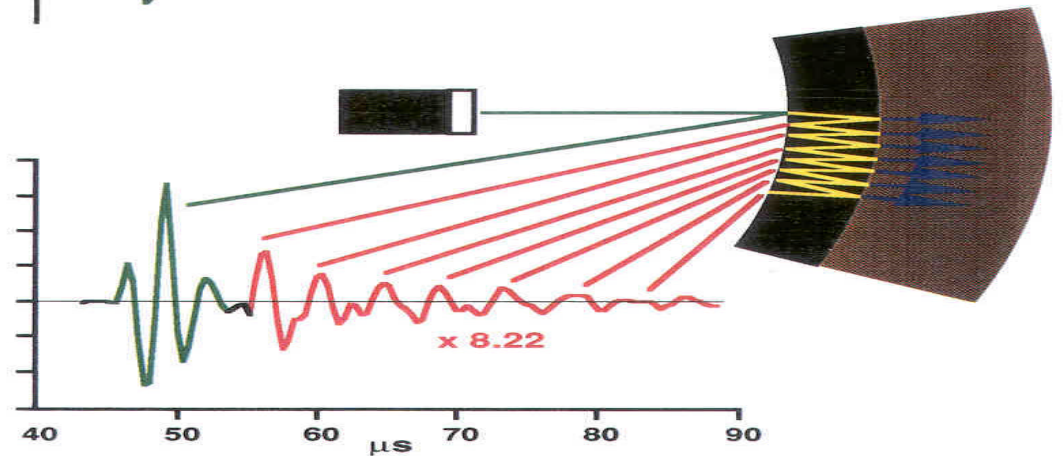
# Principle : The resonance technique



Free pipe



Good cement



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# Acoustic Impedance

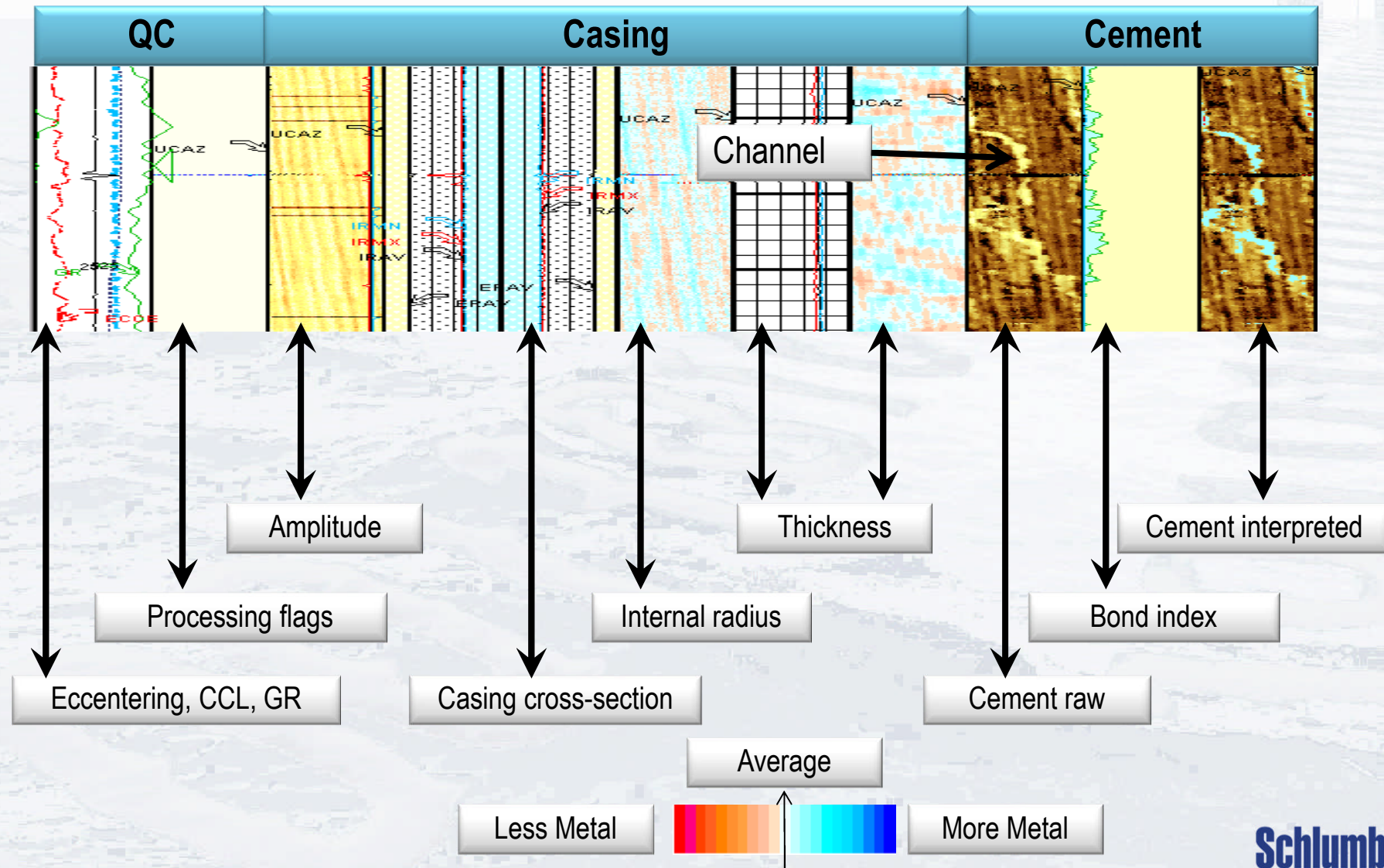
$$Z = \rho \cdot v$$

Material	Density g/cc	Velocity m/s	Z MRayl
Gas	<0.35	~330	<0.1
Water	1.0	1500	1.5
Drilling fluids	1.0-2.5	1300-1800	1.5-3.5
Cement Slurry	1.0-2.0	1500-1800	1.8-3.0
Cement (Lite )	1.4	2200-2600	3.0-3.6
Cement (Cl. G)	1.9	2800-3700	5-7
Steel	7.8	5900	46

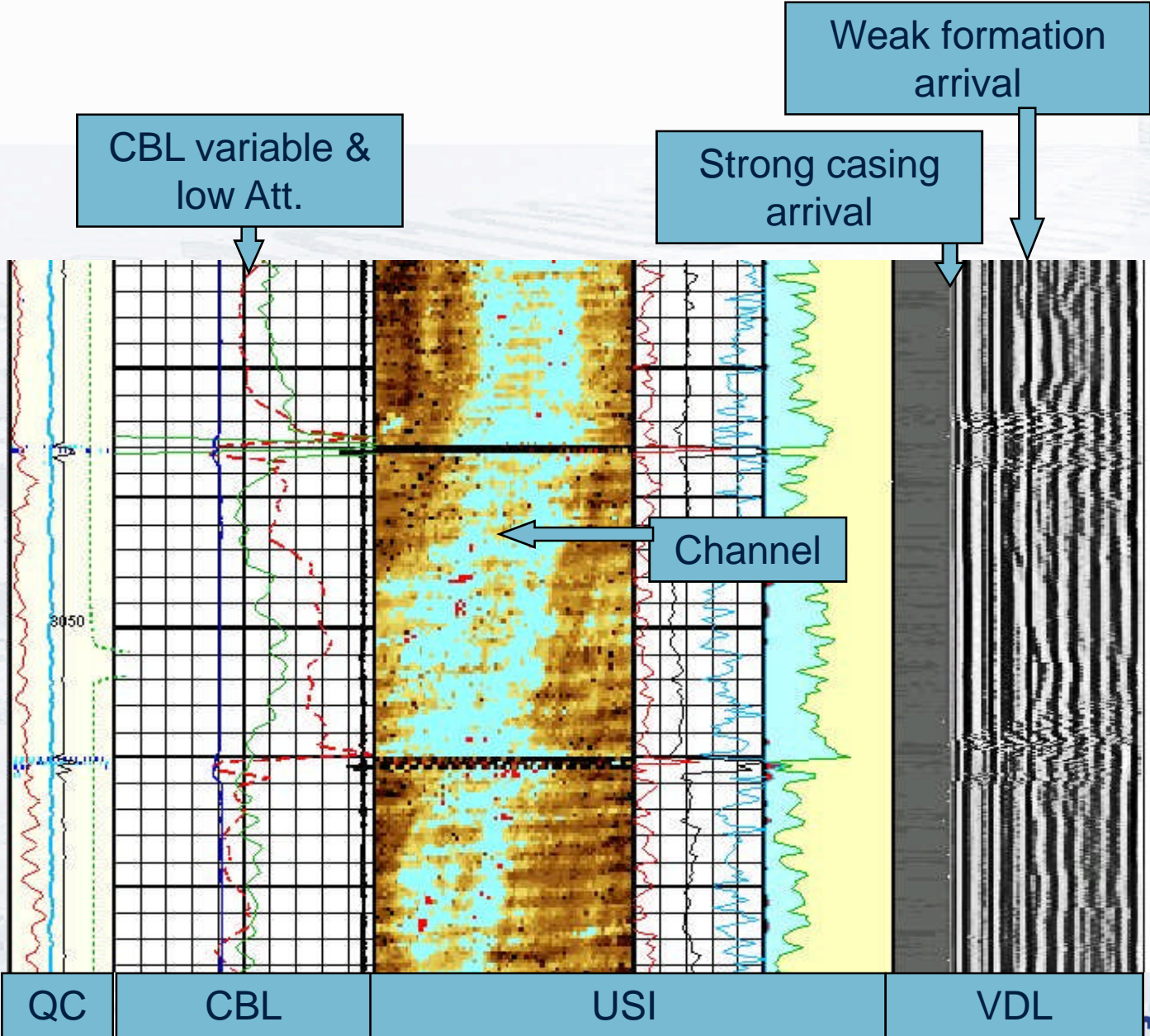
\*Clear fluids K=1

\*Weighted muds K~0.85-1.0 (function of solids)

# Ultrasonic Imager Composite Presentation



# Channel



# USI - Threshold Based Interpretation

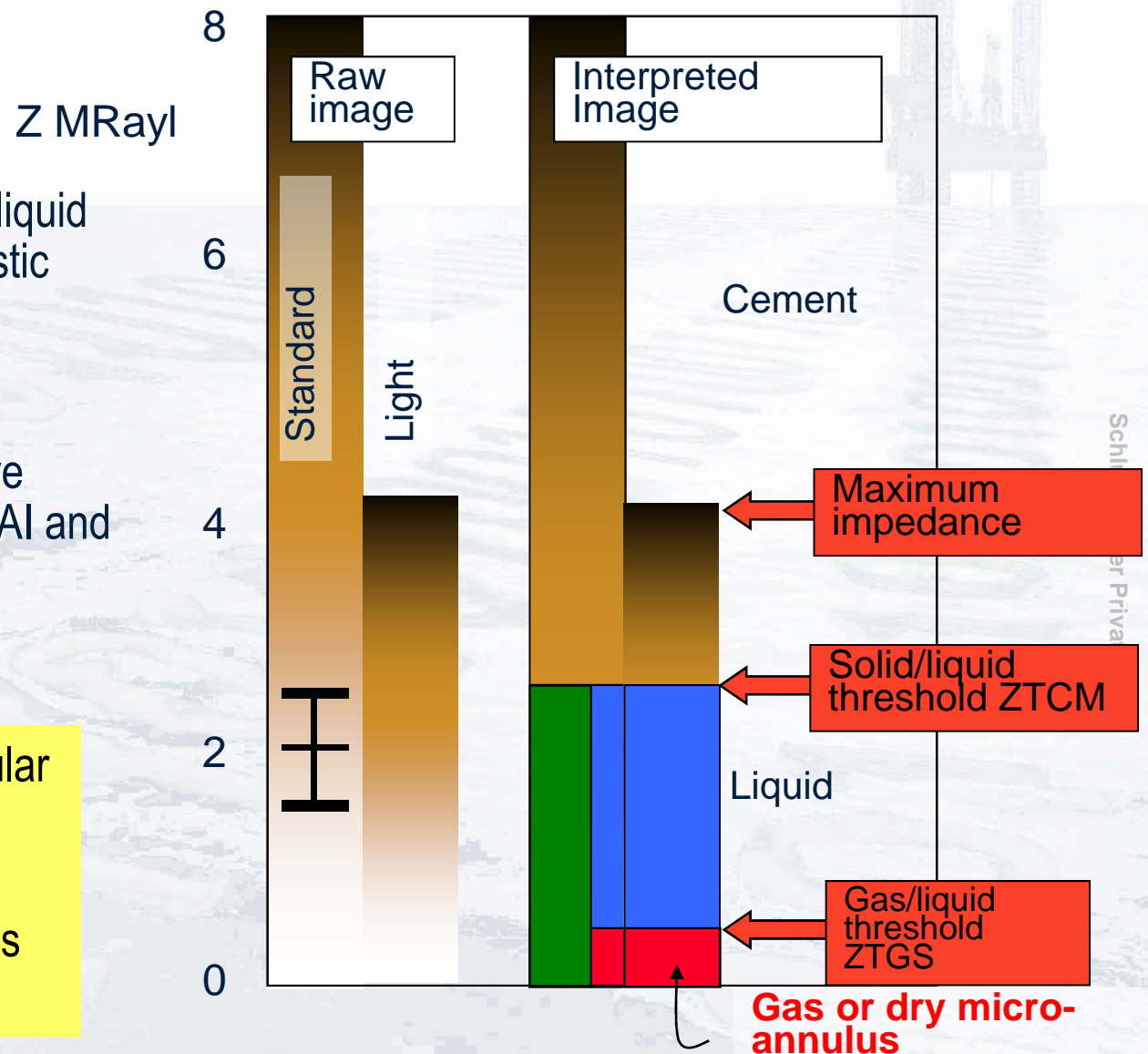
The USI discriminates between solid, liquid and gas/dry microannulus using acoustic impedance (AI) thresholds.

Real time statistical analysis to improve squeeze no squeeze decisions in low AI and microannulus situations.

Microdebonded = green

ZTCM is threshold above which annular liquid does not exist

ZTGS is threshold below which is Gas or micro debonded cement

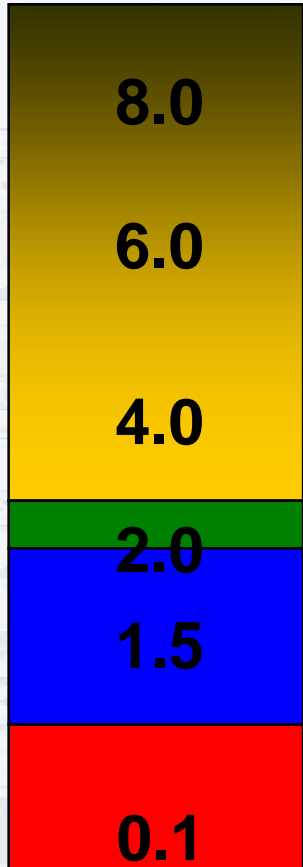


Liquids are statistically “calm” when compared to solids.

Realtime Microdebonding helps tell low AI solids from liquids

# Acoustic Impedance (AI) values

Z (MRayl)



Ultra High Density Cement

High Density Cement

15.8 ppg Cement

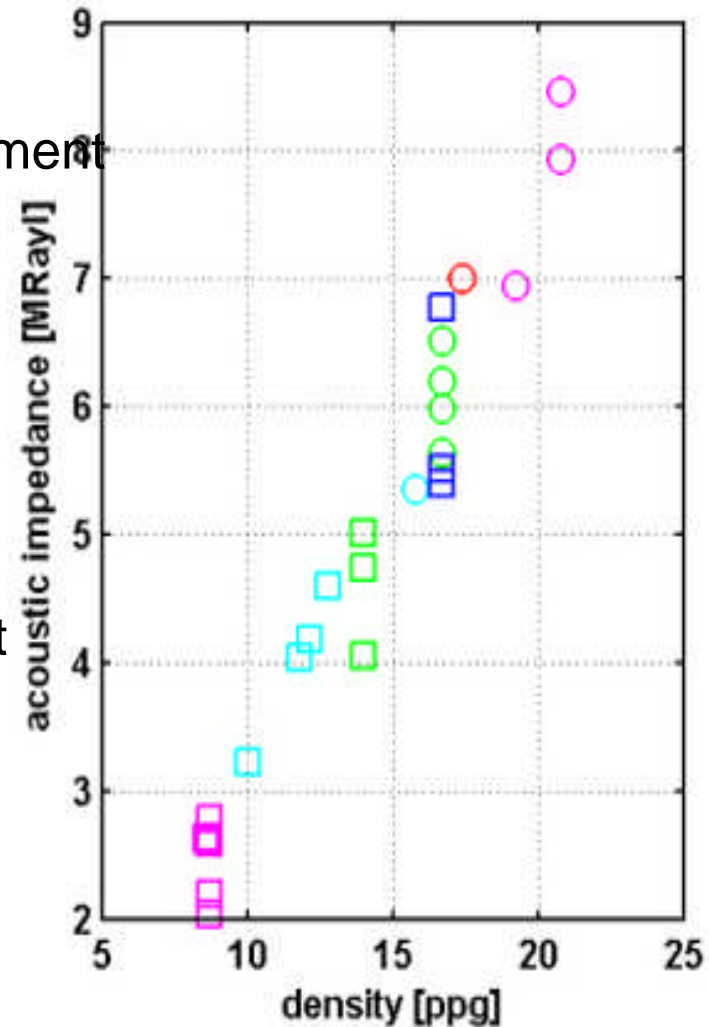
LiteCRETE\* Cement

Foamed Cement

Contaminated Cement

Water

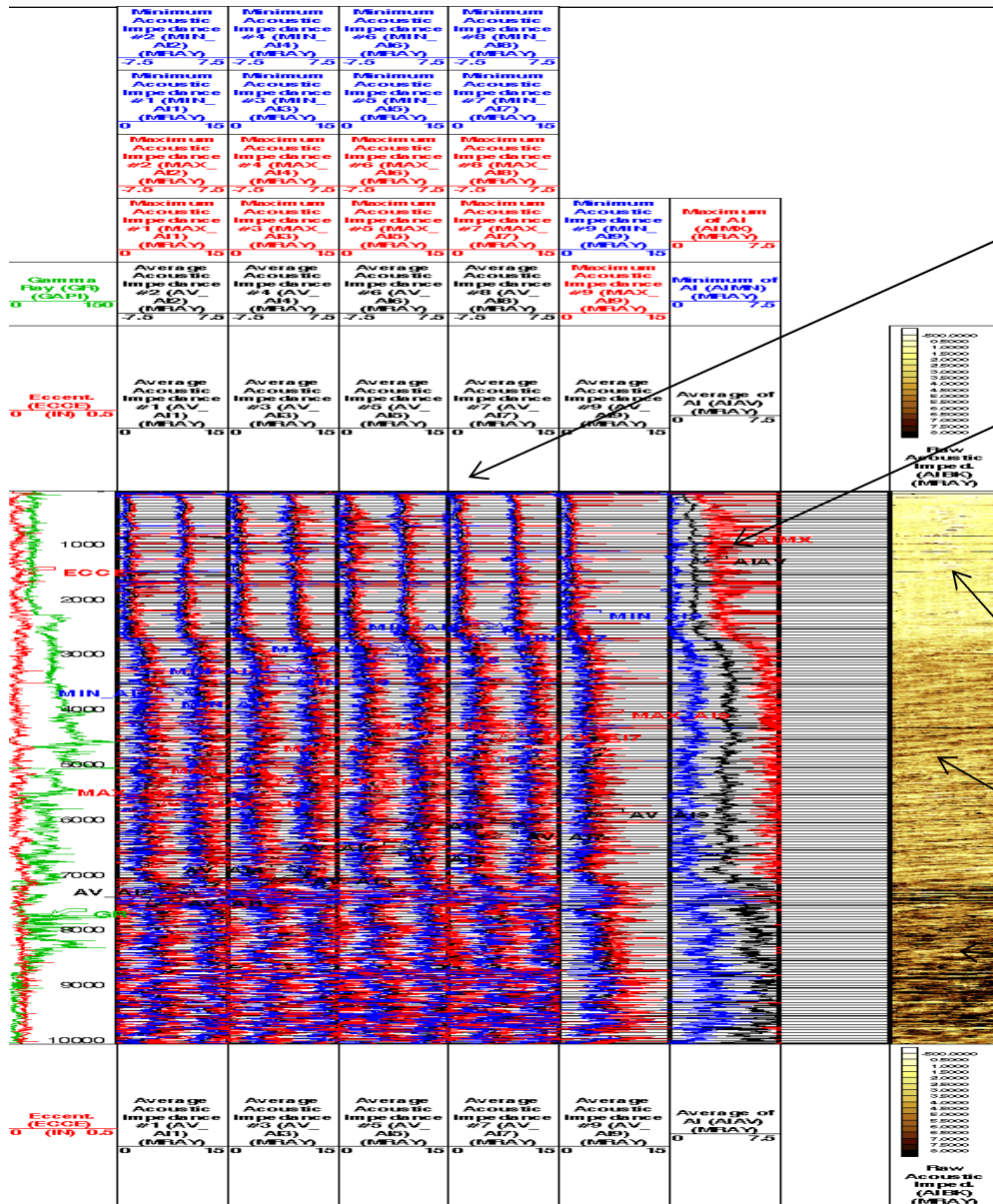
Gas



- "G" + Silica-1
- "G" + Silica-2
- "G" Neat
- CemCRETE-1
- CemCRETE-2
- CemCRETE-3
- CemCRETE-4
- CemCRETE-5
- DensCRETE-1
- DensCRETE-2
- DensCRETE-3
- DuraSTONE
- FlexSTONE-1
- FlexSTONE-2
- FlexSTONE-3
- LiteCRETE-1
- LiteCRETE-2
- LiteCRETE-3
- LiteCRETE-4
- LiteCRETE-5
- SqueezeCRETE-1
- SqueezeCRETE-2
- SqueezeCRETE-3
- LiteCRETE UL-1
- LiteCRETE UL-2
- LiteCRETE UL-3
- LiteCRETE UL-4
- LiteCRETE UL-5
- LiteCRETE UL-6

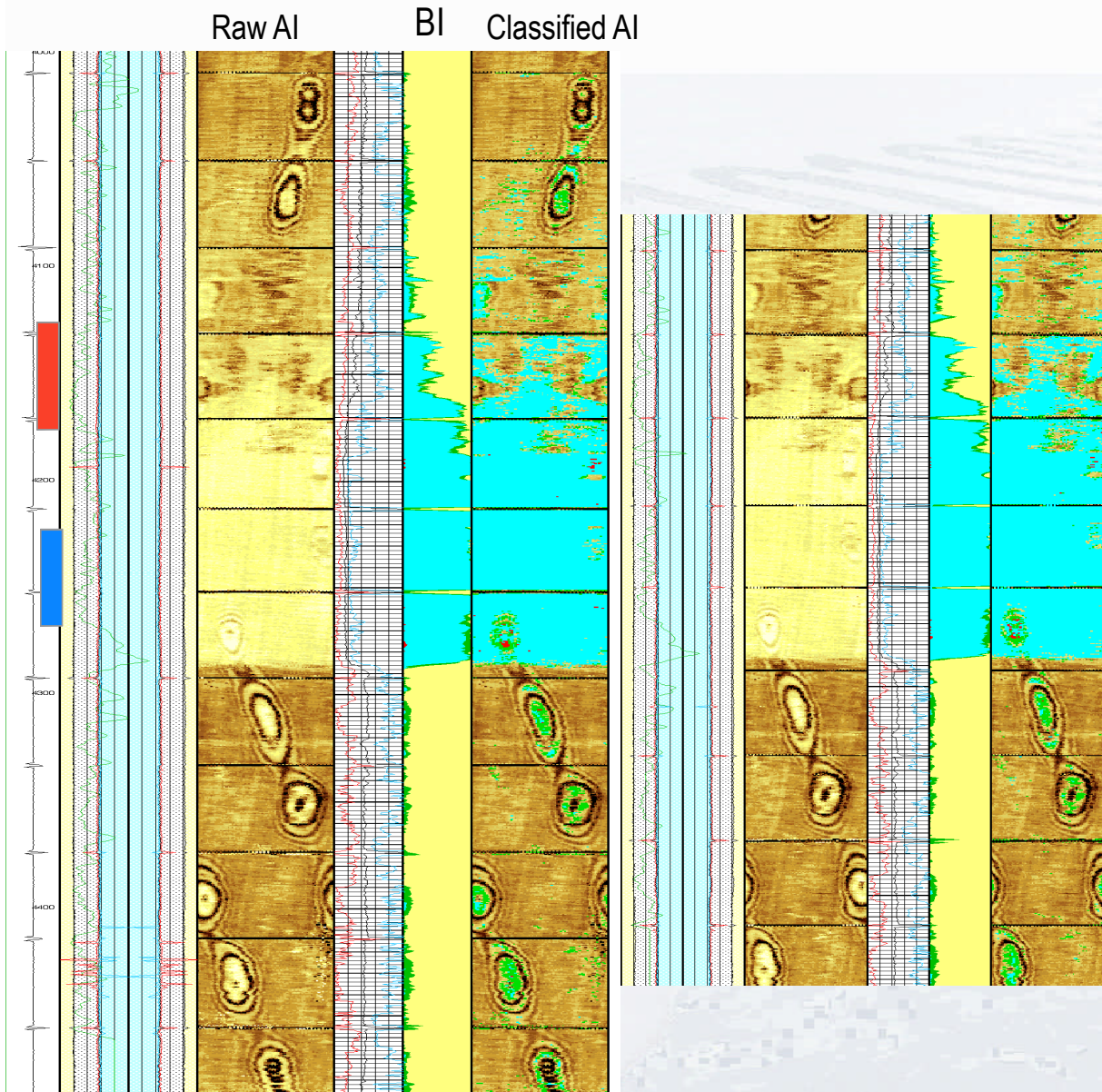
$$AI = \text{Density} * \text{Velocity}$$

# Compressed Goodwin Presentation - USI



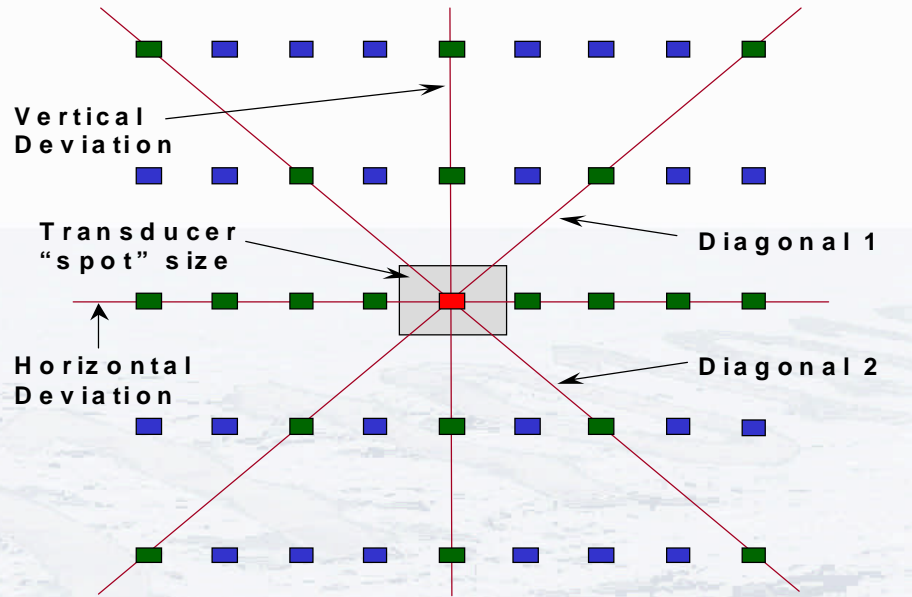
- Graphical display of statistical variance
- Shows Min/Max/Average Acoustic Impedance in each of 9 40 degree quadrants
- Shows Min/Max/Ave over each radial depth
- 1" /1000 ft can reveal AI patterns not easily seen in 5"/100 ft
- AI Ave of liquid = ~ 2 mrayls ( less variance)
- AI Ave of 11.5# lead = ~ 4 mrayls
- AI of Tail = ~ 6 mrayls

# USI in a Slow setting, extended cement system Carbonate water flood - Permian



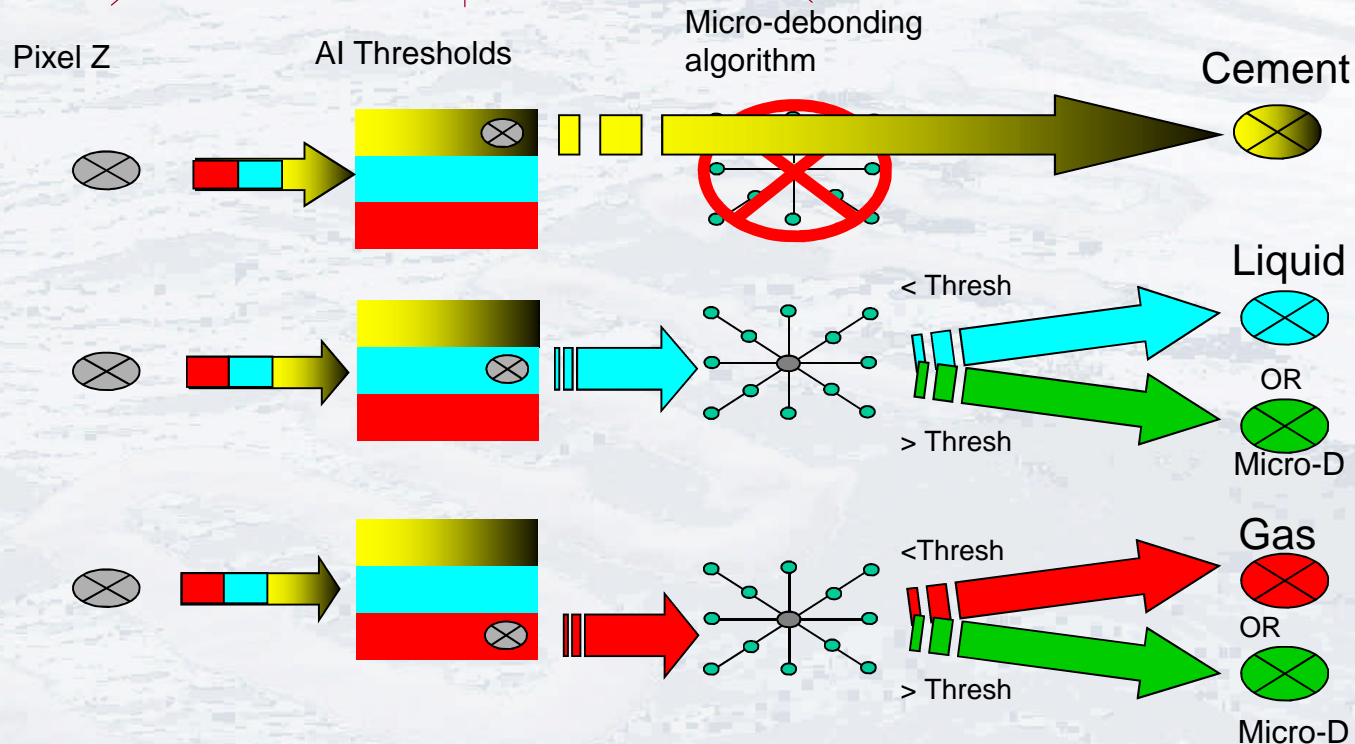
1. Radial mapping of acoustic impedance outside casing
2. Main pass on Left, Repeat on Right
3. Allows better interpretation of channels and contamination
4. “Galaxy Patterns” occur where casing is in contact with borehole wall – can aid in ID of high or low side channels
5. Here Cement placement was initially good over entire interval.
6. Red and blue zones are at different pressures and crossflow voided cement during setting.

# MICRO-DEBONDING CEMENT PROCESSING



Real time processing for statistical variation of Acoustic Impedance

- 4 checks done – must pass all 4 to be a microdebonded solid (green)



Only values below ZTCM are subjected to microdebonding logic

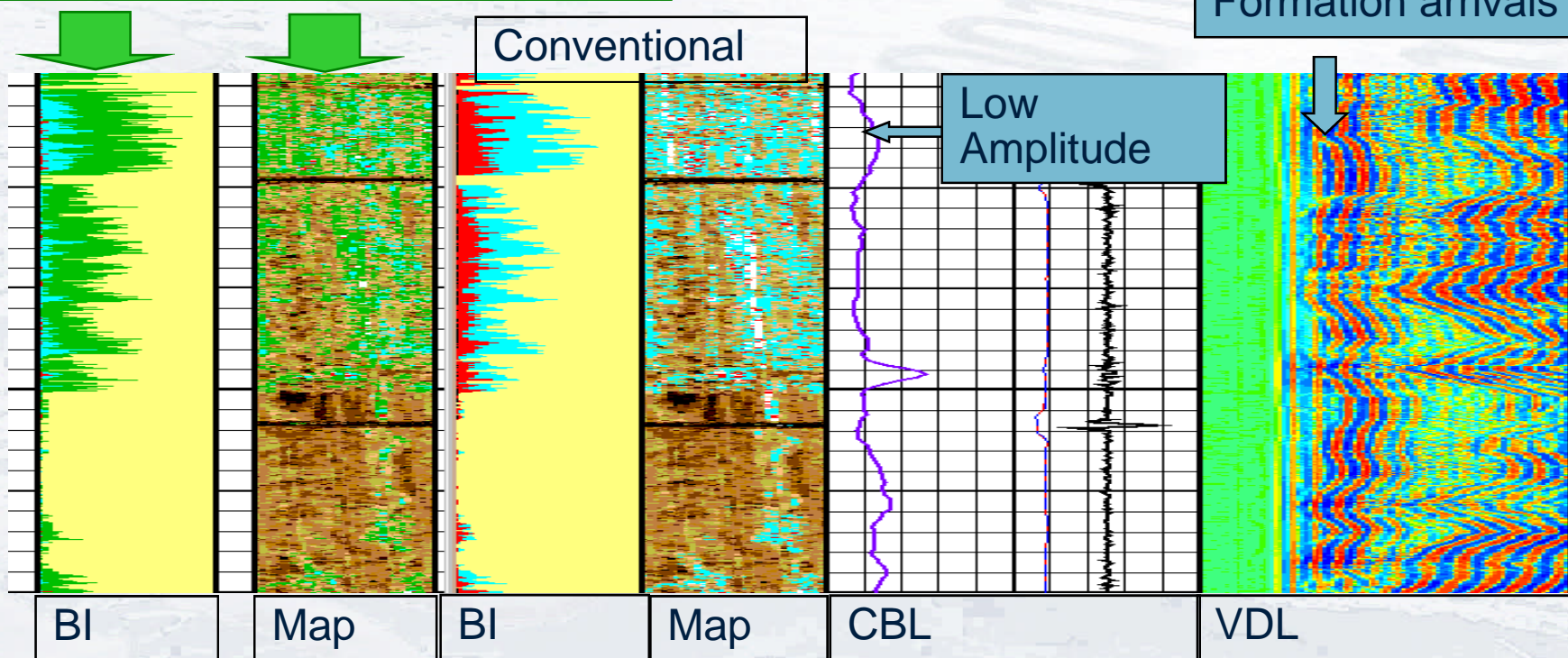
“Pixel” is colored based on outcome

# USI micro-debond logic

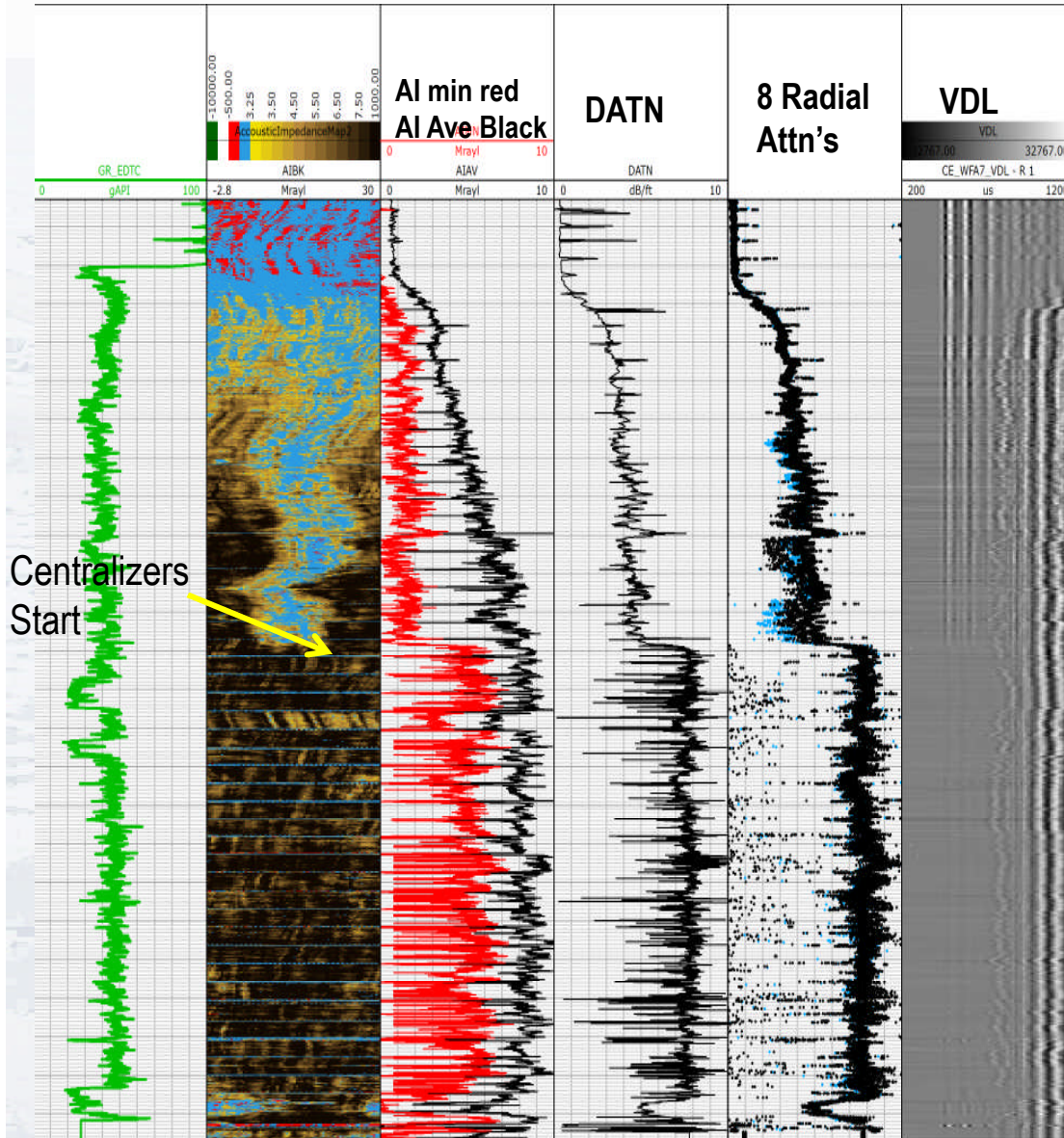
Automatically classifies patchy low-impedance material as **micro-debonded cement**

Helps interpretation of light and foam cement

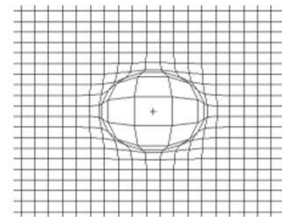
Micro-debond presentation



# Ultrasonic vs. CBL ( Sonic Scanner with 8 Radial Attenuations)

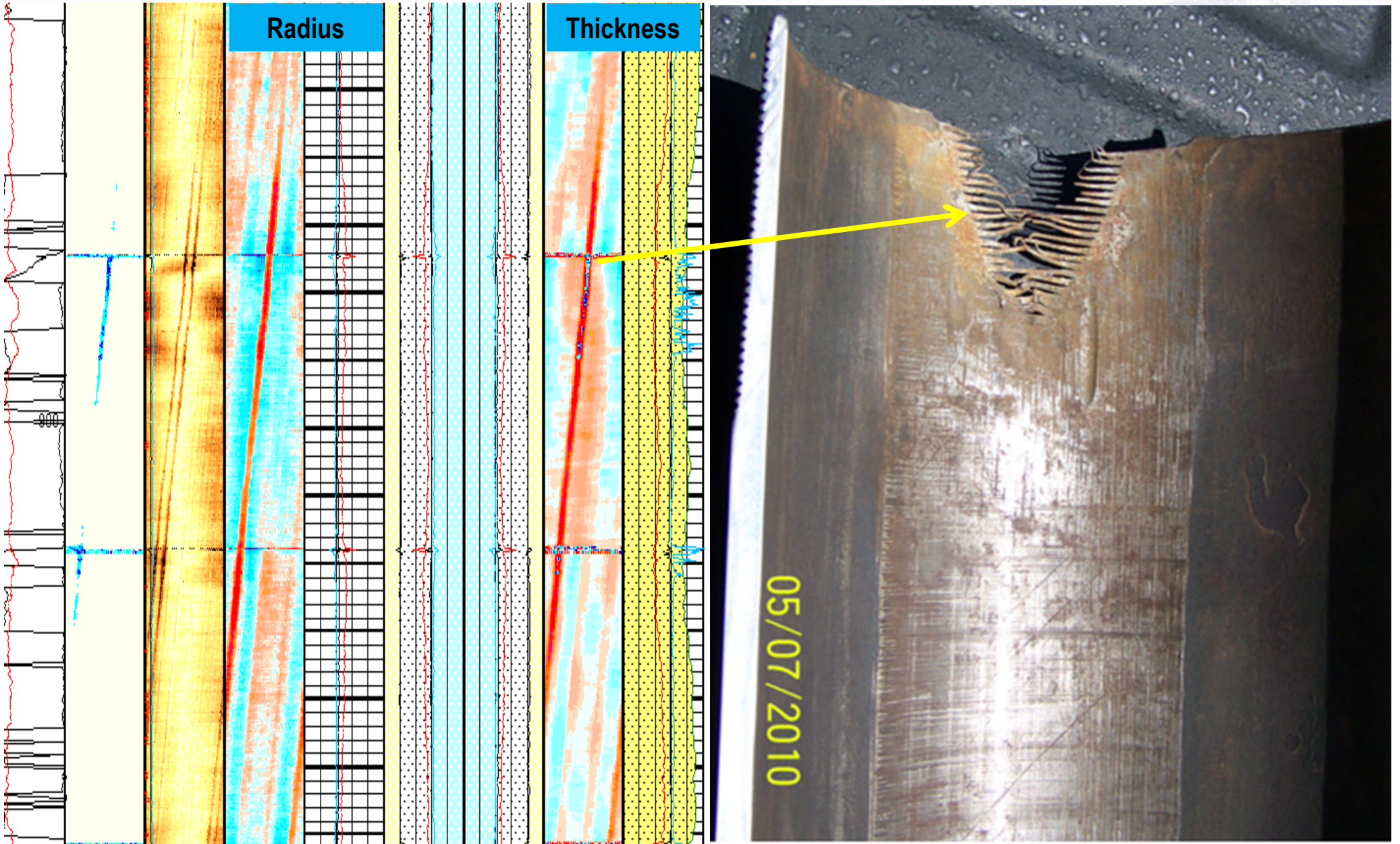


- Channel clearly defined by USI high resolution measurement
- Minimum Impedance curve reads liquid in channel. Average AI shows decay to TOC
- CBL Radial Attenuations in channel affected by surrounding bonded pipe and do not read free pipe until above TOC
- CBL Radial attenuations in well bonded pipe affected by channel
- Same affect with RCBL tools as well
- CBL Transmitter is Omni directional – hurts resolution even though 8 channels

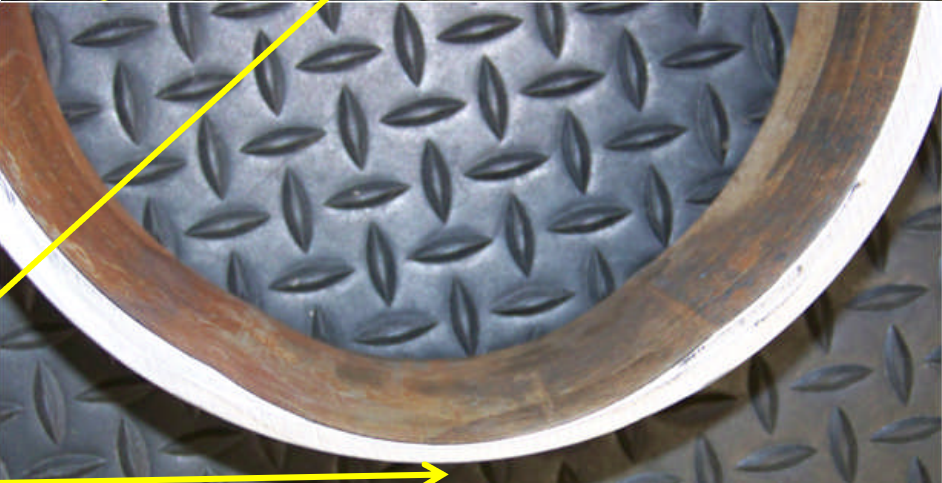
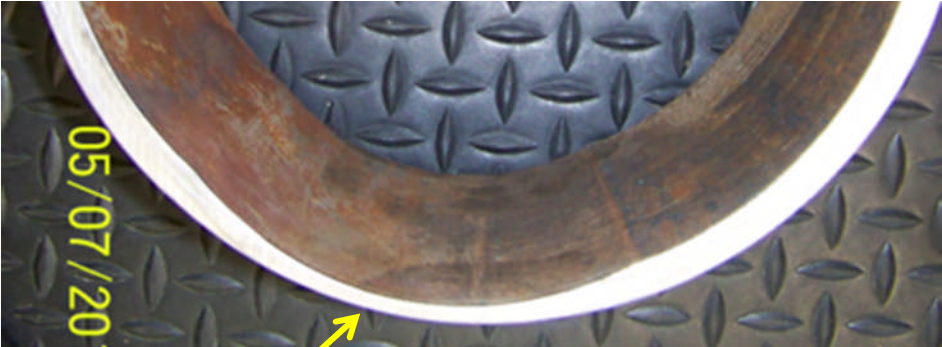
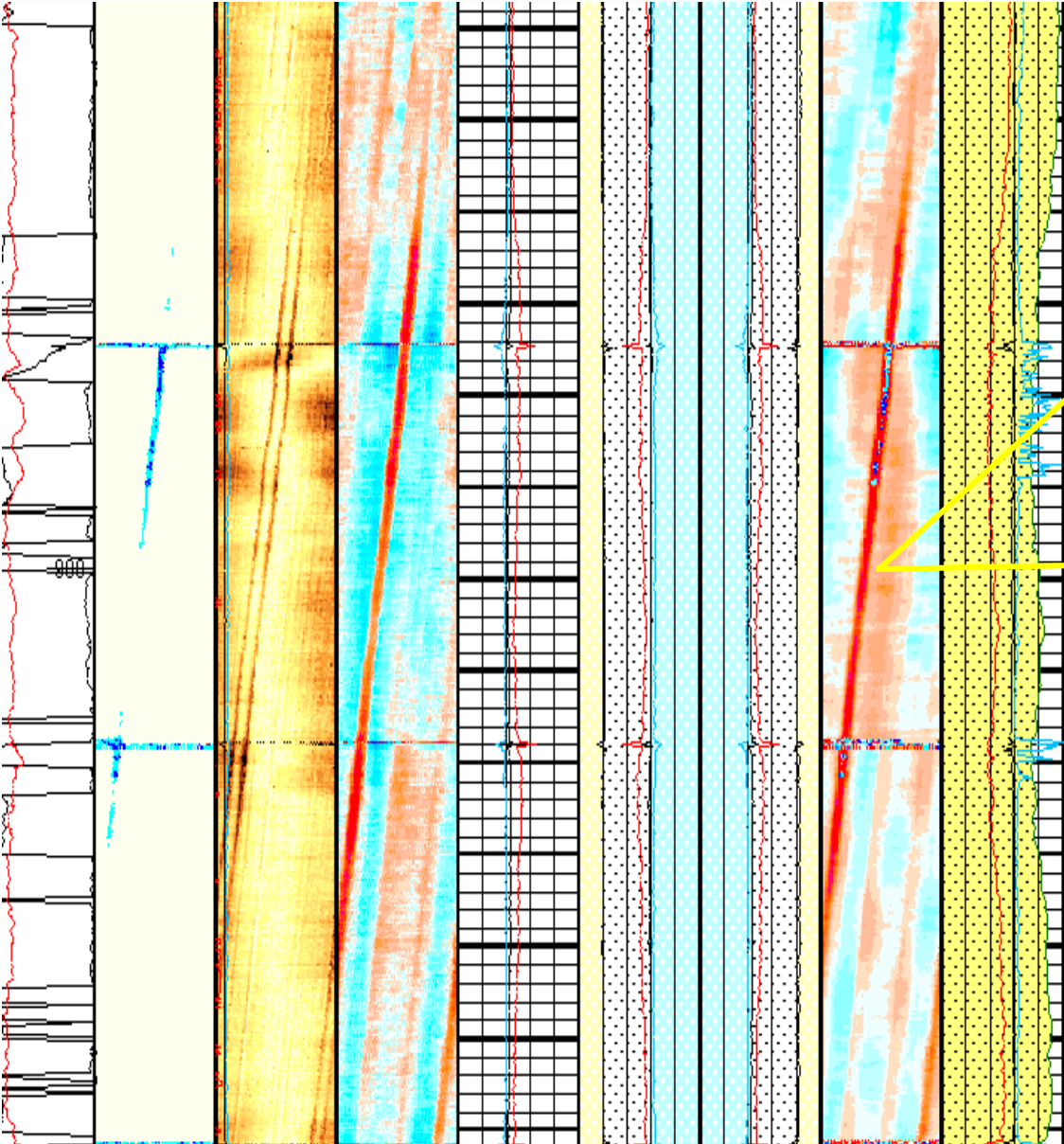


**Schlumberger**

# Drill Wear in 9 5/8" Casing



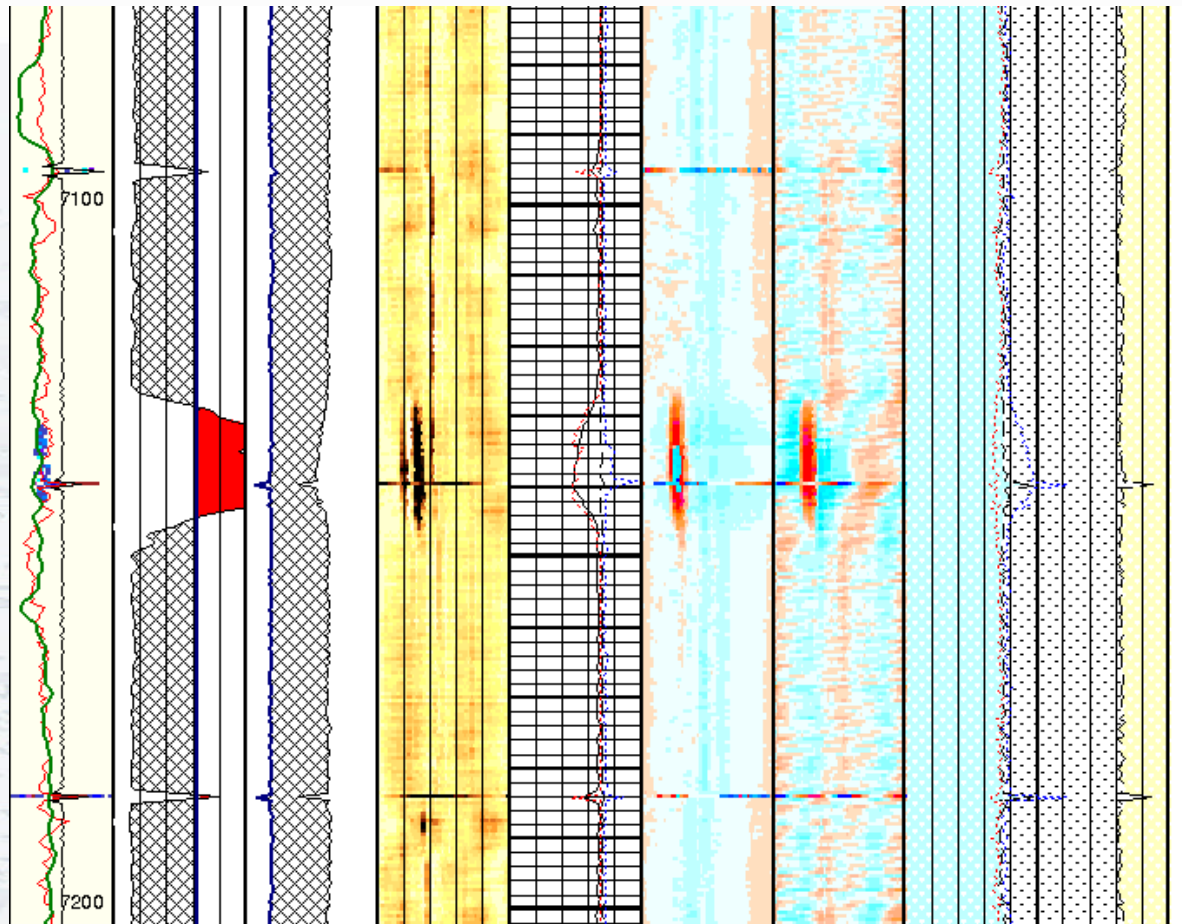
# Drill Wear in 9 5/8" Casing



# Customized Drillwear presentation



Schlumberger Private



API  
Flag

AMP THK THK RAD RAD & THK

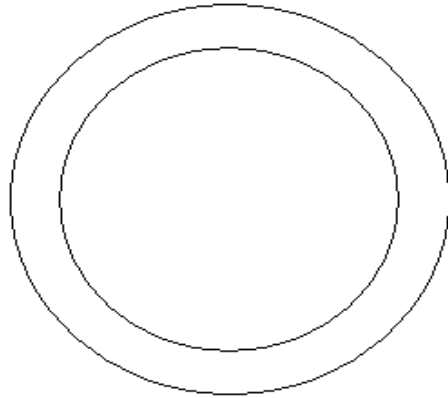
Flags thickness below API ratings

Radial Thickness allows minimum burst to be accurately calculated to determine need for frac string.

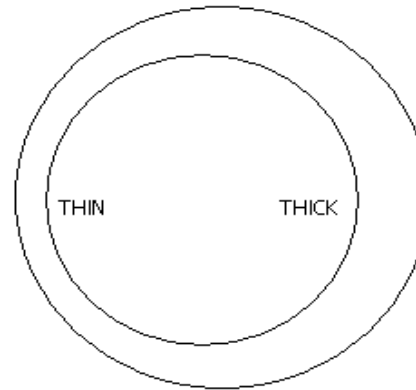
Done concurrently with cement information to determine external support

# COMMON DOWNHOLE TUBULAR GEOMETRY

PREFERRED CROSS-SECTION

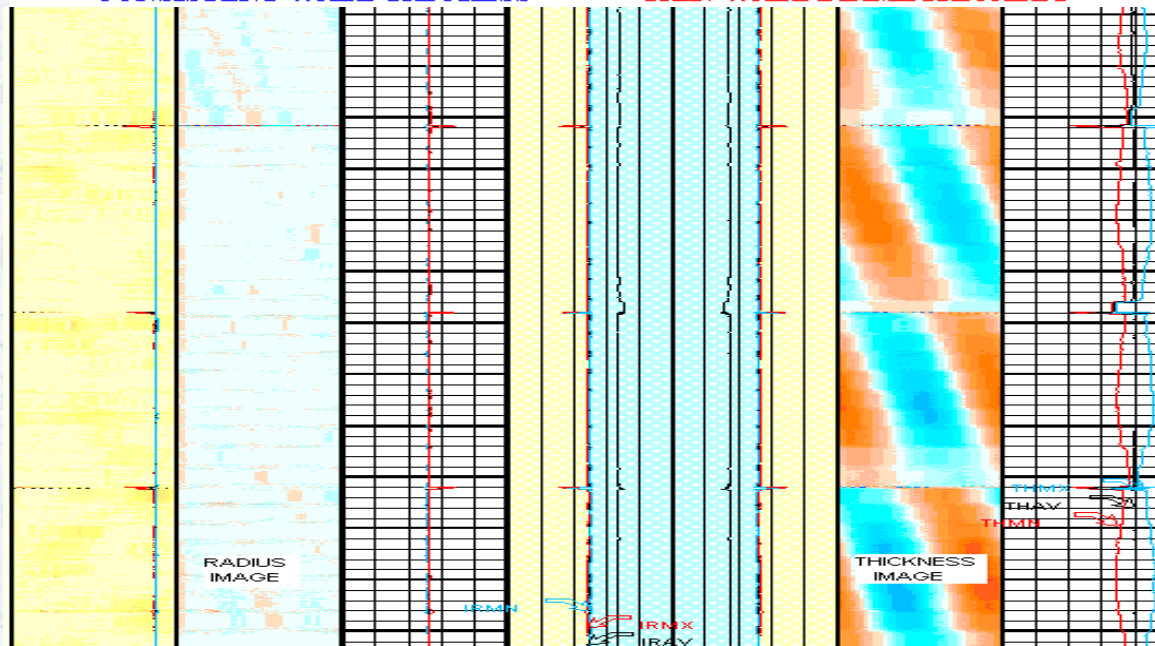


COMMON CROSS-SECTION



CONSISTENT WALL THICKNESS

THIN WALL DIAMETRICALLY



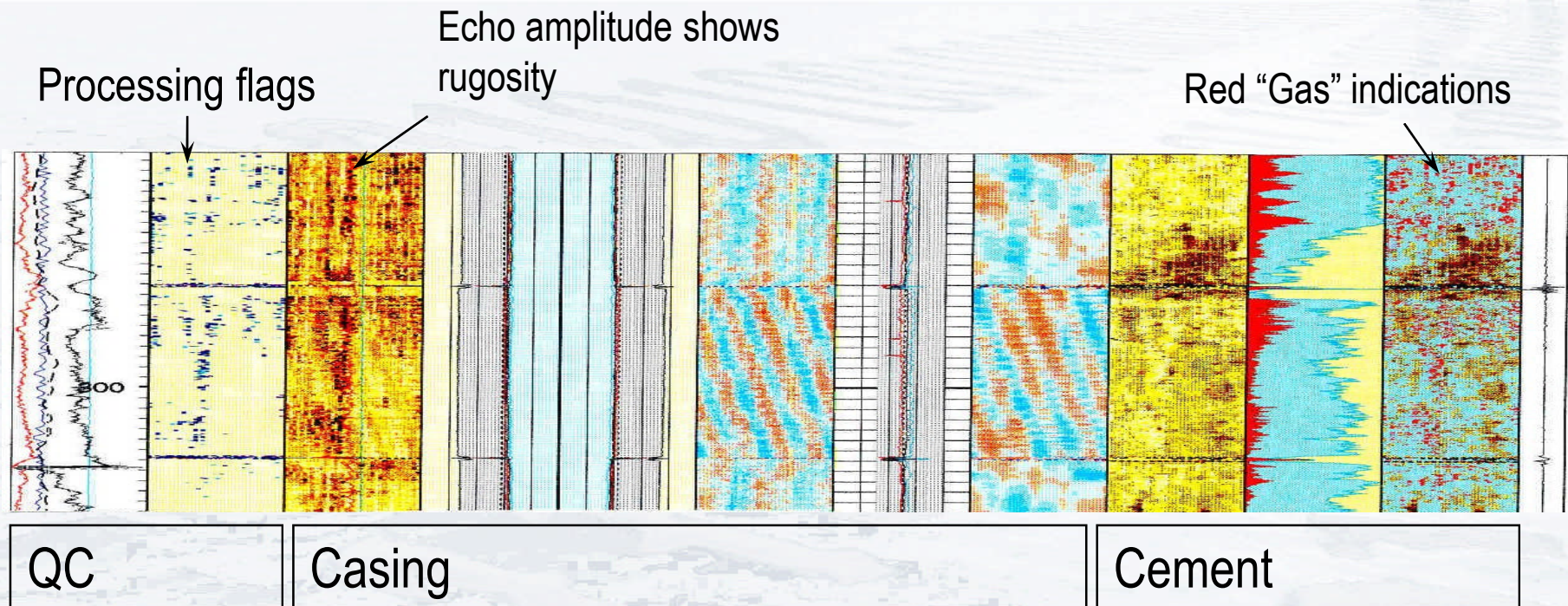
API +/- 12.5% from nominal

Burst will be less than expected without direct thickness measurement

Thickness is needed to compute accurate burst strength

Mechanical Caliper will not see this reduction in thickness & Burst strength

# Poor casing condition affects cement evaluation



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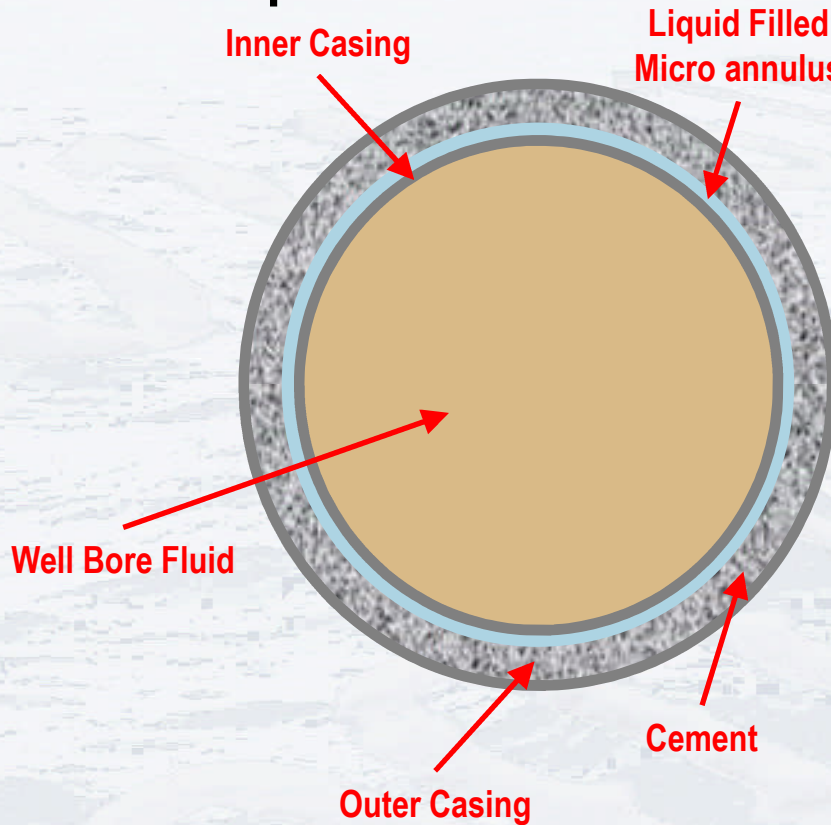
Processing flags and amplitude image show that gas indications are an artifact of internal rugosity

# Causes of Microannulus

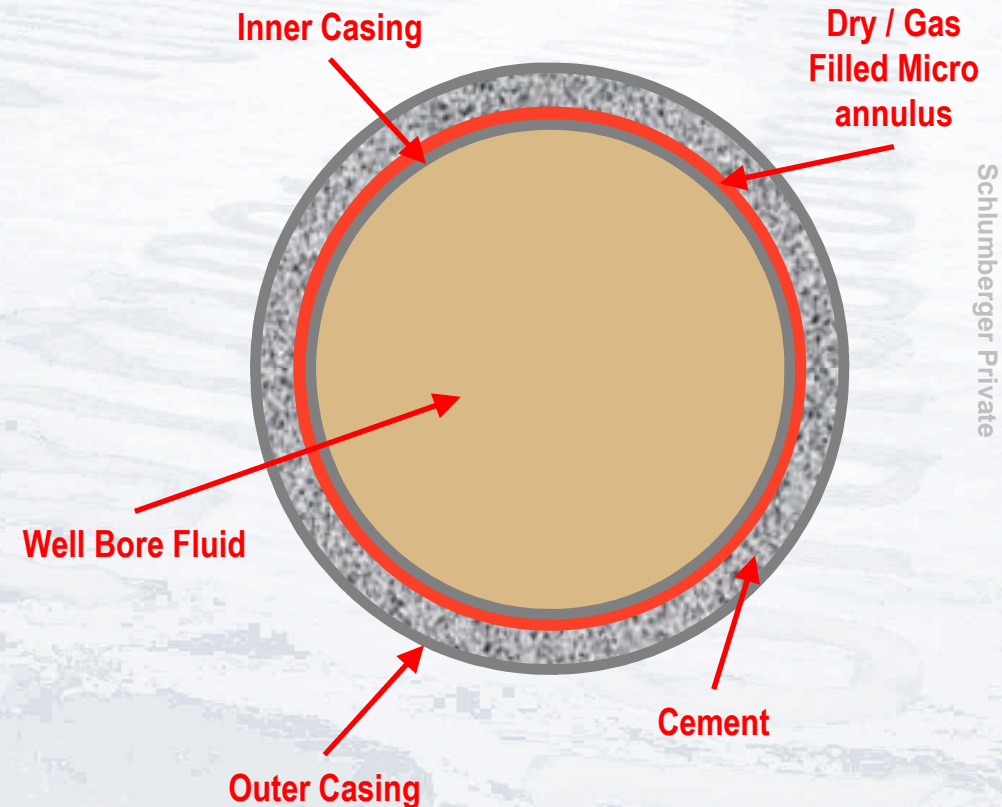
- **Changes in casing state of stress from curing time until log time**
  - Pressure testing casing while cement set – Hydraulic stimulation cycles
  - Floats not holding – holding pressure on casing while cement cures
  - Swapping of heavy displacement fluid to lighter completion fluid
  - Relaxation of tension held on casing by drilling rig during cement curing
  - Thermal stress – cooling of a hot well
- **Coatings which affect the ability to bond cement to casing**
  - Insufficient removal of OBM/SOBM
  - Heavy mill varnish
  - Engineered coatings for corrosion prevention
- **Low confining stress of formation or insufficient mud cake removal**
  - Cement should have lower Young's Modulus than surrounding rock
- **Bulk volume changes – shrinkage of cement slurries**
  - Chemical shrinkage – volume of reaction products of hydration is less than that of the reactants 6.25 cm<sup>3</sup>/100g Portland cement at 100% hydration – can lead to loss of internal pressure in cement
  - Bulk Shrinkage – external volume reduction seen due to chemical shrinkage, less than total chemical shrinkage. Largest affects when cement is cured without access to excess water
  - Curing in multistring or other impermeable no source of water environments

# Microannulus

## Liquid Filled Microannulus



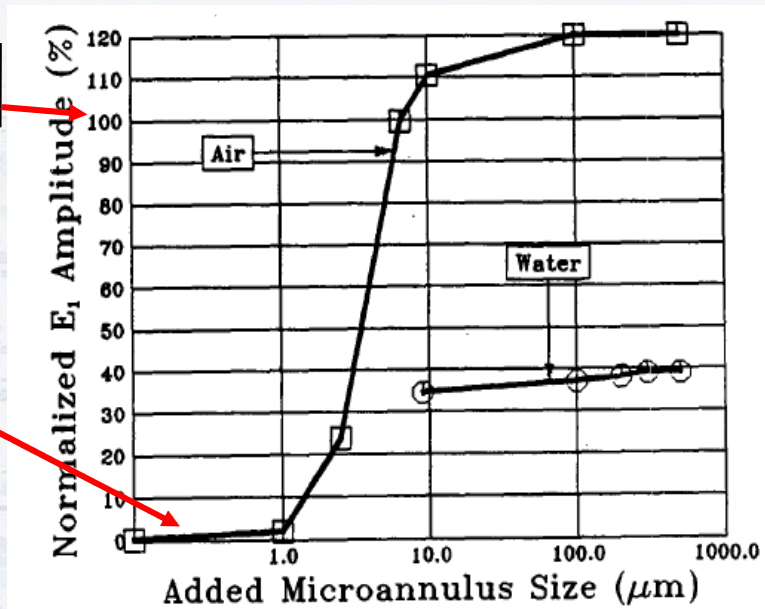
## Dry / Gas Filled Microannulus



A small gap between casing and cement formed by pressure and temperature changes, or a mud or oil film left on the casing. USI and CBL respond in different ways

# Micro Annulus: CBL vs USI

from SPE paper 025377



No bond

100% bond reading

100% bond reading

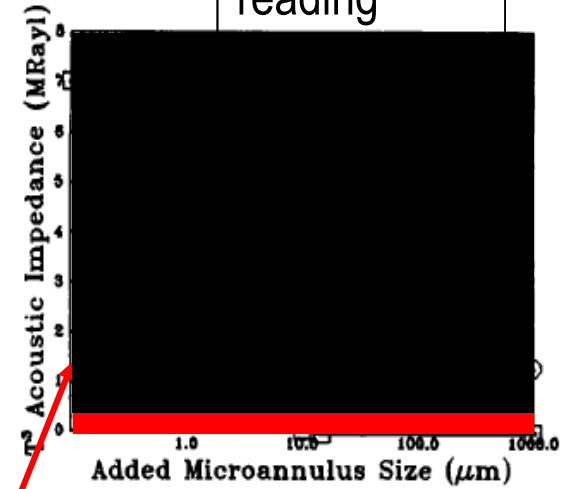


Fig. 6: microannulus effects on ultrasonic measurements in casing 3 - T<sup>3</sup> processing.

No Bond

Based on the above, we can conclude that if the micro annulus is small, the CBL reads more accurate in dry micro annulus and USIT/Isolation Scanner is more accurate in liquid filled micro annulus



No bond

100% bond reading

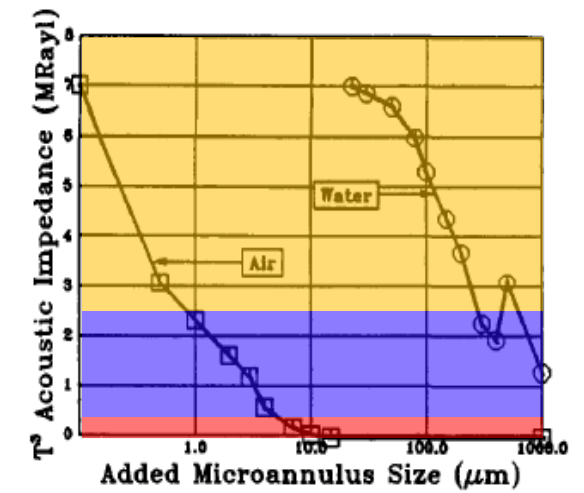
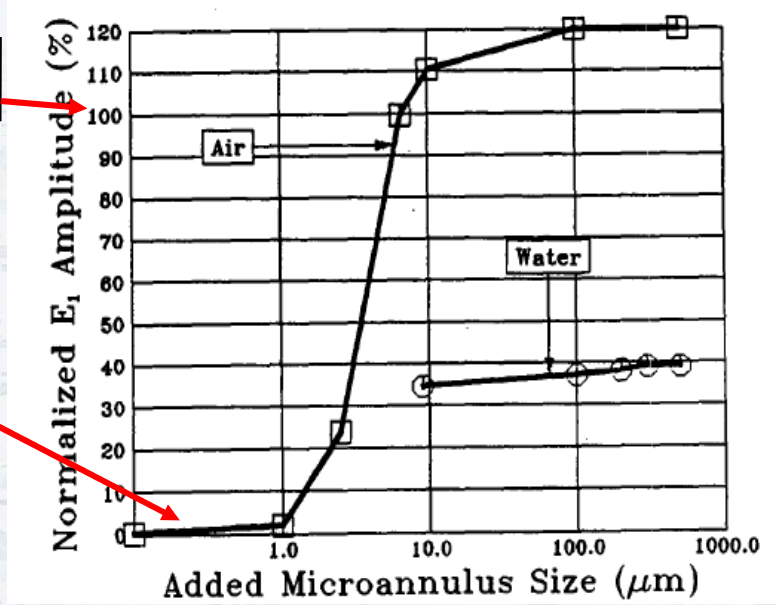
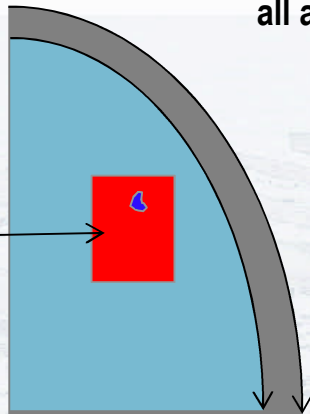


Fig. 6: microannulus effects on ultrasonic measurements in casing 3 - T<sup>3</sup> processing.

Based on the above, we can conclude that if the micro annulus is small, the CBL reads more accurate in dry micro annulus and USIT/Isolation Scanner is more accurate in liquid filled micro annulus

# Microannulus and the Measurement



Magnitude of shear bonding can vary in all azimuths and even within beam width

- AI < ZTGS mrayl
- AI between ZTGS & ZTCM
- AI > ZTCM mrayl

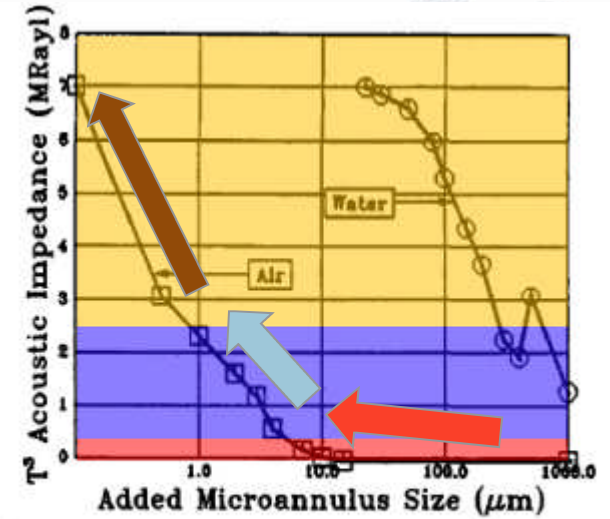
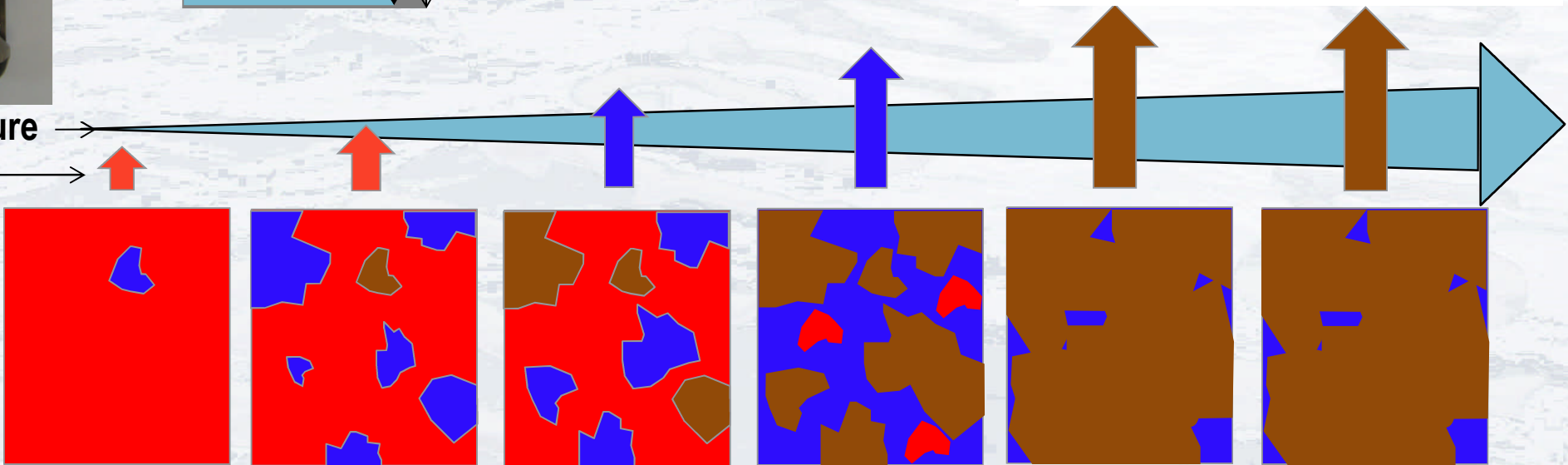


Fig. 6: microannulus effects on ultrasonic measurements in casing 3 - T<sup>3</sup> processing.

Pressure →  
AI →



- With MA – Once pressure starts to improve Shear Bond – Shear bond and AI increase with pressure until a point
- When shear bond stops improving – true AI and FA can be measured, until then they cannot.

# Micro Annulus

## Cement Bond Log

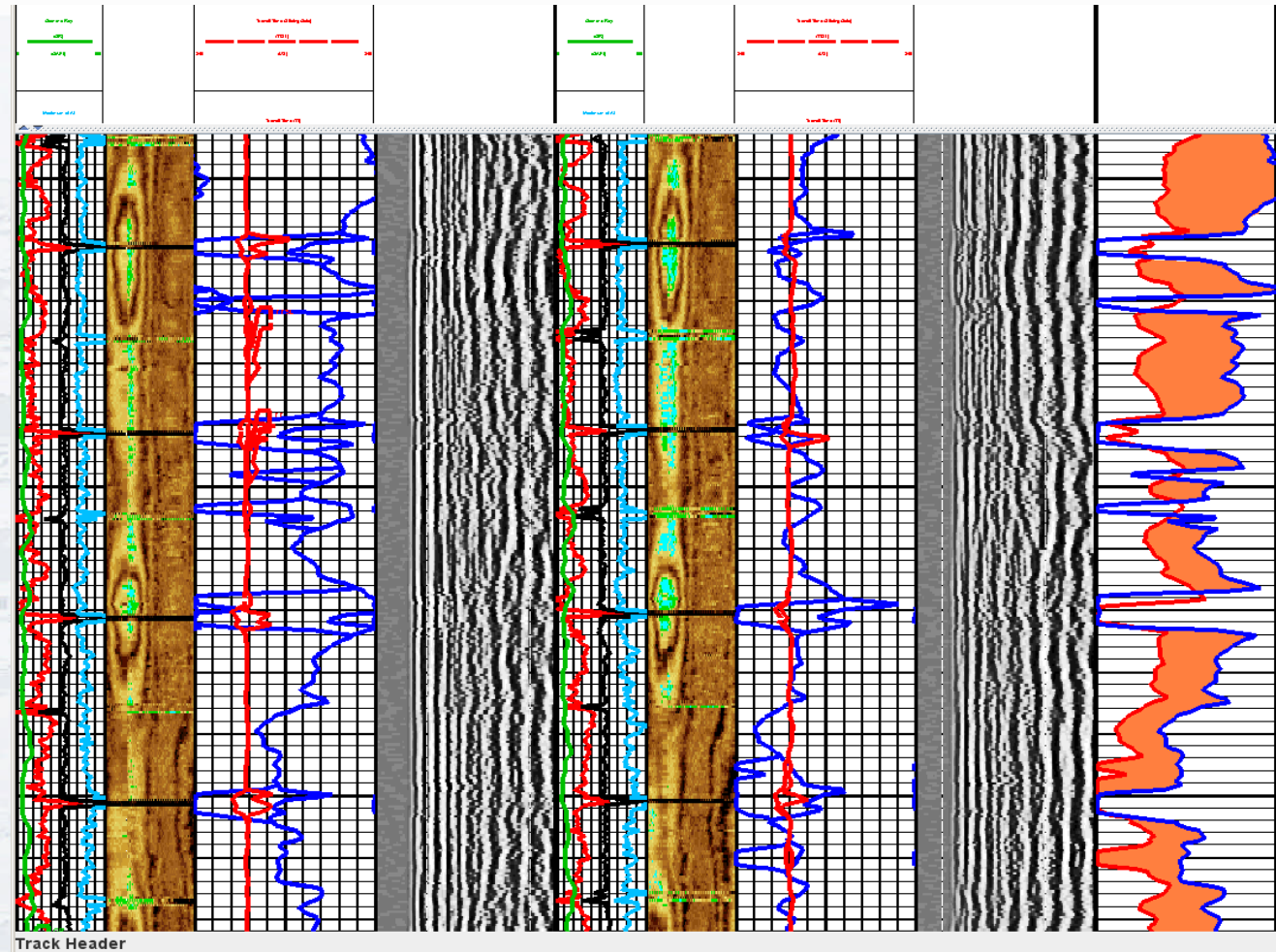
- ✓ Strongly affected by Liquid filled microannulii
  - ✓ Will read too high an amplitude in liquid micro annulus.
- ✓ Not strongly affected by gas filled microannulii (very small aperture)

## Ultra Sonic Logs

- ✓ Not generally affected by most Liquid filled microannulii (<200 um)
- ✓ Large Liquid Microannulii (>600um) affect
- ✓ Will give better results in pipe that can't be pressured up where liquid microannulii exist
- ✓ Strongly affected by gas filled microannulii (very small aperture)
  - ✓ Appears as red image usually around entire pipe or may be blotchy

- Pressure test casing after cement evaluation
- Understand well history - Be prepared to run logs under pressure
- Running both tools combined improves evaluation

# Wet Microannulus

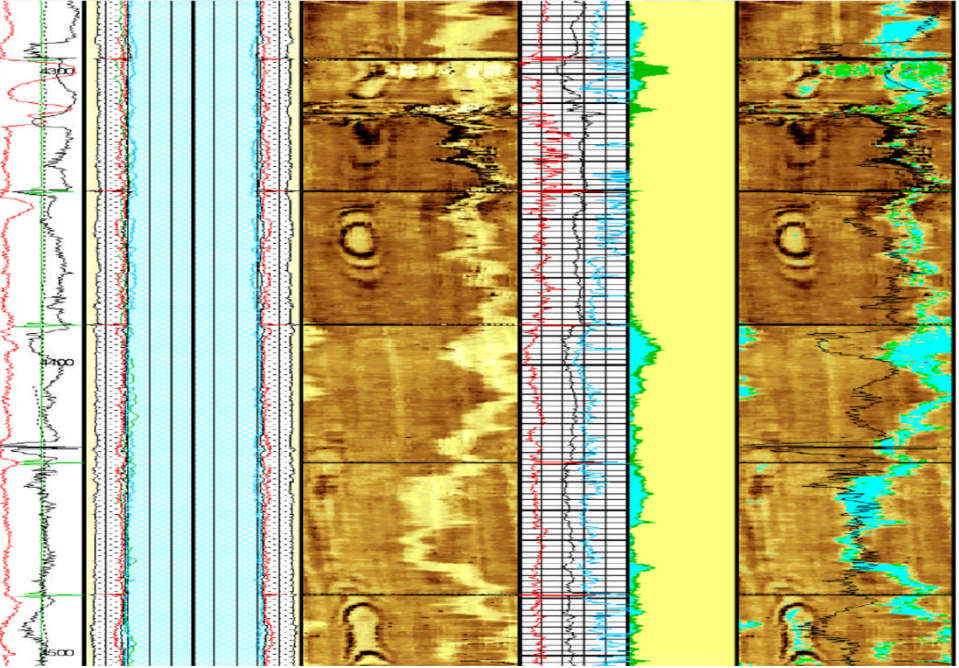


# USI Cement Presentation

Image rotation (UCAZ) (DEG)	Min of Internal radius (IFMN) (IN)	Min of Internal radius (IFMX) (IN)
0 360	2.9 (IN) 1.9	1.9 (IN) 2.9
Azimuth of eccent. (AZEC) (DEG)	Gamma Ray (GF) (GAPI) 100	
0 360		
Cable Speed (CS) (F/HR)	External radius Average (ERAV) (IN)	Internal radius Maximum (IRMX) (IN)
0 2000	2.9 (IN) 1.9	1.9 (IN) 2.9

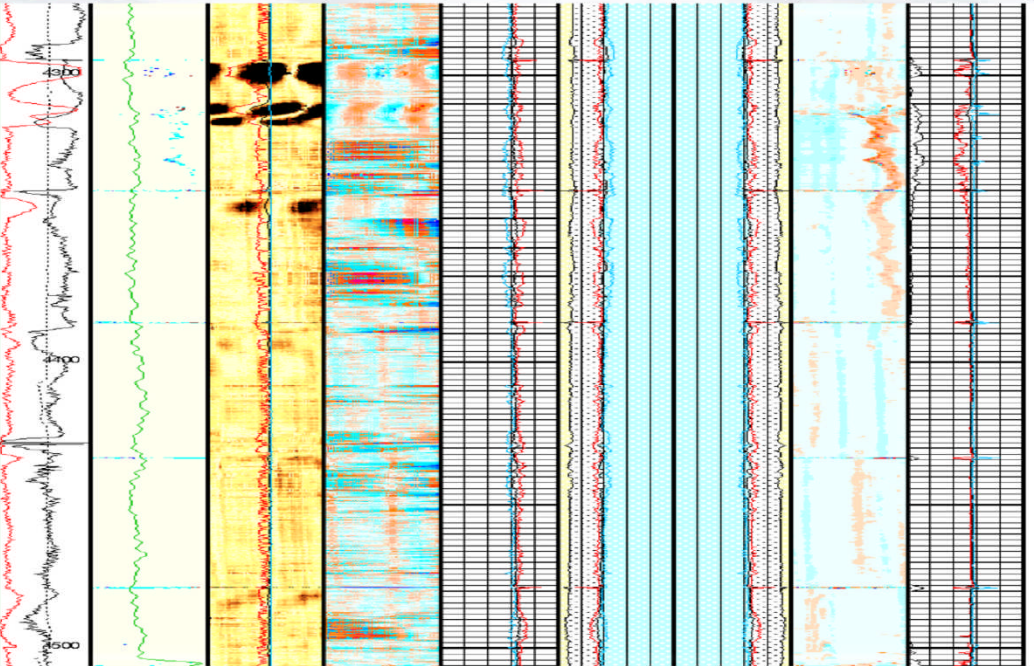
Hi Res mapping of cement and external and internal corrosion

Eccent. (ECCE) (IN) 0.5	Internal radius Average (IRAV) (IN)	External radius Average (ERAV) (IN)	Flaw Acoustic Imped. (AIBK) (MRAY)	Minimum of AI (AIMN) (MRAY) 10	Bonded	Azimuth of eccent. (AZEC) (DEG) 360
0 (IN) 0.5	2.9 (IN) 1.9	1.9 (IN) 2.9	0 8000.0000 0.5000 1.0000 1.5000 2.0000 2.5000 3.0000 3.5000 4.0000 4.5000 5.0000 5.5000 6.0000 6.5000 7.0000 7.5000 8.0000	0 (MRAY) 10		



# USI Composite Pres

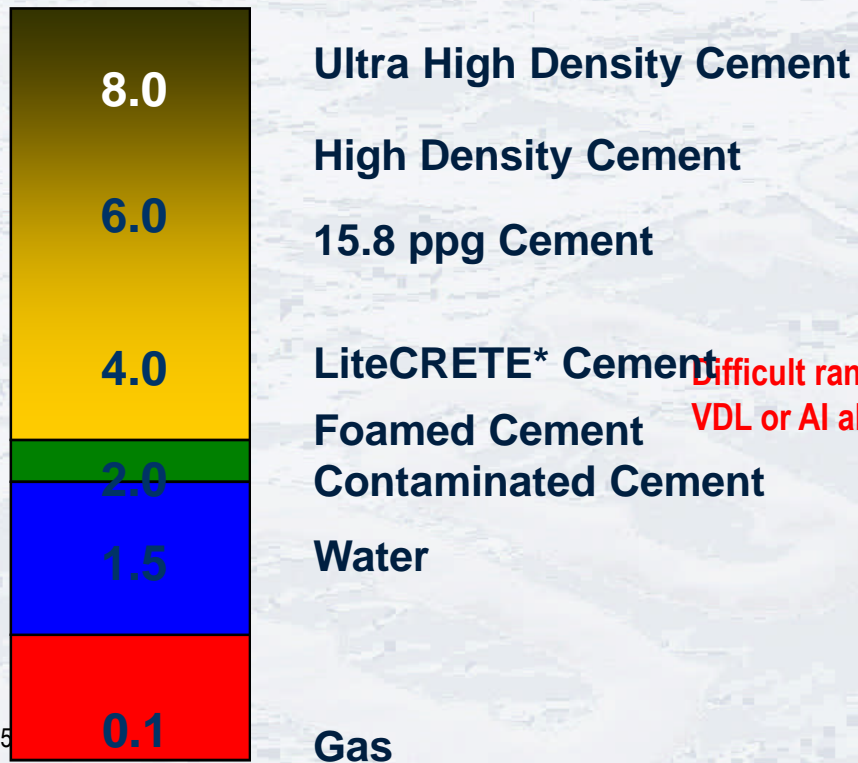
Image rotation (UCAZ) (DEG)	Amplitude of echo minus Max (AWBK) (DE)	Min of Internal radius (IFMN) (IN)	Min of Internal radius (IFMX) (IN)	Casing Wear
0 360	Maximum of Amplitude (AWMB) (DE) 75	2.9 (IN) 1.9	1.9 (IN) 2.9	
Azimuth of eccent. (AZEC) (DEG)	Average of Amplitude (AWAV) (DE) 75	Internal radius Maximum (IRMX) (IN)	Internal radius Maximum (IRMX) (IN)	Maximum of Thickness (THMC) (IN) 0.5
0 360		1.9 (IN) 2.9	2.9 (IN) 1.9	0 (IN) 0.5
Cable Speed (CS) (F/HR)	Min. of Amplitude (AWMB) (DE) 75	Internal radius Average (IRAV) (IN)	Internal radius Average (IRAV) (IN)	Average of Thickness (THAV) (IN) 0.5
0 2000		1.9 (IN) 2.9	2.9 (IN) 1.9	0 (IN) 0.5
Process. flag (UFLG) (---)		Internal radius Average (IRAV) (IN)	Internal radius Average (IRAV) (IN)	Min of Thickness (THMN) (IN) 0.5
		1.9 (IN) 2.9	2.9 (IN) 1.9	0 (IN) 0.5
Eccent. (ECCE) (IN) 0.5	Gamma Ray (GF) (GAPI) 100	Min of Internal radius (IFMN) (IN)	External radius Average (ERAV) (IN)	External radius Average (ERAV) (IN)
0 (IN) 0.5		1.9 (IN) 2.9	2.9 (IN) 1.9	1.9 (IN) 2.9
		Internal radii minus Ave (IRBK) (IN)	External radius Average (ERAV) (IN)	Metal Loss (LC01) (---) 0.5
		0 8000.0000 0.0760 0.0680 0.0600 0.0520 0.0440 0.0360 0.0280 0.0200 0.0120 0.0040 0.0000 -0.0040 -0.0120 -0.0200 -0.0280 -0.0360 -0.0440 -0.0520 -0.0600 -0.0680 -0.0760		0 (---) 0.5



# CBL and Traditional USI Limitations

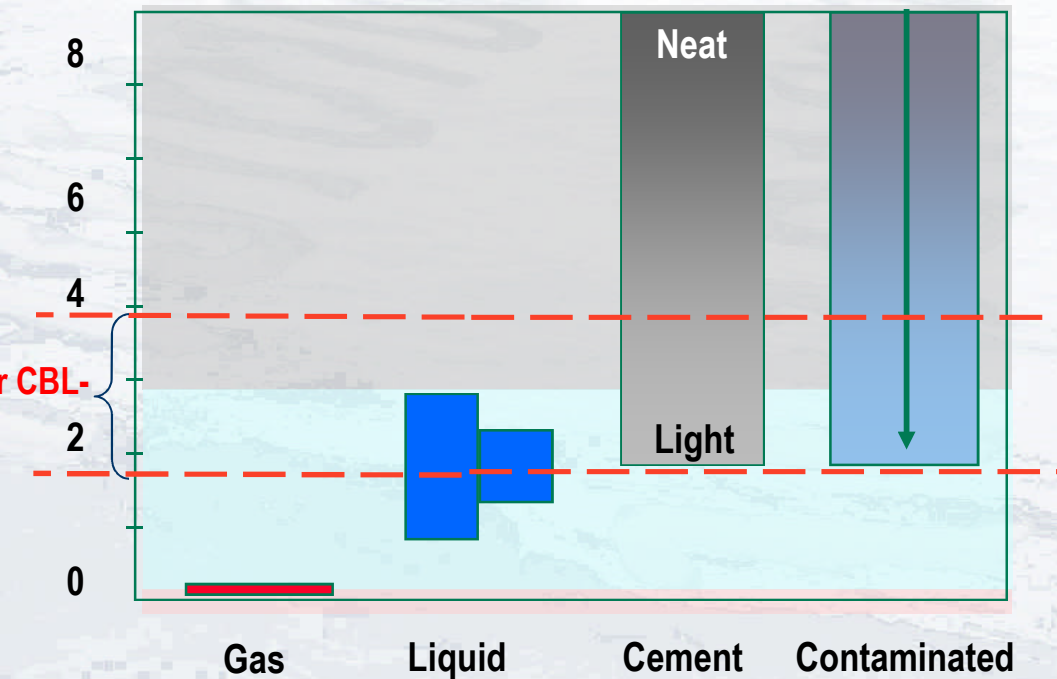
- **Low-density cement evaluation** - When annular liquid and cement are close in Acoustic Impedance (AI), hard to set thresholds
- **Contaminated cement** - AI will be lower than expected

Z (MRayl)



Difficult range for CBL-  
VDL or AI alone

Acoustic impedance



Increasing contamination

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# Isolation Scanner Principle

Combines USI (ultra sonic imager) measurement:

- Excitation of **thickness mode** of the casing
- Resonance created in casing
- Single transducer send pulse records waveform
- Measures acoustic impedance immediately behind the casing

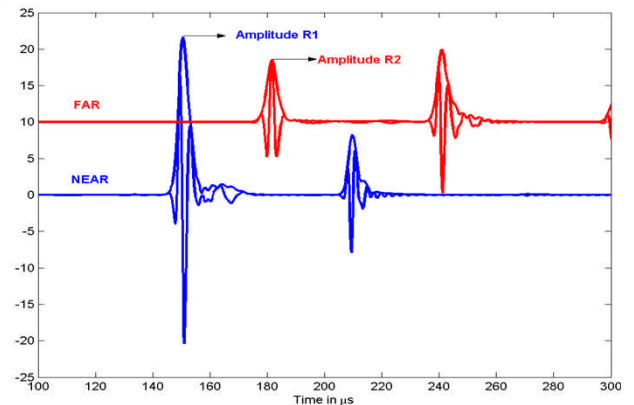
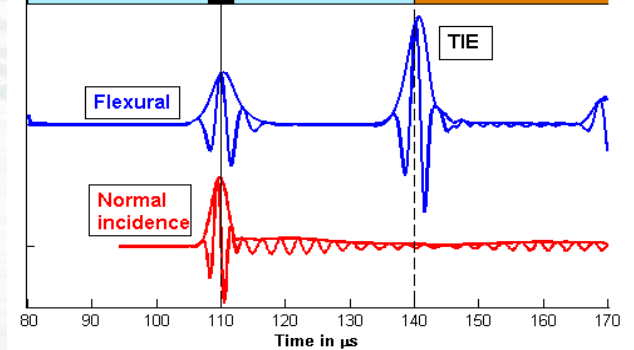
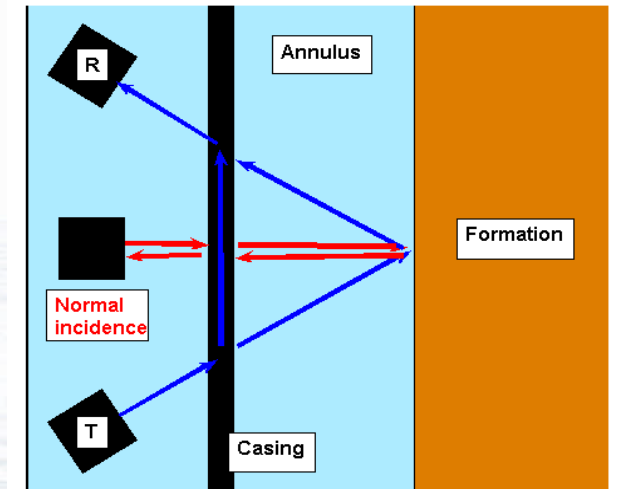
with FWI (flexural wave imager) measurement:

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

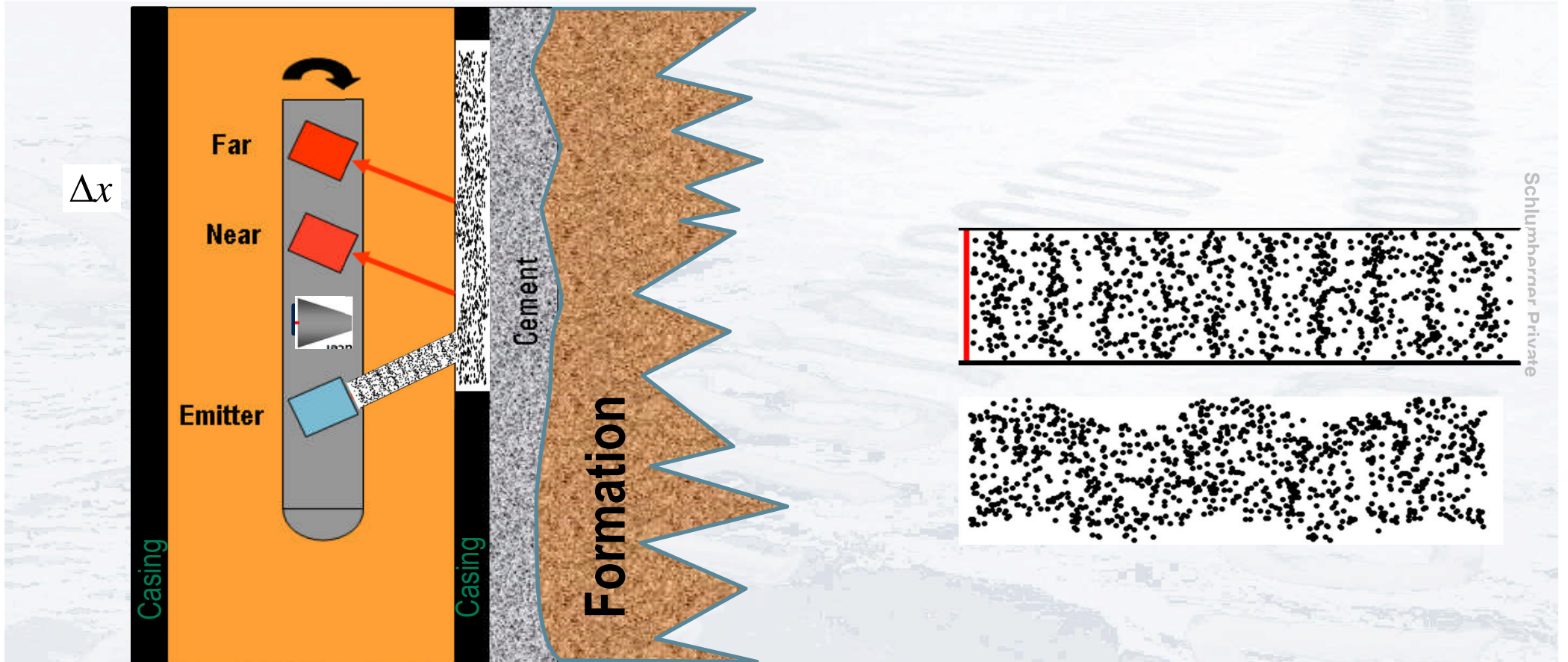
**Flexural Attenuation**

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

Third Interface Echo ( TIE ) measurement can detect reflections from outer casing string or borehole to compute casing standoff and the velocity of the annular material

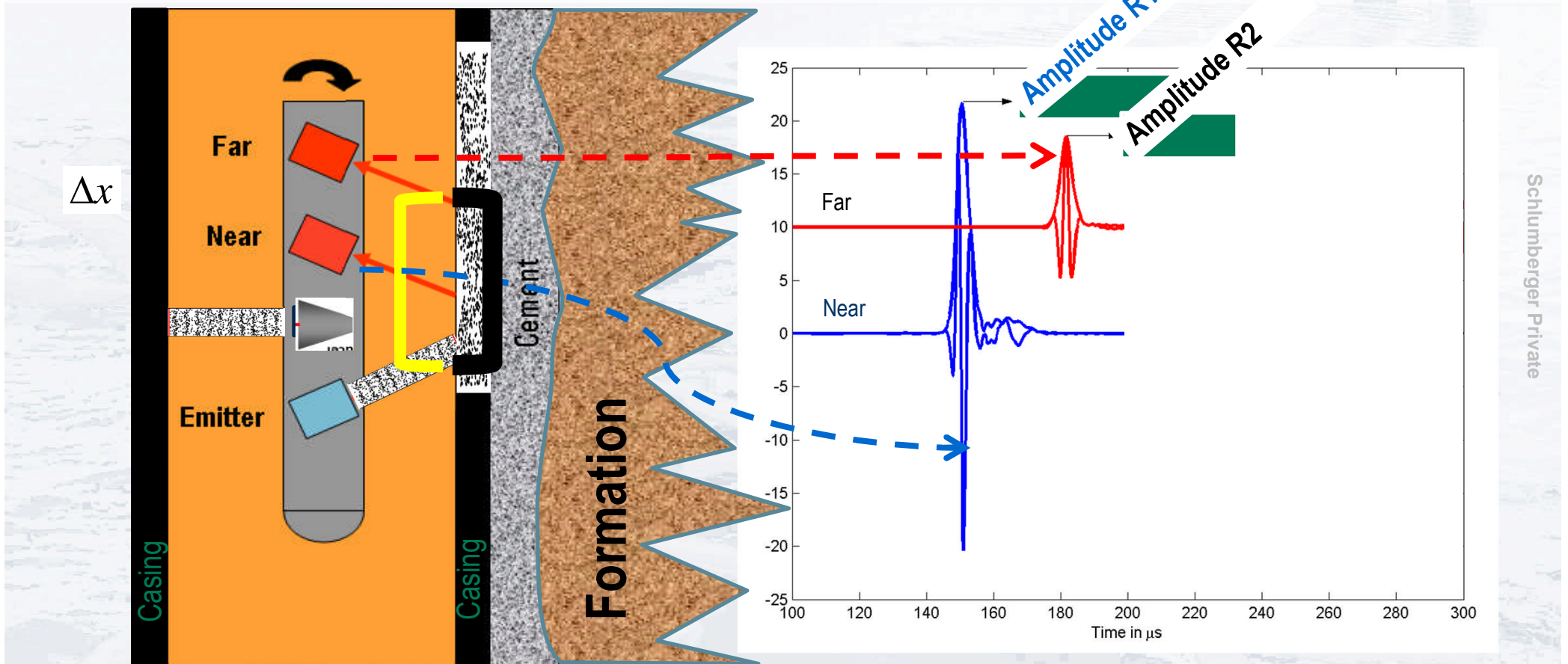


# Isolation Scanner – Adds Flexural Attenuation



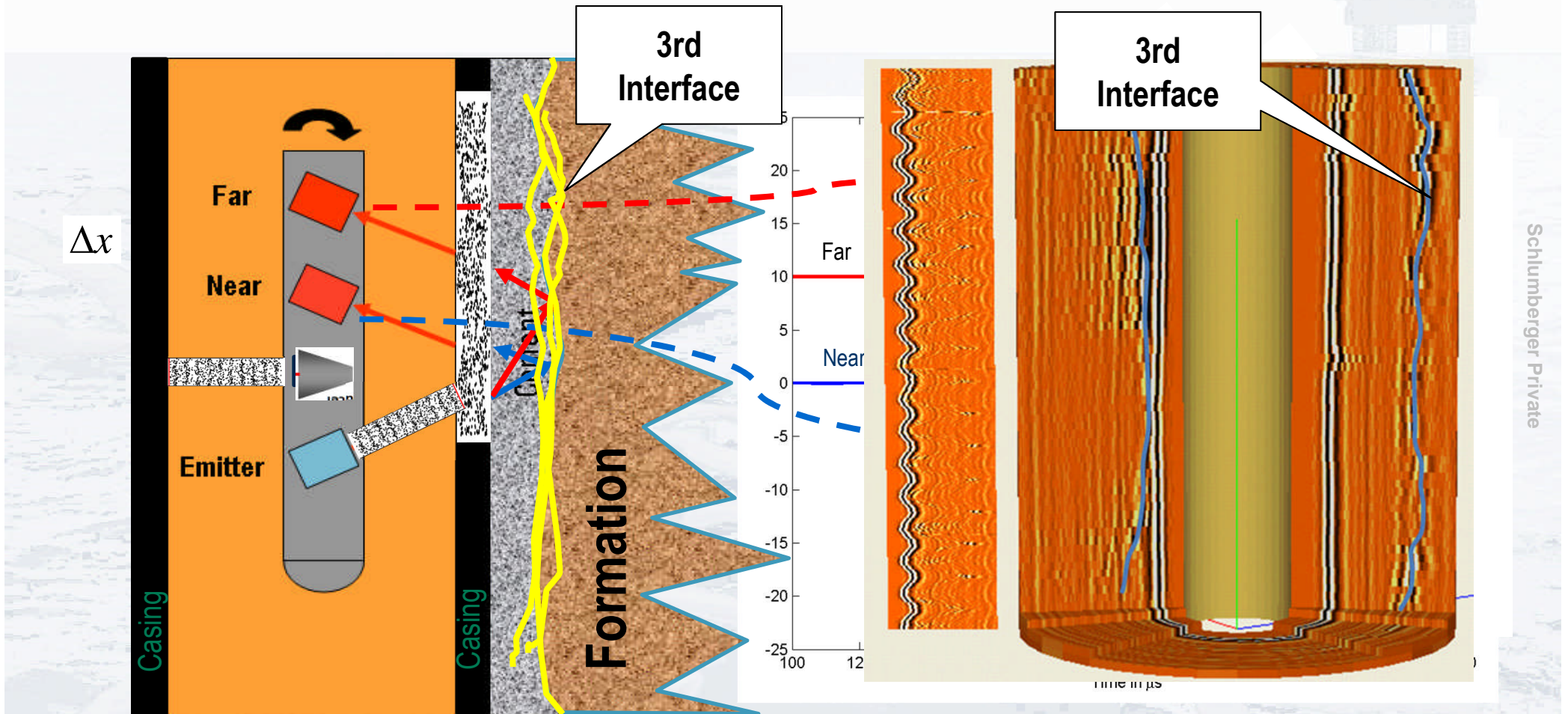
Animation courtesy of Dr. Dan Russell, Grad. Prog. Acoustics, Penn State

# Isolation Scanner – Adds Flexural Attenuation



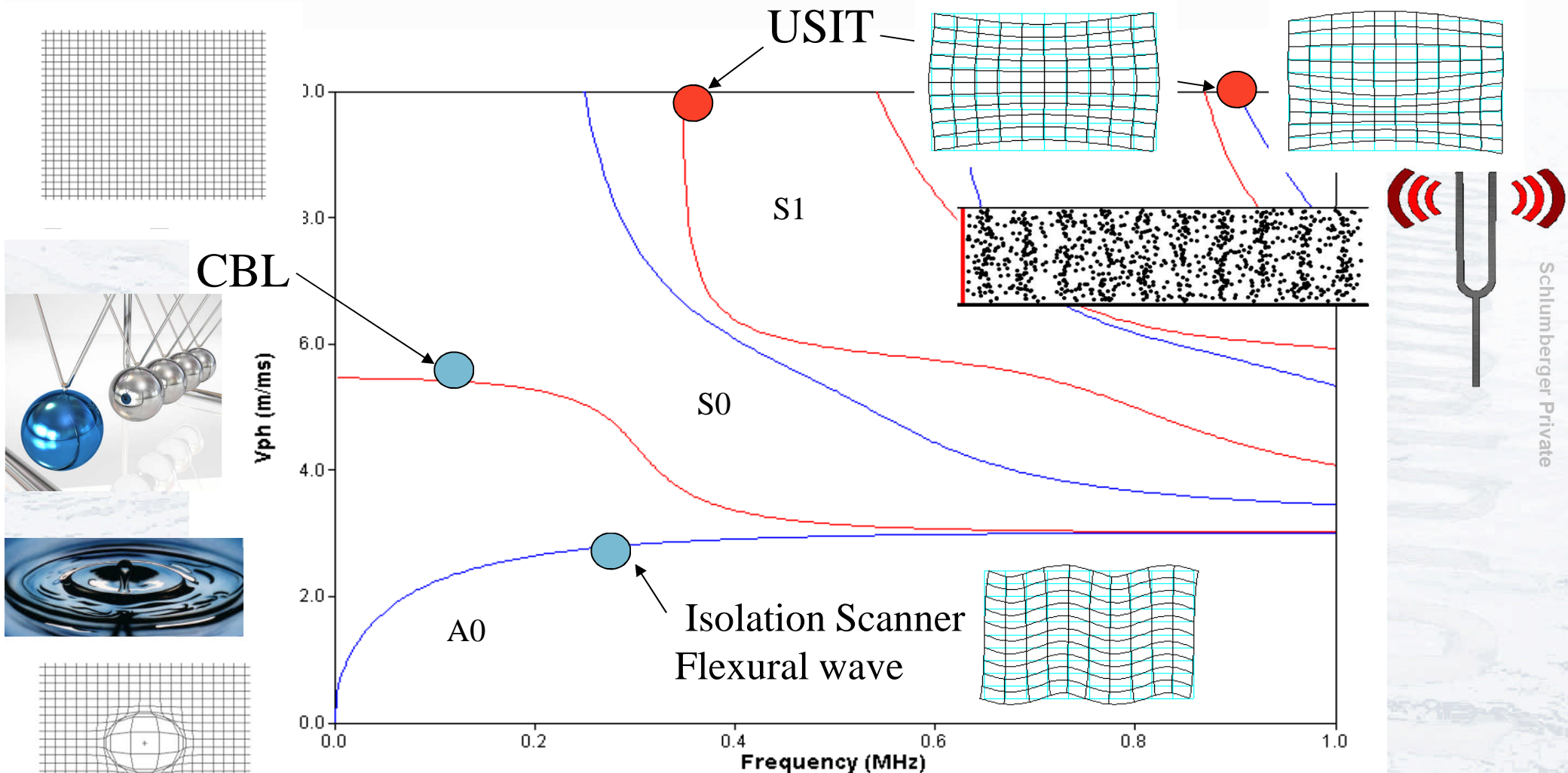
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# Isolation Scanner – Adds Third Interface Echo (TIE)



# Cement Evaluation Tools

## Different Physics of Measurement



**Running CBL with USI/IBC aids interpretation**



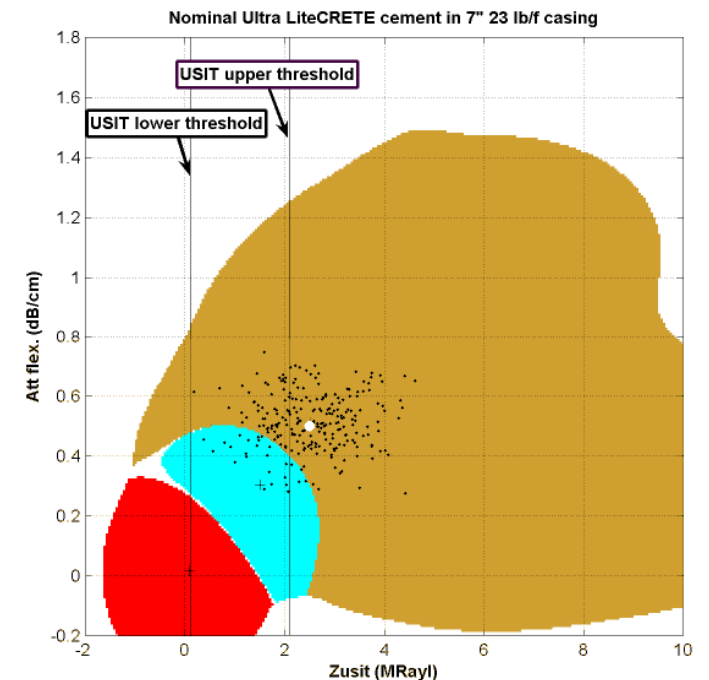
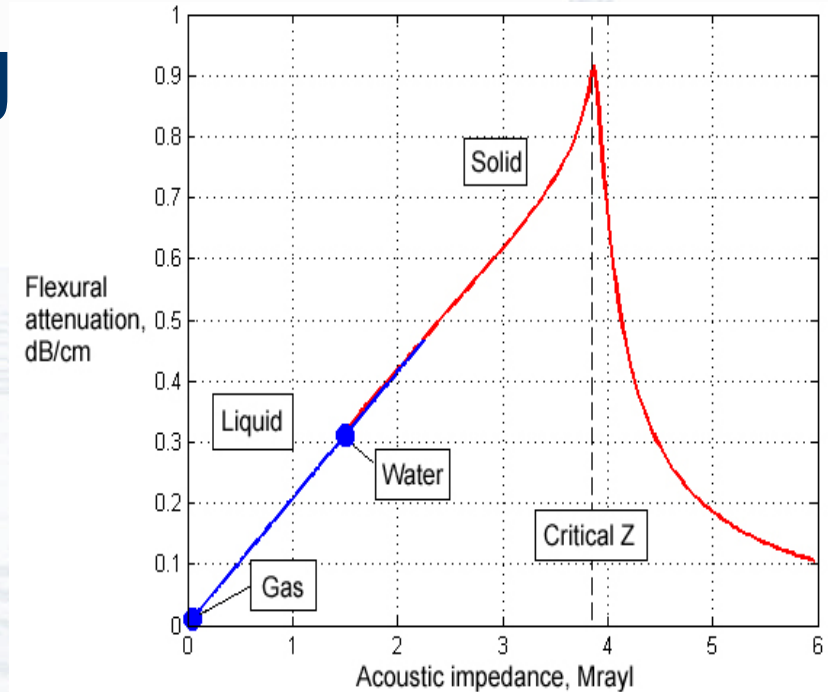
# Isolation Scanner SLG Mapping

## Traditional USI methods

- Set Acoustic Impedance (AI) **thresholds** to discriminate between solid, liquid, and gas (SLG).
- Realtime Statistical Microdebonding approach used to tell low impedance solids from liquids

## Isolation Scanner\* service

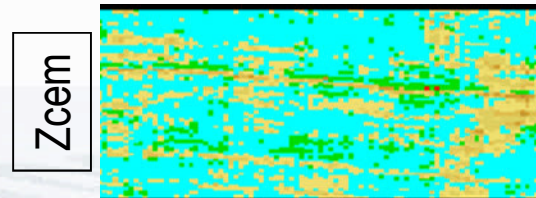
- Adds new Flexural Attenuation (FA) measurement
- **Crossplots** AI and FA to classify annulus material as solid, liquid, or gas.
- Calibrated Flex Attenuation very sensitive to light or contaminated cements, less sensitive to z mud
- Also adds ability to image casing position in wellbore



# Material Identification in the Annulus

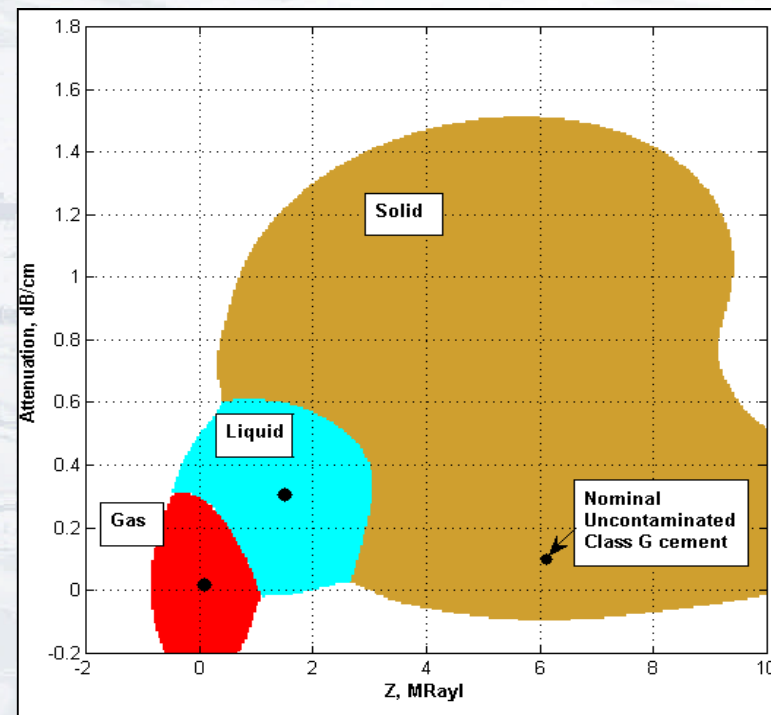
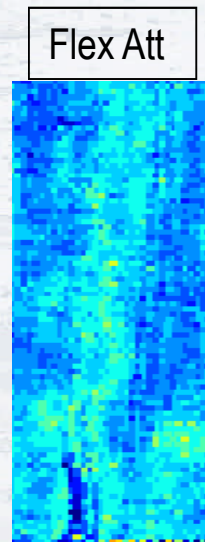
## Traditional ultrasonic methods

- 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
- Calibrated Flexural attenuation very sensitive to light or contaminated cements, less sensitive to ZMUD.



# Isolation Scanner – Applications

## Lightweight cements

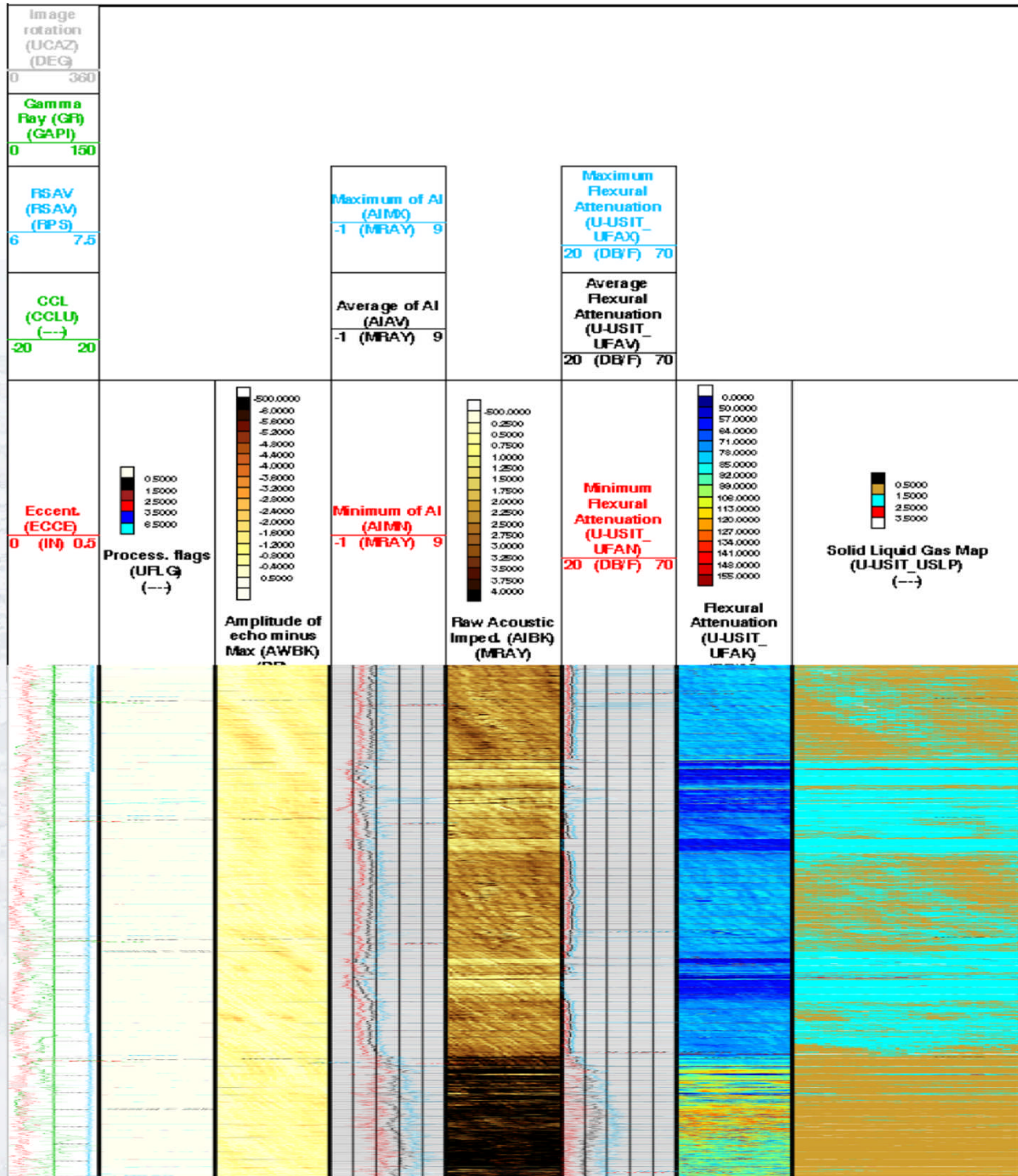
- ✓ Flexural Attenuation measurement very sensitive to low impedance slurries by design or by accident (contamination). Generally cements < 12.5 ppg or 3.5 mrayls. USI ok if cement AI has large difference from annular mud
- ✓ Use of Flexural Attenuation with AI eliminates the need for the ZTCM pick and statistical variance to separate low impedance cement from liquids

## Casing Position in the wellbore

- ✓ Third Interface Echo ( TIE) useful to improve casing centralization programs to improve cement placement

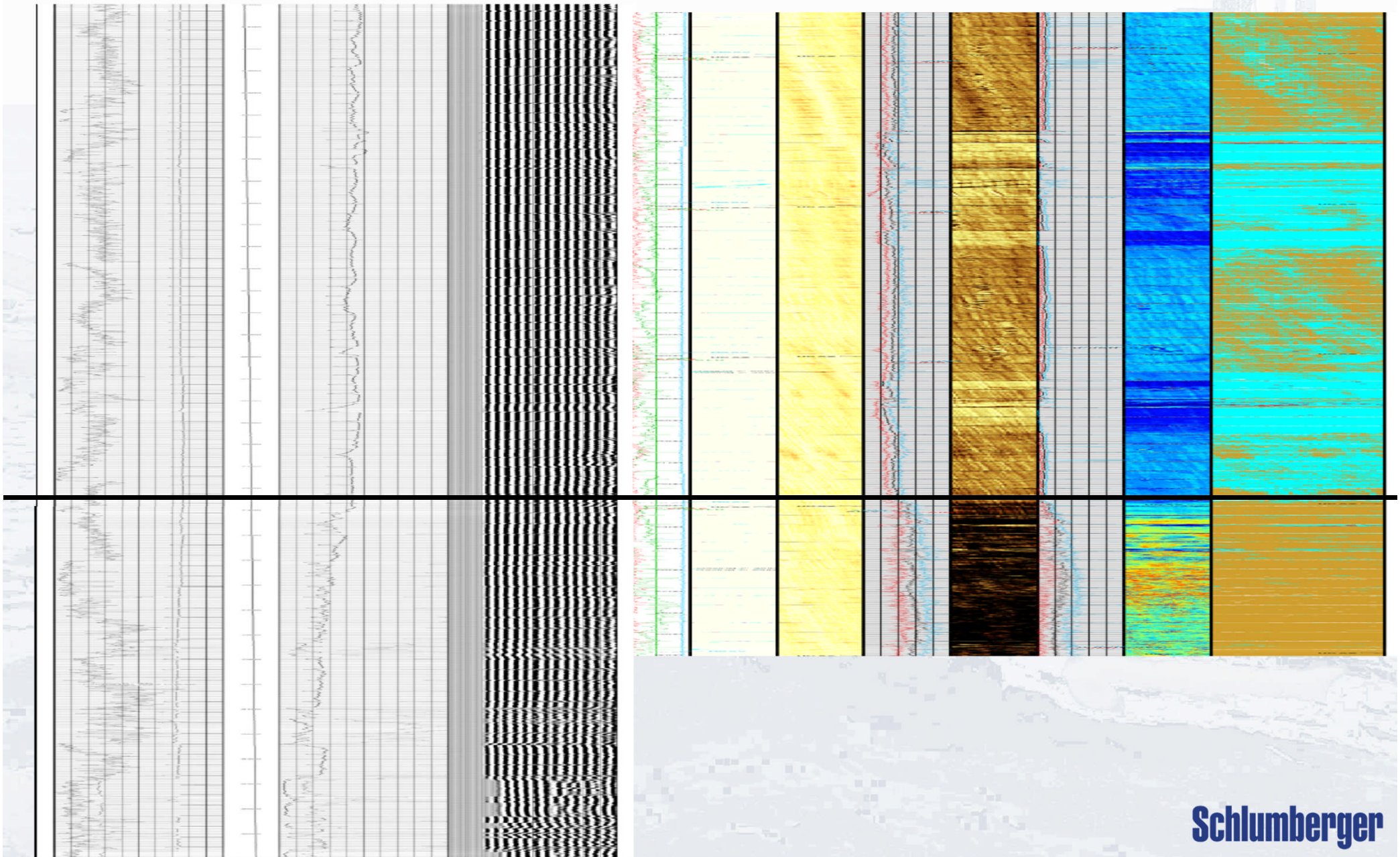


# SLG Presentation



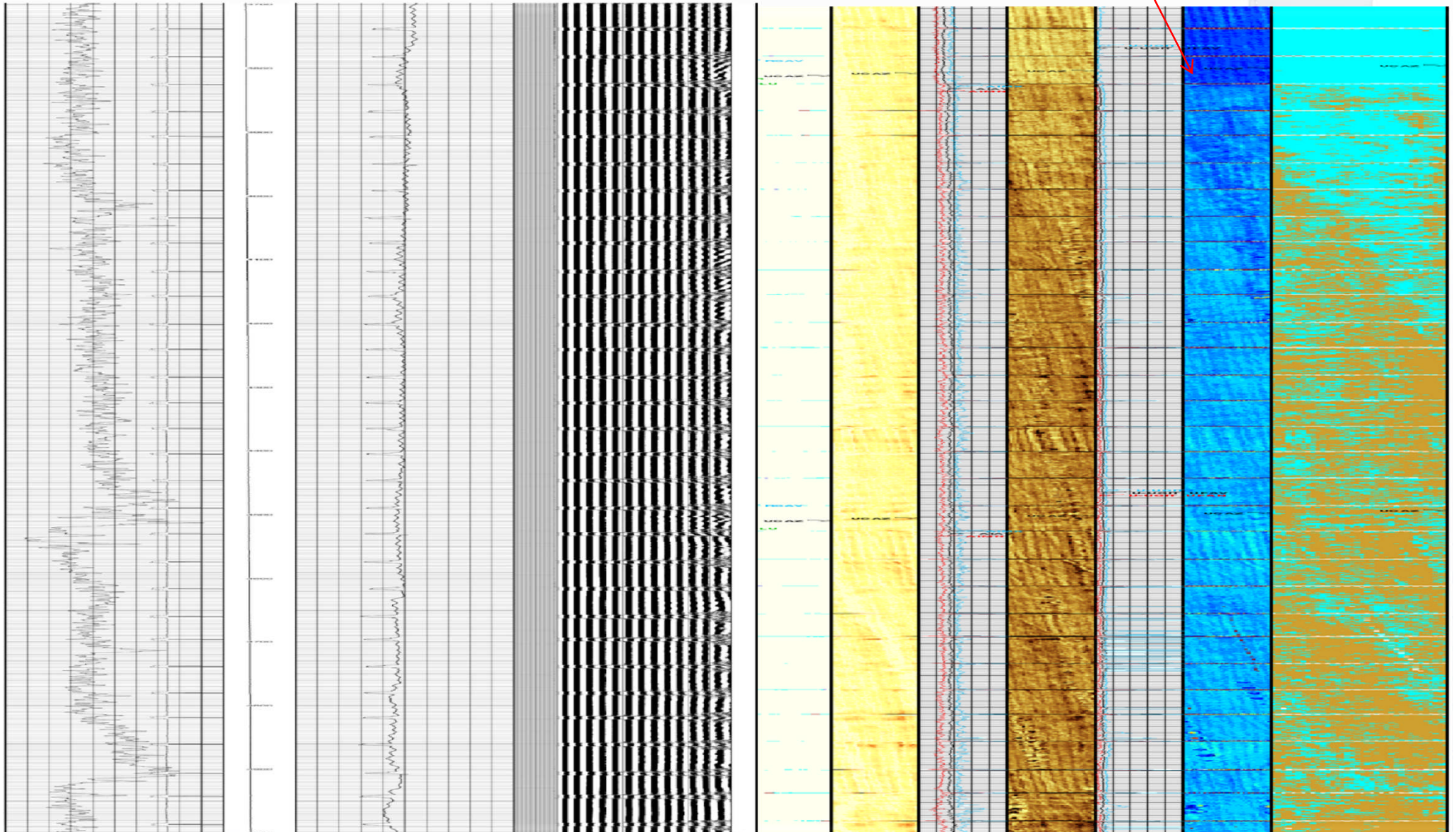
68 SLB  
5/19/2016

# Isolation Scanner Vs. CBL Lead (11.5 #) and Tail (15#)



# Light cement – Missed by CBL seen by Isolation Scanner State Wanted to Squeeze - Approved Isolation Scanner

TOC ~3810' vs design 3350'



# Case Study: Williston Basin

## Minimizing Squeeze and Frac string costs

### ■ Fit for Purpose Technologies

#### – Ultra Sonic Imager (USI)

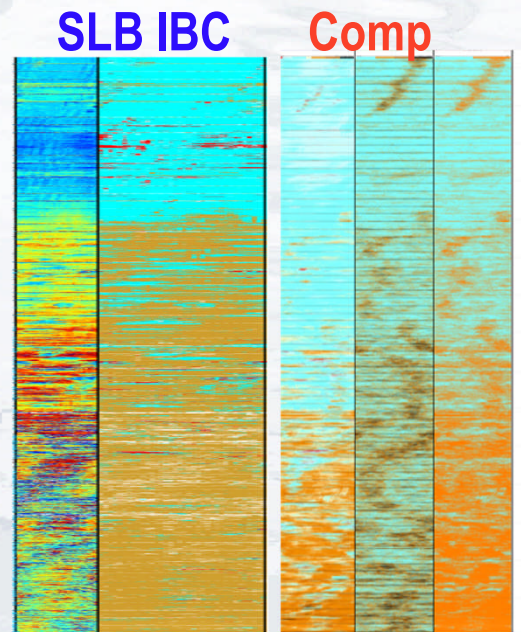
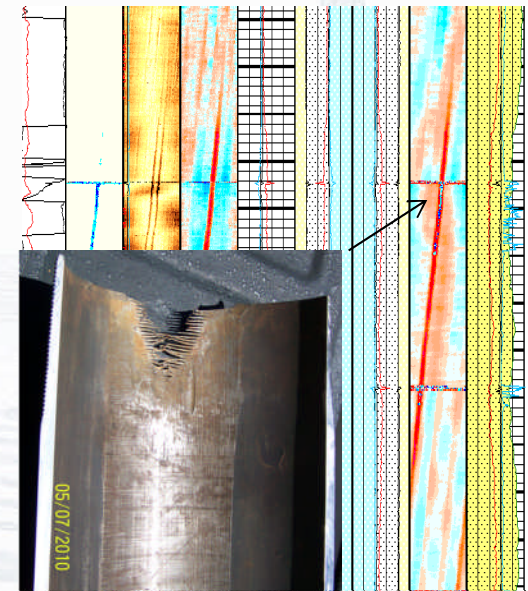
- Excellent cement and channel evaluation in heavier cements
- Superior internal and external corrosion evaluation
- Up to 72 radial thickness and radius measurements every 0.6"

#### – Iso-Scanner (IBC) – Superior Lightweight Cement Evaluation

- Proprietary Flexural Attenuation and Third Interface Echo measurements
- Proving TOC where no other tools can - NDIC approval
  - Preventing needless \$250k squeeze attempts
- Drillwear evaluation to eliminate \$150k frac strings
- Optimizing casing centralization programs to eliminate channels

### ■ Results Client

- Saved Client X squeeze and frac string cost after NDIC rejected competitor CBL in 11.5 ppg LiteCrete system
- Saved Client Z cost of frac string and squeeze after Competitor Ultrasonic log failed to find top of 12.9 ppg conventional cement
- Lighter slurries = higher TOC = better casing protection
- IBC gives confidence can meet stiffening environmental regulations

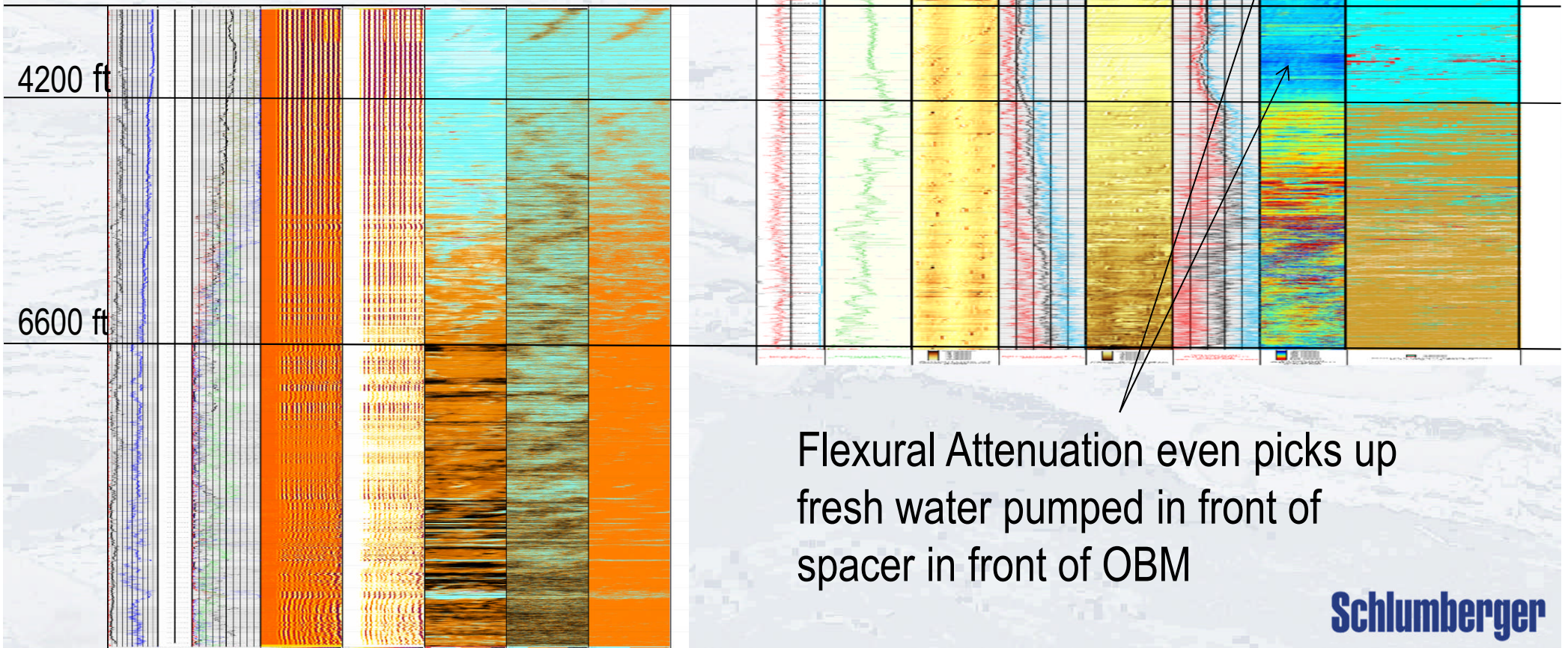


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# Isolation Scanner (IBC) log from 1600 to 6600 ft

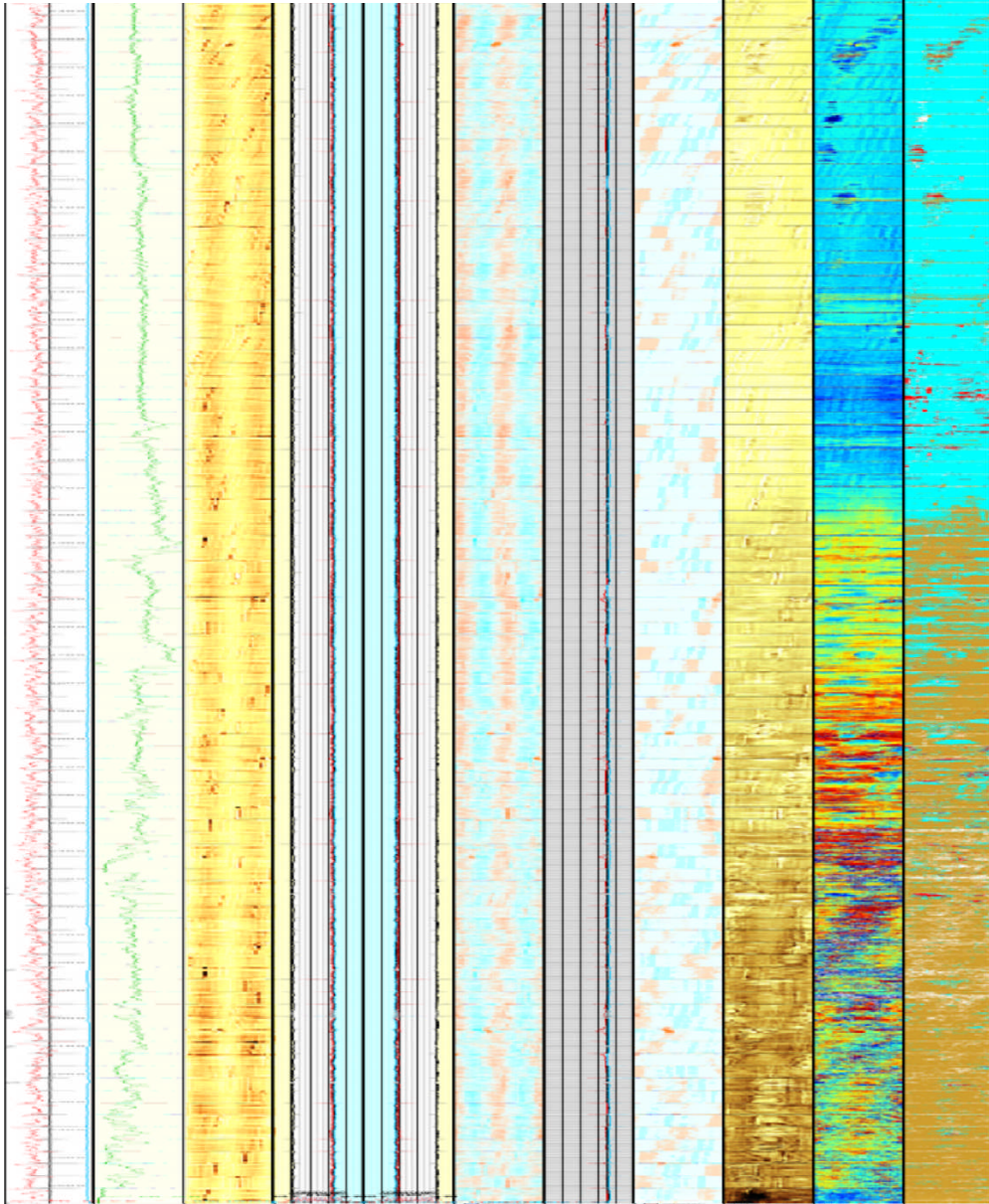
## Competitor log 3200 to 9600 ft

- CAST M and ACE (Left) stopped at 3590 ft run prior to pressure testing ( Includes CBL)
- IBC run under 1000 psi after casing had been **pressure tested to 9500 psi**
- 12.6 ppg lead slurry



Flexural Attenuation even picks up fresh water pumped in front of spacer in front of OBM

# Isolation Scanner Annular fluid typing



**Annular 10 ppg OBM Drilling mud**

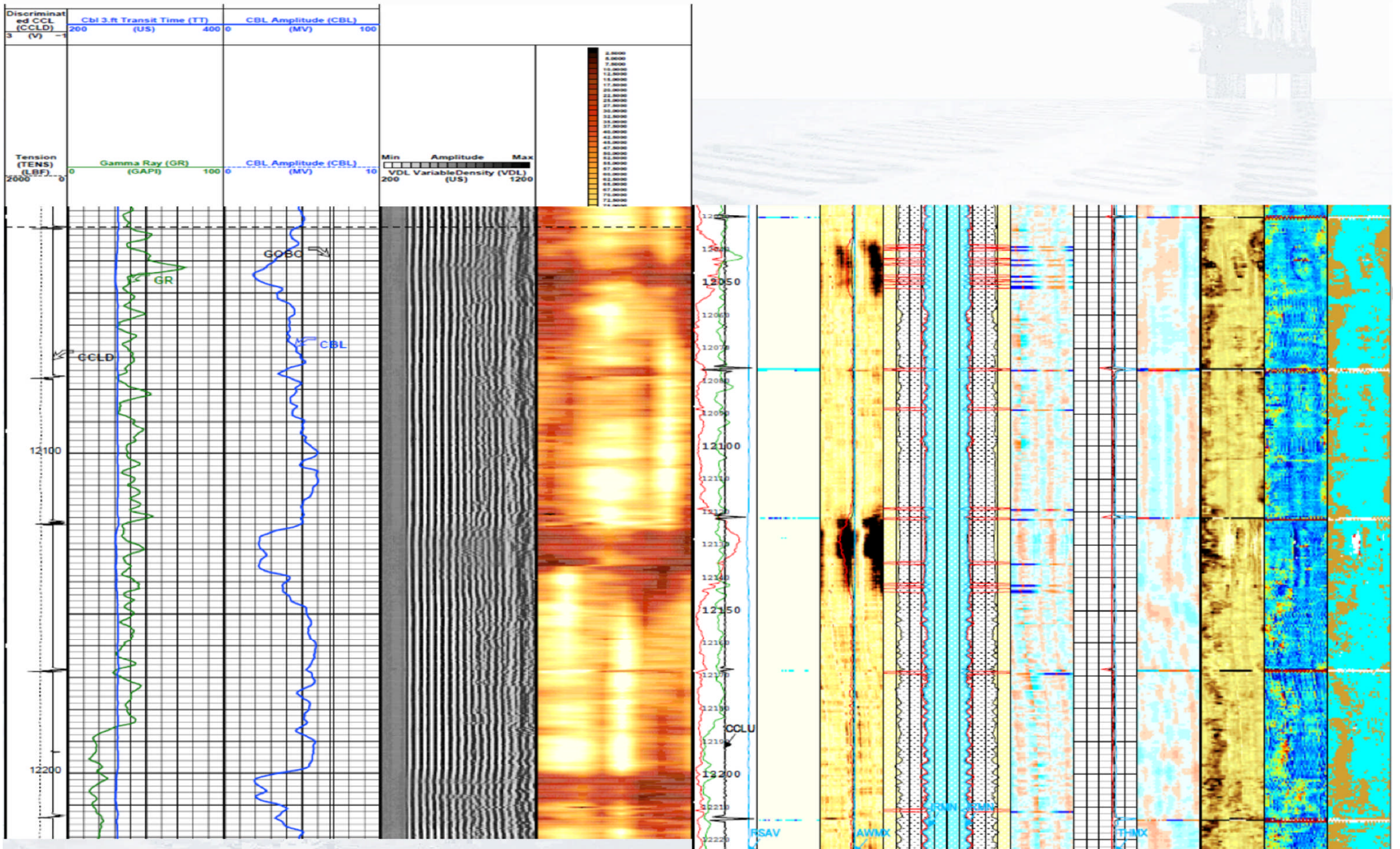
10 ppg Weighted Spacer

Fresh Water pumped in front of lead

4205 ft Top of 12.5 ppg lead

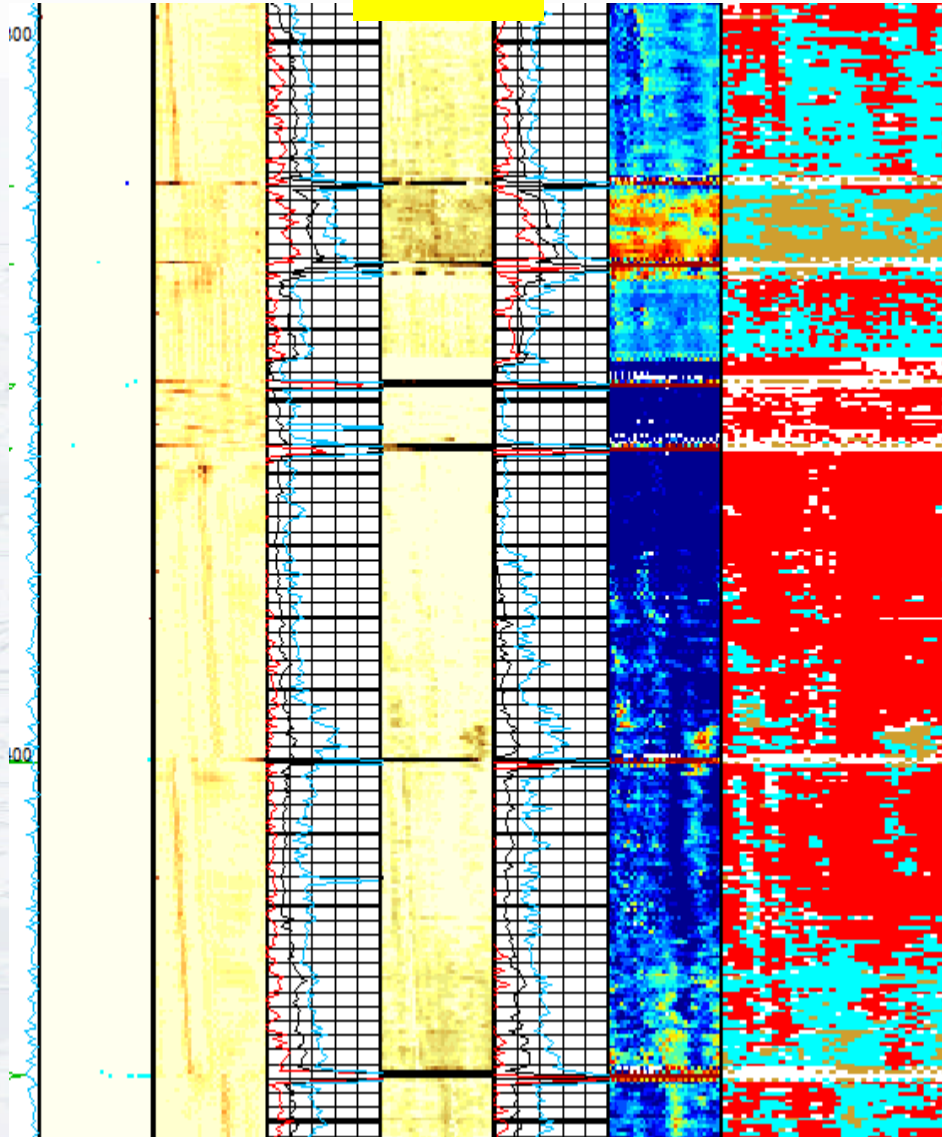
5300 ft Top of 15.2 ppg lead

# Eccentering Effect

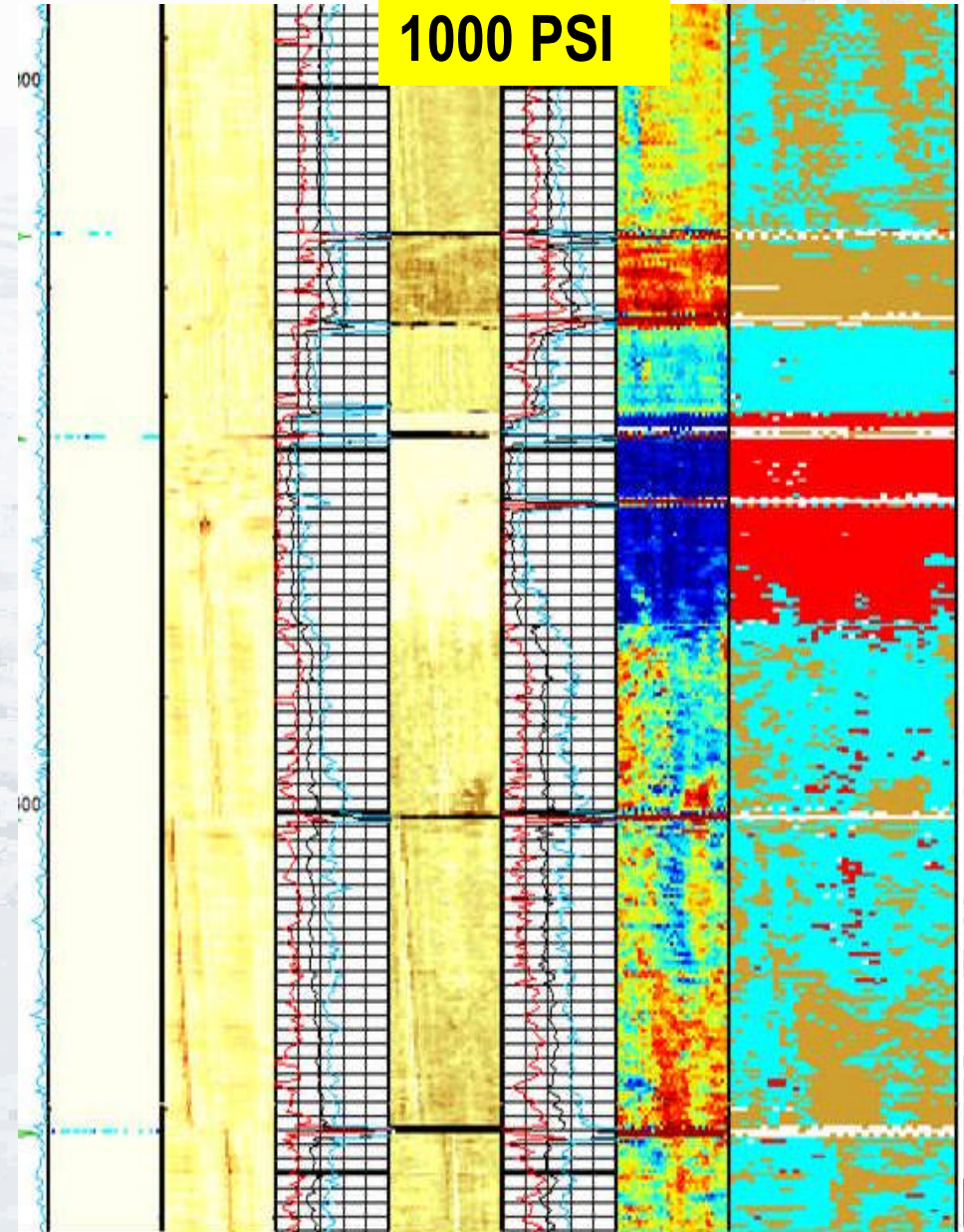


# What is going on here?

0 PSI

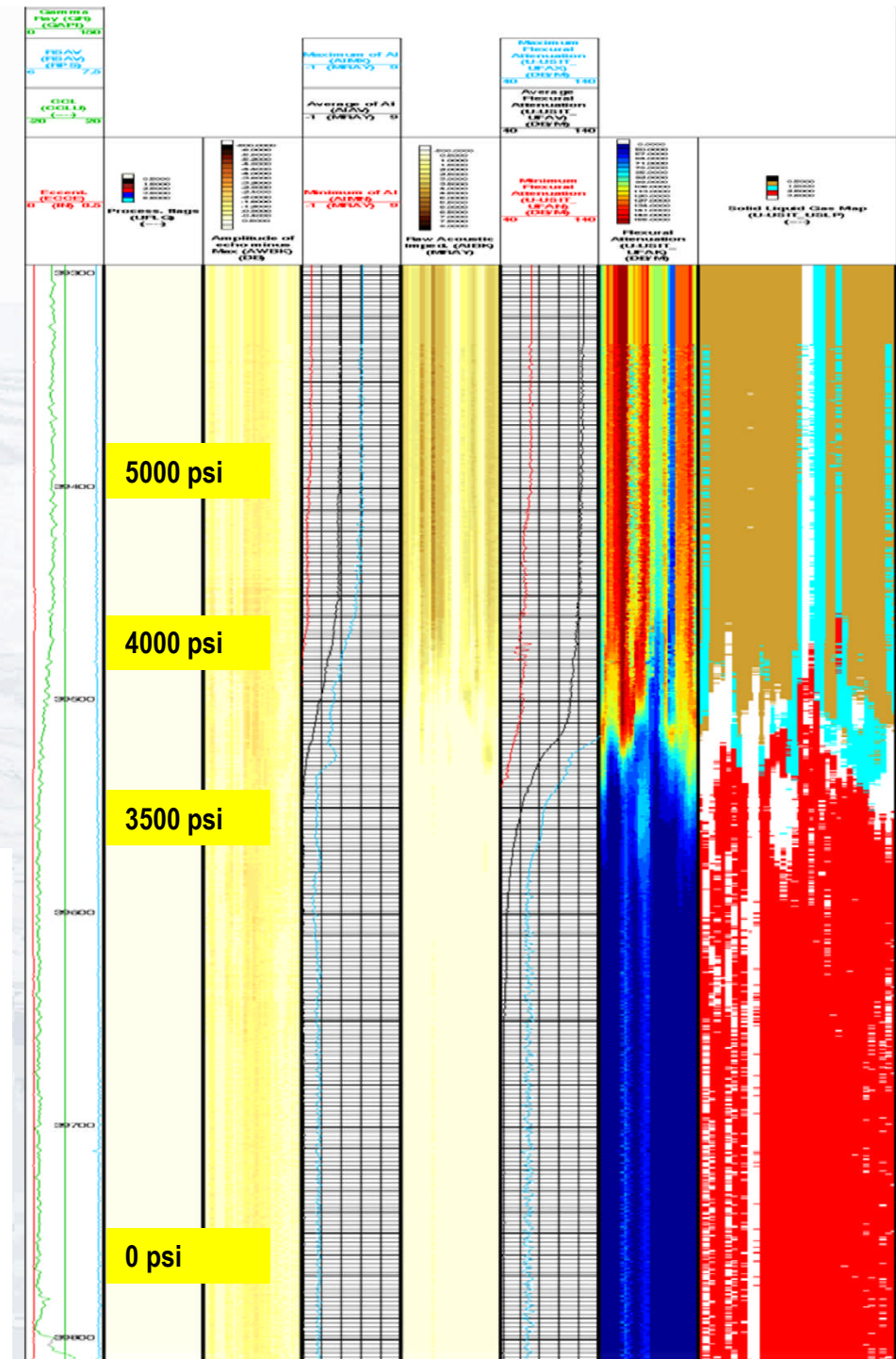
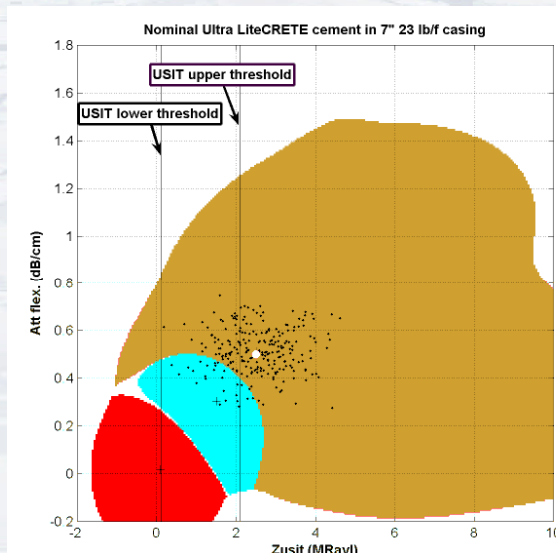


1000 PSI

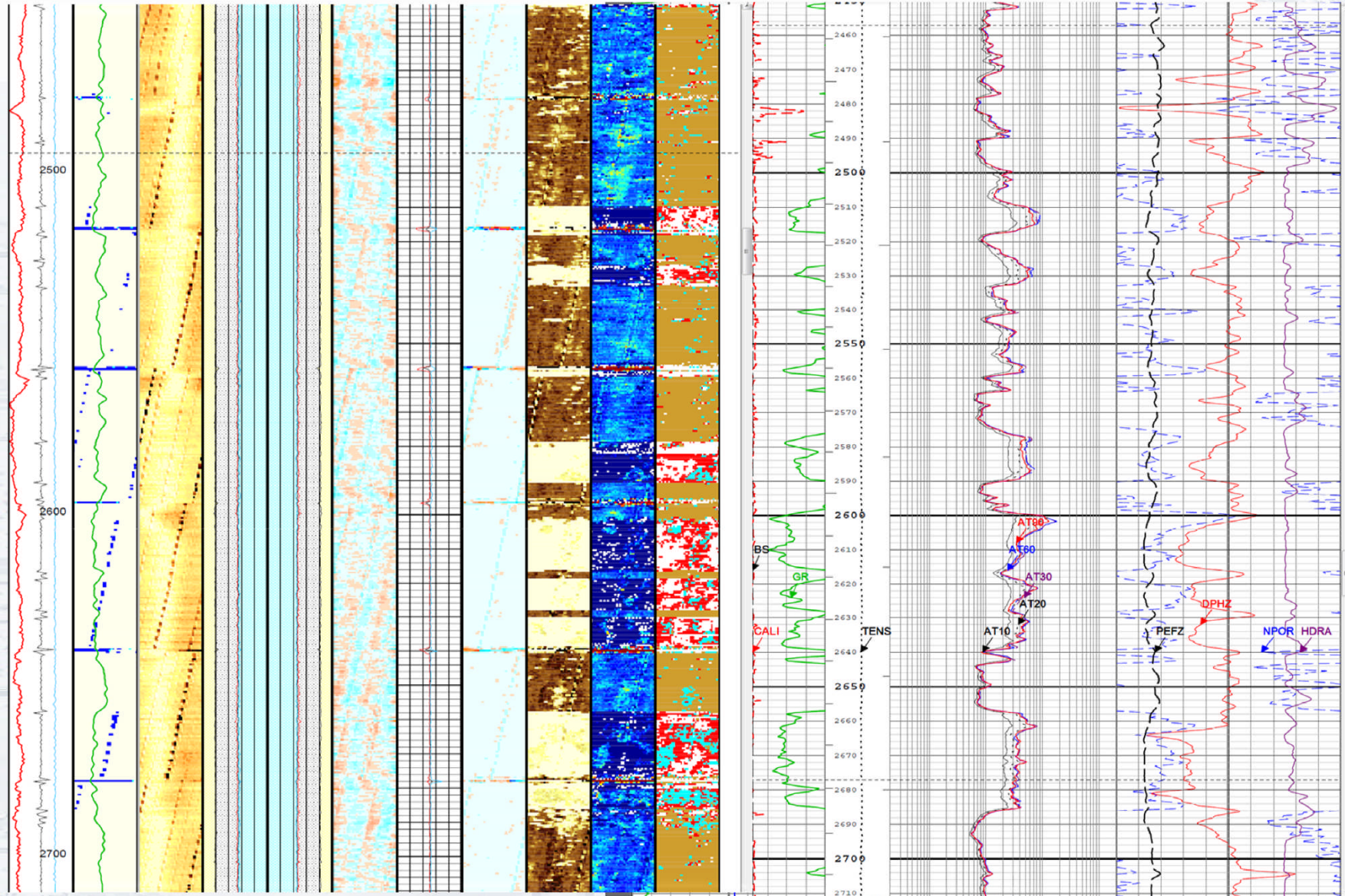


# Microannulus Removal Gas migration - IBC

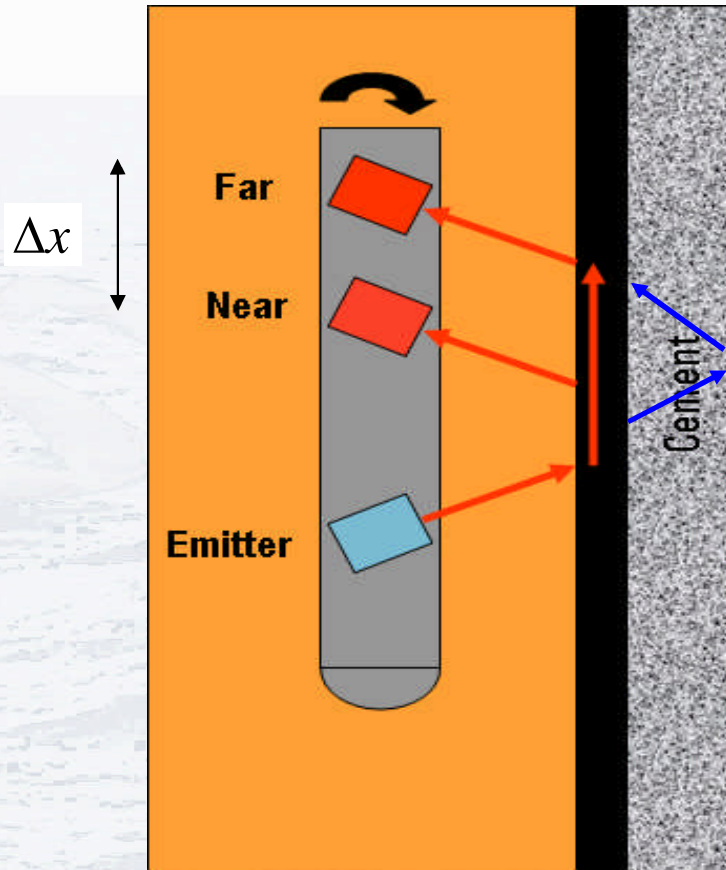
- Some wells have large microannulii
- Some due to mechanical reasons like floats not holding or logging post frac or pressure testing
- Some due to cement curing properties, especially in cooler areas in the shallow vertical sections
- Acoustic tools can't fully measure cement properties until cement has good shear bond to the casing to dampen the signal
- **Sometimes 1000 psi is simply not enough**
- Note improvement in FA, AI as dry microannulus bridged



# IBC vs Invasion Profile – 15.8 ppg tail 12.5 lead

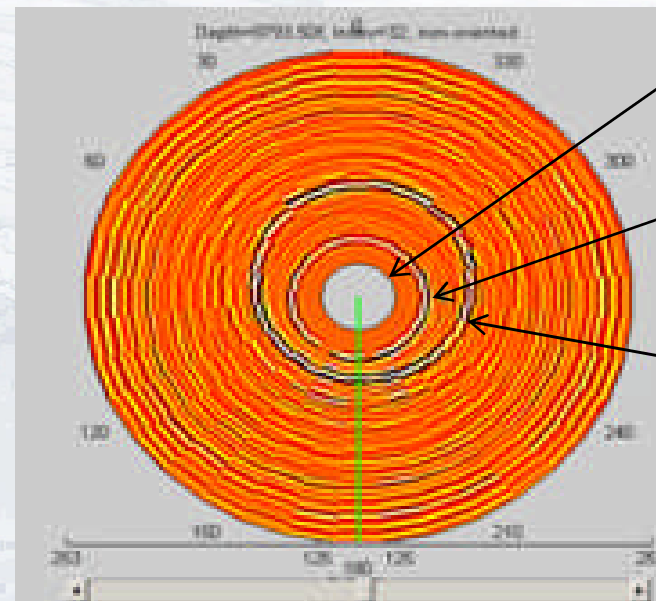
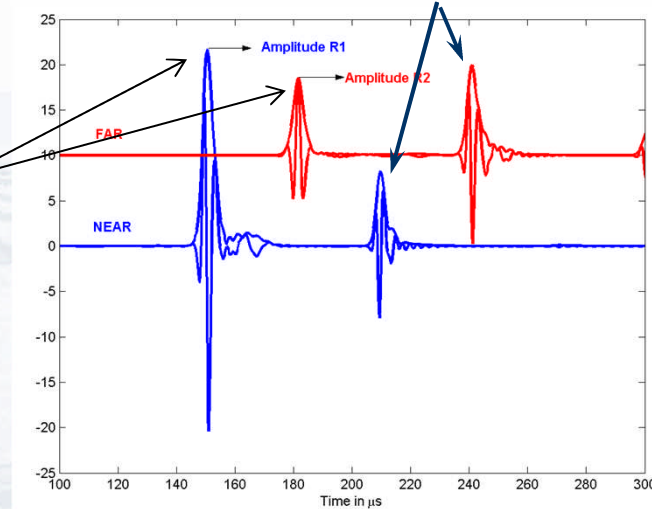


# Third Interface Echo (TIE) Response



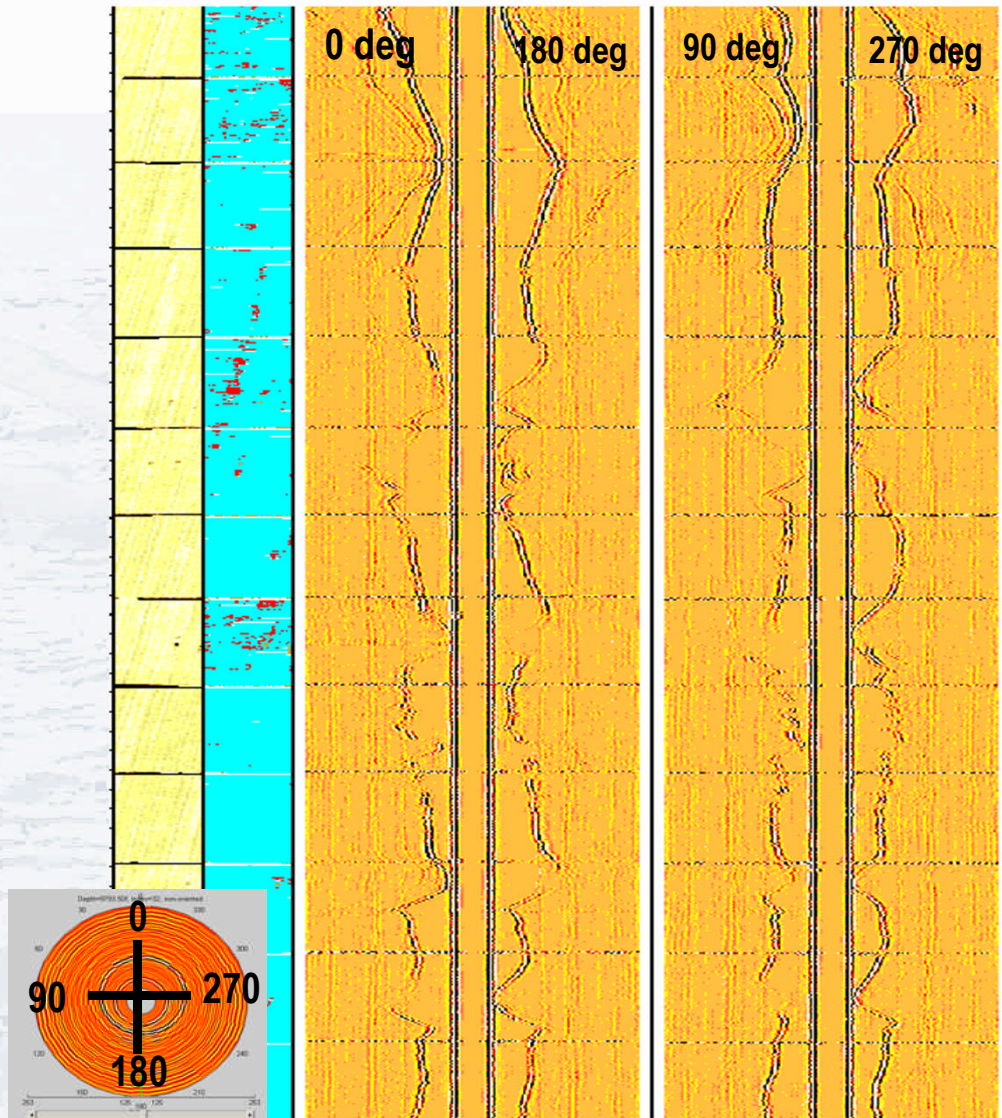
Casing Echo Arrivals

3<sup>rd</sup> Interface Echo (TIE) Arrivals



- ✓ Waveforms from near or far viewed as 360 degree VDL in slider plot tool
- ✓ 36 waveforms per rotation
- ✓ Tool spins at 7.5 rps

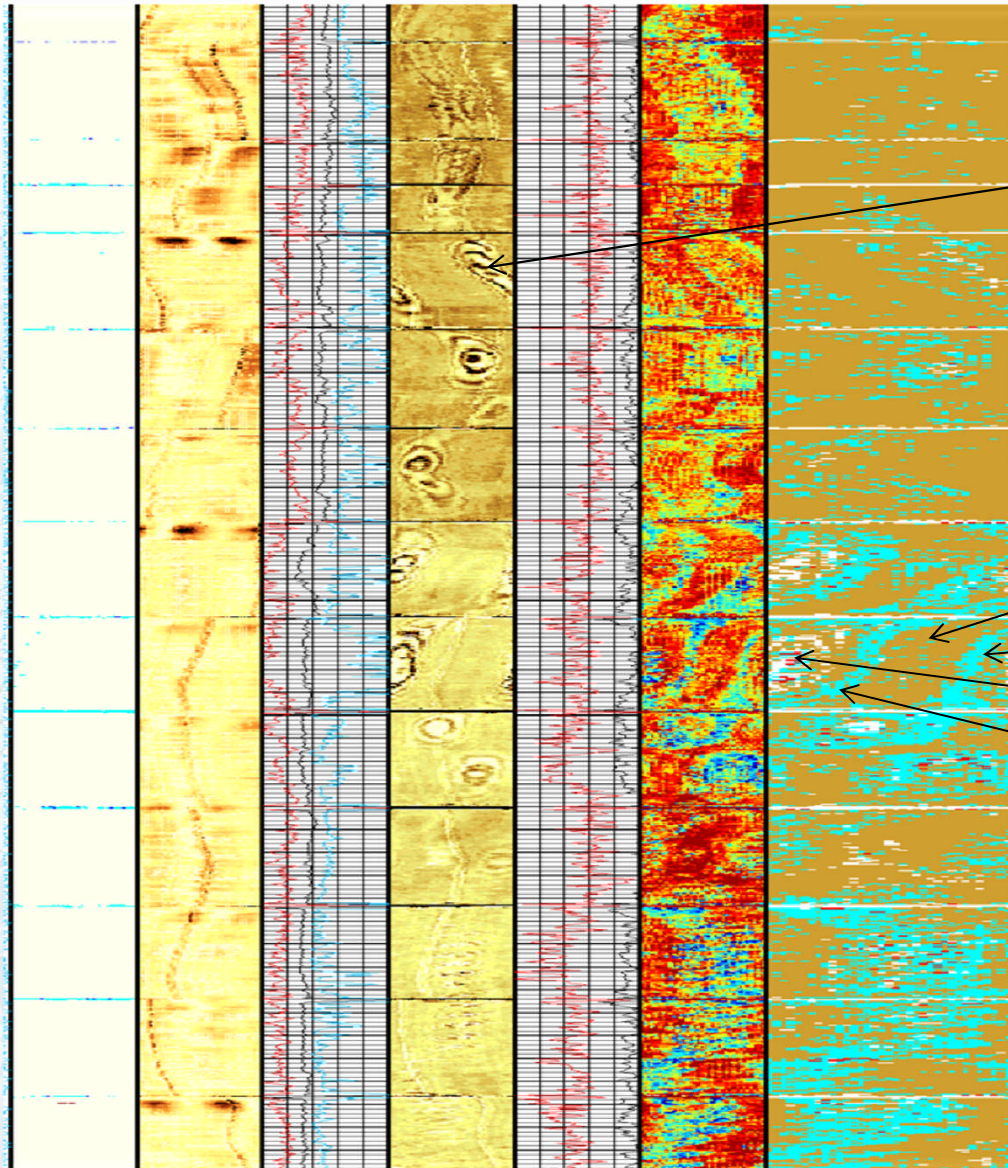
# VDL Wide – Presentation – 2D representation of TIE



- Allows position of casing to be mapped in the borehole – helps define channel location
- Casing is vertical lines
- Tool zero showing on far left with time increasing right to left
- Tool 180 just to the right of it with time increasing left to right
- Together they make a cross section
- 90/270 to the right of it.

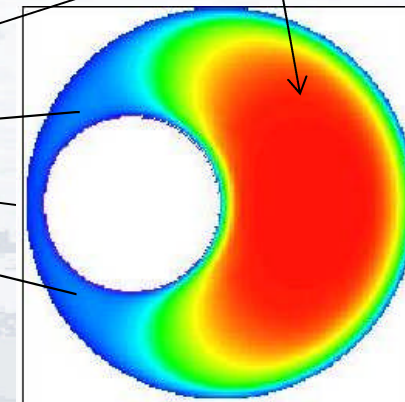
# Low side Channel

## Fix with pipe movement & centralization

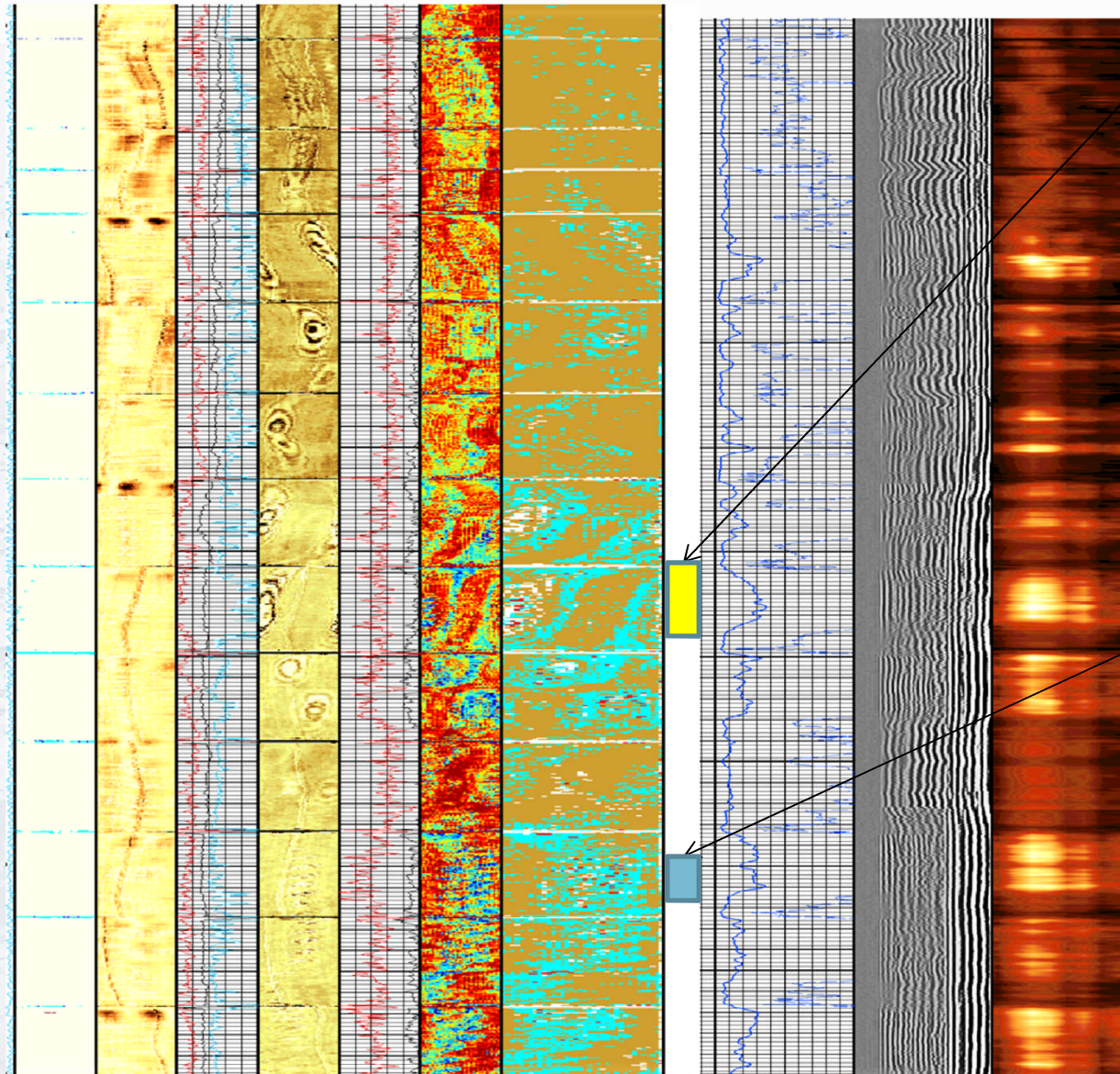


Galaxy Patterns – Casing contact

Cement



# Radial CBL ( SCMT ) and Isolation Scanner Squeeze decision clarity



Squeeze perfs

- X52' – X56'
- X88' – X92'

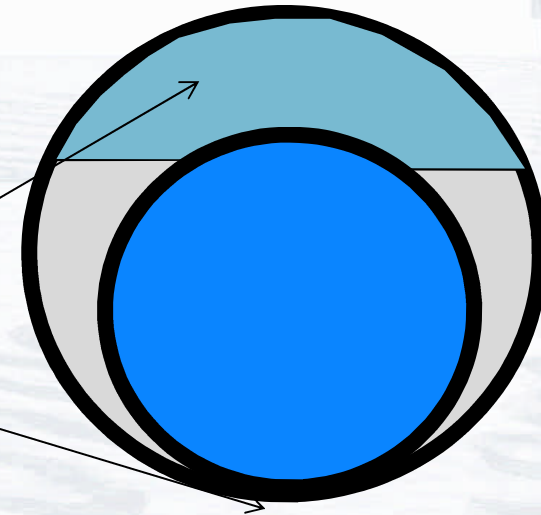
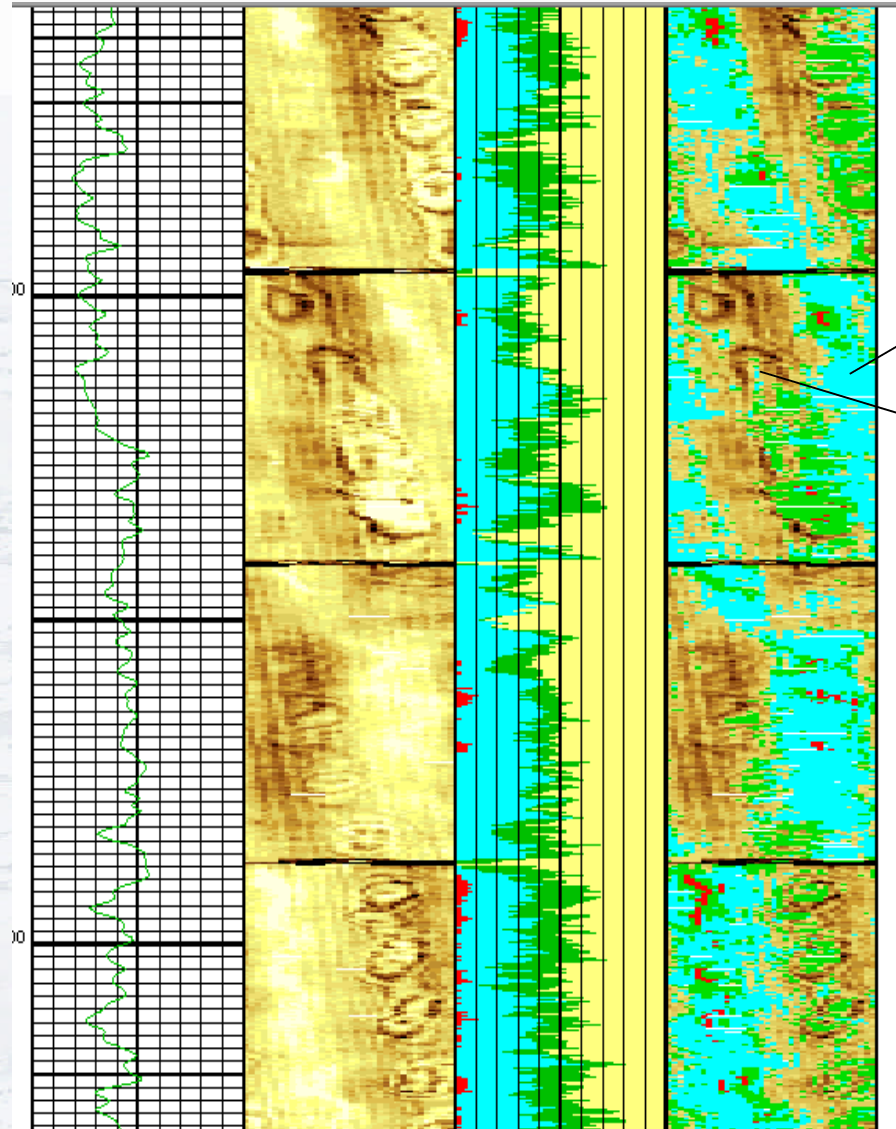
Circulated at 0.3 BPM 1900 psi on this interval

• Squeeze perfs

- X96-X00
- X12-X16

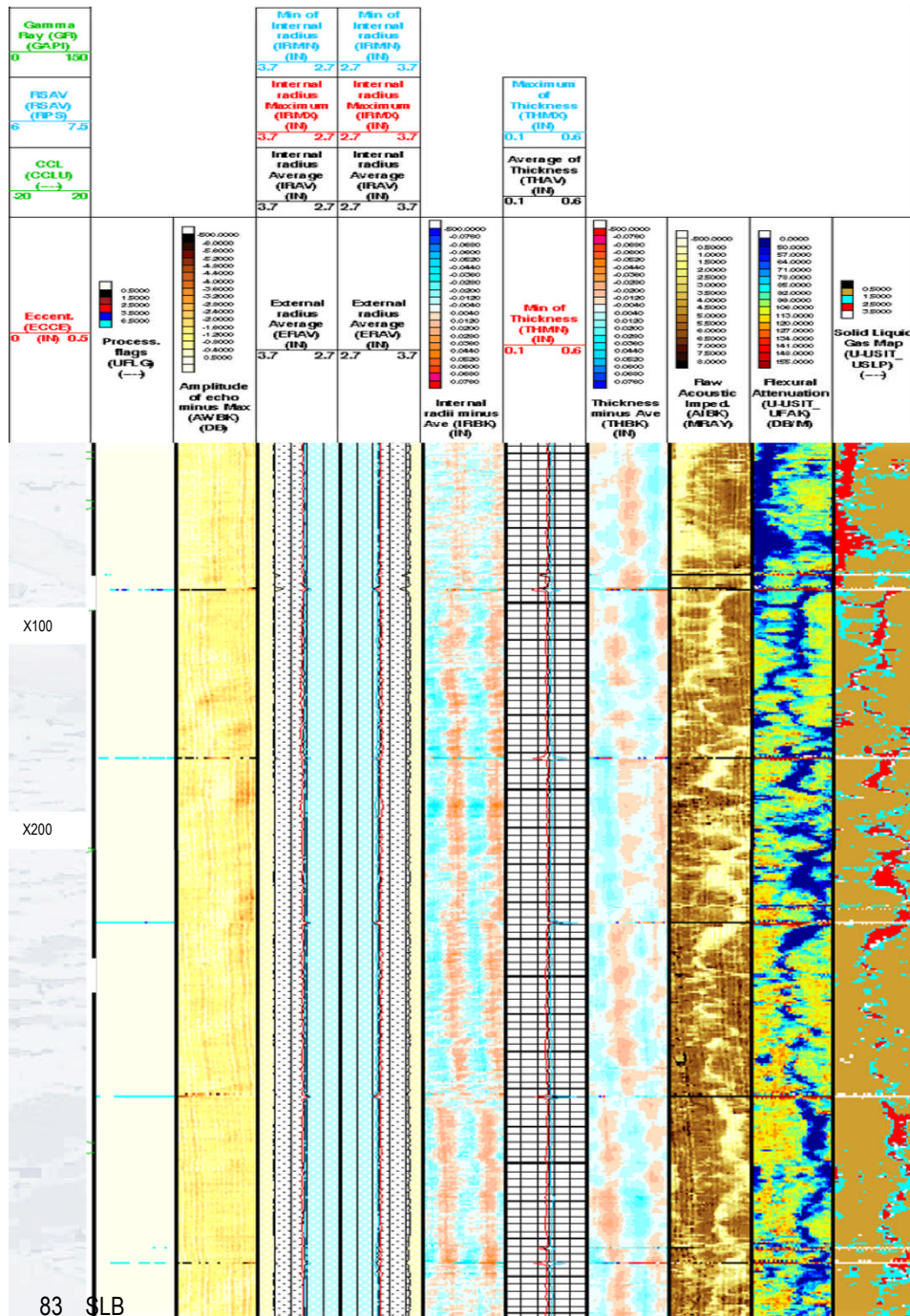
Circulated at 1.5 bpm with 500 psi.

# High side channel



Many times channels are on the low side where pipe against the way hurts mud removal – can be fixed with centralization and/or pipe movement during cementing

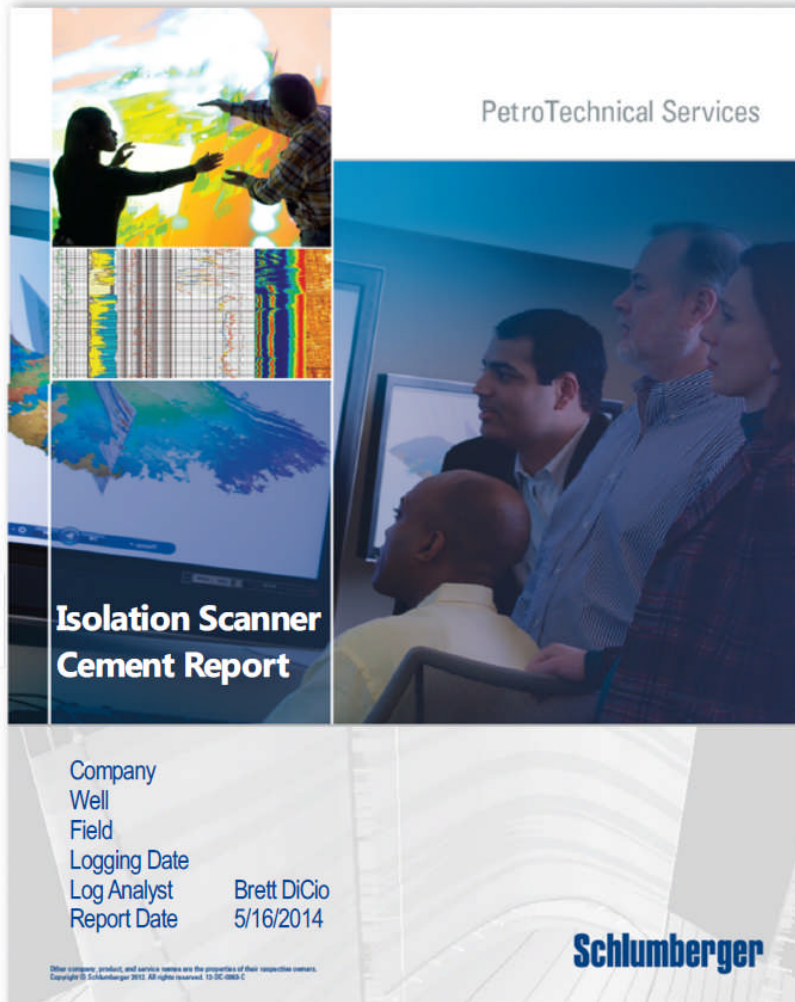
High side channels commonly relate to rheology issues with mud removal and water loss.



# Isolation Scanner Post placement Channel

1. Tortuous, narrow channels are often the result of post placement invasion of reservoir fluids into well due to slow hydration and high water loss cements. Common in extended lead cements
2. Understanding a channel like this exists is the first step to understanding the cause and future prevention
3. Channels provide areas for corrosive attack, shortens asset life
4. State laws moving from proving TOC to proving isolation, so elimination of channel causes is critical.

# PTS Well Integrity Analysis



- Reports can be done for
  - Corrosion Evaluation
  - Cement Evaluation
- Zonal Isolation summaries
- Joint by joint summaries
- Defect visualization and interpretation
- Burst analysis
- Invizion – Integrated solutions

# CBL vs. UltraSonic Primary Measurements

## CBL Measurements

- **Amplitude**
  - used to relate to cement quality
- **Variable Density Log – VDL**
  - qualitative information about cement to formation bond

## UltraSonics - USI / Isolation Scanner

- **Radial Acoustic Impedance mapping**
  - Cement property mapping – detect contaminated cements
  - Channel detection
- **36/72 radial thickness measurements**
- **36/72 radial caliper measurements**
- **Casing Inner Surface Reflectivity**
  - Amplitude mapping for inner surface rugosity
- **Flexural Attenuation Mapping**
  - Improved sensitivity to light cements
- **Third Interface Echo ( TIE ) mapping**
  - Casing position in wellbore

Ultrasonics provide superior channel and light weight cement evaluation  
Adding CBL-VDL to Ultrasonics can help with interpretation

**Ultrasonic information helps improve the Well Integrity Process - faster**

# Achieving Cement Integrity is a Process

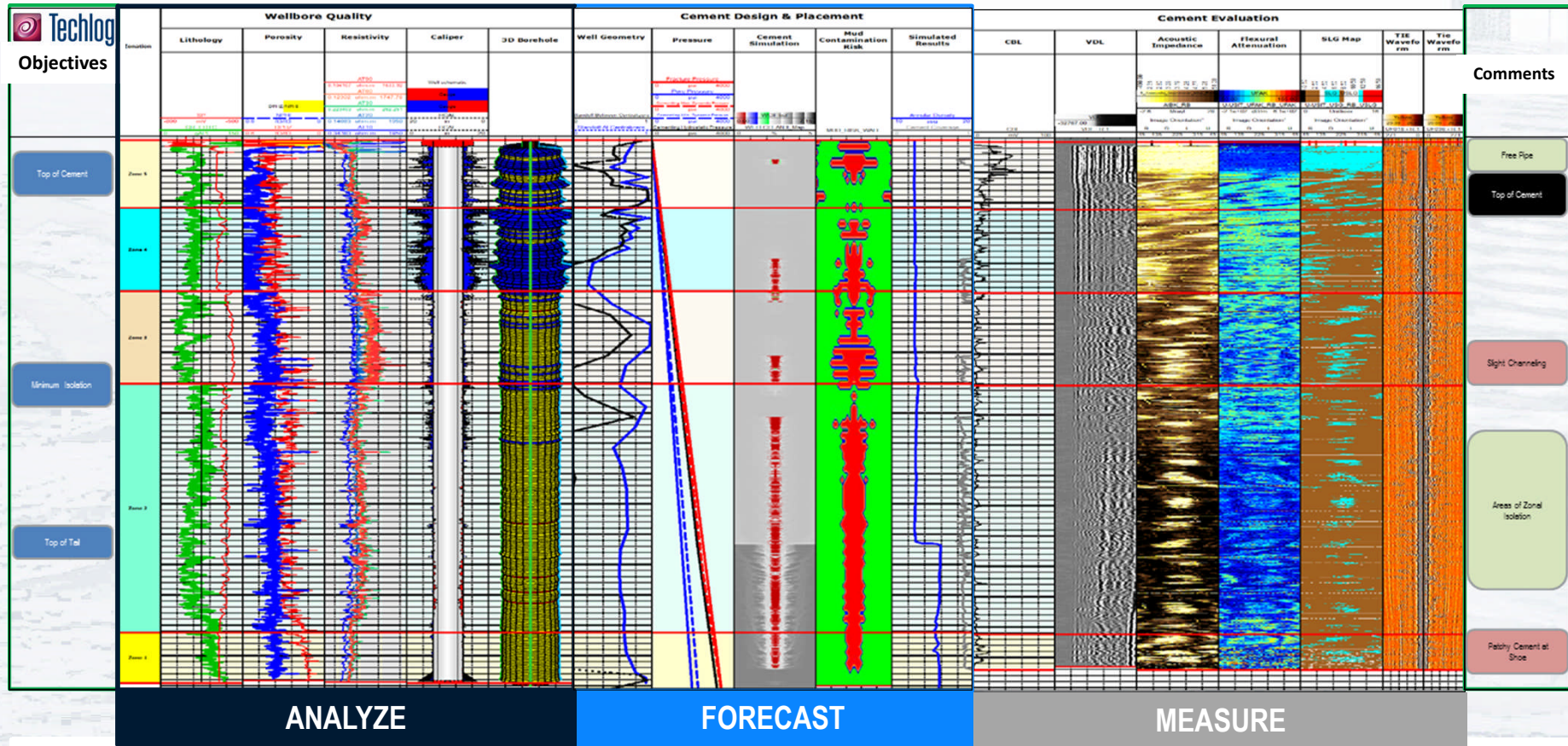
Sources/Conduits for Fluid migration & poor cement – plan to eliminate all sources

- Microannulus – pressure induced and/or cement/casing induced
- Mud Removal – OBM film on casing – filter cake on wall, mud or air drilled paste
- Eccentered Casing – channels and mud removal
- Extended cement properties
- Contamination of cements – shallow gas mapping

## Process of Improvement

- Silver Bullet solution is not probable as many sources exist
- Continuous improvement requires information of causes of poor cement
- Allows cementing practices to be tweaked to prevent same issue on next well
- **USI & Isolation Scanner provide this imaging clarity to help evolve best practices**
  - **CBL -VDL in combination is valuable in interpretation of Microannuli and cement to formation bond**

# Invizion Evaluation Well Integrity Services Workflow



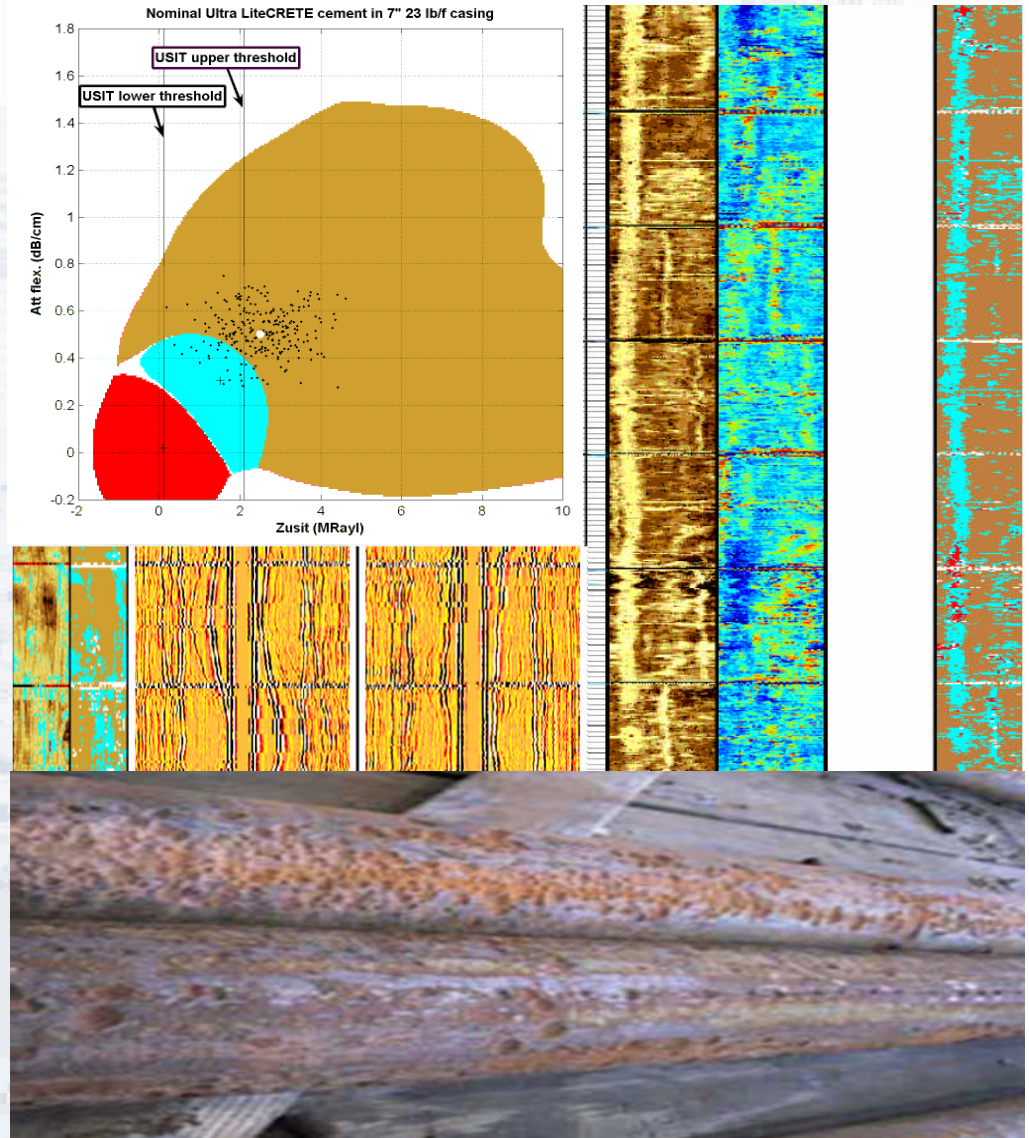
Schlumberger Private

Comments: What are the outcomes and why? Now can correlate and use interpretation to improve the next well

# Questions ???

Dirk Valstar  
NAL Well Integrity Domain Champion  
Houston, Tx

832.205.4736 cell  
281.285.4203 office  
valstar1@slb.com



# Why Cement Evaluation ????

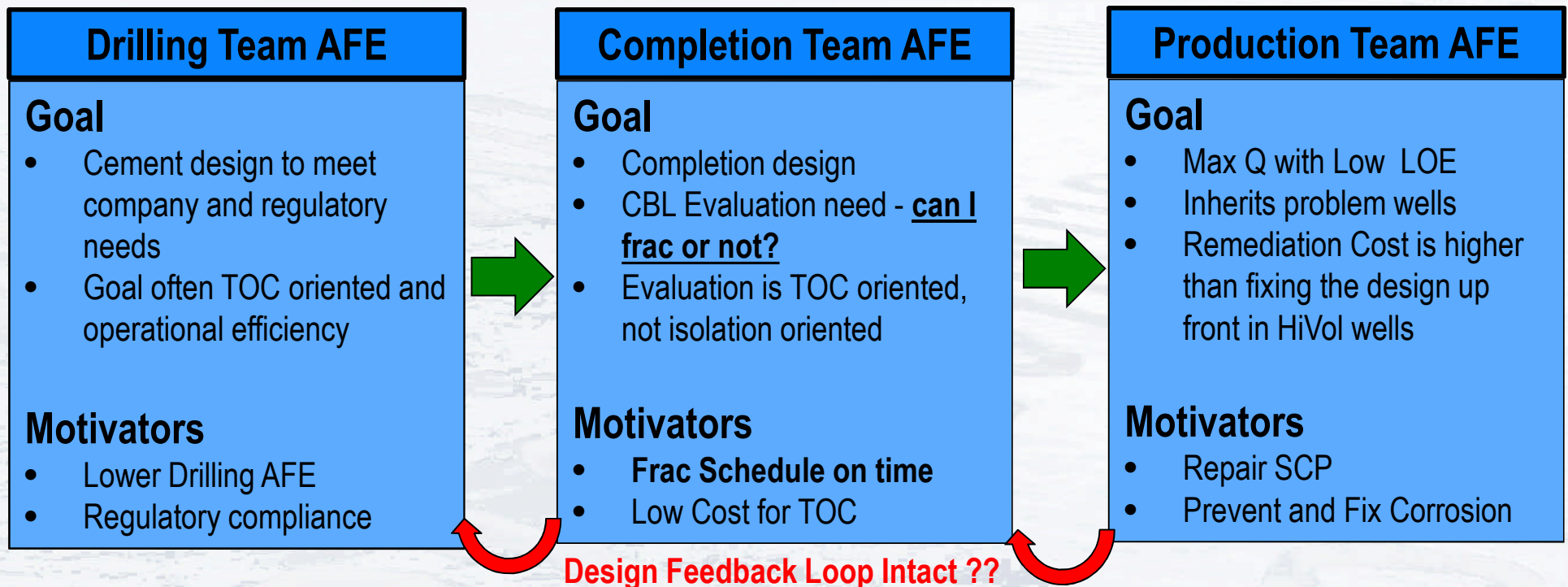
- Isolate water from hydrocarbon zones
- Environmental – Isolate Aquifers and prevent HC to surface
- Completion Design – Hydraulic Isolation for fracturing
- Protect Casing from Corrosion

## SLB - Cement Evaluation Tools

- Cement Bond Logs - CBL, SCMT, SSLT, Sonic Scanner
- Ultra Sonic Measurement – USI, Isolation Scanner
- Ultra Sonic & Flexural Attenuation Measurement – Isolation Scanner
  - Provides Improved Cement Analysis in Low Impedance cements
  - LiteCretes, Ultralite Cretes, Contaminated Cements, Foam Cements

# Organization Communication Workflow ???

## Factory Construction Implications

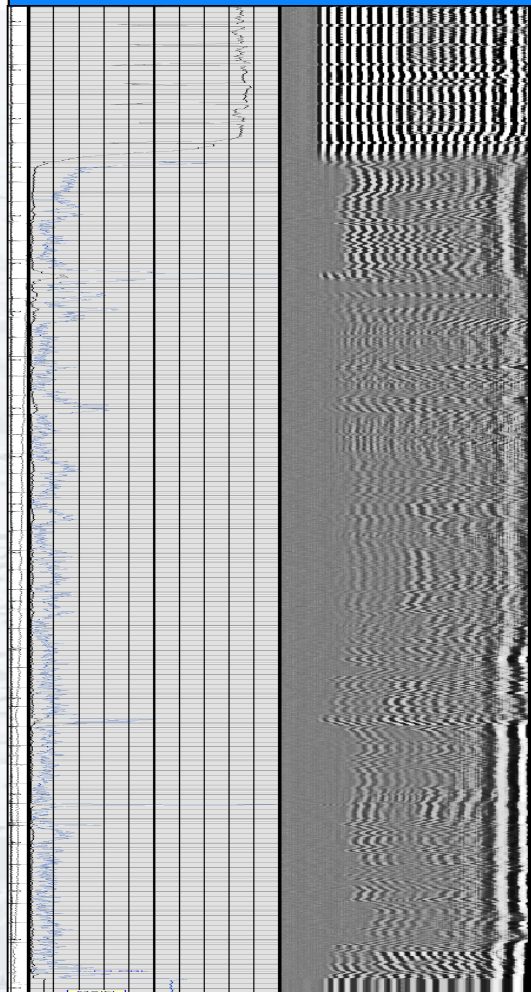


Schlumberger Private

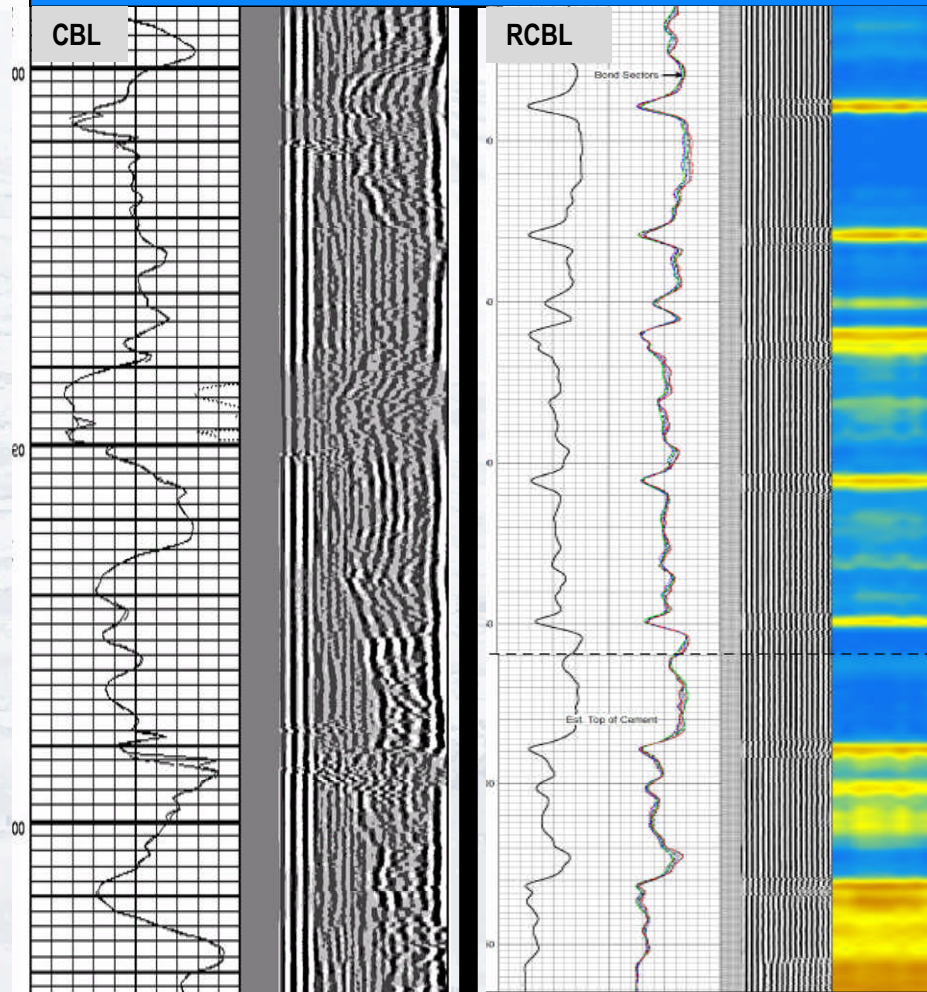
- TOC does not mean Top of Isolation
- Completed wells pass to Production as do issues like SCP and poor corrosion protection
- **Remediation Costs of issues like SCP higher than prevention costs in the design phase**
- Low cost in the design phase often leads to larger cost over the life of the well
- Feedback loop on cement design issues seldom occurs leading to Hi Vol replication of issues

# CBL/RCBL - Too low resolution for causal analysis

What we want to see - CBL



What we often get !! CBL and RCBL



Why is bond poor?

- Voids ?
- Channel?
- Contamination?
- Microannulus?

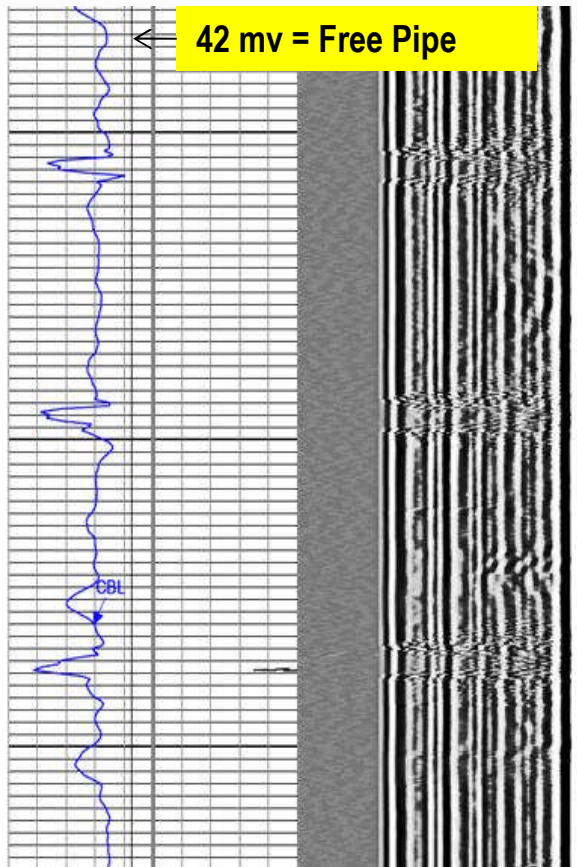
What do we fix?

What to change in design for next well?

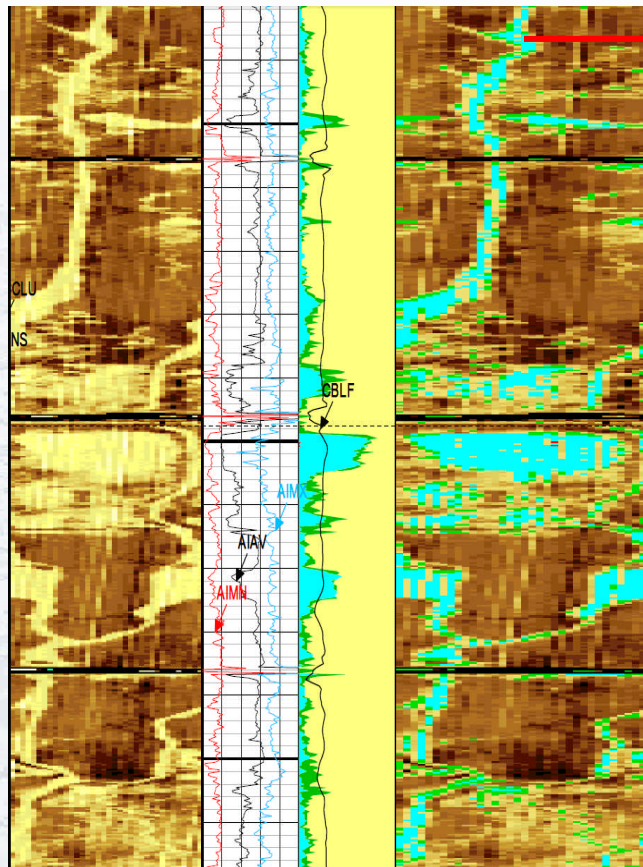
Not free pipe, not good bond  
No actionable information on what to fix next time

# Problem - Annular pressure on 13 3/8" Permian Basin

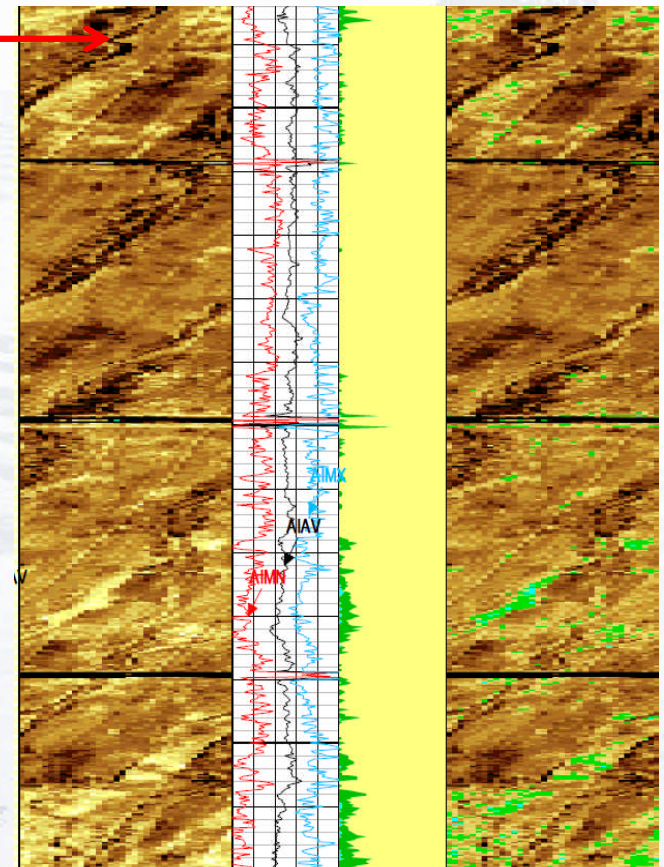
## How do you fix it?



CBL – Shows an Issue – no help in root cause or remediation



USI – Defines flow path area and cause – Post Placement Channel

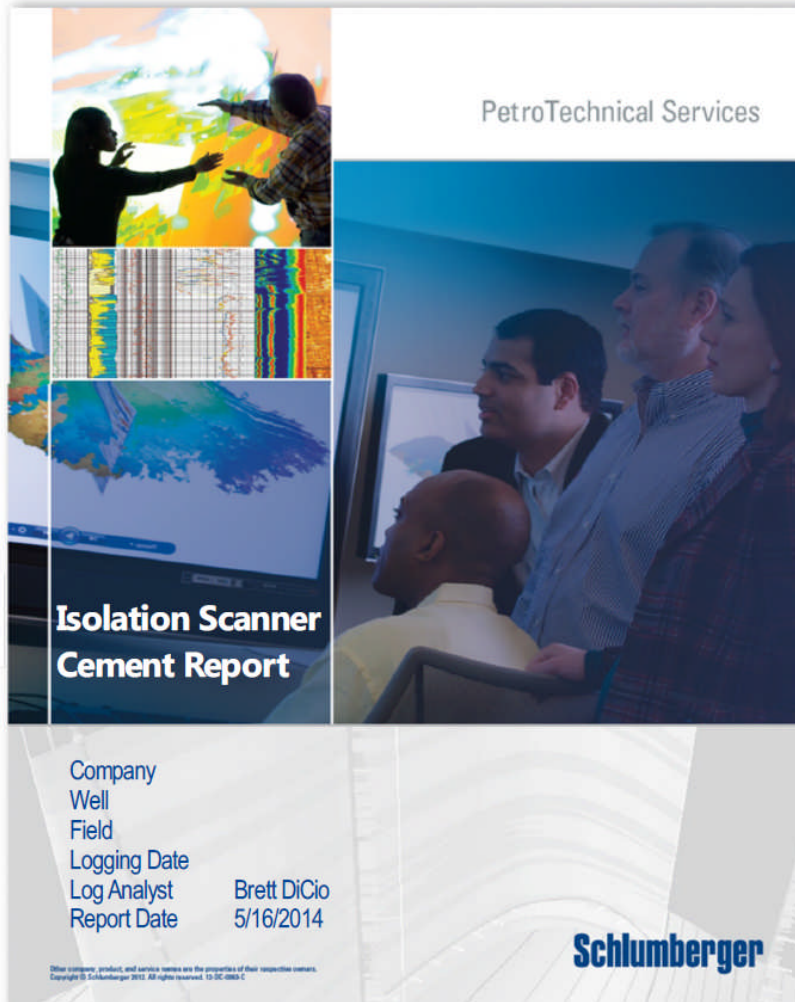


Post Squeeze - Imaging Aids Squeeze success & aids design of next well.

Where do you squeeze ??

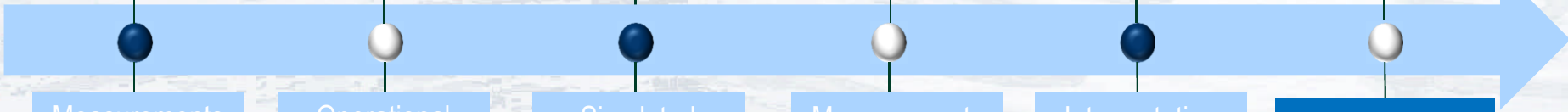
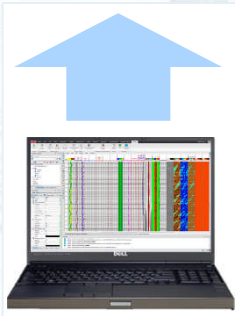
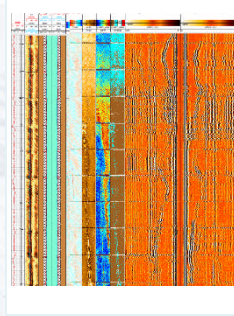
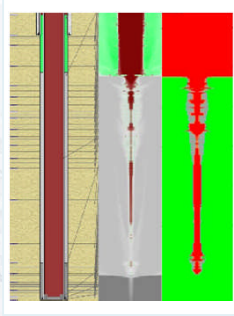
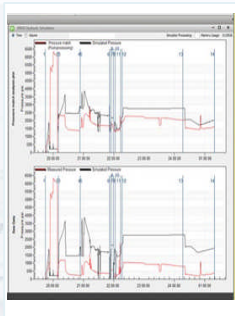
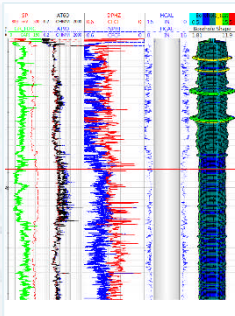
Post placement channel fixes: lower water loss and speed setting time

# PTS Well Integrity Analysis



- Reports can be done for
  - Corrosion Evaluation
  - Cement Evaluation
- Zonal Isolation summaries
- Joint by joint summaries
- Defect visualization and interpretation
- Burst analysis
- Invizion – Integrated solutions

# Invizion Evaluation workflow



Measurements  
**Wellbore Quality**

Operational  
**Barrier Placement**

Simulated  
**Fluids Placement Forecast**

Measurements  
**Cement Evaluation logs**

Interpretation  
**Integrated Analysis**

**Recommendations and Lessons Learned**

Objectives, Formation characterization, Drilling: What the hole is telling us?

Cement placement? Operational Events analysis  
How is your barrier placed?  
TOC based on Hydraulics.

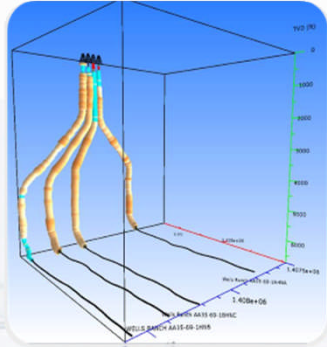
Simulate annular fluid placement based on job acquired data.

Correlates all logs and fluid placement forecast.  
TOC and vertical/horizontal seal interpretation

Increases Interpretation confidence by using all available elements to qualify WBE

Achieve Well Integrity objectives.  
What is the real reason behind APB/SCP?  
Improve investors' confidence

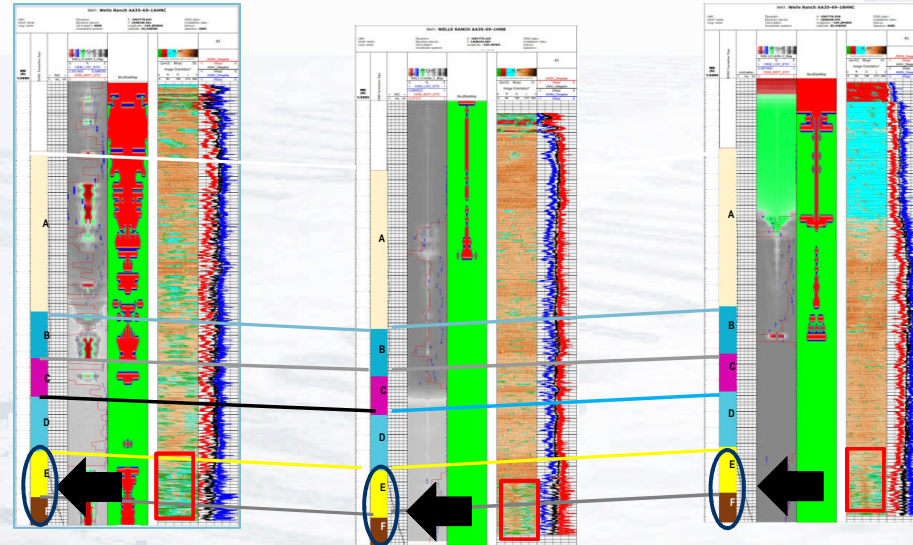
# Avoid APB in a well pad – DJ Basin



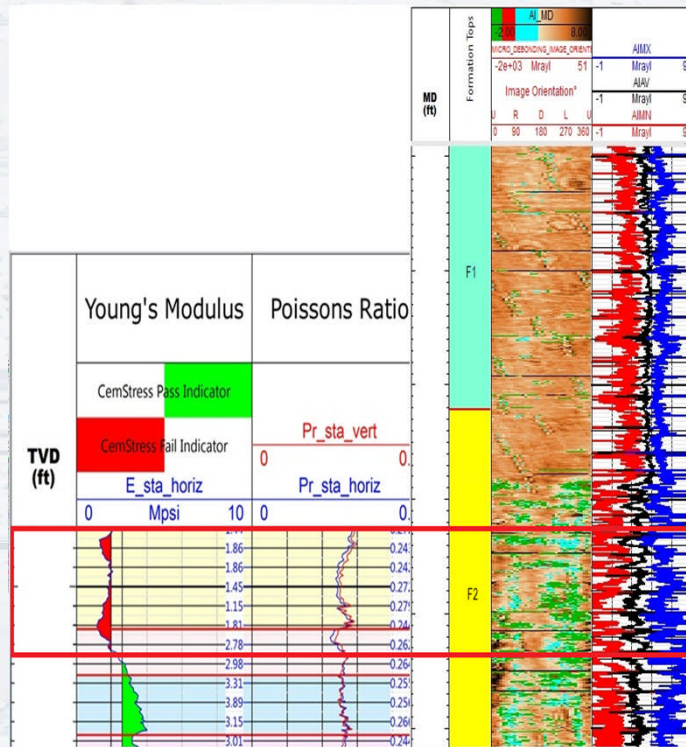
Well #1

Well #2

Well #3



Compared: Lithology- Deviation-Fluid placement forecast simulation-USIT Cement evaluation logs



## Steps for pad performance improvement

Improved fluid design and centralisation

## Identify similarities and trends between wells:

Fluid Placement, Centralization, Geology

Formation Stresses vs. Cement System (Traction failure)

Use Cement system adequate to sustain changes in stresses