The Dark Art of Cement Bond Log

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Overview

- Purposes of Cement Bond Logging
- Typical Cementing Problems
- Petrophysical Methods for Cement Bond Evaluation
- Acoustic Methods in Detail
- Log Quality Control
- Basic Cement Bond Log Interpretation
- Examples

Purposes Of Cement Bond Logging

Good cementing is needed for:

- Hydraulic isolation of the casing annulus and permeable intervals
- Casing mechanical support
- Perforation holes' stability

Little test

Do you have hydraulic isolation at the proposed perforation interval:

- **ICV[1] = 15m^3, pumped 20m^3 plus displacement volume, no returns at surface**

- **ICV = 15m^3, pumped 20m^3, 3m^3 of returns, but the level has dropped as soon as the pump stopped**

- **ICV = 15m^3, pumped 20m^3, 3m^3 of returns, 3 days later –still solid cement cake at surface**

[1] ICV – Integrated Cement Volume

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Little test – answers…

Hydraulic isolation:

- ICV = 15m^3, pumped 20m^3 plus displacement volume, no returns at surface

  Inconclusive (most likely, no)

- ICV = 15m^3, pumped 20m^3, 3m^3 of returns, but the level has dropped as soon as the pump stopped

  Inconclusive (most likely, no)

- ICV = 15m^3, pumped 20m^3, 3m^3 of returns, 3 days later –still solid cement cake at surface

  Inconclusive (most likely, yes…

  but would you bet your life on it?)

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Cement Bond Logging

- Continuous downhole measurement over the entire cementing intervals
- Good quantitative measurement of cement quality and placement
- Allows to plan remediation work
- May provide clues for cementing programs' improvements

- Solid conclusive answers if done properly
- Inconclusive or just wrong if any shortcuts are taken

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Typical Cementing Problems

1. Incorrect volumes

- Too little / too much pre-wash, slurry, displacement
- Unexpected fluid losses (including the losses increase after the casing run)

What is wrong here?

Integrated Hole/Cement Volume Summary

Hole Volume = 5.29 M3

Cement Volume = 5.29 M3 (assuming 0.00 IN casing O.D.)

Computed from 410.3 M to 265.9 M using data channel(s) BS

Integrated Hole Volume Minor Pip Every 10 F3

Integrated Hole Volume Major Pip Every 100 F3

Integrated Cement Volume Minor Pip Every 10 F3

Integrated Cement Volume Major Pip Every 100 F3

Time Mark Every 60 S

2. Cement composition

- Too little / too much retardants
- Density
- Viscosity
- pH
- Water salinity
- Reactions with formation minerals (esp. clay minerals, limestone, dolomite)
- Reactions with mud components (esp. water-polymer mud systems)

3. Pumping procedure

- Flow rate is too slow / too fast
- Stop-overs or pump break-downs
- Stages and valves…

Effects (in order of significance):

- No cement behind casing
- Channeling
- Poor quality cement behind casing
- Poor formation bond
- Micro-annulus
- Cement mechanical degradation
- Cement chemical degradation

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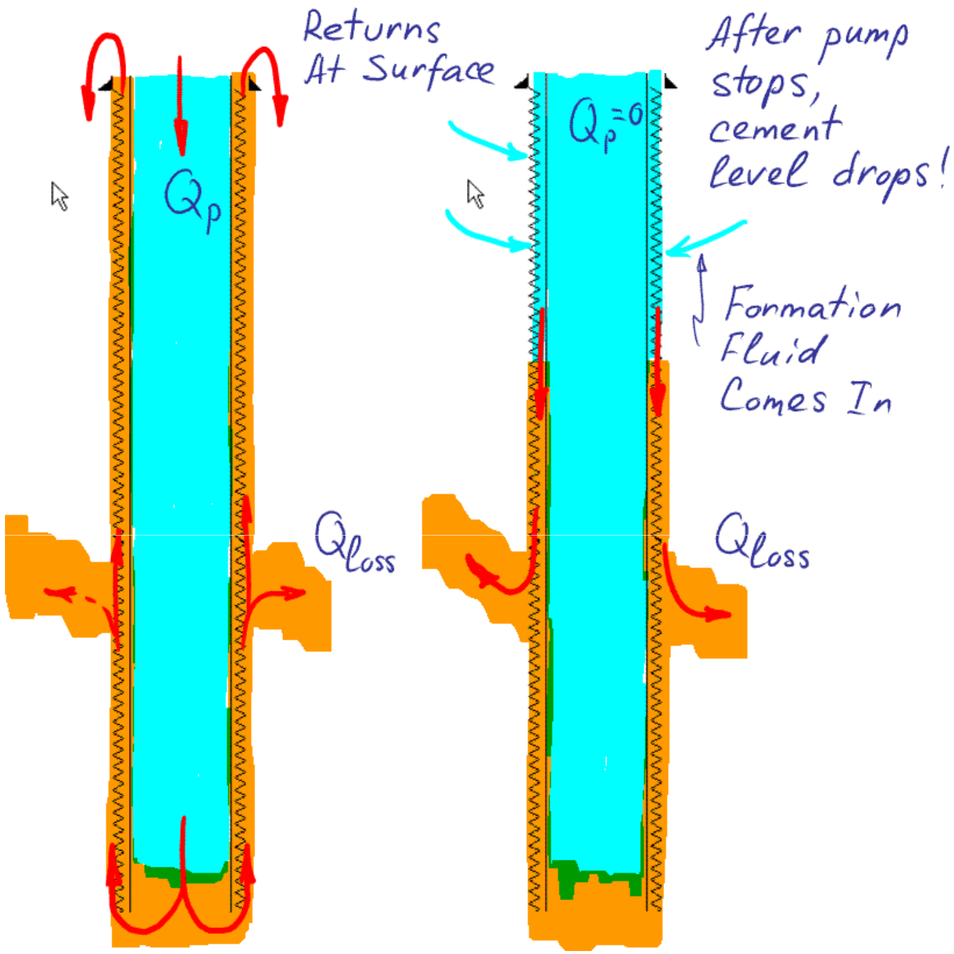
Volume effect:

- **No cement behind casing:**
  - **Not enough slurry**
  - **Too much displacement fluid pumped**
  - **Not enough displacement fluid pumped (so you probably have some bigger problem here!)**

- **Cement / fluid return at surface is not a guarantee of proper cement placement**



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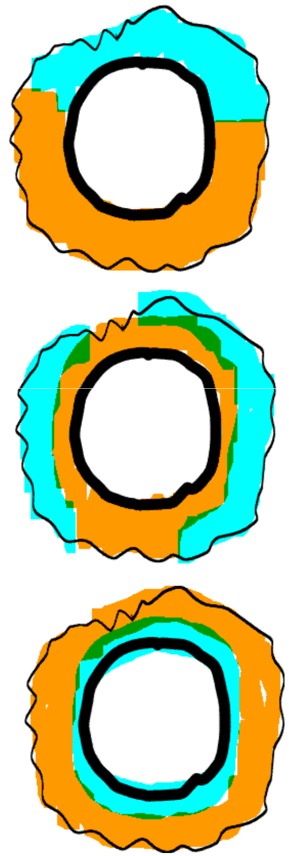
Placement effects:

- Channeling
  - Physical effects (e.g. flow rate)
  - Chemical effects (e.g. clay minerals)
  - Insufficient pre-wash
- Poor formation bond
  - Mostly chemical effects (e.g. clay minerals)
  - Insufficient pre-wash
- Micro-annulus
  - "Aggressive" cementing programmes
  - Low casing grades



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Material effects:

- Poor quality cement behind casing
  - Chemical effects (e.g. clay minerals, water-based polymers)
  - Insufficient pre-wash
- Cement mechanical degradation
  - Vibration
  - Perforation
- Cement chemical degradation
  - Very unusual for modern slurries

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Petrophysical Methods for Cement Bond Evaluation

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Non-petrophysical methods

- Surface cement samples
- Pressure / rate / density record
- Returns observation
- Pressure tests
- LOT / FIT

- “Nullius in verba!” (Horace)

Petrophysical methods

- Temperature Log
- Neutron Log
- Acoustic Logs
  - Sonic Log (CBL / VD or Sector CBL)
  - Ultrasonic Log
  - Combination Log

Acoustic Logs

- Tool response is related to Acoustic Impedance:

  $Z = \rho / S * 304.6$ in MRay, 1Ray=kg/s/m^2

  S – slowness, μs/ft ρ – density, SG

Steel (bulk):	S=51.4,	ρ=7.80	Z=46.2
Steel (pipe):	S=57.3,	ρ=7.80	Z=41.5
Cement:	S=58-72,	ρ=1.76-2.72	Z=7.46-14.3
Water/Brine:	S=189,	ρ≈1	Z=1.61
Mud:	S≈200,	ρ=1.03-1.8	Z=1.45-2.70
Formation:	S=40-400,	ρ=1.5-2.7	Z=1.2-21

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Acoustic Logs (2)

- **Reflection coefficient from Acoustic Impedance:**

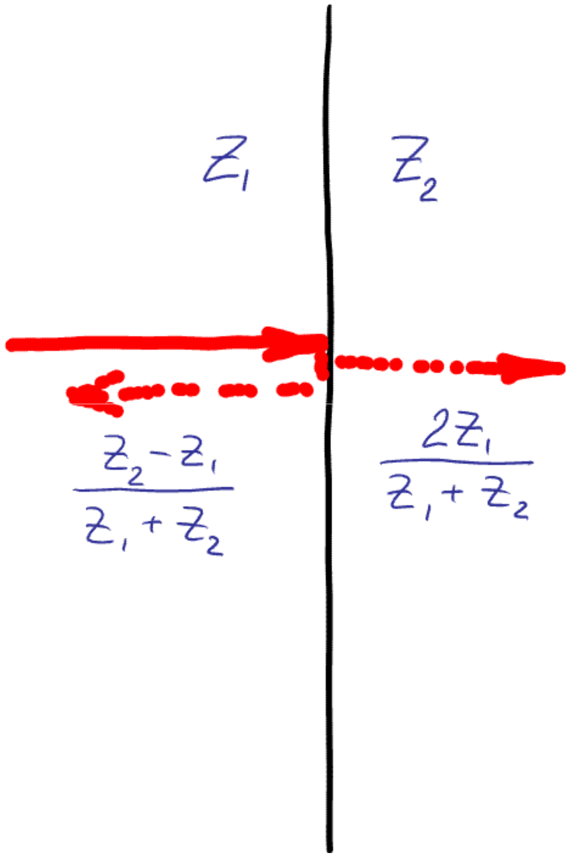
  $C_R = (Z_2 - Z_1) / (Z_1 + Z_2)$

- **Transmission coefficient from Acoustic Impedance:**

  $C_T = 2^*Z_1 / (Z_1 + Z_2)$

- **Note:**

  $C_R + C_T = 1$



Acoustic Logs (3)

- Due to the great contrast between fluids, steel and cement, sound reflections provide excellent way of determining the cement presence and quality
- De-facto industry standard
- Regulatory requirement in many countries

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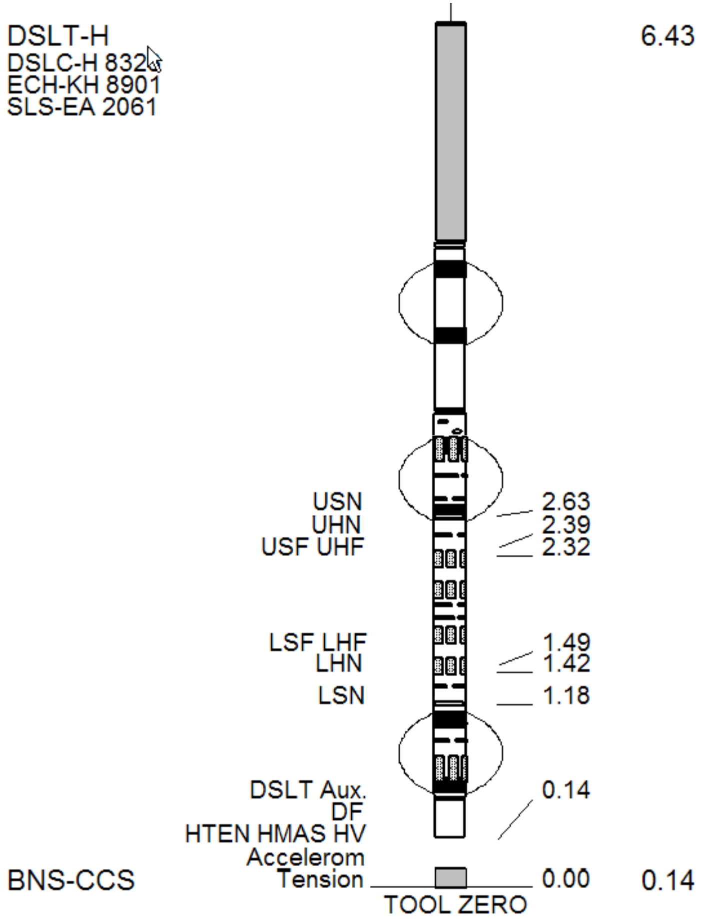
Acoustic Methods in Detail

Acoustic Log (CBL-VDL)

- Cement Bond Log (CBL) – 3 ft between the transmitter and the receiver
- Visual Density Log (VDL) – 5 ft between the transmitter and the receiver

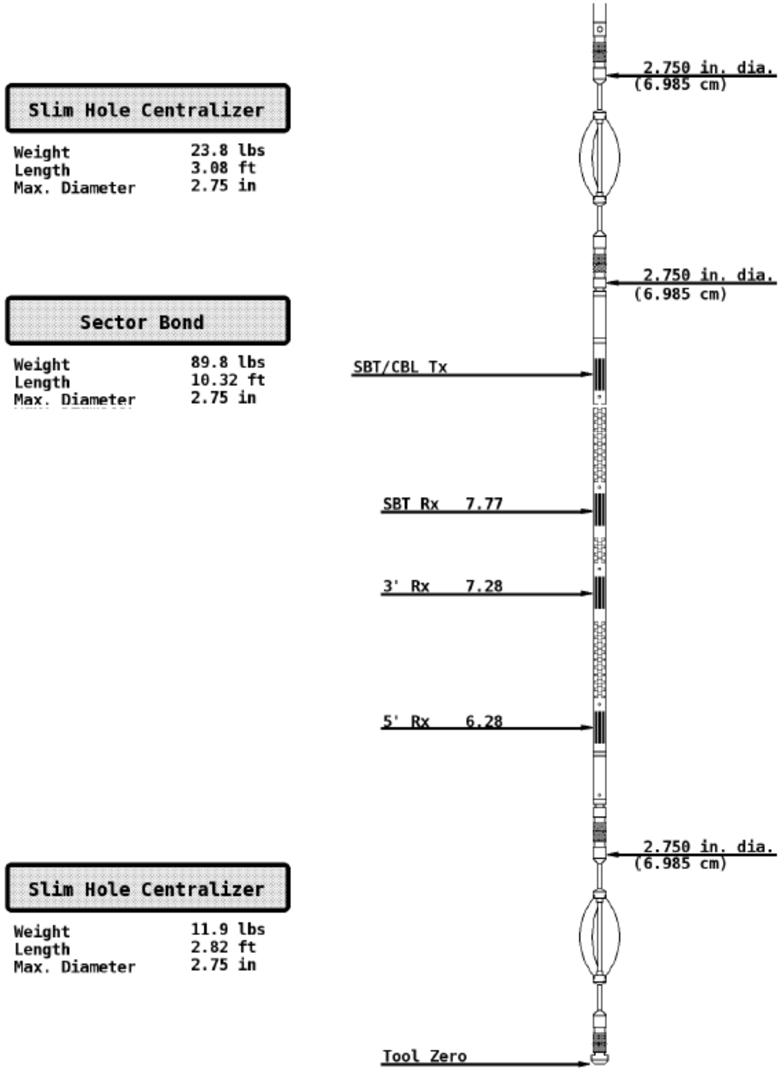
- DSLT – Schlumberger Ltd.



Acoustic Log (Sector CBL)

- **Cement Bond Log (CBL) – 3 ft between the transmitter and the receiver**
- **Visual Density Log (VDL) – 5 ft between the transmitter and the receiver**
- **8 ”sectoral” piezoelectric receivers, providing rough cement image at 45^0 steps**

- **SBT – Weatherford International**



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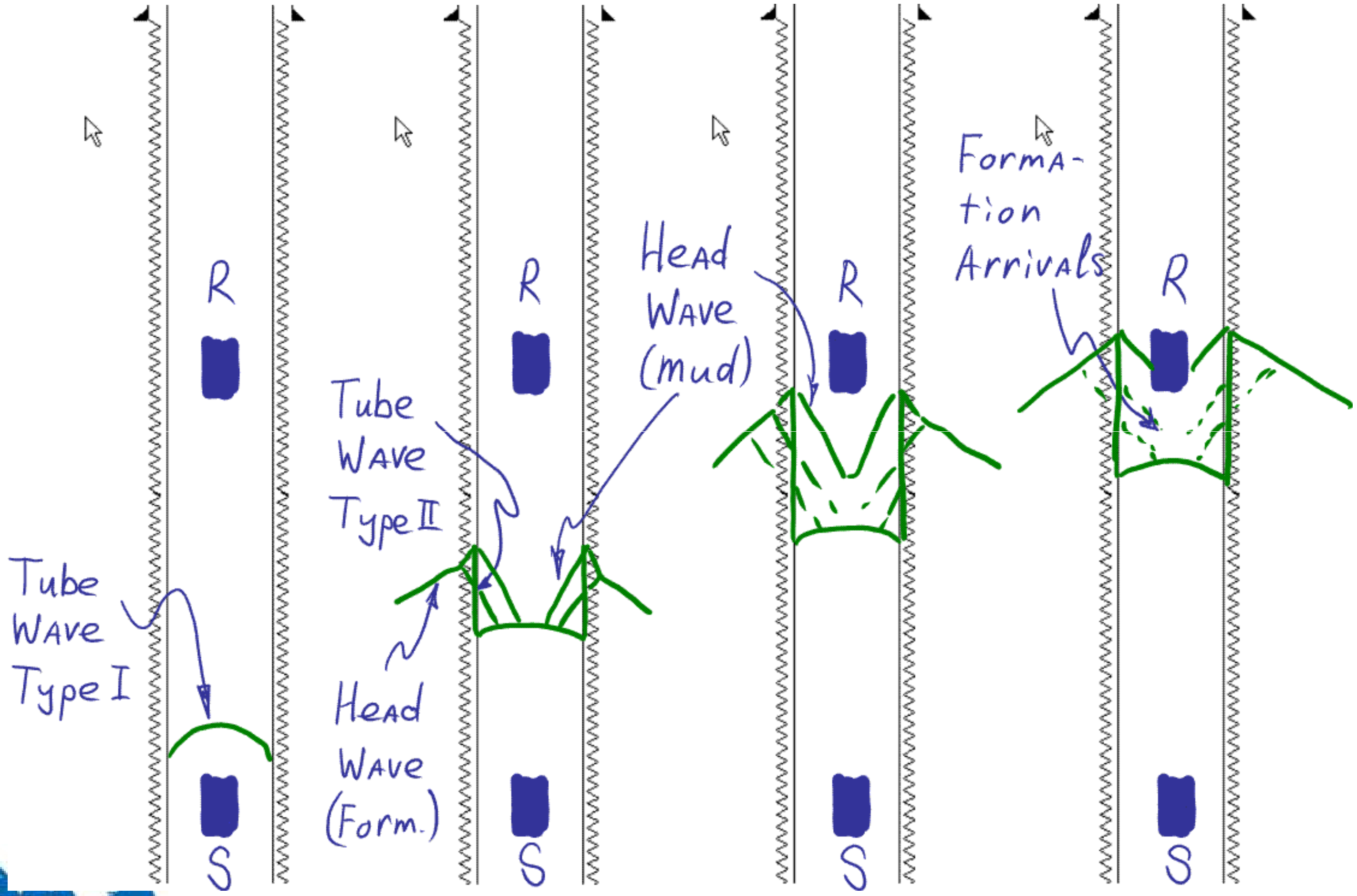
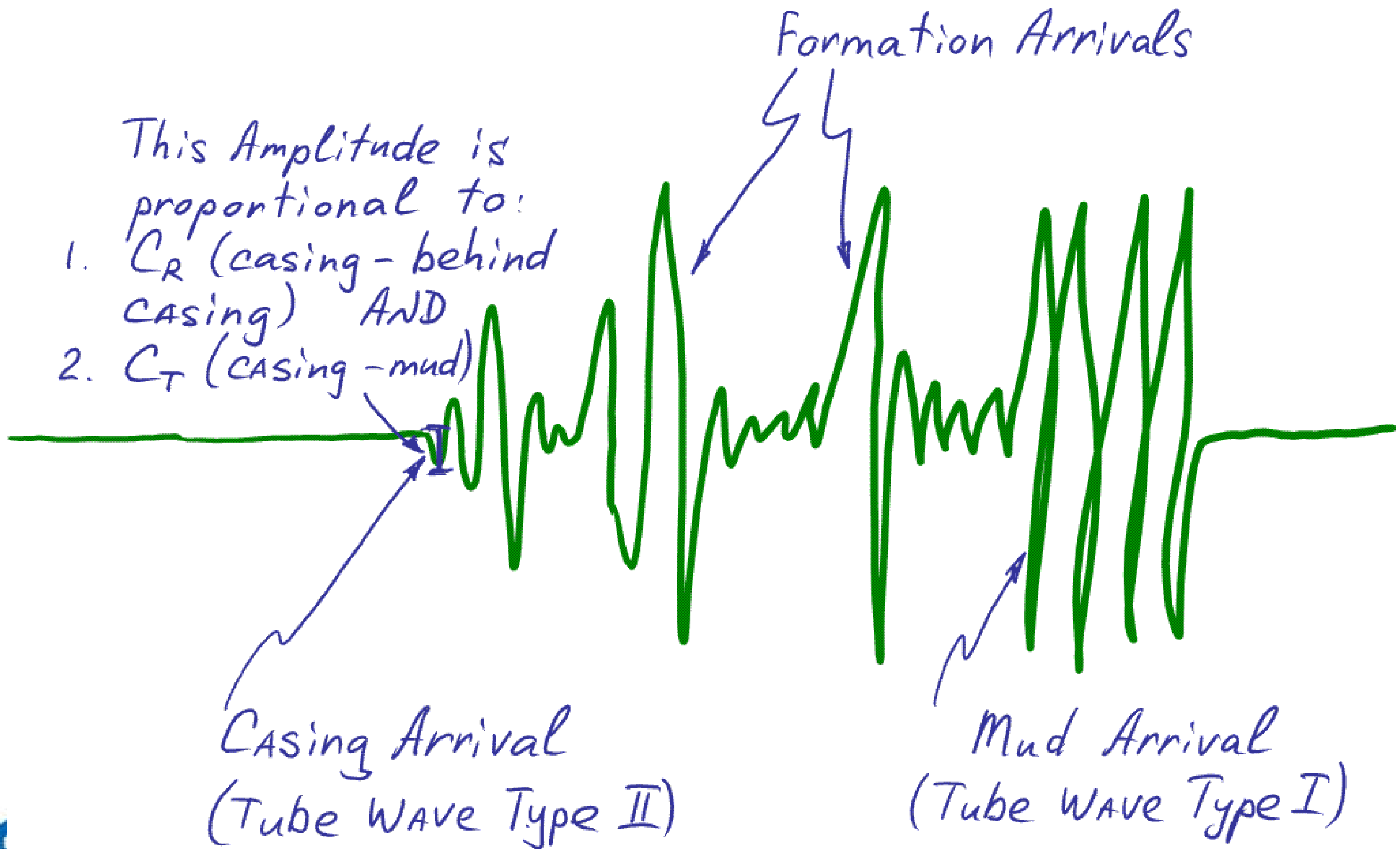
Sound propagation in casing



Waveforms at receiver



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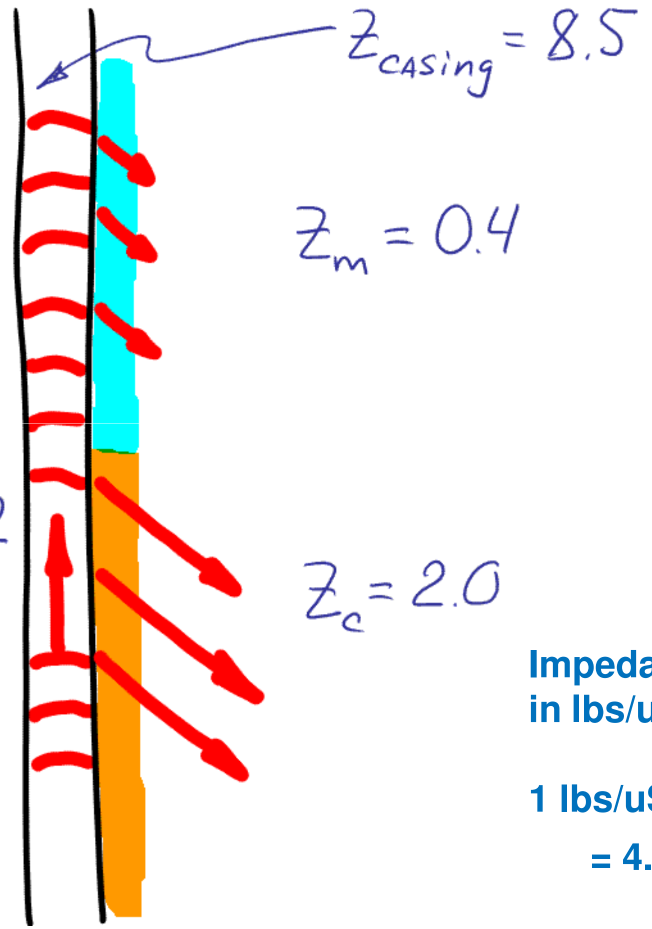
Cement dissipates tube wave II

$$C_R = \frac{0.4-8.5}{8.5+0.4} = -0.91$$

$$C_T = \frac{2\cdot 8.5}{8.5+0.4} = 1.91$$

$$C_R = \frac{2.0-8.5}{8.5+2.0} = -0.62$$

$$C_T = \frac{2\cdot 8.5}{8.5+2.0} = 1.62$$



Impedance in lbs/uS/ft2

1 lbs/uS/ft2 =

= 4.881 MRay

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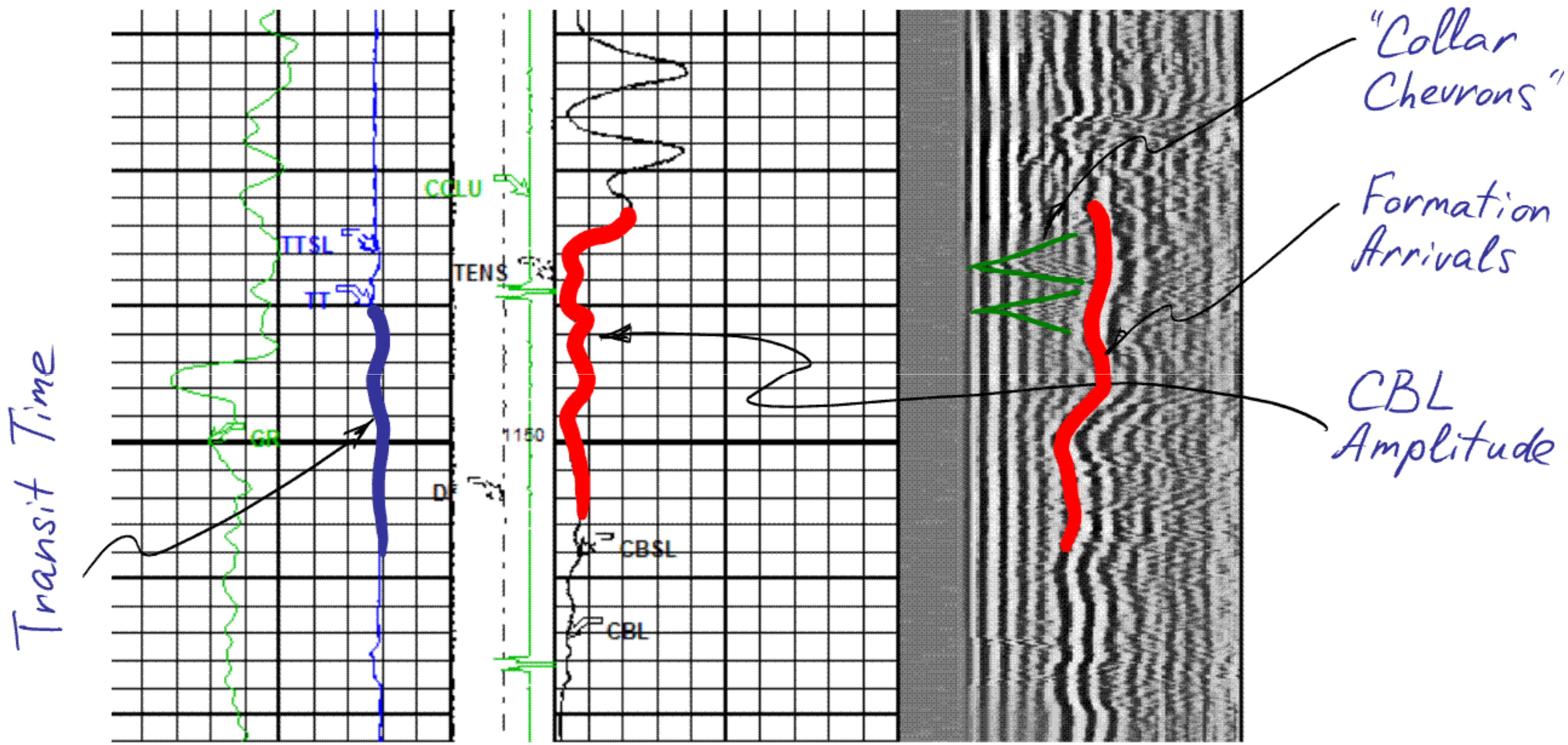
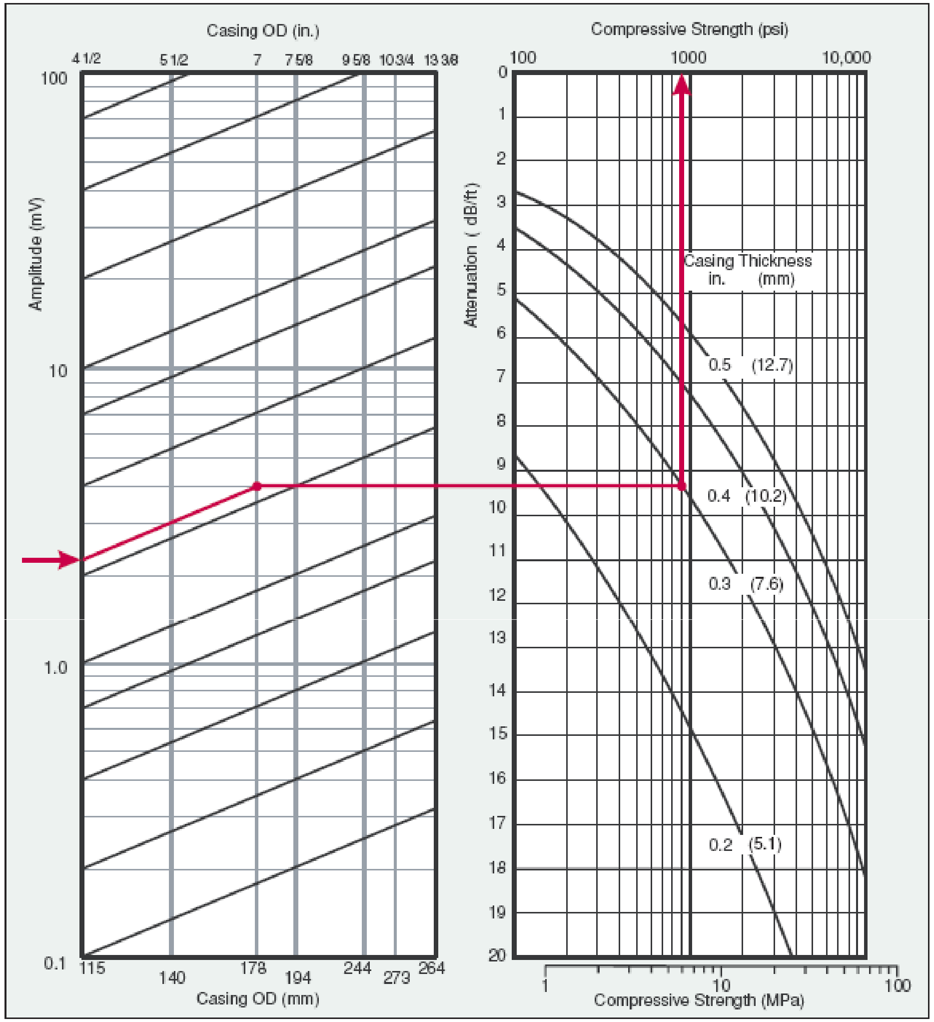
CBL Log Components



CBL Log Components (2)

- VDL “wavetrain” provides means for qualitative interpretation and log quality control
- CBL amplitude provides means for quantitative interpretation of content behind casing – the lower the CBL, the better the cement.
- Transit time is the most important quality indicator



CBL Interpretation Charts (Cem-1, GN 8-7, etc)

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CBL Uncertainty

- CBL is an “integrating” tool
- Same response for:
  - 100% cemented pipe with low compressive strength cement
    OR
  - Partially cemented pipe with high compressive strength cement (e.g. channels)

    OR
  - Micro-annulus

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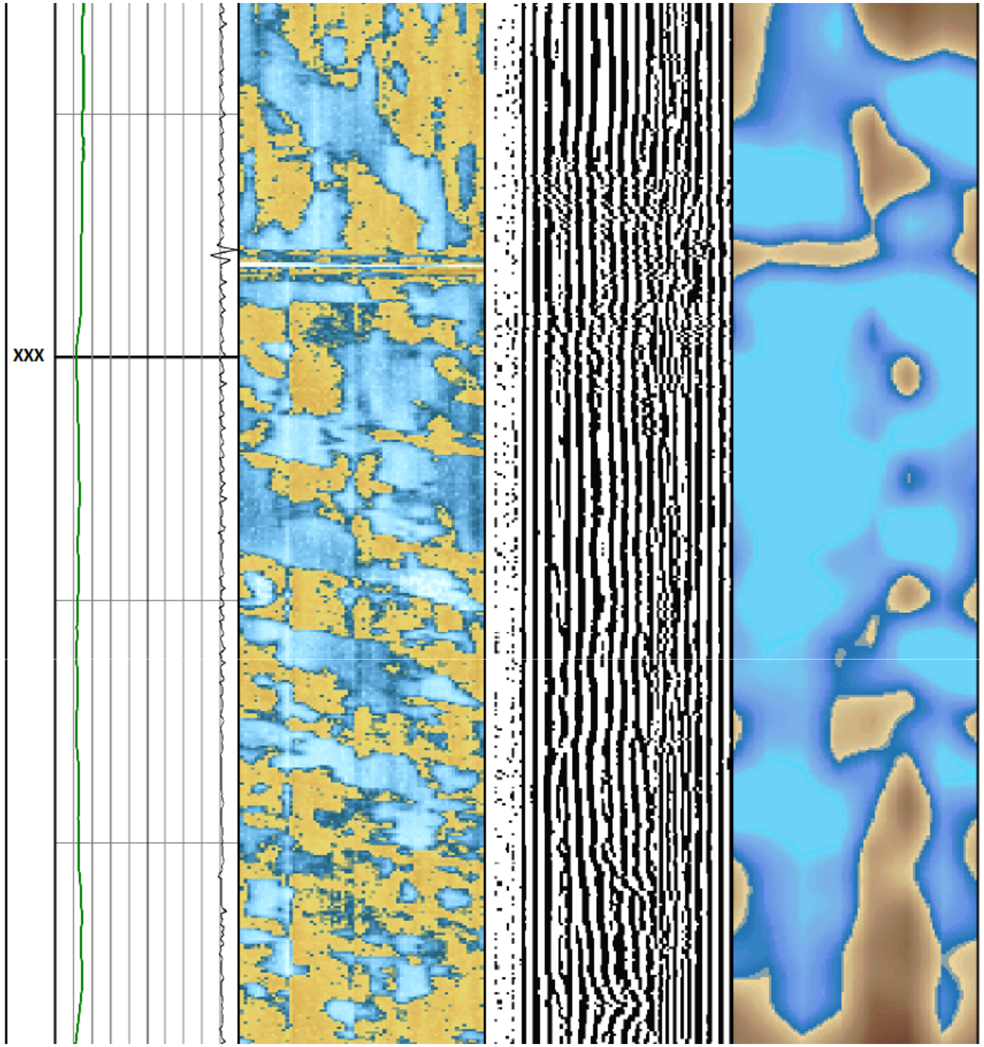
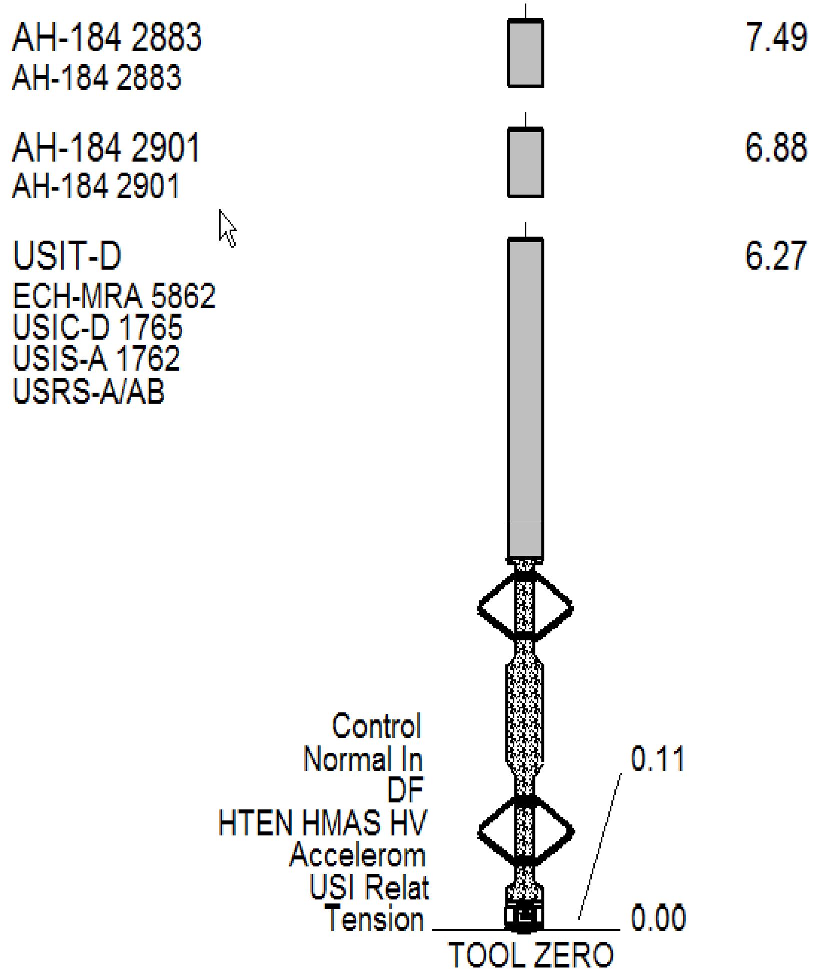


Sector CBL

Ultrasonic tools

- **Resolve CBL uncertainty by metering 360º surrounding**
- **Schlumberger (USIT) or Weatherford URS – one rotating transducer**
- **Isolation Behind Casing Tool (IBC) – three rotating transducers**



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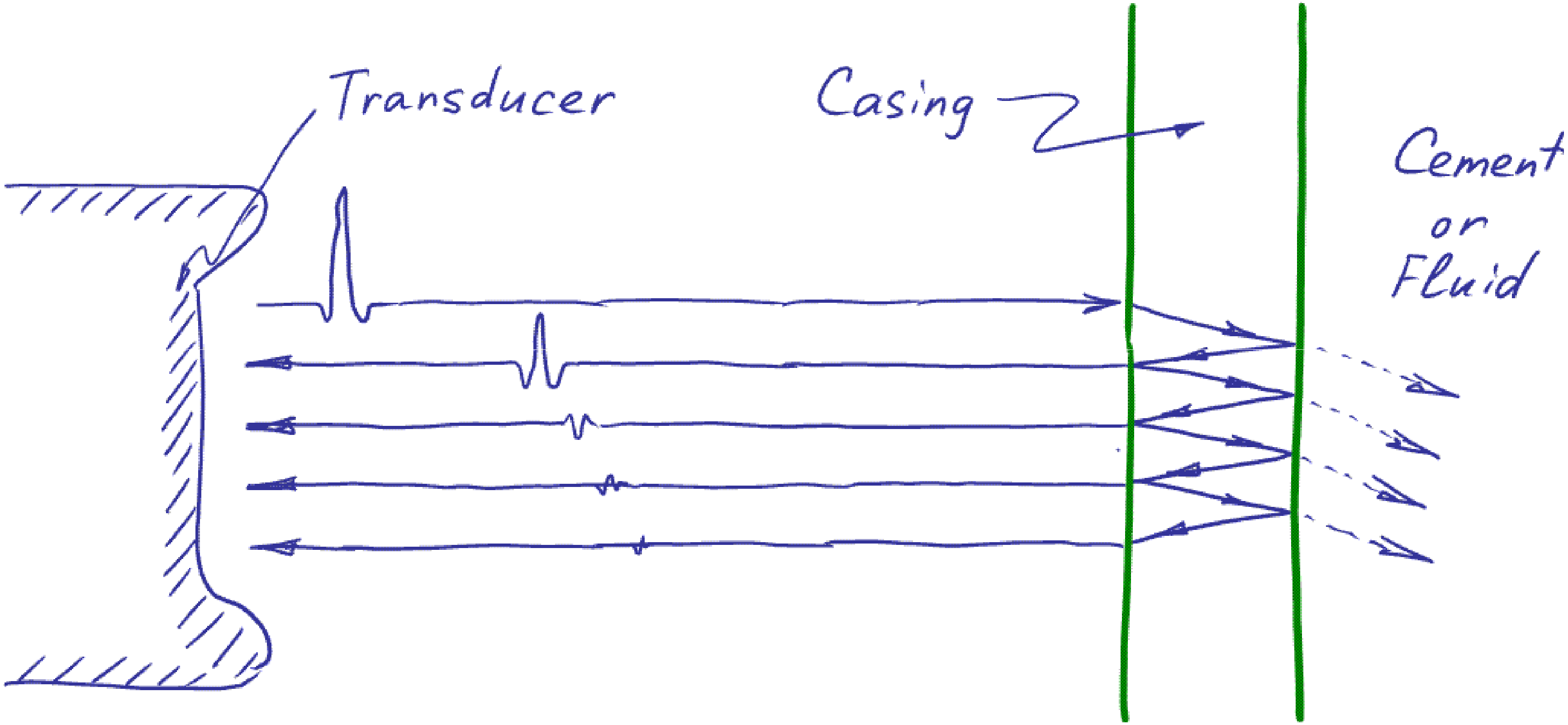
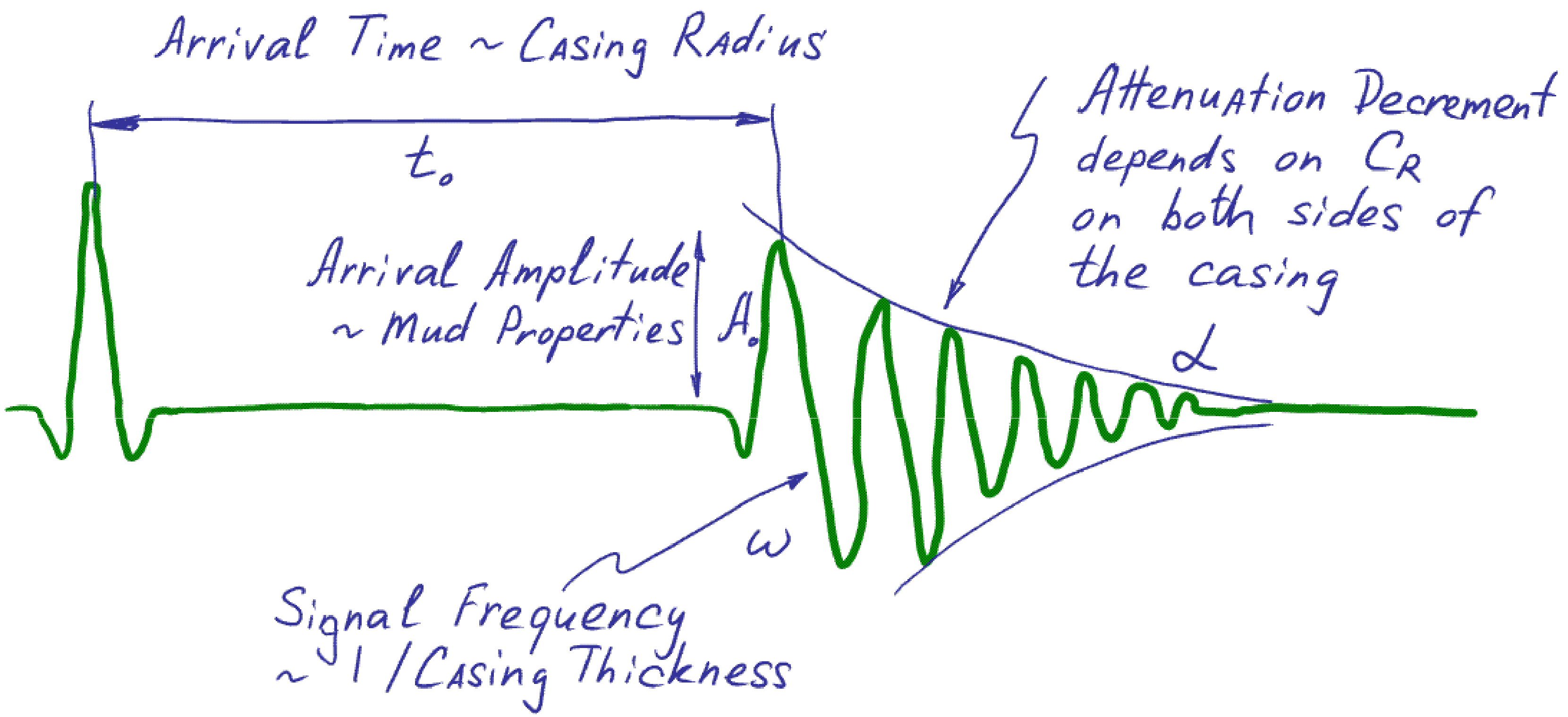
Ultrasonic tool principle

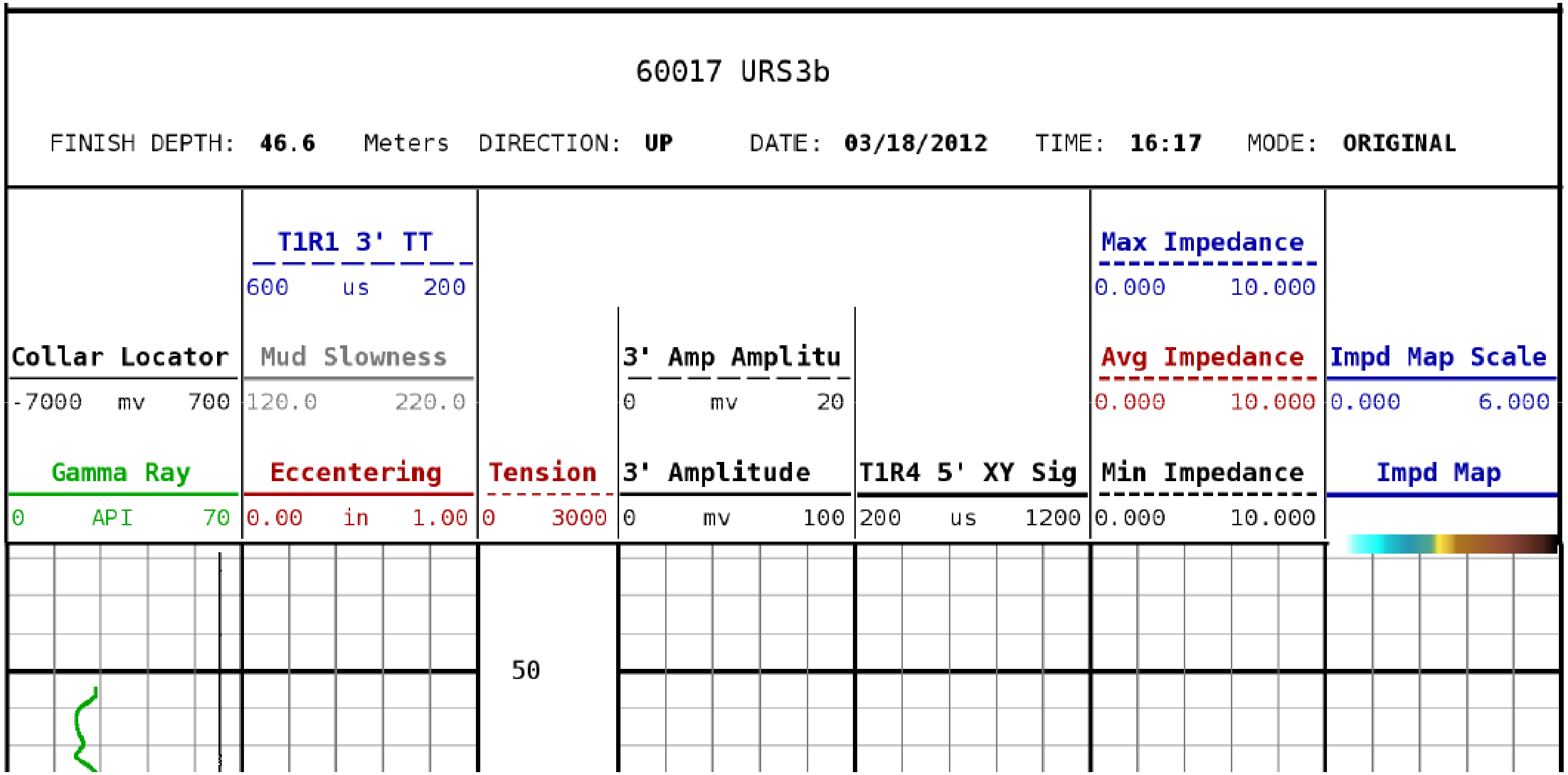


Ultrasonic tool principle (2)



$$A \cong A_0 \, Sin(\omega \cdot (t - t_0)) \cdot Exp(-\alpha \cdot (t - t_0)), \quad t > t_0$$

Ultrasonic Presentation (Cement)



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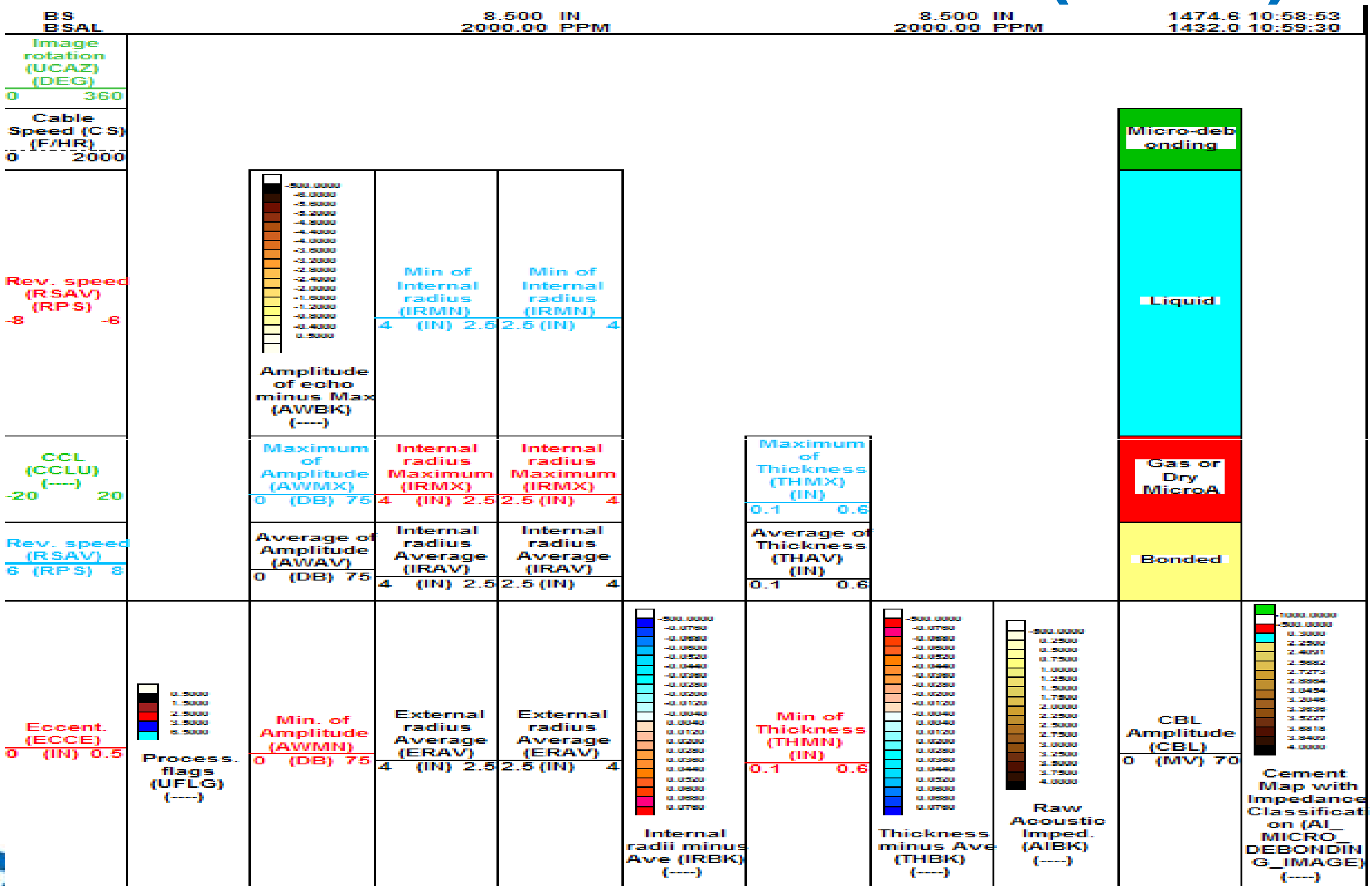
Courtesy of Schlumberger Ltd.

Ultrasonic Presentation (C&C)



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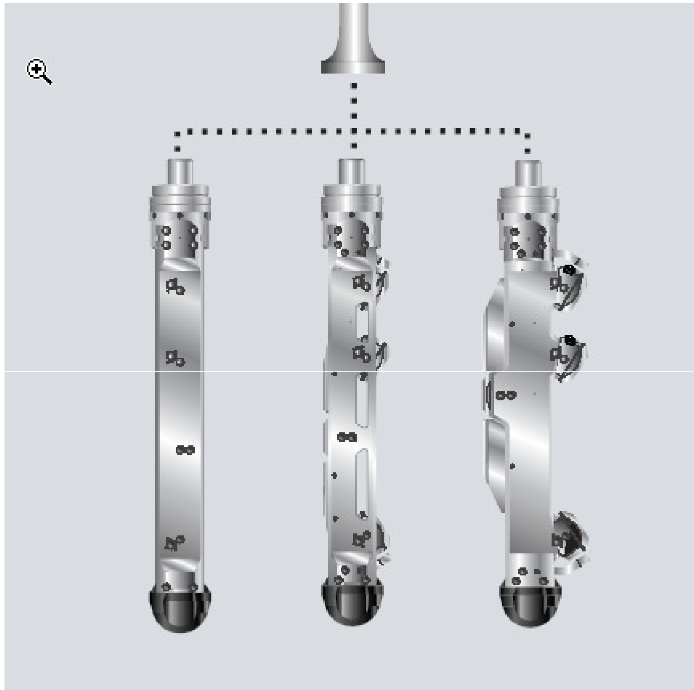
Ultrasonic limitations

- Have difficulty detecting formation bond
- May give false readings in high-viscosity mud
- Cannot distinguish between Micro-Annulus and absent cement
- Ideally, should always run in combination with CBL/VDL

- IBC can be run without CBL/VDL, but the service does not provide the standard 3’ and 5’ logs
  - Combine with CBL/VDL if possible

Combination logs



“Nolite id cogere, cape malleum majorem”
-If it does not want to go, don’t force it.
Just take bigger hammer.

Courtesy Schlumberger Ltd.

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Log Quality Control

Tool positioning: centering

- Both Ultrasonic and CBL/VDL have to be perfectly centered (typically anything above 0.2" is unacceptable)

- Off-center effects:
  - CBL shows lower amplitudes (e.g. "better cement")
  - VDL arrivals "smeared" (e.g. "bad cement"?)
  - Ultrasonic shows "channels" in direction perpendicular to offset and casing thickness increase in the same direction

- For both type of tools, eccentering is easy to see

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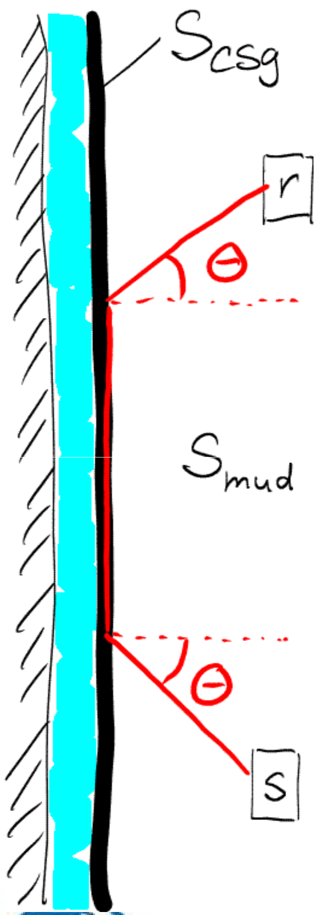
Tool positioning: tilt

- Both Ultrasonic and CBL/VDL should not run “tilted” (that may happen due to centraliser failure)

- Tilt effects:
  - CBL shows lower amplitudes (e.g. “better cement”)
  - VDL usually unaffected
  - Ultrasonic shows “channels” in direction of tilt and casing thickness increase in the same direction

- For Ultrasonic tuul, tilt, especially sporadic tilt due to jerky cable motion, may pass undetected, resulting in wrong interpretation

Transit Time should be right!



$$S_{mud} \sin\Theta = S_{csg} \cdot \sin 90^\circ$$

$$\sin\Theta = S_{csg} / S_{mud}$$

$$TT = 2TT_{mud} + TT_{csg}$$

$$TT = 2 \cdot \frac{d}{2} \frac{1}{\cos\Theta} S_{mud} + \left(L - 2\frac{d}{2} \cdot tg\,\Theta\right) S_{csg}$$

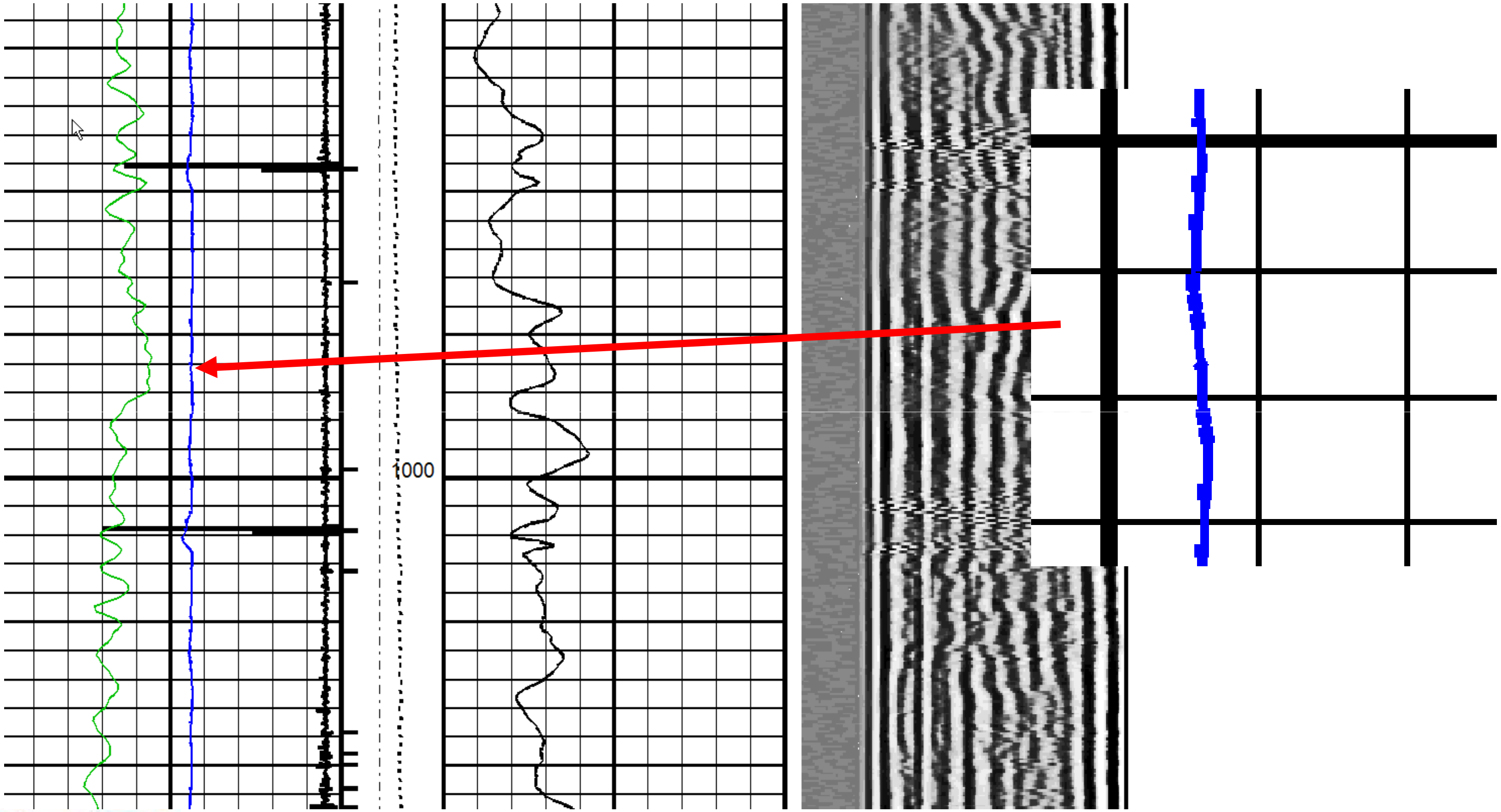
d - casing inner diameter
L - sonde spacing

$$\cos\Theta = \sqrt{1 - \frac{S_{csg}^2}{S_{mud}^2}} = \frac{\sqrt{S_{mud}^2 - S_{csg}^2}}{S_{mud}}$$

$$TT = \frac{d \cdot S_{mud}^2}{\sqrt{S_{mud}^2 - S_{csg}^2}} + L S_{csg} - \frac{d S_{csg} \cancel{S_{mud}}}{\sqrt{S_{mud}^2 - S_{csg}^2}} \frac{S_{csg}}{\cancel{S_{mud}}} =$$

$$= L S_{csg} + d\sqrt{S_{mud}^2 - S_{csg}^2}$$

TT should not change fast



TT should not change fast (2)

- TT should be within ±0.5 μs on each of the casing segments
- Changes at the casing collars are expected
- Minor changes on casing jewellery are possible
- Gradual change from TD to surface is OK (S_{mud} changes with temperature)
- Fast-changing TT indicates poor tool centering or sporadic tilt

CBL must be calibrated!

- If CBL reads above Free Pipe amplitude or below 100% amplitude – suspect poor tool calibration
- Fluid Compensation Factor (FCF) should be used with caution

Basic Cement Bond Log Interpretation

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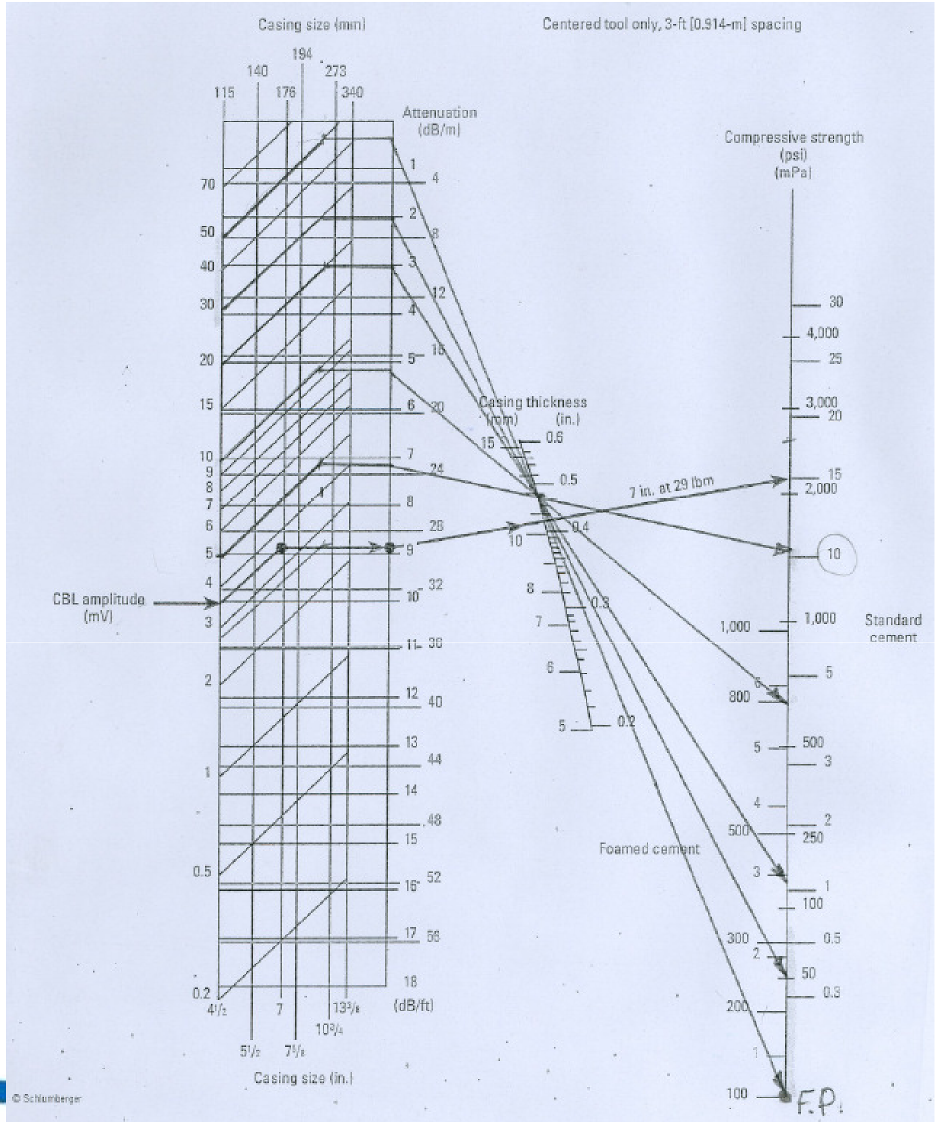

1. Calculate Min and Max amplitudes

- Casing Thickness
- Free Pipe CS = 0 MPa
- Fully cemented pipe:
  - Normal 10 MPa
  - Foamed 6 MPa
  - OR: use lab data if available

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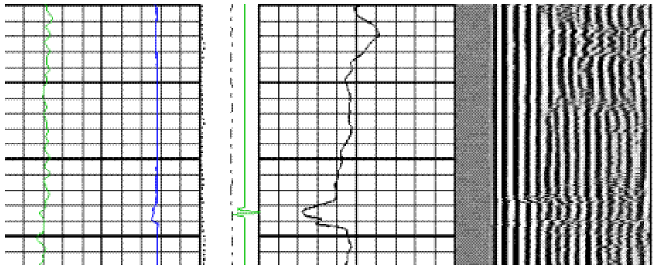
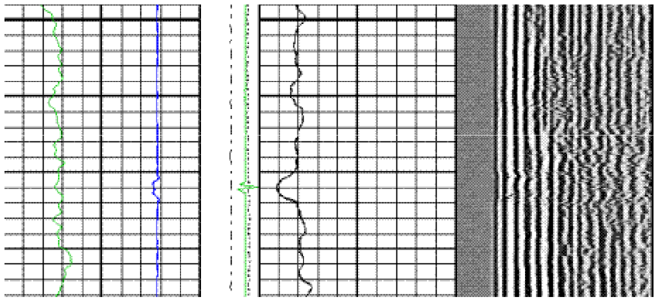
2. Perform "CBL Triage"



→ Poor Cement



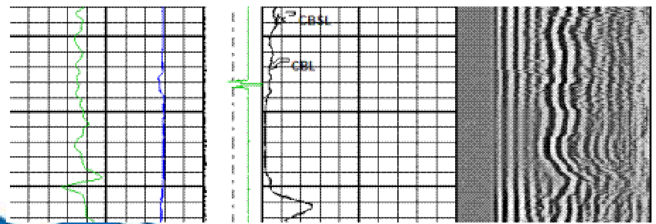
→ Intermediate Case

Low Compressive Strength?

Channels

Micro-Annulus

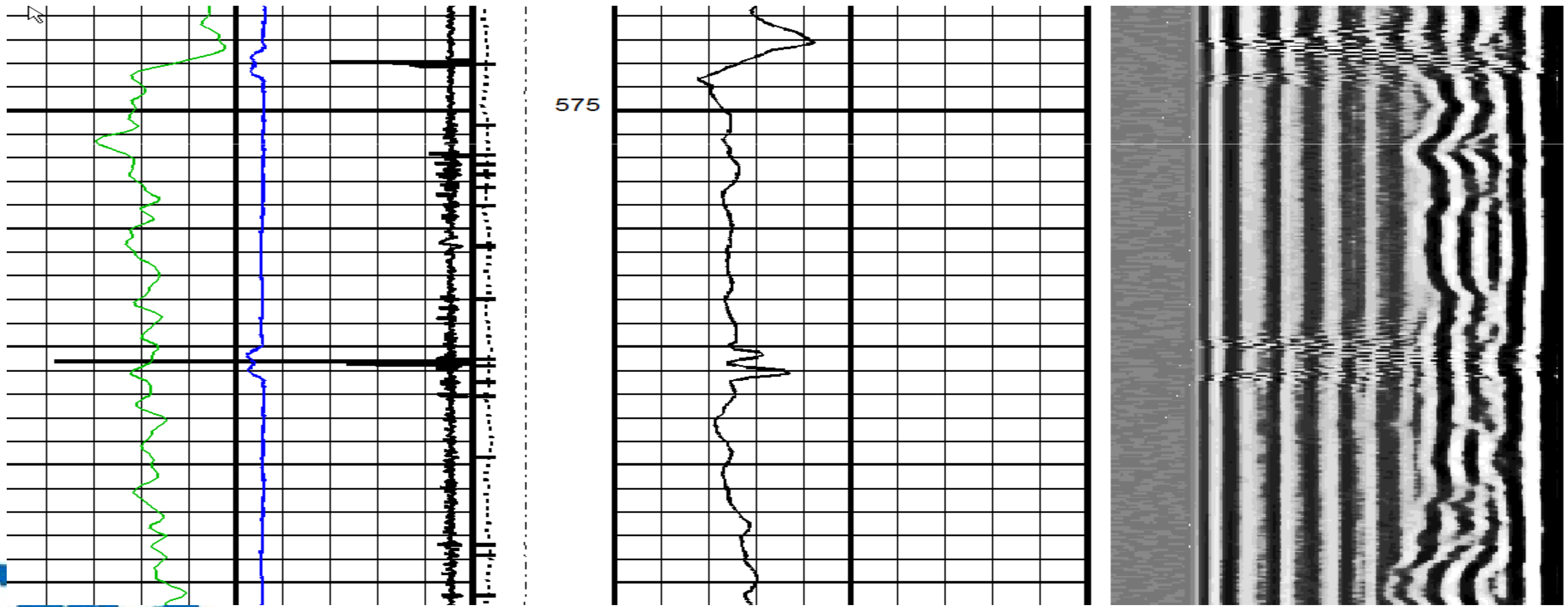
Check VDL, then use Ultrasonic



→ Good Cement

3. Determine Formation Arrivals

- Prominent formation arrivals indicate channeling as opposed to weak cement or micro-annulus
- Decide to follow path 4a or 4b



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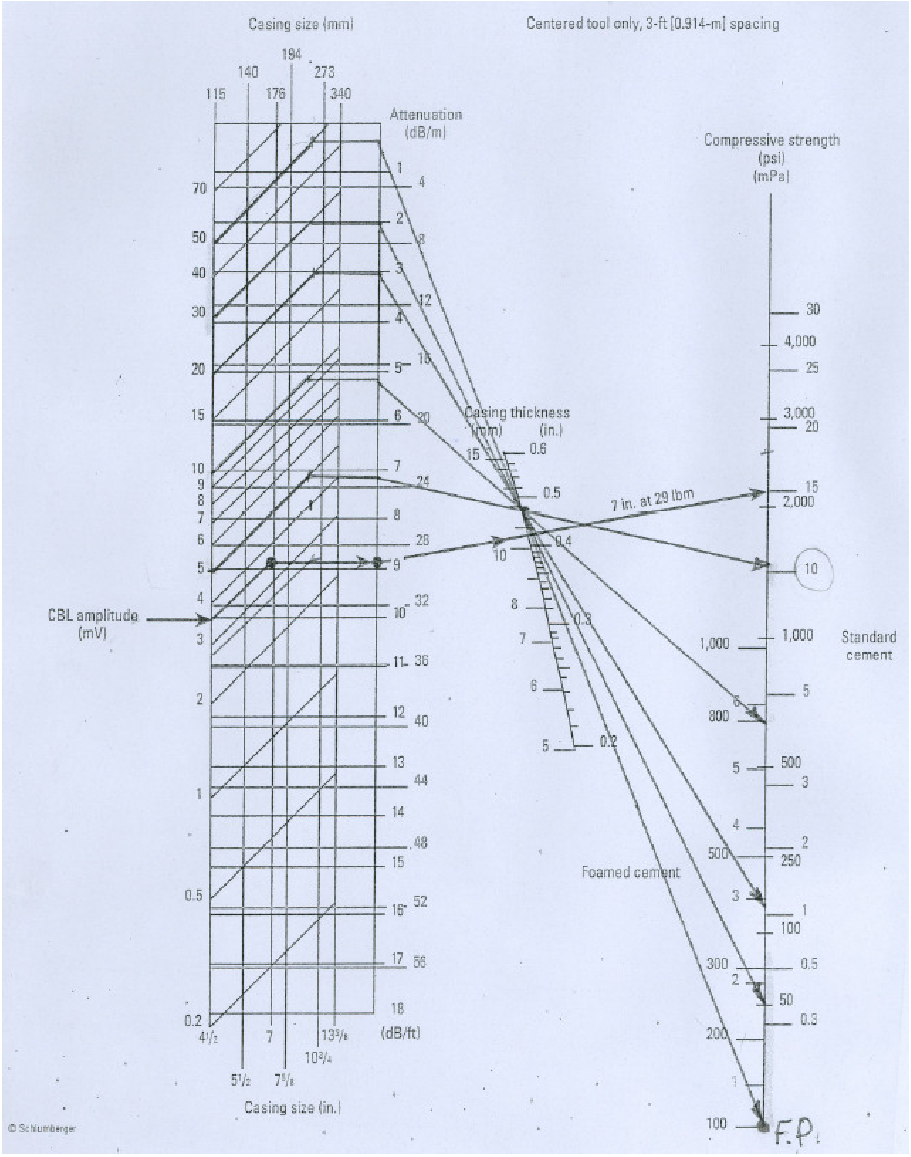
4a. Calculate C.S. (from Cem-1)

Weak cement or Micro-annulus case



4b. Calculate % of coverage

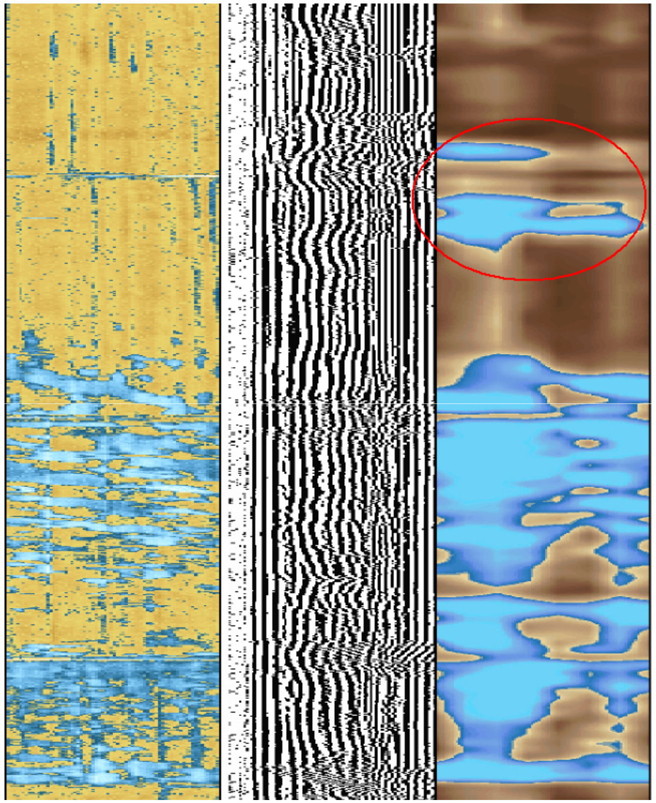
Cement coverage = $(A_{cbl}-A_{100\%})/(A_{free}-A_{100\%})$

Channeling case

5. Micro-annulus or Weak Cement?

- Micro-annulus is caused by two factors:
  - Aggressive cementing program (low retardants, high pumping rates) AND
  - Low-grade casing
- CBL/VDL alone cannot distinguish between micro-annulus or low compressive strength cement

- Micro-annulus can be positively resolved by SCBL-URS combo or by IBC



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Cement Bond Interpretation (Recap)

Step 1: Determine CBL amplitude limits

Step 2: Perform CBL Triage

Step 3: Check formation arrivals

Step 4a: Calculate C.S. OR Step 4b: Calculate Coverage

Step 5: Distinguish between micro-annulus or low weak cement
(e.g. by sector bond)

Locate zones of interest and decide on hydraulic isolation

References

- Shell Production Handbook v3, The Hague, 1991
- P. Theys, Log data acquisition and quality control, 1999
- Schlumberger Log Interpretation charts, 2004
- Weatherford Log Interpretation charts, 2009

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