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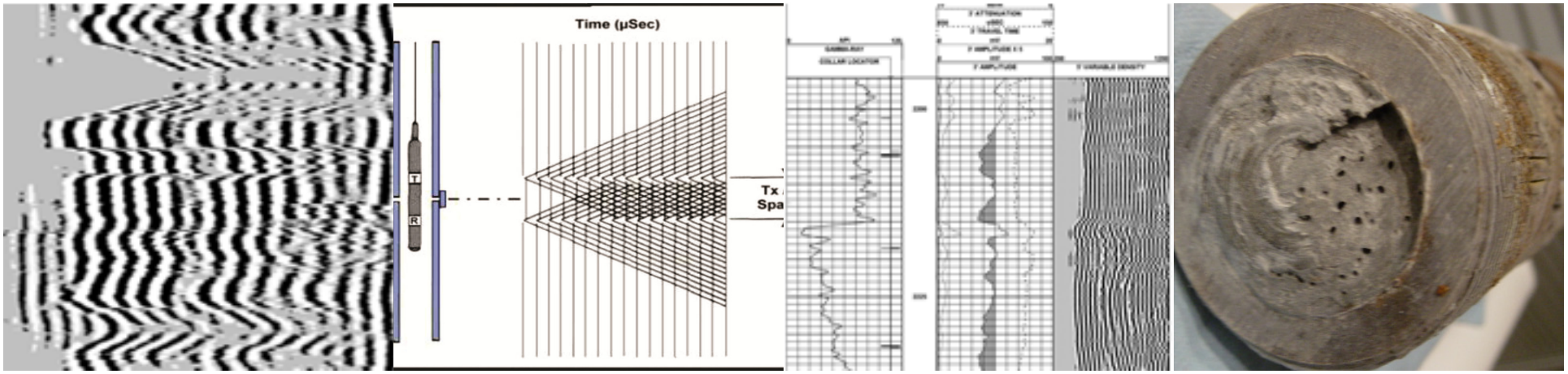
SPE “Back to Basics”
Bond Log Theory and Interpretation

April 16th, 2013

Ian Cameron, P.Eng. FMC Technologies formerly PureEnergy Providing Superior Value



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Topics:

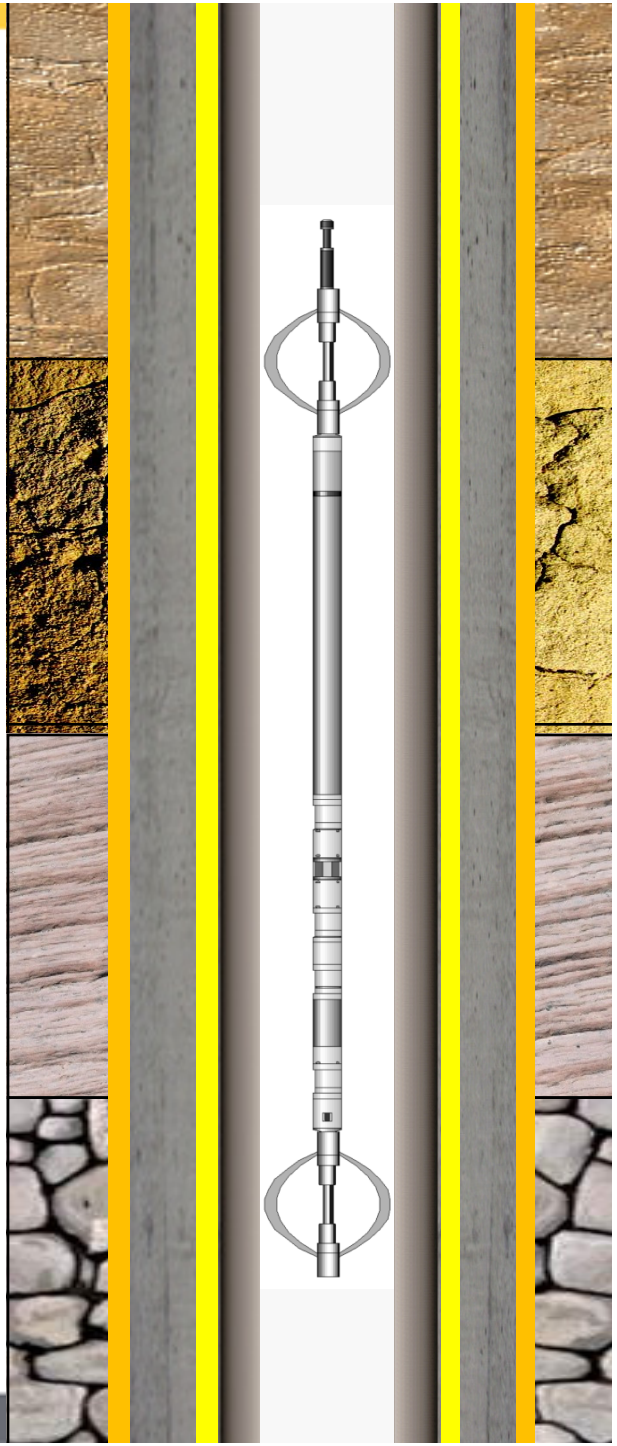
- Quick basics of purposes of cement & scenarios bond logs run in
- How traditional acoustic bond logs work and what is measured and presented
    - Amplitude
    - Travel Time
    - Variable Density Log (VDL)
- Examples of good cement bond and free pipe and what things to look for
- Channeling – why run a radial investigation log
- Amplitude and cement compressive strength build up over time
- Surface Casing Vent Flow Gas Migration considerations
- Micro-annulus
- Light Weight Cement
- Cyclic Steam Stimulation example showing cap rock cement bond
- Media coverage and the oil industry under the microscope

Purpose of Cement

- Cement is used for:
  - structural support to the casing to reduce the risk of a casing failure
  - providing hydraulic & gas isolation
  - preventing production of unwanted formation fluids
  - isolating intervals to ground water (ERCB)
  - providing structural strength and isolation during fracturing

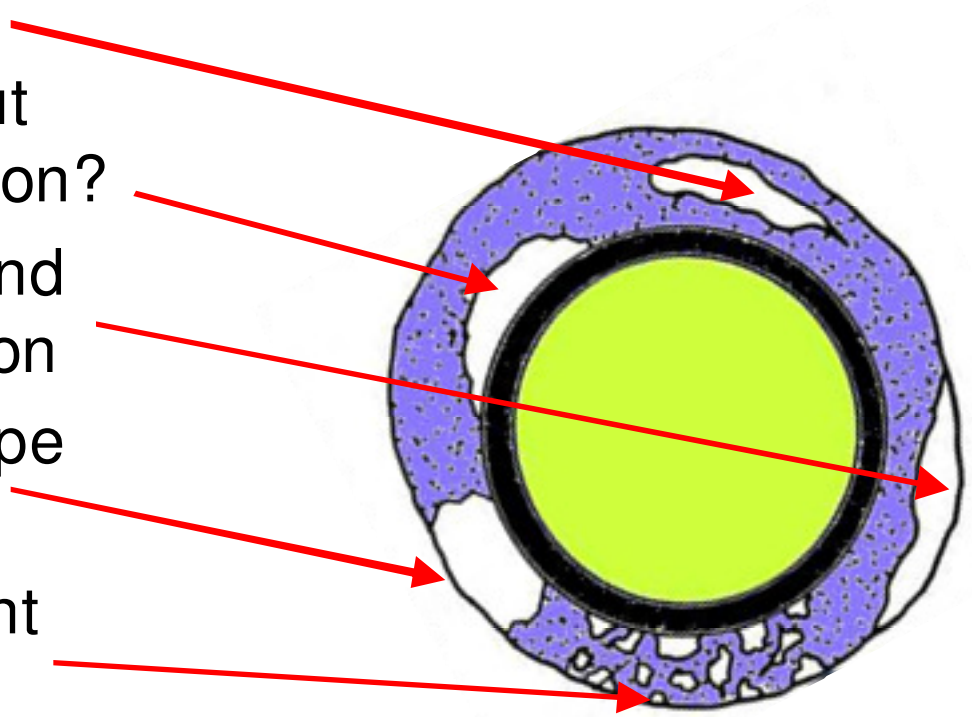
Reasons for Bond Log

- Bond logs are run to determine:
  - Cement to casing relationship
  - Cement to formation relationship
  - Evaluate cement conditions:
    - Channeling
    - Compromised cement (i.e. gas cut, dehydrated, etc.)
    - Cement stages
    - Cement top
    - Microannulus



Scenarios to keep in mind for bond log evaluation:

- Channeled cement
- Poor bond to pipe but good bond to formation?
- Good bond to pipe and poor bond to formation
- Poor bond to both pipe and formation
- Compromised cement (i.e. gas cut cement)



Traditional Acoustic Bond Tool Example

- Collar Locator
- Gamma Ray

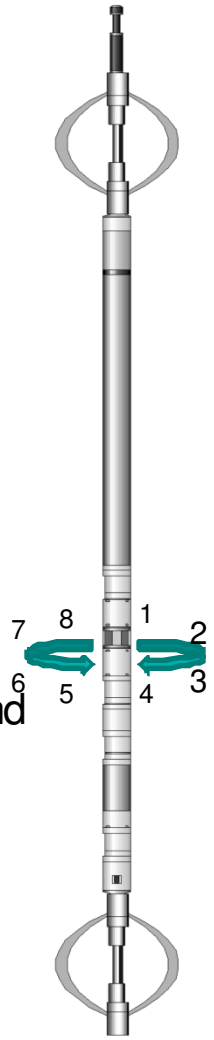
- Acoustic Transmitter
- 3ft Receiver
- 5ft Receiver

Cement Bond Log (CBL)

Radial Bond Log (RBL)

Radial Receivers

- 2ft spacing
- Usually 8 radials



Bow Spring Centralizer

Collar Locator (CCL)

Gamma Ray & Telemetry

Transmitter

2ft Radial Receivers
3ft Receiver

5ft Receiver

Bow Spring Centralizer

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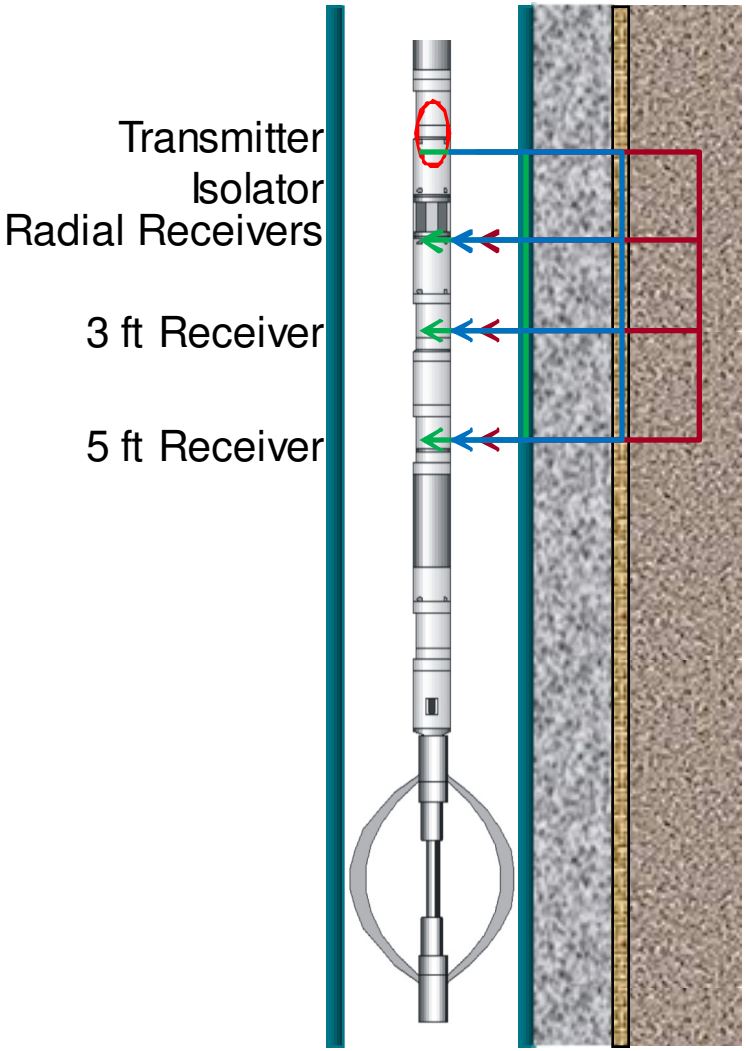
What is Measured on Bond Logs

- Recorded on *ALL* sensors:
  - *Amplitude* (strength of the first arrival)
  - *Travel Time* (time it takes for the signal to go from transmitter to receiver)
  - *VDL – Variable Density Log* (entire waveform from 1st arrival and reverberations up to 1200 µs…from one pulse)



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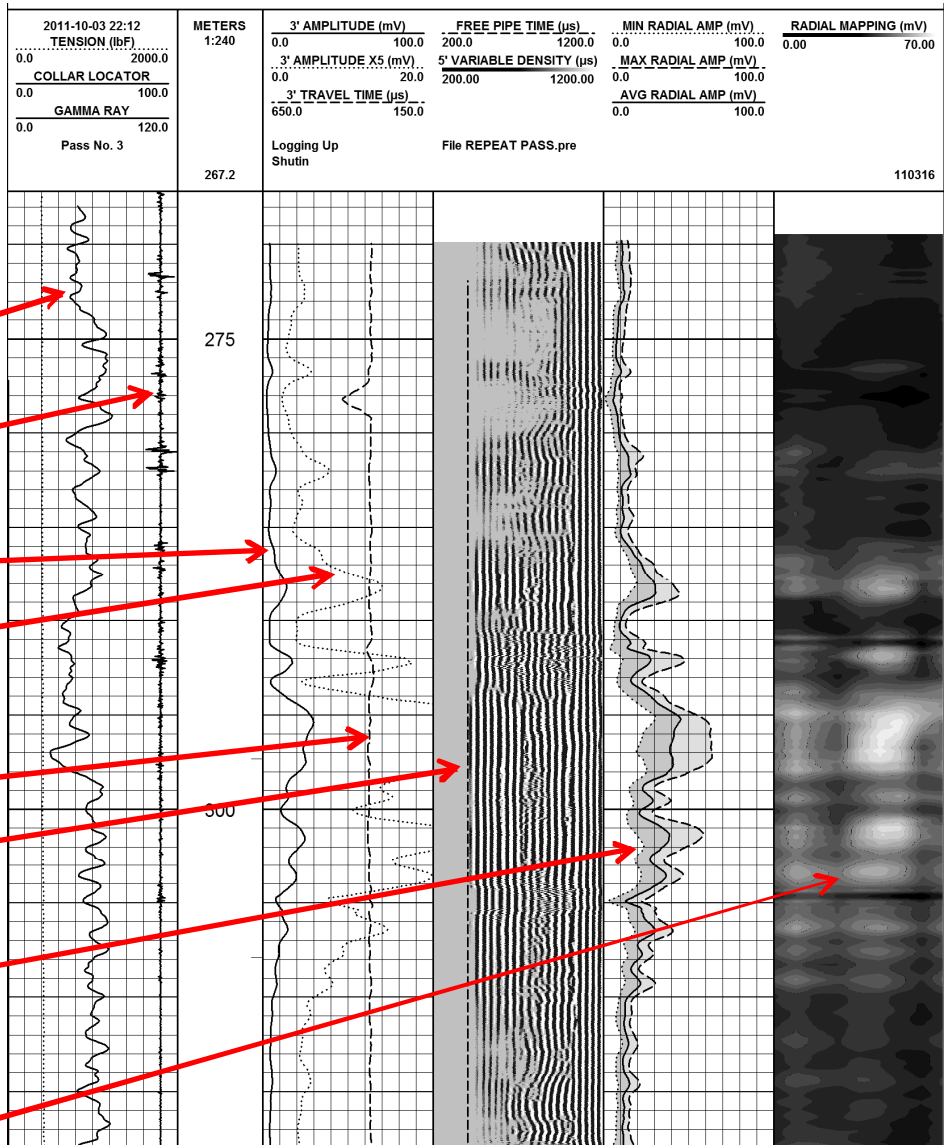
What is Measured & Presented on Radial Bond Logs

- Presented on the log:
  - Natural Gamma Ray
  - Casing Collar Locator
  - Amplitude from the 3ft
  - Amplitude x 5
  - Travel Time from the 3ft
  - VDL from the 5ft
  - Amplitudes from the eight / six radials (if RBL)
  - Min, Max and Average of the Radials (if RBL)



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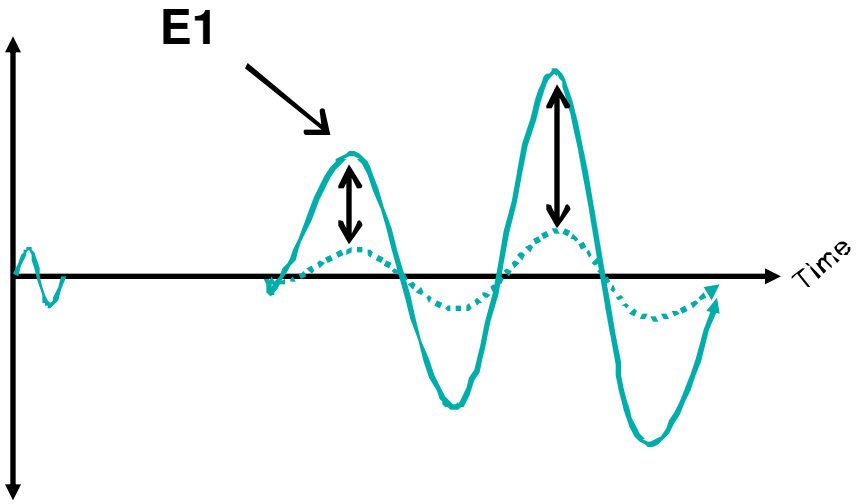
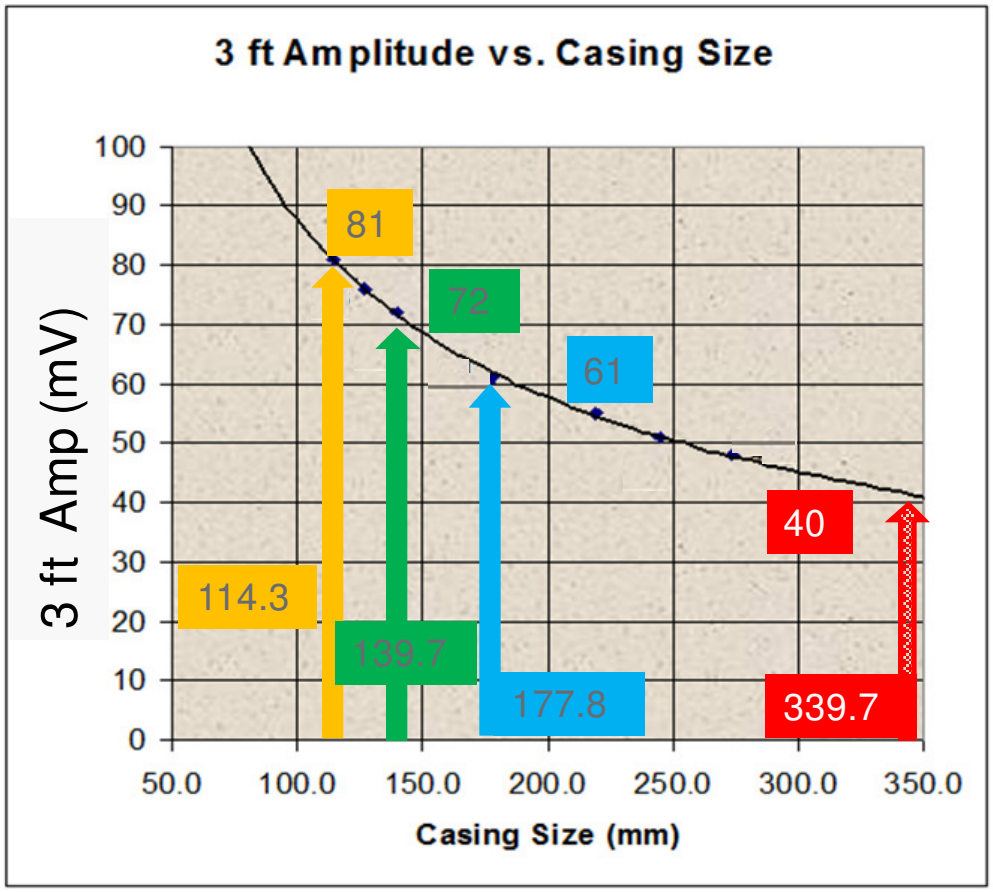
Theory of Measurement Amplitude and Travel Time

- Require a volunteer ****
- Strike an unsupported casing:
  - It rings with a high amplitude (lack of cement) 1st peak = E1
  - Strike a supported casing it thuds with a low amplitude (good evidence of cement)
  - The loss / attenuation of signal is related to the quality of cement and is how “Bond” is measured.



Amplitude Signals vs. Pipe Size of "free" pipe

* immersed in water

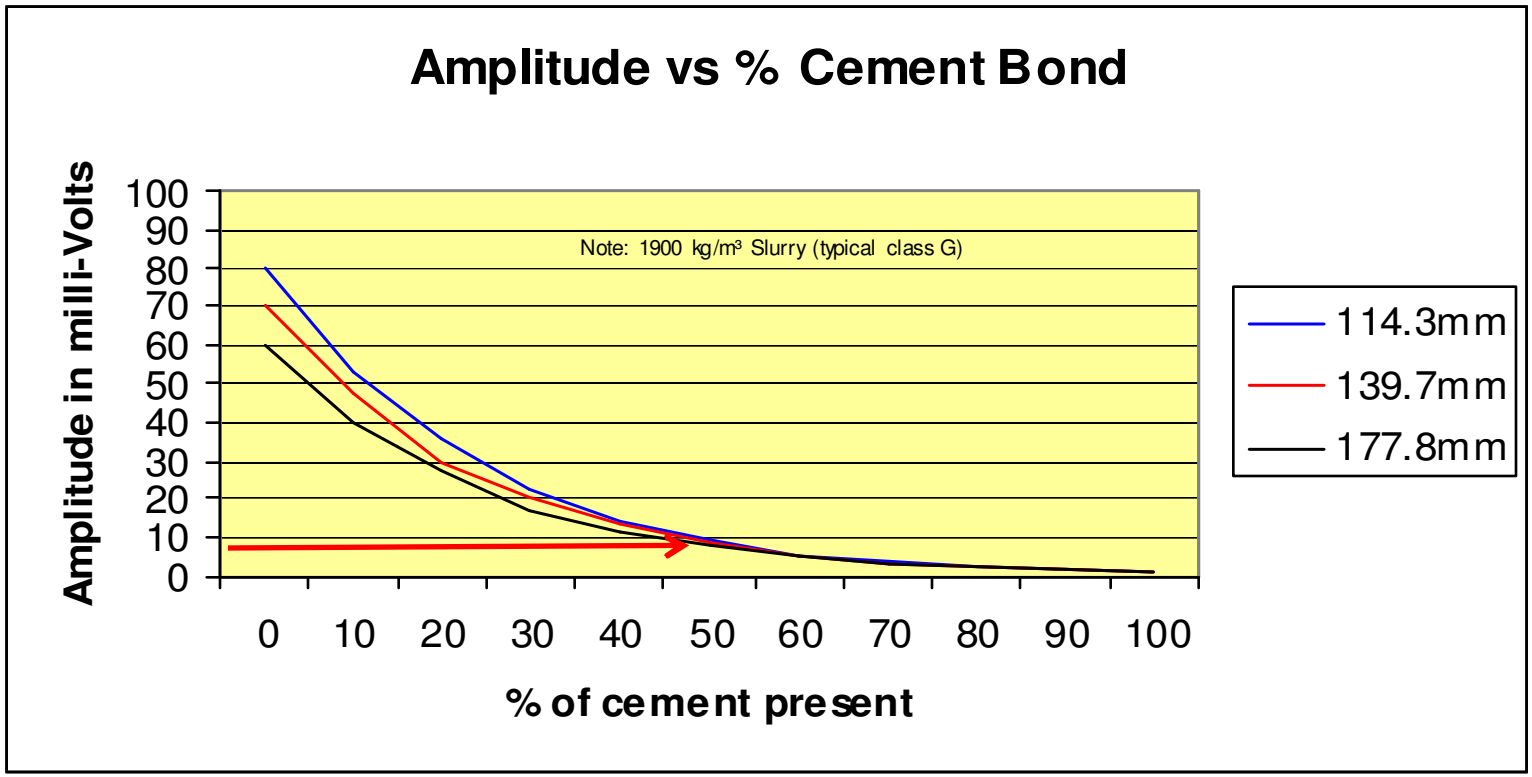


Challenge is as casing sizes get larger, the range of measurement from no cement to fully cemented gets smaller.

- **How much cement do I have for the amplitude in question?**

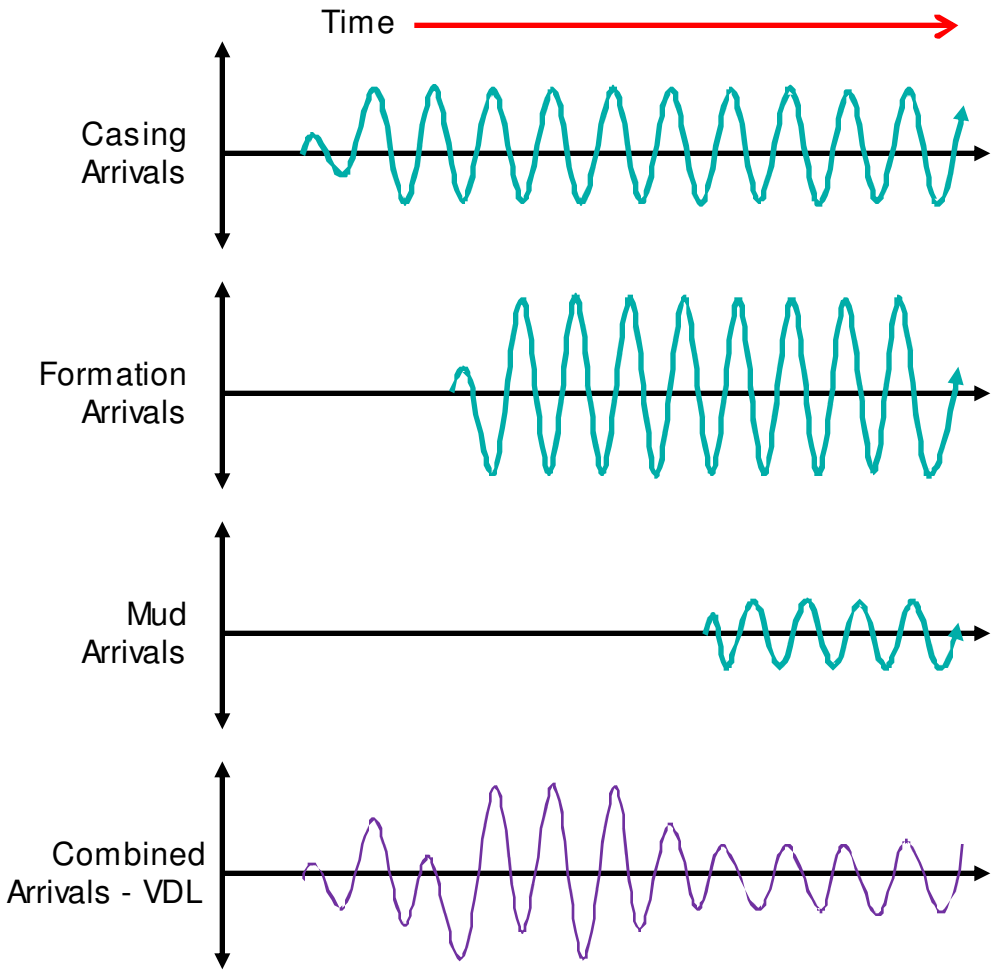
Challenges are that:

- Non-linear relationship.
- As the amount of cement increases, the corresponding amplitude drops very little ➔ hence the “x5” scaling for low amplitudes.
- Larger casing sizes mean less amplitude range to measure from.



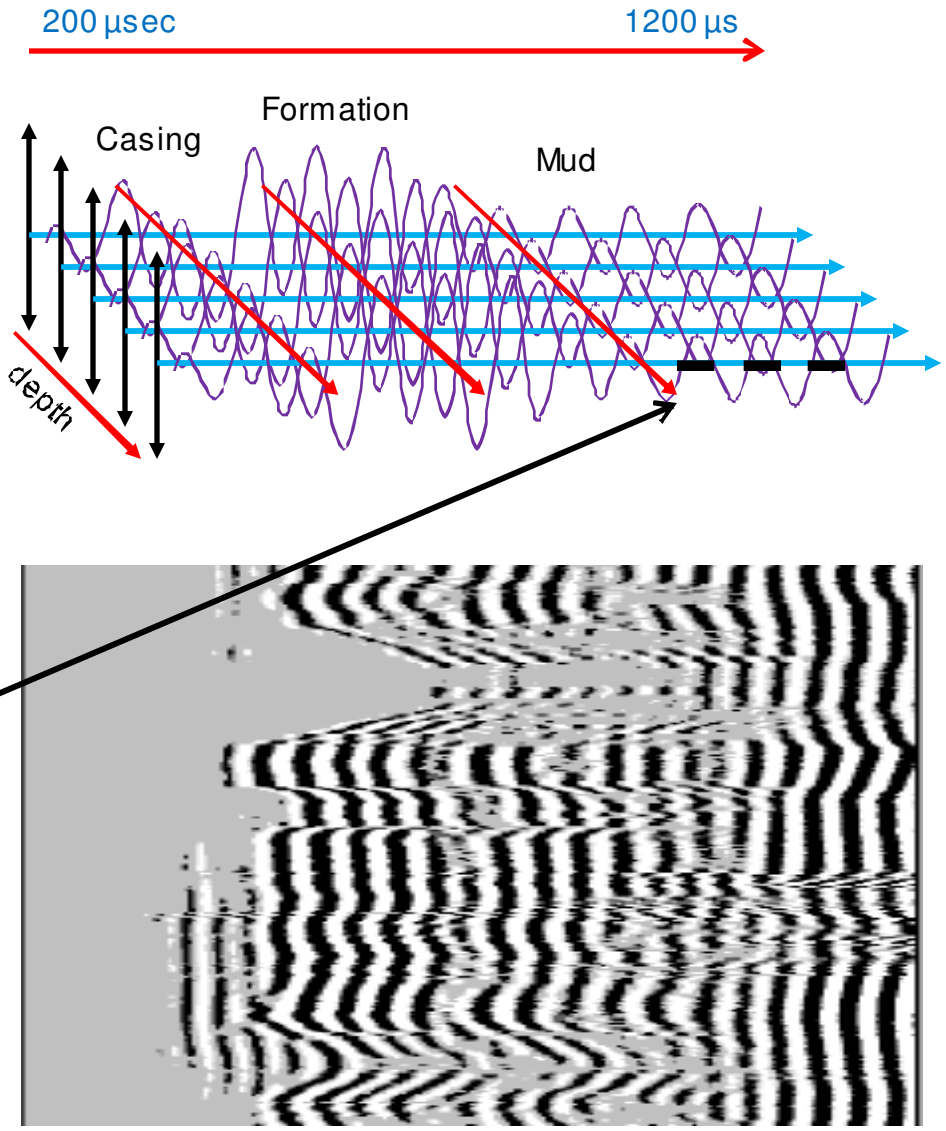
VDL
Variable Density Log

- After the transmitter fires, the waveform arrives at the sensors via different paths:
  - Casing
  - Formation
  - Mud
- Arrival times are a function of:
  - Distance traveled
  - Slowness of medium (~density)
- The waveform recorded at each sensor is a combination of all arrivals present



VDL
Variable Density Log

- VDL displays multiple “slices of data” side by side
  - 200 – 1200 µs for 3’ VDL
- Arrival patterns start to become apparent
- To make a 2D picture of the 3D image:
  - Positive peaks are shaded black
  - Negative peaks are shaded white
- Casing arrivals should be consistent but formation arrivals “*should”* change with lithology



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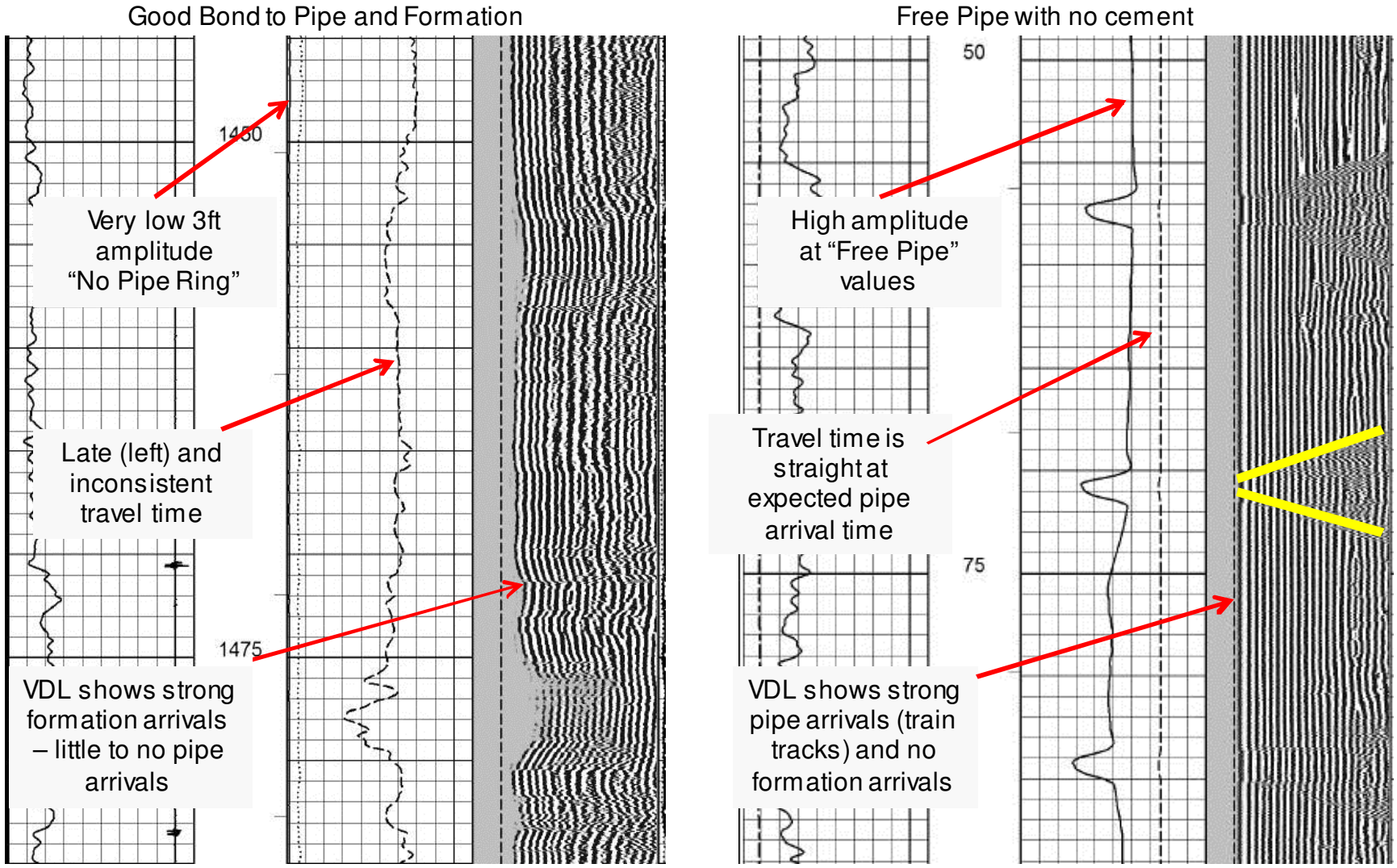
Amplitude, Travel Time & VDL – Example Extremes



Note: L to R: standard *Amplitude* scaled *0-100 mV*; standard *Travel Time* scaled *650-150 µsec, VDL scaled 200 – 1200 µsec*

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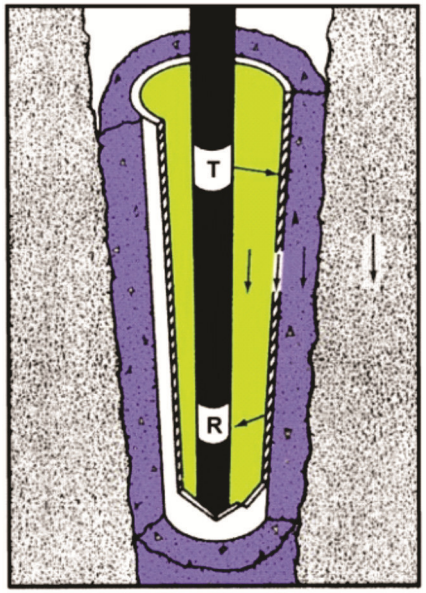
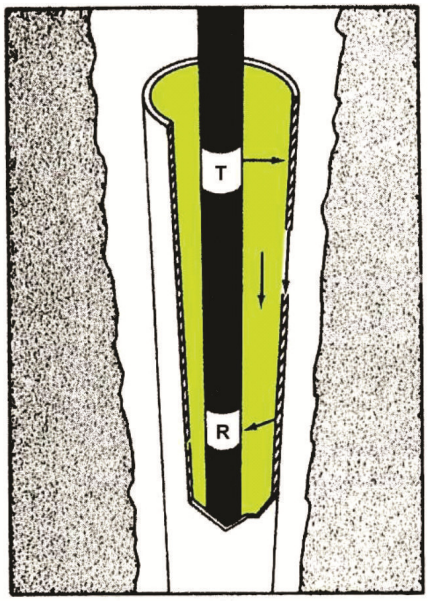
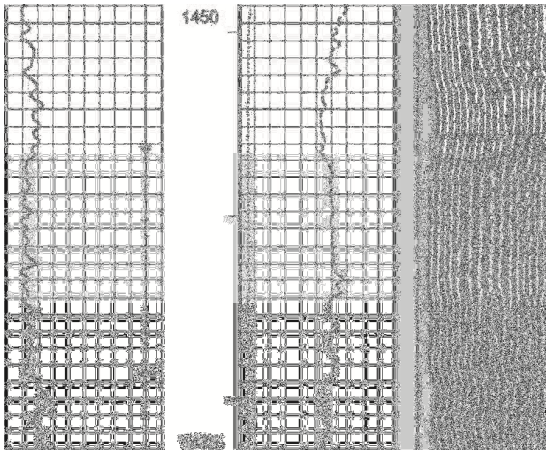
VDL Example Summary

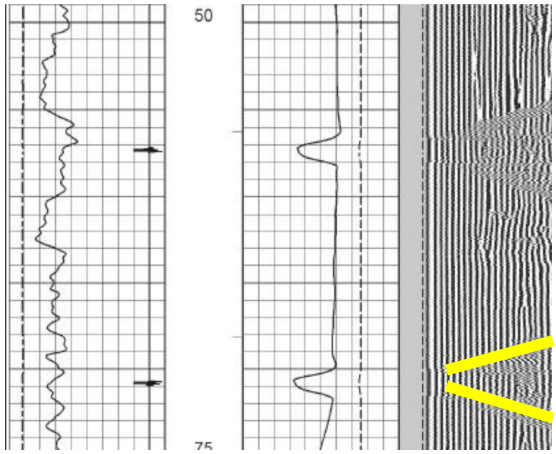


Good bond to both pipe and formation



Free Pipe





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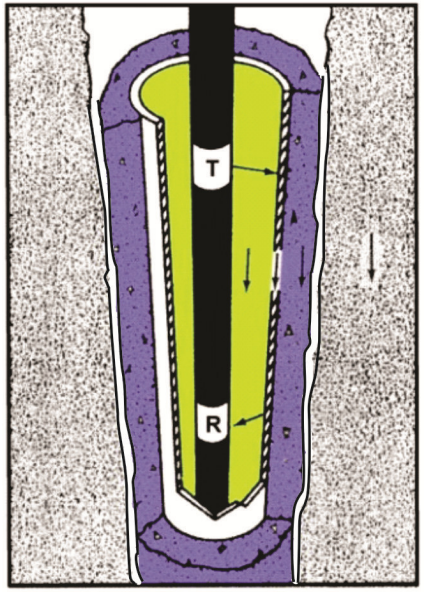
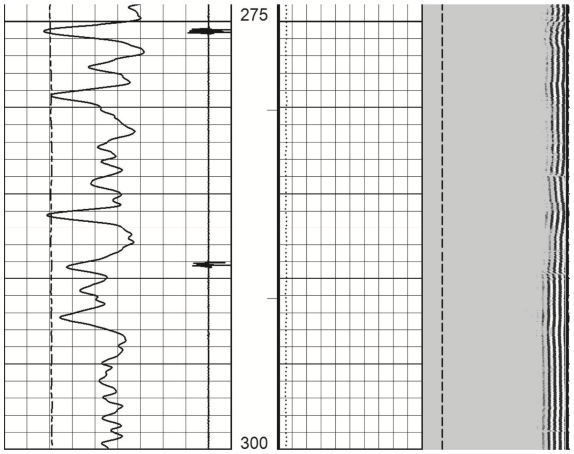
VDL Example Summary



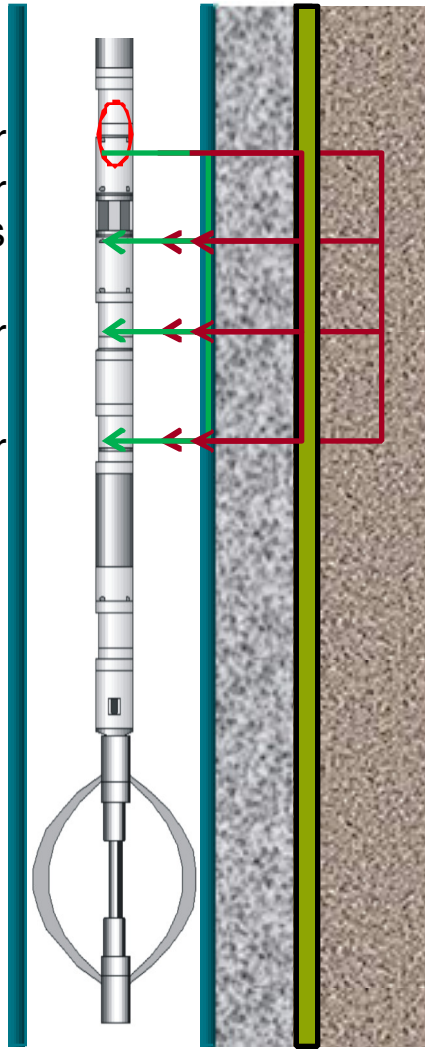
Good bond to pipe but
poor bond to formation



Transmitter
Isolator
Radial Receivers

3 ft Receiver

5 ft Receiver



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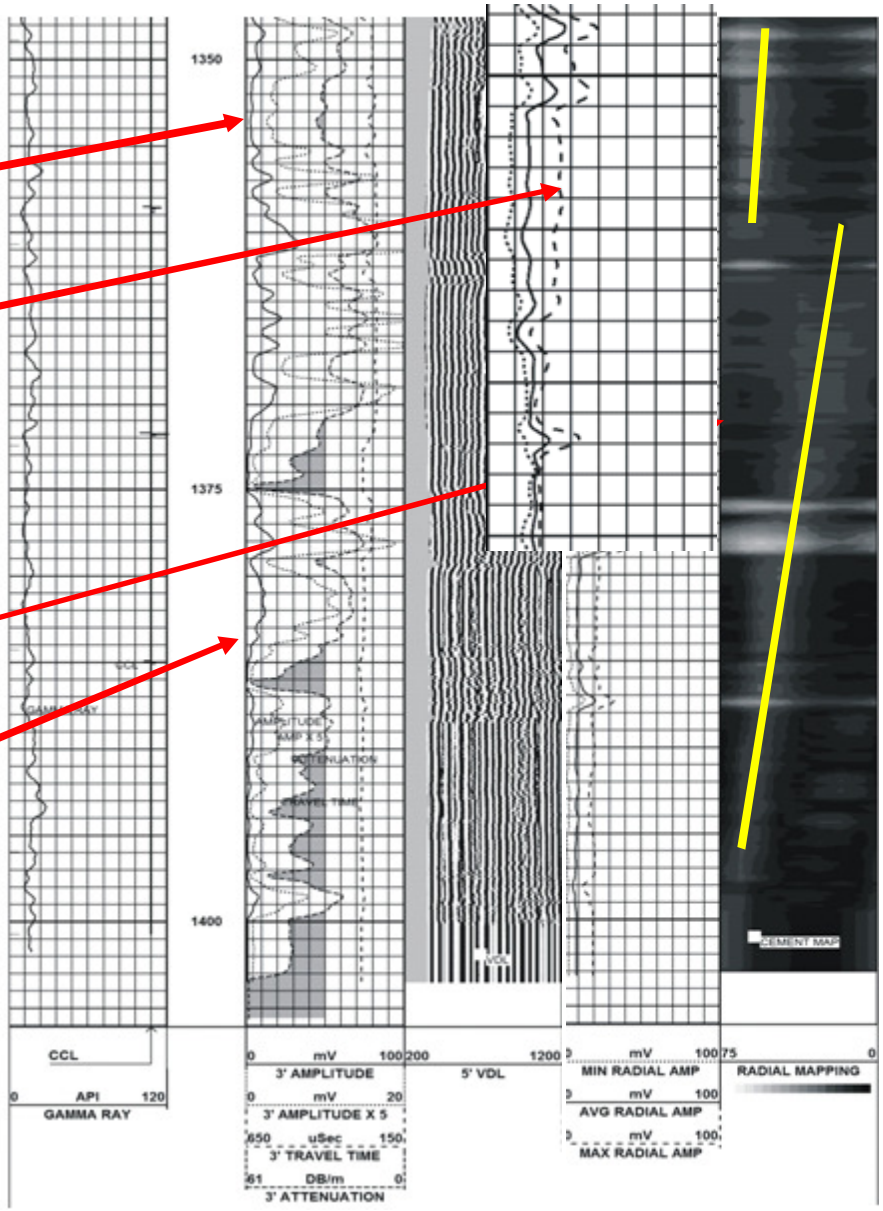
Channeling

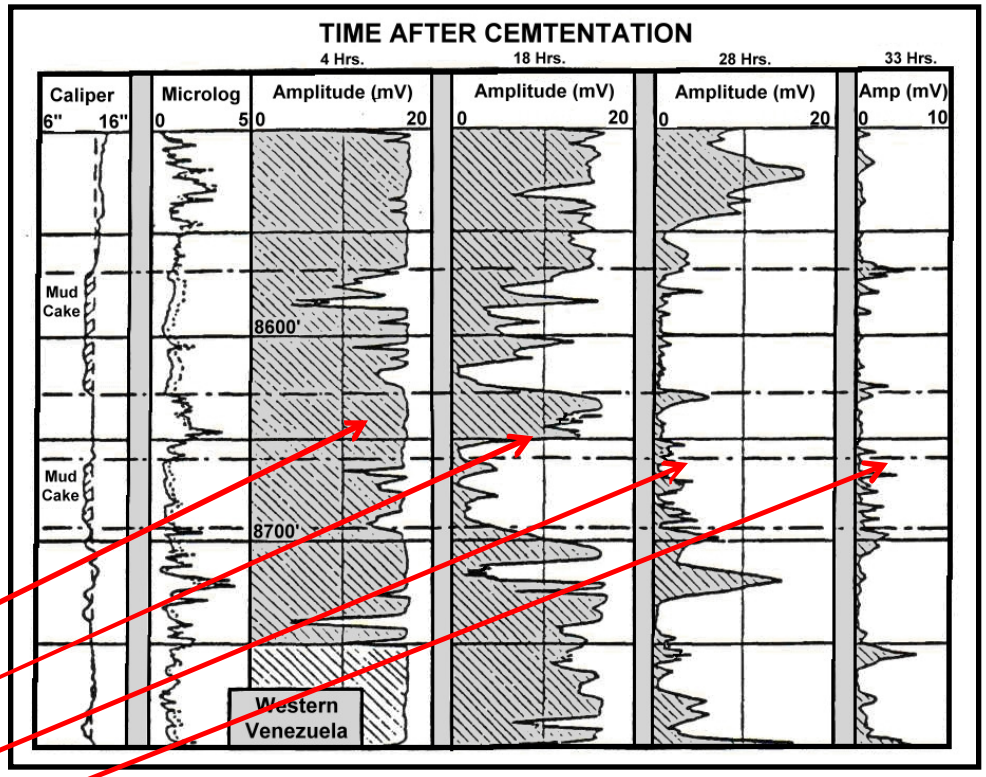
- CBL outputs show overall good cement
- Radial outputs show inconsistency of several of the radial receivers
- Image mapping of 8 x 2’ amplitudes shows channel of lower compressive cement
- Single CBL 3’ amplitude can not identify channeling
- VDL is also inconclusive



Amplitude changes caused by Compressive Strength vs. Time

- Green cement
  - Low compressive strength hence higher than normal amplitudes
  - Rule of thumb is to not run bond logs up to 48 hours after cementing (cement types such as thermal cements may vary)

- Chart shows the reduction in amplitude with time after cementing
  - 4 hours
  - 18 hours
  - 28 hours
  - 33 hours



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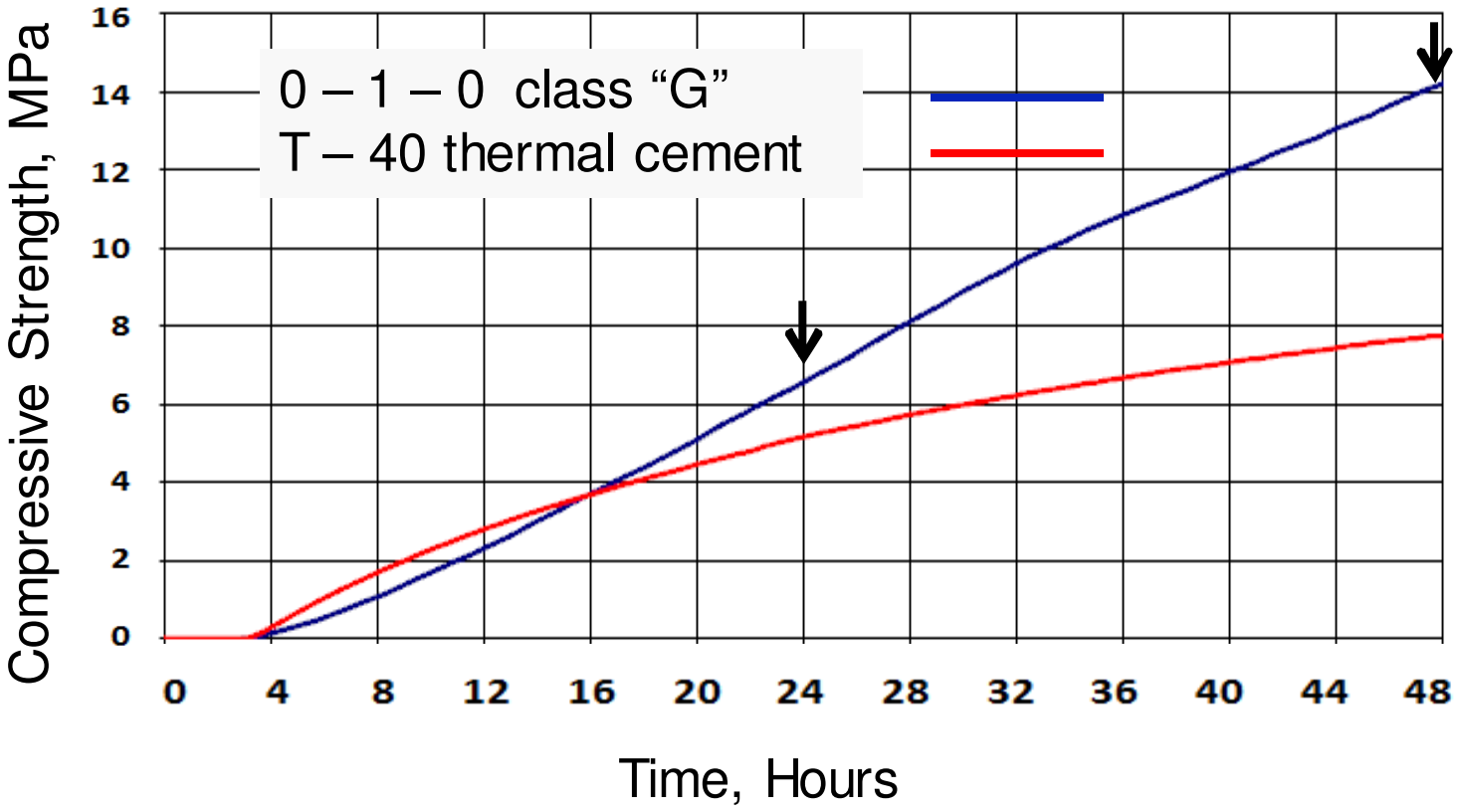
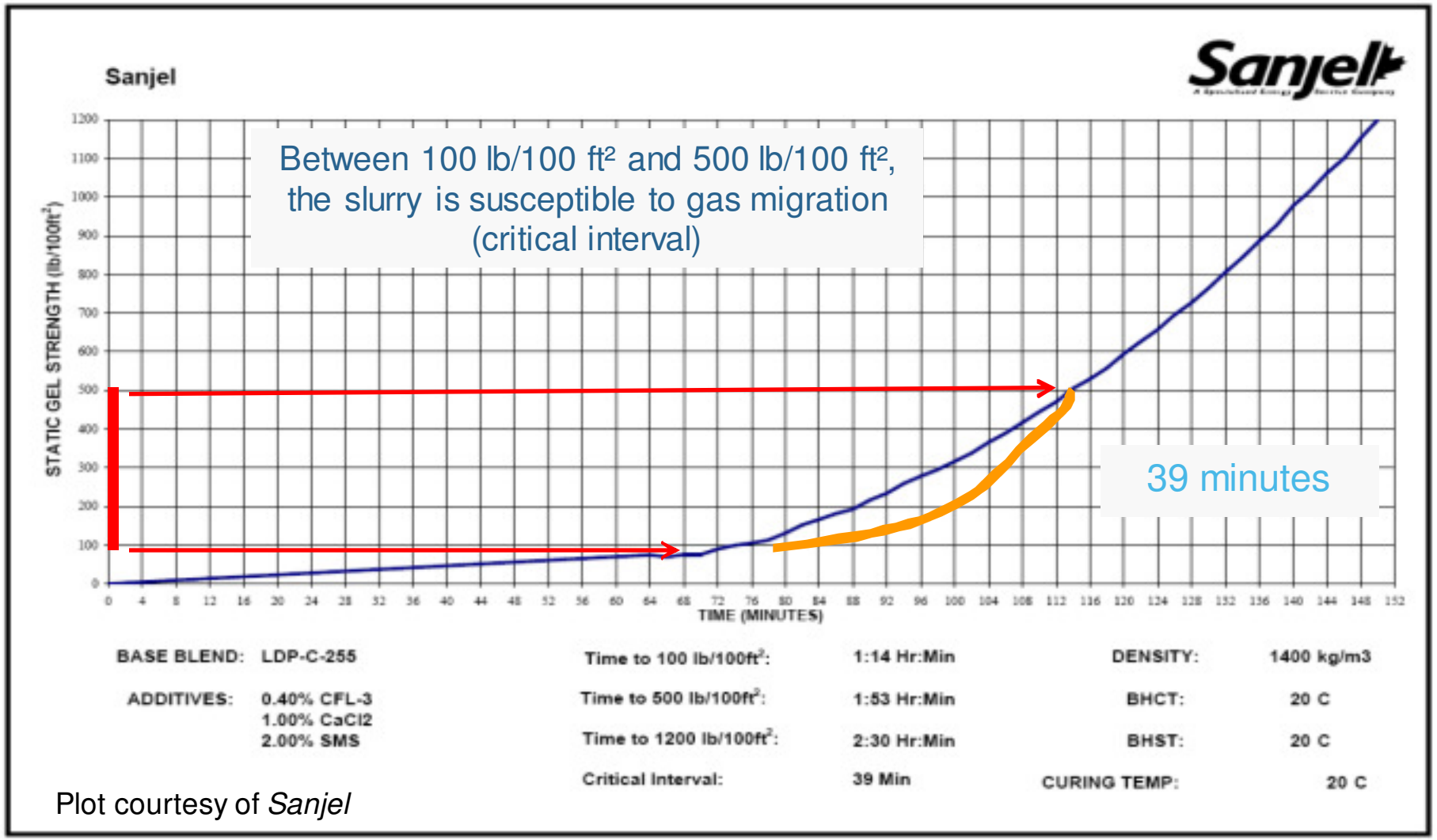
Cement Compressive Strength Chart Examples



Plot courtesy of *SanJel*

Gel Strength vs. Time

- When cement is partially setup it starts to become self-supportive & looses it's ability to hold back gas
- As a result worm hole channels can form during the critical phase



Plot courtesy of *Sanjel*

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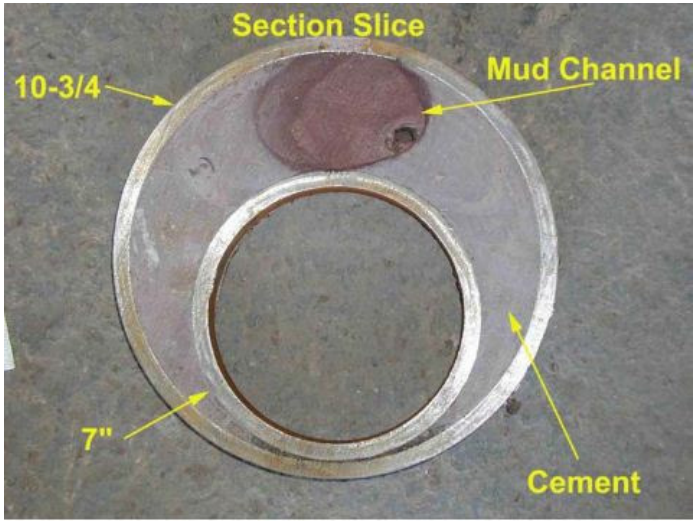
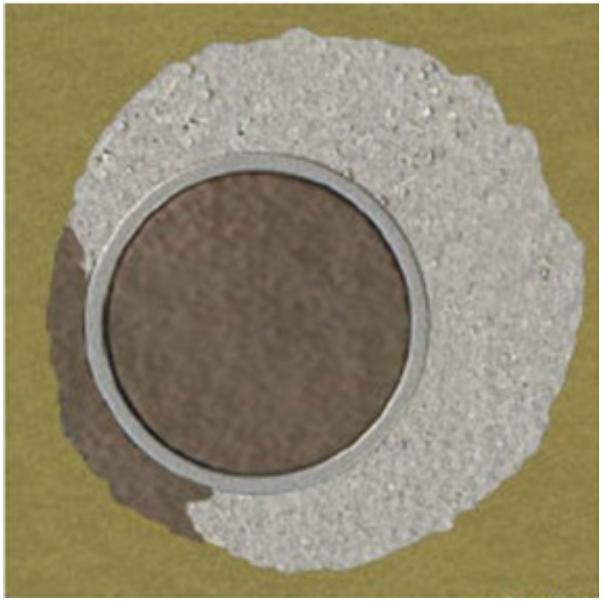
Bond log considerations of SCVF/GM

- Poor Primary Cementing/Hole conditioning
  - Mud Contaminated cement
  - Gas Cut Cement
  - Channeled cement
- Decentralized casing string
  - Vertical
  - Slant
  - Horizontal



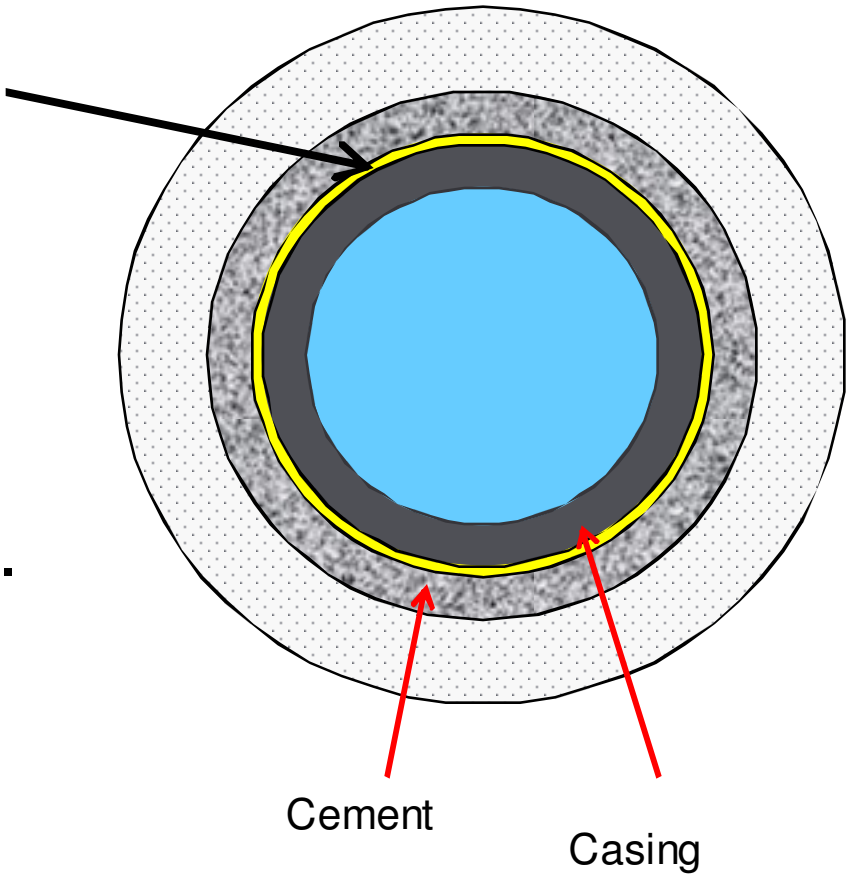


Video demonstrating SCV surging through cement

Micro-annulus

- Micro-separation (yellow) between pipe and cement (< 1 mm) caused by a drop in temperature or pressure

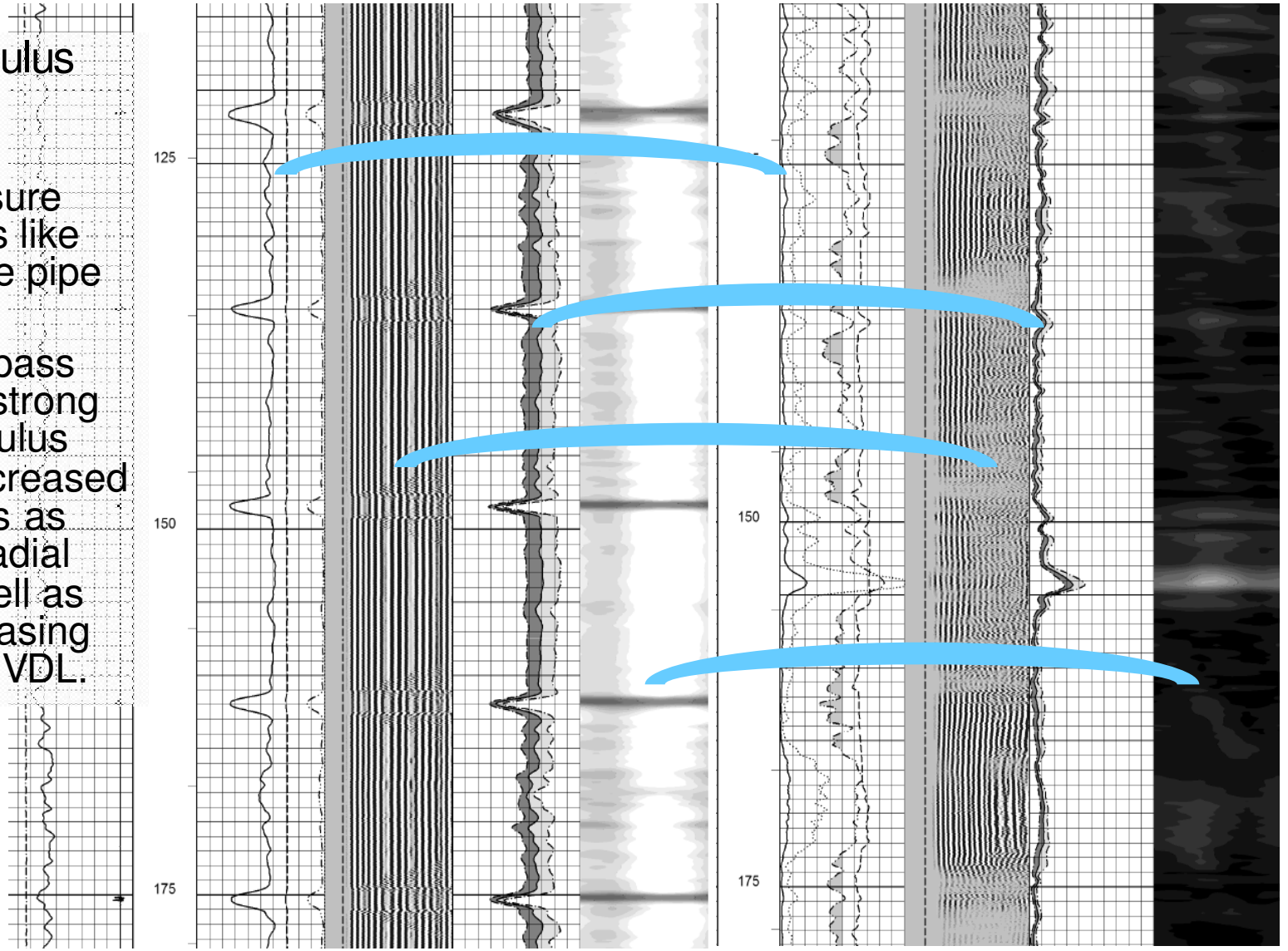
- Identified by doing a "pressure pass" to a "non-pressure pass" comparison.



Do I need a Pressure Pass?

Micro-annulus Example

- Non-pressure pass looks like mostly free pipe
- Pressure pass indicates strong micro-annulus due to decreased amplitudes as seen on radial map as well as reduced casing arrivals in VDL.



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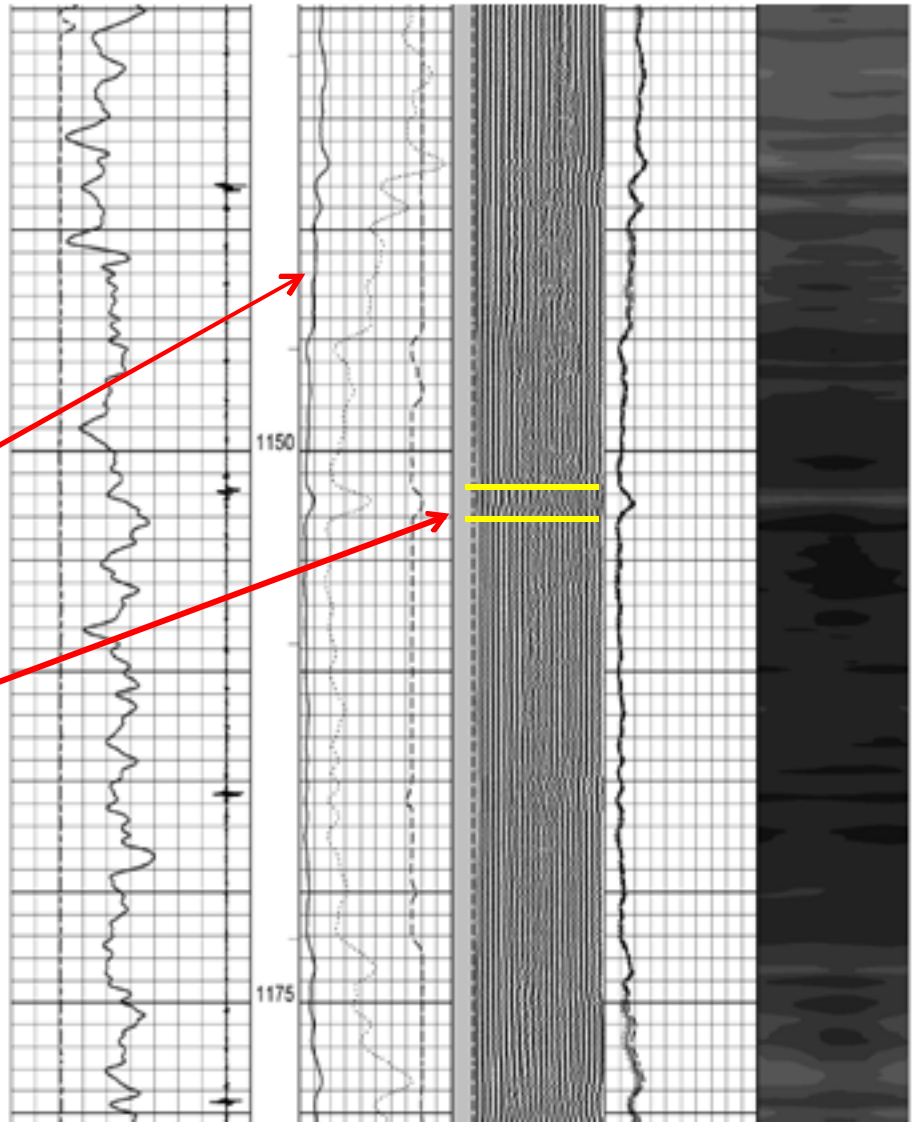
Well Conditions That Affect Bond Logs – *Light Weight Cement*

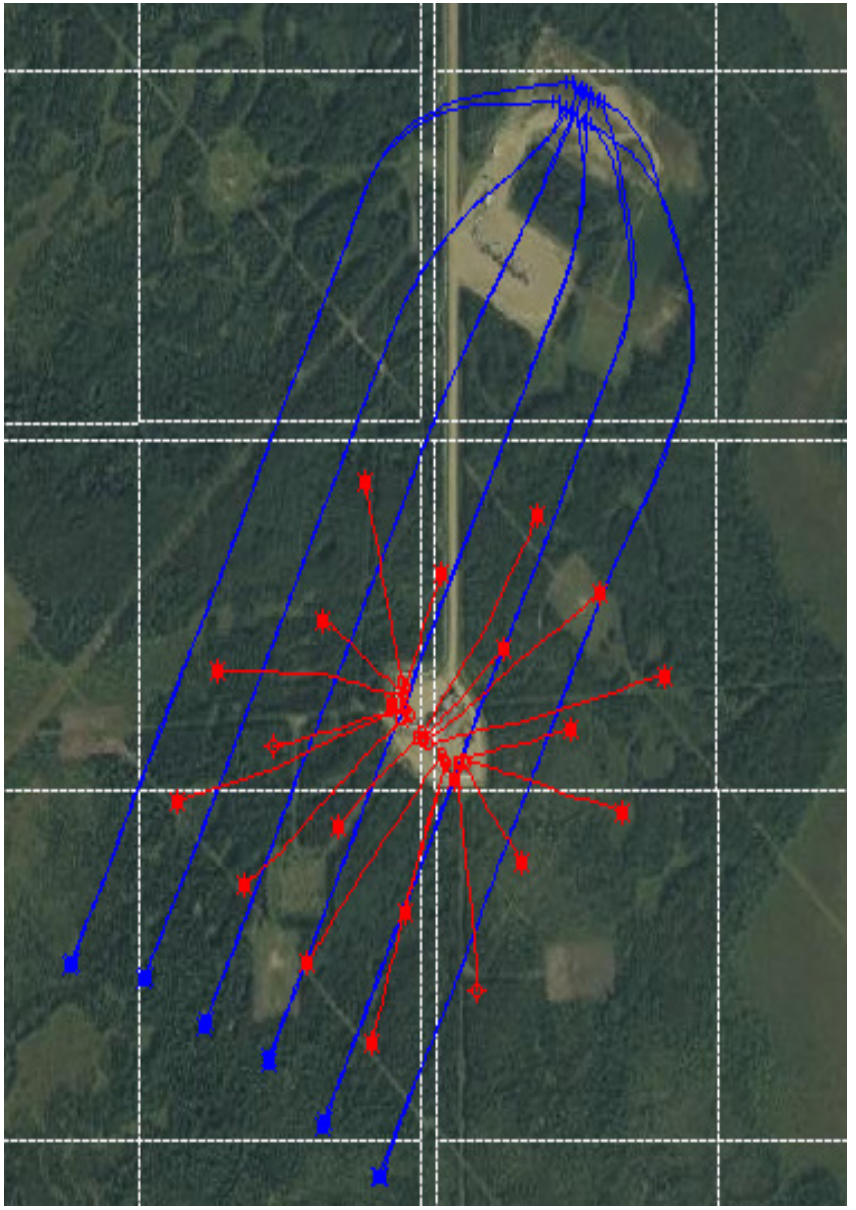
- Pipe is allowed to carry some pipe arrivals even under perfect bonded conditions
- 3ft amplitudes may range between 5-10 mV (depending on density)
- Formation arrivals, if present, may have a faded appearance
- Collars DO NOT chevron but may exhibit a straight line response
- Cementing information from the well is critical for interpretation:
  - Stages, Cement Density, Volumes

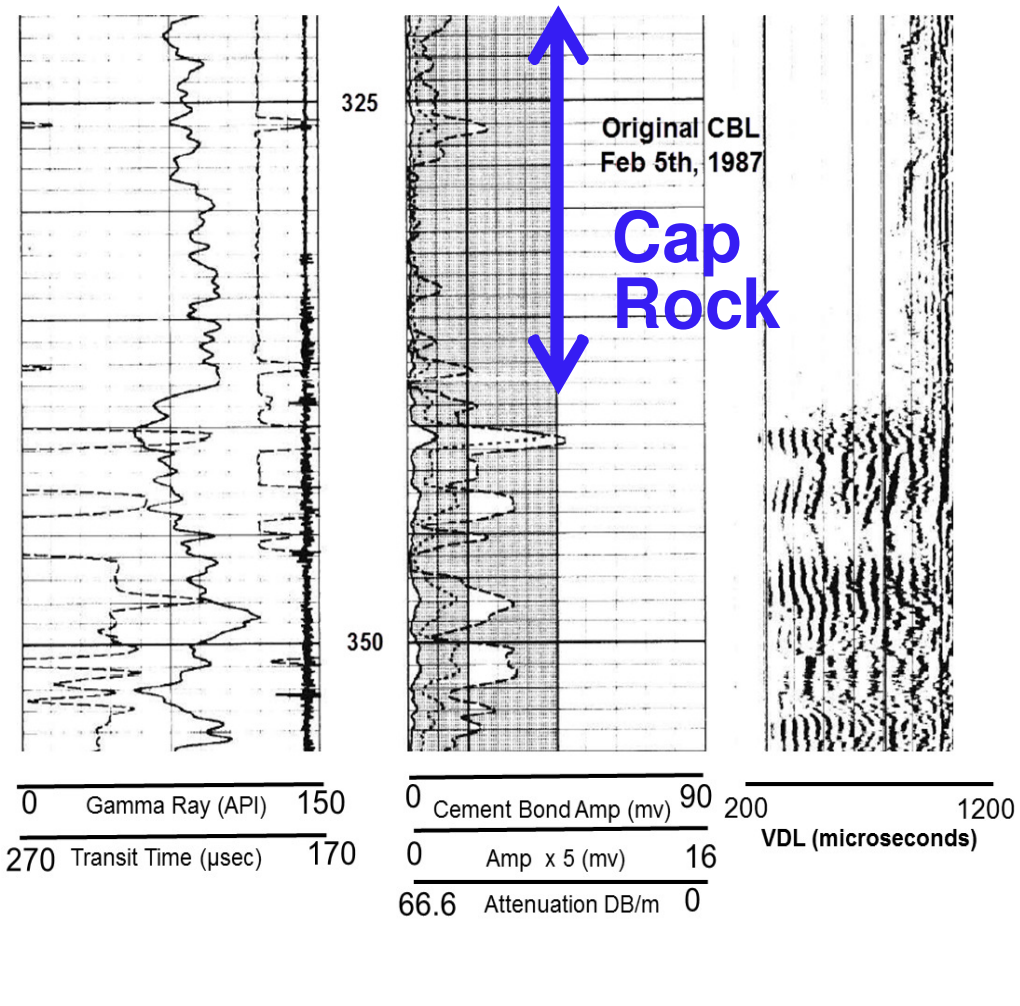


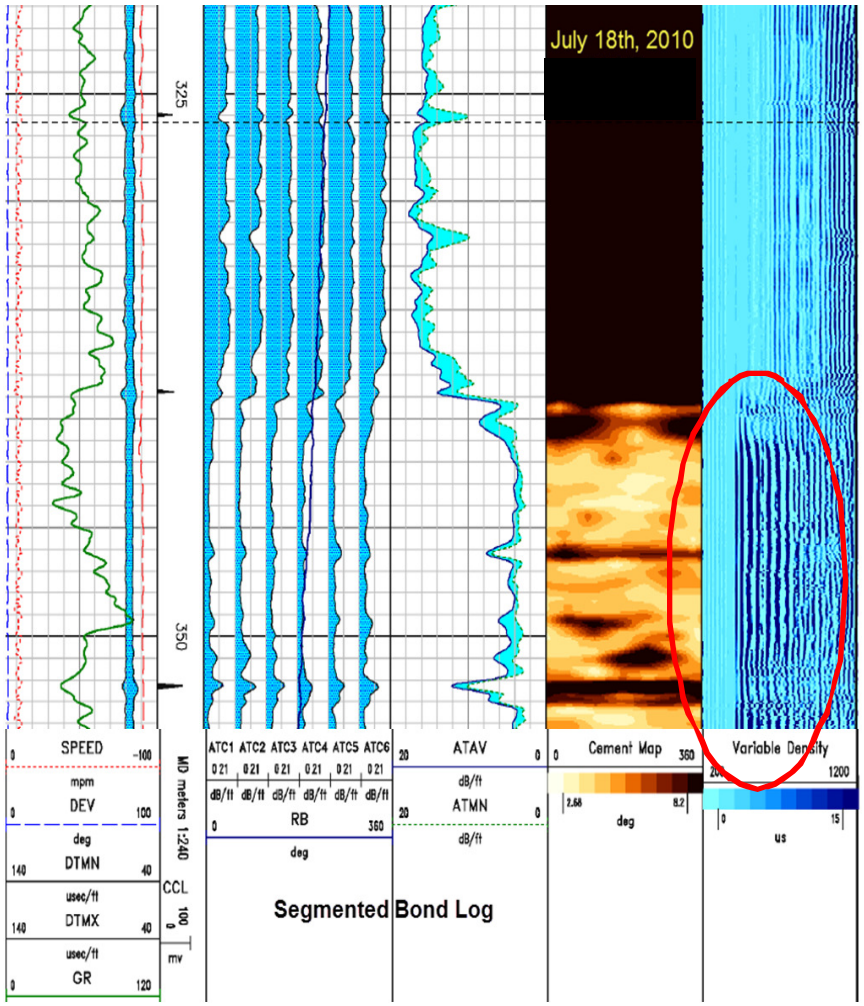
1550 kg/m3 cement

CSS & SAGD WELLS

- 22 Drills Terminated In Clearwater in 1987 (+/- 440m TVD)
- Target Grand Rapids Production
- Casing: 177.8mm L-80 34.2 kg/m
- Cement:
  Standard Thermal 'G' + 40% Silica
- All Cemented to Surface
- No SCVF/GM Issues
- Ground Water Isolation
- 1 – 3 Cyclic Steam Stimulations
- Cum Oil: 16,758 m3
- Cum Steam Injected: 218,173 m3
- Operating Conditions:
  - 8.5 - 9.0 MPa
  - 300 - 305 ˚C
- No History of Isolation Issues







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Media Coverage from March 2013 National Geographic:

"A recent U.S. Geological Survey study of decades-old wells in eastern Montana found plumes of salt water migrating into aquifers and private wells, rendering the water from them unfit for drinking. And catastrophic casing failures can happen at any time. The EPA is now investigating a 2011 blowout during fracking in a well near Killdeer that pierced the aquifer the town relies on."

http://ngm.nationalgeographic.com/2013/03/bakken-shale-oil/dobb-text

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We put you first.
And keep you ahead.

Thank you for attending the SPE “Back to Basics” Bond Log Theory and Interpretation

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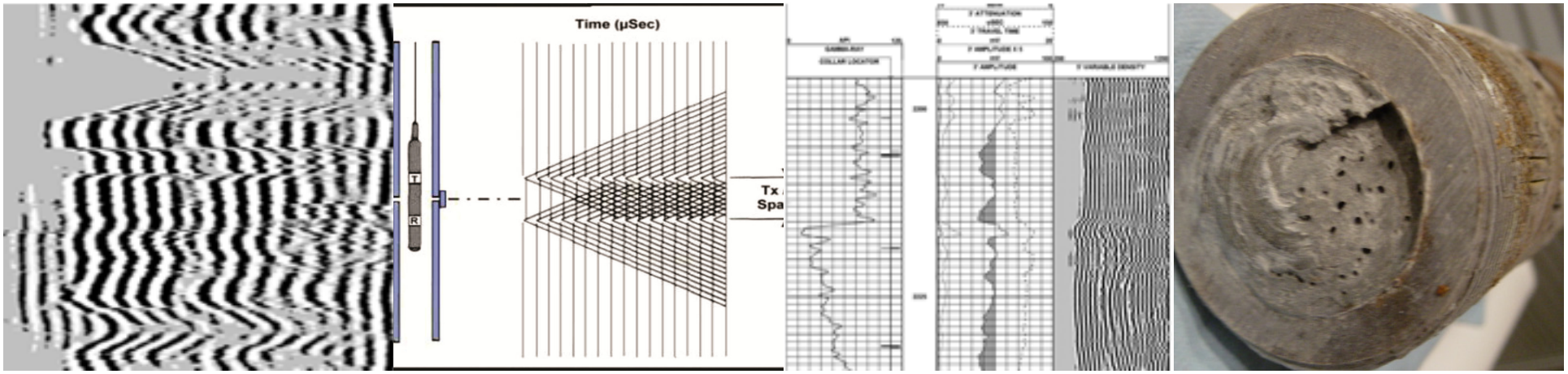
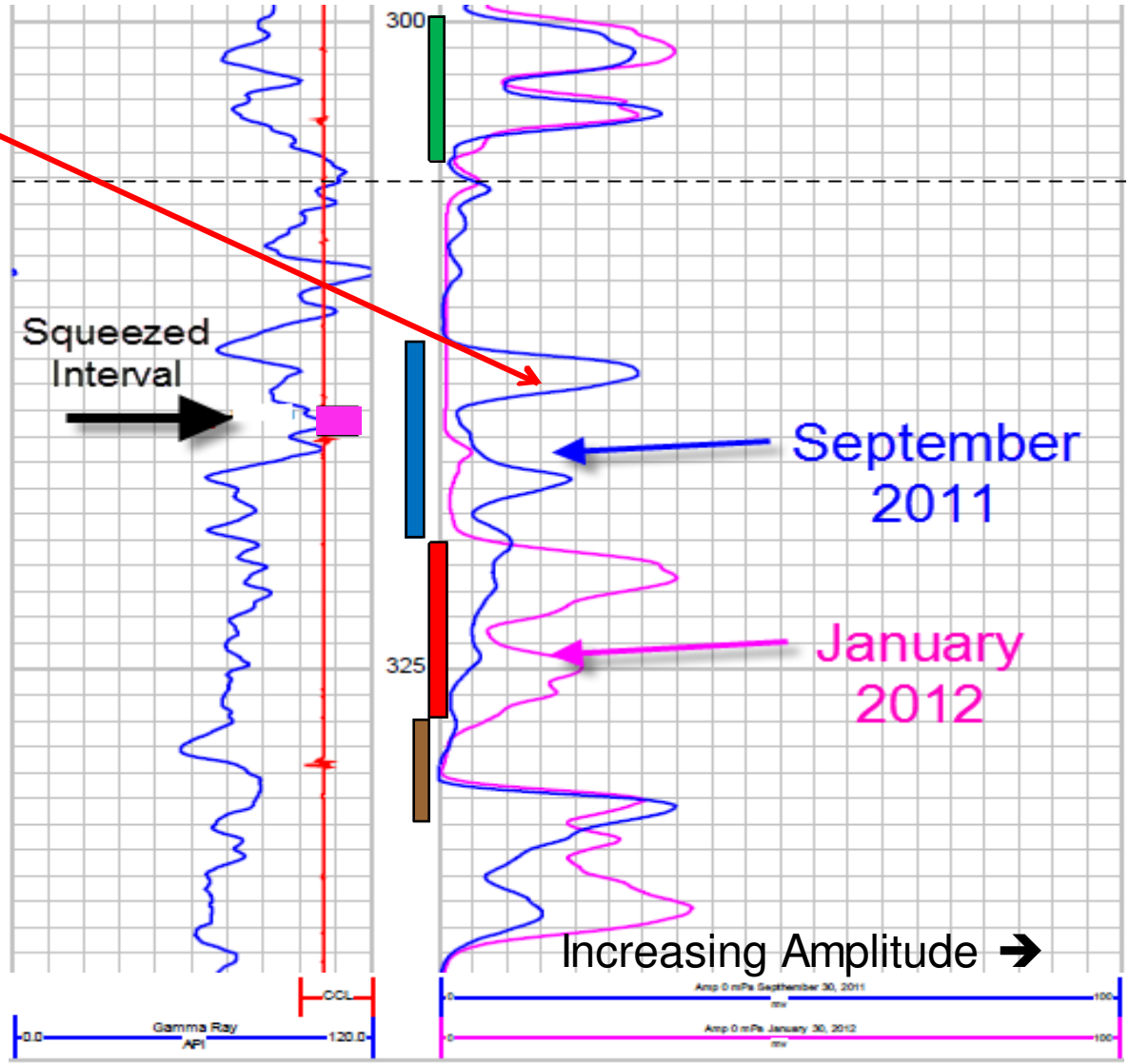
Honorable mention: Jude Reid for assistance in helping to build this presentation



"I don't want to do a pressure pass in case I create a micro-annulus"

- Bond log Sept shows areas of lower quality cement prior to a cement squeeze intervention on a SCVF repair.
- Bond log January done after cement squeeze showing placed cement **(312.5-320m).**
- The comparison of 3' amplitudes indicate the previous cement did degrade from before squeeze to after in other areas of the well.
- This was likely caused by the increase in pressure from cementing damaging the already compromised cement **(320-327m).**
- Note how **300-305m** **or** **327-331m** did not change however.



Wellbore preparation and result of mud mixing with cement and potential impact on a bond log

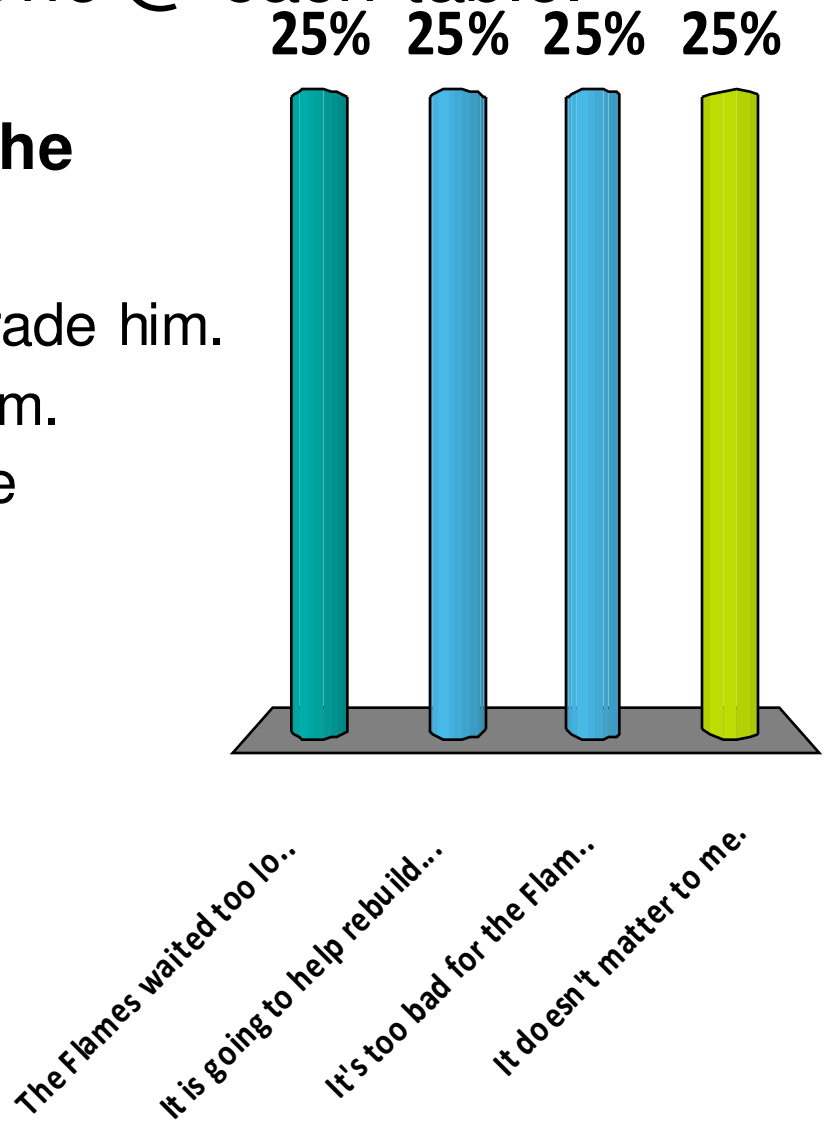
All of the above samples appear to be solid, however compressive strengths – hence amplitudes on a bond log – are significantly different

Samples courtesy of Gary Batcheller – GWB Consultants

Interactive participation quiz using Turning Point's electronic response cards. One @ each table.

CBC: How do you feel about Jarome Iginla being traded to the Pittsburgh Penguins?

1) The Flames waited too long to trade him.
2) It is going to help rebuild the team.
3) It's too bad for the Flames but he deserves a shot at the Cup.
4) It doesn't matter to me.



I use bond logs to their full capacity when considering Cap Rock Integrity or SCVF?

1. True – I am very comfortable interpreting bond logs
2. False – still need some more practice – hence why I am here
3. False – I do not know how to interpret a bond log
4. N/A – I just wanted a company sponsored lunch and heard about “Bond”.