Well Integrity Assessment for Two Monitoring Wells at Cranfield Field

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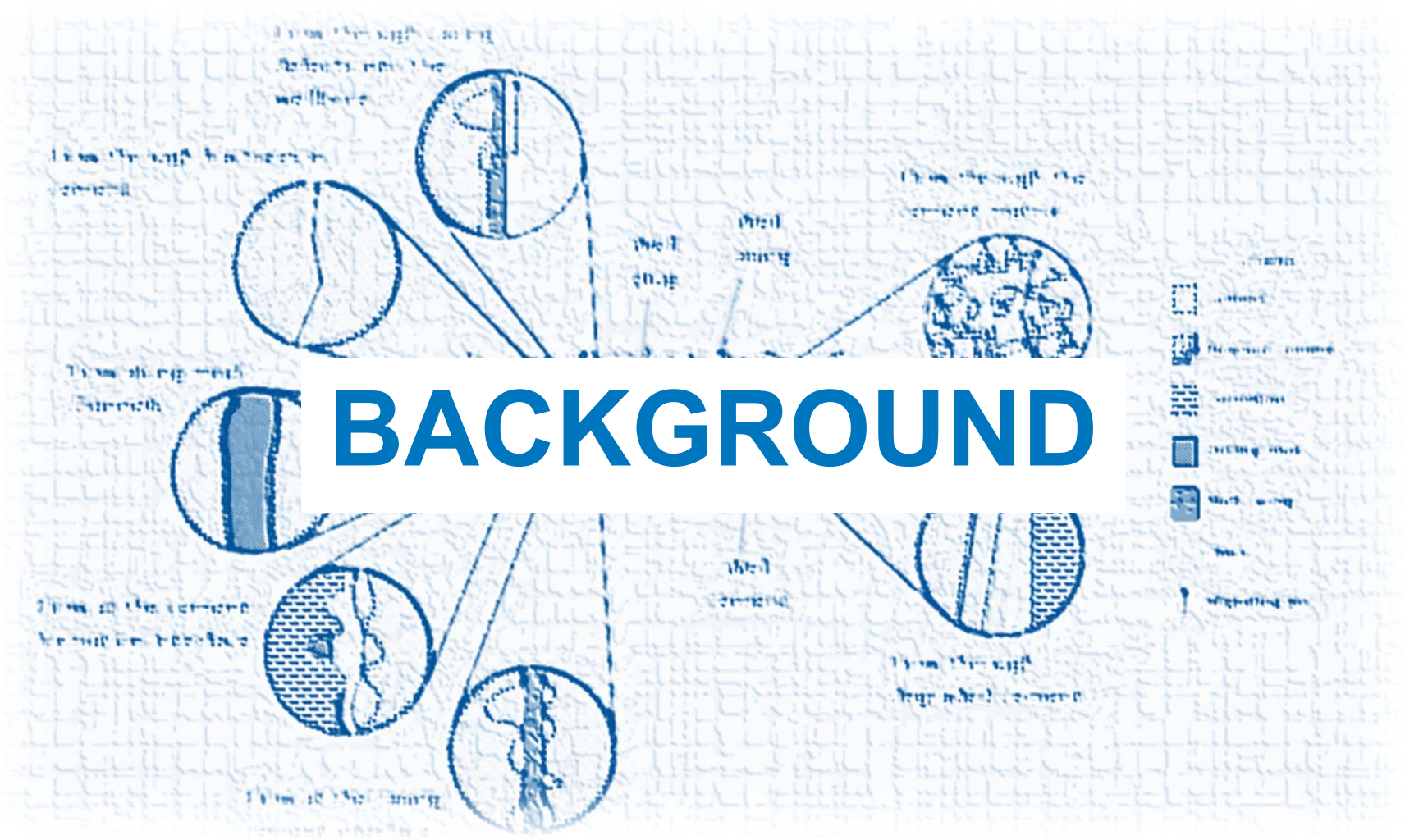
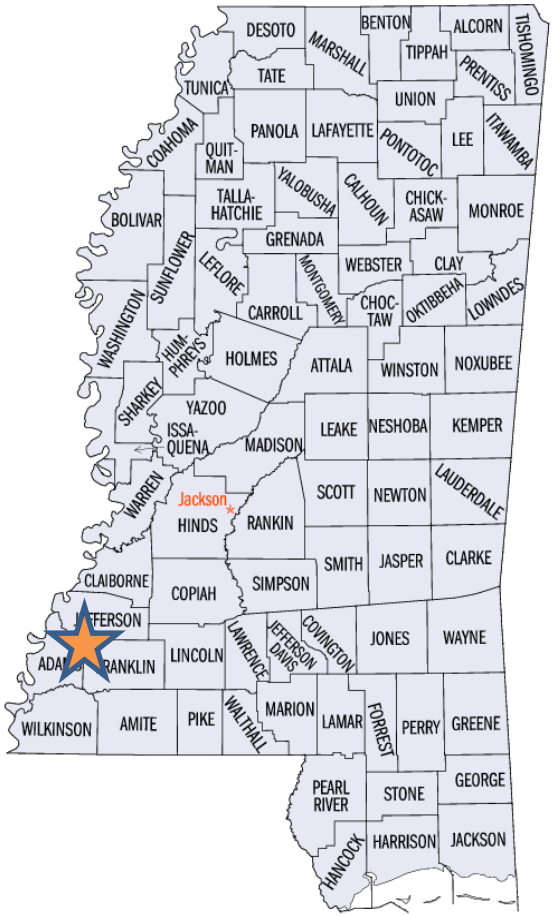
This work was supported by DOE NETL funding agreement DE-FE-0026585



BACKGROUND

Background: Cranfield Field, Mississippi

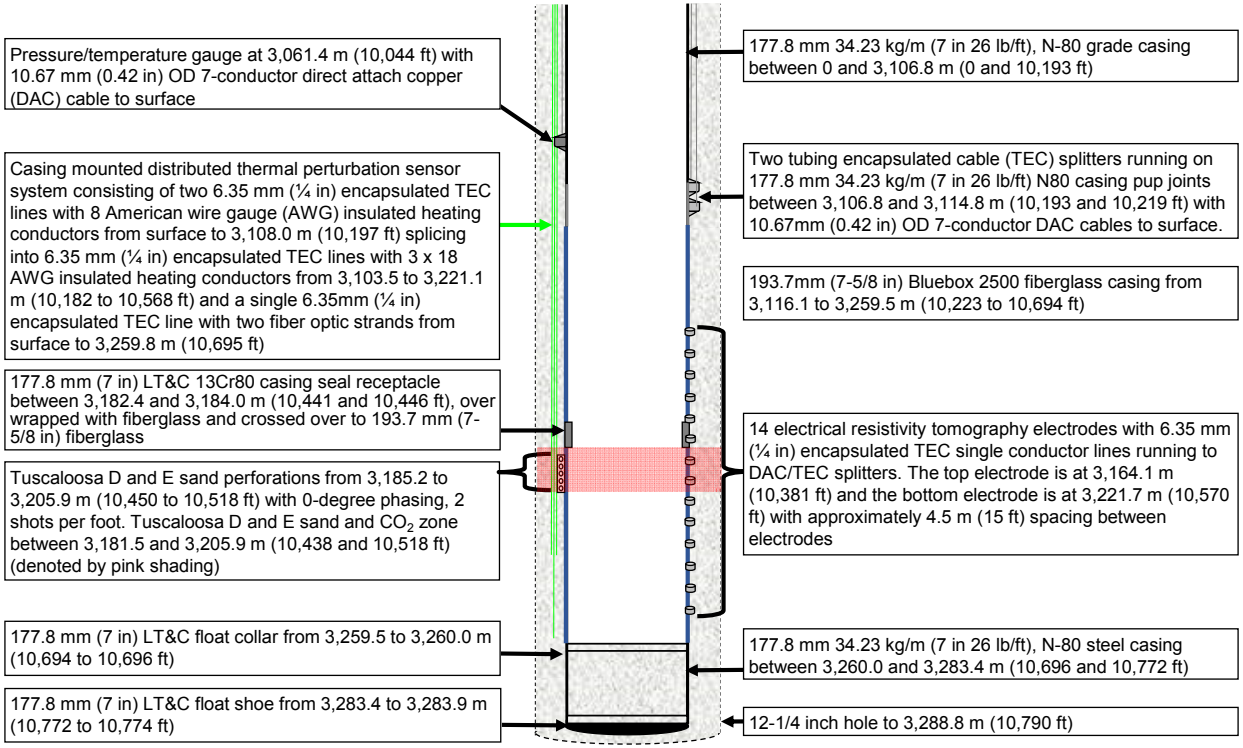
- SECARB's Phase II Gulf Coast Stacked Storage Project
- Monitoring Wells Studied in an EOR Setting
  - CFU 31F-2 and CFU 31F-3, 7 years old
- Injection commenced December 1, 2009 and continued into June 2015. Breakthrough was seen in CFU31F-2 on December 12, 2009 (12 days after injection).



Cranfield CFU31F-2 and CFU31F-3 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 (CFU31F-2)

CFU31F-2



Fiberglass Casing

Cement Slurries

Well	Slurry	Cement	Mass (sacks)	Yield (ft3/sack)	Volume (bbls)	Density (ppg)
CFU31F-2	Lead	35:65:6	565	1.48	148.5	12.8
CFU31F-2	Tail	Class H + Silica Flour	440	1.91	149.69	16.2
CFU31F-3	Lead	35:65:6	770	1.48	202.38	12.8
CFU31F-3	Tail	Class H + Silica Flour	465	1.91	158.19	16.2

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Potential Migration Pathways

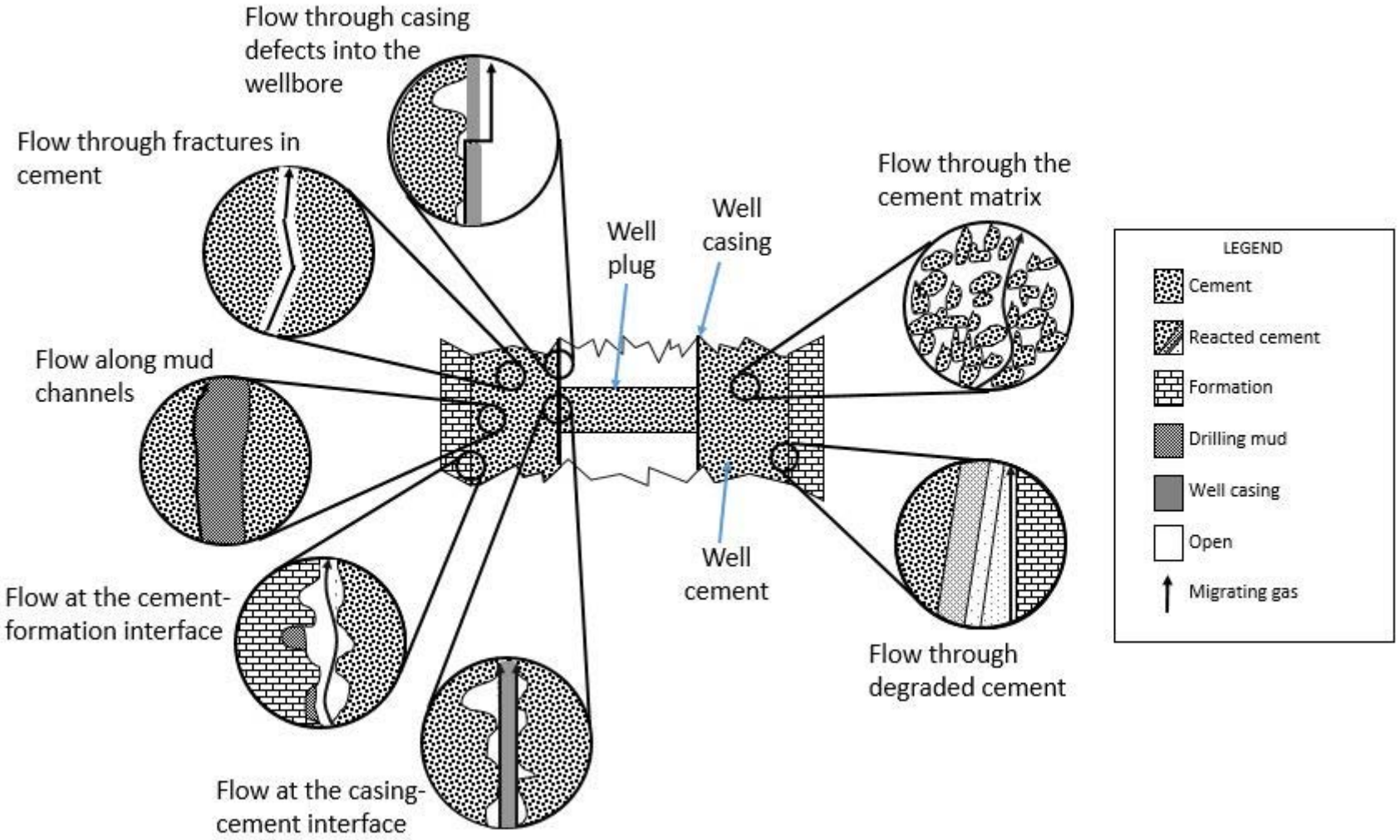

Figure from Duguid et al. [1]

Typical cement

Composition

Phase	Abbreviation	Percent
$Ca_3Si_2O_7 \cdot 4H_2O$	C-S-H	50-70
~~$Ca(OH)_2$~~	~~CH~~	~~20-25~~
$3(3CaO \cdot Al_2O_3 \cdot CaSO_4 \cdot 12H_2O)$	AFm	10-15
$4CaO \cdot (Al,Fe_2O_3) \cdot 13H_2O$	AFt	

Carbonation Reactions

- CO_2 dissociation
- $CO_2 + H_2O \leftrightarrow H_2CO_3^* \leftrightarrow H^+ + HCO_3^- \leftrightarrow 2H^+ + CO_3^{2-}$

- Cement dissolution
- ~~$Ca(OH)_2(s) + 2H^+ + CO_3^{2-} \rightarrow CaCO_3(s) + 2H_2O$~~
- $Ca_3Si_2O_7H \cdot 4H_2O(s) + 2H^+ + CO_3^{2-} \rightarrow CaCO_3(s) + SiO_xOH_x(s)$

- ~~$Ca(OH)_2(s) + H^+ + HCO_3^- \rightarrow CaCO_3(s) + 2H_2O$~~
- $Ca_3Si_2O_7H \cdot 4H_2O(s) + H^+ + HCO_3^- \rightarrow CaCO_3(s) + SiO_xOH_x(s)$

Precipitation of $CaCO_3$ blocks connected pores and reduces permeability

- Calcium carbonate dissolution
- $CO_2 + H_2O + CaCO_3(s) \leftrightarrow Ca^{2+} + 2HCO_3^-$
- $2H^+ + CaCO_3(s) \leftrightarrow CO_2 + Ca^{2+} + H_2O$

Opens pores blocked by $CaCO_3$ precipitation and additional porosity created by the dissolution of cement reaction products

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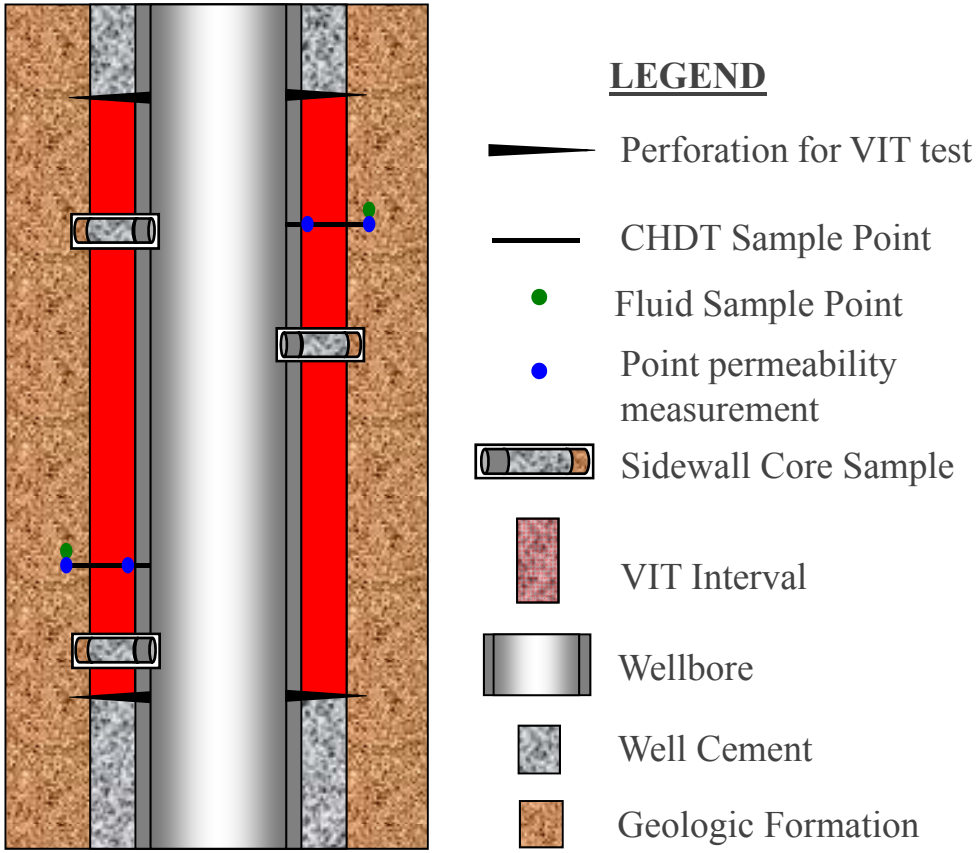
METHODS

Data Collection

- Logging Tools
- USIT* ultrasonic imager tool (2009)
- Isolation Scanner* cement evaluation service(2015)
- DSLT* Digital Sonic Logging Tool (2009)
- SCMT* slim cement mapping tool (2015)

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



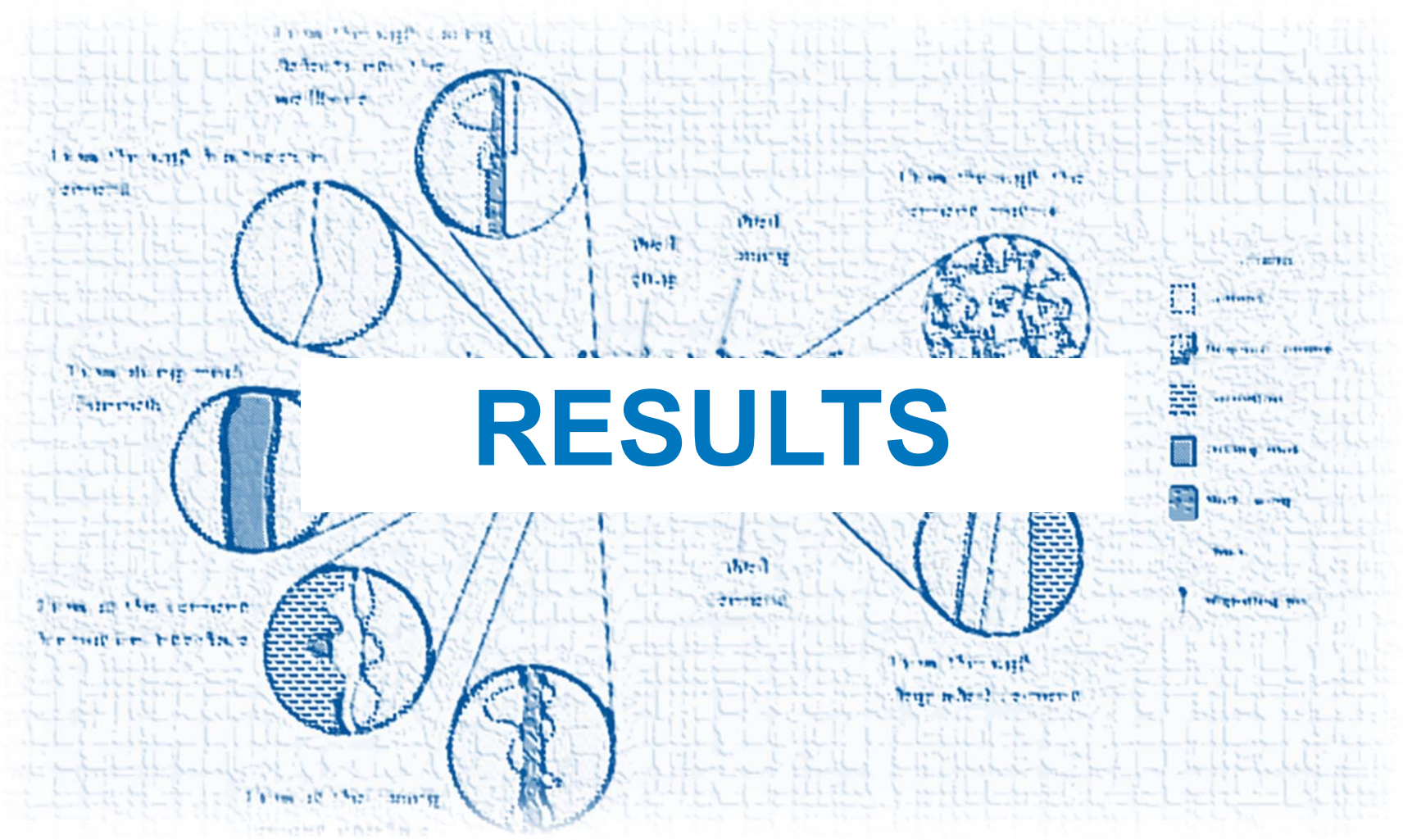
Lab Analyses on Core Samples

- Micro Computed Tomography (Micro-CT)
  - Analysis with a TriFoil Imaging eXplore CT 120 Small Animal X-Ray CT Scanner with a Custom generator producing 5 kW peak power. The analyzer had a feature detectability of 4 microns. The energy was between 40–120 kV with a maximum current of 50 mA.

- Laser Ablation Inductively Coupled Plasma Mass Spectroscopy (LA-ICP-MS)
  - Analysis with a Perkin Elmer Nexion 350D ICP-MS and a Photo Machines Excite He1Ex 193nm Laser with a 50 x 50 mm spot size. A NIST 612 standard was used before and after the scans on each sample to account for machine drift. Lines were collected at 20mm/s.

- Environmental Scanning Electron Microscopy (ESEM) with Energy Dispersive X-ray Spectroscopy (EDS)
  - Analysis with a FEI QUANTA 200 SEM in ESEM Mode. The analysis was conducted on portions of the sectioned samples that were polished to 1 micron prior to analysis. Excitation energy ranged from 10 to 20 KV.

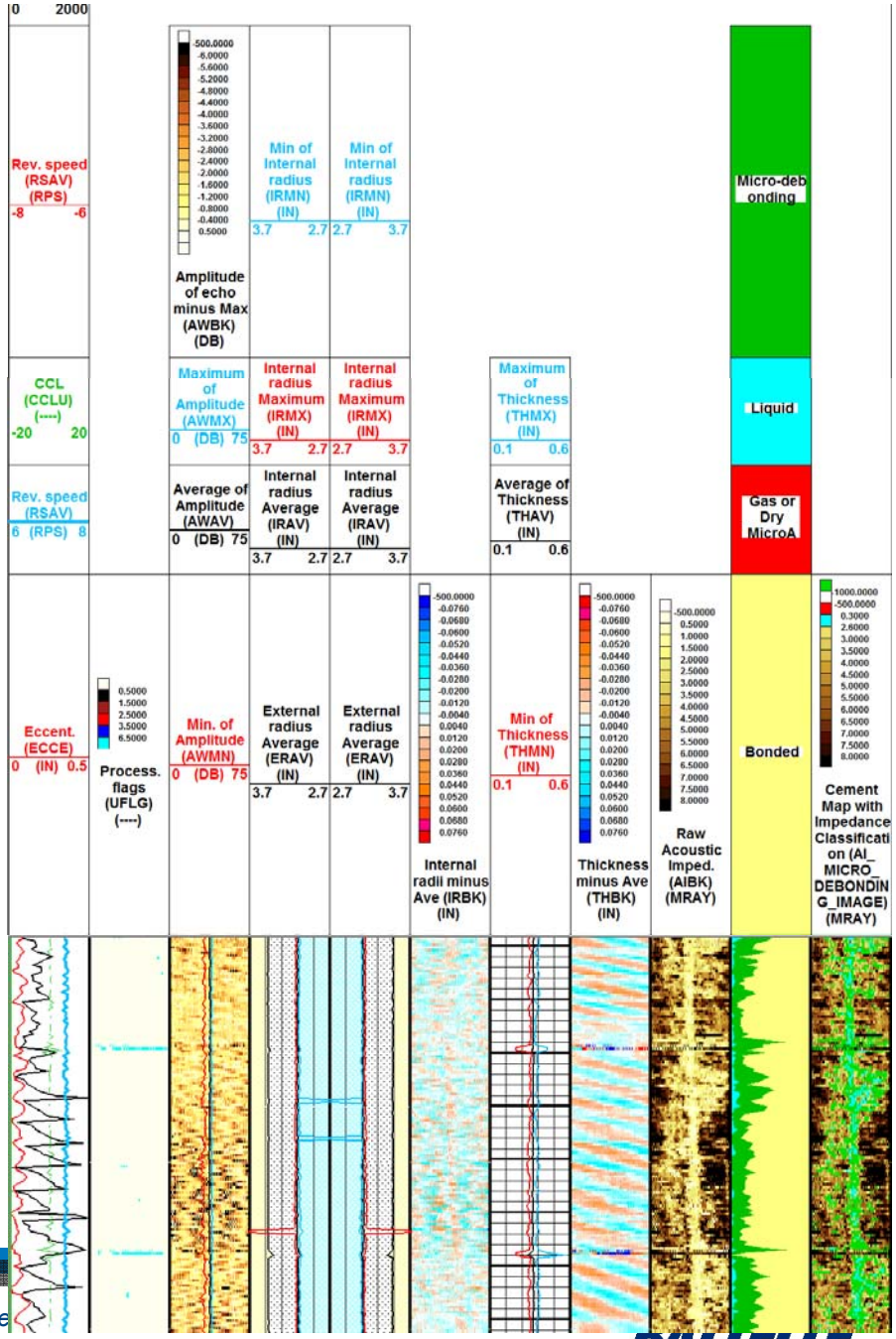
- X-ray Diffraction (XRD)
  - Analysis with a Rigaku MiniFlex 600 analyzer. The samples were run using a 40Kv voltage and a 15mA current. The radiation source was an interlock CU tube. Scans were run from 5 to 80 degrees at 1 degree per minute.



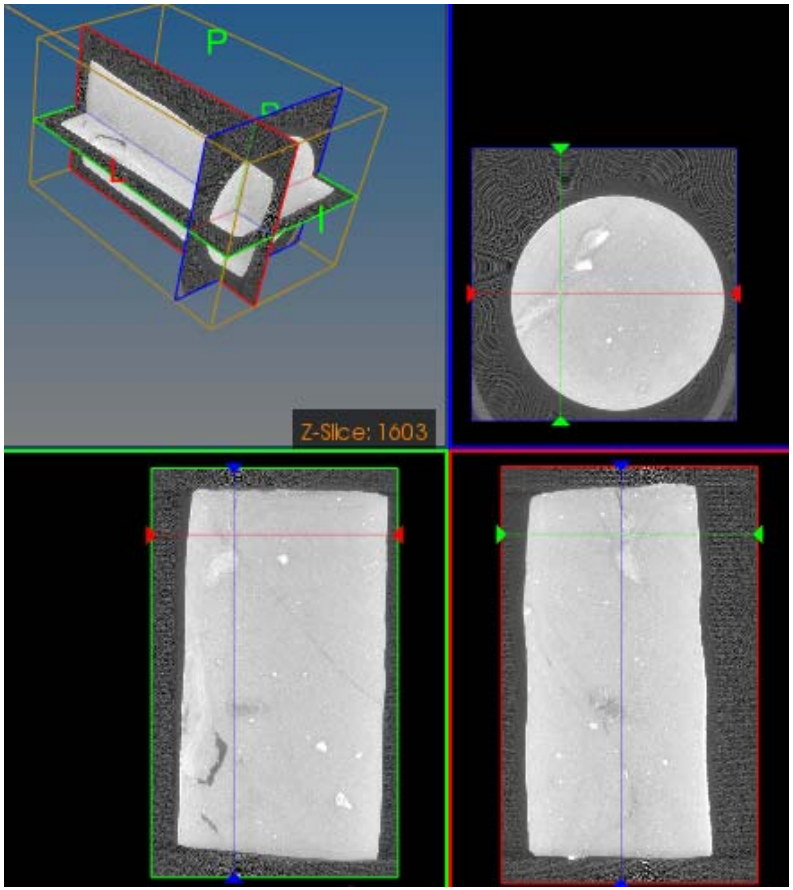
RESULTS

Control Line in CFU31F-2

- Control lines visible in the microdebonding image tracks in both wells as a vertical micro-debonded or fluid-filled features
- Not visible in the fiberglass section
- Visible in 2009 and 2015 ultrasonic logs

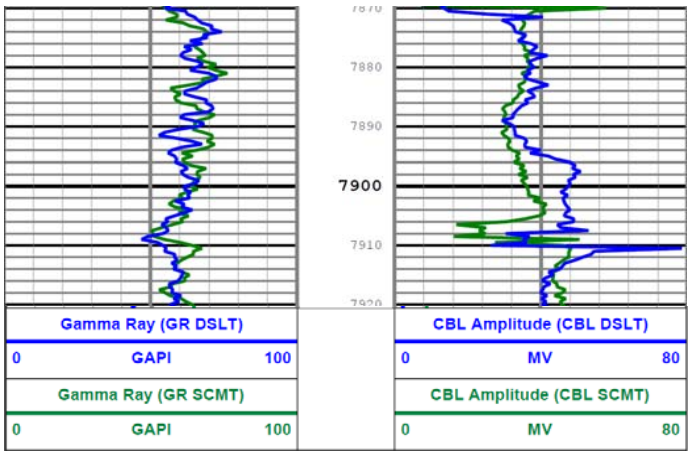


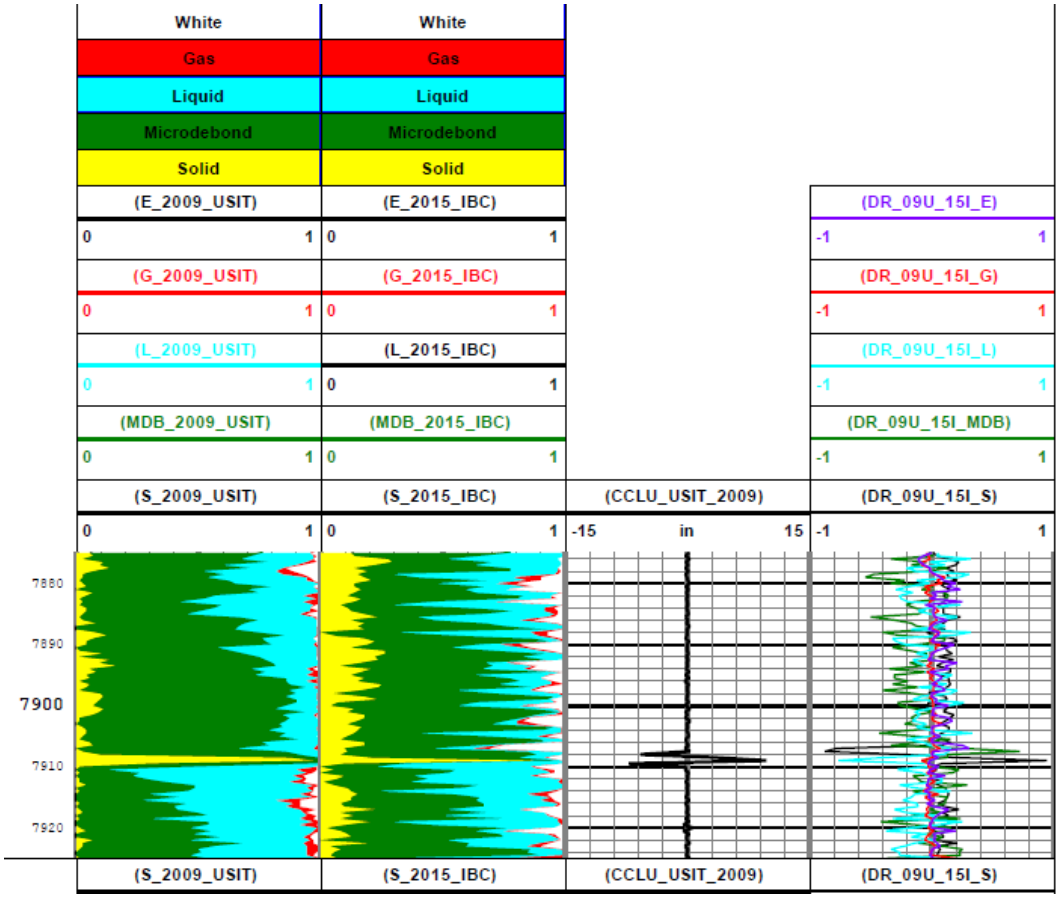
CFU31F-2 7900 ft



- Crack with visible reaction front perpendicular to the wellbore
- Micro-CT shows filled and unfilled portions of the crack

CFU31F-2 Log Analysis at 7900 ft

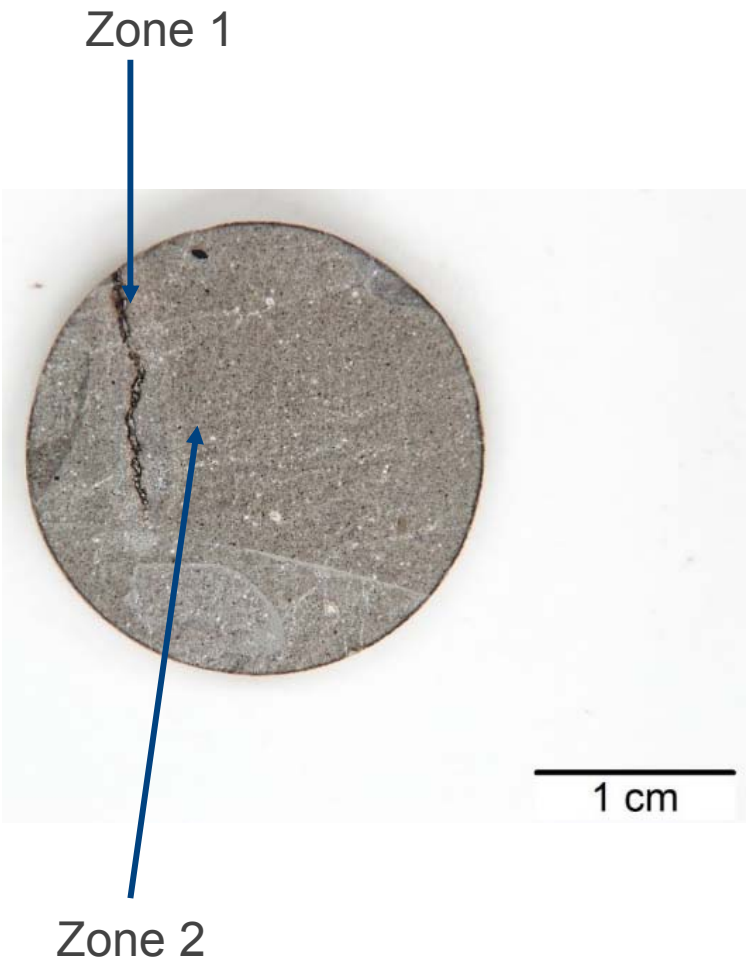




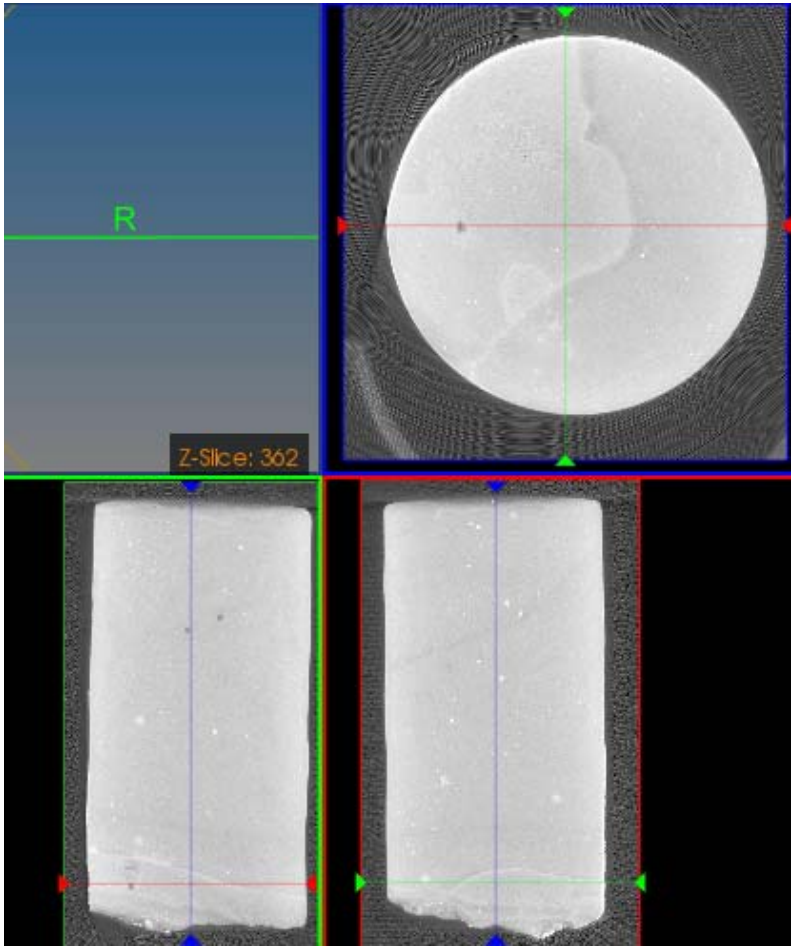
- CBLs show a decrease in amplitude (increased bond)
- Ultrasonic logs show a decrease in solid behind the casing

CFU31F-2 7900-ft XRD

Phase name	Zone 1 Weight %	Zone 2 Weight %
Quartz	20	42
Tilleyite	26	18
Tobermorite M	11	5.8
Calcium Silicate Hydrate	10	10
Brownmillerite, Fe-rich	10	7.2
Calcite	19	10
Halite	4.7	6

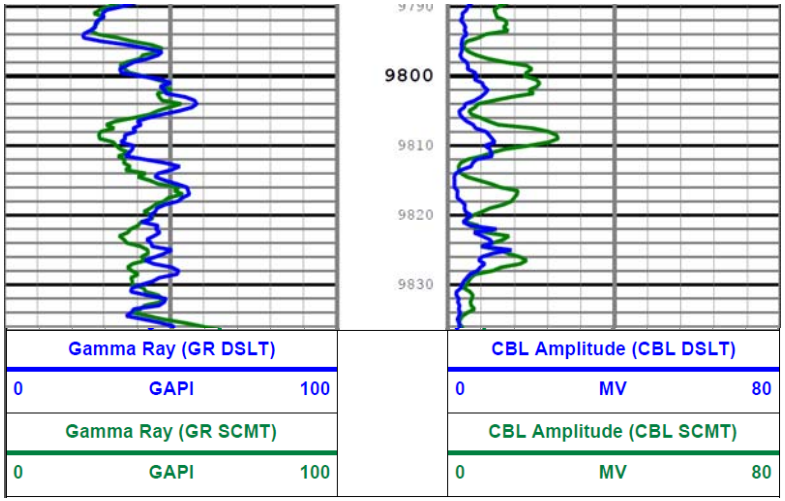


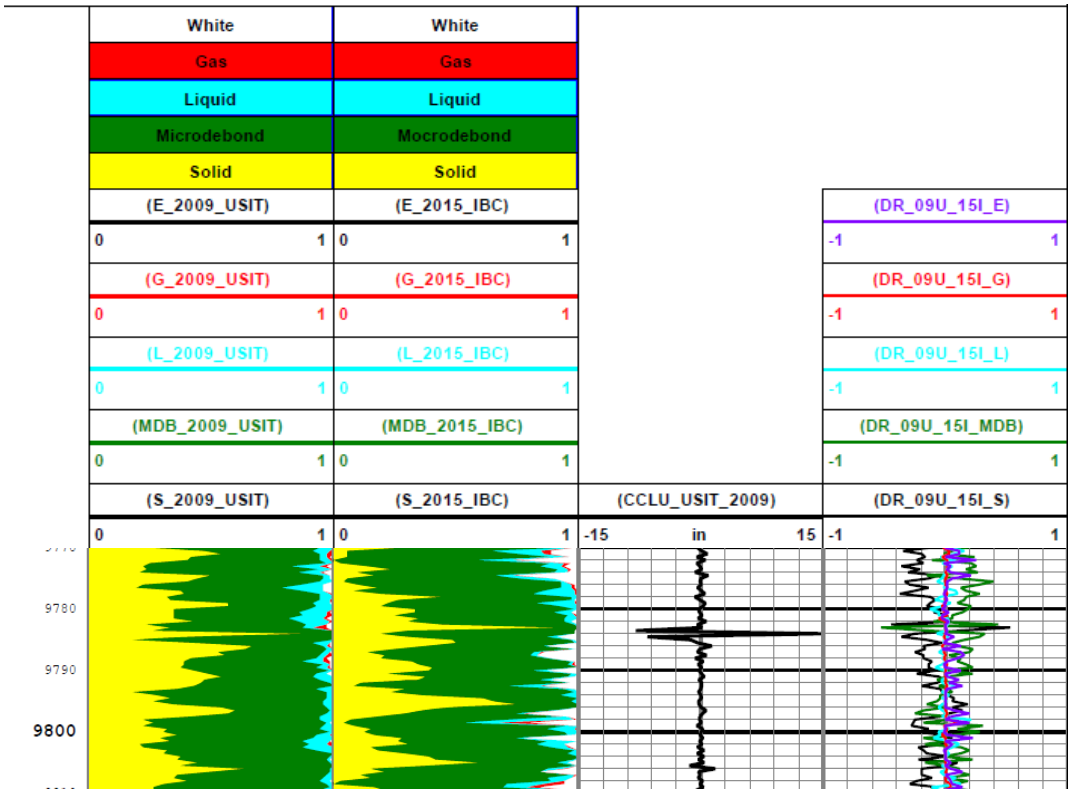
CFU31F-2 9800 ft



- Visible reaction fronts in the casing side of the sample
- Micro-CT shows multiple reaction fronts

CFU31F-2 Log Analysis at 9800 ft

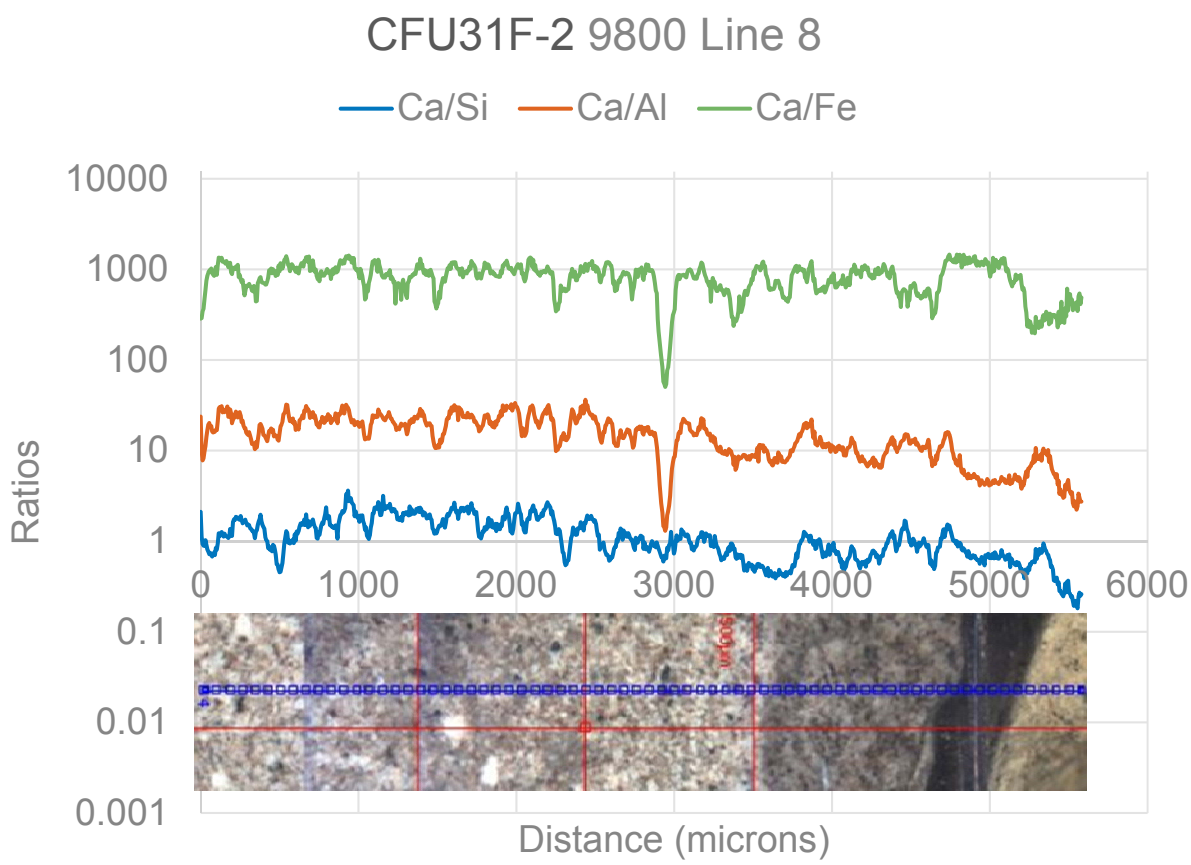


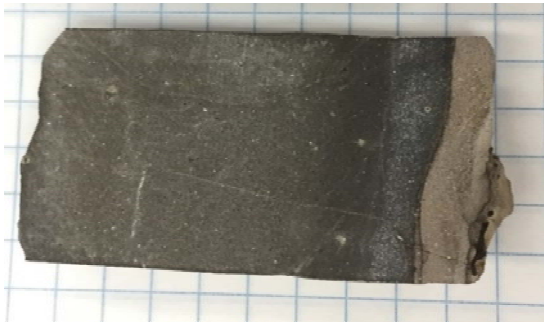


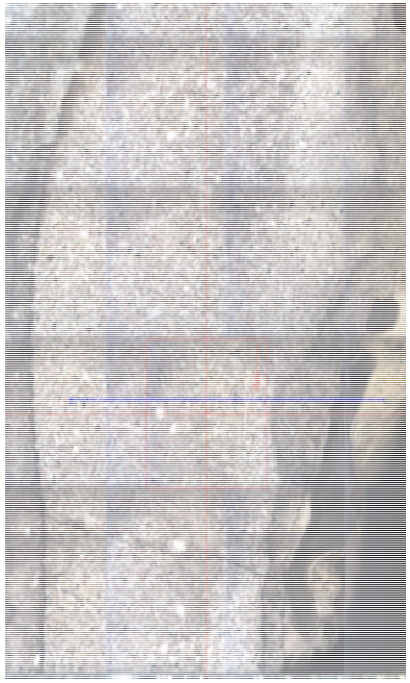
- CBLs show an increase in amplitude (decreased bond)
- Ultrasonic logs show a decrease in solid behind the casing

Reaction Fronts in MSCT sample at 9800 ft

CFU31F-2 9800-ft LA-ICP-MS 2



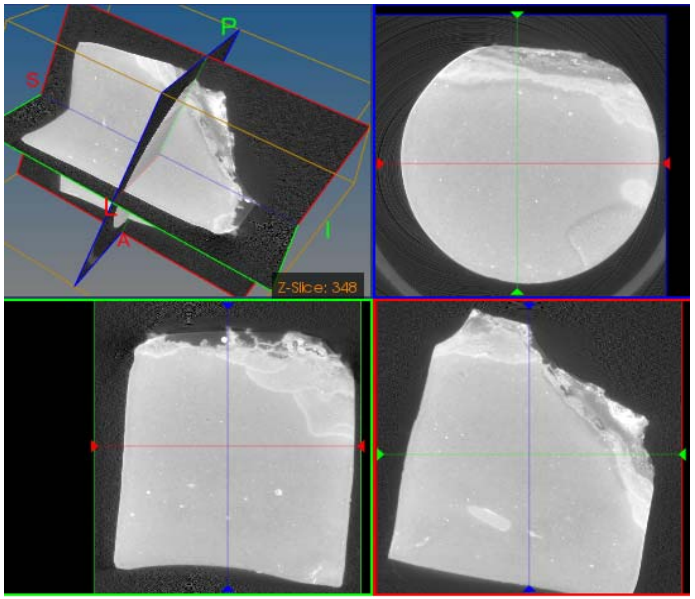


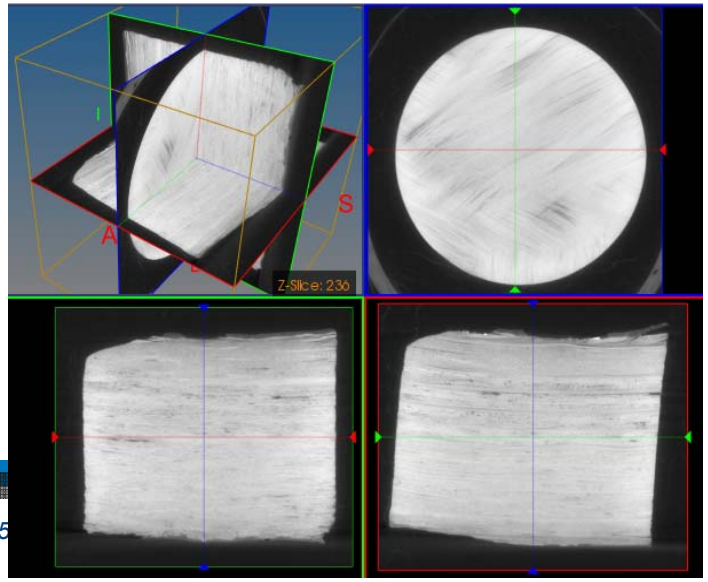


CFU31F-2 9800-ft XRD

Phase name	Zone 1 Weight %	Zone 2 Weight %	Zone 3 Weight %
Tobermorite	2.3	40	25
Quartz	18.4	25.5	24
Calcite	63	10.3	22
Aragonite	11.7	-	-
Vaterite	0.7	-	2
Zeolite UTD-1	2.2	-	-
Brownmillerite	-	5.6	13
Tilleyite	-	7	14
Srebrodolskite	1.4	2.8	-
Calcium Silicate Hydrate	-	7.3	-
Gehlenite	-	1.4	-

CFU31F-3 10380 ft





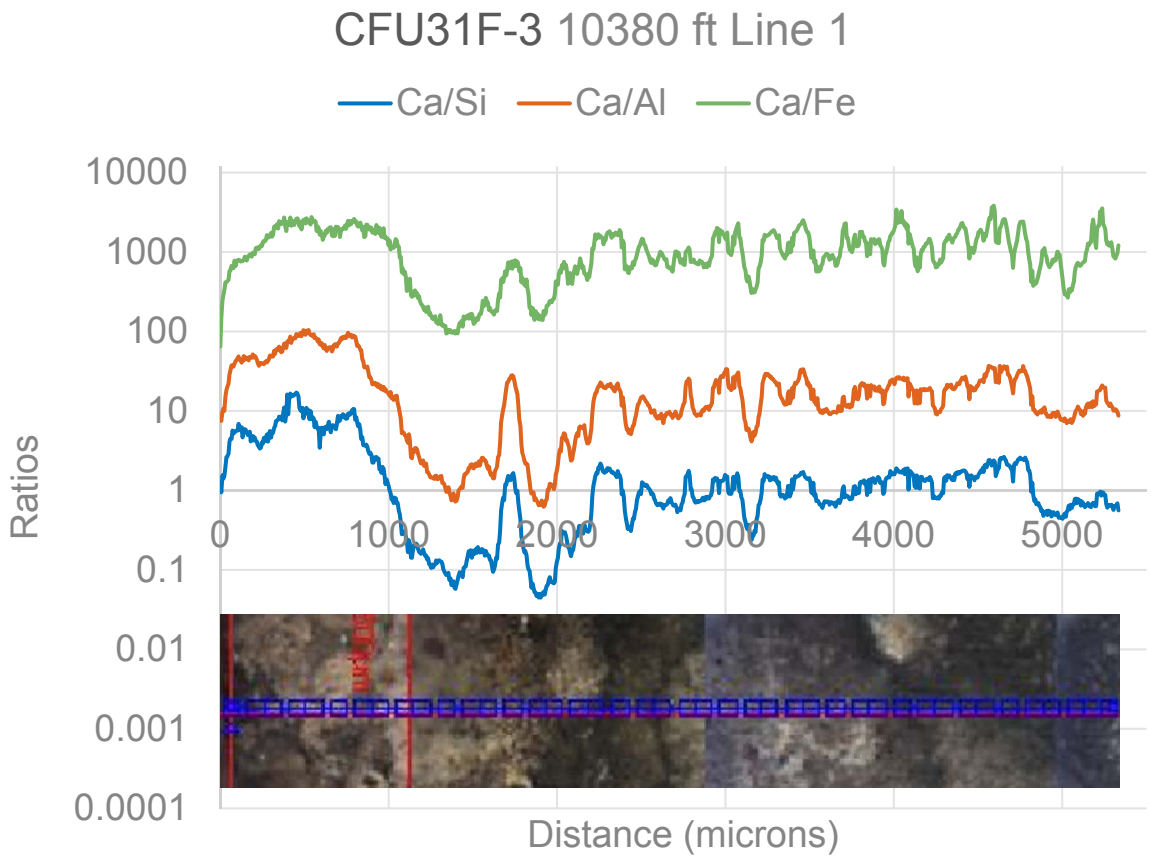
- Cored control line
- Reaction fronts leading away from control line/cement-casing interface
- Micro-CT shows multiple reaction fronts

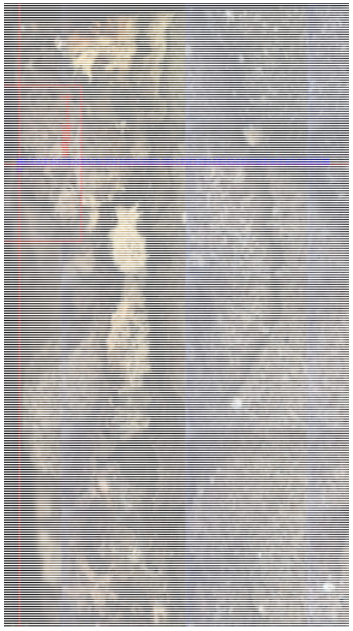
10380-ft Cement Sectioned

LA-ICP-MS

ESEM
XRD

CFU31F-3 10380-ft LA-ICP-MS

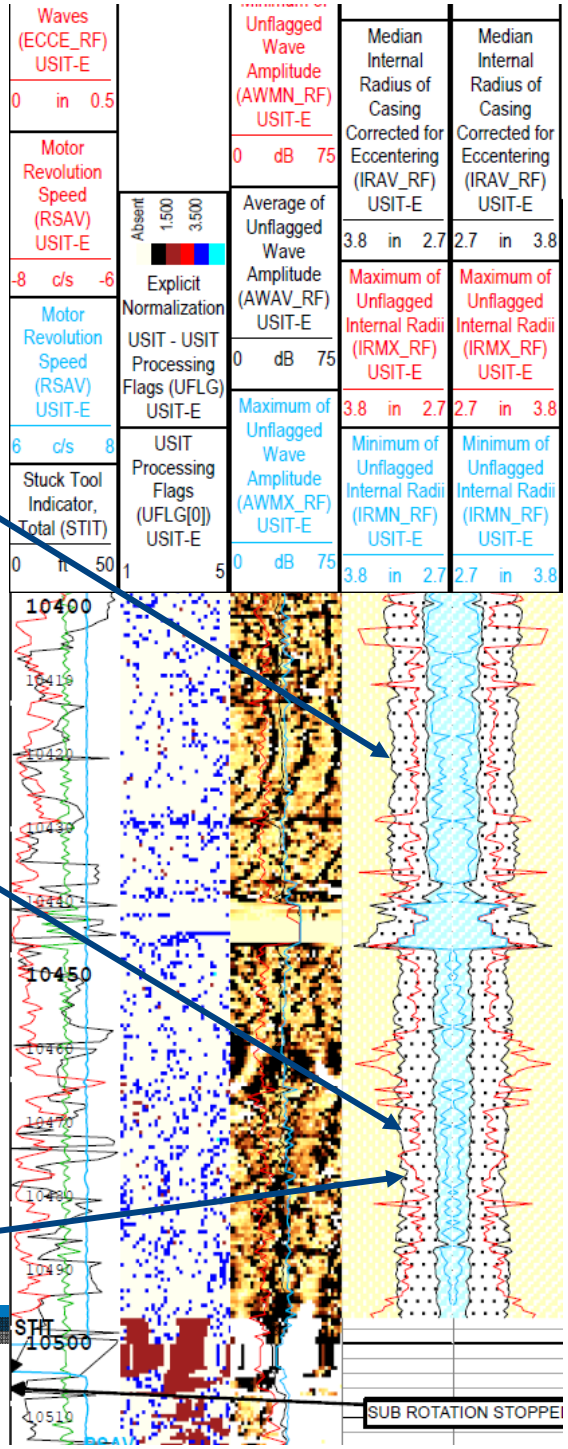


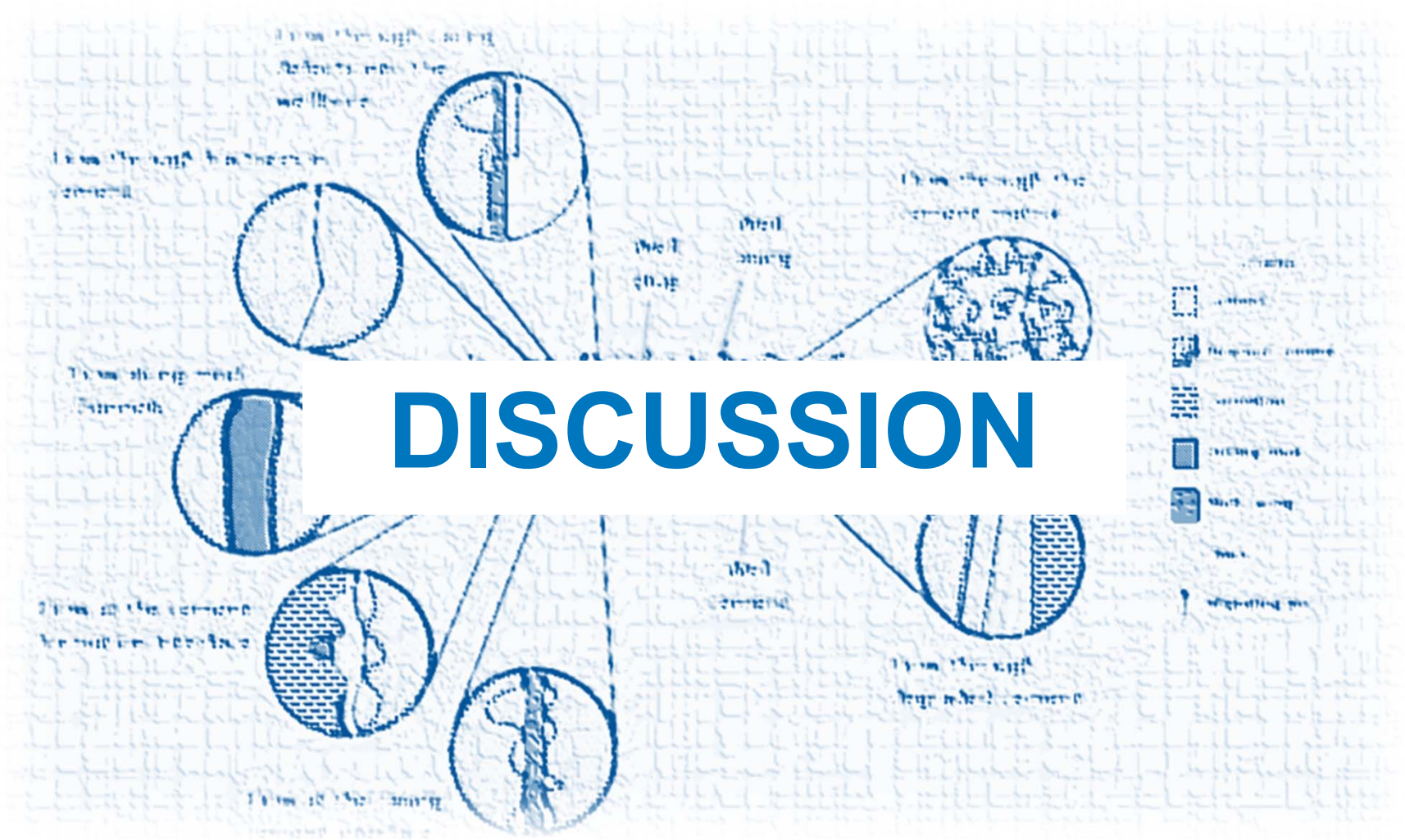


CFU31F-3 10380-ft XRD

Phase name	Zone 1 Weight %	Zone 2 Weight %	Zone 3 Weight %
Halite	2.3	15	15.2
Quartz	8.4	10.7	19
Calcite	84	15	12
Vaterite	-	19	-
Faujasite-Ca, dehydrated	-	3	-
Tobermorite M	4.2	-	16.2
Tobermorite 9A	-	38	-
Tilleyite	0.4	-	19
Brownmillerite, Fe-rich	0.1	-	7.1
Wollastonite, ferroan 1A	0.6	-	11

Fiberglass Casing Degradation





DISCUSSION

Discussion

- Control lines and hardware are visible as low acoustic impedance features between the CO_2 reservoir at the log top-of-cement indicating that they are not bonded to the casing and could represent a migration pathway.

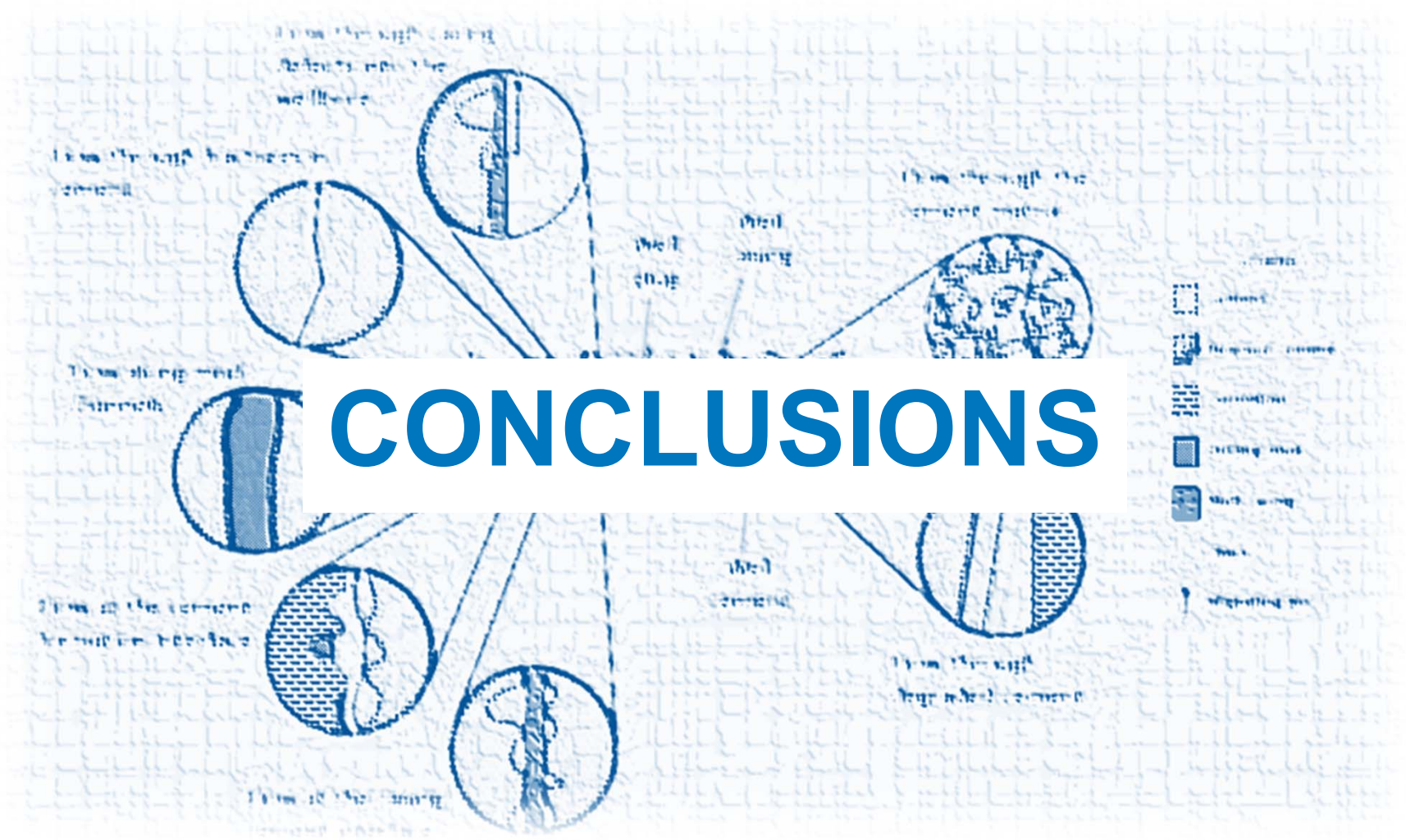
- Deterioration of the acoustic impedance and CBL signals in the logs is evident over much of the section that was relogged in 2015.

- Each of the cores collected in each well showed carbonation.
  - Both XRD and LA-ICP-MS indicate carbonation occurring at the cement-casing and cement-formation interfaces.
  - LA-ICP-MS shows increases in Ca/Si that are likely calcium carbonate fronts and decreases in Ca/Si near the edges of the sample that indicate calcium depletion.

Discussion

- The core collected at 10380 ft consisted of casing, control line, and cement. The cement portion of the core showed visible reaction fronts moving into the sample from the control line / casing side.
  - XRD conducted on the sample show carbonation in each of the zones analyzed.
  - The carbonation is highest adjacent to the control line / casing interface, with 84 percent calcite, and smallest near the formation with 12 percent calcite.

- The degradation of the fiberglass casing in the reservoir CO_2 zone can be seen in both the logs and the casing samples collected. The logs show the worst damage in the CO_2 zone with less damage above the CO_2 zone and the least damage below the CO_2 zone.



CONCLUSIONS

CONCLUSIONS

- High carbonation along the interfaces and the geometry of the damage to the fiberglass casing indicate that CO_2 is migrating along the casing.
  - buoyant CO_2 will migrate up from the reservoir causing more damage above the CO_2 zone than below the CO_2 zone.

- Time-lapse comparison of cement bond amplitude data and acoustic impedance maps imply a deterioration of cement bond or cement along much of the long-string section.

- Analysis of sidewall cores using XRD and LA-ICP-MS validates the log interpretation by confirming the degradation of cement (carbonation) along the casing-cement interface.

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CONCLUSIONS

- The ultrasonic image maps also clearly identify the control lines and monitoring technology attached to the outside of the casing. The sidewall core through the control line at 10380 ft confirms that CO_2 is migrating along the control line.
  - Study of other wells with external lines should be conducted to see of the results of the this study are normal or an exception.

REFERENCES

REFERENCES

1. Duguid, A., Carey, J.W., Celia, M., Chuganov, N., Gasda, S., Ramakrishnan, T.S., Stamp, V., and Wang, J., "Baseline integrity property measurement of legacy oil and gas wells for carbon storage projects," *Greenhouse Gases Science and Technology,* In Press.
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3. Carey JW, Wigand M, Chipera SJ, WoldeGabriel G, Pawar R, Lichtner PC, Wehner SC, Raines MA, Guthrie GD Analysis and performance of oil well cement with 30 years Of CO_2 exposure from the SACROC Unit, West Texas, USA. International J of Greenhouse Gas Control 2007:1:75–85.

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It can be done

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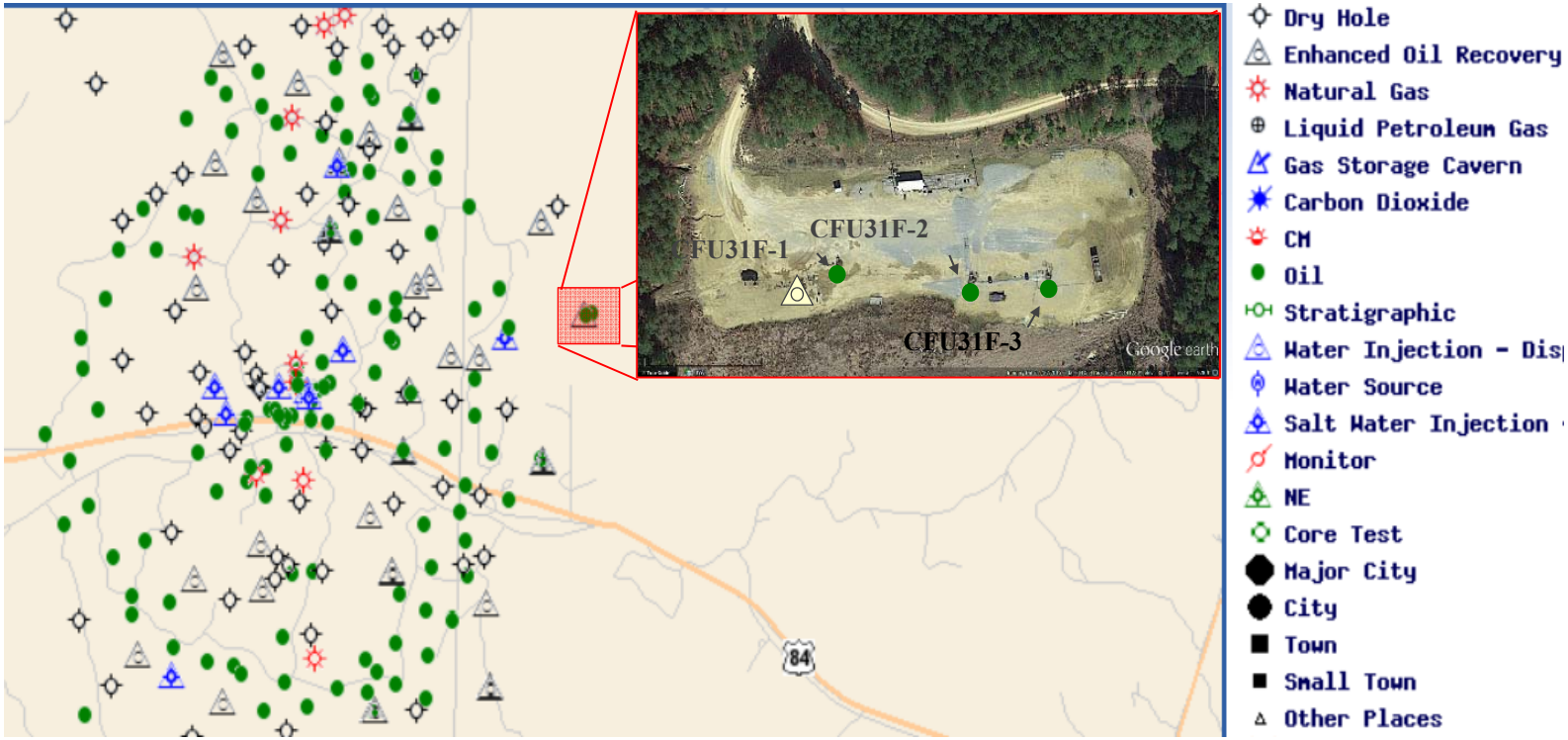
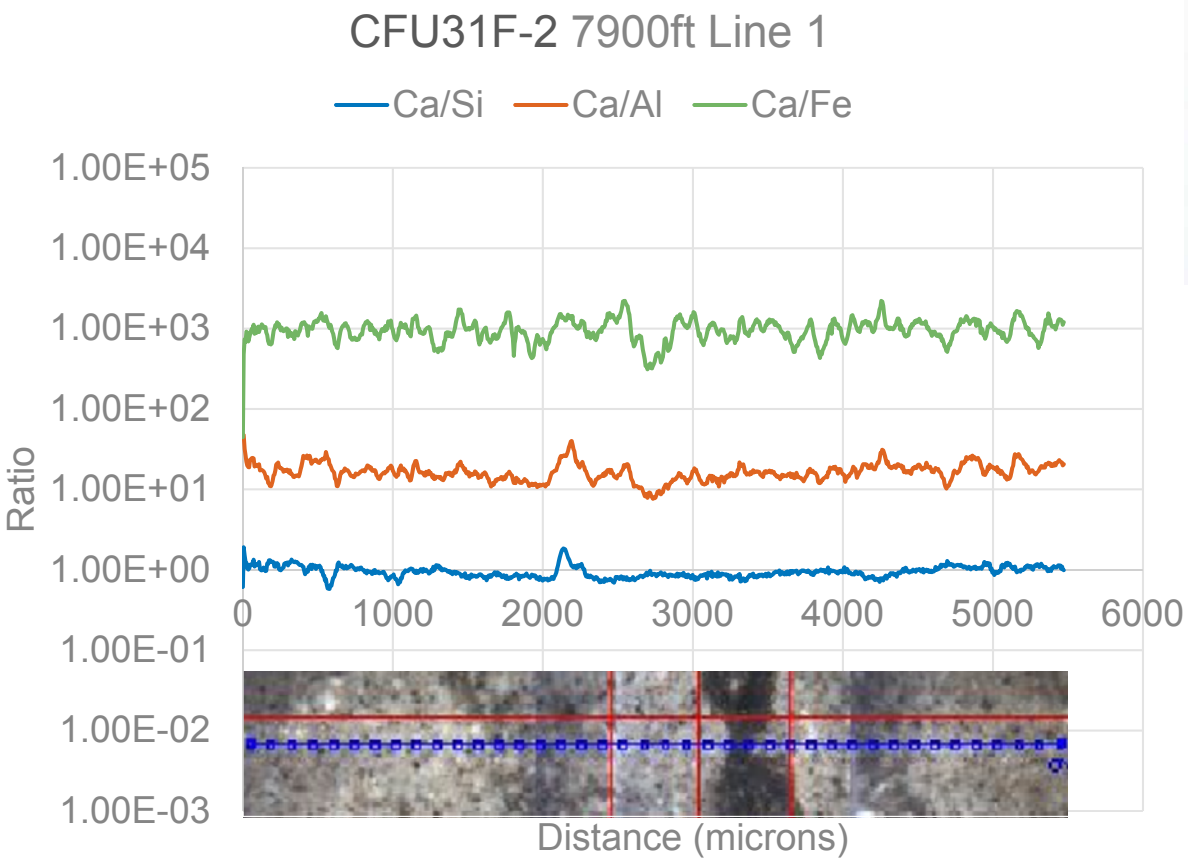
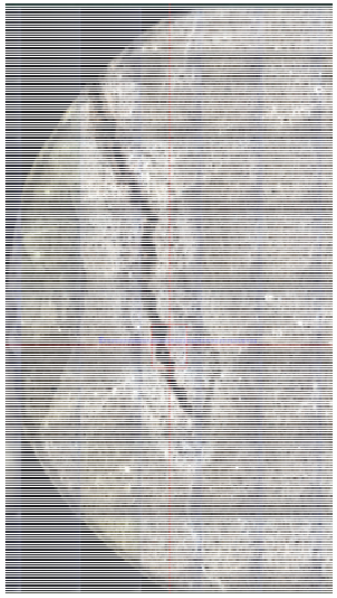
Cranfield Field

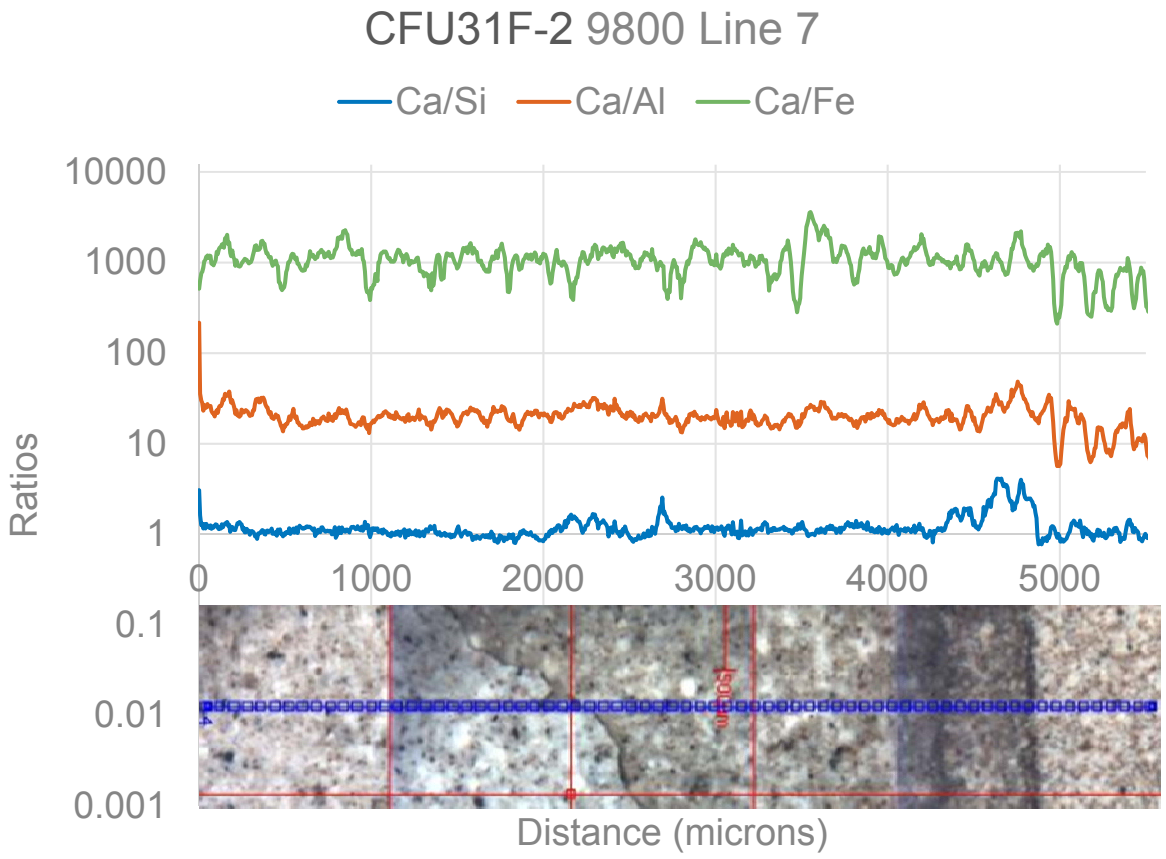


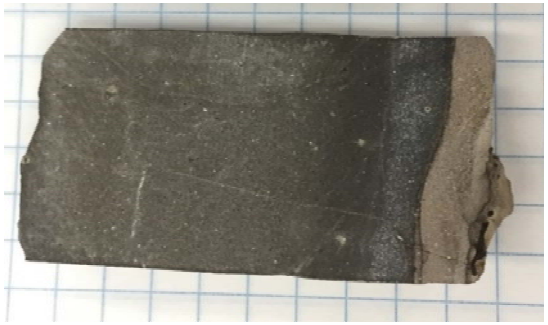
CFU31F-2 7900-ft LA-ICP-MS

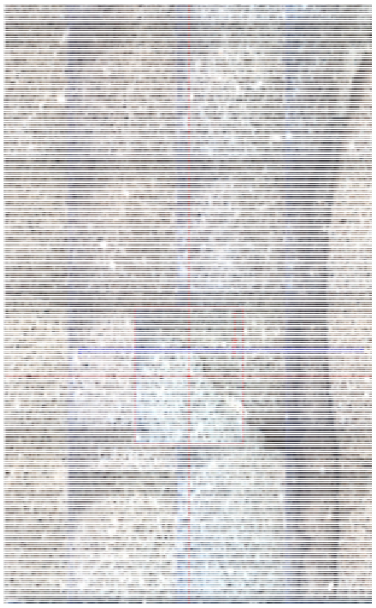




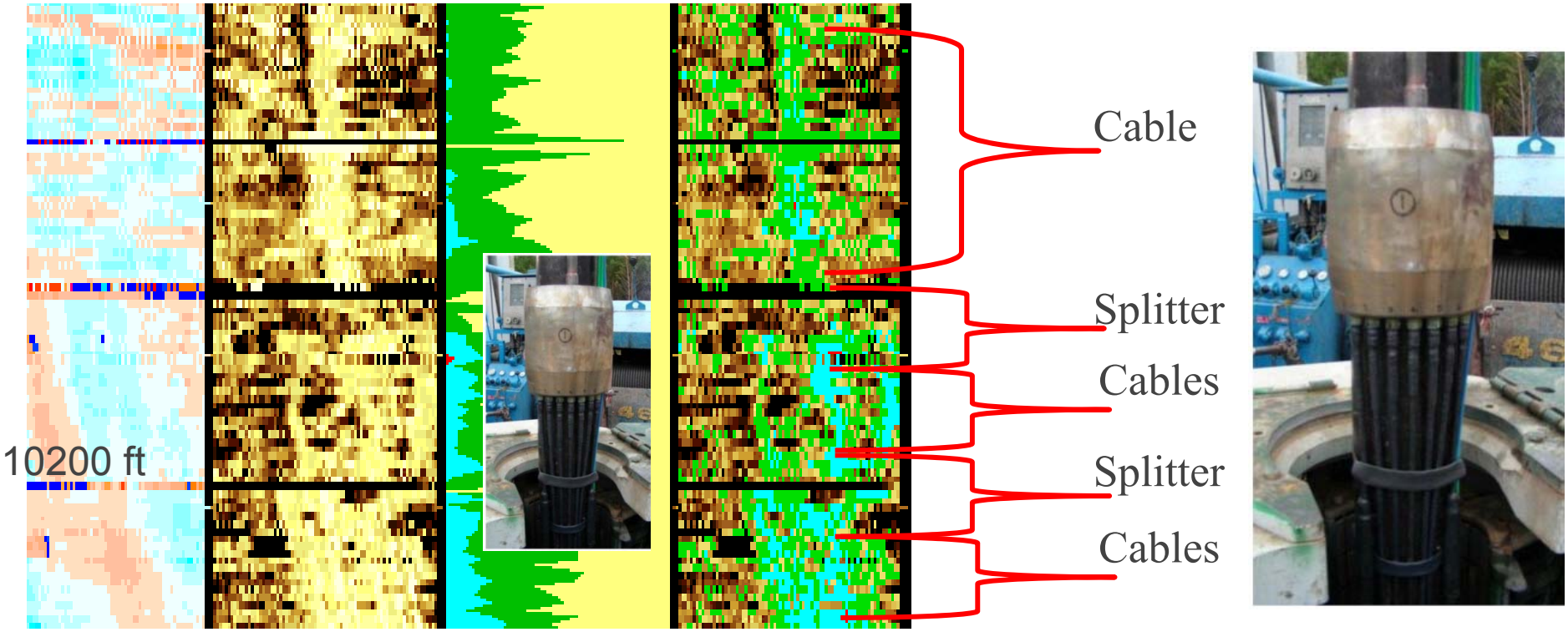
CFU31F-2 9800-ft LA-ICP-MS 1







Jewelry and Control Lines (10200 ft)



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