SECARB Anthropogenic Test Update

Carbon Storage and Oil and Natural Gas Technologies Review Meeting

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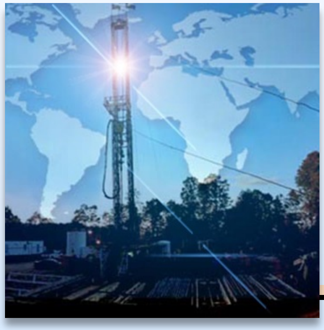
Presentation Outline

1. Project Introduction
2. Project Status
3. VSP Results
4. Simulation Update
5. Supporting Information



SECARB Anthropogenic Test Introduction

Project Goals and Objectives

Baseline 1 year	Injection 2 years	Post 3 years
APR 2011 to AUG 2012	SEP 2012 to SEP 2014	SEP 2014 to SEP 2017

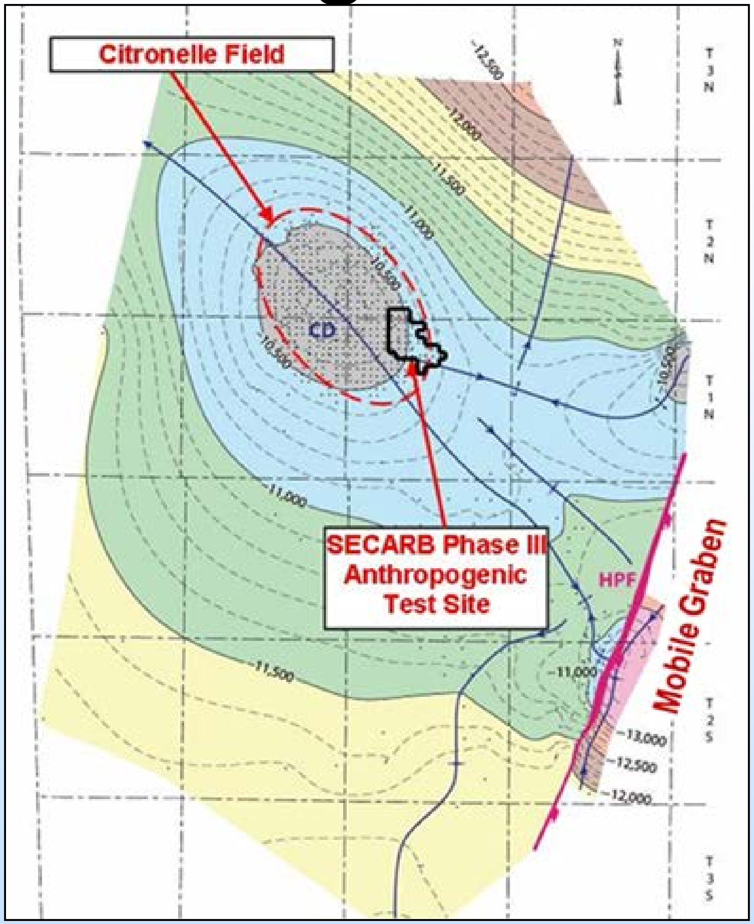
1. Test the CO_2 flow, trapping and storage mechanisms of the Paluxy;
2. Demonstrate how a saline reservoir's architecture can be used to maximize CO_2 storage and minimize the areal extent of the CO_2 plume;
3. Test the adaptation of commercially available oil field tools and techniques for monitoring CO_2 storage;
4. Test experimental CO_2 monitoring activities, where such technologies hold promise for future commercialization;
5. Begin to understand the coordination required to successfully integrate all four components (capture, transport, injection and monitoring) of the project; and
6. Document the permitting process for all aspects of a CCS project;
7. Facilitate and enable CCS commercialization.

Project Accomplishment: Demonstration to Full-Scale Commercialization

SECARB Demo Goes Commercial!

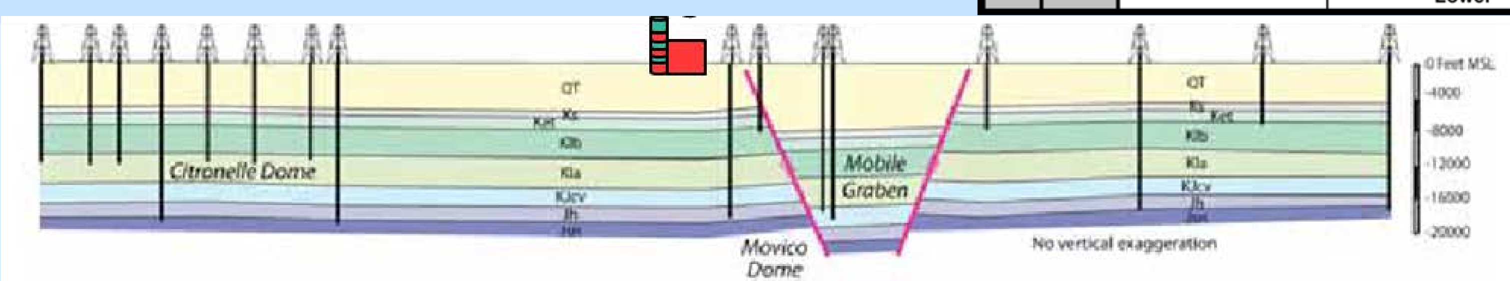
- NRG Energy (Houston, TX)
- Interest in Plant Barry Demonstration
- Plant scale-up to 240 MW
- Post-combustion slip-stream
- Captures 5,200 tons CO_2/day or 90% of CO_2
- Pipeline to Hill Corps West Ranch Oil Field (70 miles)
- EOR 300 bbls/day to 15,000 bbls/day!
- 60 million bbls Recoverable Oil

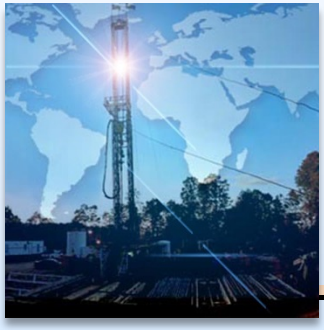
Storage Site: The Citronelle Oilfield



System	Series	Stratigraphic Unit	Major Sub Units	Potential Reservoirs and Confining Zones
Tertiary	Plio-Pliocene		Citronelle Formation	Freshwater Aquifer
	Miocene	Undifferentiated		Freshwater Aquifer
	Oligocene		Chickasawhay Fm.	Base of USDW
		Vicksburg Group	Bucatunna Clay	Local Confining Unit
	Eocene	Jackson Group		Minor Saline Reservoir
		Claiborne Group	Talahatta Fm.	Saline Reservoir
		Wilcox Group	Hatchetigbee Sand	Saline Reservoir
	Paleocene		Bashi Marl	
			Salt Mountain LS	
		Midway Group	Porters Creek Clay	Confining Unit
Cretaceous	Upper	Selma Group		Confining Unit
		Eutaw Formation		Minor Saline Reservoir
		Tuscaloosa Group	Upper Tusc.	Minor Saline Reservoir
			Mid. Tusc. Marine Shale	Confining Unit
			Lower Tusc. Pilot Sand Massive sand	Saline Reservoir
	Lower	Washita-Fredericksburg	Dantzler sand	Saline Reservoir
			Basal Shale	Primary Confining Unit
		Paluxy Formation	'Upper' 'Middle' 'Lower'	Injection Zone
		Mooringsport Formation		Confining Unit
		Ferry Lake Anhydrite		Confining Unit
		Donovan Sand	Rodessa Fm. Upper' 'Middle' 'Lower'	Oil Reservoir Minor Saline Reservoir Oil Reservoir

Structure map and cross section by GSA





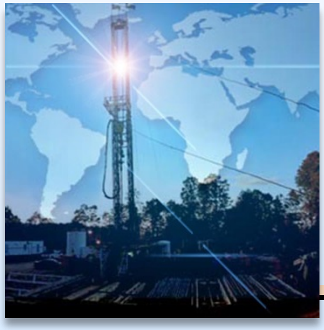
Project Status

Storage Project Status

- Injected 114,104 metric tonnes from Aug. 22, 2012 – Sept. 1, 2014
- Three-year Post-Injection Site Care (PISC) Period
- PISC Activities
  - Soil CO_2 flux measurements
  - Shallow and deep groundwater sampling
  - Reservoir Temperature/Pressure monitoring
  - Pulse-neutron logging
  - Final VSP survey (Jan. 2017)
  - Reservoir simulation updates

Storage Project Status - continued

- Submitted the UIC permit closure request to the State regulator for review on May 19, 2017
  - Basis for closure includes multiple lines of evidence (e.g., seismic surveys, well logs, tracer sampling, groundwater sampling…) and long-term model predictions
  - Regulatory feedback pending
- Closure Activities
  - Temporary or permanent abandonment of project wells and transfer of test site to oilfield operator
  - Oil and Gas Board of Alabama accepted jurisdiction over the D 9-9#2 well


VSP Results

Vertical Seismic Profile (VSP)

- A key component of the MVA was to capture a vertical seismic profile prior to, and following injection of CO_2
- The chief objective of the VSP was intended to delineate the plume's location in the subsurface
- This technique could also be applied to capture migration of the plume over time.

VSP Acquisitions

- Geophones were run into the injection well to capture the seismic response generated at 9 offset well locations concentrically located around the receiver.

- A baseline survey took place in 2012
- Post injection VSP was conducted in January 2017.

Procedural Differences Between Analyses

2012

- 80 level array
- 25ft receiver spacing
- 24000lbs Vibroseis source
- Water filled well
- Array deployed with tubing conveyed system
- Analog Geophones

2017

- 10 level array
- 50ft spacing (staggered 500ft to achieve 2000ft aperture)
- 64000lbs Vibroseis source
- Mud filled well
- Well lubricator needed for deployment and well control
- Digital Geophones

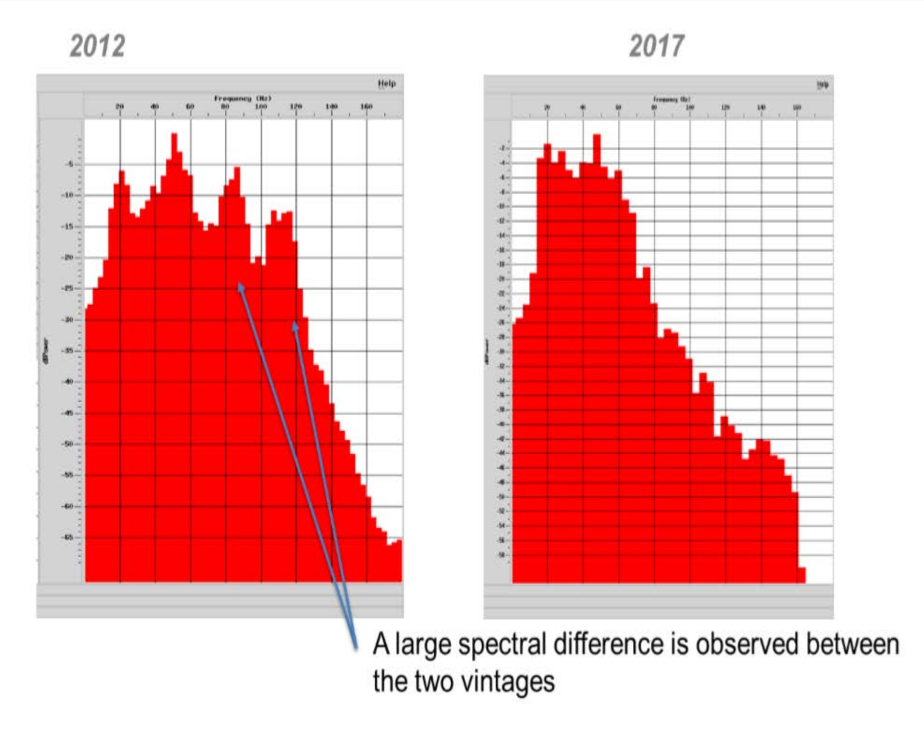
Key Variations in Analysis Protocol

- Poor tool availability and well constraints necessitated a shorter two-sensor array for the post-injection monitoring survey
- The two level tool was moved up and down the well over the same 2000 foot interval
  - This resulted in a sparse dataset with samples every 500 ft
- The seismic source was different in both analyses (24,000 lbs vs. 64,000 lbs).

Spectral Analysis

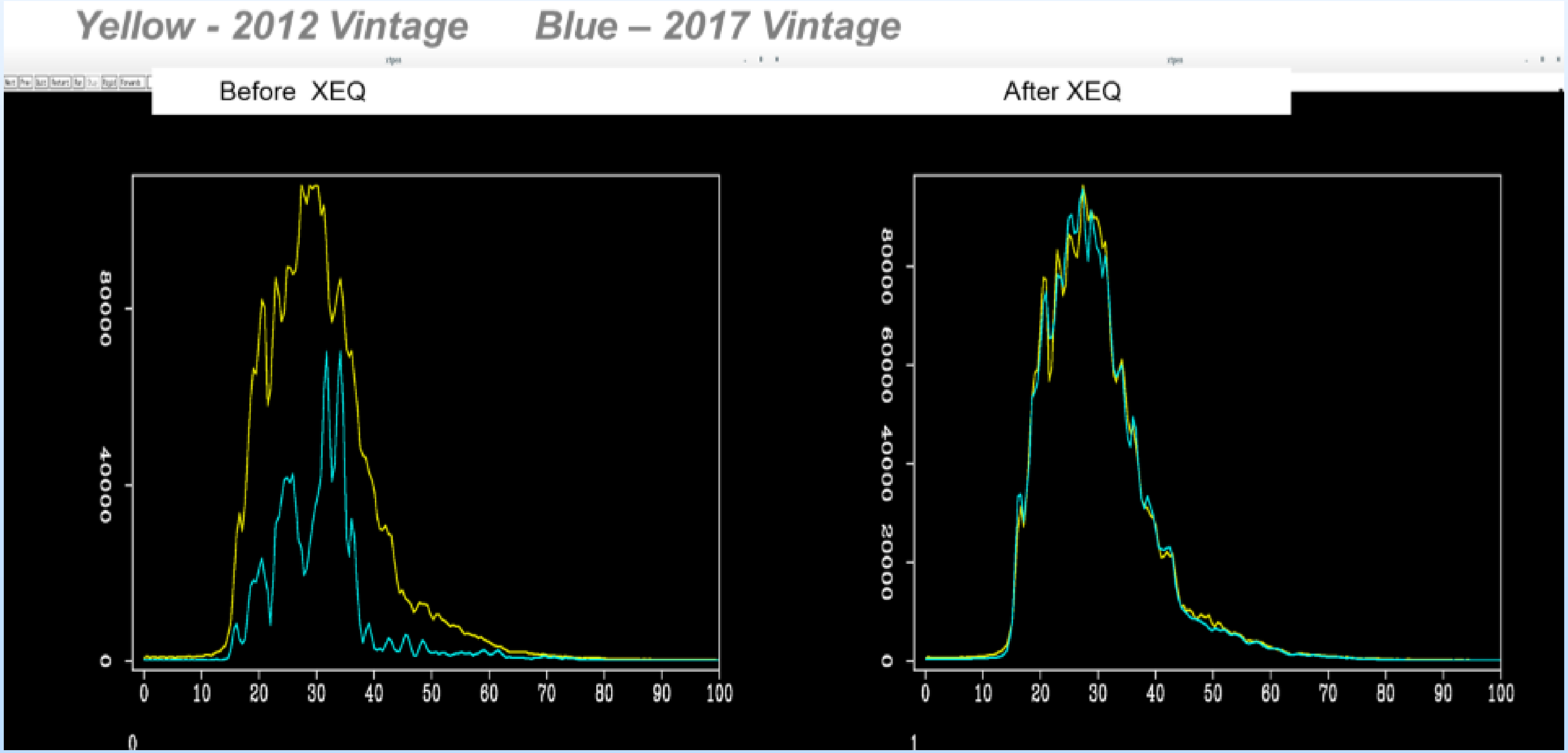
- Spectral analysis for a selected source from the 2012 80-level data (left) and from the 2017 10-level data (right).

- The same source-frequency sweep was used for each.
- The spectra of 2012 has higher resonant modes due to the smaller Vibroseis.
- The 2012 vintage also includes resonant modes due to tube wave energy.

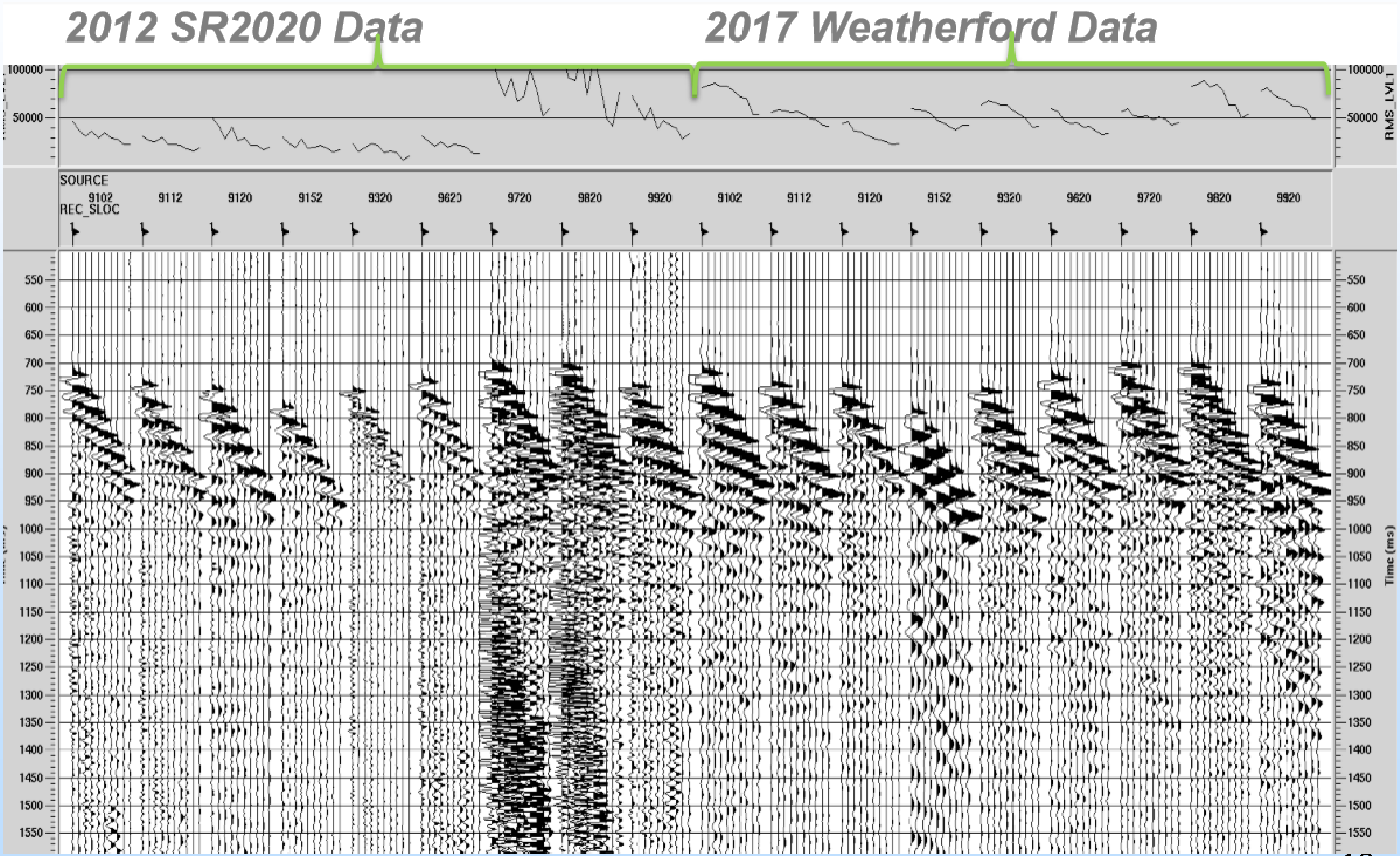


Comparison of Spectral Analysis Before and After Cross Equalization Processing

Spectra of data before (left) and after (right) cross-equalization (XEQ) processing.
The XEQ processing steps have reduced the spectral variation between the two data vintages.

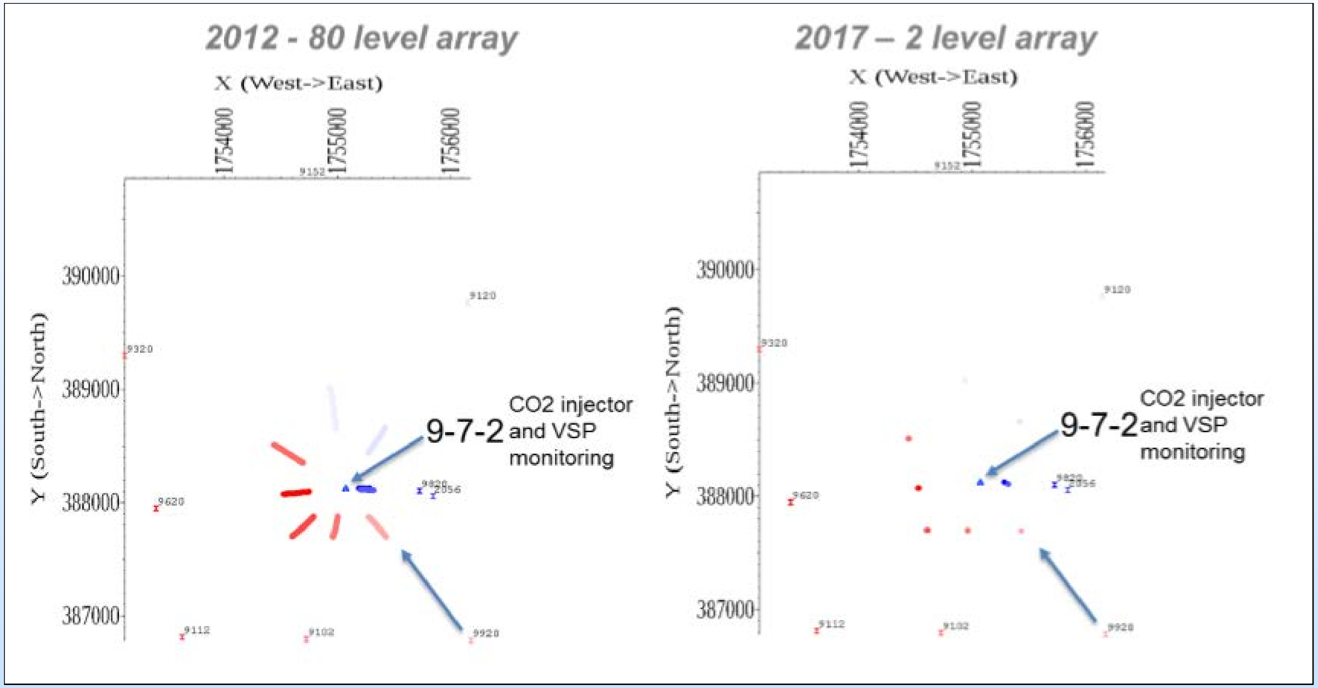


Amplitude Scalar Global Match



Comparison of Subsurface Array Coverage

- Subsurface illumination coverage of the target zone



2012 – 80 level array   2017 – 2 level array

- For the array to see any CO_2 anomaly, the plume must intersect with the coverage pattern.

Data Assessment

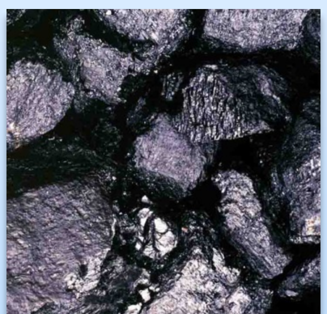
- Various seismic processing techniques were conducted to equalizing the sources from the baseline and monitor surveys
  - This would delineate any difference in the seismic response associated with the CO_2 injection.
- Time-lapse processing was conducted to remove any differences generated by changes in the sensors, the source weight and ground conditions.

HOWEVER:

- Seismic processing yielded large residuals that make it difficult to assess the propagation of the CO_2 at this particular location.
- The input data from the post-injection survey suggests acquisition conditions were much too different to begin with.

VSP Conclusions

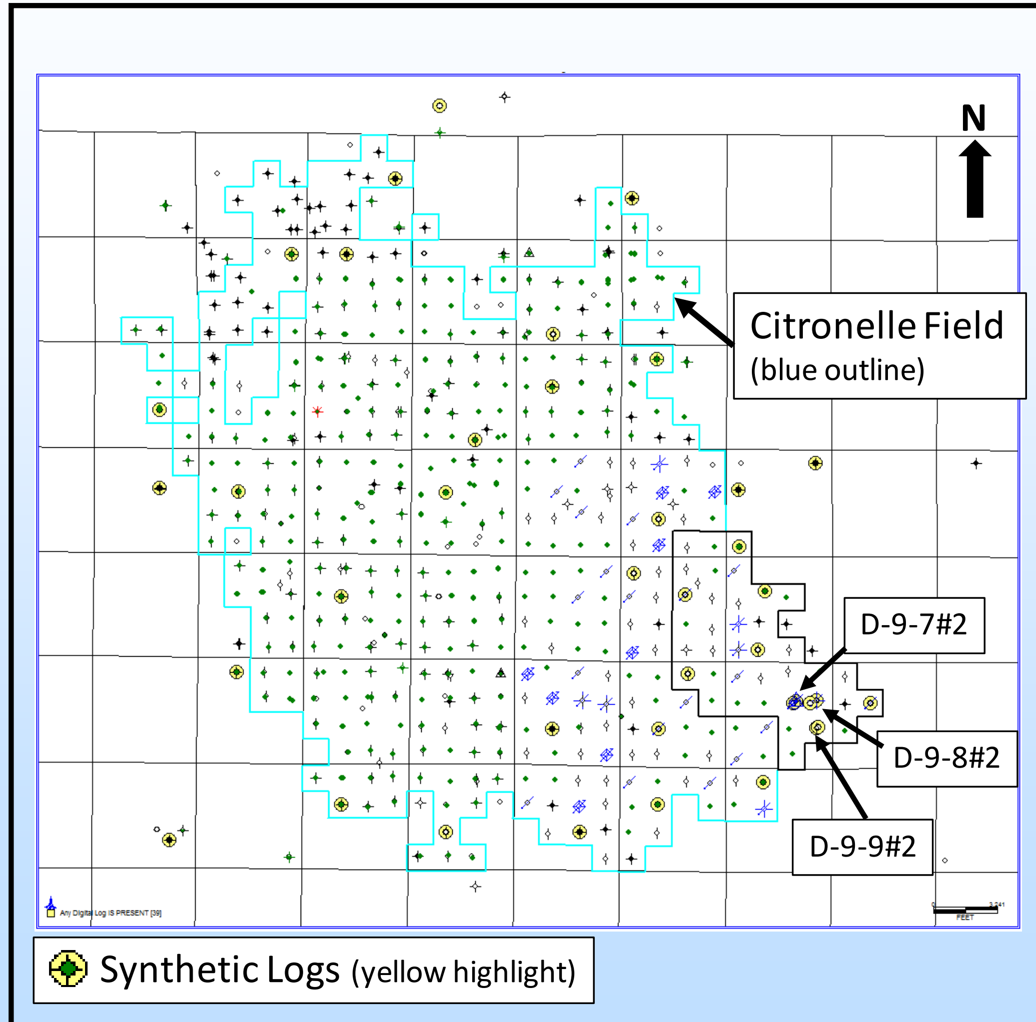
- Two vintages of VSP data were acquired in well D9-7#2 of the Citronelle CO2 storage facility in 2012 and 2017.
- Each vintage was acquired with a different seismic sensor, a different seismic source, and in different well conditions on top of environmental and surficial seasonal changes.
  - These changes make comparing the different data vintages difficult even after carefully processing the seismic data
- In terms of future work for monitoring the subsurface using these type of technologies it is important to consider using repeatable tools.
- It is possible that using another monitoring well, where a larger seismic array can be deployed may be beneficial to create a denser dataset.
- Having more densely-sampled datasets, by using either more sensors or more sources, could help detect very weak CO2-related signals that may be buried within high levels of noise.



Simulation Update

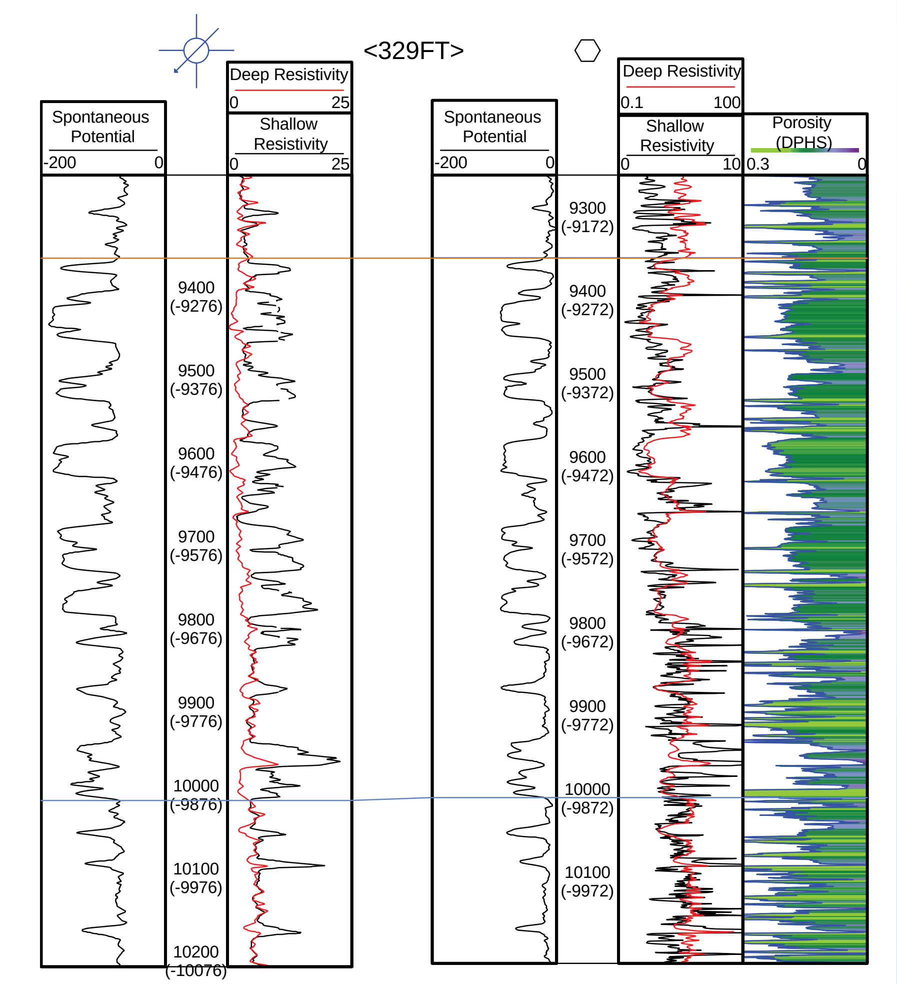
Updating the Porosity and Permeability Maps

- The previous model had constant porosity and permeability per layer.
- The synthetic porosity logs, generated for the Commercial Scale Project, were used to create porosity maps.
- Porosity-Permeability transforms were developed from the Citronelle Whole Core dataset.
- The transforms were then used to generate permeability maps for the existing layers in the numerical model (55 total).



Some Background - Synthetic Logs Generated Using a Neural Network

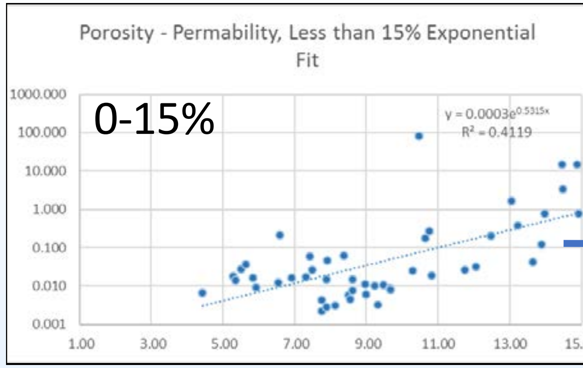
- 400+ total wells in Citronelle field on 40-ac spacing.
- Most of the legacy/vintage wells have resistivity logs only and no porosity logs.
- Digitized the SP & resistivity curves for 36 well logs.
- 3 new wells with modern porosity logs were drilled on well pads with existing abandoned wells.
- Using the paired wells (new + vintage) a neural network approach was used to predict porosity.

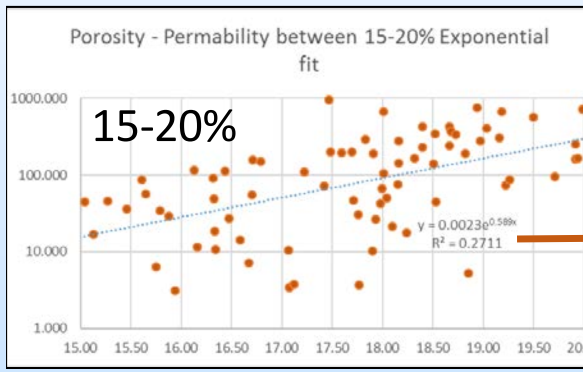


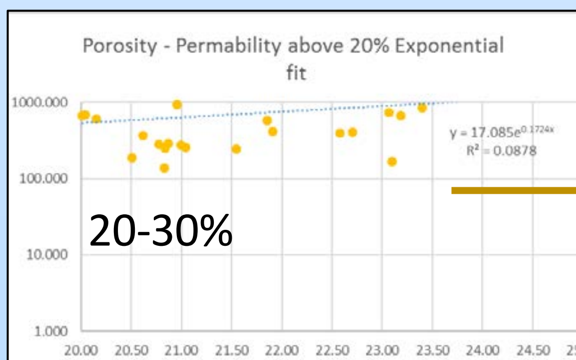
Porosity-Permeability Transforms Results

- Using the whole core dataset from the **D-9-7#2**, **D-9-8#2** and **D-9-9#2** wells Porosity and Permeability Transforms were developed for 3 porosity ranges

- The transforms were then applied to the porosity maps (for the appropriate ranges) to create the permeability maps.

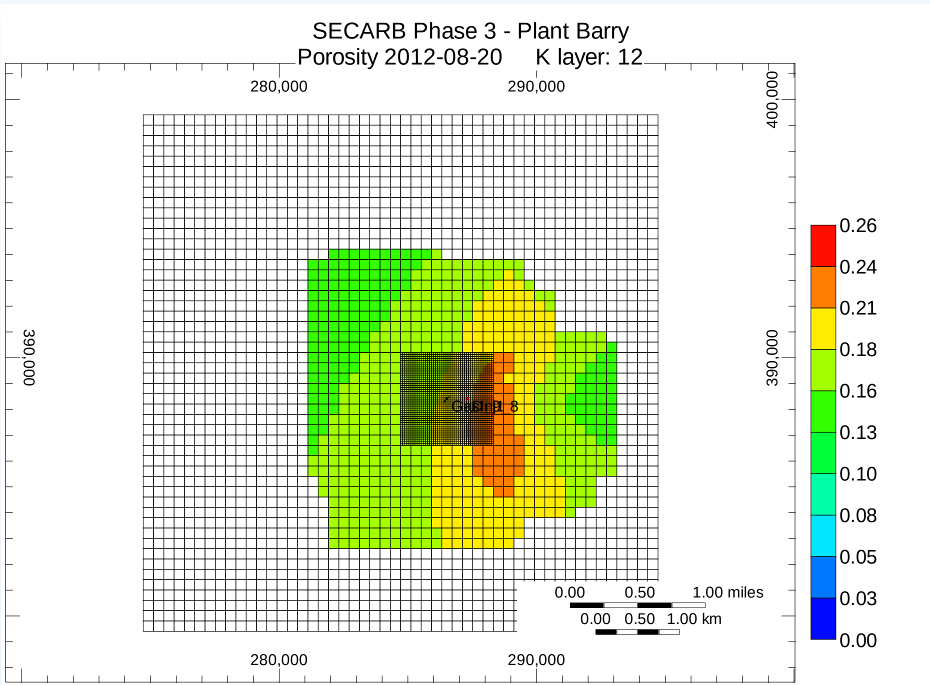




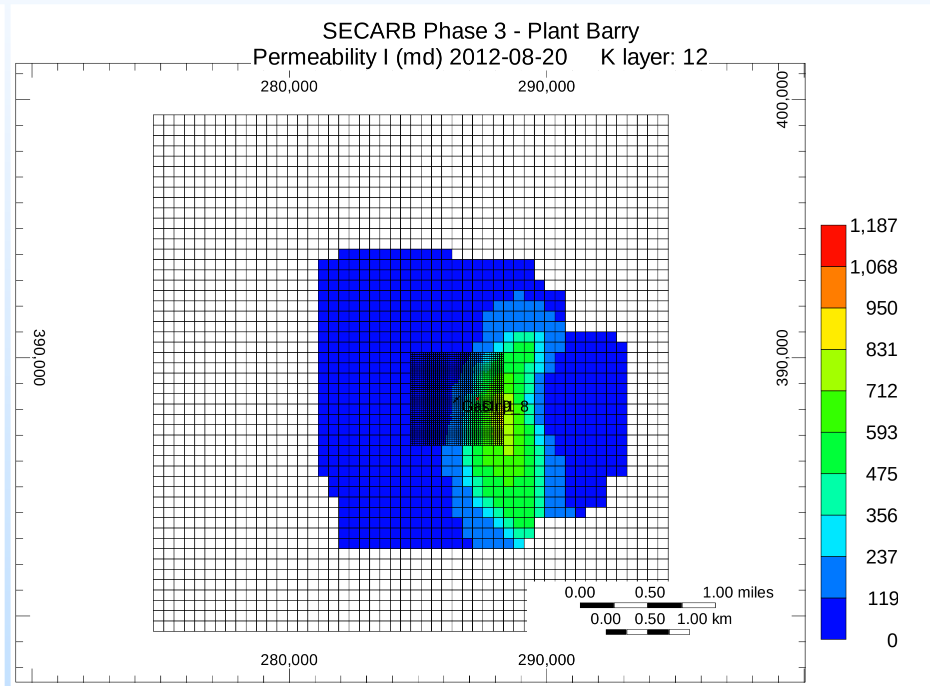


Porosity value	***Porosity Range***		
	>20% exponential	**15-20% exponential**	**>15% exponential**
5	**40**	0.04	0.004
6	**48**	0.08	0.007
7	**57**	0.14	0.012
8	**68**	0.26	0.021
9	**81**	0.46	0.036
10	**96**	0.83	0.061
11	**114**	1.50	0.10
12	**135**	2.70	0.18
13	**161**	5	0.30
14	**191**	9	0.51
15	**227**	16	0.87
16	**270**	28	1.48
17	**320**	51	2.52
18	**380**	92	4
19	**452**	167	7
20	**537**	300	12
21	**638**	541	21
22	**758**	976	36
23	**901**	1,758	61
24	**1070**	3,169	104
25	**1272**	5,711	177
26	**1511**	10,292	301
27	**1795**	18,549	512

Porosity and Permeability Map Examples 9460 Sand

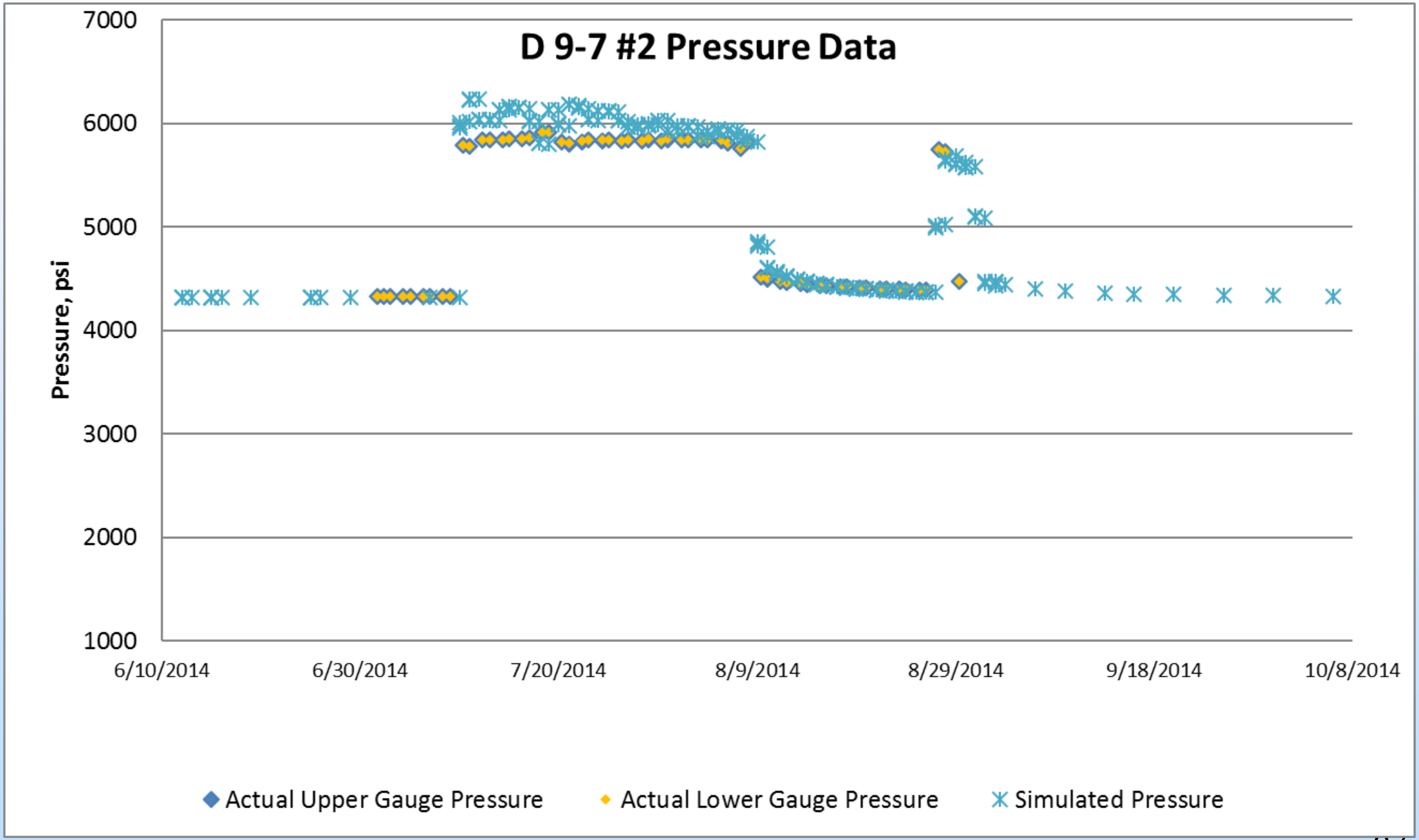


Porosity

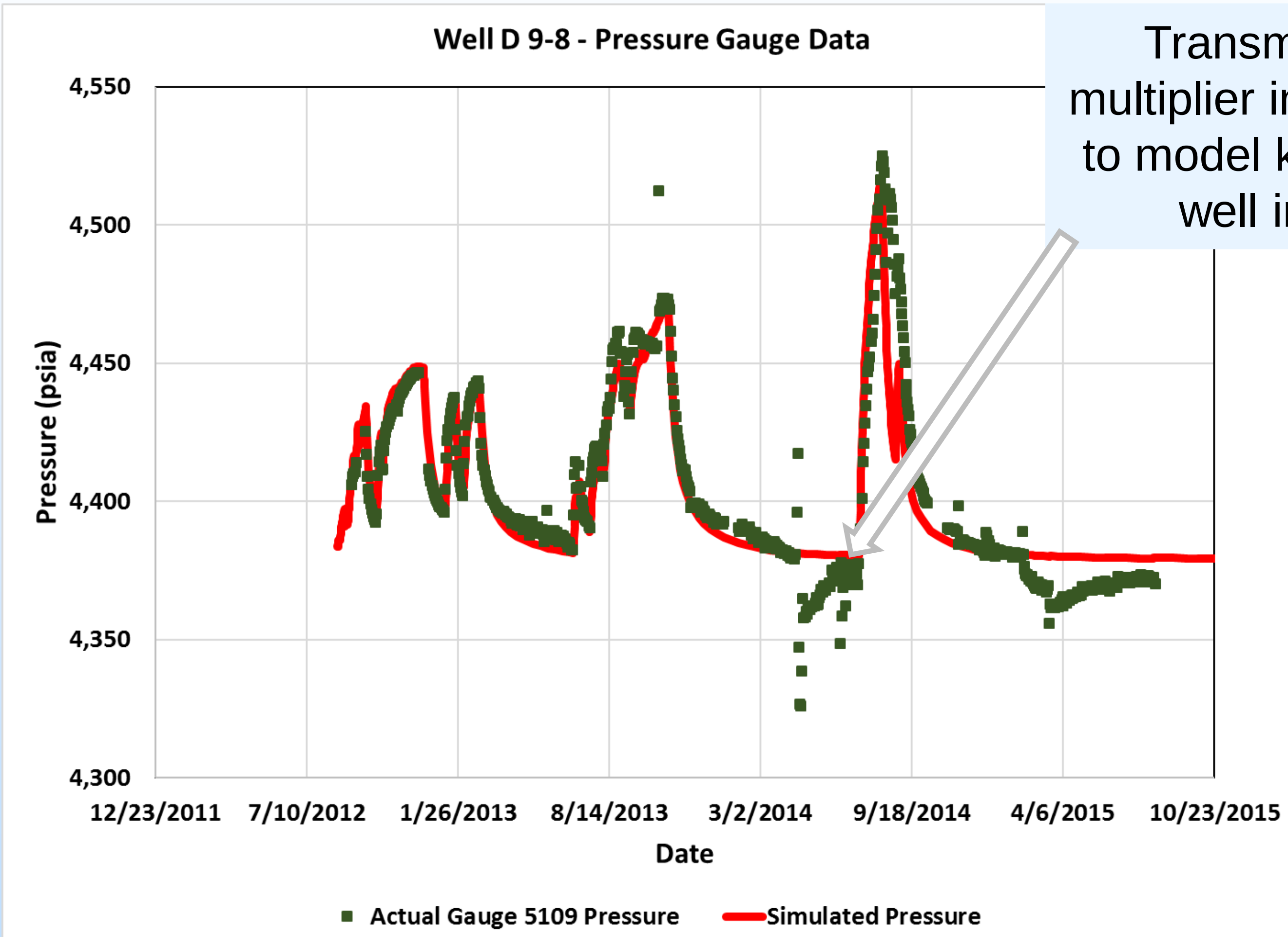


Horizontal Permeability

Injector Well D 9-7#2 Bottomhole Pressure Match



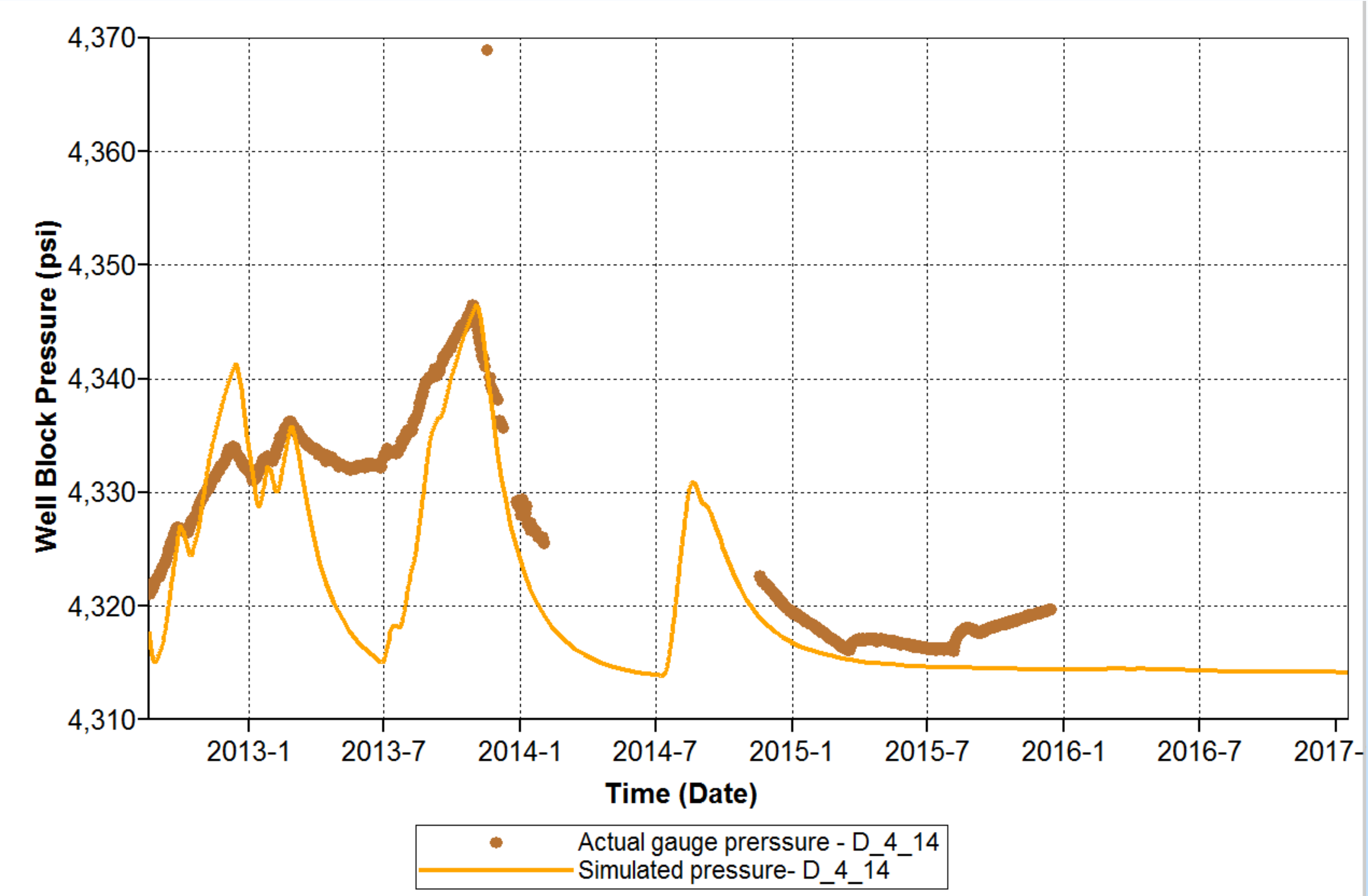
In-Zone Monitoring Well D 9-8#2 Pressure Response Match



Transmissibility multiplier implemented to model killing of the well in 2014

Well D 9-8#2 is located 870 feet east of the injector.

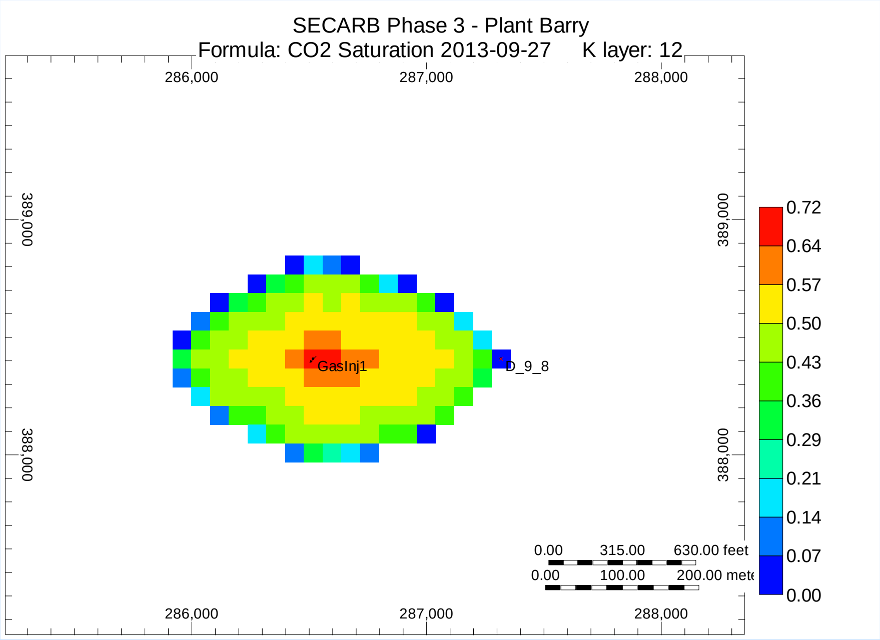
In-Zone Monitoring Well D 4-14 Pressure Response Match



Well D 4-14 is located 3,500 feet northwest of the injector.

Matching CO_2 Breakthrough

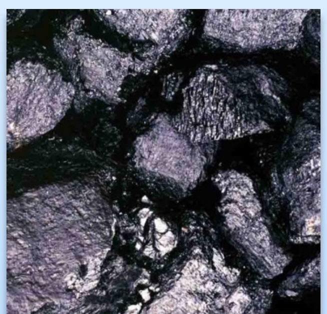
The model predicts breakthrough in the 9460 sand a little early (end of September 2013) as compared to PNC logs results (after April 2014).



CO2 Plume Top View

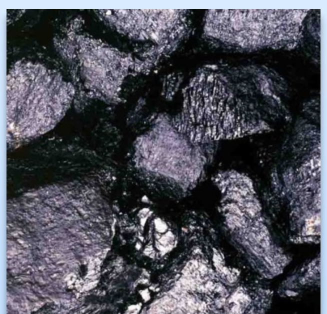
CO_2 Plume 3D View

Z/X Aspect Ratio = 7



Questions?





Supporting Information

Organizational Chart