Statistical Analysis of CO_2 Exposed Wells to Predict Long Term Leakage through the Development of an Integrated Neural-Genetic Algorithm

A Collaborative Project

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National Energy Technology Laboratory

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Outline

- **Objective of Project**
- **Methodology**
- **Project Schedule**
- **Accomplishments to Date**
  - **Data Mining**
  - **Software Development**
  - **Field Testing & Data Analysis**
- **Summary**

Objective of Project

The overall objective of this project is the development of a novel computer model for predicting long-term leakage risks of wells exposed to CO_2.

The final goal is to deliver DOE and public a useful tool for evaluating the risk of long-term leakage of wells in future CO_2 sequestration projects.

Methodology

- **Create likely leakage scenarios for specific well attributes** (injection wells, producing wells, abandoned wells, and wells subjected to corrosion). The goal of this stage is to understand the major leak mechanisms in different well conditions.
- **Develop a neural-genetic algorithm model to predict leakage risks for CO2 –exposed wells.** The goal of this stage is to develop a comprehensive computer model ready to be validated using field data.
- **Verify model results by conducting field sampling** including side wall cores samples, pressure testing data, and well logs of existing wells and compare the results with the model's results. This is a stage to verify the accuracy of the computer model with field data.

Project Schedule

Year	2013				2014				2015				Team Member and Role
Quarter	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	
Task 1: Project Management and Planning													Guo (PI), Nygaard (Co-PI), Duguid (Co-PI)
Task 2: Data Mining													Guo (PI), Nygaard (Co-PI), Duguid (Co-PI)
Task 3: Statistical Analysis of Database													Nygaard (Co-PI)
Task 4: Developing Leakage Scenarios													Guo (PI), Nygaard (Co-PI), Duguid (Co-PI)
Task 5: Constructing Preliminary Neural-Genetic Algorithm													Guo (PI), Sedaghat and Li (programmers)

Phase I

Phase II

Year	2014				2015				2017				Team Member and Role
Quarter	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	
Task 6: Constructing Comprehensive Neural-Genetic Algorithm													Guo (PI), Sedaghat and Li (programmers)
Task 7: Field Work Confirmation of Leakage Scenarios													Duguid (Co-PI)
Task 8: Field Sample Analysis													Guo (PI), Sedaghat and Li (data analysts)
Task 9: Verification of Model with Field and Lab Results													Guo (PI), Sedaghat and Li (data analysts)
Task 10: Risk Study, Mitigation Actions, and Standard Recommendations													Guo (PI), Nygaard (Co-PI), Duguid (Co-PI)

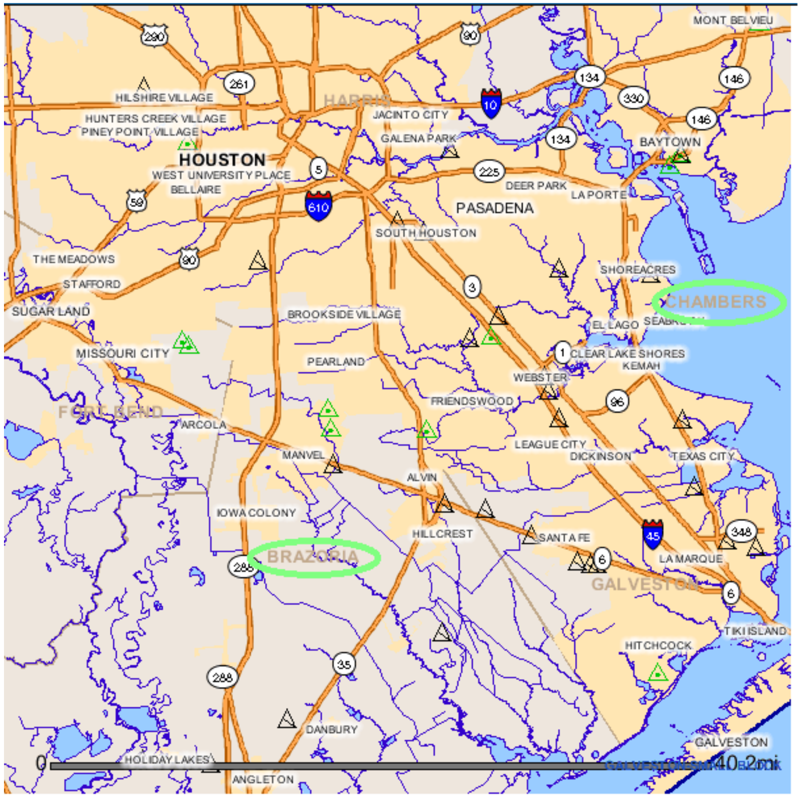
Phase II

Phase III

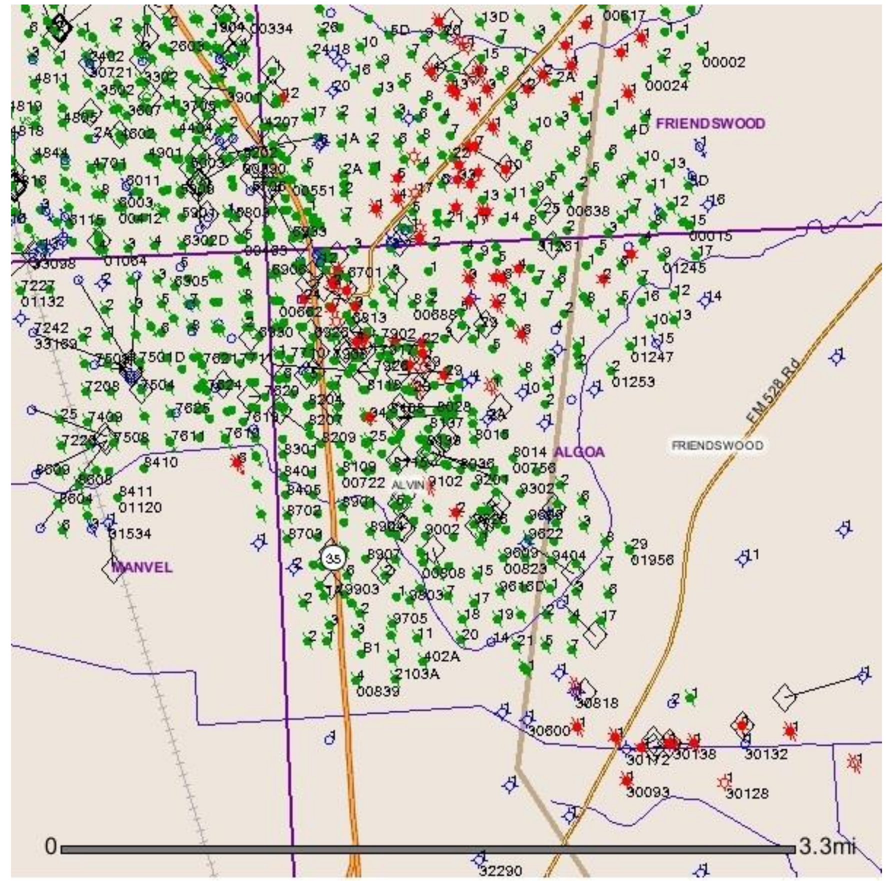
Accomplishments to Date

- ✓ Phase I: Data Mining
- ✓ Phase II: Neural-Genetic Modeling
- ➢ Phase III: Field Testing

Review of Phase I

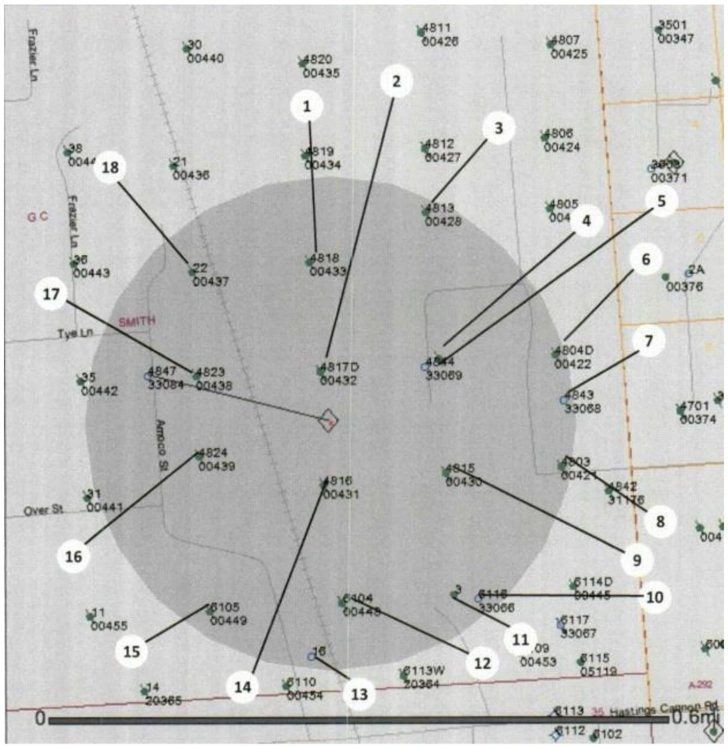


Oyster Bayou Oil field



West Hastings Oil Field

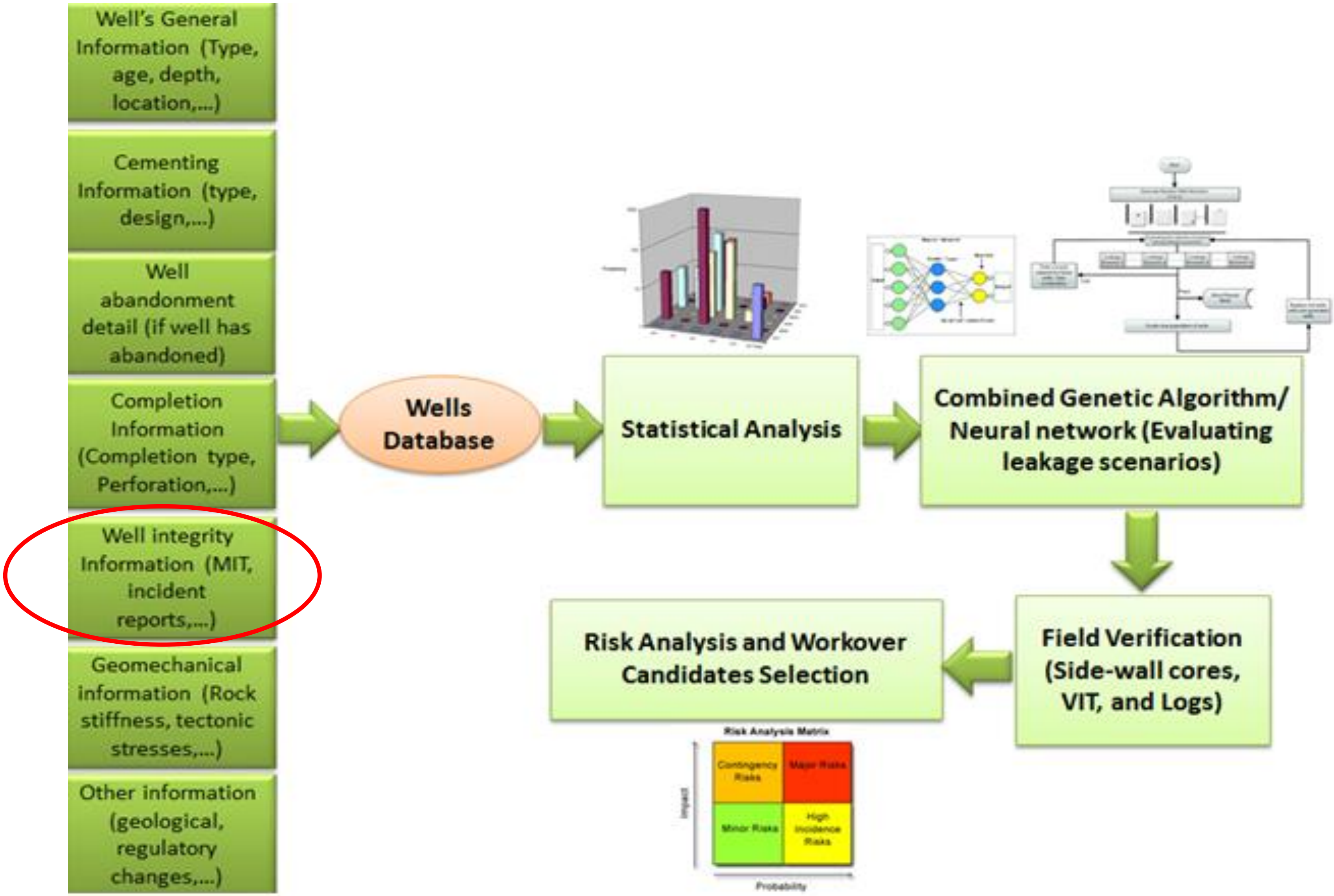
Data Collected from 510 wells



1/4 Mile Radius of Well 4847

Oil Field	CO_2 Injection Wells	Plugged Wells	Subtotal
Oyster Bayou	56	372	428
West Hastings	27	55	82
TOTAL	83	427	510

72 parameter values for each well



Well Integrity Information

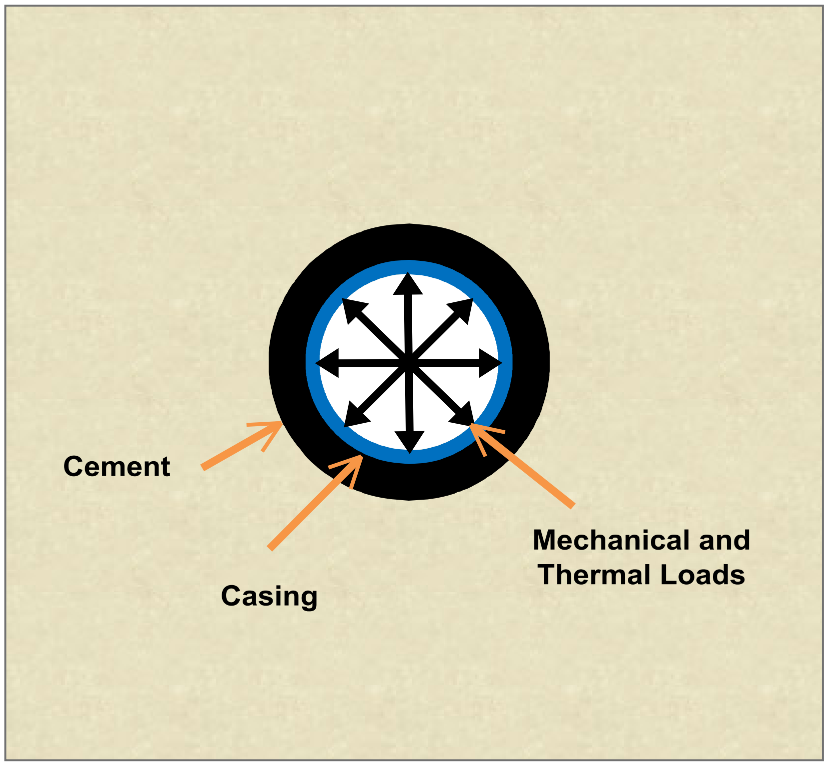
A. Analytical solutions

- The maximum permissible pressure (MaxPP)
- The minimum permissible pressure (MinPP)

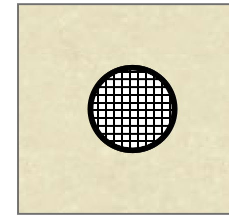
B. Finite-element modeling

- Mechanical loads
- Thermal load

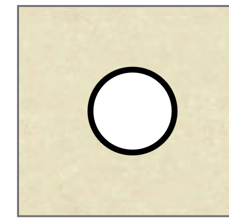
Staged approach to finite-element modeling including thermal and mechanical loads has been developed



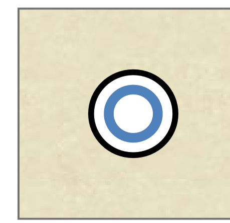
Step 1- Loading the model with in-situ stress (horizontal and vertical stresses)



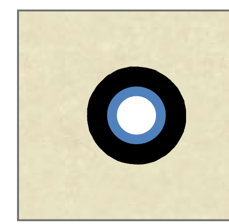
Step 2- Simulating of drilling step by removing wellbore elements and applying mud weight



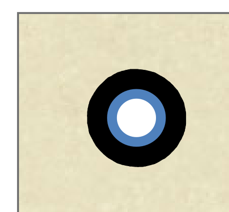
Step 3- Adding casing elements to the model



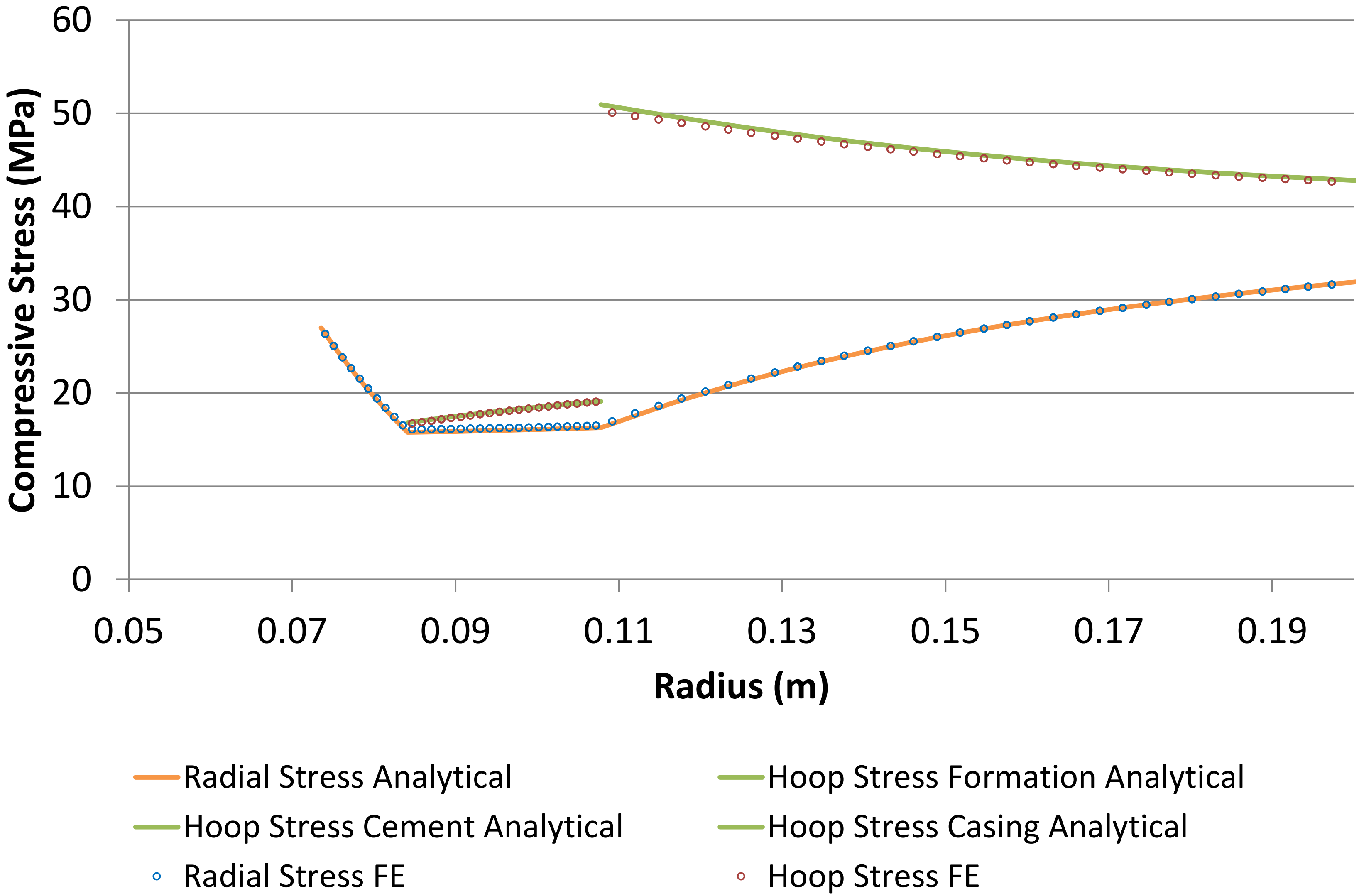
Step 4- Adding cement elements to the model



Step 5- Applying mechanical and thermal loads to the cased wellbore

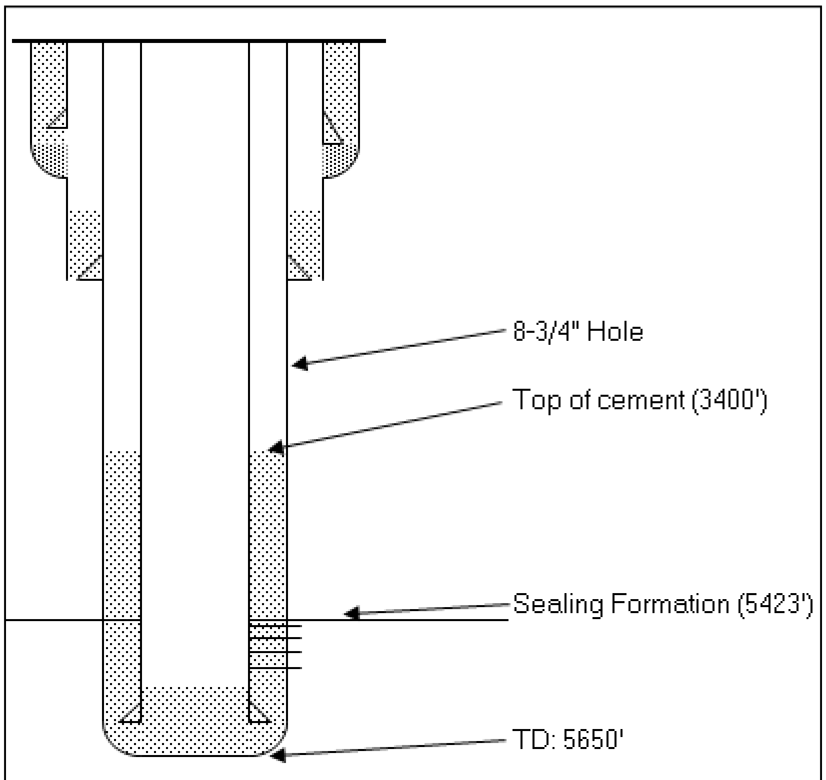


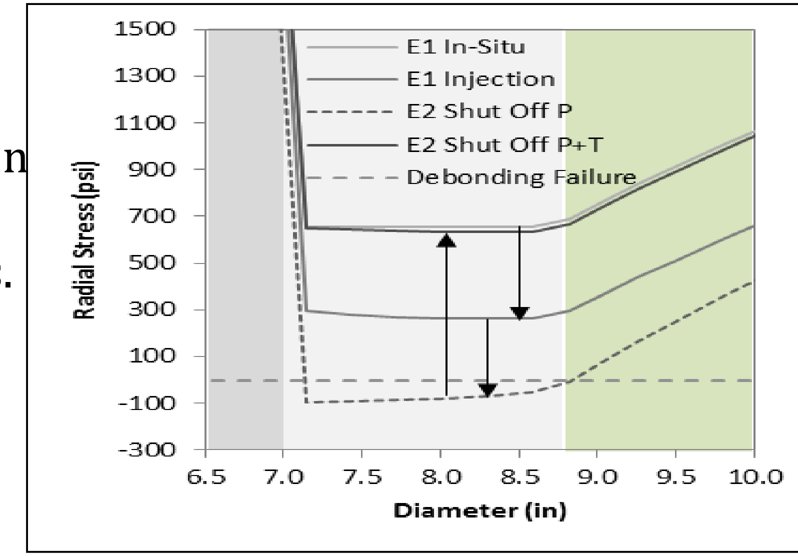
The developed Finite Element model have been verified with analytical models for simple cases

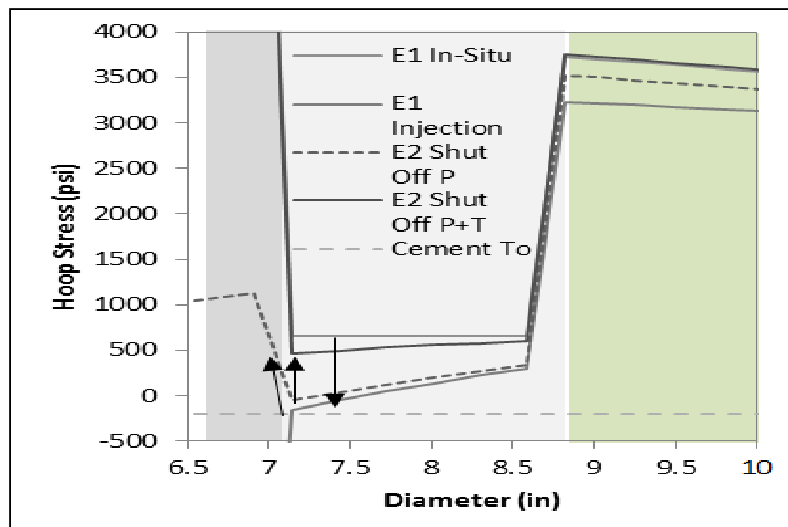


Finite Element Model for well integrity analysis shows that de-bonding can create leakage pathways during CO2 injection

Actual CO_2 Injection Well (Schlumberger Carbon Services)
Cores gathered along the production section
Lab samples made to replicate cement composition to obtain material parameters.



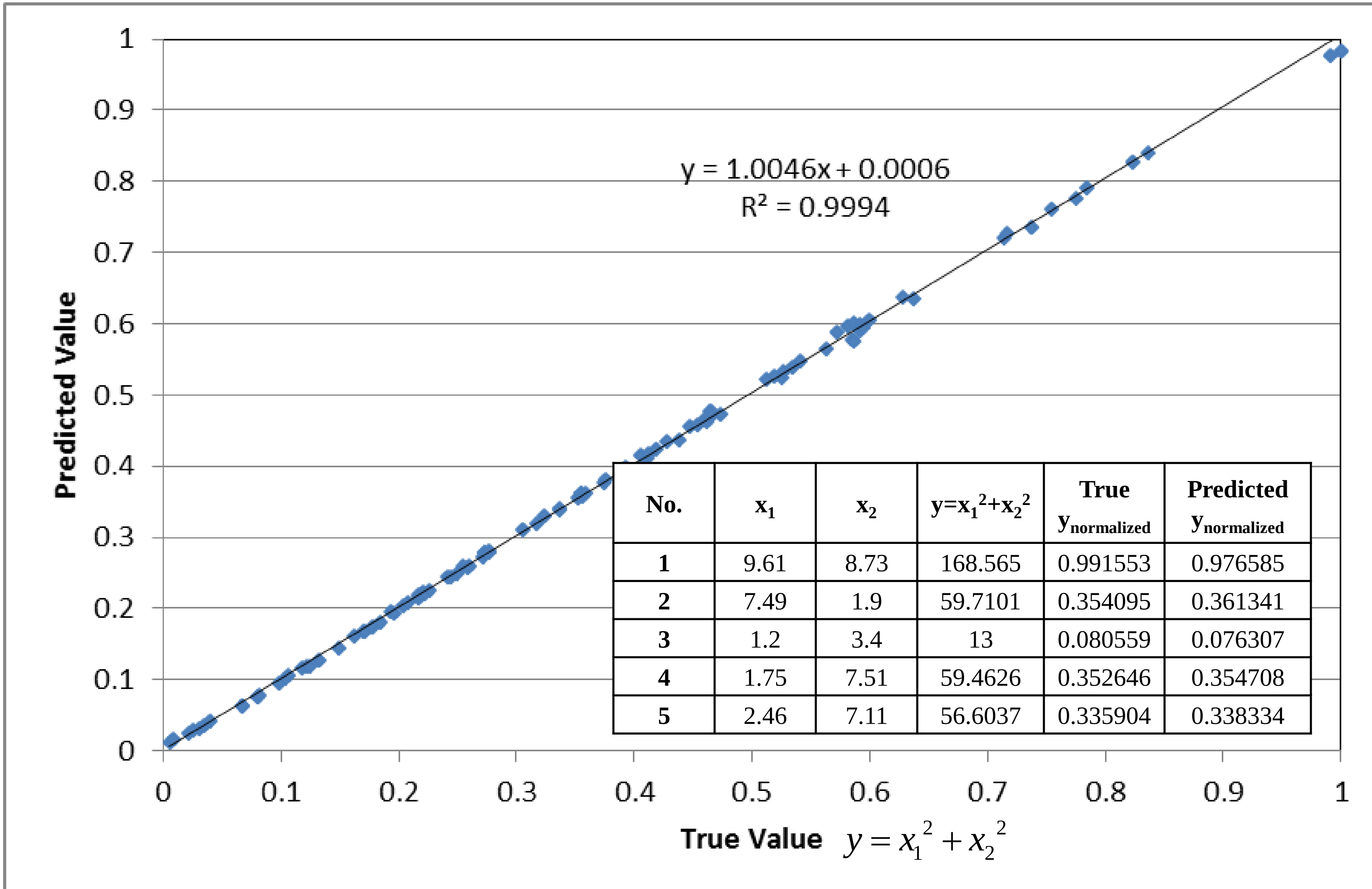




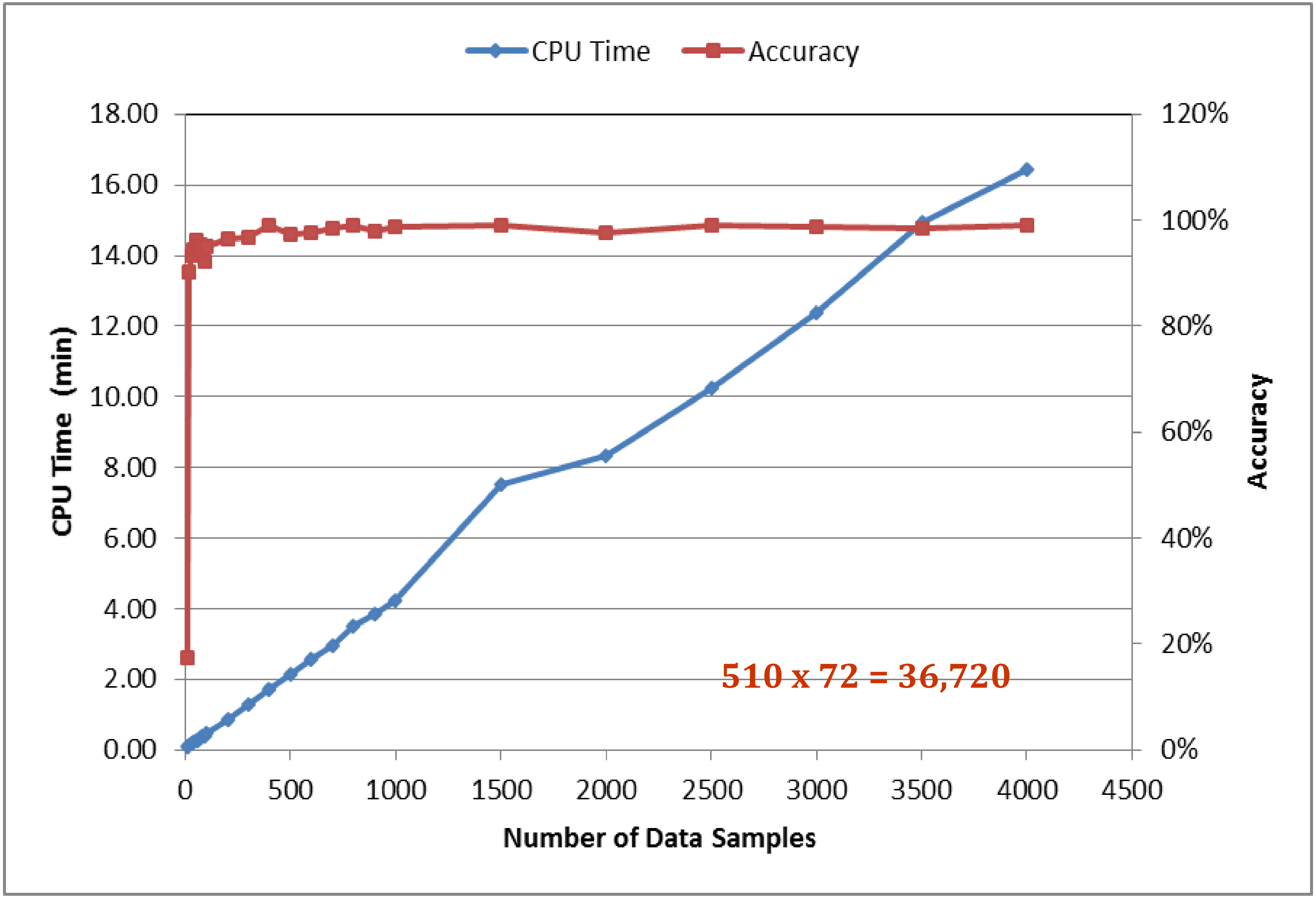
Review of Phase II

- **Software Development**
    - Neural-Genetic Model for CO_2-Explosed wells
    - Finite Element Model for well integrity analysis
- **Field Work**
    - logs
    - Pressure transient tests
    - Sidewall core samples

Neural-Genetic Model for CO2-Explosed wells



No.	x_1	x_2	$y=x_1^2+x_2^2$	True $y_{normalized}$	Predicted $y_{normalized}$
1	9.61	8.73	168.565	0.991553	0.976585
2	7.49	1.9	59.7101	0.354095	0.361341
3	1.2	3.4	13	0.080559	0.076307
4	1.75	7.51	59.4626	0.352646	0.354708
5	2.46	7.11	56.6037	0.335904	0.338334

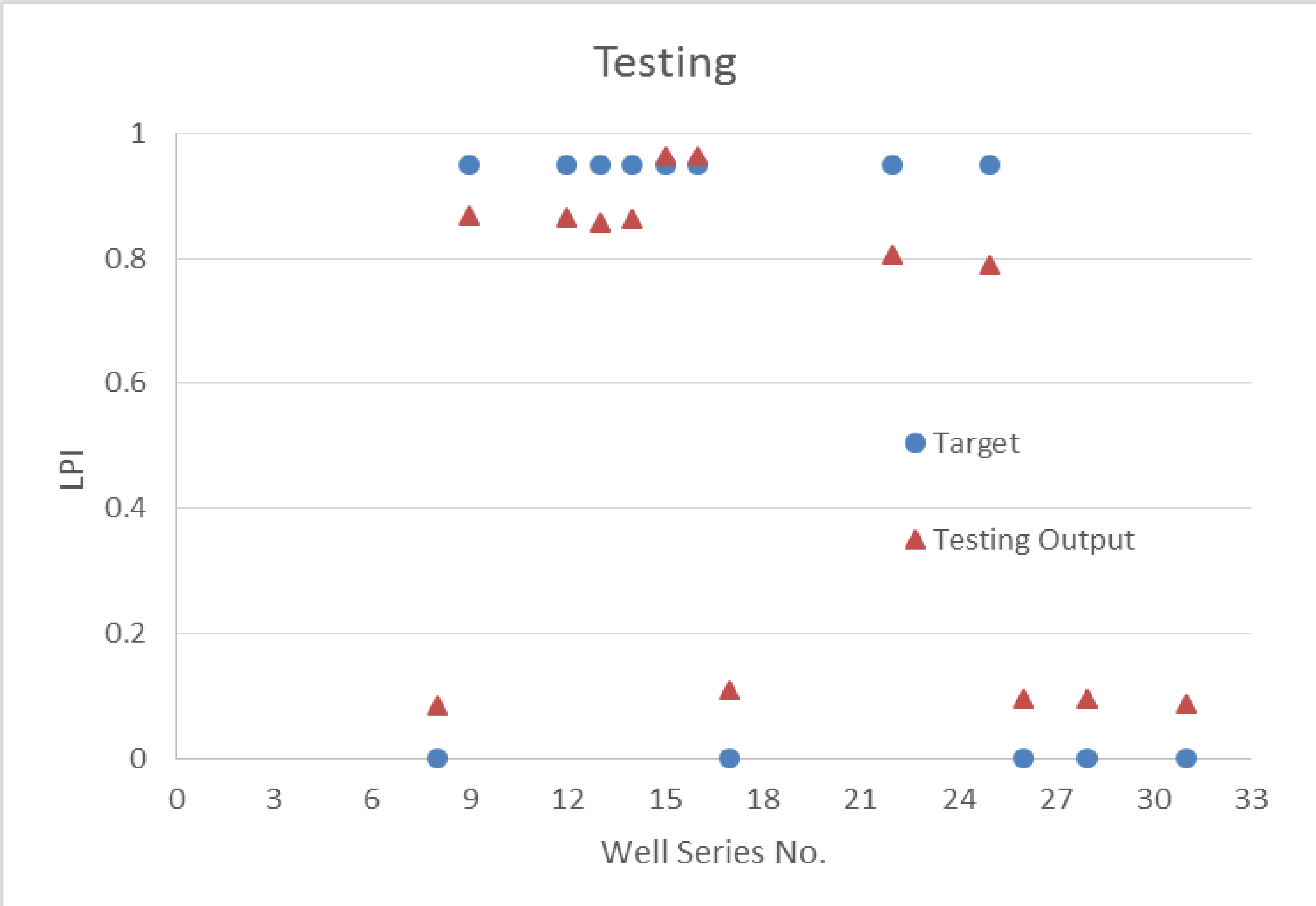


CPU Time
Accuracy
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
CPU Time (min)
120%
100%
80%
60%
40%
20%
0%
Accuracy
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Number of Data Samples
510 x 72 = 36,720

Leakage-safe Probability Index (LPI)

1. Well Schematic Indicator (WSI)
2. Cement Sheath Integrity Indicator (CSII)
3. Cement Type Indicator (CTI)
4. Well Age Indicator (WAI)

LPI=f(WSI, CSII, CTI, WAI)



Testing
1
0.8
0.6
0.4
0.2
0
LPI
0
3
6
9
12
15
18
21
24
27
30
33
Well Series No.
Target
Testing Output

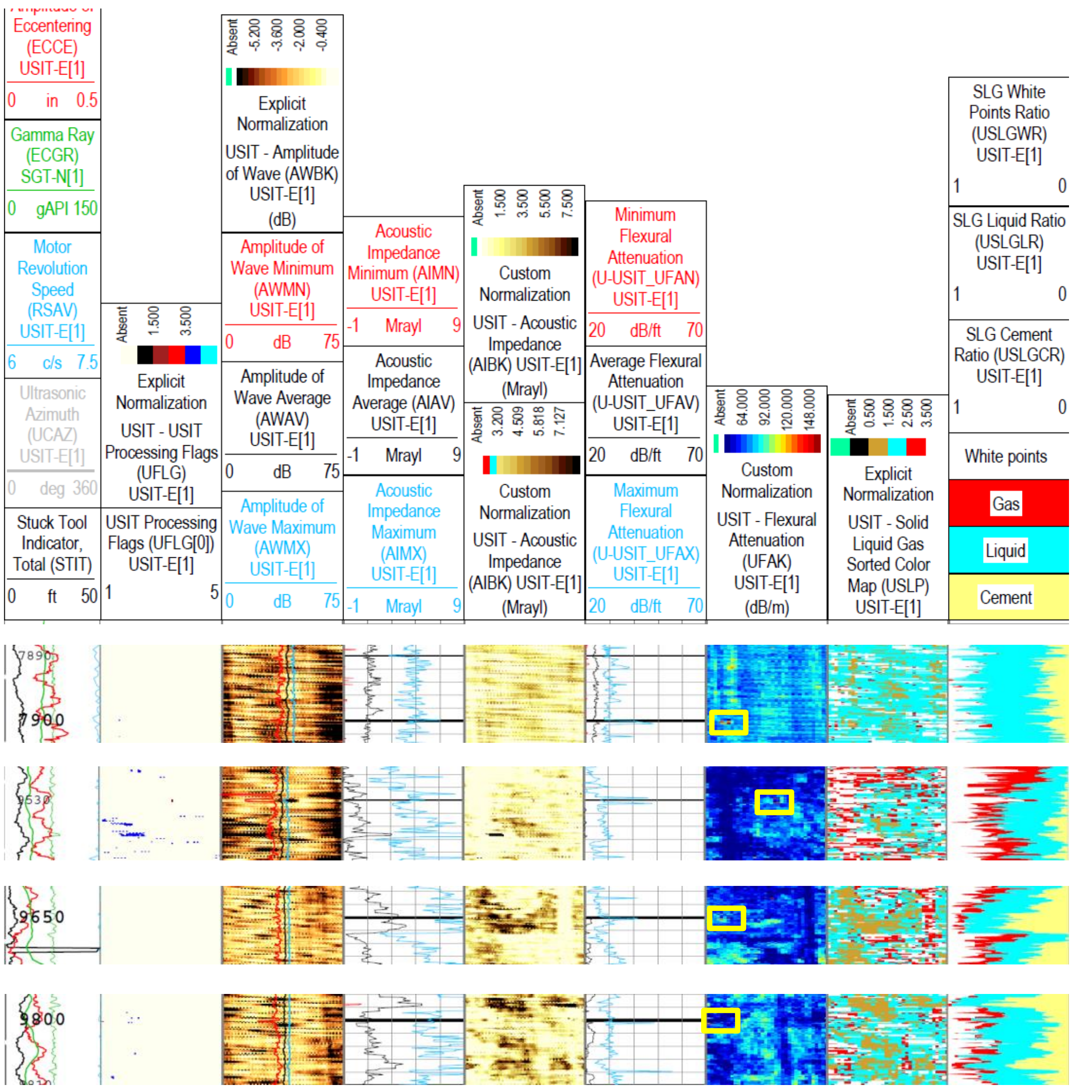
Preliminary Field Verification of the Model

Cranfield field site in southwest Mississippi Well CFU31F2

- Cement sidewall core at 3 depths (7,900 ft – 9,800 ft)
- Pressure data at 9,535ft
- Micro de-bonding log at 9,000ft-10,000ft
- Isolation scanner log 7,000ft-10,000ft

Leakage-Safe Probability Index (LPI) = 0.780.

Cement sidewall core at 3 depths



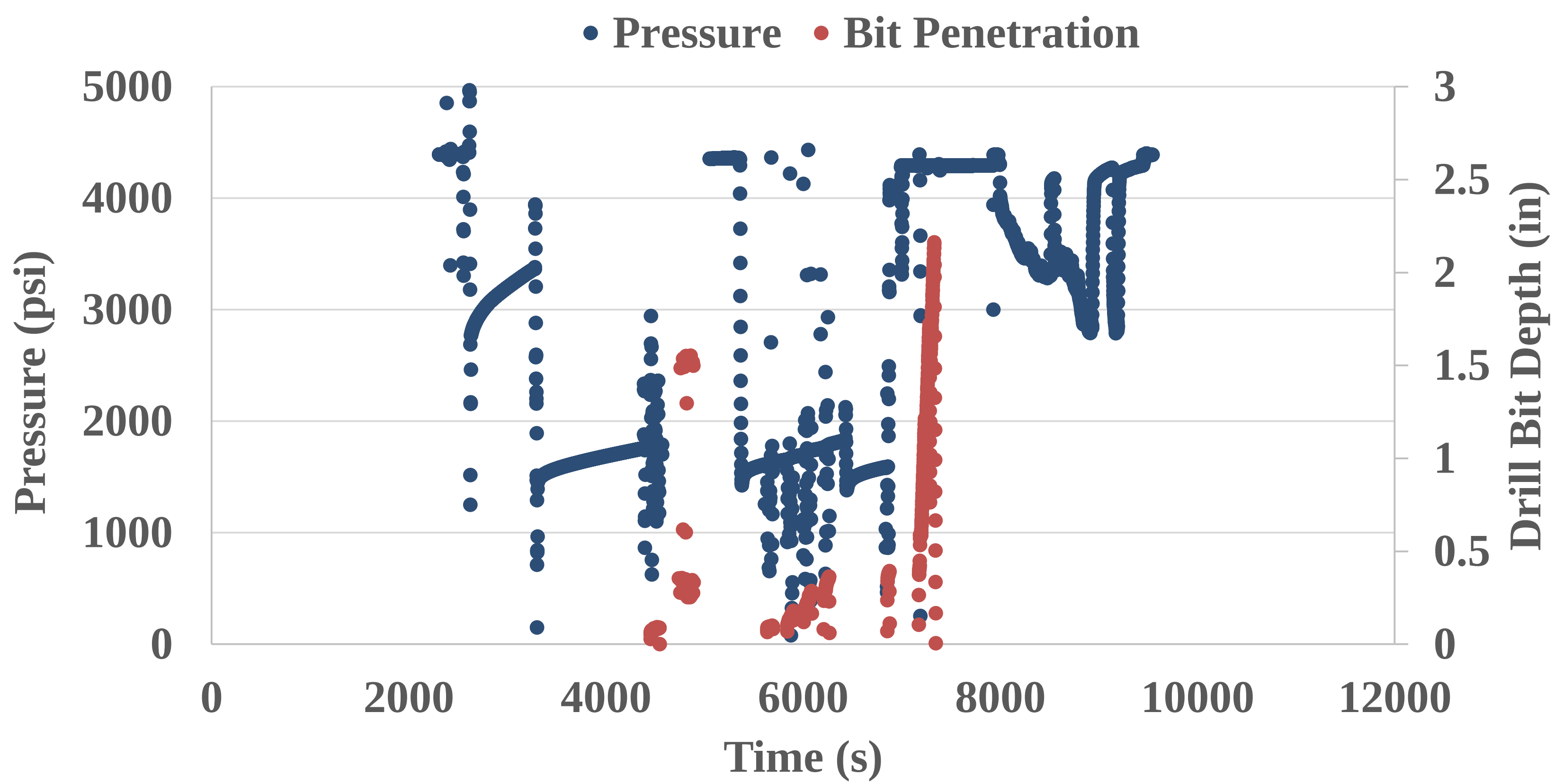
7,900

9,530

9,800

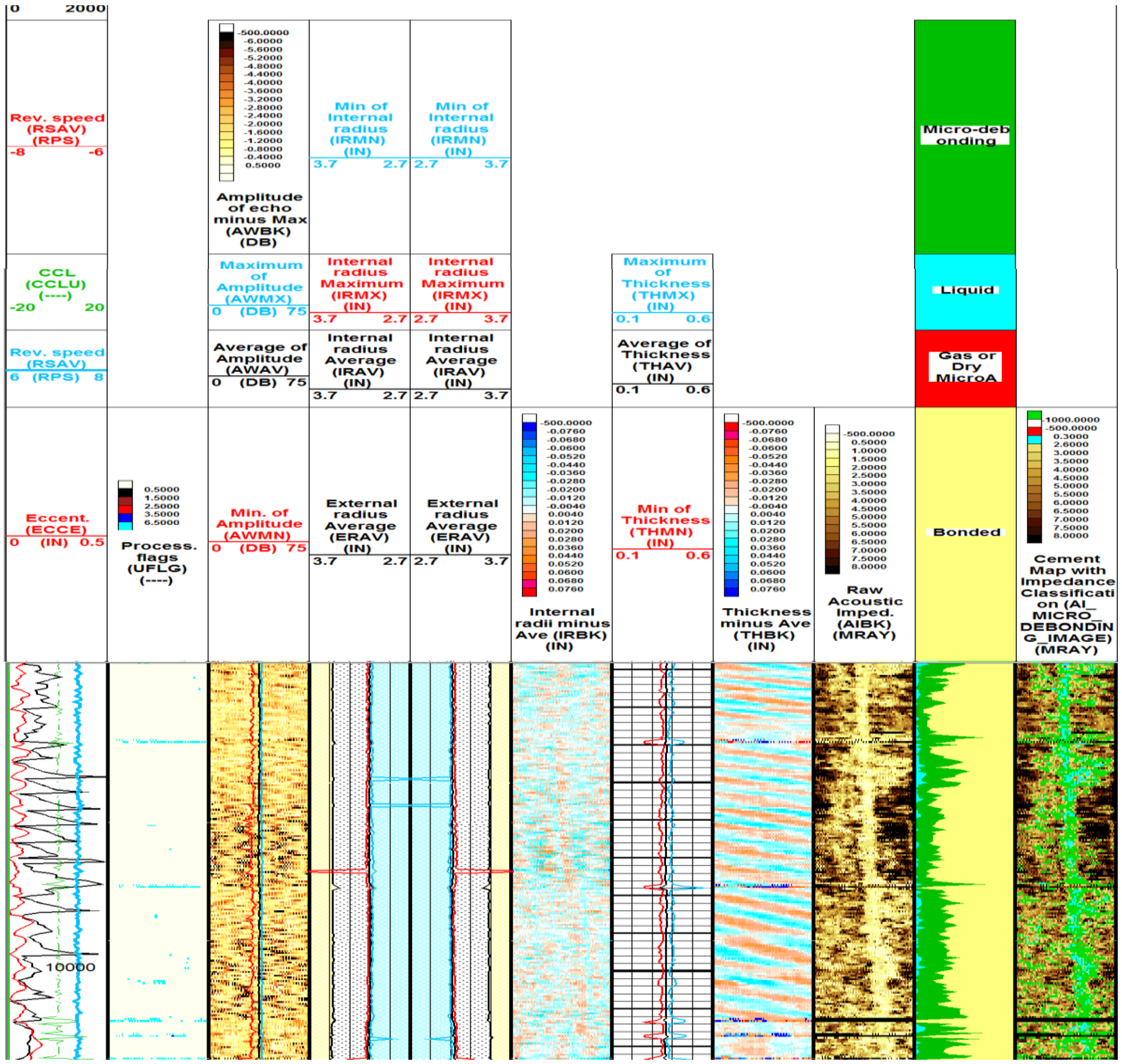
21

Pressure data at 9,535ft

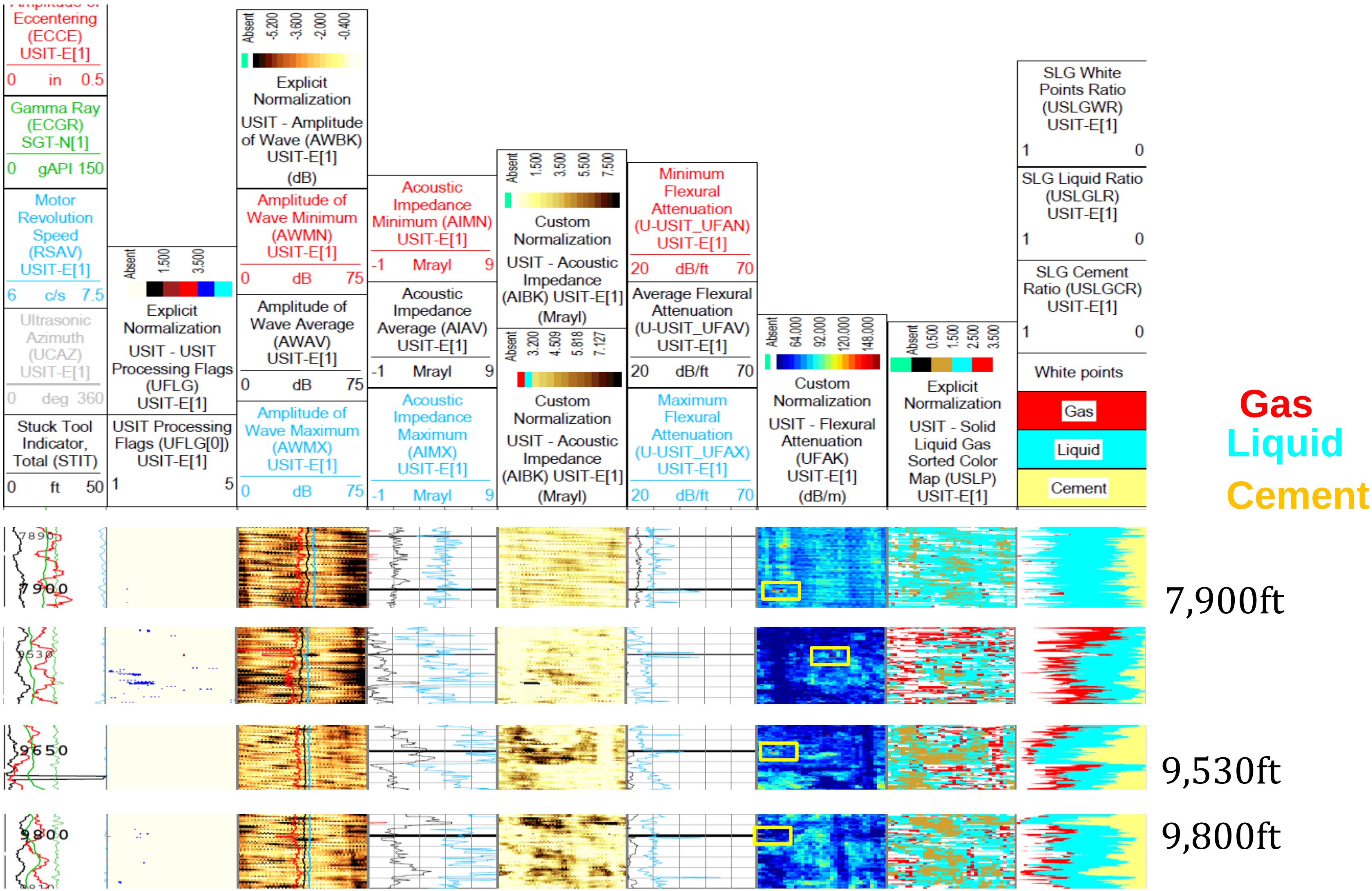


Formation pressure is 4,300psi
Inner casing pressure: 1,750psi
Minimum Permissible Pressure (MinPP) = 2,835psi

Micro debonding log at 9,000ft-10,000ft



Isolation scanner log 7,000ft-10,000ft



Field Testing & Data Analysis

Dr. Andrew Duguid

Field Testing at Cranfield Field

- SECARB's Phase II Gulf Coast Stacked Storage Project

- Characterization for Well Integrity

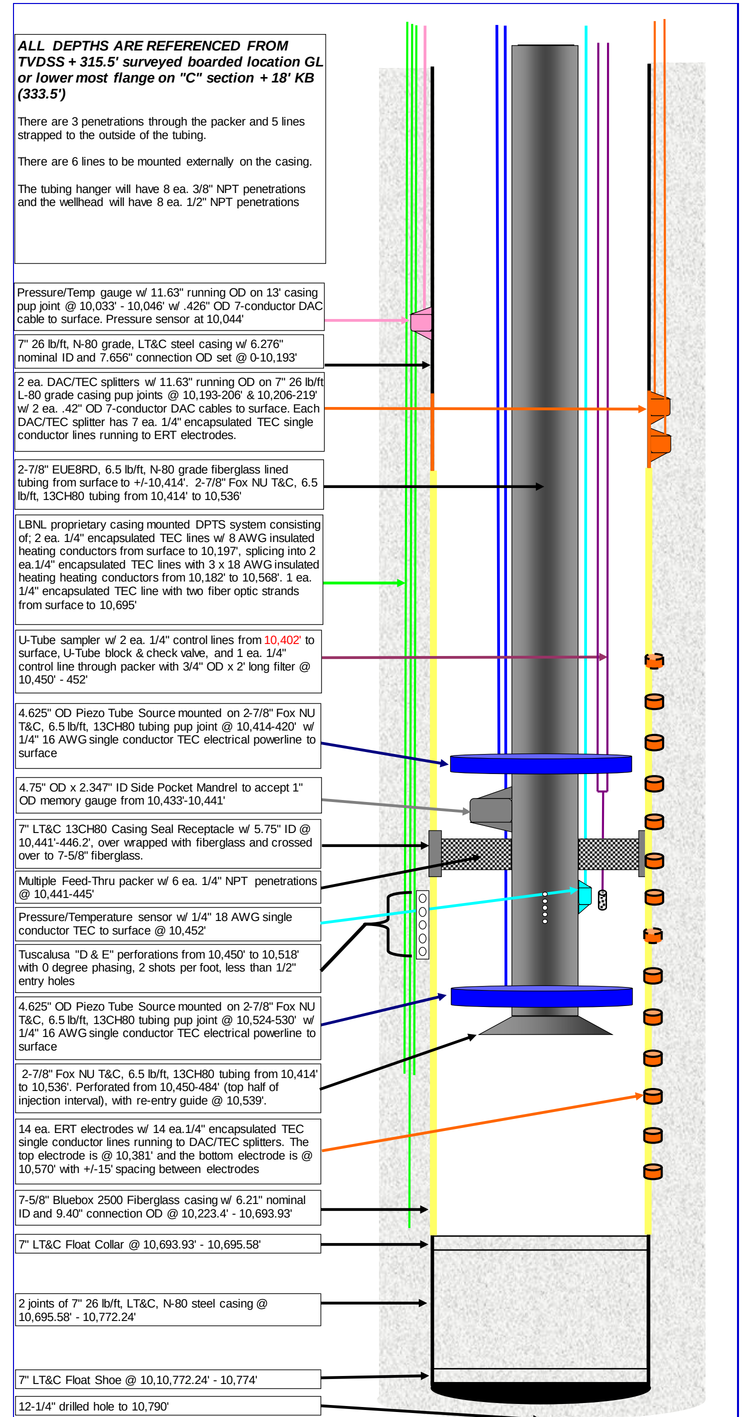
– To be used in the overall project models

- Two Wells

– Samples in and above the production zone

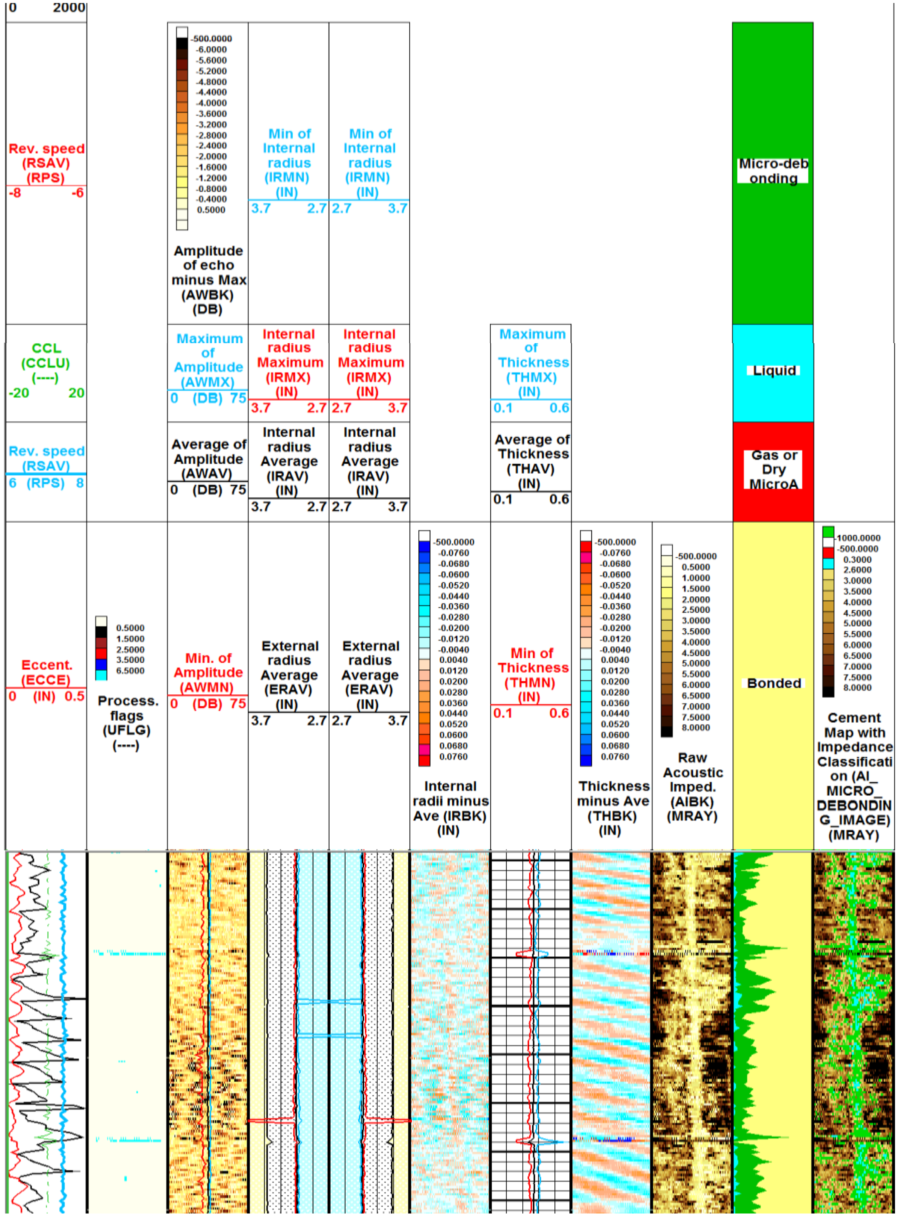
Cranfield CFU31F2 and CFU31F3

- 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)



Existing Data

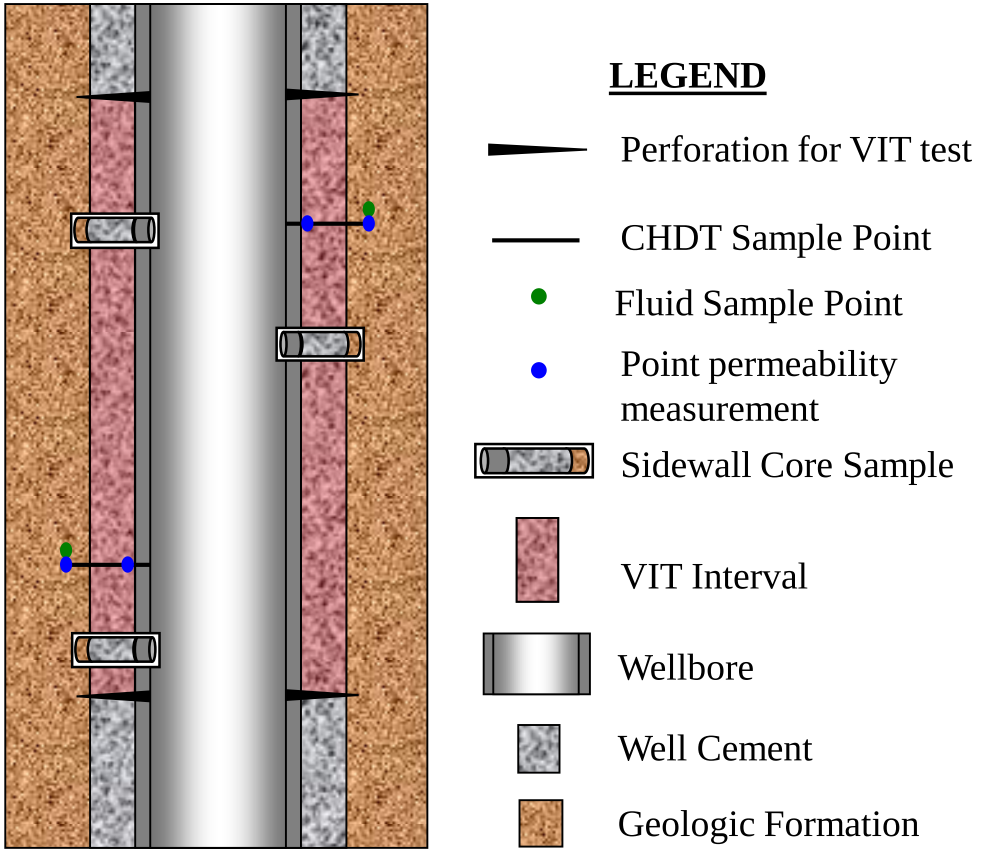
- Reservoir Saturation Tool
  - Gas (CO_2) saturation changes between 2009 and 2015
- Ultrasonic Imager Tool
  - Casing maps, cement maps, solid, liquid, and gas identification, jewelry locations
- Construction Records
  - Joint locations, material changes, electrode locations, gauge locations



New Data

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

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

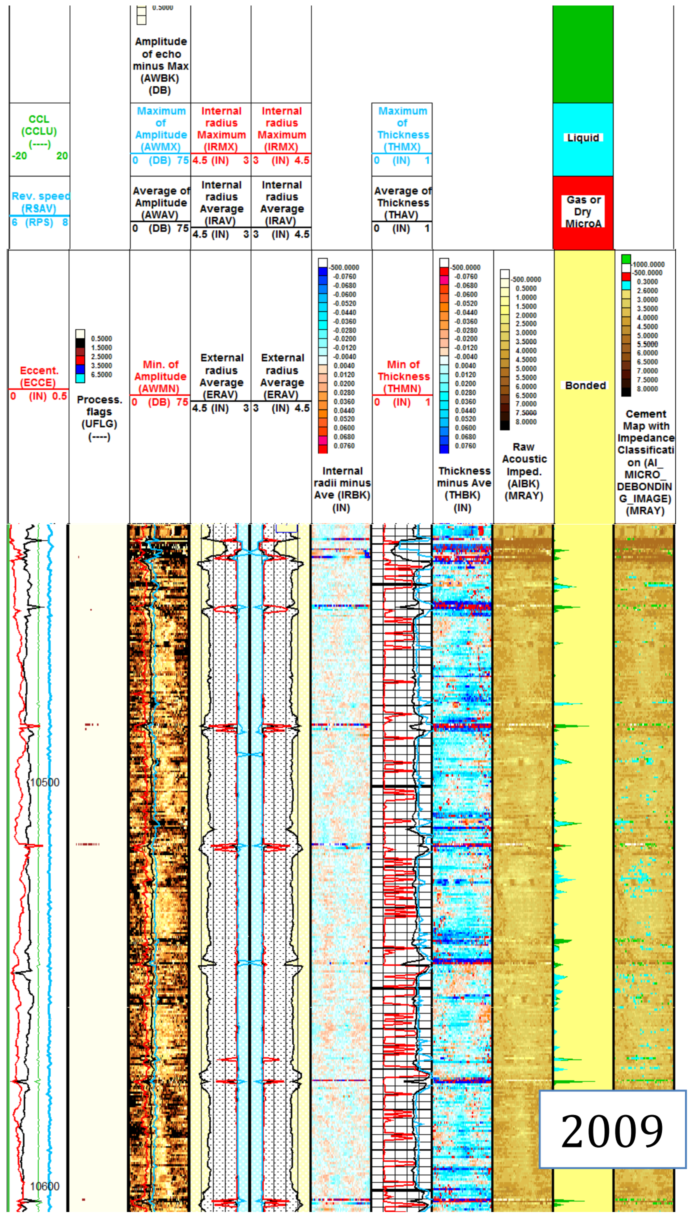


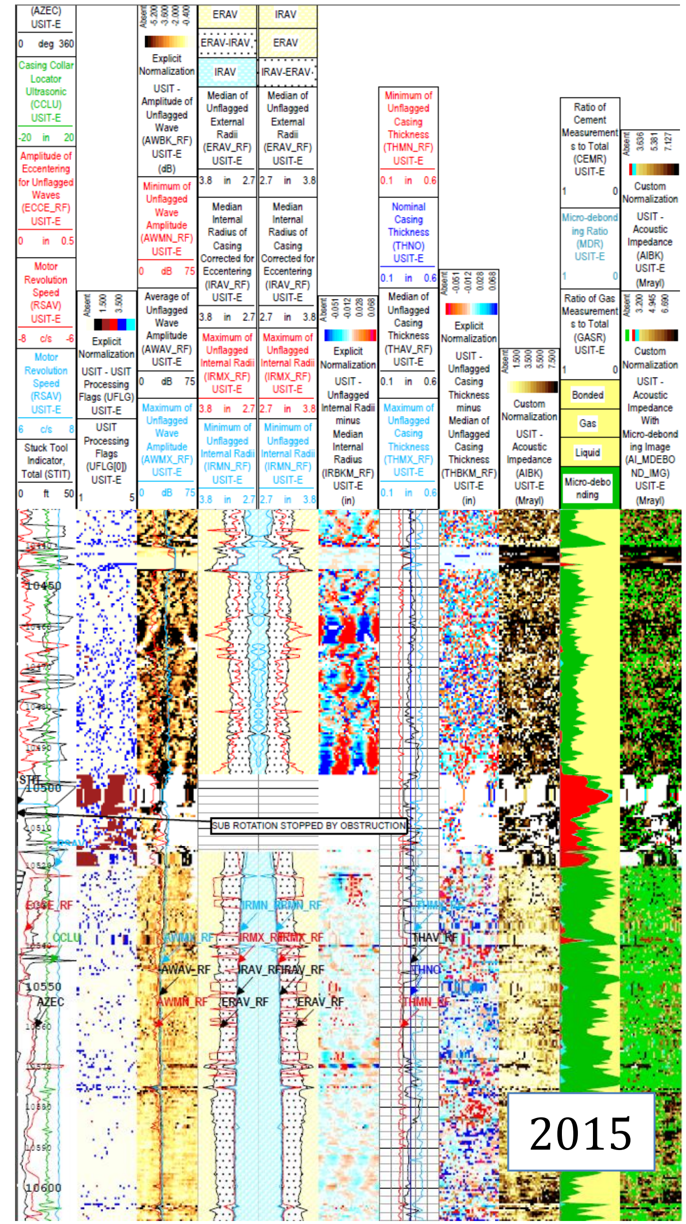
Data Analysis

- Log Comparisons
  - 2009 USIT to 2015 Isolation Scanner
  - 2009 CBL to 2015 Slim Cement Logging Tool (CBL)
- Core Assessment
  - Planning to make the most of each core
    - Non-destructive
    - Destructive

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

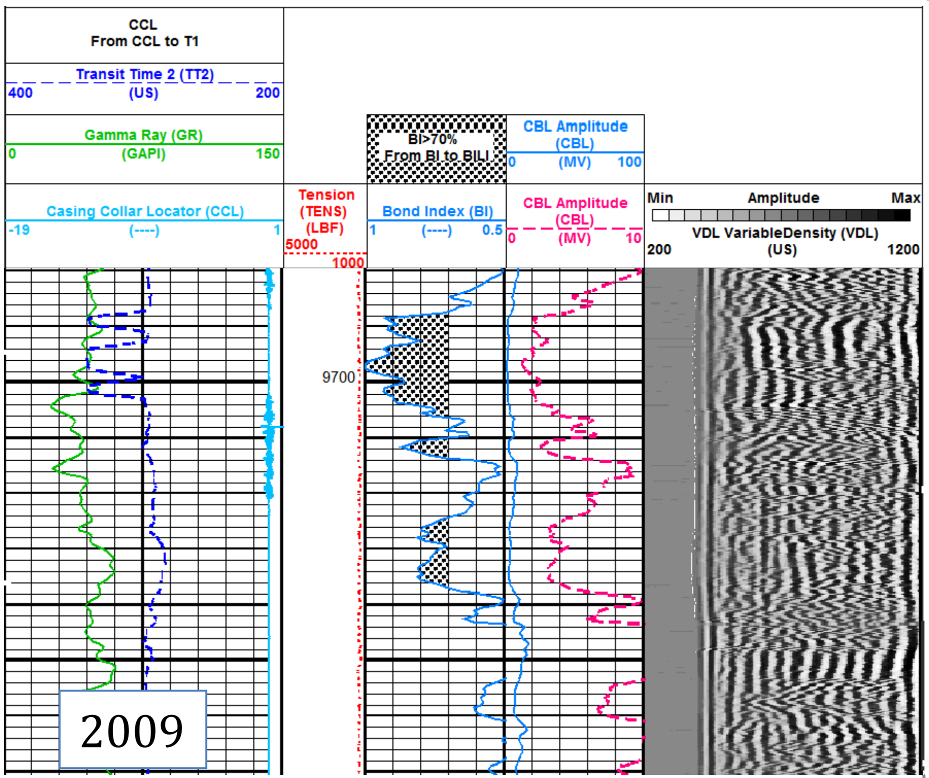
- Fiberglass casing installed to allow monitoring
- Casing degradation of casing in the CO_2 zone.
  - Suggests fiberglass may not be appropriate for this application
  - Note: Casing specification for CO_2 was downgraded after installation

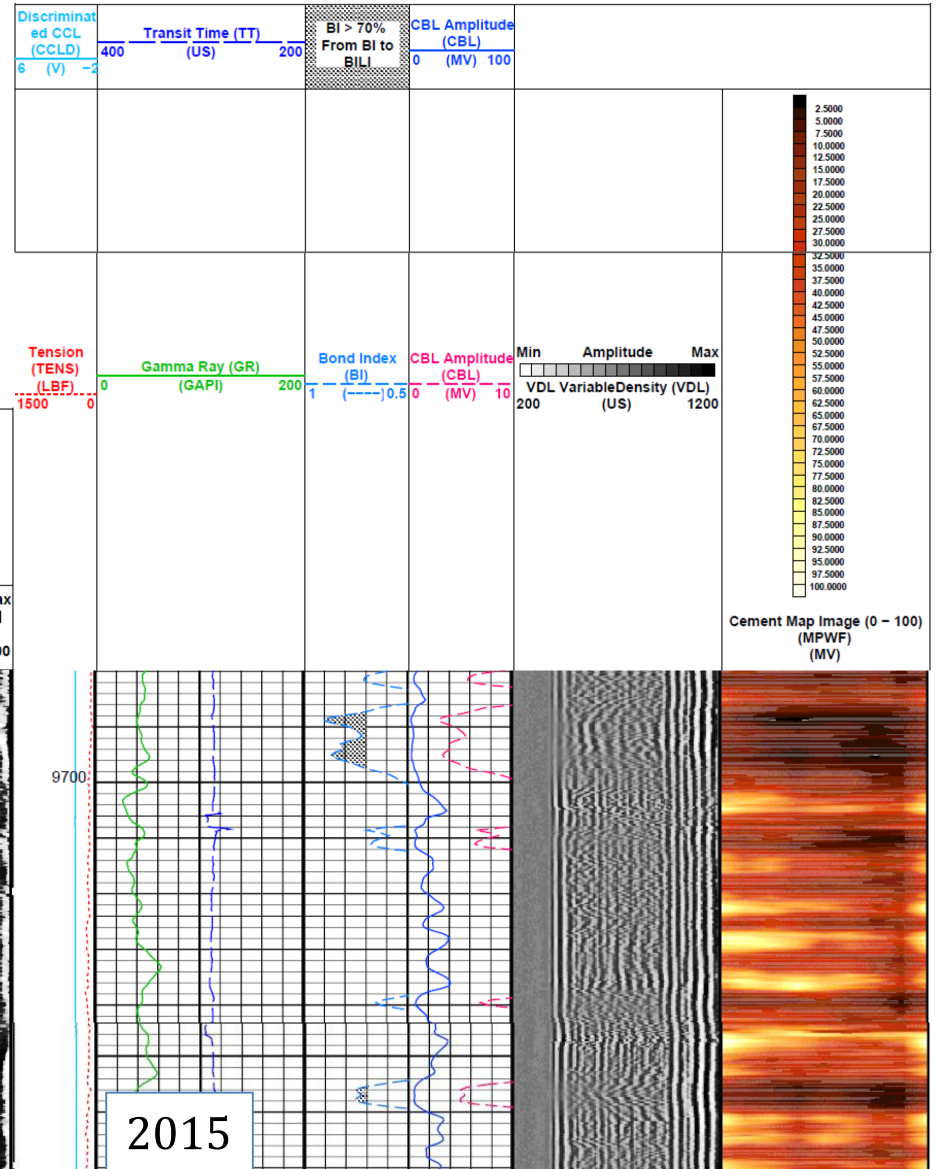




Log Analysis: Loss of Bond in CBL Logging in Steel Section (CFU 31F2)

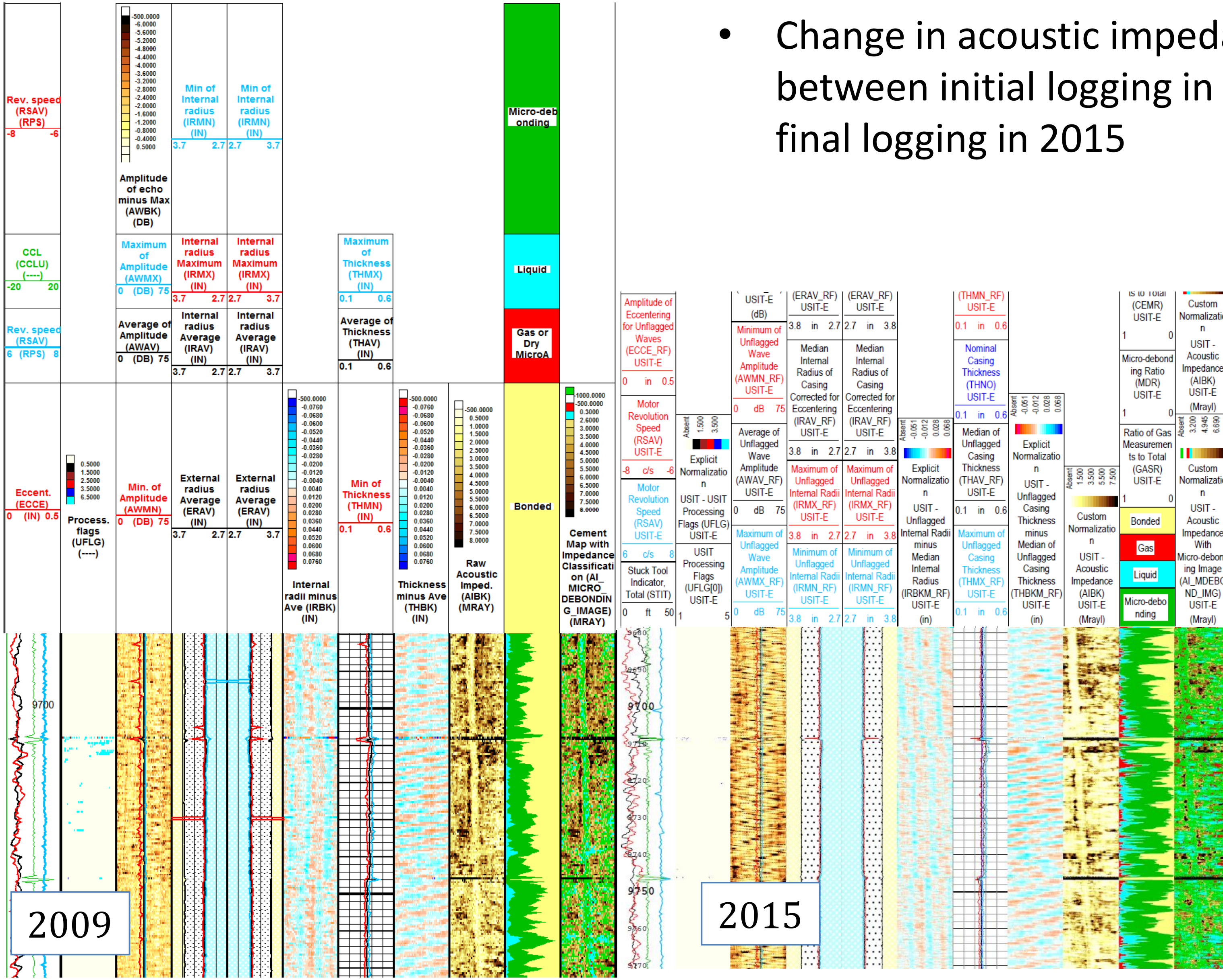
- Loss of bond in CBL track between initial logging in 2009 and final logging in 2015





Log Analysis : Loss of Acoustic Impedance in Steel Section (CFU 31F2)

- Change in acoustic impedance track between initial logging in 2009 and final logging in 2015



Sidewall Core Analysis

- Non-Destructive
  - Surface Mapping
  - Surface XRD
  - TBD
- Destructive
  - Porosity
  - Permeability
  - XRD
  - ESEM
  - Mechanical Properties

7,900

9,530

9,800

CFU31F2 Sidewall Cores

Summary

1. A Neural-Genetic Model has been developed for predicting leak probability of CO2-Explosed wells.

2. A finite element model has been established for predicting integrity of CO2-injection wells.

3. Field logs/tests/sampling have been run and partially analyzed.

4. The next step is to validate models with field data.

Synergy Opportunities

1. The Neural-Genetic Model for predicting leak probability of CO_2-Explosed wells is open for testing by collaborative researchers and the industry upon DOE's permission.

2. Field test data are available to share by others upon DOE's permission. We are seeking collaborative research partners for future development.

Publications

1. Ben Li, Boyun Guo, Hui Li, Yucai Shi. 2015. An Analytical Solution to Simulate the Effect of Cement/Formation Stiffness on Well Integrity Evaluation in Carbon Sequestration Projects, *Journal of Natural Gas Science & Engineering*, 27, 1092- 1099.
2. Ben Li, Boyun Guo, Hui Li, Yin Feng and Jim Lee. 2015. Leak Risk Assessment for Plugged Wells in Carbon Sequestration Projects, *Journal of Sustainable Energy Engineering* , Vol. 3, No. 1, 44-65.
3. Ben Li, Boyun Guo, Hui Li, and Yuanlong Zhou. 2015. Well Degradation Assessment and Leakage Risk Prediction in a Carbon Sequestration Project Using Neural Networks, *Journal of Sustainable Energy Engineering*, Vol. 2, No. 4, pp. 331-349(19).
4. Ben Li, Boyun Guo, Hui Li, Yin Feng and Jim Lee. 2015. Leak Risk Assessment for Plugged Wells in Carbon Sequestration Projects, *Journal of Sustainable Energy Engineering* (2015).
5. Yucai Shi, Ben Li, Boyun Guo, Zhichuan Guan, Hui Li. 2015. An Analytical Solution to Stress State of Casing-Cement Sheath-Formation System with the Consideration of Its Initial loaded State and Wellbore Temperature Variation, *International Journal of Emerging Technology and Advanced Engineering*, Volume 5, Issue 1 (Jan. 2015), pp59-65.
6. Xiaohui Zhang and Boyun Guo. “A Review of CO_2 Behavior During Geological Storage and Leakage Assessment,” *International Journal of Recent Development in Engineering and Technology* (October, 2014), Vol. 3 (4), 14-23.

Anticipated Benefits from the Project

The project will conduct research under DOE's *Fossil Energy Research and Development* Area of Interest 1, Studies of Existing Wellbores Exposed to CO_2.

The project will perform analysis of available industry and regulatory data to assess risks of well failure by various factors such as age of construction, region, construction materials, incident reports, logging and Mechanical Integrity Testing.

The computer model developed in this project will **contribute** to the DOE programs' effort of <u>ensuring 99% CO_2 storage permanence in the injection zone(s) for 1000 years and support the development of Best Practices Manual.</u>

Organization Chart

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