The Frio & Cranfield Injection Projects, USA

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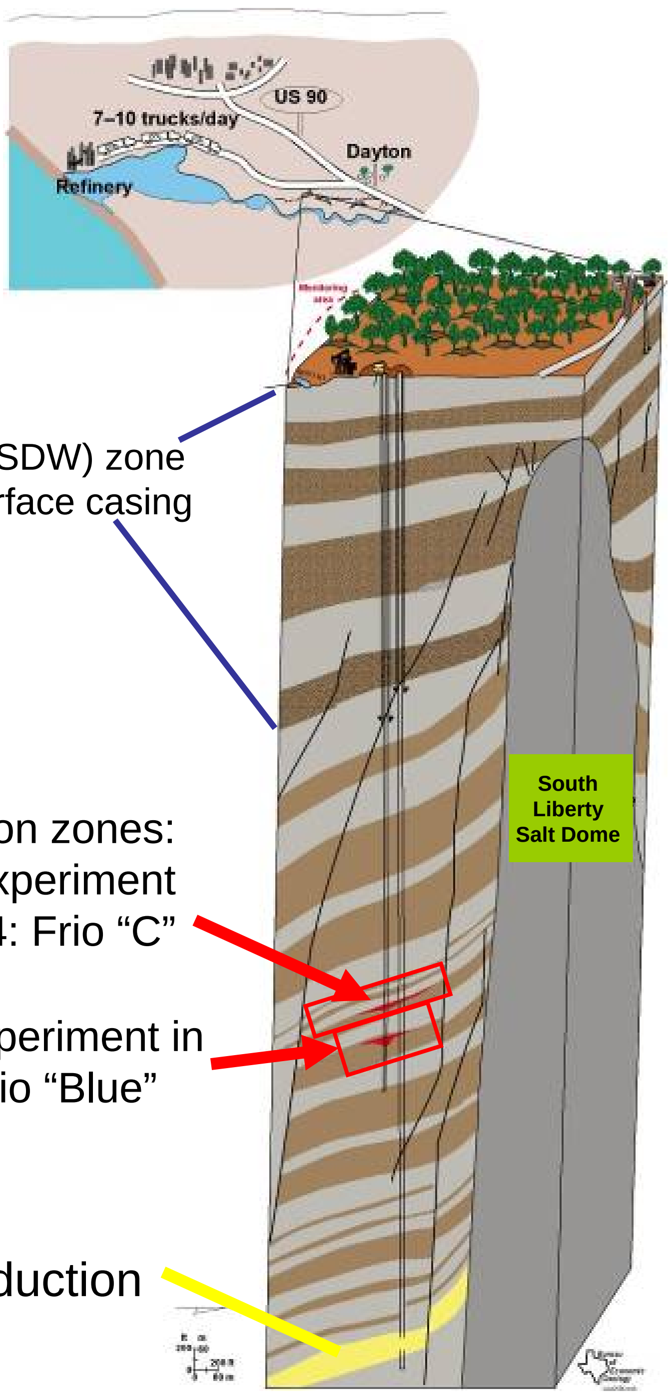
CAGS

Canberra, Australia

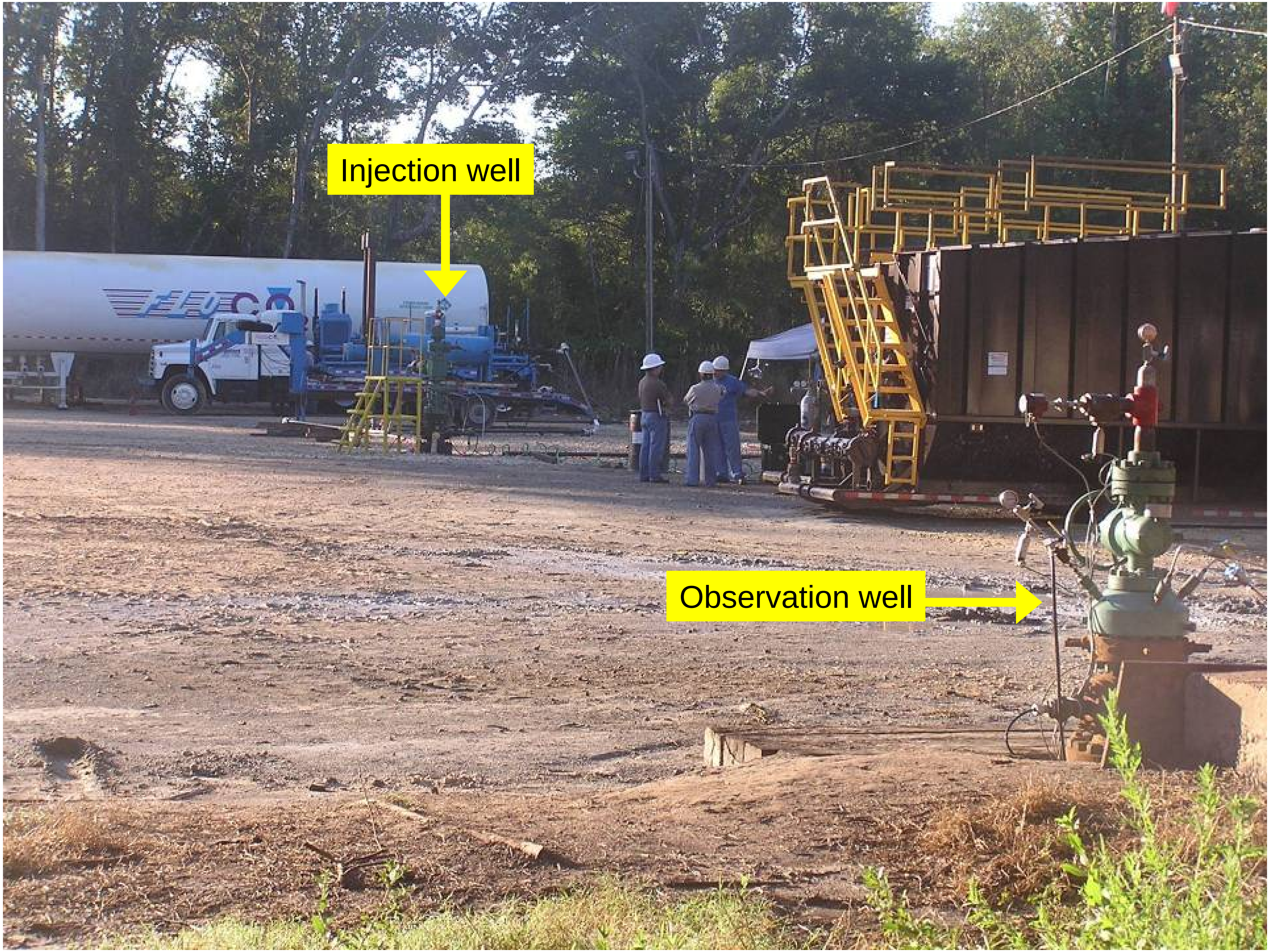
Frio Brine Pilot Site: Two Test Intervals 2004 & 2006



- **Purpose:** demonstrate feasibility and monitoring techniques, evaluate model predictions
- **Setting:** salt dome flank, Frio sandstone, 1,500 m depth.
- **Scope:** 1000's of tons over days
- **Monitoring:** chemistry (tracers), pressure and temperature, logs, seismic

Frio Brine Pilot Research Team

- **Bureau of Economic Geology, Jackson School, The University of Texas at Austin:** Susan Hovorka, Tip Meckel, Jeff Kane, Andrew Tachovsky, Abhijit Mukarjee, Mark Holtz, Shinichi Sakurai, Seay Nance, Joseph Yeh, Paul Knox, Khaled Faoud, Jeff Paine
- **Lawrence Berkeley National Lab, (Geo-Seq):** Larry Myer, Tom Daley, Barry Freifeld, Rob Trautz, Christine Doughty, Sally Benson, Karsten Pruess, Curt Oldenburg, Jennifer Lewicki, Ernie Majer, Mike Hoversten, Mac Kennedy, Paul Cook, Duo Wang, Ray Solbau, Jonathan Ajo-Franklin
- **Schlumberger:** T. S. Ramakrishna, Nadja Mueller, Austin Boyd, Mike Wilt
- Oak Ridge National Lab: Dave Cole, Tommy Phelps, David Riestberg, Phil Szymcek
- **Lawrence Livermore National Lab:** Kevin Knauss, Jim Johnson
- **Alberta Research Council:** Bill Gunter, John Robinson, Bernice Kadatz
- **Texas American Resources:** Don Charbula, David Hargiss
- **Sandia Technologies:** Dan Collins, "Spud" Miller, David Freeman; Phil Papadeas
- **BP:** Charles Christopher, Mike Chambers
- **SEQURE – National Energy Technology Lab:** Curt White, Rod Diehl, Grant Bromhall, Brian Stratizar, Art Wells
- **Paulsson Geophysical:** Bjorn Paulsson
- **University of West Virginia:** Henry Rausch
- **USGS:** Yousif Kharaka, Bill Evans, Evangelos Kakauros, Jim Thordsen
- Praxair: Glen Thompson, Joe Shine, Dan Dalton
- **Australian CO2CRC (CSIRO):** Jim Underschultz, Kevin Dodds, Don Sherloc
- **Core Labs:** Paul Martin and others

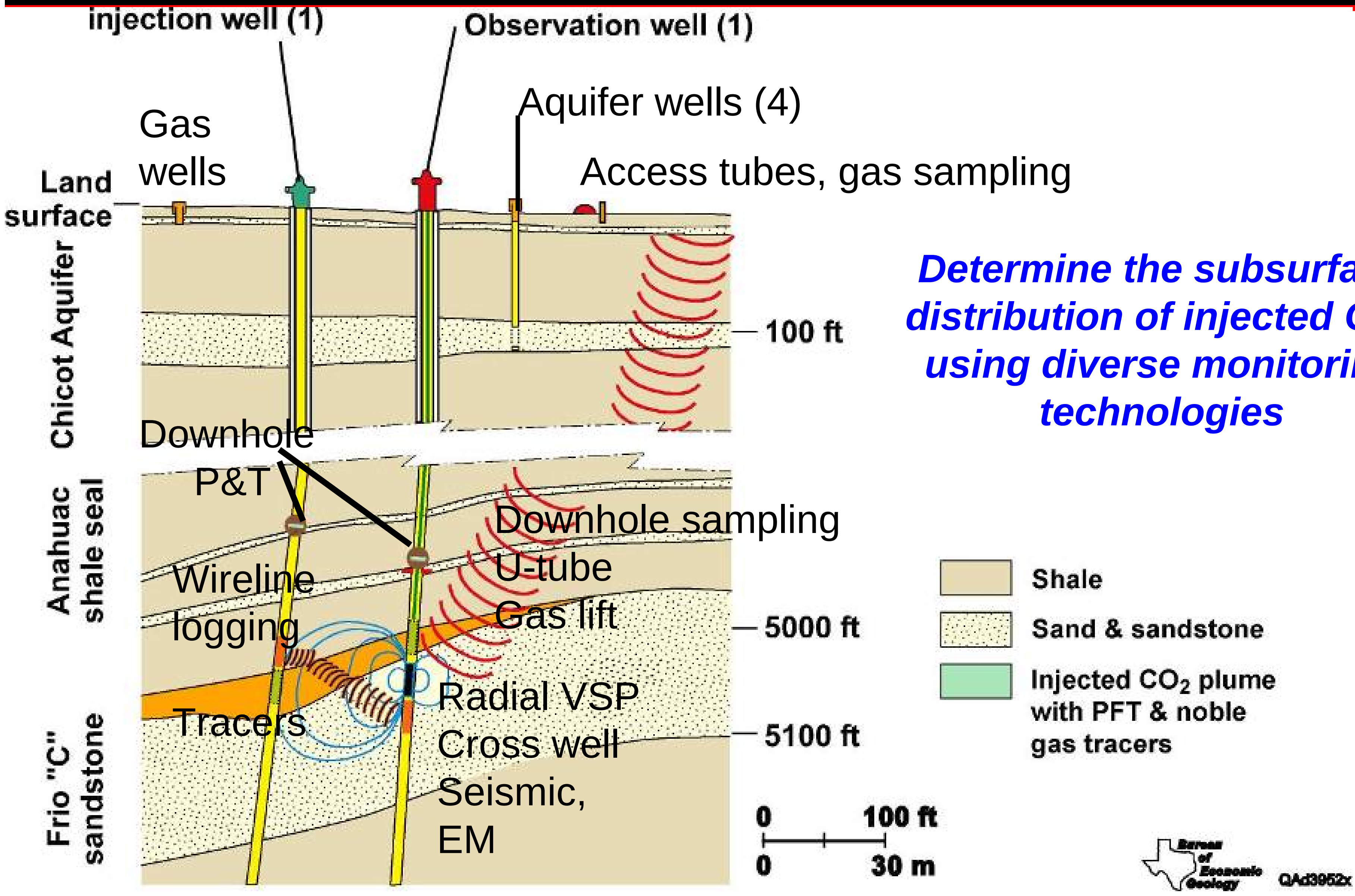

Injection well
Observation well


BETHLEHEM

Frio Pilot Injection: Phase II

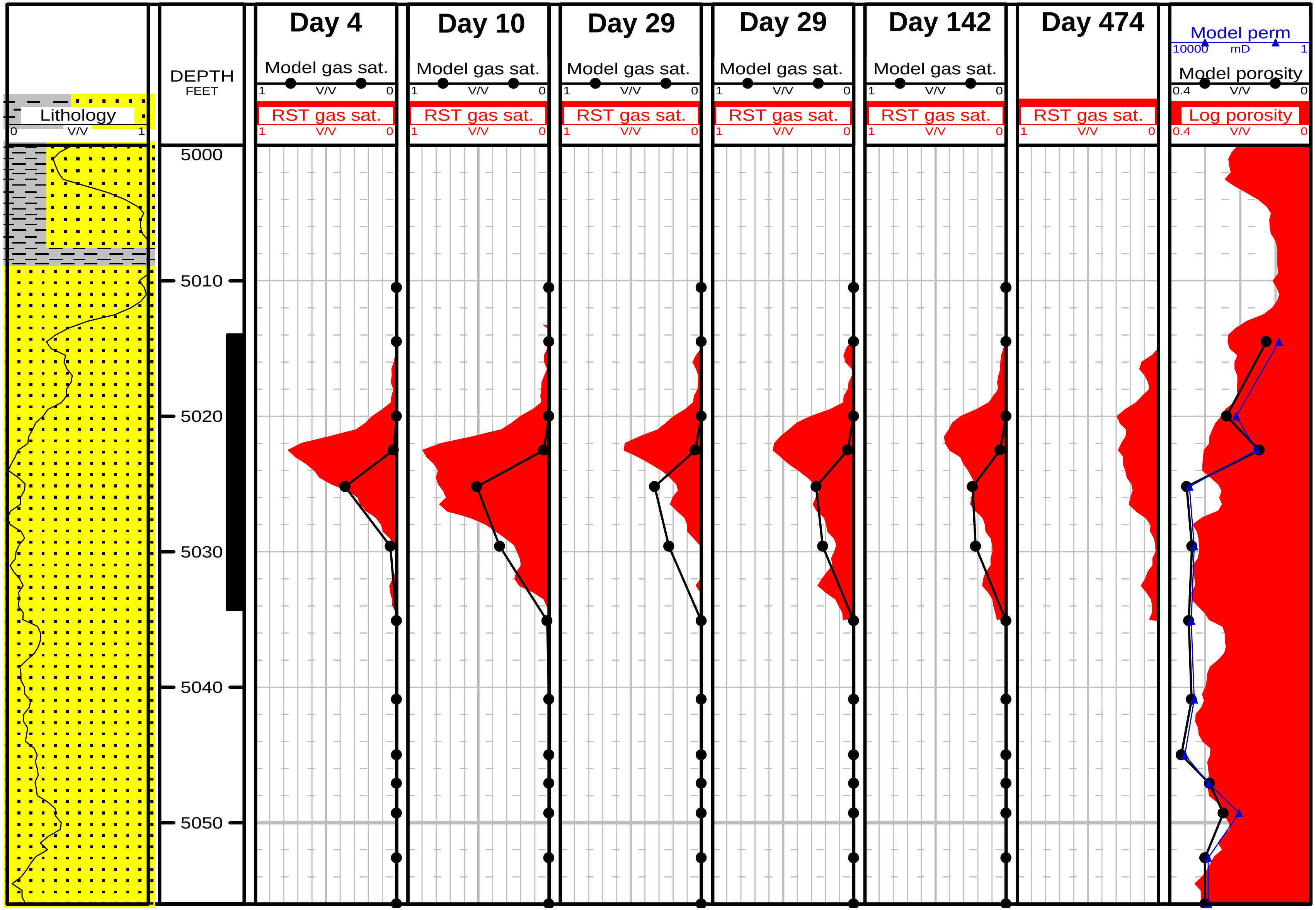
- 800 Tons
- Tracer studies: 4 PFT's and two methanated partitioning tracers (ORNL)
- Geochemical lab (USGS): aqueous tracers and in-line pH and cond.
- On-site Gas Chromatograph (UT-PE)
- U-Tube (LBNL): water & gas @ reservoir conditions in both wells, on-site Mass Spectrometer (SF5, Kr, Xe)
- Cross-well seismic (LBNL); CASSM
- Hosted CSIRO-AUS deuterated methane tracer test (Otway)
- Visitors: MIT, Battelle, Taisei Corp (Japan), China Petroleum Corporation

Frio Pilot: Cross-Comparison of Multiple Types of Measurements

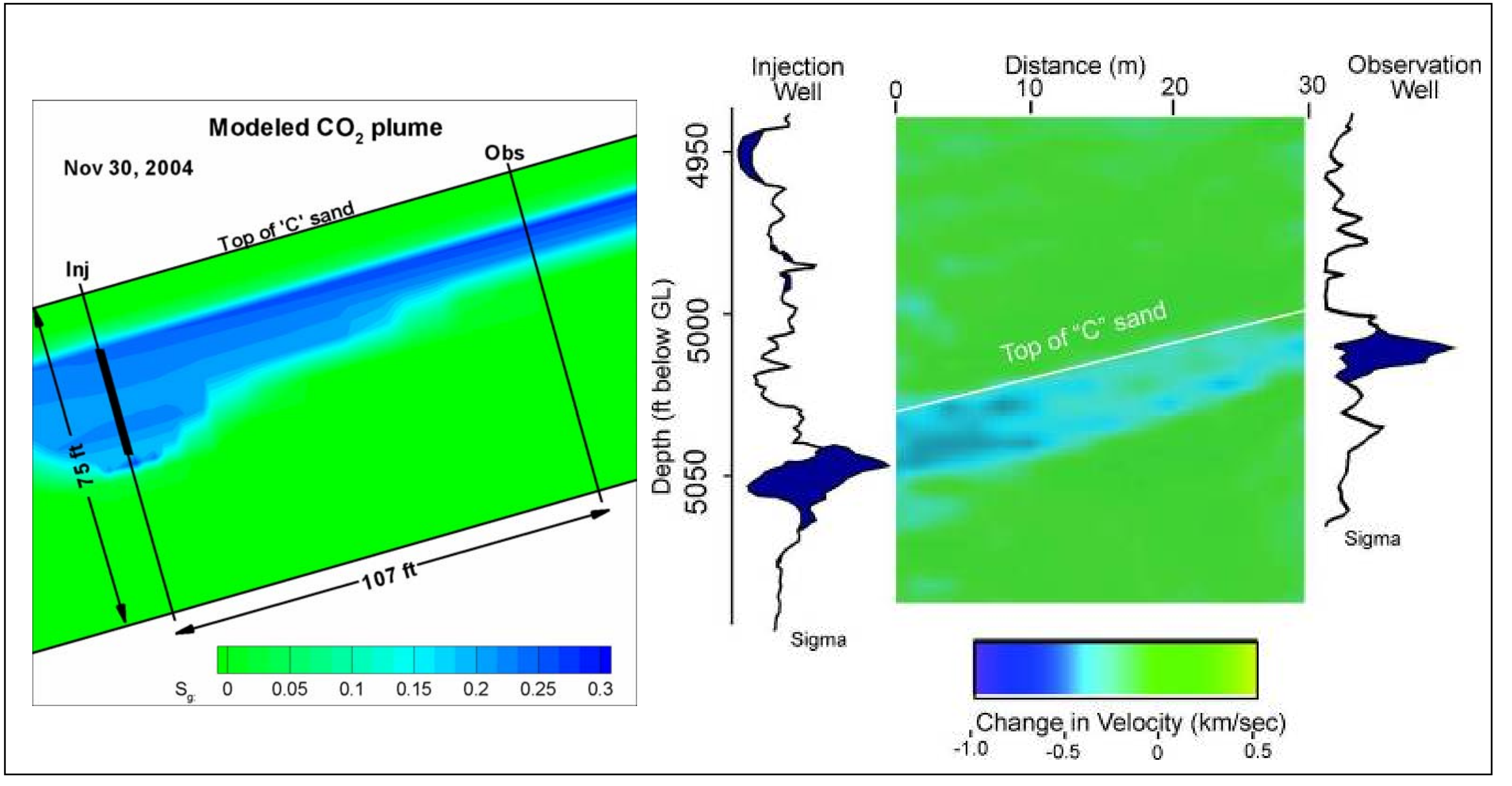


Determine the subsurface distribution of injected CO_2 using diverse monitoring technologies

Frio I injection – RST in monitor well (updip)



FRIO II (2006): CO_2 Saturation Observed with Cross-well Modeled vs. Seismic Tomography

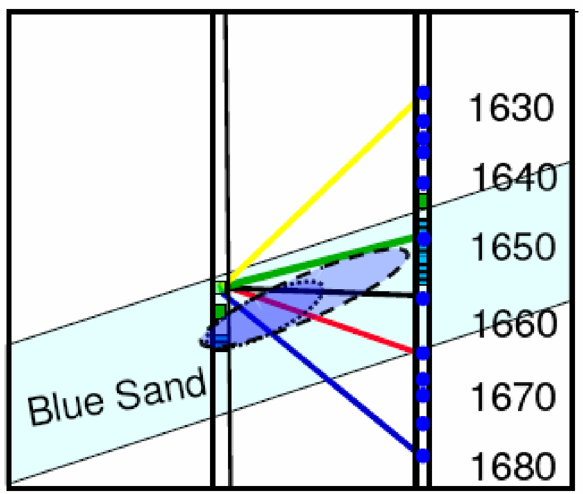


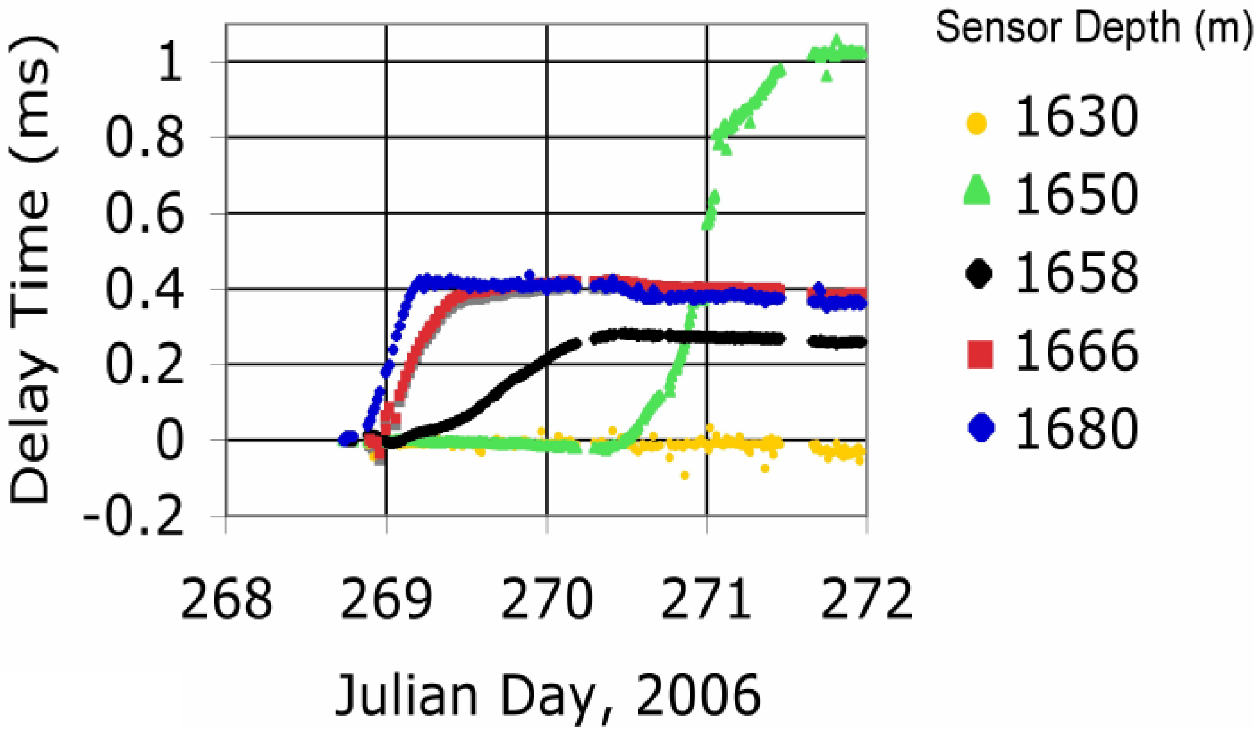
Tom Daley and Christine Doughty, LBNL

FRIO II (2006): CO_2 Saturation Observed with Cross-well Modeled vs. Seismic Tomography

Traveltime Response to CO2 Injection

Real time detection using continuous source cross-well seismic





Daley et al., 2007

Short Term Geochemistry

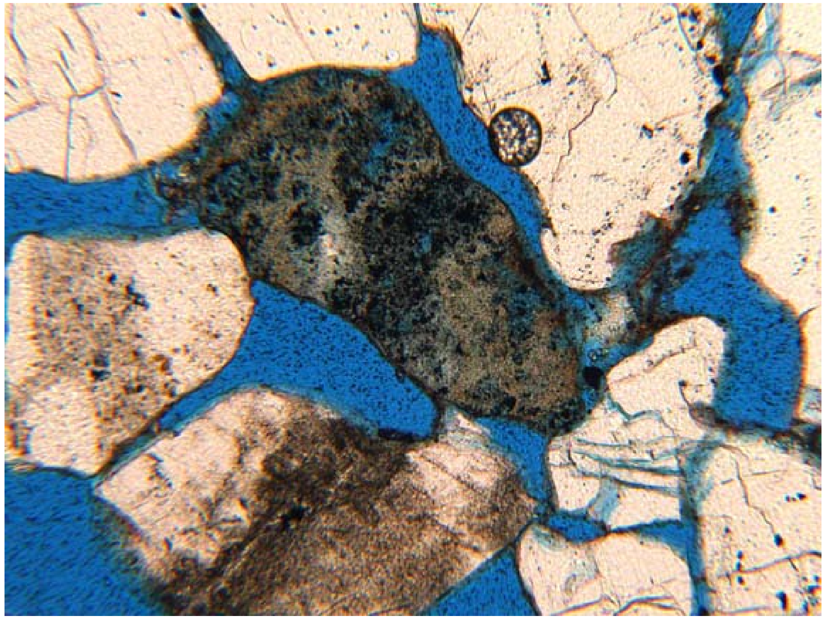
$$CO_2 + H_2O \Leftrightarrow H_2CO_3$$
$$H_2CO_3 \Leftrightarrow H^+ + HCO_3$$

Some percentage dissolves into Brine; Carbonic Acid

Aqueous solubility of CO_2 f(P,T,Ionic Strength)

Generally lower at high T & Salinity, and higher at elevated pressure (compete with depth)

Reactions with grain coat minerals



FRIO INJECTION RESULTS
Kharaka et al., Geology, 2006

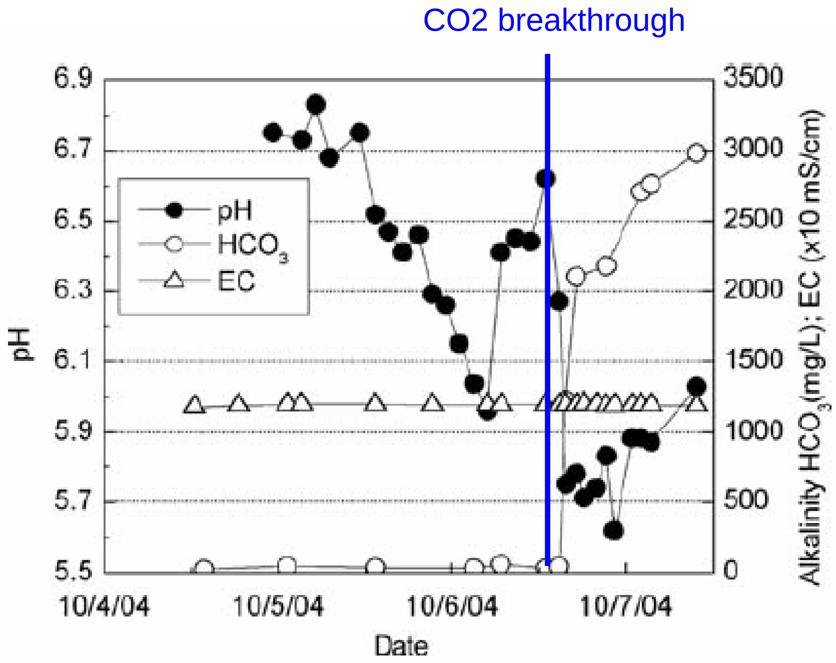


Figure 1. Electrical conductance (EC), pH, and alkalinity of Frio brine samples from "C" sandstone of observation well determined on-site during CO_2 injection on 4–7 October 2004. Note sharp drop of pH and alkalinity increase with breakthrough of CO_2 on 6 October.

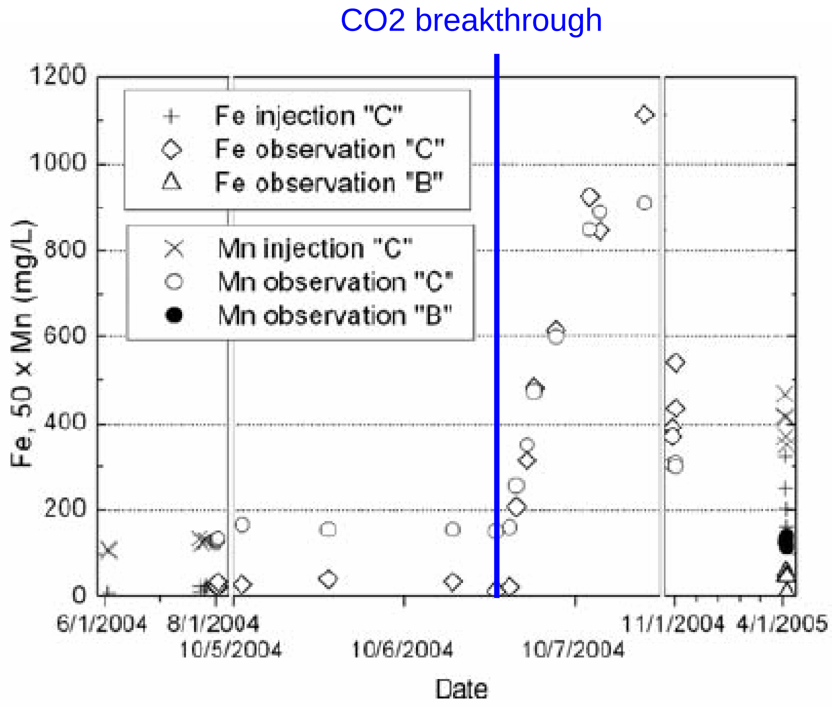
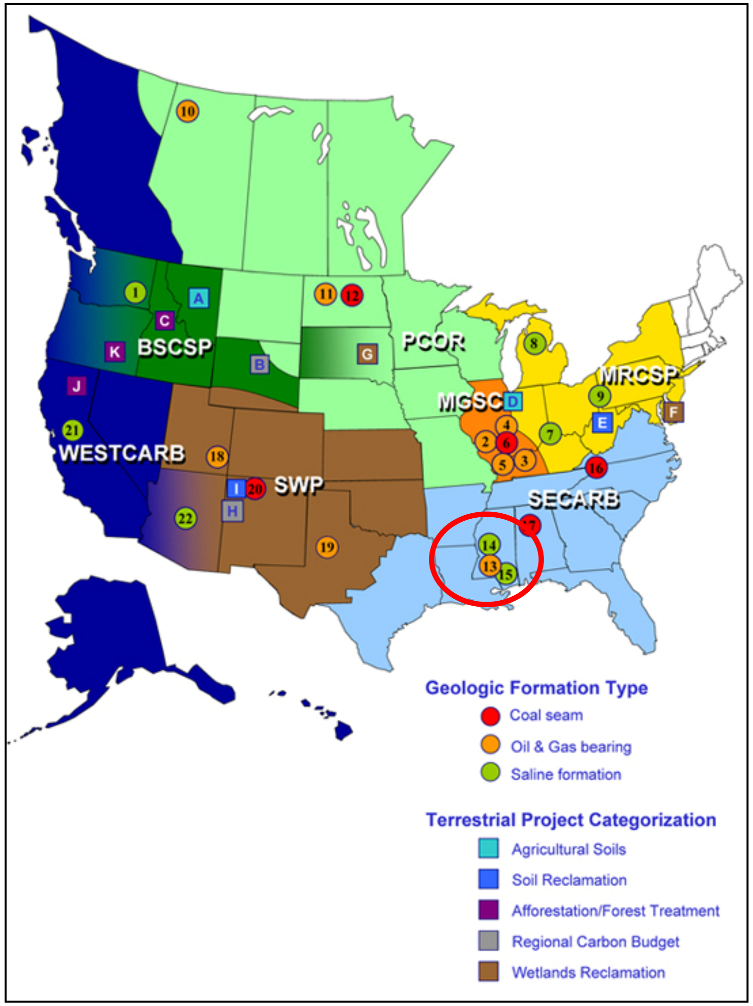


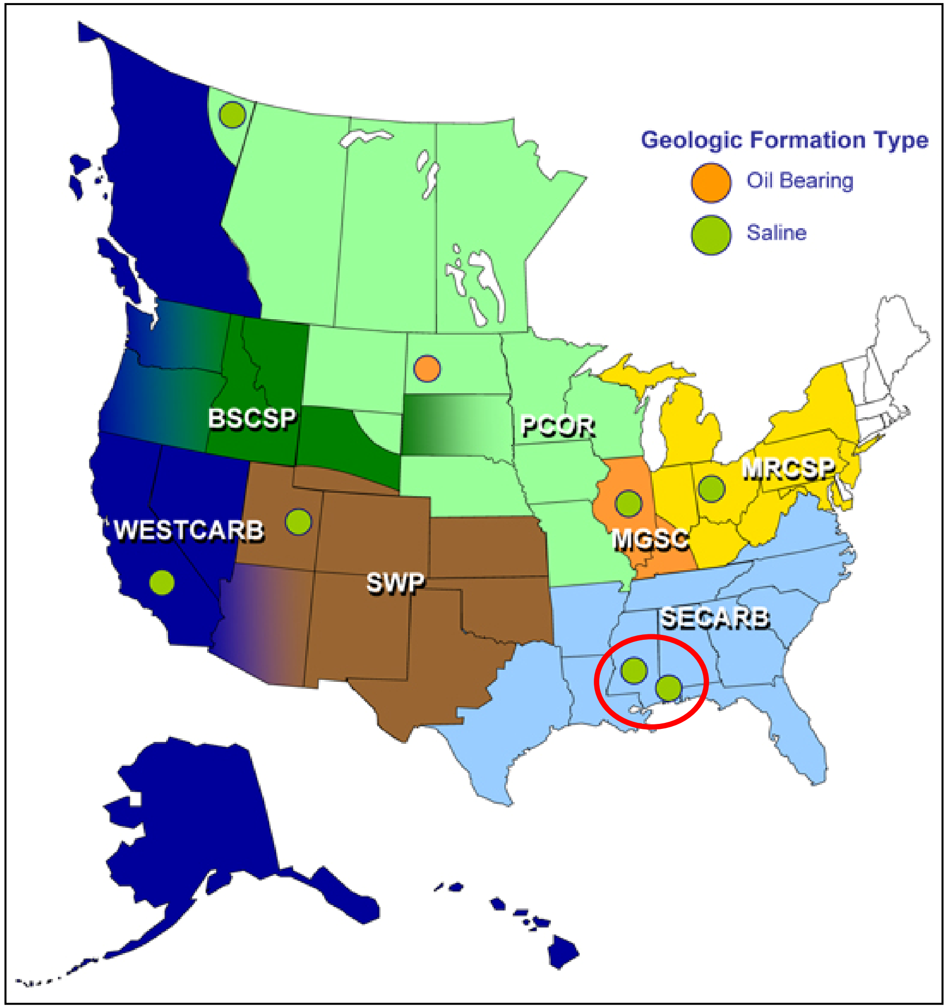
Figure 2. Concentrations of Fe and Mn in Frio brine from June 2004 to April 2005. Note sharp increases in metal content during 6 October 2004 at time of CO_2 breakthrough.

RCSP Phase 2 & 3: SECARB @ Cranfield, MS

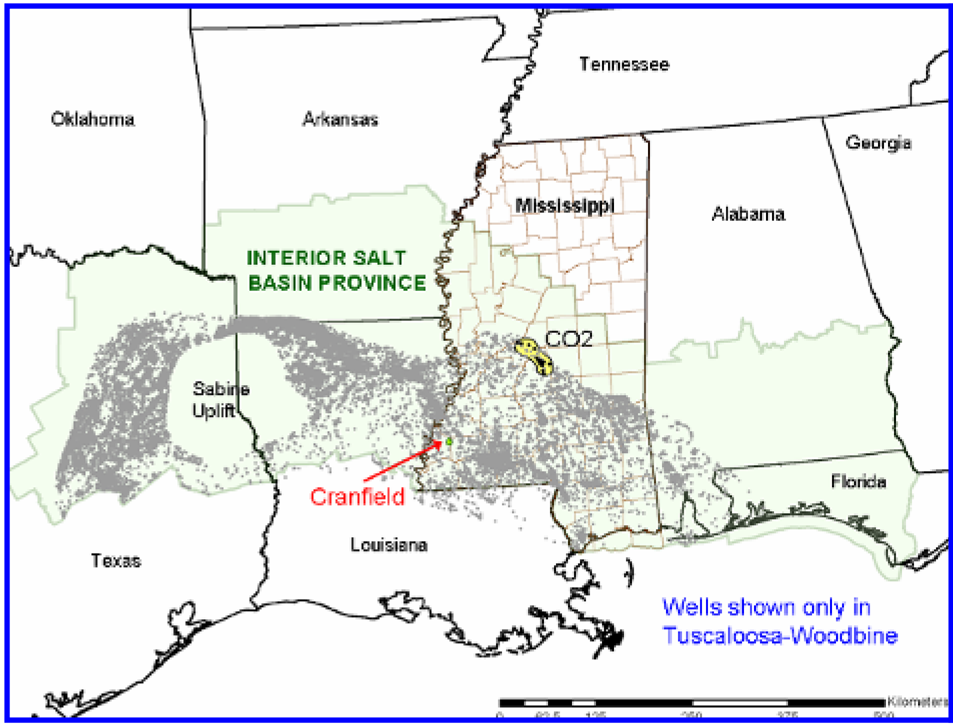
Phase 2: EOR

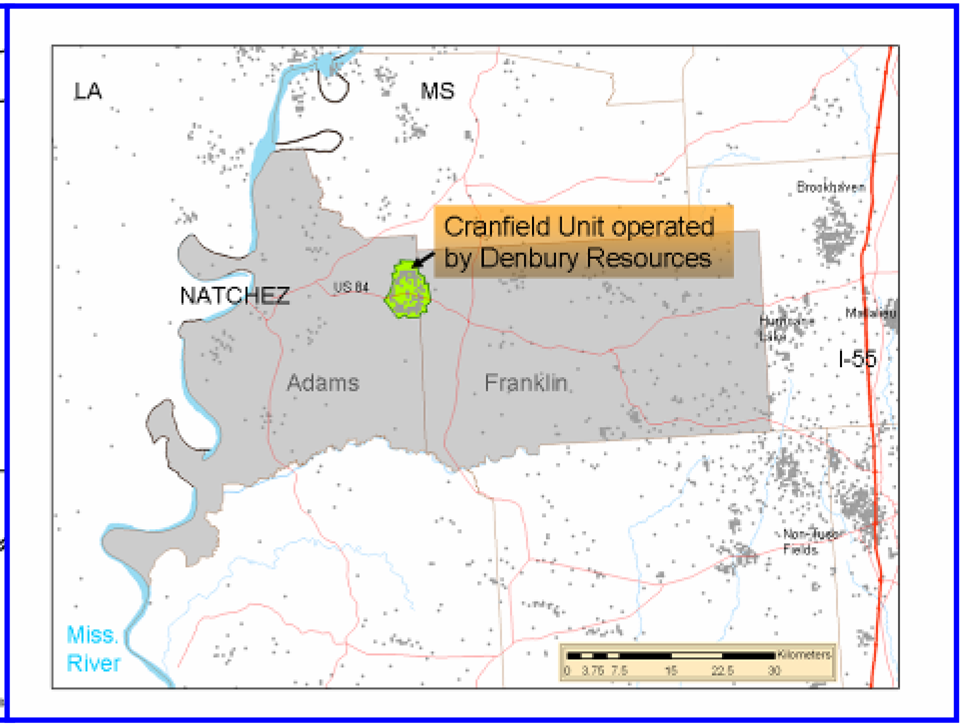


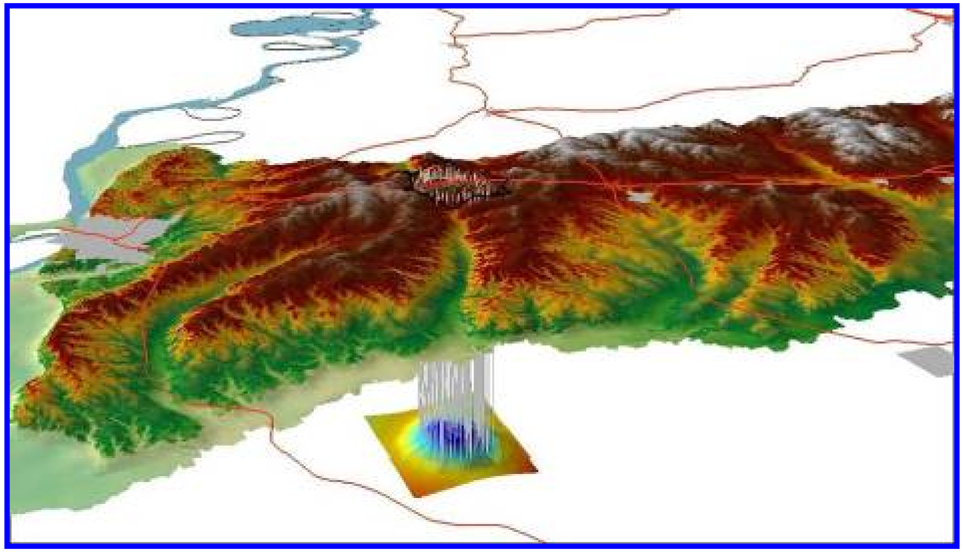
Phase 3: Brine



SECARB Phase 2 Project: Cranfield Unit, SW Mississippi

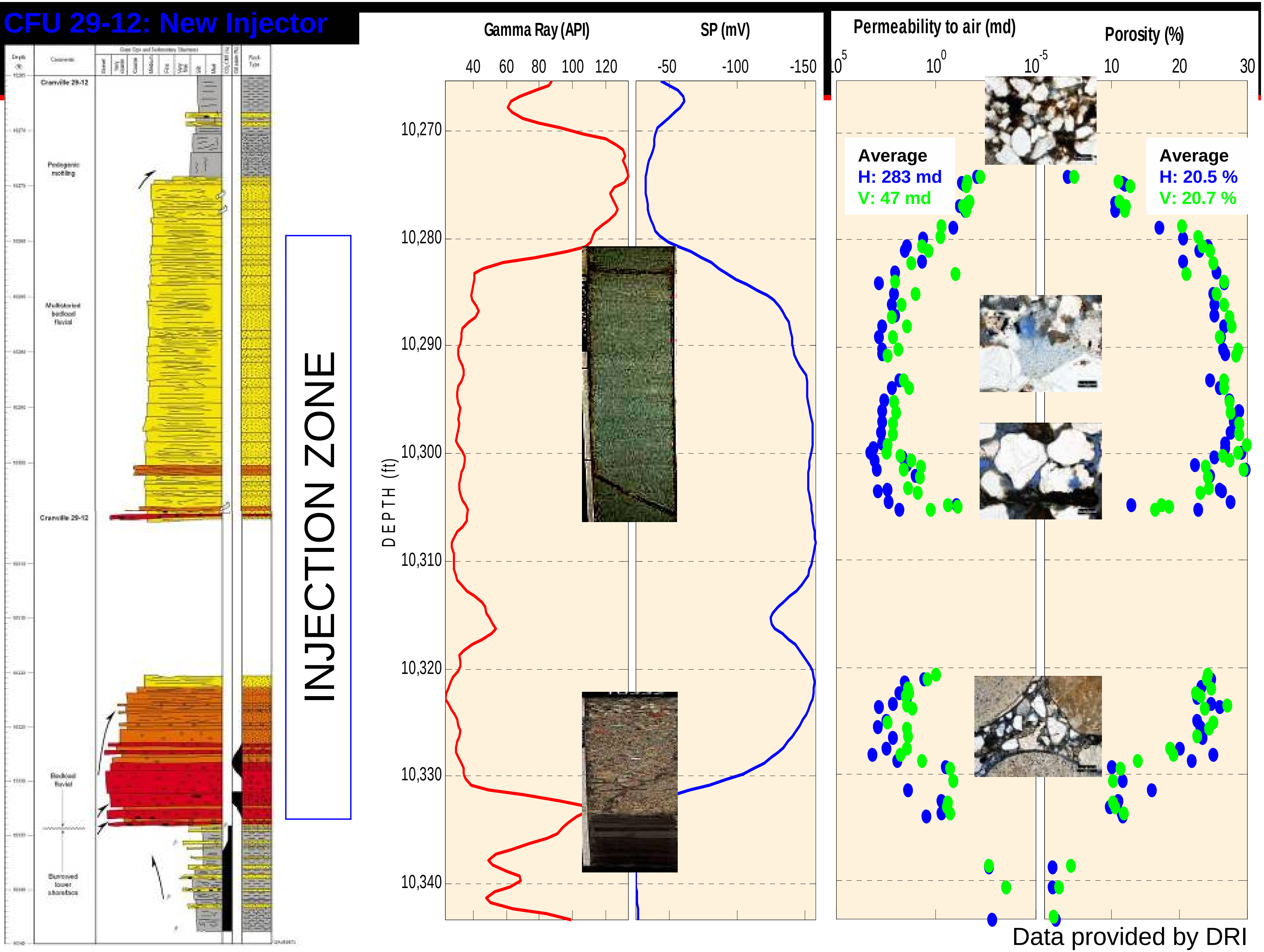






3,000 m depth (10,300 ft)
Gas cap, oil ring, downdip water leg
Original production in 1950's
Strong water drive
Shut in since 1965
Returned to near initial pressure
CO2-EOR initiated 2008 with coincident
Monitoring in RCSP Phase 2&3

CFU 29-12: New Injector



Data provided by DRI

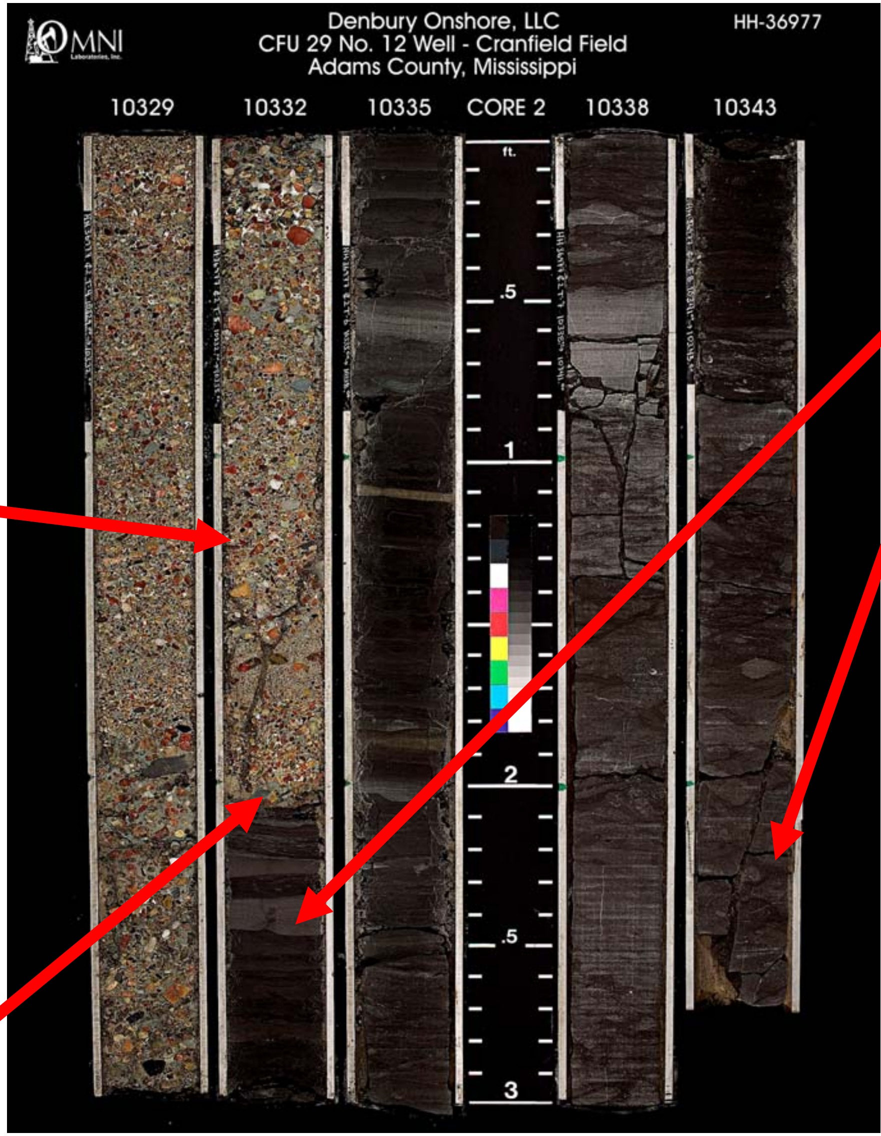
Core Box 1

Top

Chert Pebble Conglomerate

Braided Stream

Sharp Basal Contact



Marine Mudstone

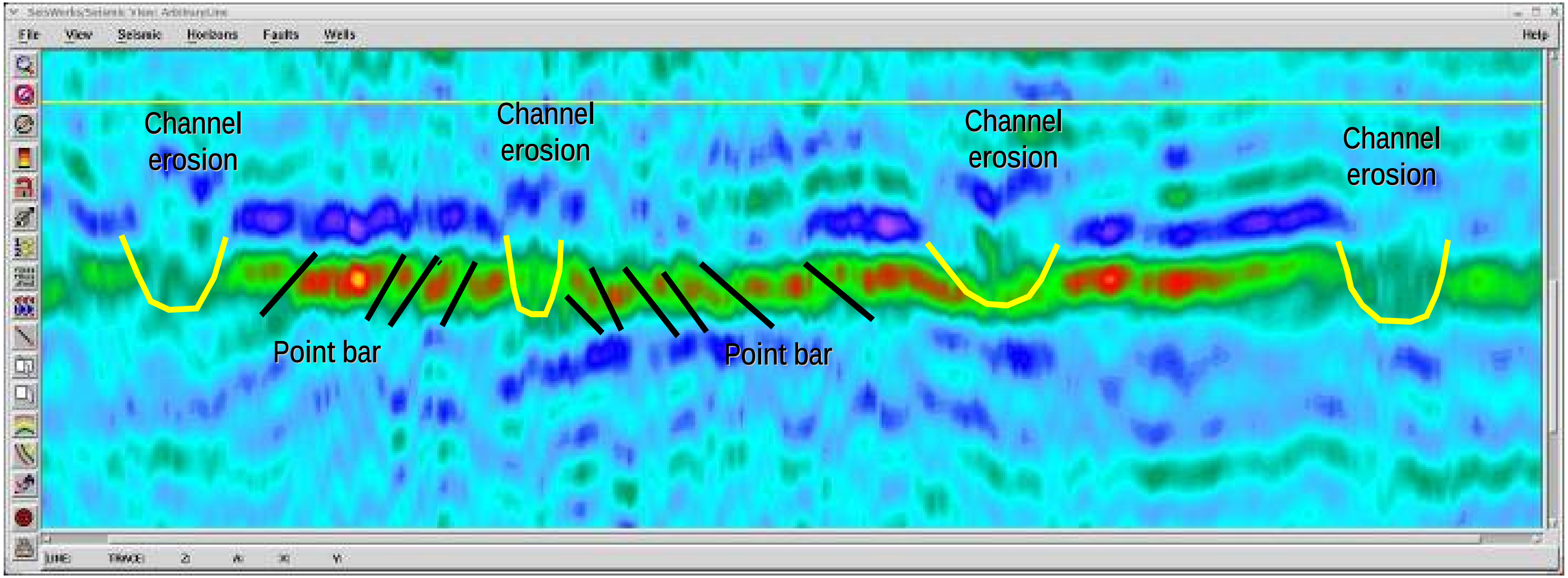
Lower Shoreface

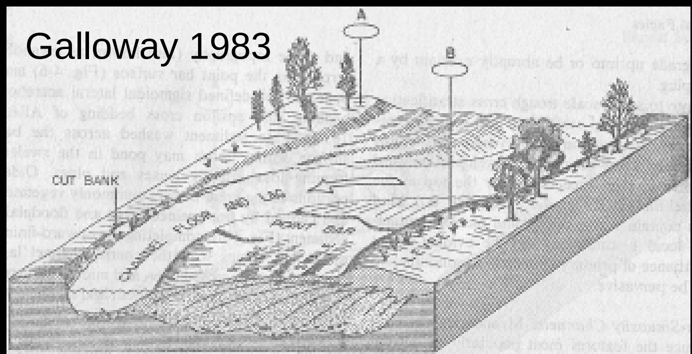
Shell fragments (oyster, gastropod) and Trace fossils

Bottom

Fluvial Depositional Environment

Stratal slicing seismic interpretation

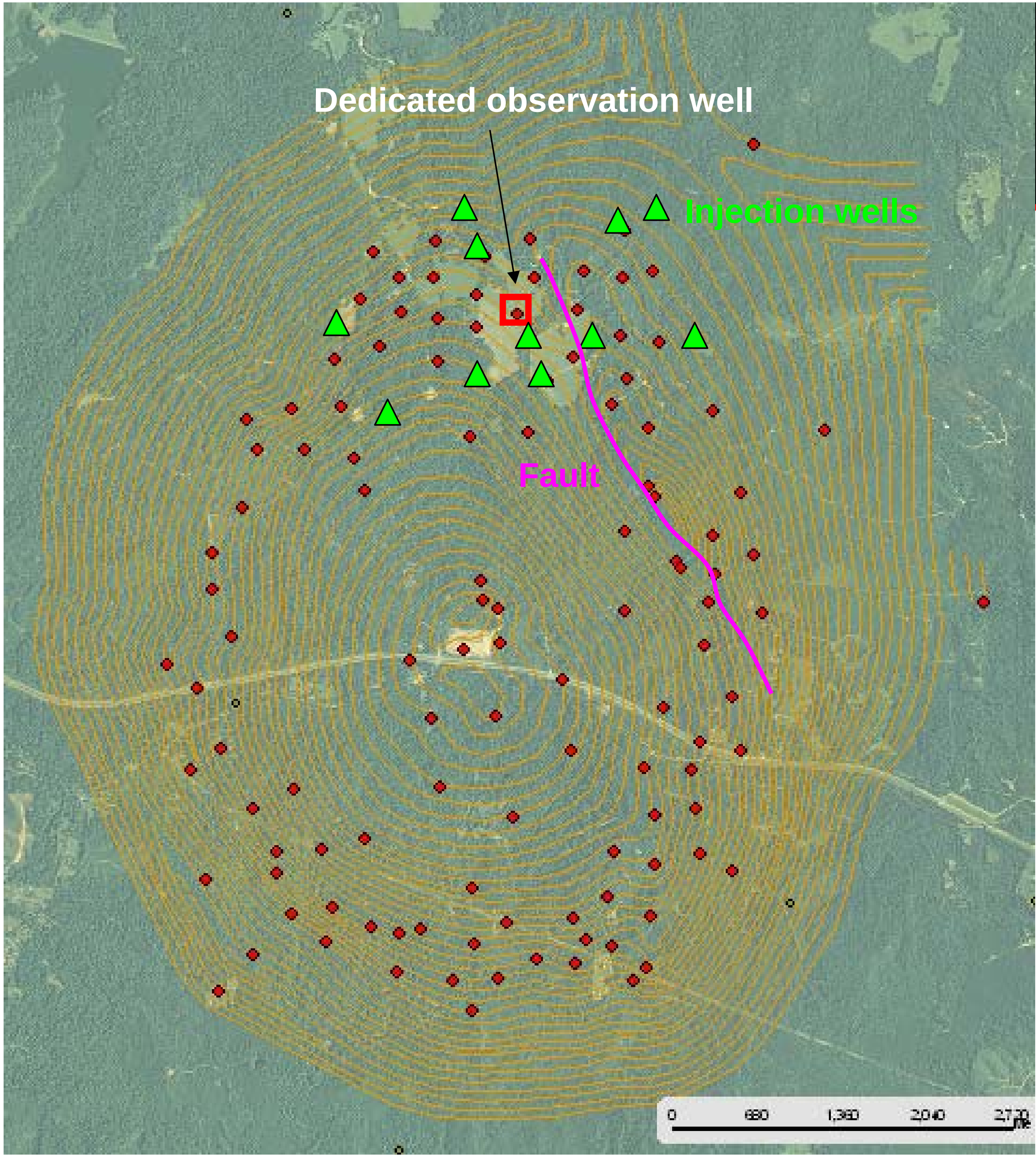


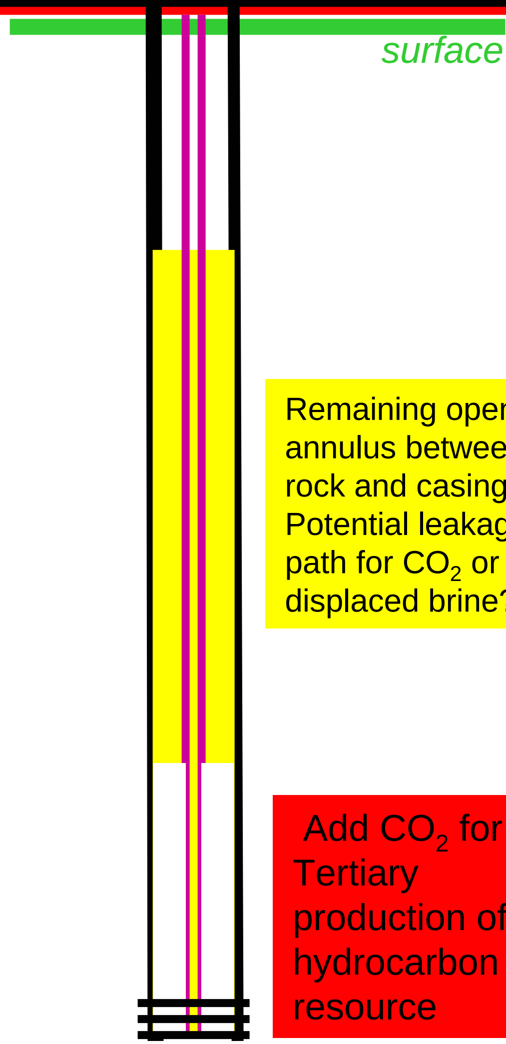


Meander fluvial model

Hongliu Zeng, BEG

Problems:
1) Many wells- How Good is Cement?
2) How will fault in reservoir perform?

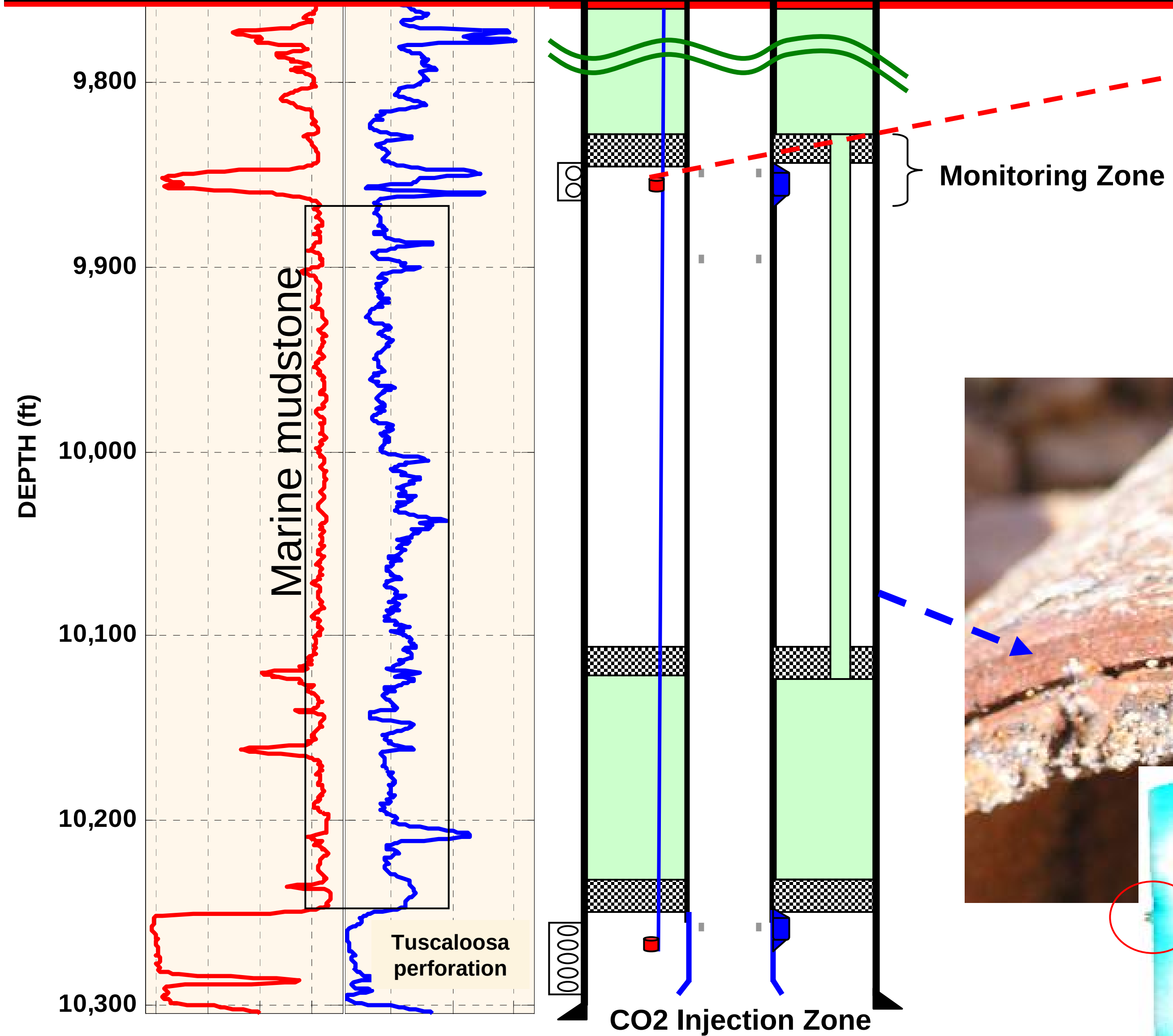


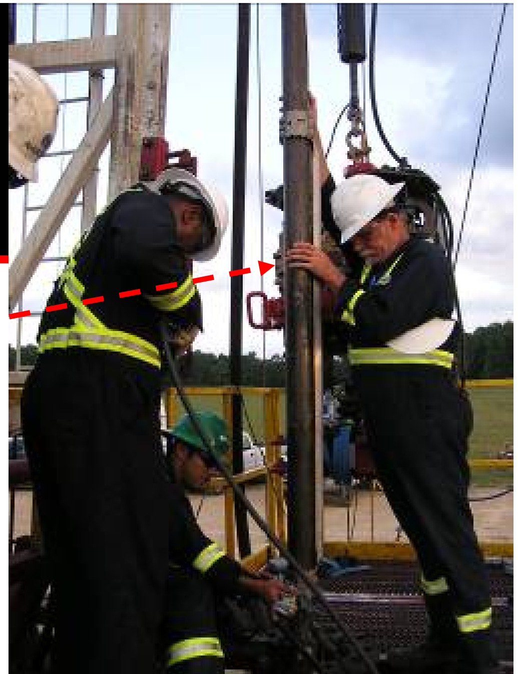


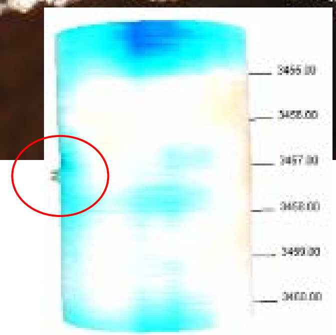
Remaining open annulus between rock and casing= Potential leakage path for CO_2 or displaced brine?

Add CO_2 for Tertiary production of hydrocarbon resource

Monitoring Well Completion

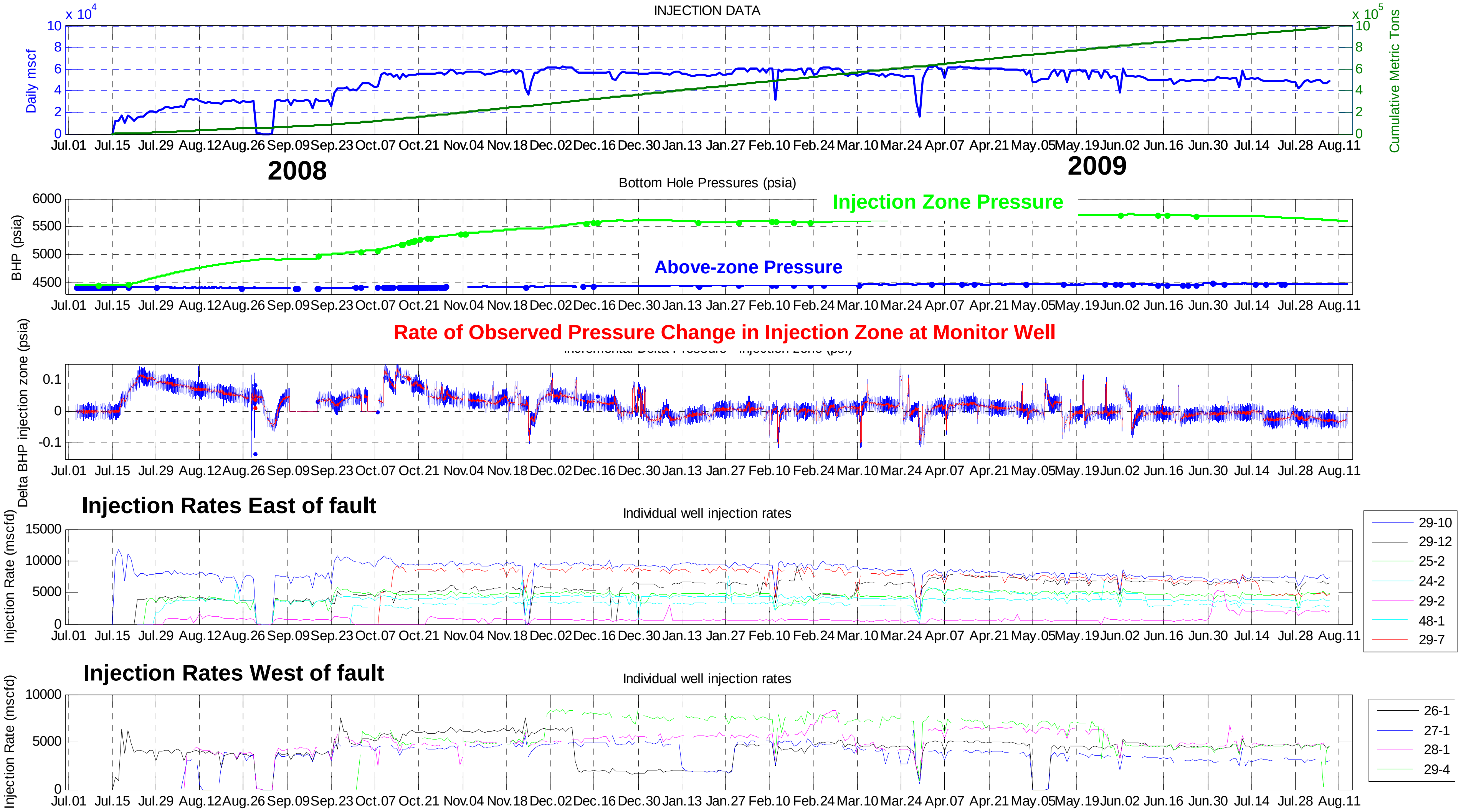






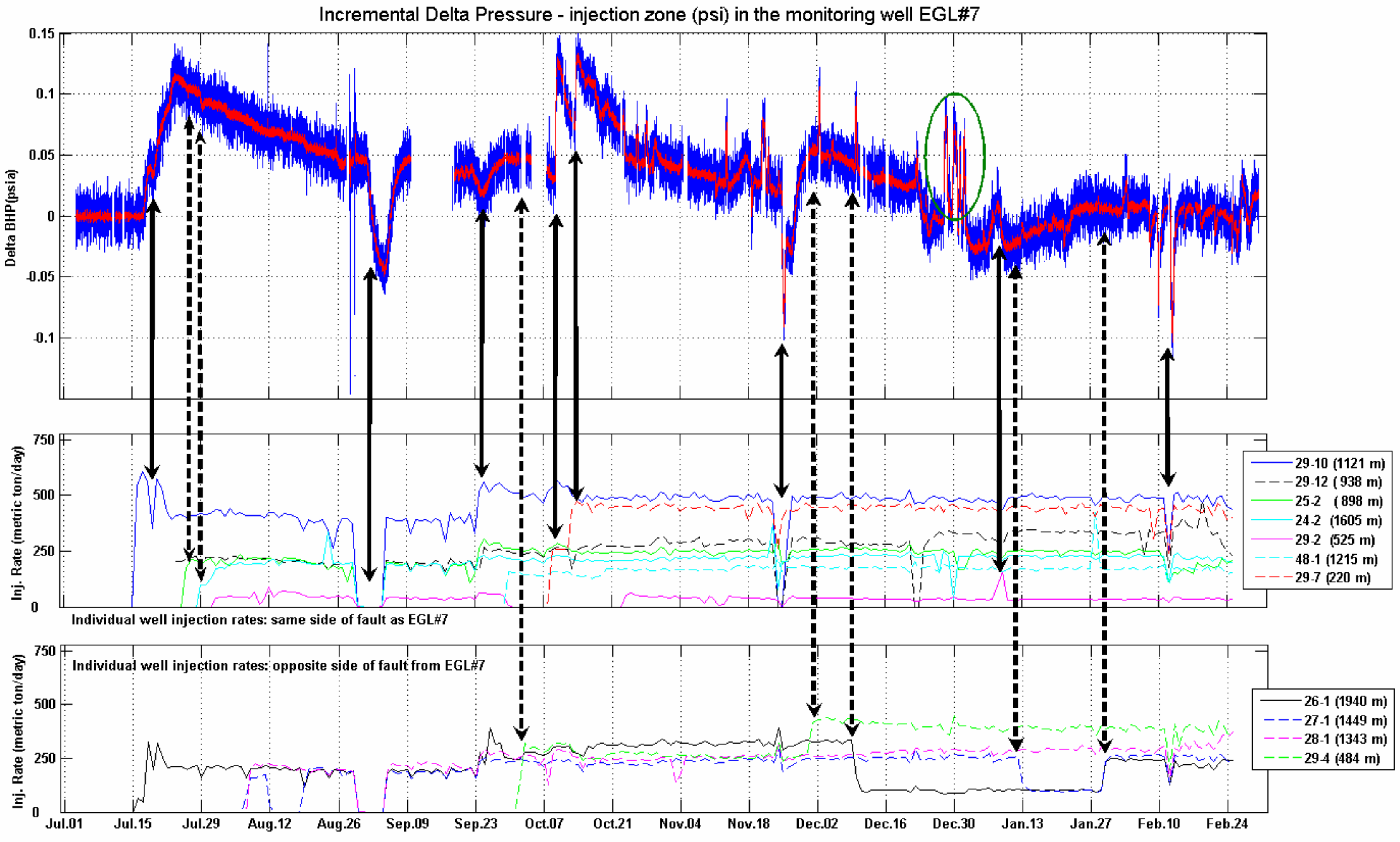

Re-entry of 60-year-old production well for continuous monitoring
FIELDPORT
Satellite transmission
Monitoring well
Denbury Onshore, LLC
CRANFIELD FIELD
ELLA G LEES #7
ADAMS COUNTY, MS
Tubing data

Continuous field data from dedicated monitoring well



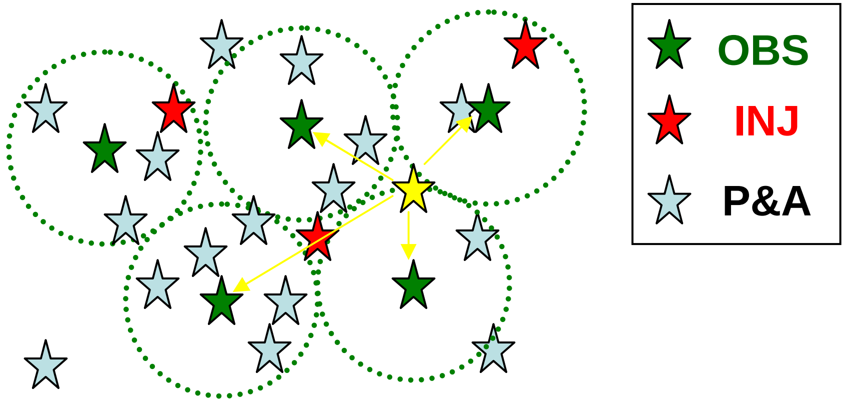
Continuous field data from dedicated monitoring well

- Large perturbations related to changes in injection rate obvious
  - Serve as proxy for sensitivity of leakage detection
- Even small perturbations observable (100's tons/day flux from 1 km)
- Fault observed to be sealing (no pressure communication across fault)



Phase 2 Interim Results

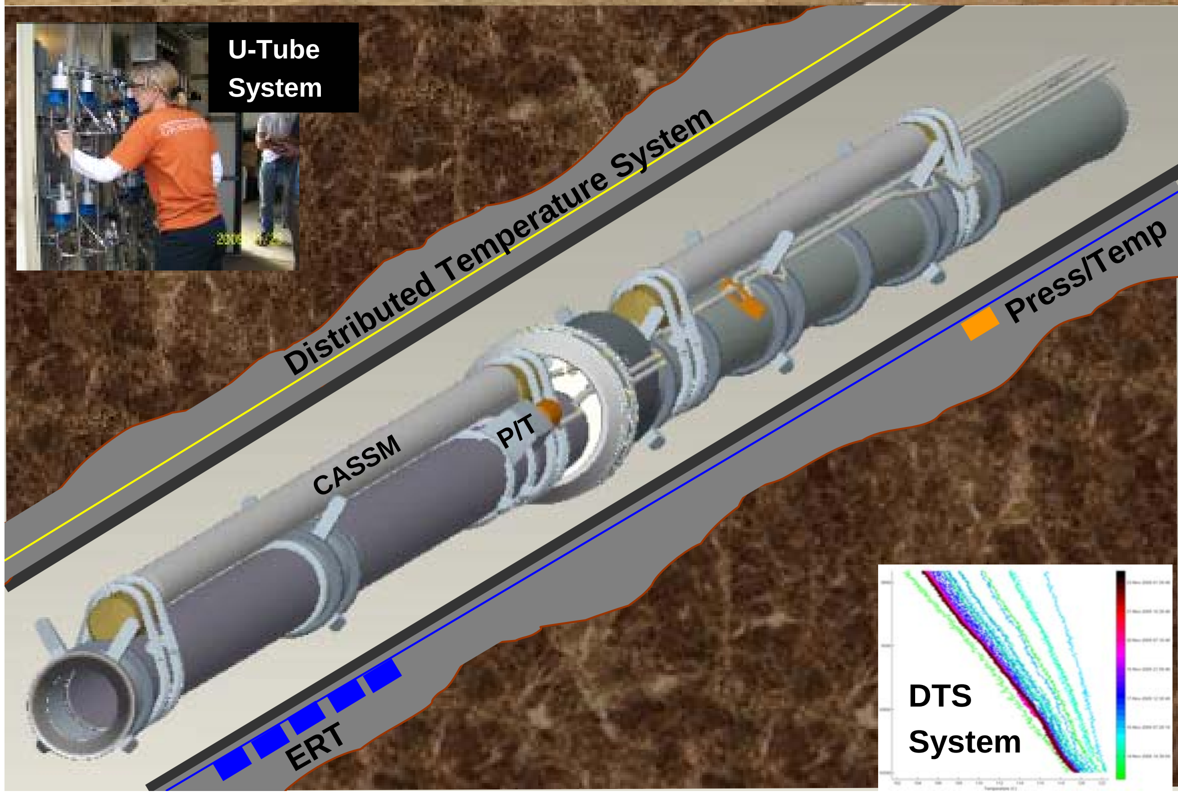
- **Old Wells Reasonable Integrity**
  - No above-zone pressure communication
  - ~ 40 wells – 2 km radius OBS well
- **Small leaks should be detectable**
  - Small pressure changes observable
  - ***Could locate out of zone migration***
- **Monitoring design implication**
  - Pressure is change - sensitive
  - Detectable change in 100’s ton/day @ 1Km
  - <5% gain/loss of contemporaneous total field rate

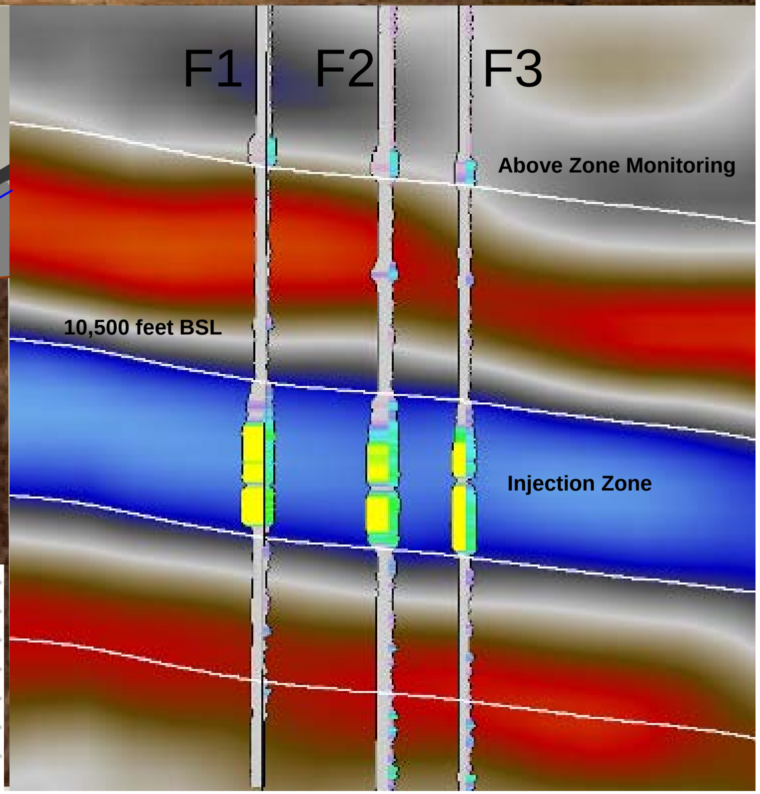


Could use variable responses at different OBS to triangulate on problem area.

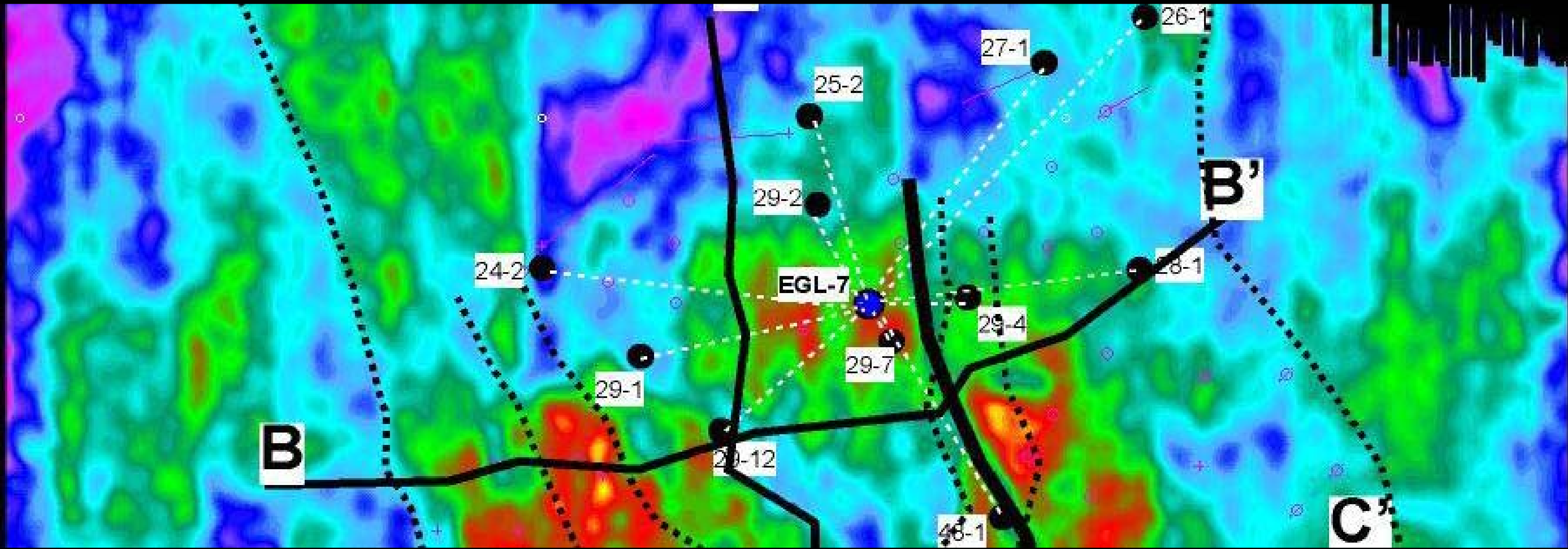
Cranfield Phase 3 Project: Cranfield, MS

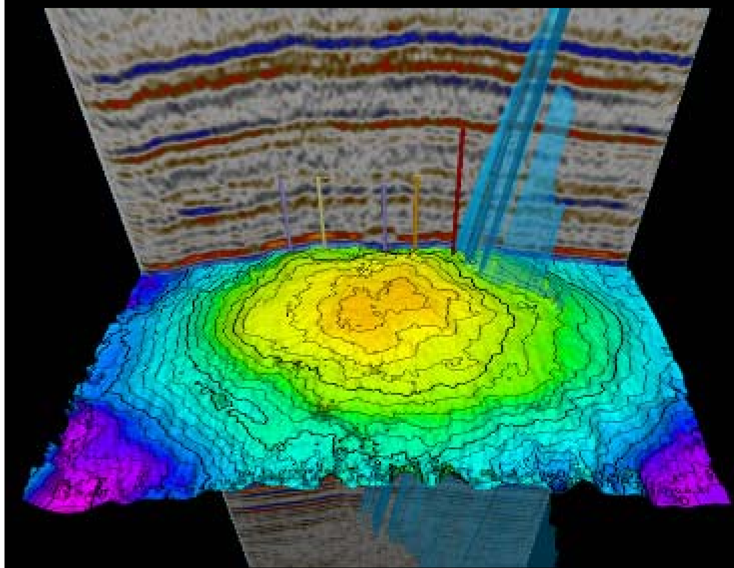
3,000 m depth, Inj. Rates 5-10 MMSCFD; December 2009

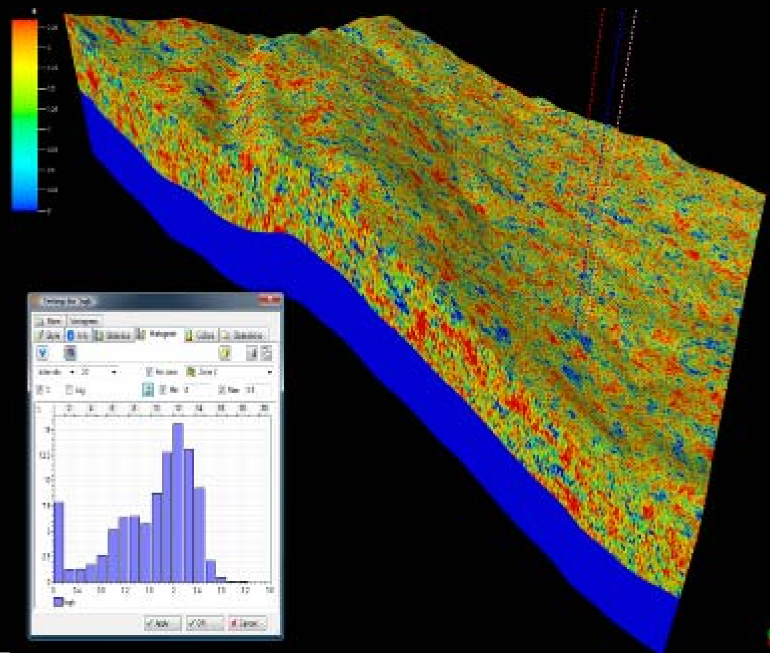




Integrated Reservoir Characterization & Performance

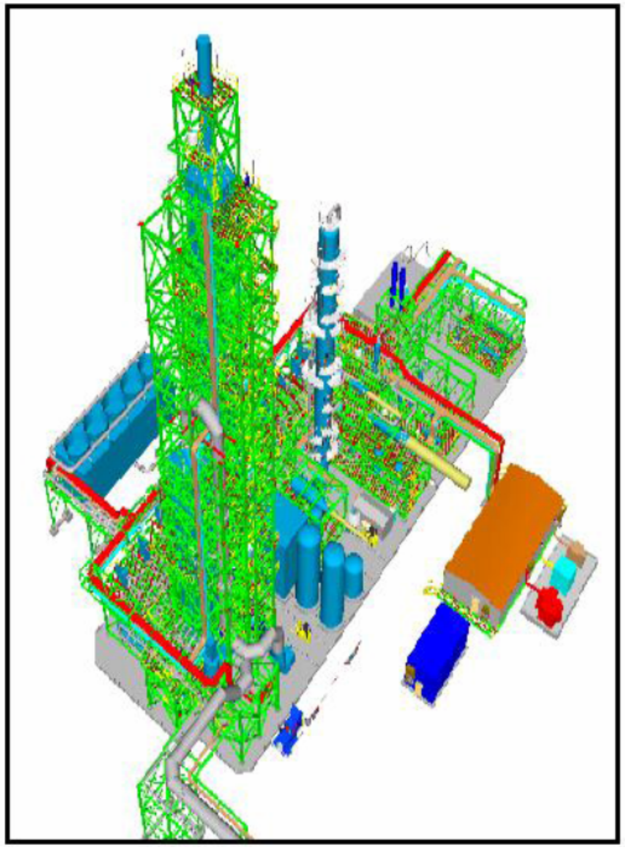






SECARB Phase 3: Anthropogenic Test

- **Sequestration Objectives:**
- – Build geological and reservoir maps for test site
- – Conduct reservoir simulations to estimate injectivity, storage capacity, and long-term fate of injected CO2
- – Address state/local regulatory and permitting issues
- – Foster public education and outreach
- – Inject 125,000 metric tons of CO2 per year for four years
- – Conduct longer-term monitoring for 3-4 years post-injection



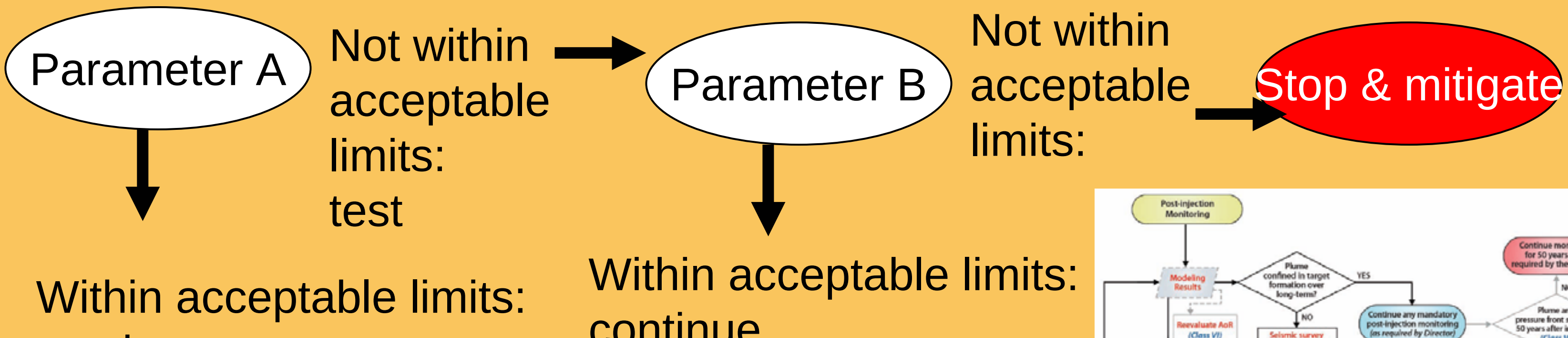
Anthropogenic CCS Team:

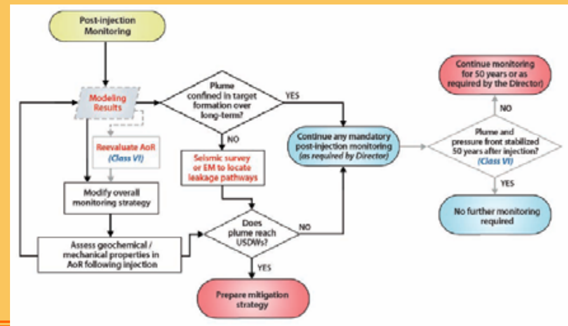
- EPRI Alabama Power
- EPRI's Utility Partners Southern Company
- Advanced Resources International
- Denbury Resources
- Geological Survey of Alabama
- Mitsubishi Heavy Industries

Need for Parsimonious Monitoring Program in a Mature Industry

"First Bad Thing" concept

- Standardized, dependable, durable instrumentation, reportable measurements
- Possibility of above-background detection:
  - Need for a follow-up testing program to assure both public acceptance and safe operation
- Hierarchical approach:



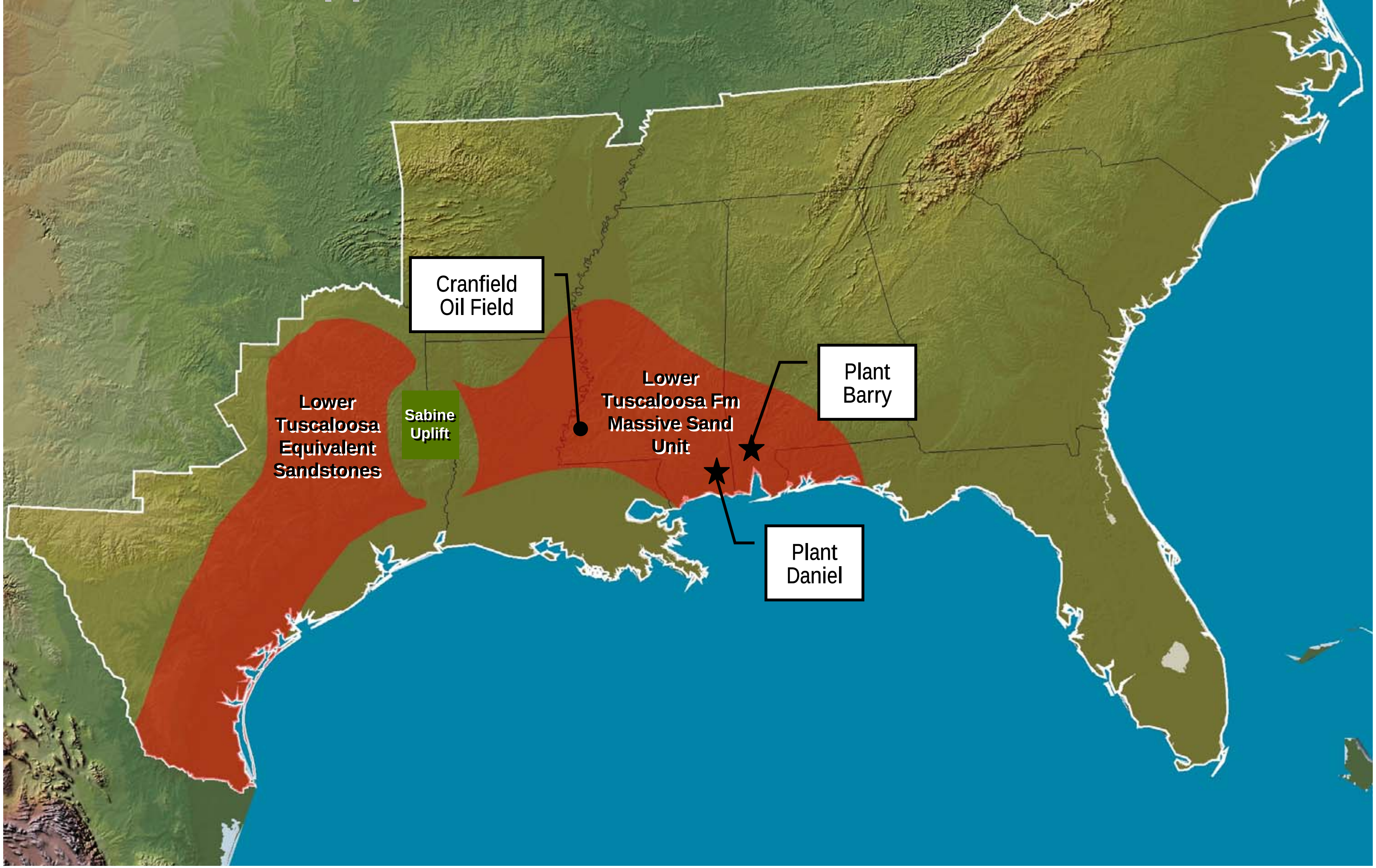


Gulf Coast Carbon Center (GCCC)

www. gulfcoastcarbon.org

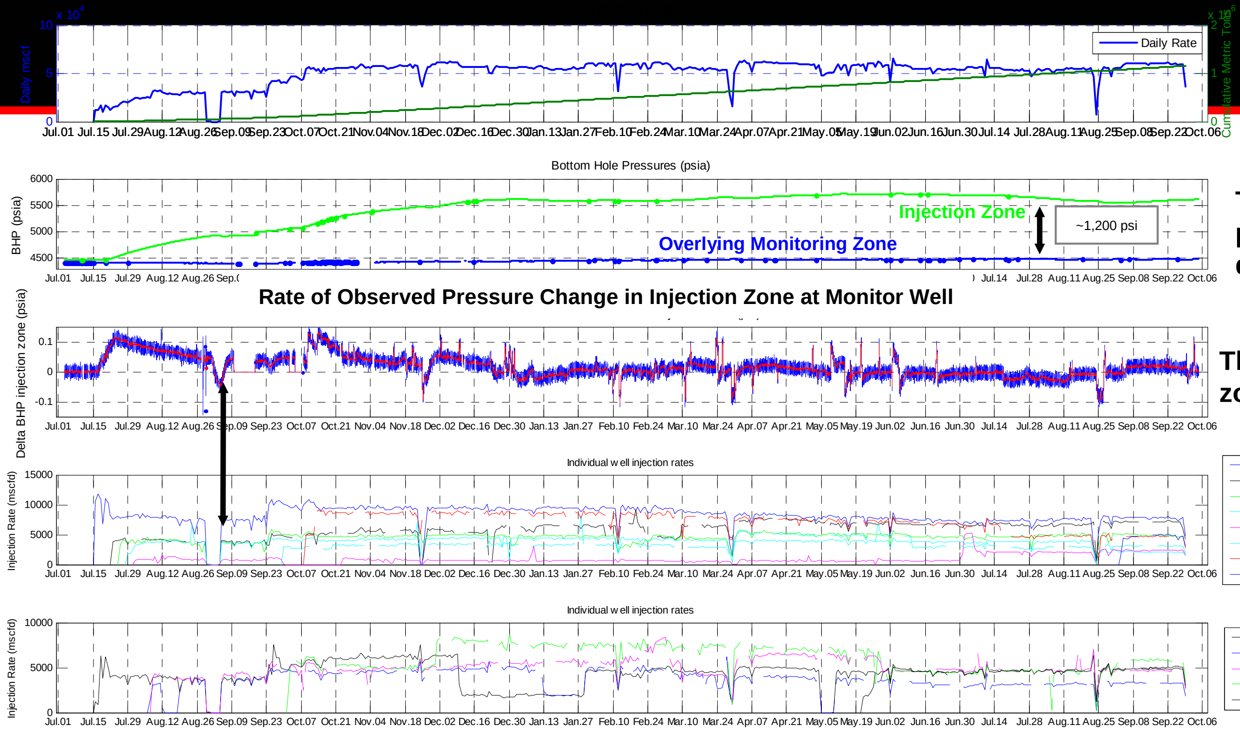
Director Scott Tinker GCCC Team:
Sue Hovorka, Tip Meckel, J. P. Nicot,
Ian Duncan, Becky Smyth, Changbing Yang, Katherine Romanak
Jiemin Lu, Jong Choi + *students*

The Lower Tuscaloosa Massive Sand Unit and Mississippi Test Site Location



15 Months Continuous Pressure Monitoring

Injection zone & overlying monitoring zone

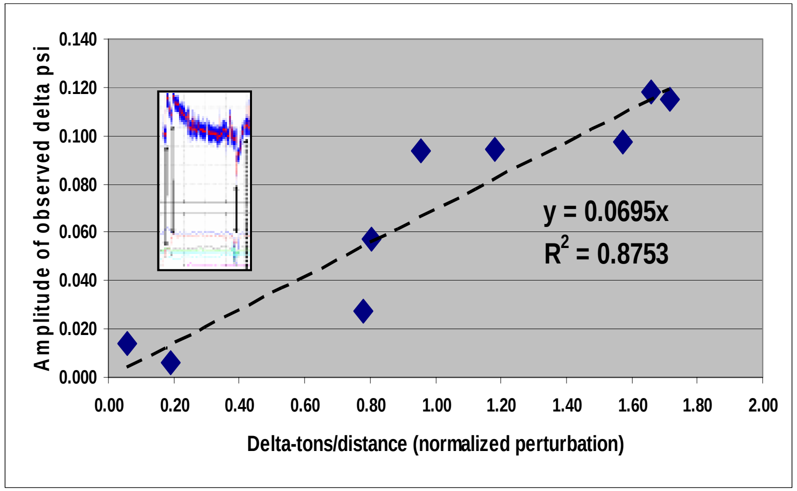


11 injection wells.

The reservoir pressure has risen over 1200 psi during the injection, and has leveled off due to hydrocarbon recovery.

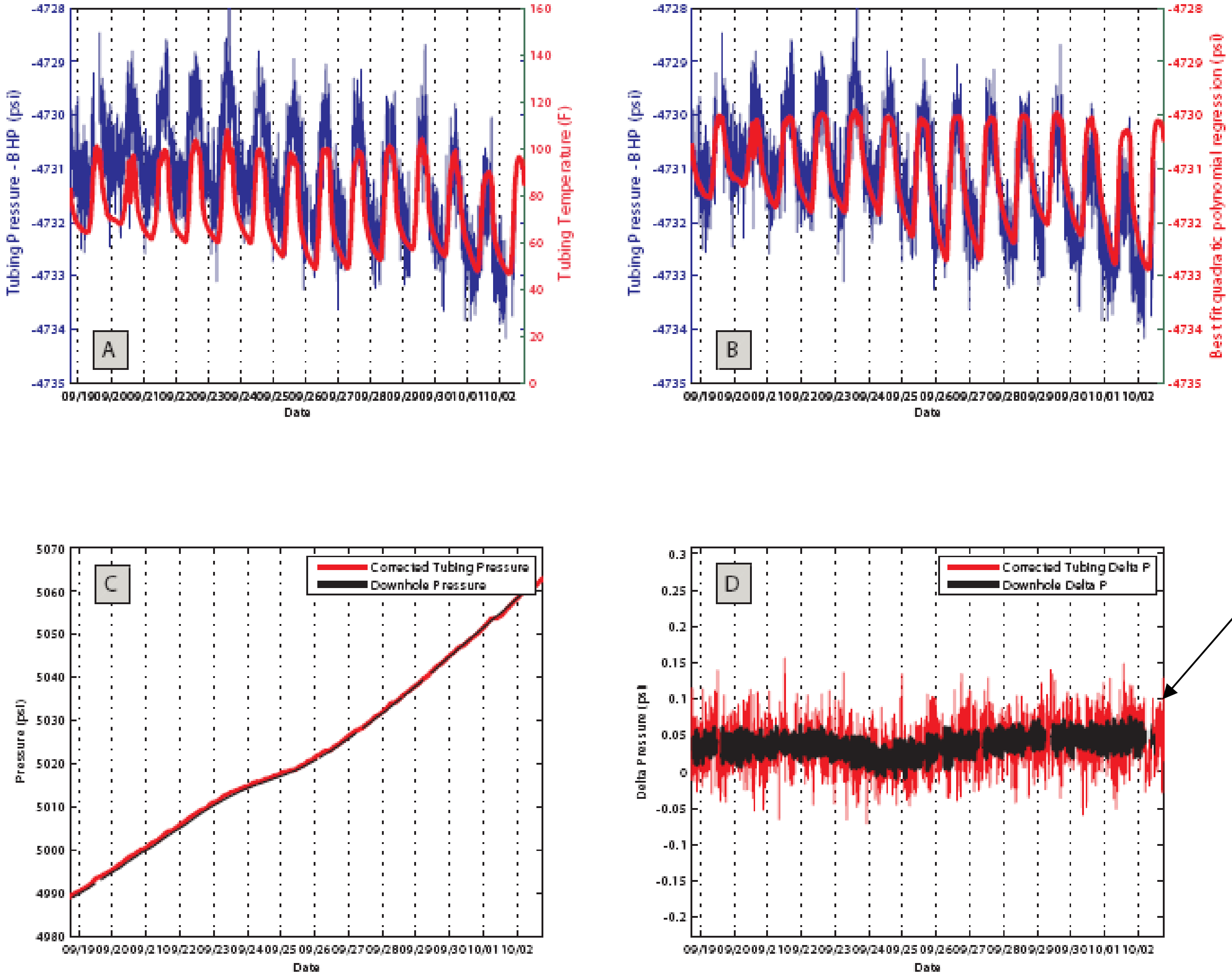
The rate of pressure change in the injection zone allows gauge sensitivity to be determined.

Event	Date	Basis	Change MSCFD	Metric Tons	Amplitude of Delta.P (psi)	Effective Distance (ft)	Effective Distance (m)	Response per tonne (amp. delta psi/ton)	normalized perturbation	Magnitude Delta.P (psi)
(A) Hurricane Ike	7/19/2008	Individual well (29-10)	-4,099	-213	-0.006	3368	1121	2.82E-05	0.19	0.006
(E) 25-2 startup	7/26/2008	individual well (25-2)	3,400	176	no response	2946	898			
(F) 24-2 startup	7/29/2008	individual well (24-2)	1,862	97	no response	5266	1605			
(B) Hurricane Gustav (below)	8/30/2008	Field wide	-19,296	-1002	-0.094	complex		9.37E-05	0.95	0.094
(G1) 29-4 startup	10/2/2008	individual well (29-4)	2,586	134	no response	1586	484			
(C1) Closest injector on (29-7)	10/6/2008	Individual well (29-7)	6,000	260	0.095	723	220	3.65E-04	1.18	0.095
(C2) Closest inj. increase (29-7)	10/13/2008	Individual well (29-7)	3,416	177	0.057	723	220	3.21E-04	0.81	0.057
November reduction (below)	11/24/2008	complex	-24,788	-1286	-0.115	complex		8.93E-05	1.71	0.115
(G2) 29-4 rate increase	12/1/2008	individual well (29-4)	2,624	136	no response	1586	484			
(H) 26-1 rate decrease	12/10/2008	individual well (26-1)	-4,568	-237	no response	6366	1940			
(D) 29-2 increase	1/6/2009	Individual well (29-2)	2,397	124	0.028	525	160	2.22E-04	0.78	0.028
(I) 27-1 rate decrease	1/13/2009	individual well (27-1)	-2,587	-134	no response	4754	1449			
February reduction (below)	2/11/2009	complex	-18103	-940	-0.118	complex		1.26E-04	1.66	0.118
Late March reduction (below)	3/28/2009	complex	-20010	-1039	-0.097	complex		9.39E-05	1.57	0.097



The <u>table above</u> captures the **magnitude of rate of pressure change** and related injection rate metrics to assess sensitivity of the monitoring technique. <u>Plot to right</u> shows normalized pressure perturbations versus amplitude of rate of pressure change, and indicates broadly characteristic pressure response in field to various perturbation magnitudes and distances that can be used to predict sensitivity to leakage.

Comparison of processed surface pressure sensitivity with downhole gauge



Tubing data corrected for Temperature and tubing fluids carries useful downhole information.

Implications for monitoring design being evaluated.

Monitoring Technology: Lessons Learned