Logging to identify well integrity changes and flow paths

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IEAGHG Monitoring and Modeling Network Combined Meeting.
July 6-October 8, 2016

Funded by DOE NETL [DE-FE-0001040] and [DE FE0009284]

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Collaborators

- Robert Butsch, Schlumberger Carbon Services,
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- Boyun Guo, University of Louisiana at Lafayette
- Susan Hovorka, University of Texas at Austin
- Runar Nygaard, Missouri University of Science and Technology

Well leakage risk

- Well leakage risk is a significant consideration for CO_2 storage.

Integrity Monitoring

- Logging and monitoring can provide data to determine if there are potential flow paths in a well and how integrity changes over time.

Outline

- Background
- Log examples
- Discussion
- Thoughts

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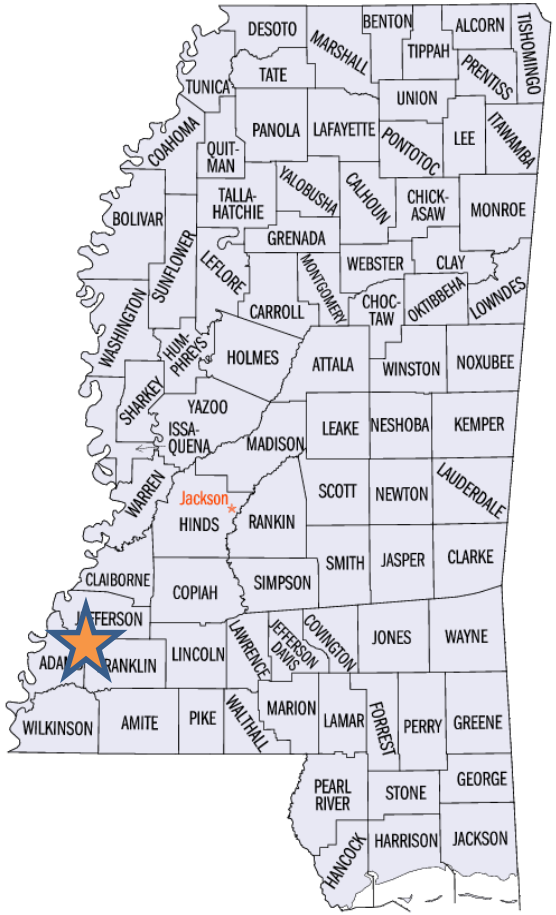
Need for Time-Lapse Integrity Monitoring

- Time-lapse monitoring of wells may be necessary to ensure long-term storage of CO_2.
  - Time-lapse monitoring can be used to identify changes to cement, casing, and cement-casing bond
  - Tools may include ultrasonic imaging tools, cement bond logging tools, corrosion monitoring tools, and saturation monitoring tools

Background: Cranfield Field, Mississippi

- SECARB's Phase II Gulf Coast Stacked Storage Project
- Three Monitoring Wells Studied in an EOR Setting
  - Samples in and above the production zone
  - EGL7 68 years old
  - CFU 31F2 and CFU 31F3 7 years old
- All wells showed good cement in places and potential integrity issues in other places.



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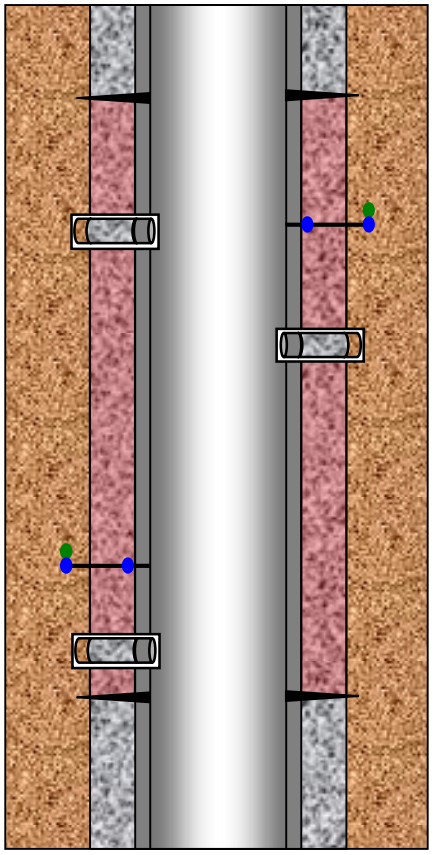
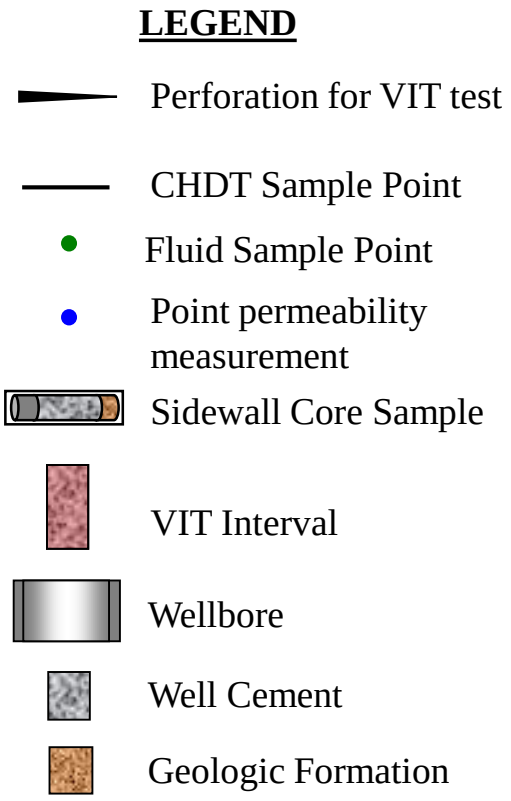
Data Collection Through Logging

- Logging Tools
- USIT* ultrasonic imager tool
- Isolation Scanner* cement evaluation service
- Sonic Scanner* acoustic scanning platform
- SCMT* slim cement mapping tool

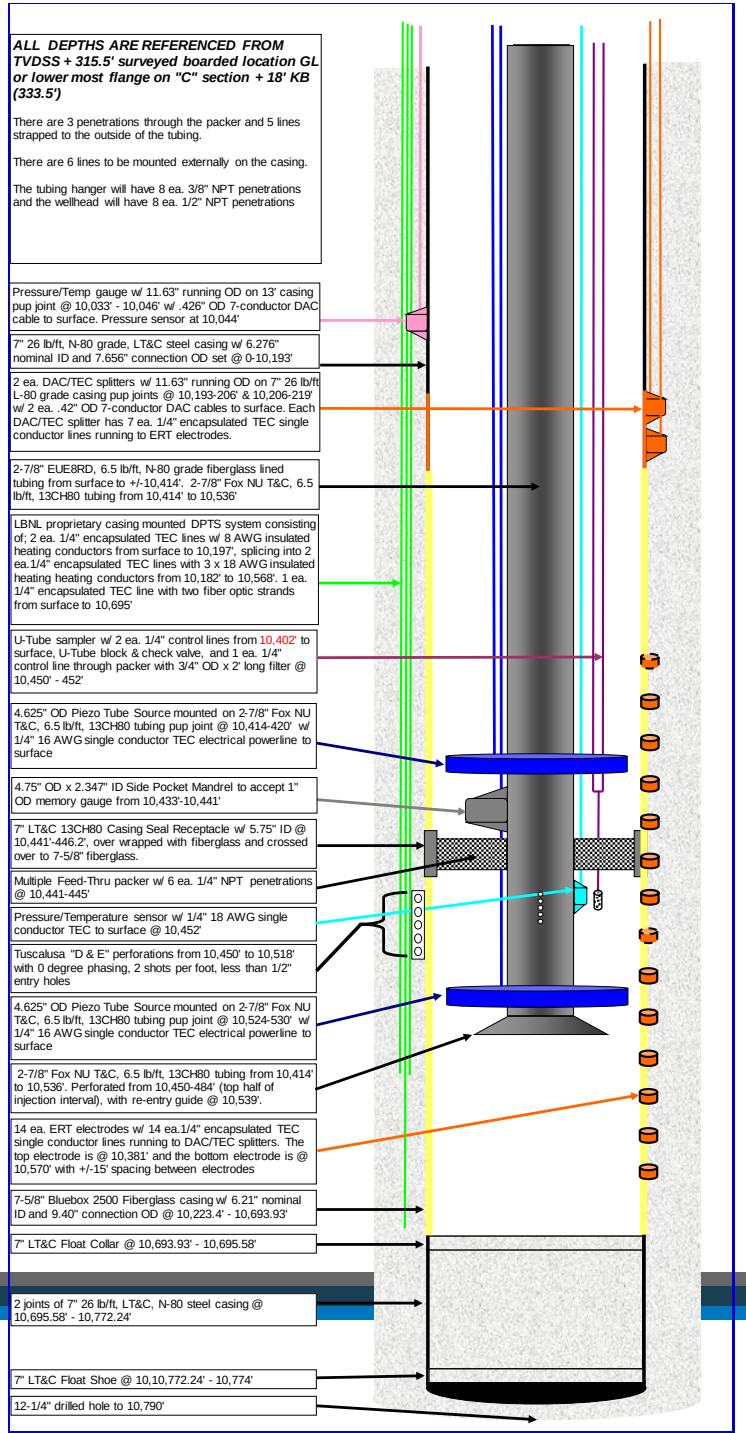
- Testing and Sampling Tools
- CHDT* cased hole dynamics tester
- MSCT* mechanical sidewall coring tool



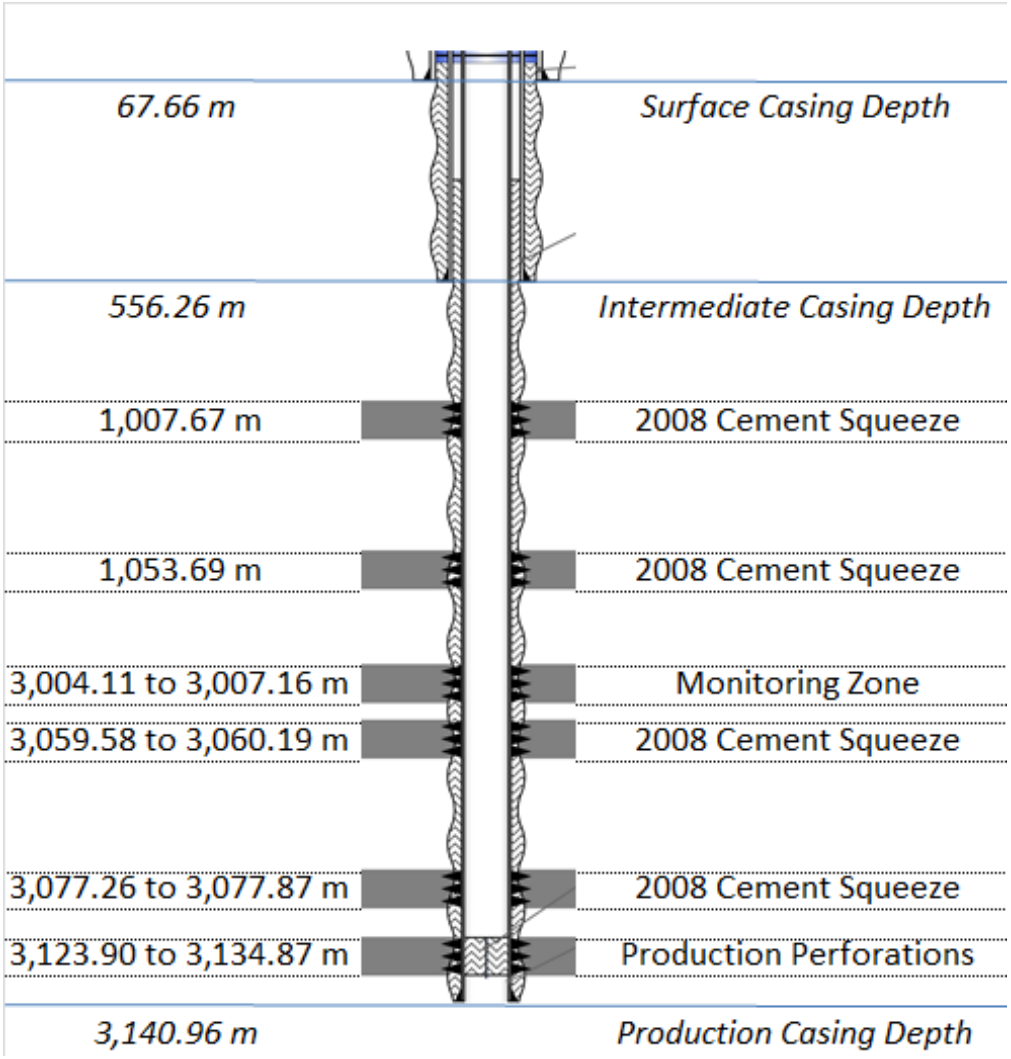


Cranfield CFU31F2 and CFU31F3

- Monitoring Wells
  - Constructed in 2009 and P&A'd 2015
  - Very similar construction
- 7-in 26lb N80 to ~10,200ft
- 7 5/8-in Bluebox 2500 from ~10,200 to ~10,700ft
- 7-in 26lb N80 to ~10,700ft to TD (~10,790ft)
- Electrodes and other jewelry in the well
- 12 ¼-inch bit (large cemented annulus)
- Production reservoir ~10,435ft to ~10,518ft (CFU31F2)



Cranfield Field Ella G Lees #7



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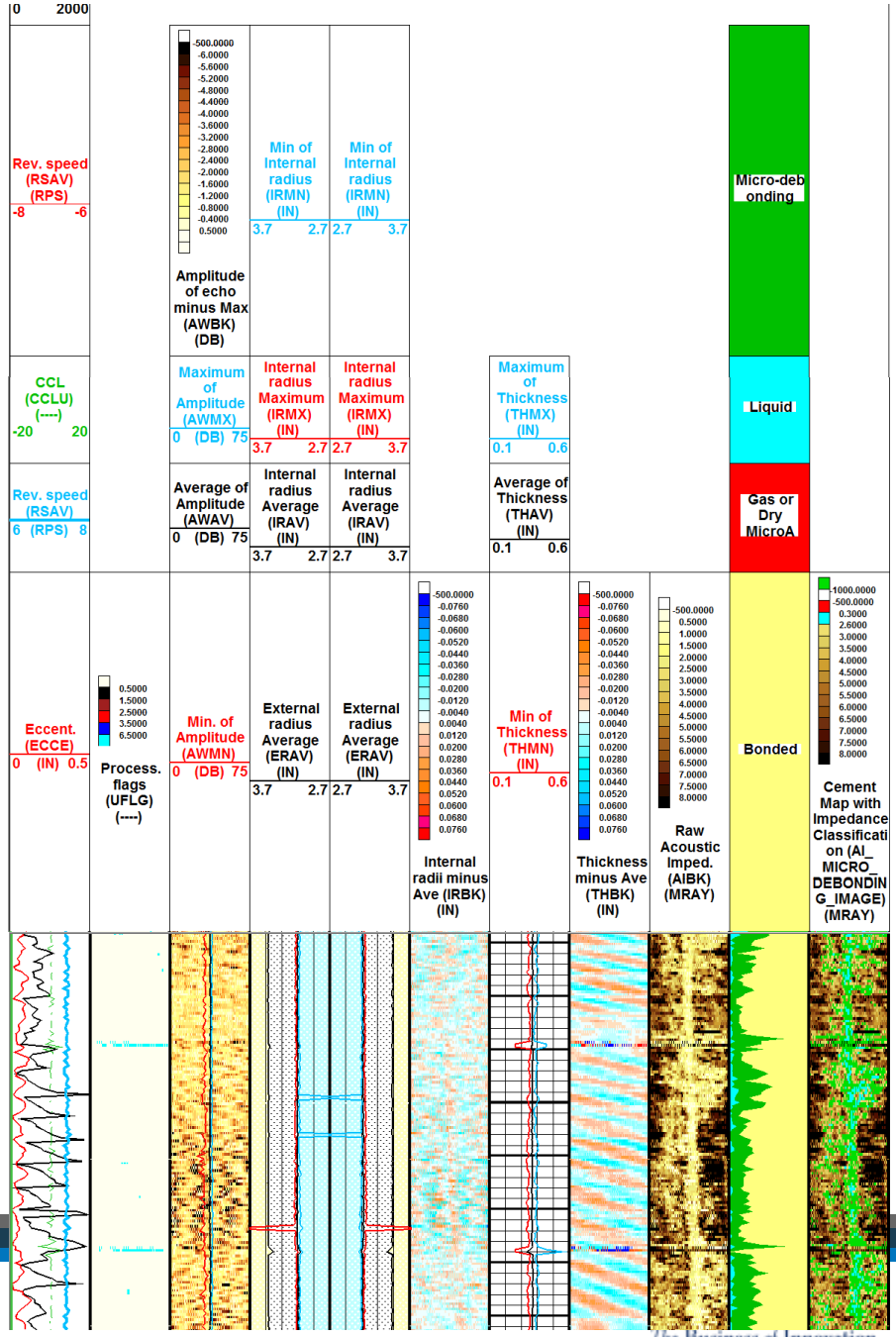
Potential Flow Pathways: Cemented cable (CFU31F3)

- Ultrasonic Imager Tool
  - Casing maps, cement maps, solid, liquid, and gas identification, jewelry locations
- Cemented cable for monitoring equipment
  - Possible leakage path due to poor cement or poor bond under cable.



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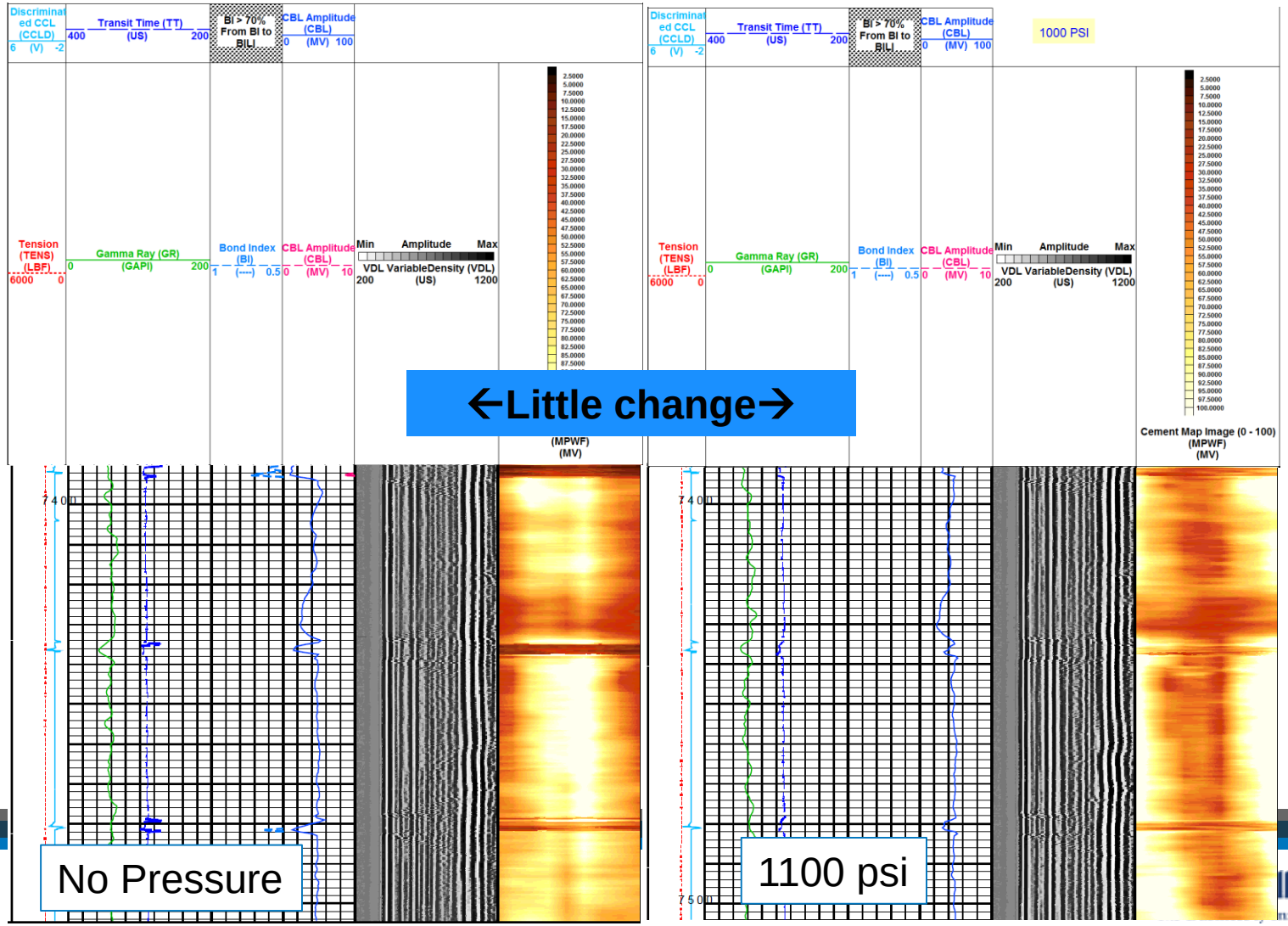
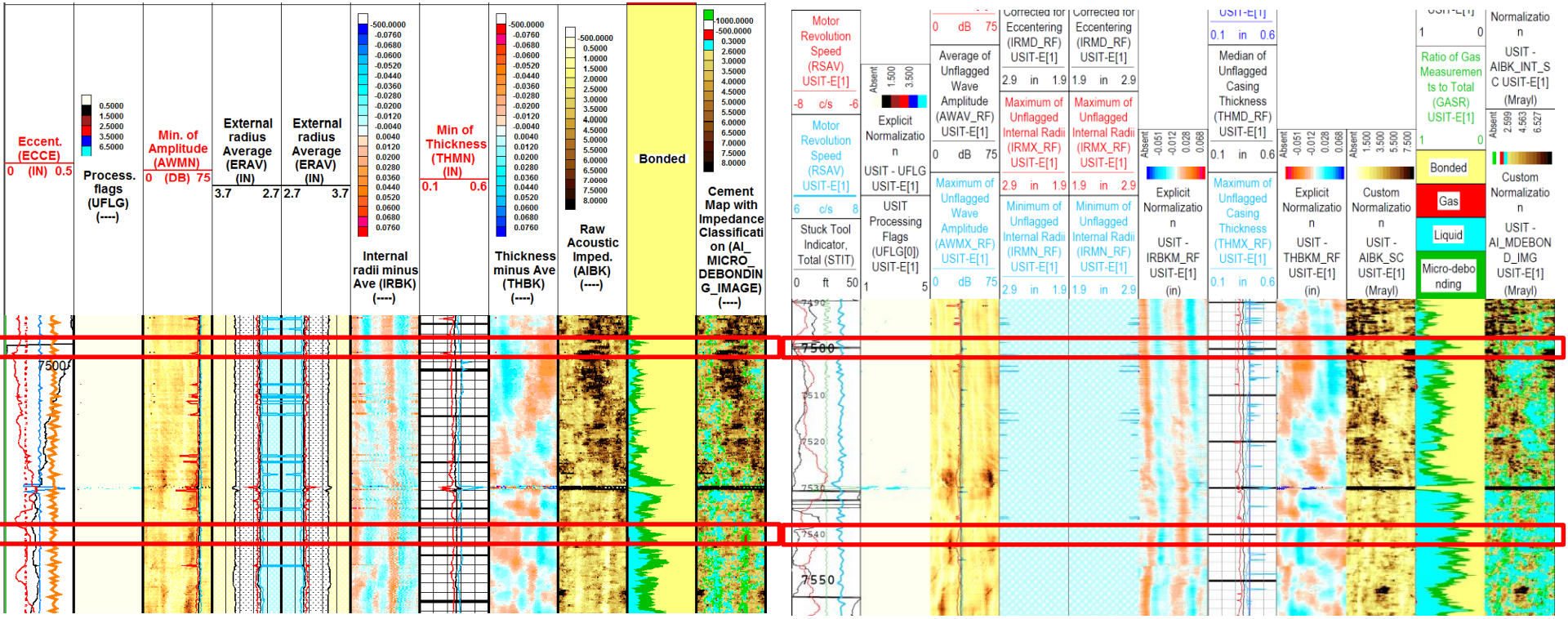
Potential Flow Pathways: Annulus EGL7 SCMT

- No change to log response with pressure implies that annulus did not close. Annulus larger that 70 microns.



Potential Flow Pathways: Poor Cement Zone (EGL7)

- "Cement" material removed during cased-hole flow testing in 2013
  - Later analysis showed cement minerals in removed material
  - Constant flow rate achieved until tool plugged, Annulus aperture estimated to be 0.2 to 0.4 mm



2008 2013

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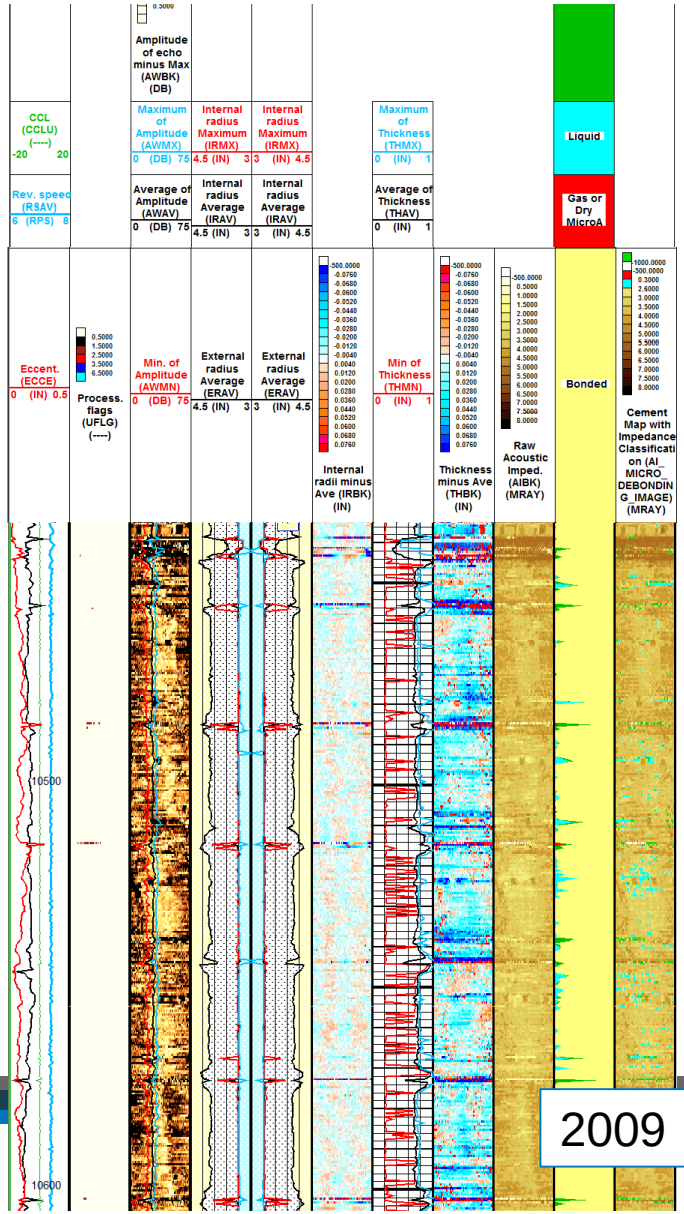
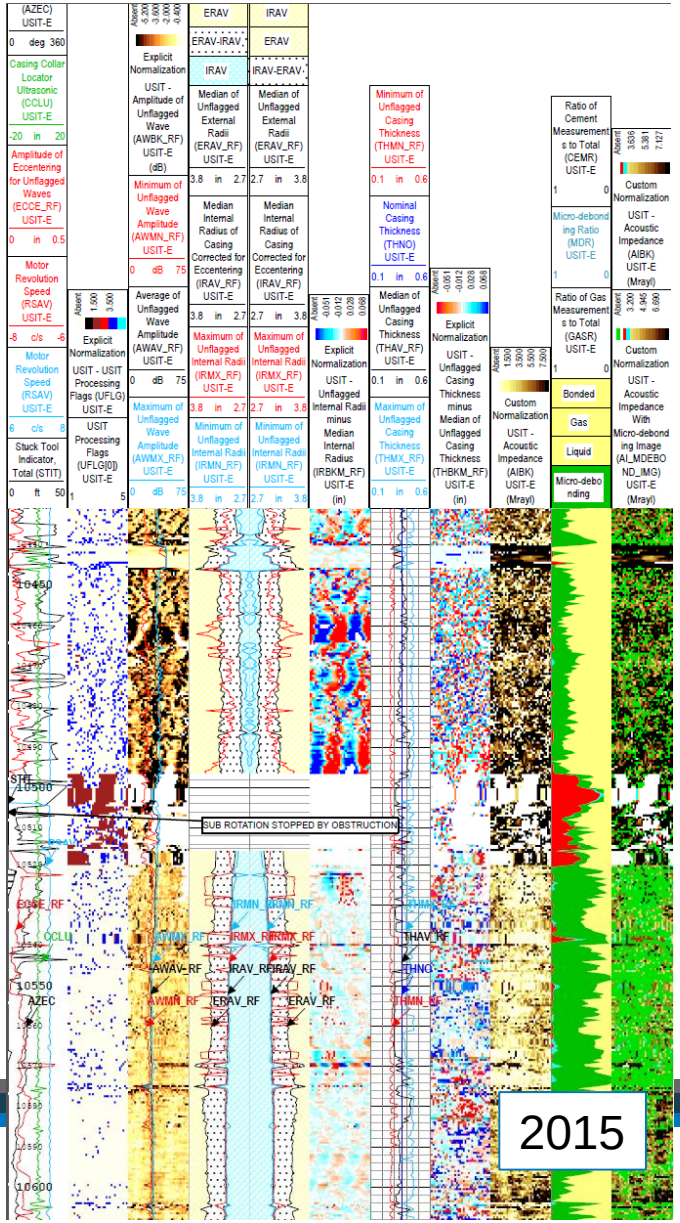
Integrity Change: Casing Collapse? Time-Lapse Ultrasonic Logging in Fiberglass Casing (CFU 31F3)

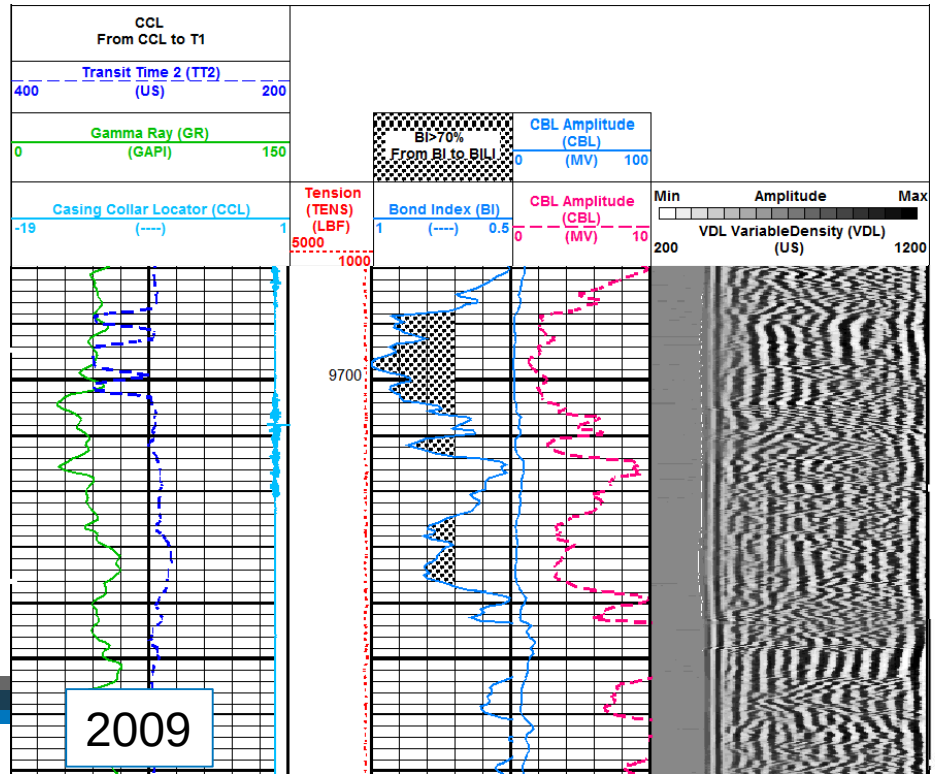
- Fiberglass casing installed to allow monitoring
- Casing degradation of casing in the CO2 zone.
  - Suggests fiberglass may not be appropriate for this application

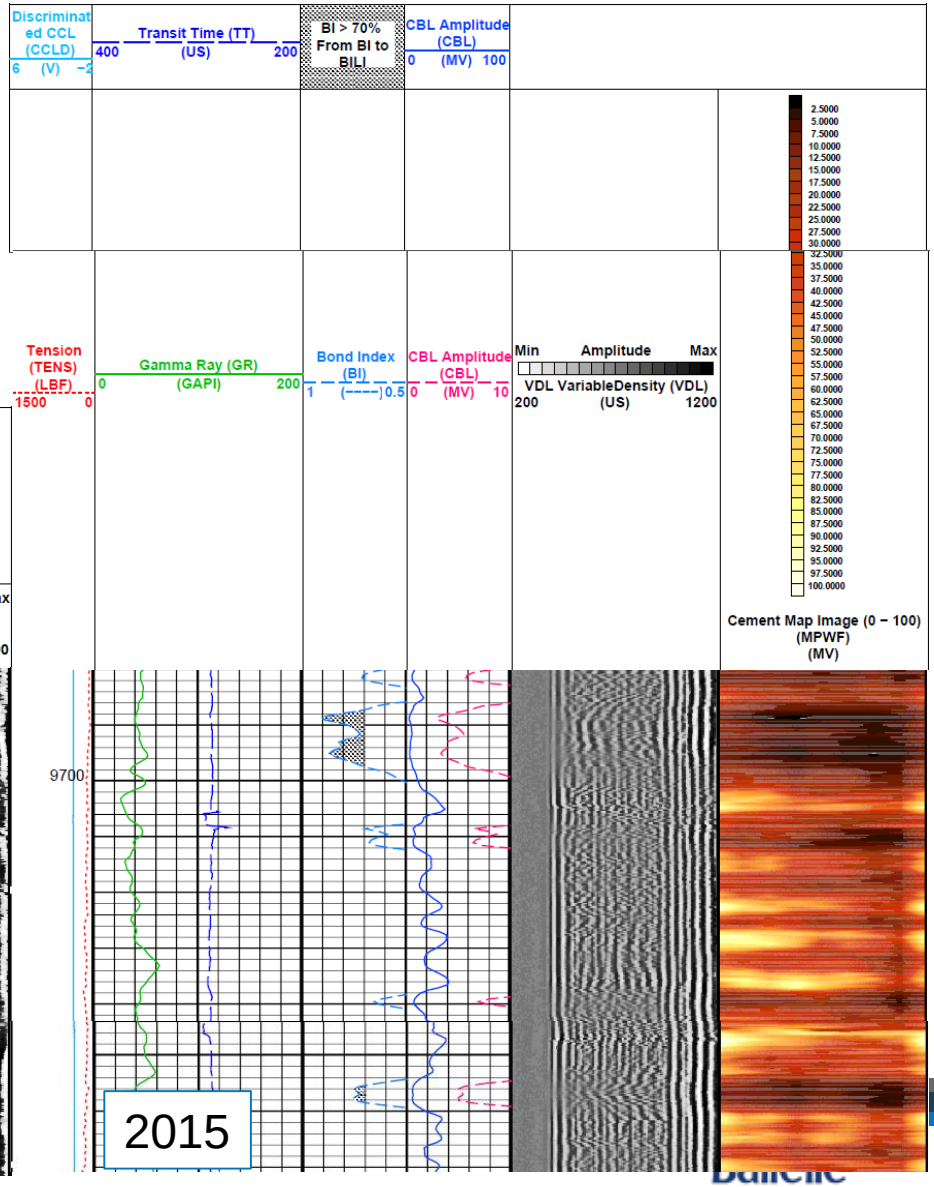




Integrity Change: Loss of Bond in CBL Logging in Steel Section (CFU 31F2)

- Loss of bond in CBL track between initial logging in 2009 and final logging in 2015





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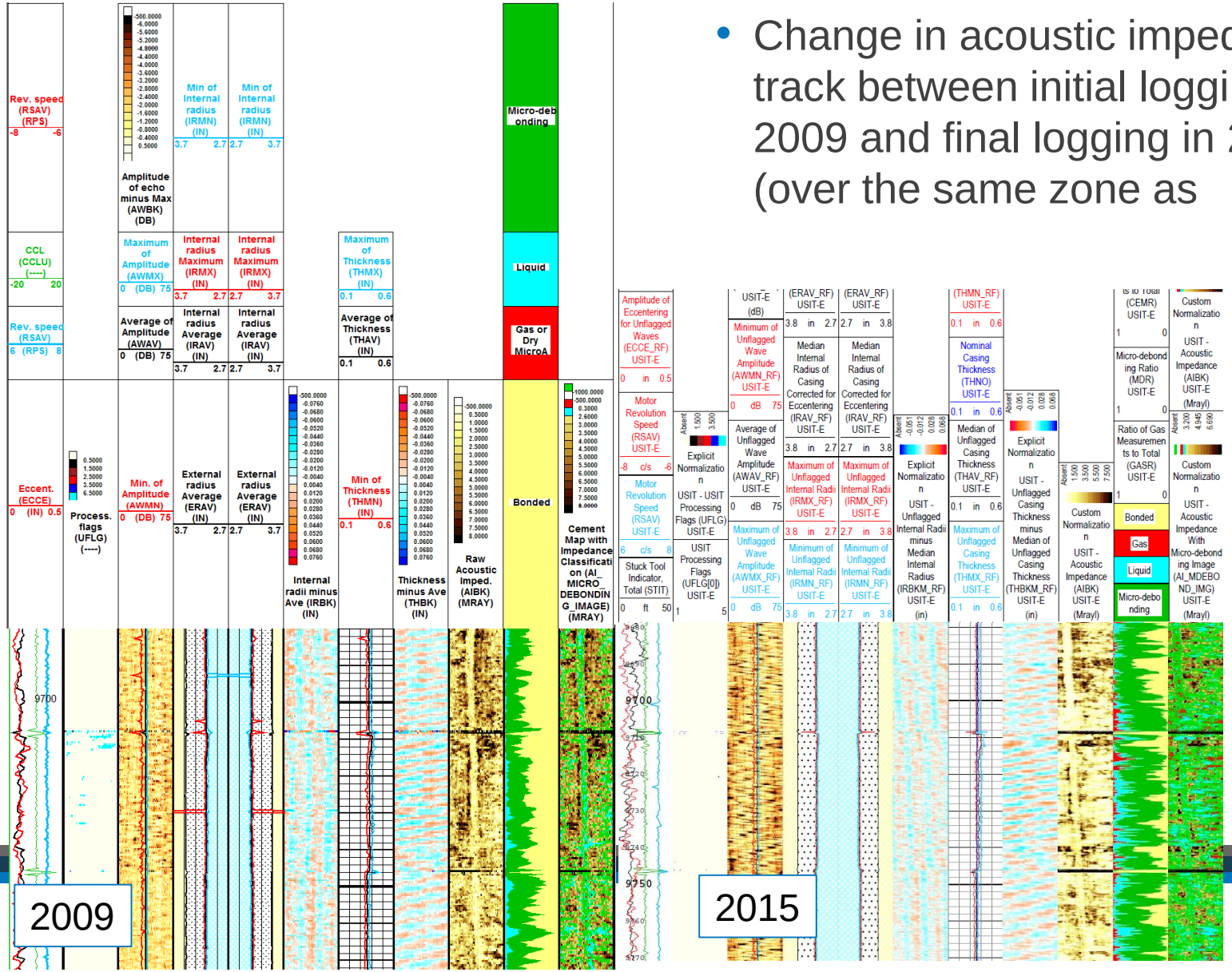
Integrity Change: Loss of Acoustic Impedance in Steel Section (CFU 31F2)



- Change in acoustic impedance track between initial logging in 2009 and final logging in 2015 (over the same zone as

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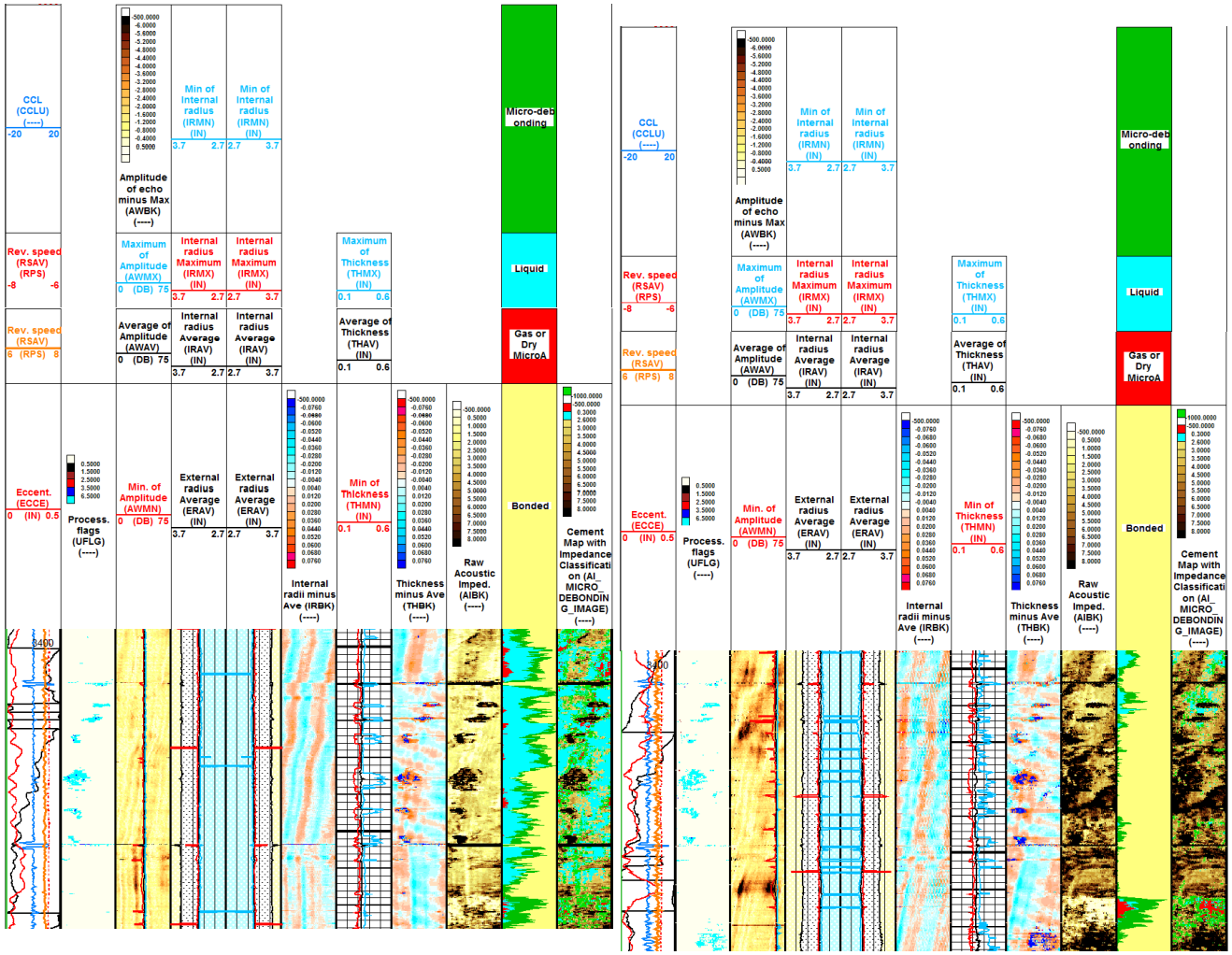
Integrity Change: Cement Squeeze (EGL7)



- Gain of cement due to cement squeeze between initial logging in February, 2008 and reclogging in April, 2008

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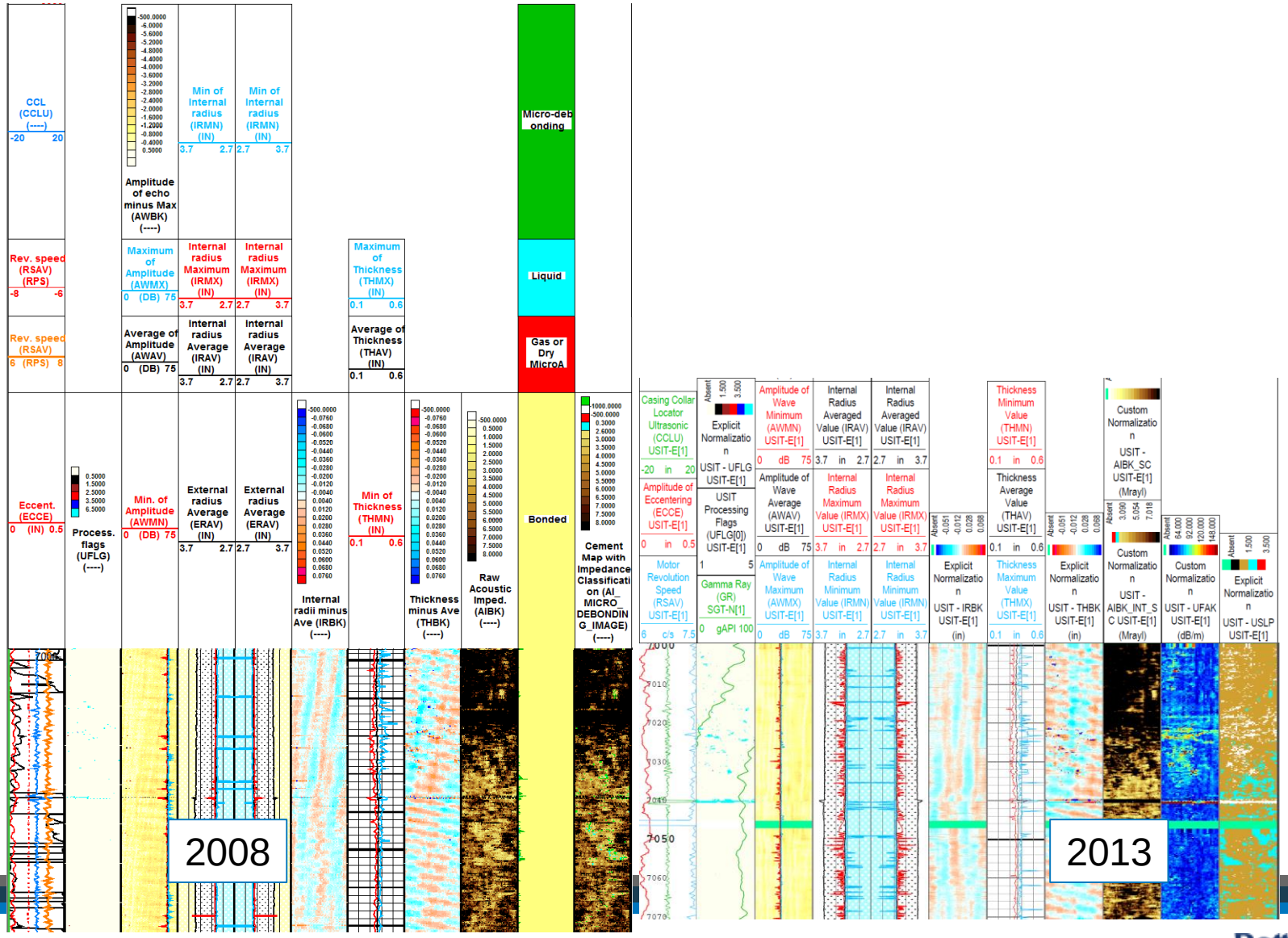
Good Cement: No Change (EGL7)



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Summary/Discussion

- Changes to well integrity were identifiable over a short period (5 to 6 years) in and above the CO_2 zone
- Potential pathways were identified in all wells
- All of the wells still maintained overall integrity
- Short-term changes imply more study is needed to understand the importance of changes in log response due to CO_2 exposure, general well aging, and well operations. Studies should address:
  - Timing or repeat surveys
  - Reasons to repeat
  - Types of surveys to repeat
  - How changes in time relate to actual integrity
  - Others?

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Thoughts for monitoring wells

- Selection of monitoring wells and monitoring technologies should be considered carefully to ensure that monitoring related leakage risks are not significant to the project
  - Both materials and external hardware should be designed to withstand CO_2 exposure and maintain isolation.
  - Lines running along the casing may be difficult to cement
  - Casing, gauges, other special equipment need to be constructed from CO_2-resistant materials if their failure could affect overall well integrity

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Thank You!

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Backup Slides

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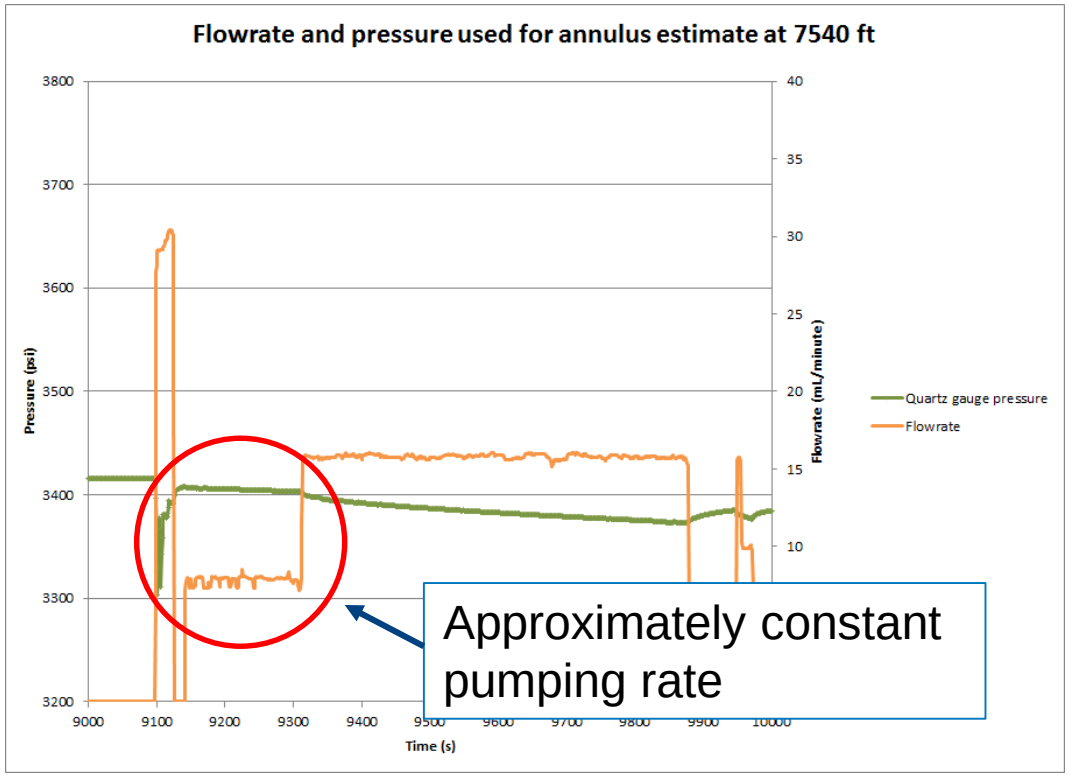
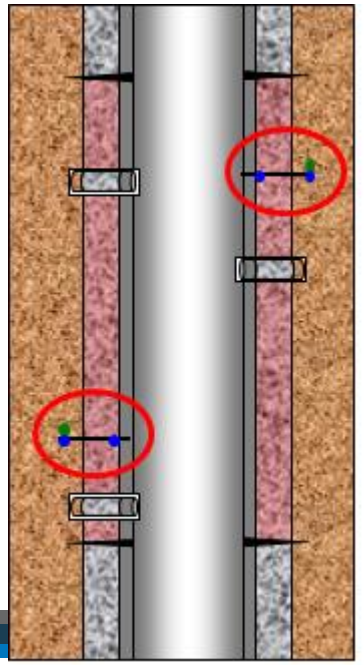
EGL7– CHDT





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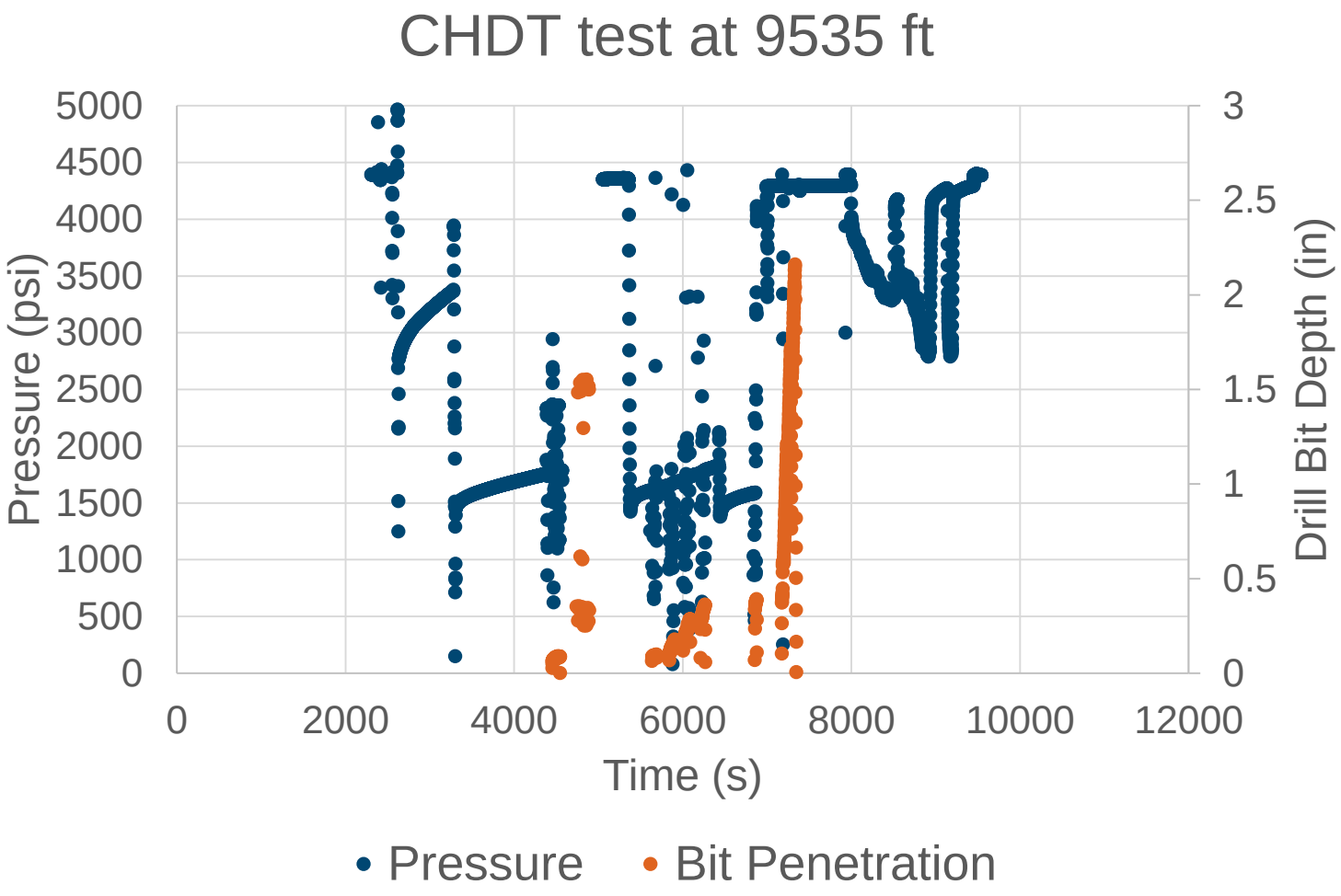
CFU31F2 CHDT Testing



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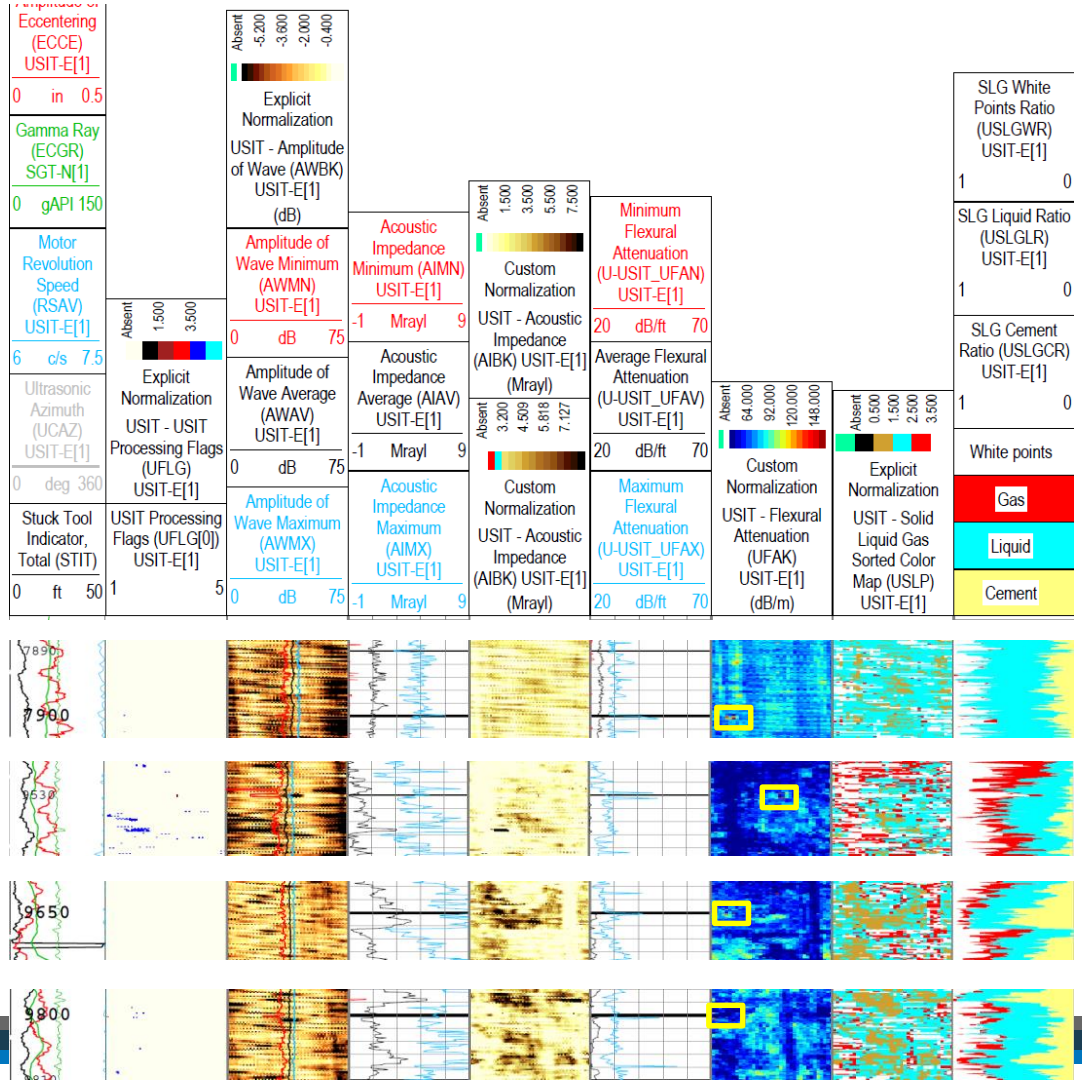
CFU31F2 Sidewall Cores



7,900

9,530

9,800

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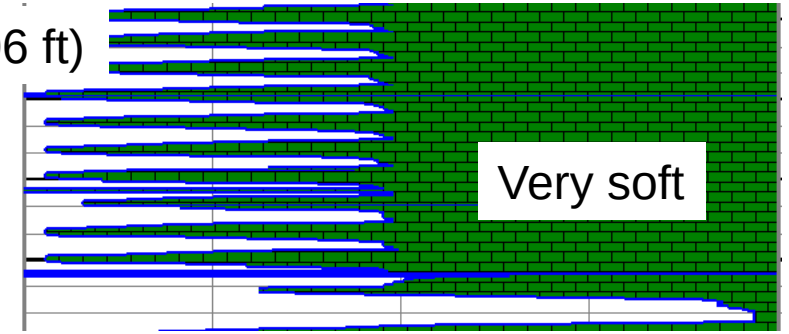
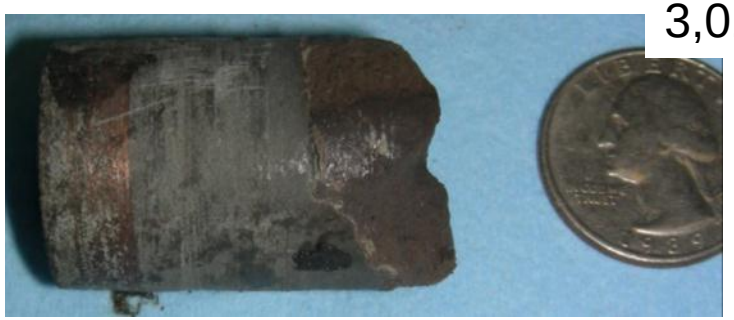
EGL7 Cased-Hole Sidewall Coring

2,135.42 m (7,006 ft)

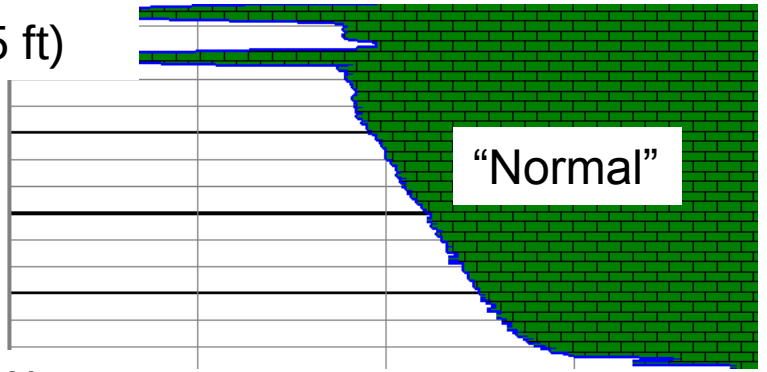
4786.40
4796.40
4806.40
4816.40
4826.40
4836.40
4846.40
4856.40





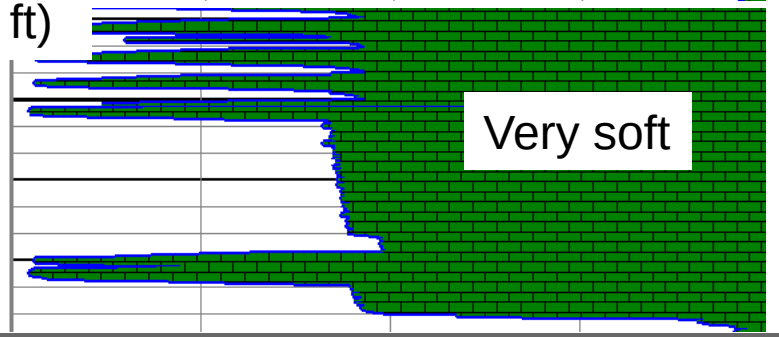
3,011.27 m (9,879.5 ft)

2517.20
2527.20
2537.20
2547.20
2557.20
2567.20
2577.20
2587.20
2597.20
2607.20



3,012.64 m (9,884 ft)

5225.20
5235.20
5245.20
5255.20
5265.20
5275.20
5285.20
5295.20
5305.20
5315.20



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EGL7 XRD: Bulk Samples

SAMPLE DEPTH (m)	SiO_2	$CaCO_3$	$Ca(OH)_2$	Ca_2SiO_4	$Ca_3(SiO_4)O$	$Ca_3(SiO_4)O$	$Ca_3Al_2(SiO_4)_3$	$(Mg0.80_4Ca0.196)_3Al_2(SiO_4)_3$	$Ca_3Al_2(SiO_4)(OH)_8$	$Ca_2(SiO_4)6H_2O$
	Quartz	Calcite	Portlandite	Dicalcium silicate	Haturite	Tricalcium silicate oxide	Grossular	Pyrope	Katoite	Calcium Silicate Hydrate
3,011.27	1	14	16	23	6	7	6	5	5	18
3,012.64	1	6	21	6	0	0	0	8	34	25

3,011.27 m (9,879.5 ft)

3,012.64 m (9,884 ft)

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Mechanical and Petrophysical Properties

Sample Depth (m)	Test Fluid	Temperature (°F)	Confining Pressure (psi)	Length (in)	Diameter (in)	Permeability (mD)
3011.27	2% KCl	240	4400	0.582	0.936	0.000186
3012.64	2% KCl	240	4400	0.623	0.86	0.0146

Sample Depth	Sample Length	Sample Diameter	Bulk Density	Dry Bulk Density	Grain Density	Ambient Porosity	Gas Permeability	NOB Stress
(m)	(cm)	(cm)	(g/cc)	(g/cc)	(g/cc)	(%)	(md)	(psi)
3011.27	1.478	2.37	2.25	2.134	2.668	20.02	>0.01	400
3012.64	1.552	2.098	1.812	1.707	2.641	35.36	1.76	400

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CFU 31F3 MSCT Cores in Fiberglass

Above Production Interval

In Production Interval

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Casing Expansion (Lower Bound on Annulus)

Casing expansion = 70.55 μm (0.00278 in)

Circumferential Hoop Stress

$$\sigma_c = \frac{p_i r_i^2 - p_o r_o^2}{r_o^2 - r_i^2} - \frac{r_i^2 r_o^2 (p_o - p_i)}{r^2 (r_o^2 - r_i^2)}$$

Hooke's Law

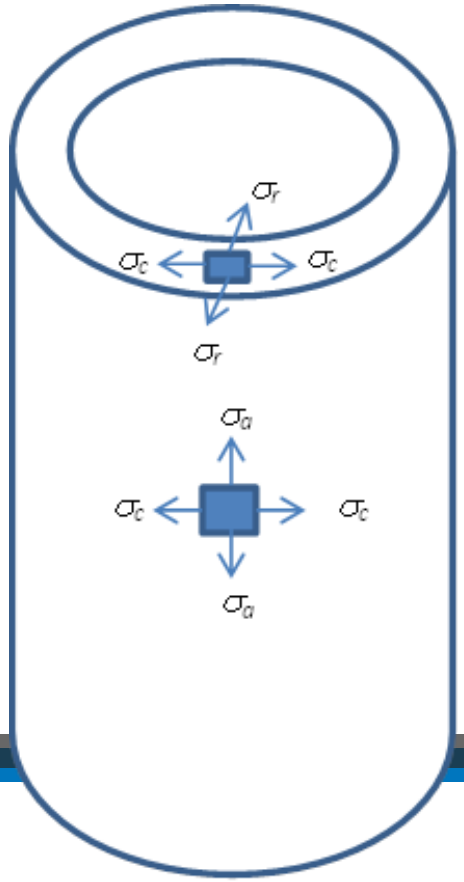
$$\varepsilon = \frac{\sigma}{E}$$

Definition of Strain

$$\varepsilon = \frac{\Delta C}{C}$$

Circumference of a Circ

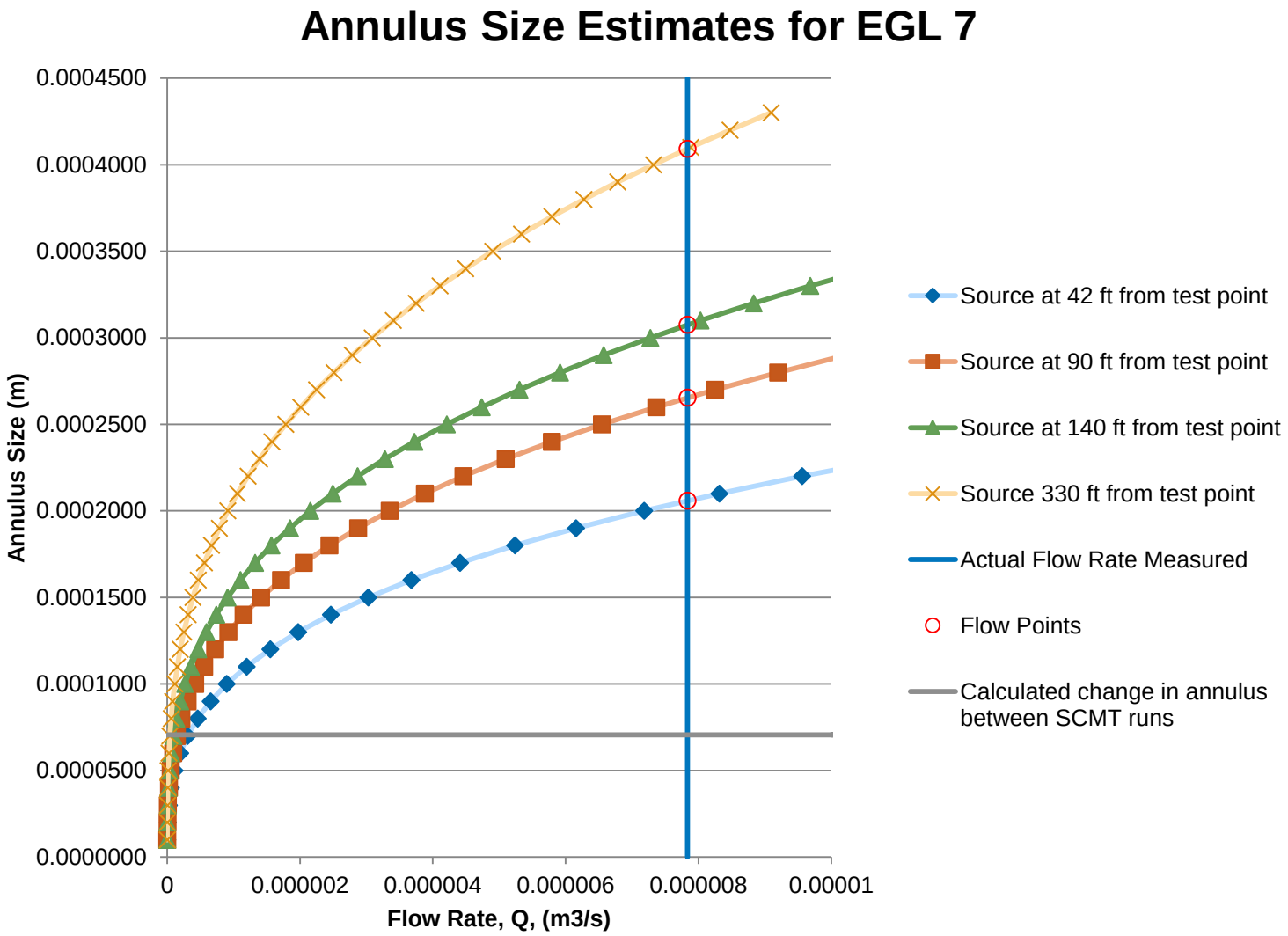
$$C = 2\pi r$$



Where:

- σ_c = Circumferential stress (psi) [**23,013 psi**]
- p_i = Pressure in the well (psi) [4,550 psi]
- p_o = Pressure outside the well (psi) [3,500 psi]
- r_i = Internal radius of the casing (in) [3.363 in]
- r_o = Outer radius of the casing (in) [7.000]
- r = Radius of interest in the casing (in) [7.000]
- ε = Strain (in/in) [**0.00079**]
- σ = Stress (psi) [σ_c]
- E = Young's Modulus (psi) [29 x 10^6 psi]
- C = Circumference (in) [21.99115]

EGL7 CHDT-Based Annulus Size Estimate



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