SECARB "Early Test" at Cranfield

DE-FC26-05NT42590

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The University of Texas at Austin

SECARB

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

12th Annual Stakeholders' Briefing

Hyatt Regency Atlanta
Atlanta, Georgia
March 8-9, 2017

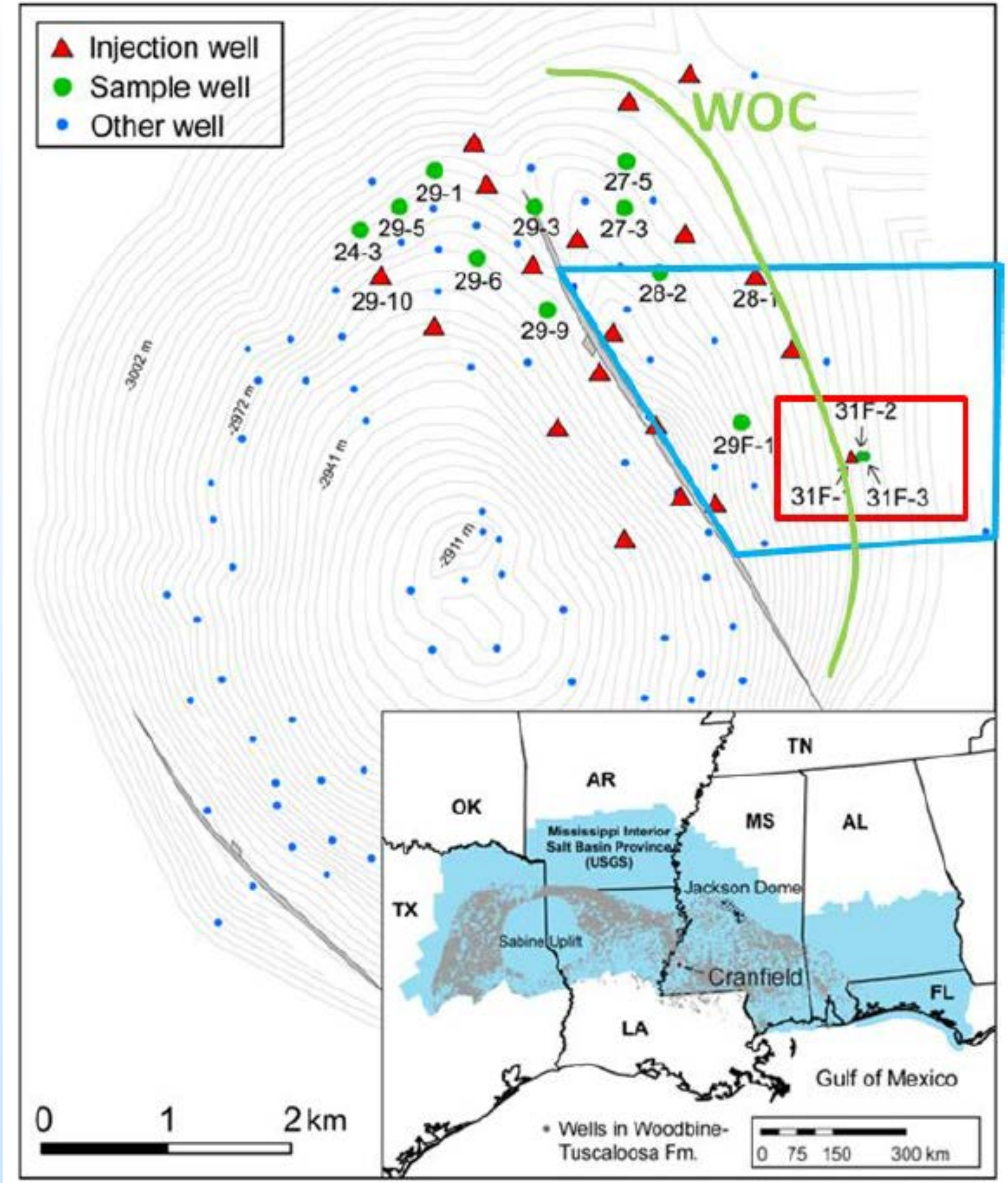
Introduction – Early Test Motivation

- MIT report “Future of Coal” 2007
  - Set 1 MMT injection goal “proceed .. as soon as possible. Several integrated large-scale demonstrations with appropriate measurement, monitoring and verification are needed. ... establish public confidence for future.”
- In 2007 scale and timing of large-scale capture in region still uncertain
  - SECARB anthropogenic test (2011)
  - >1 MMT Commercial Capture in region (2014, 2017)
- Early Test design to progress in the gap
  - Piggy-back on soon-to-start EOR project
  - Permits, source and infrastructure in place
  - Direct injection – relevant to large scale saline CCS

Introduction – Early Test design

- Large-scale storage demonstration
  - 1 MMT/year over >1.5 years
    - Periods of high injection rates
    - Result >5 years with >5 MMT CO_2 stored
- Measurement, monitoring and verification
  - Tool testing and optimization approach
  - Deploy as many tools, analysis methods, and models as possible
- Stacked EOR and saline storage

Location


Injection well
Sample well
Other well
WOC
29-1
29-5
24-3
29-10
29-6
29-3
27-5
27-3
28-2
28-1
29-9
29F-1
31F-2
31F-1
31F-3
-3002 m
-2972 m
-2941 m
-2911 m
0
1
2 km
TN
AR
OK
MS
AL
Mississippi Interior Salt Basin Province (USGS)
Jackson Dome
TX
Sabine Uplift
Cranfield
FL
LA
Gulf of Mexico
Wells in Woodbine-Tuscaloosa Fm.
0 75 150 300 km

Introduction – Major Conclusions

- Early Test Developed monitoring approaches for later commercial projects
  - Process-based soil gas method
  - Effectiveness of groundwater surveillance
  - Pressure and fluid chemistry monitoring in Above-Zone Monitoring Interval (AZMI)
  - ERT for deep CO_2 plume
  - Limitations of 4-D seismic
- Published and propagated techniques for widespread application

Scope of Work from Statement of Project Objectives

SOPO Goals

1,000,000 metric tons of CO_2 will be injected per year for up to one and a half years into the Lower Tuscaloosa saline reservoir of the flanks of the Cranfield oil field

Develop the technical scope of work, local education, permitting, outreach, MMV, and maintain the demonstration tests' schedules and budgets

Success metrics

- Site Characterization, Modeling and Monitoring Plan
- Revise location, design, and planned number of injection wells and location, design, and tool selection for observation wells.
- Subsurface Monitoring Plan Integration of assessments, tool selection, preparation of well instrument string design
- Implementation of Discontinuation Plan
- Finalize, Distribute and Archive Subsurface Data Compilation.
- Final History Match: Subsurface Plume Development, Early Test
- Finalize, Distribute and Archive Data Compilation Surface Monitoring

Note: All metrics and field activites completed April 2015

Team Structure

Gulf Coast Carbon Center
Bureau of Economic Geology
Jackson School of Geosciences
The University of Texas at Austin

SOUTHERN STATES ENERGY BOARD

SECARB Anthropogenic Test At Plant Barry/Citronelle

Denbury Resources
Field owner and injection system design, management, 4-D survey, HS&E

Vendors
e.g. well drilling, landmen

Sandia Technologies
Monitoring Systems Design, Installation, HS&E

50 Vendors
e.g. Schlumberger

Core Lab
UT DoG
Anchor QEA

MSU & UMiss
Hydro & hydrochem

Curtin University
3-D Seismic processing

Federal collaborators
Via FWP

LBNL
Well-based geophysics, U-tube and lab design and fabrication

LLNL
ERT

USGS
Geochemistry

Separately funded

NRAP
VSP deployment & analysis

NETL
Rock-water interaction

Model comparisons
LBNL SIM SEQ study

IPARS Modeling
CFSES M. Wheeler

4-D Seismic analysis
K. Spikes UT DoGS

Rock Mechanics
CFSES Sandia NL

Microseismic deployment
RITE, Japan

Groundwater controlled release
AWWA

Facilities and materials

Provided at site

Historic data (logs, production history)

Baseline 3-D seismic survey

2 new cores and 20 new open hole logs

Slim tube analyses

Roads pipelines, operations

Health and safely

15 fresh water wells

Access to roads and well pads and public acceptance (lease agreement and landmen).

CO_2 supply (5,326,750 MT)

Data from EOR operation e.g.

Mass flow at meters, BHP

Purchased by project

Three new wells with OH logs, 2 cores *

Instrumentation (ERT, CASSM) detailed area study

Additional RST logs

Repeat 3-D seismic for active part of field

224,781 tons additional CO_2 to assure meeting project metrics

Soil gas array, P-site

*Leveraged access to 3 additional injectors. “cash call” during recession

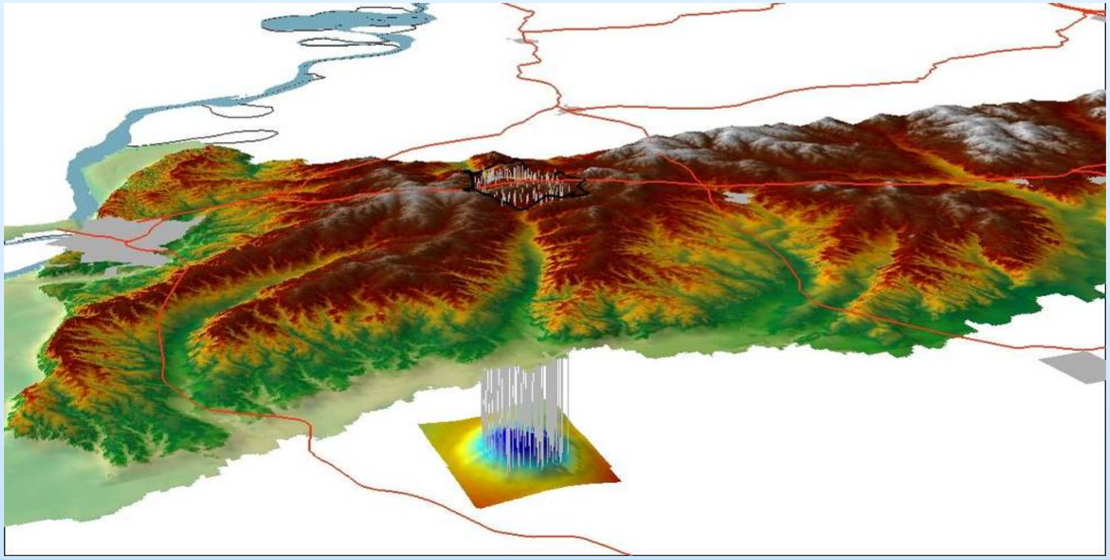
Technical Approach

- Early test was conceptualized as earliest part of the RCSP portfolio to support future integrated projects
  - SECARB Anthropogenic test
  - Other RCSP tests
  - Also future tests e.g.
    - Air Products commercial 1MMT/capture at Port Arthur
    - Petra Nova commercial 1MMT/capture near Houston

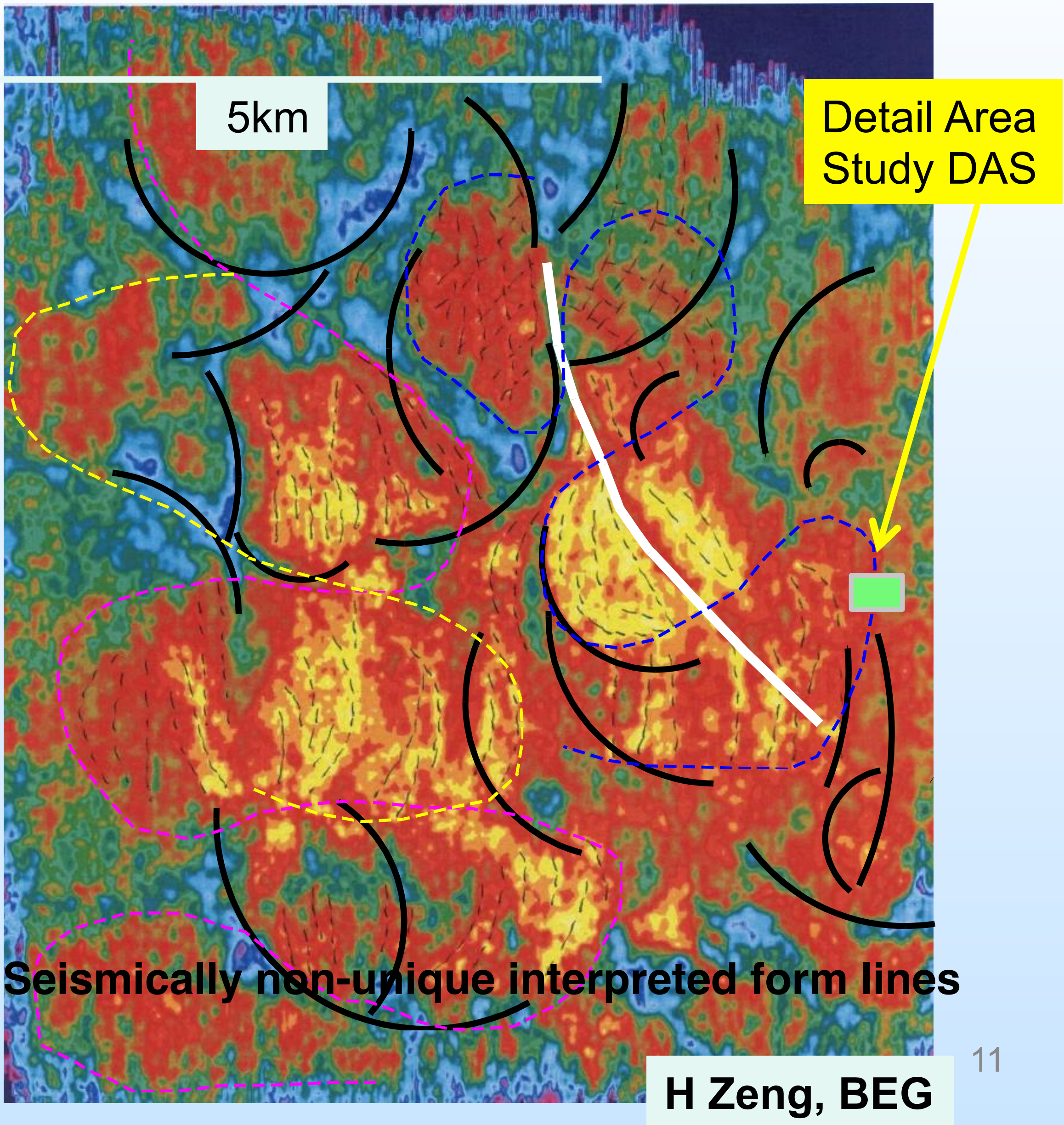
- Resulting limitations
  - Not captured CO_2 (natural source at Jackson Dome)
  - Project started with large volume direct (no WAG) CO2 injection – very analogous to saline
  - Evolved by year 3 to be dominated by recycle.
  - Complexities of hydrocarbons in part of the study area
  - No post injection period possible – injection for EOR continues commercially

Site Characterization Approach

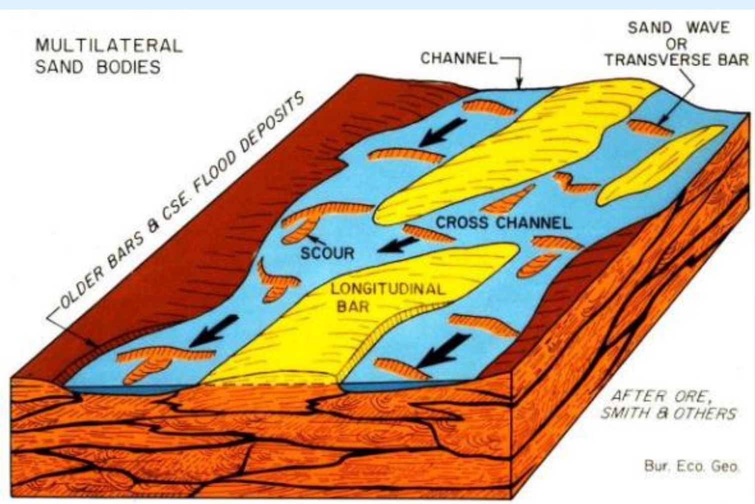
- Historical data – maps and cross sections, production history
- New 3-D seismic
- Re-evaluation of new and existing logs, new cores
  - Core analysis
  - Capillary entry pressure
  - thin sections petrography
  - XRD
  - Diverse laboratory tests

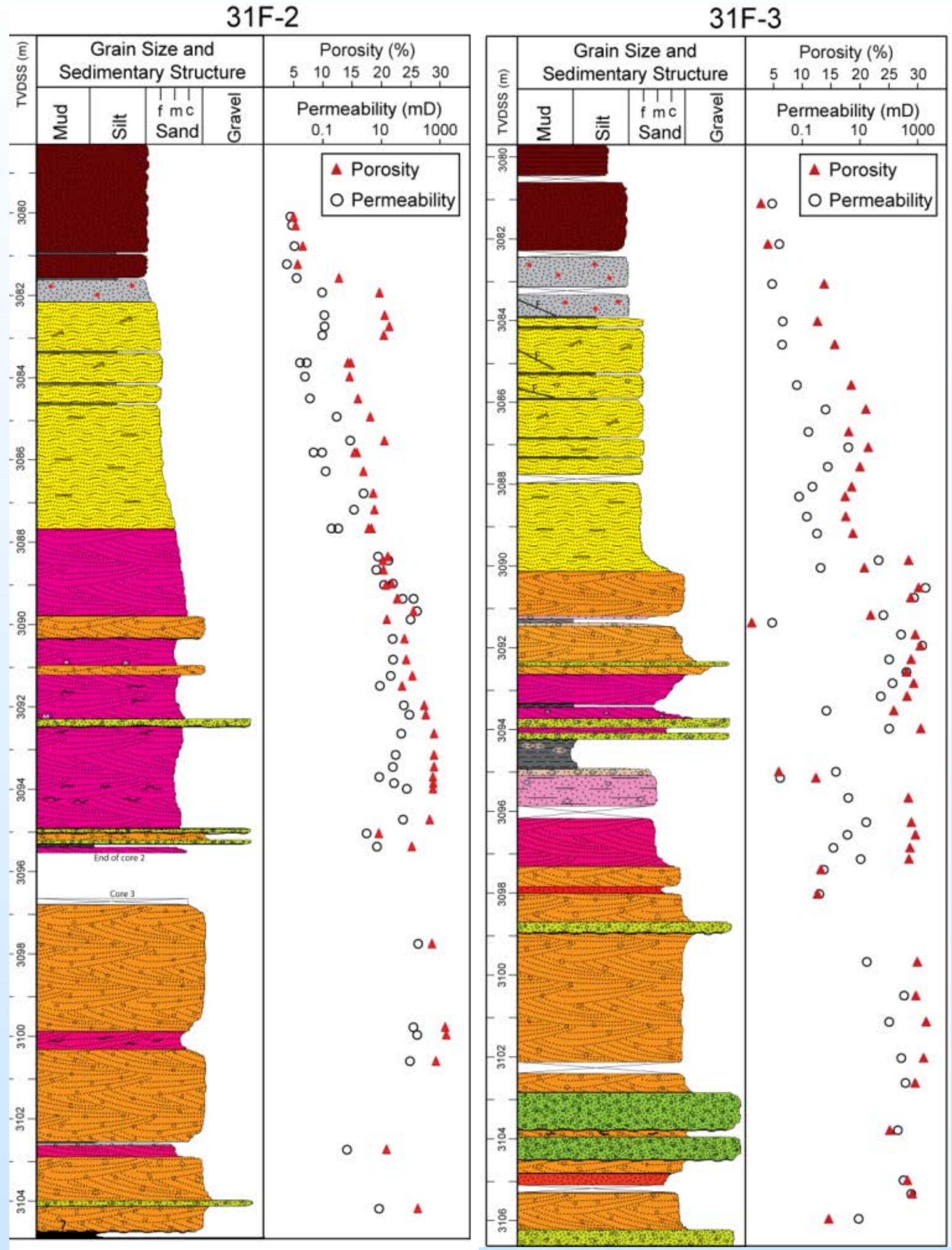


Site Characterization Approach



Amalgamated Fluvial Channels - Heterogeneity





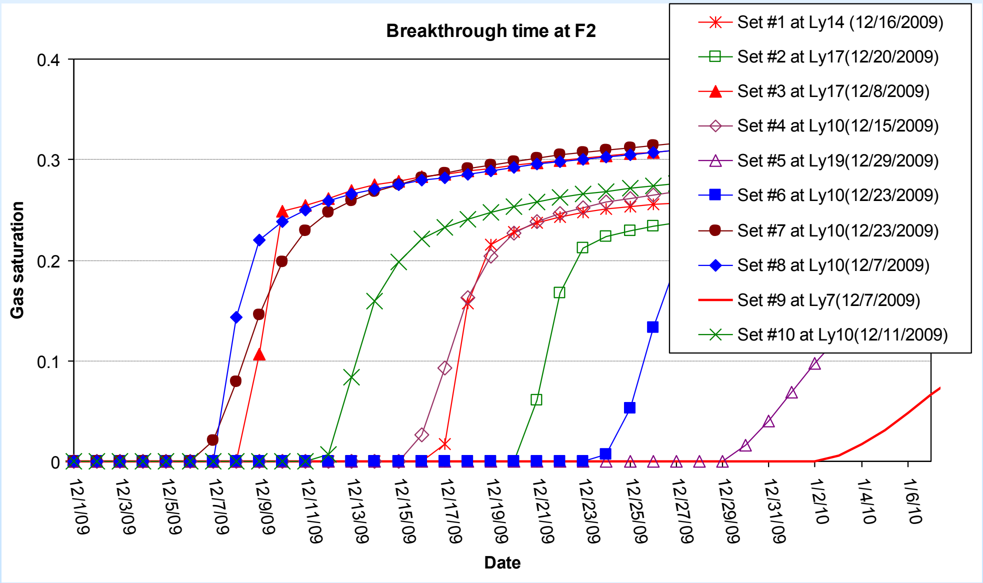
30-m apart

M. Kordi , BEG

Modeling Approach

Evaluation Criterion 2

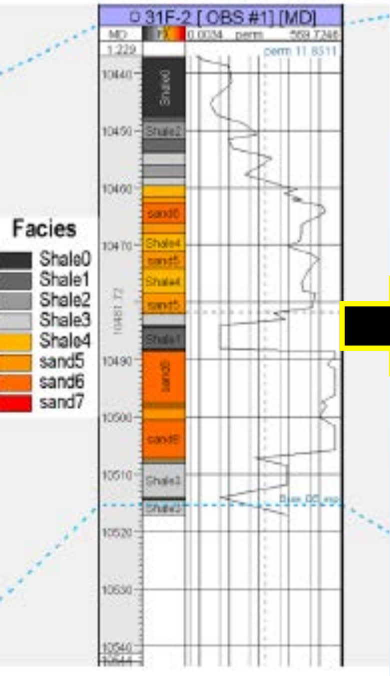
- Multiple models
  - I-PARS
  - SIM-SEQ model approach comparison
- CGM GEM
  - Probabilistic approaches
  - Match 100 realizations to subset of modeled data
  - Forward model scenarios



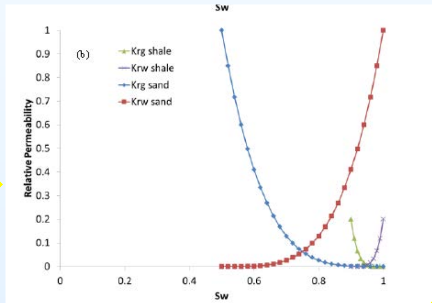
Pre-injection forward model breakthrough times to design geochemical sampling

Modeling Approach

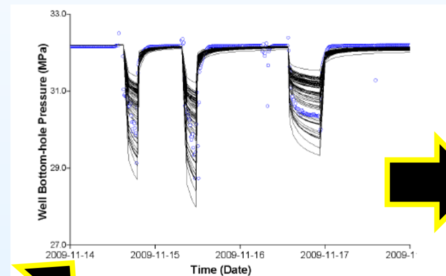
Reservoir characterization



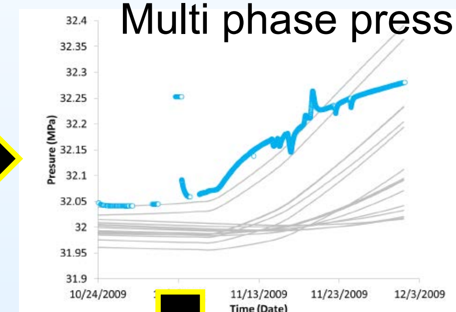
Relative permeablities

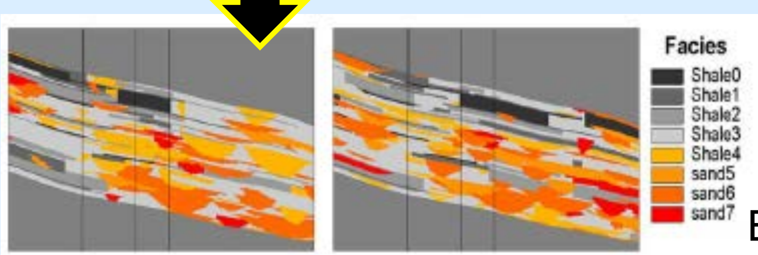


Single phase pressure

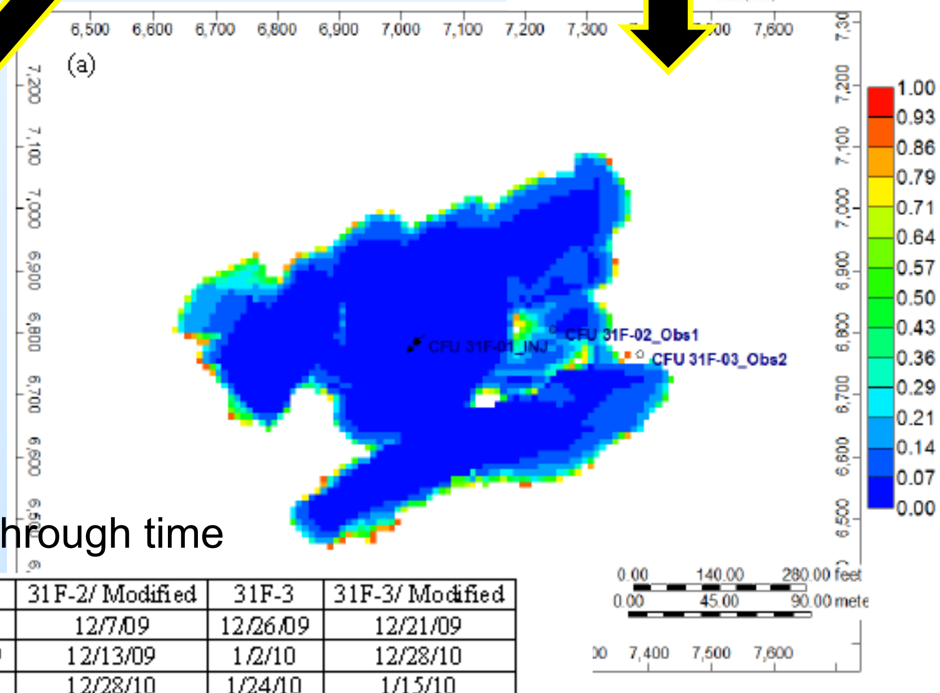


Multi phase pressure





Probabilistic realizations of reservoir architecture



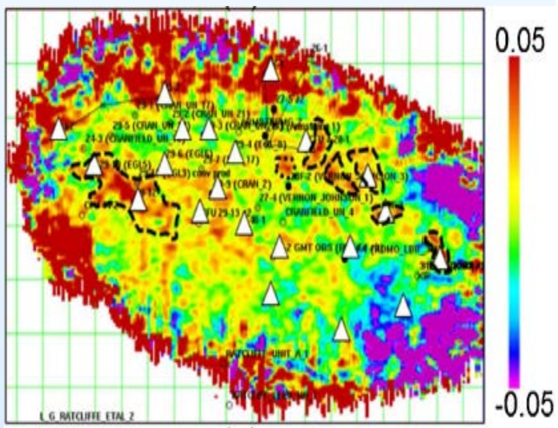
Breakthrough time

Realization Number	31F-2	31F-2/ Modified	31F-3	31F-3/ Modified
35	12/8/09	12/7/09	12/26/09	12/21/09
18	12/15/09	12/13/09	1/2/10	12/28/10
8	1/3/10	12/28/10	1/24/10	1/15/10
15	12/20/09	12/16/09	1/11/10	1/2/10
ACTUAL		12/12/09		12/16/09

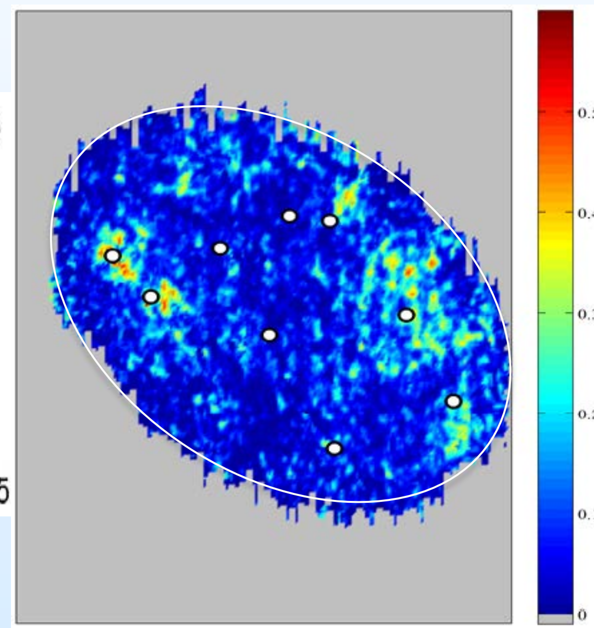
Hosseini and others, 2013
Cranfield

Modeling Approach

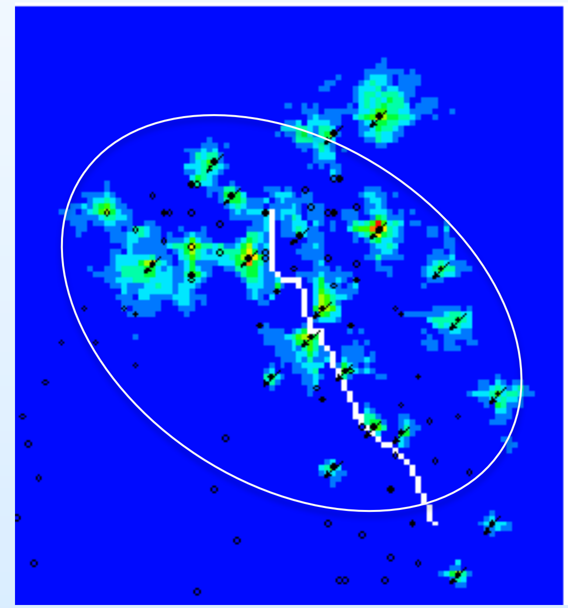
Comparing measurement to modeling



$v_p - v_s$ ratio difference
Zhang et al. (2014)

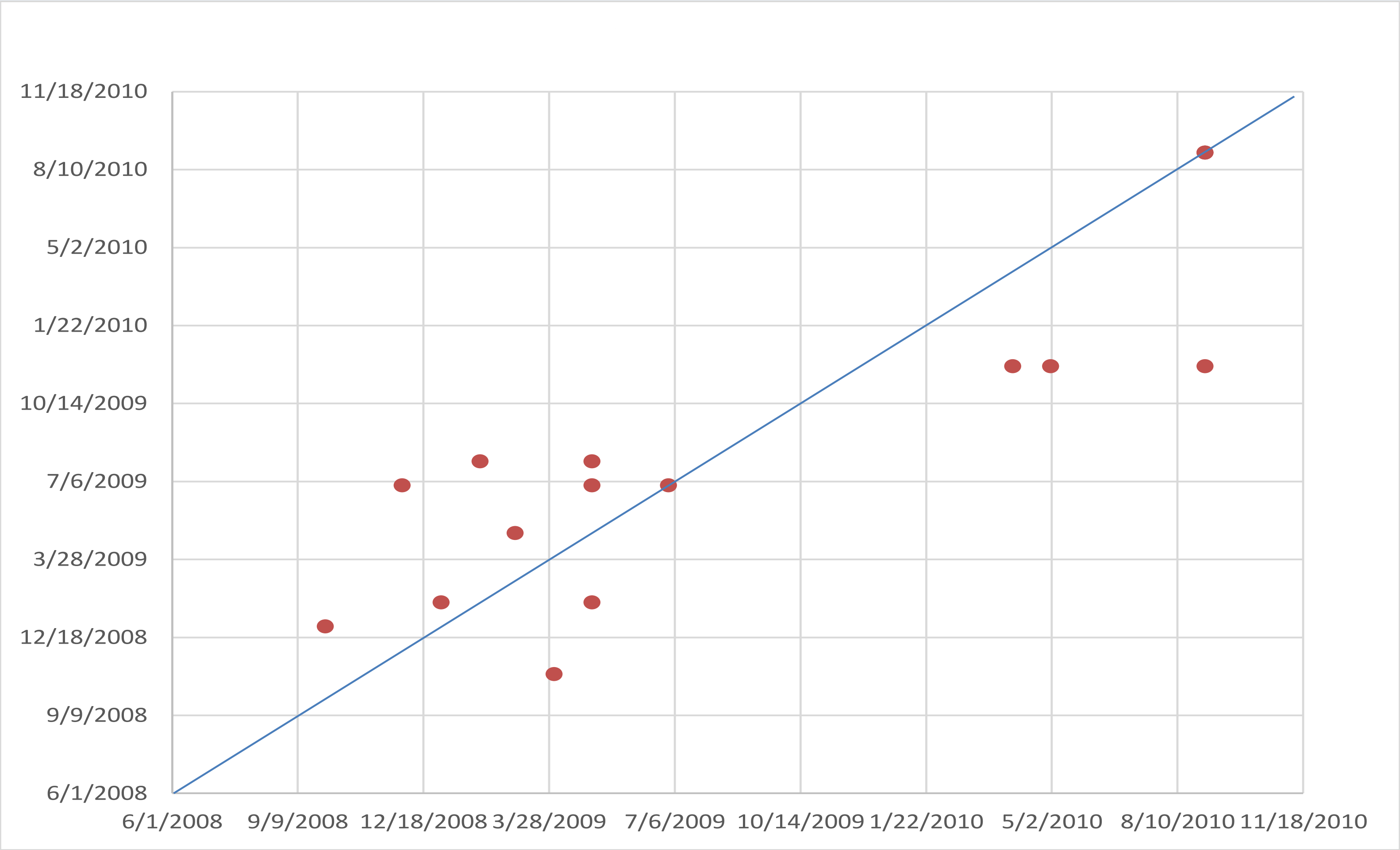


CO_2 saturation distribution estimate using rock physics 2010 from 3D seismic data (Carter 2014)



Modeled CO_2 distribution

History Match Modeled and measured CO_2 breakthrough



Analysis of Seismic Time-Lapse Observations at Cranfield

D. W. Vasco, Tom Daley, Jonathan Ajo-Franklin,
LBL

Accomplishments:

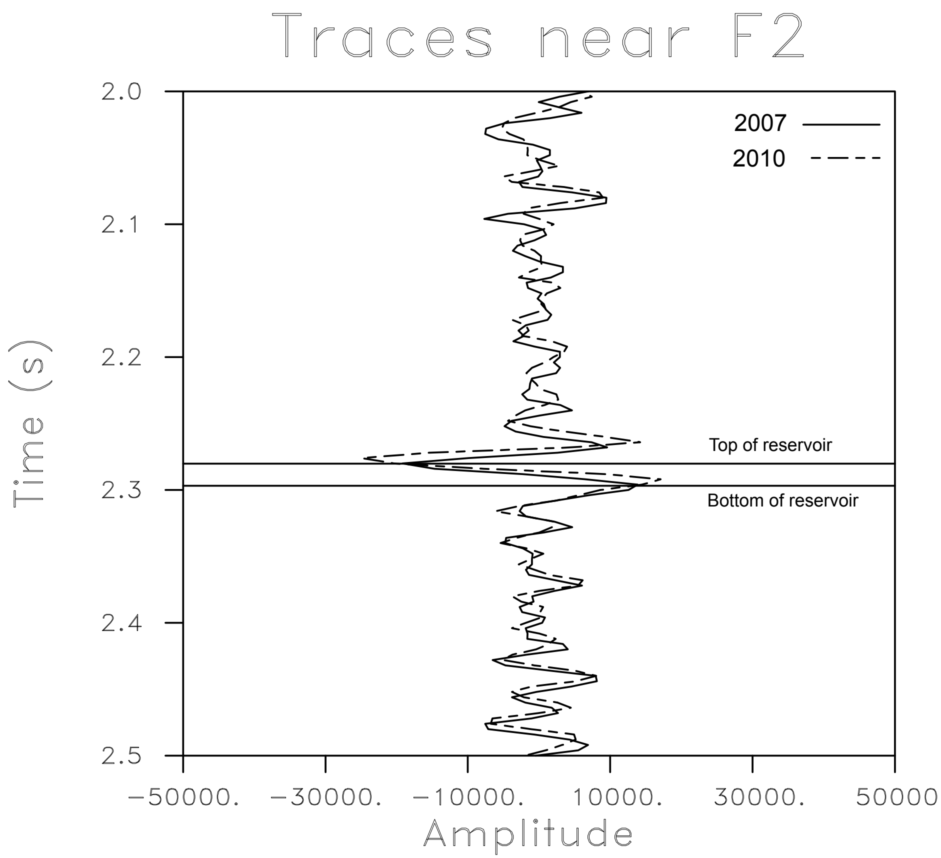
- Estimated seismic time-shifts from 4D data

- Calculated seismic velocity variations due to changes in fluid phases from compositional modeling.

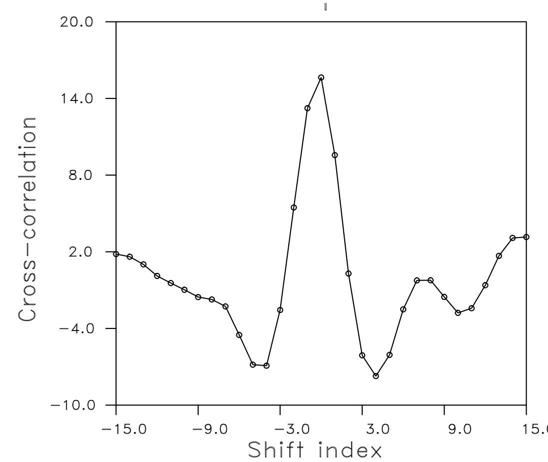
- Compared velocity changes to observed time-shifts and seismic amplitude changes

Estimating Seismic Time-Shifts

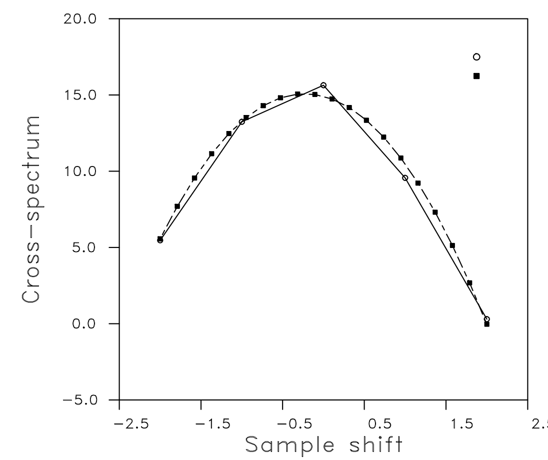
▪Line up traces using reflections from horizons just above the reservoir



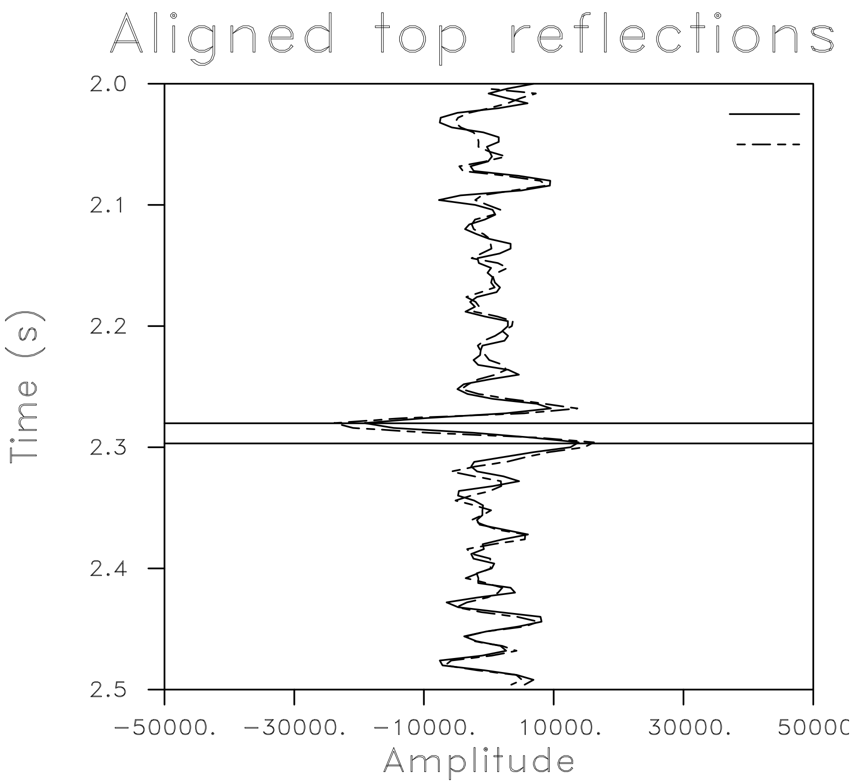
Cross-correlate

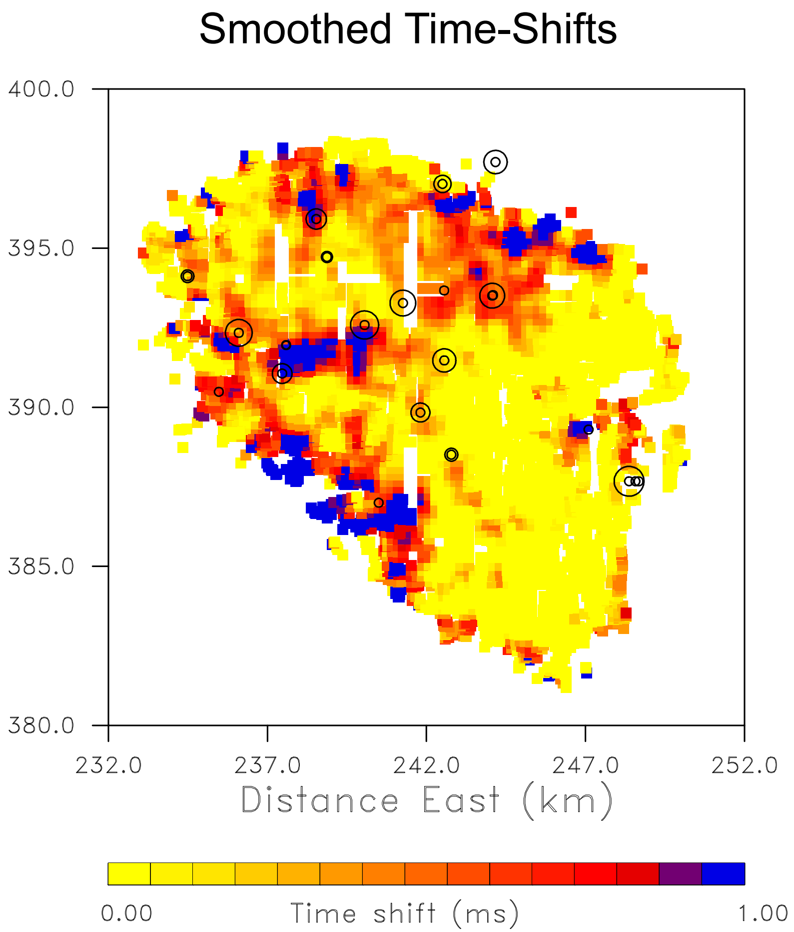


Quadratic fit for sub-sample precision

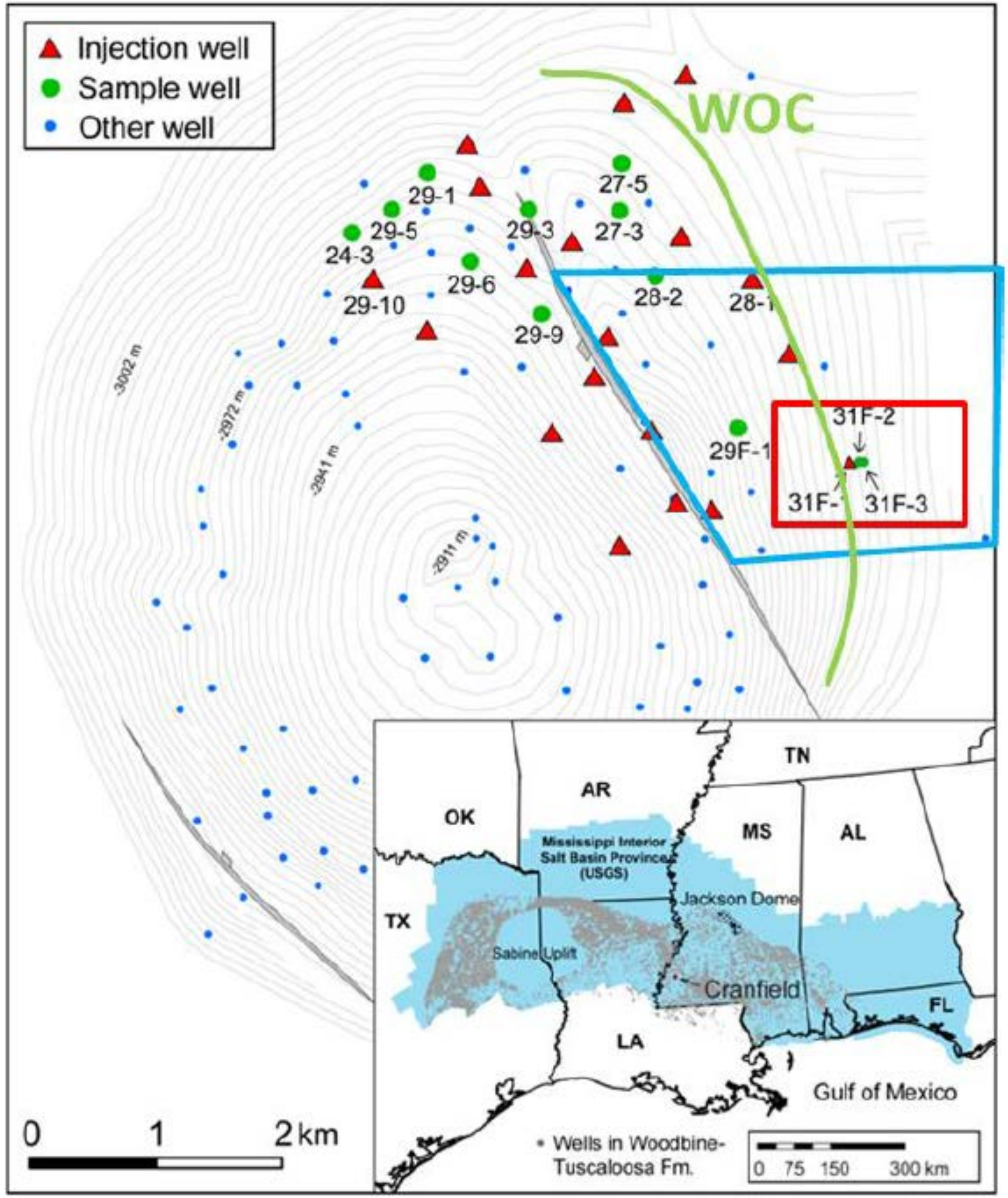


▪Calculate resulting time shifts for reflections just below the reservoir.



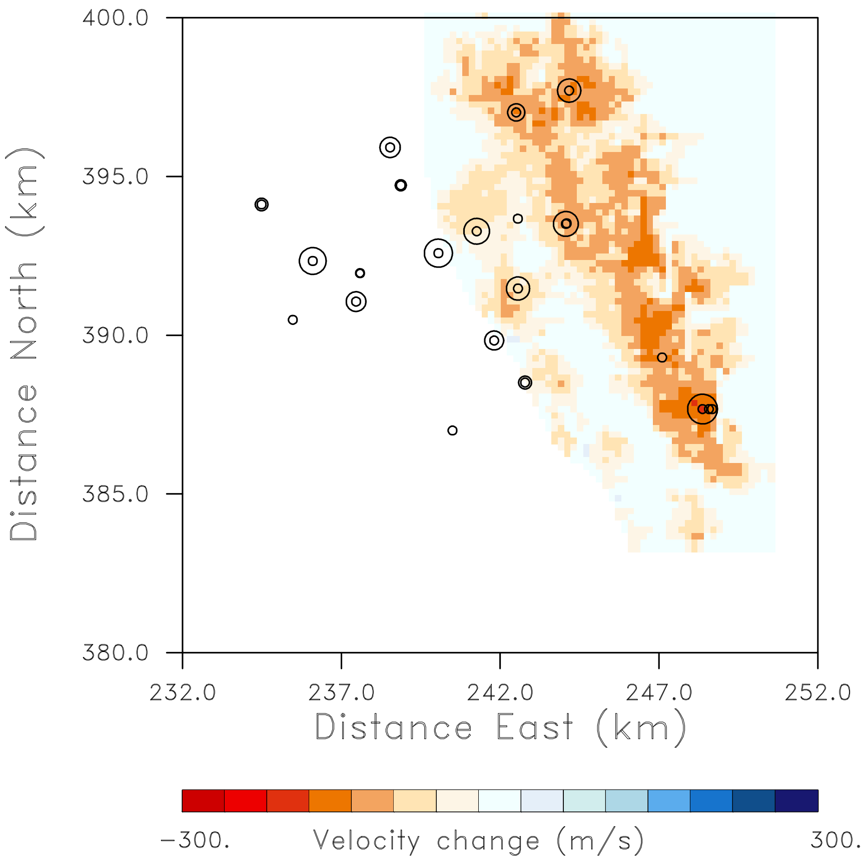


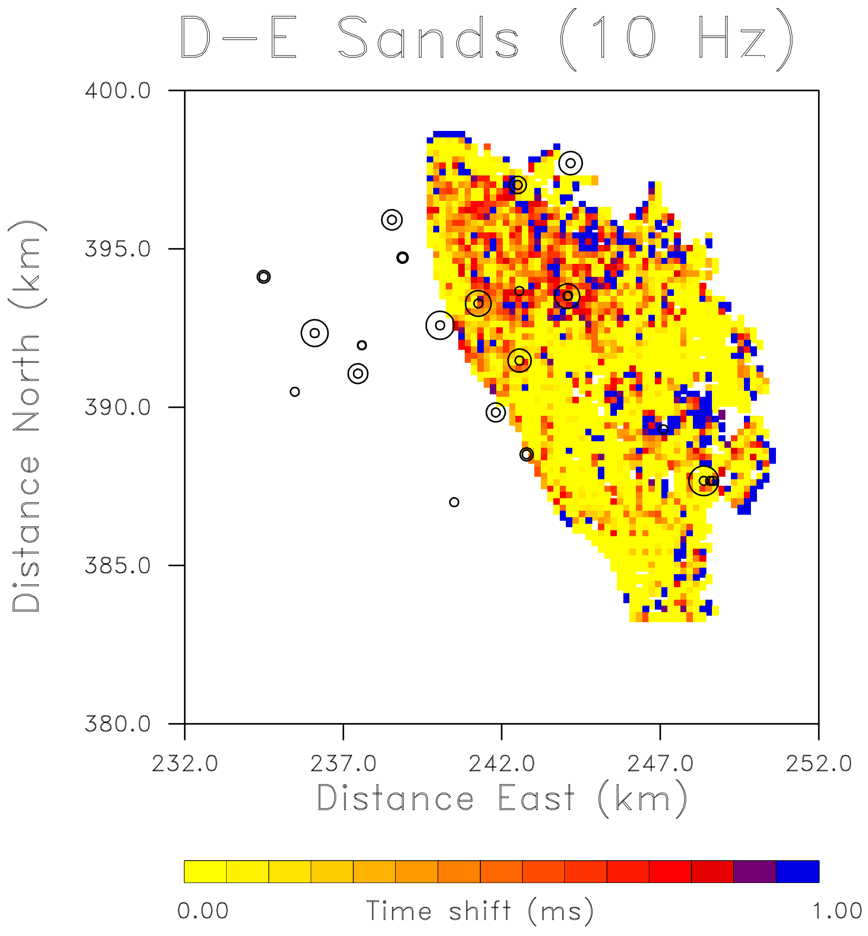
Location



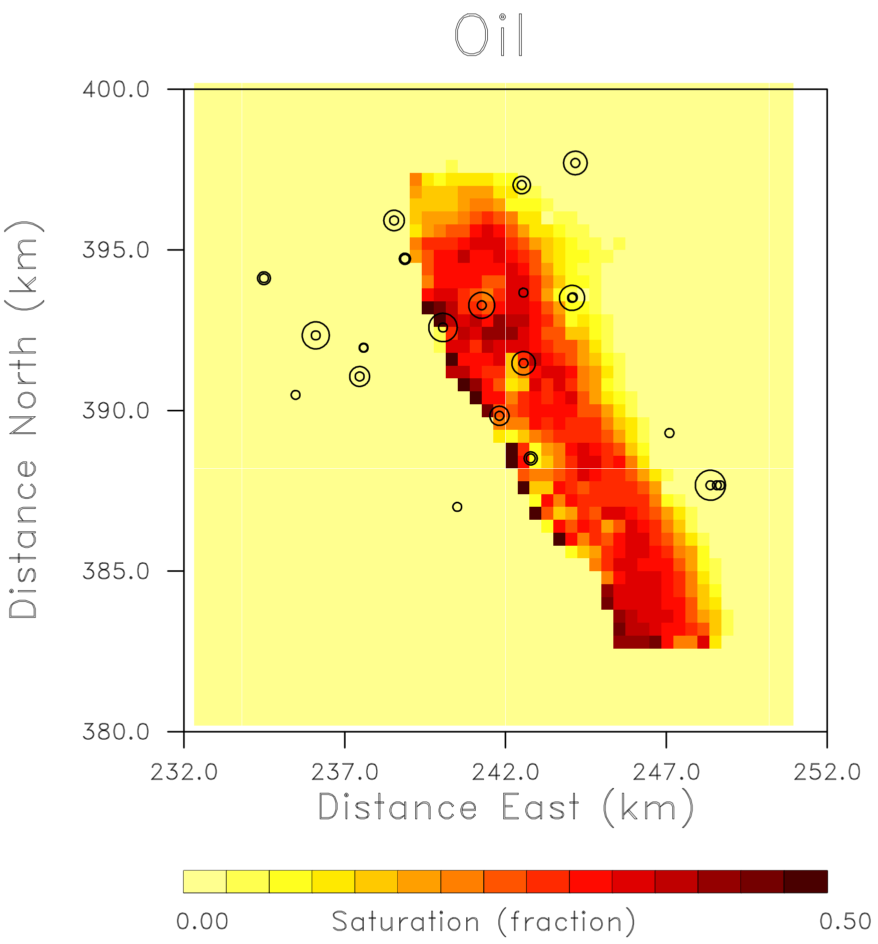
Injection well
Sample well
Other well
WOC
29-1
29-5
24-3
29-10
29-6
29-3
27-5
27-3
28-2
28-1
29-9
29F-1
31F-2
31F-1
31F-3
-3002 m
-2972 m
-2941 m
-2911 m
0
1
2 km
TN
AR
OK
MS
AL
TX
LA
FL
Mississippi Interior Salt Basin Province (USGS)
Jackson Dome
Sabine Uplift
Cranfield
Gulf of Mexico
Wells in Woodbine-Tuscaloosa Fm.
0 75 150 300 km

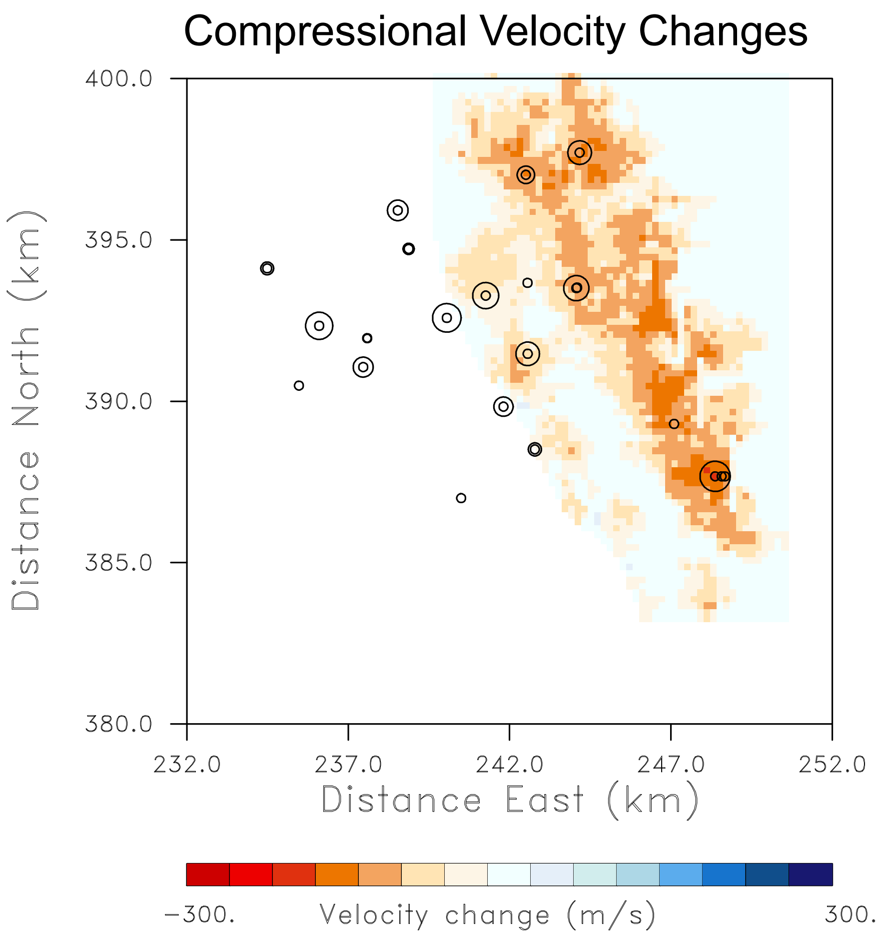
▪Largest seismic time shifts in area with greatest velocity changes



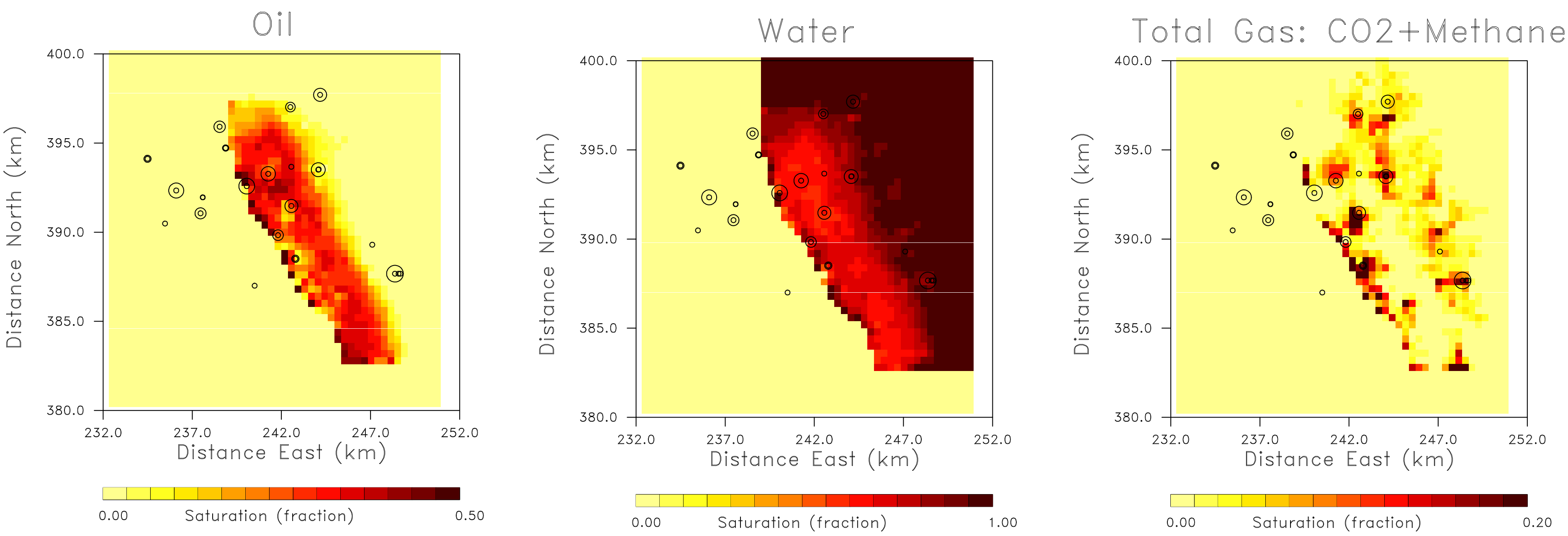


▪Biggest velocity changes due to the injection of carbon dioxide are in the water leg



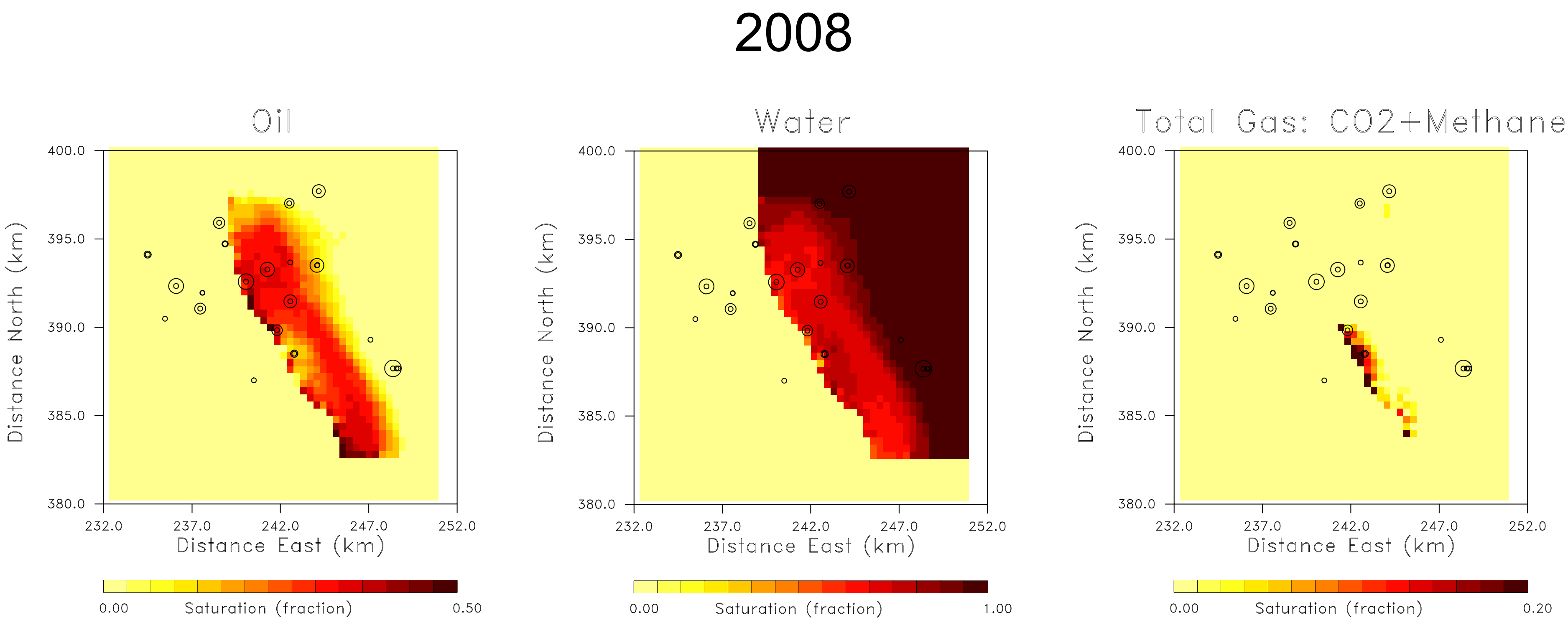


2010



Oil
400.0
395.0
390.0
385.0
380.0
232.0
237.0
242.0
247.0
252.0
Distance North (km)
Distance East (km)
0.00
Saturation (fraction)
0.50
Water
400.0
395.0
390.0
385.0
380.0
232.0
237.0
242.0
247.0
252.0
Distance North (km)
Distance East (km)
0.00
Saturation (fraction)
1.00
Total Gas: CO2+Methane
400.0
395.0
390.0
385.0
380.0
232.0
237.0
242.0
247.0
252.0
Distance North (km)
Distance East (km)
0.00
Saturation (fraction)
0.20

▪Fluid saturations from simulations by Seyyed Hosseini of Texas Bureau of Economic Geology



Accomplishments to date

- Estimated seismic time-shifts from 4D data
- Calculated seismic velocity variations due to changes in fluid phases from compositional modeling.
- Compared velocity changes to observed time-shifts and seismic amplitude changes

Conclusions: status

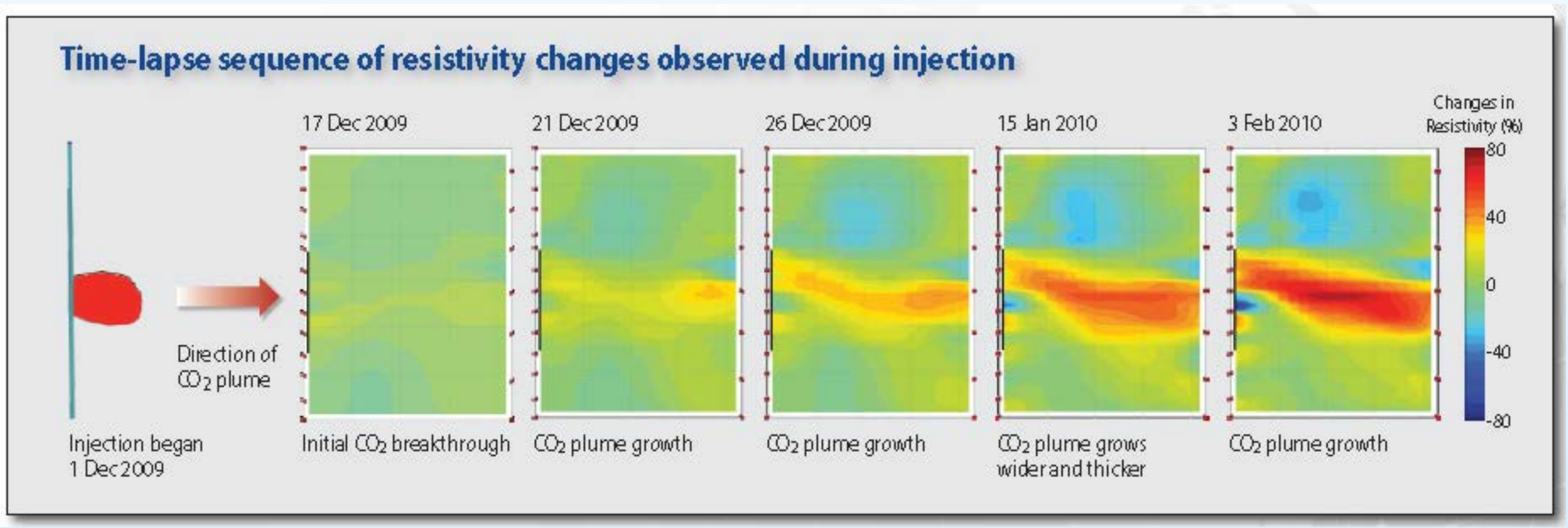
- Seismic velocity changes depend upon all fluid saturations.

- Oil saturation has a significant influence on the velocity changes due to injected carbon dioxide.

- Reservoir simulation results are compatible with observed seismic reflection data and time shifts.

LLNL Electrical Resistance Tomography- changes in response with saturation

F1 F2 F3

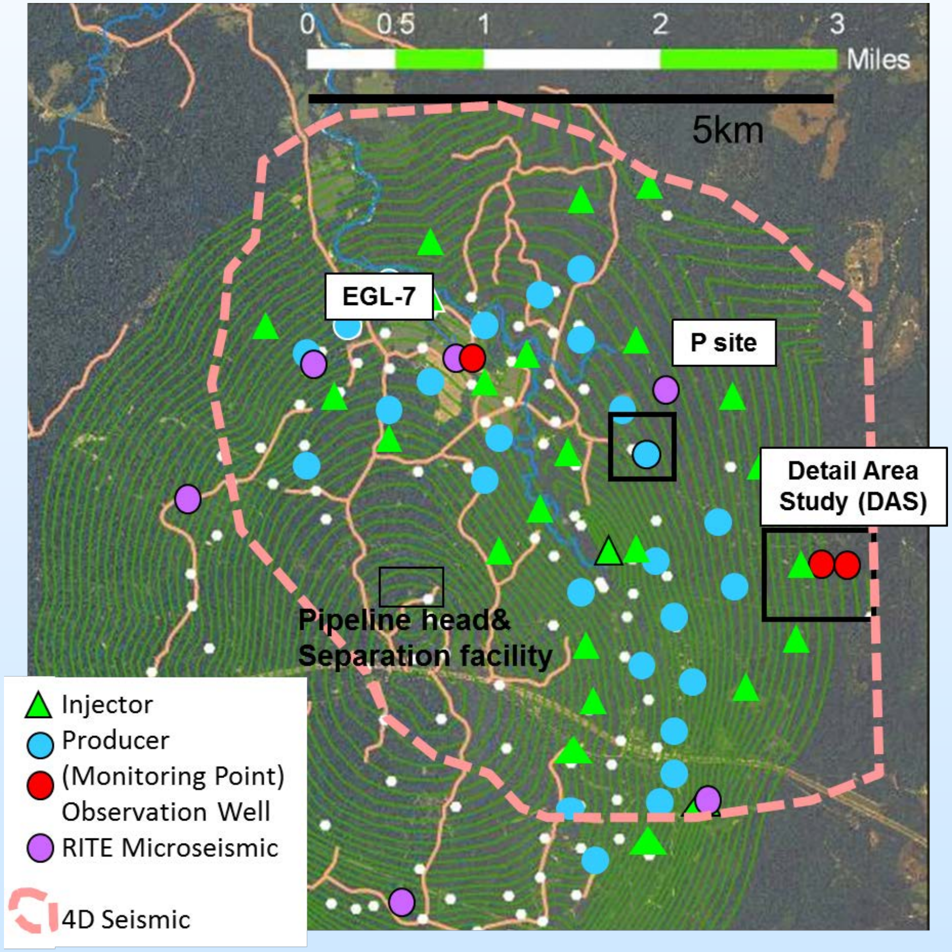


Additional work planned to extend imaging to 2015

Lawrence Livermore National Laboratory

C. Carrigan, X Yang, LLNL
D. LaBrecque Multi-Phase Technologies

MVA Approach



MVA Approach

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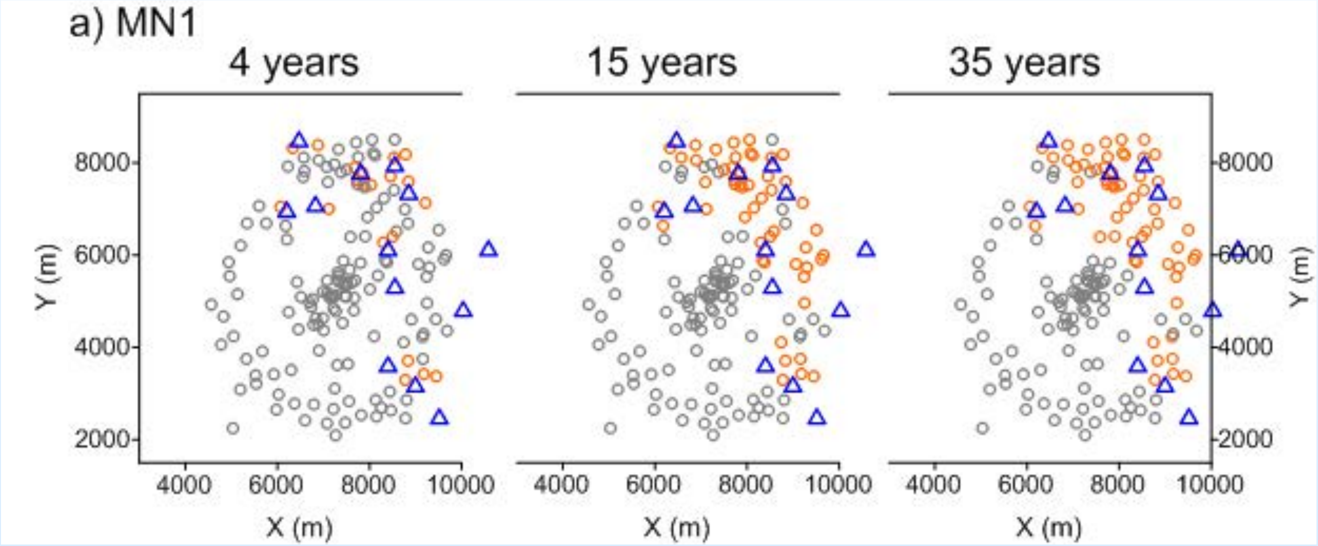
Area tested	Whole plume	Focus study
Atmosphere	Not tested	Not tested
Soil gas	Active and P&A well pads	"P site" methodology assessment
Groundwater	Monitoring well at each injector	EGL-7 UM test well, Push-pull test
Shallow production	Not tested	Not tested
AZMI	Not tested	DAS pressure EGL 7 press + fluids
Geomechanics	RITE micro seismic study	GMT (failed)
Injection zone	Geochemistry breakthrough	DAS multi-well multi-tool array

Groundwater Monitoring Network Efficiency

$ME = W↑d / W↑T$

- 20/151=0.13 by 4 years
- 50/151=0.33 by 15 years
- 58/151=0.38 by 35 years



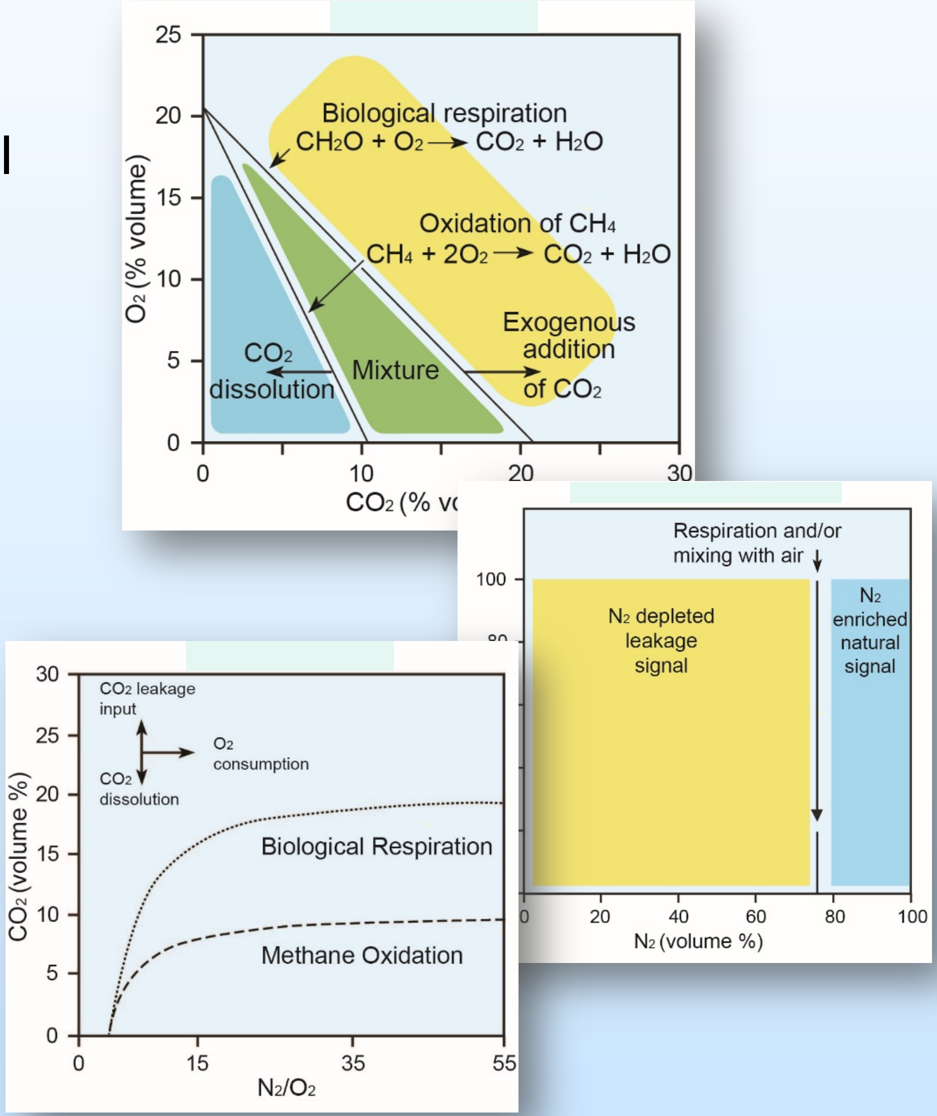
CO_2 leakage from a P&A well is detected by a monitoring net work if change in DIC, dissolved CO_2, or pH in any one of wells of the monitoring network is higher than one standard deviation of the groundwater chemistry data collected in the shallow aquifer over the last 6 years.

Changbing Yang

Process-Based Soil Gas Monitoring

- No need for years of background measurements.
- Promptly identifies leakage signal over background noise.
- Uses simple gas ratios

  (CO_2, CH_4, N_2, O_2)
- Can discern many CO_2 sources and sinks
  - Biologic respiration
  - CO_2 dissolution
  - Oxidation of CH_4 into CO_2 (Important at CCUS sites)
  - Influx air into sediments
  - CO_2 leakage



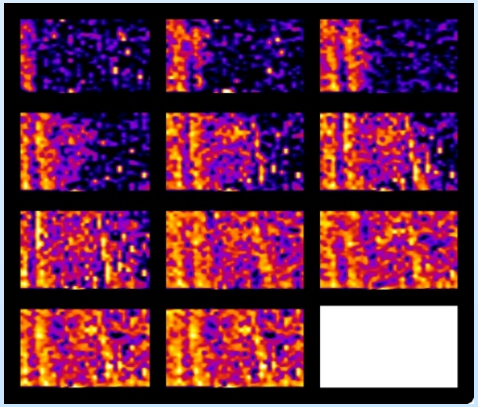
Katherine Romanak BEG

Major Technical Accomplishments

- Multiphysics CO_2 plume detection
  - Surface 4-D; Azimuthal VSP, cross well, ERT, Pulsed neutron, fiber-optic thermal, sonic logs, PNC logs
  - Limits evaluated (depth, gas)
- In-zone and Above-zone pressure method validation
  - Casing deployed BHP with real-time readout
- Minimal geochemical change in-zone, geomechanical softening
- Non-detect of microseismicity by RITE at >1000 psi pressure increase
- Reservoir response to heterogeneity – non-linear breakthrough
- Groundwater sensitivity assessment
  - Value of DIC, sensitivity to carbonate in rock matrix
  - Value for incident or allegation
- Process-based soil gas
  - Reduced sensitivity to environmental fluctuation, not dependent on baseline. Value of attribution

Rate of Progress

- All elements have been completed on plan
  - (three years injection + three “post closure”)
- Under budget
  - Major saving was not needing to purchase CO_2 to meet the project goal; commercial injection was high during early project stages
- Emphasis on publication and technical outreach
  - 91 technical papers published 2009-2017
- Leveraged by data-sharing



Coreflood micro CT J Ajo-Franklin LBNL

Potential Leakage Risks Considered

- Formal leakage/seepage risk assessment under Certification Framework (LBNL)
  - Identified wells as highest risk leakage points
    - Most wells are P&A
- Responses
  - Groundwater and soil gas measured at all injectors
    - Detailed measurements at P-site methane and CO_2 anomaly
  - AZMI pressure
    - Detection and separation of fluid flow from geomechanical response
    - Improved deployment at commercial sites

Potential Business/Project Risks Considered

- Quality of collaboration with operator
  - Details specified in contract
  - Offset by reduced risk in CO_2 supply, permitting, public acceptance
- Co-ordination with commercial activities
  - Upfront modeling of impacts
    - Impact of gas cap
    - Impact of production
  - Strong initial push toward data collection pre-production phase
  - Focus on data collection in dedicated site in water leg
  - Strong co-ordination with operations team
  - No closure phase planned

Plan to Complete

- No post- injection period possible
- Used three years after end of CO_2 purchase for multiple tasks:
  - Support increased DOE interest in EOR, e.g. supplied data to NETL economic model; NCNO projects
  - Geothermal CO_2 feasibility test (Freifeld, LBNL)
  - Harmonic pulse testing (Sun, BEG)
  - RITE microseismic
- Extensive publication and analysis
- Wide collaboration

Overall accomplishments-Key findings

- Early large volume storage project to lead of RCSP effort
- Advancement of multiple monitoring tools
  - AZMI
  - Process-based soil gas method
  - Deep ERT
- Novel scientific findings
  - AZMI geomechanical response
  - Non-linear pressure response
  - Advanced groundwater geochemical surveillance
  - No detectable microseismicity to >1000 psi pressure increase
  - Limitations of 4-D seismic 3 Km depth and in presence of methane

Lessons Learned (where is improvement needed?)

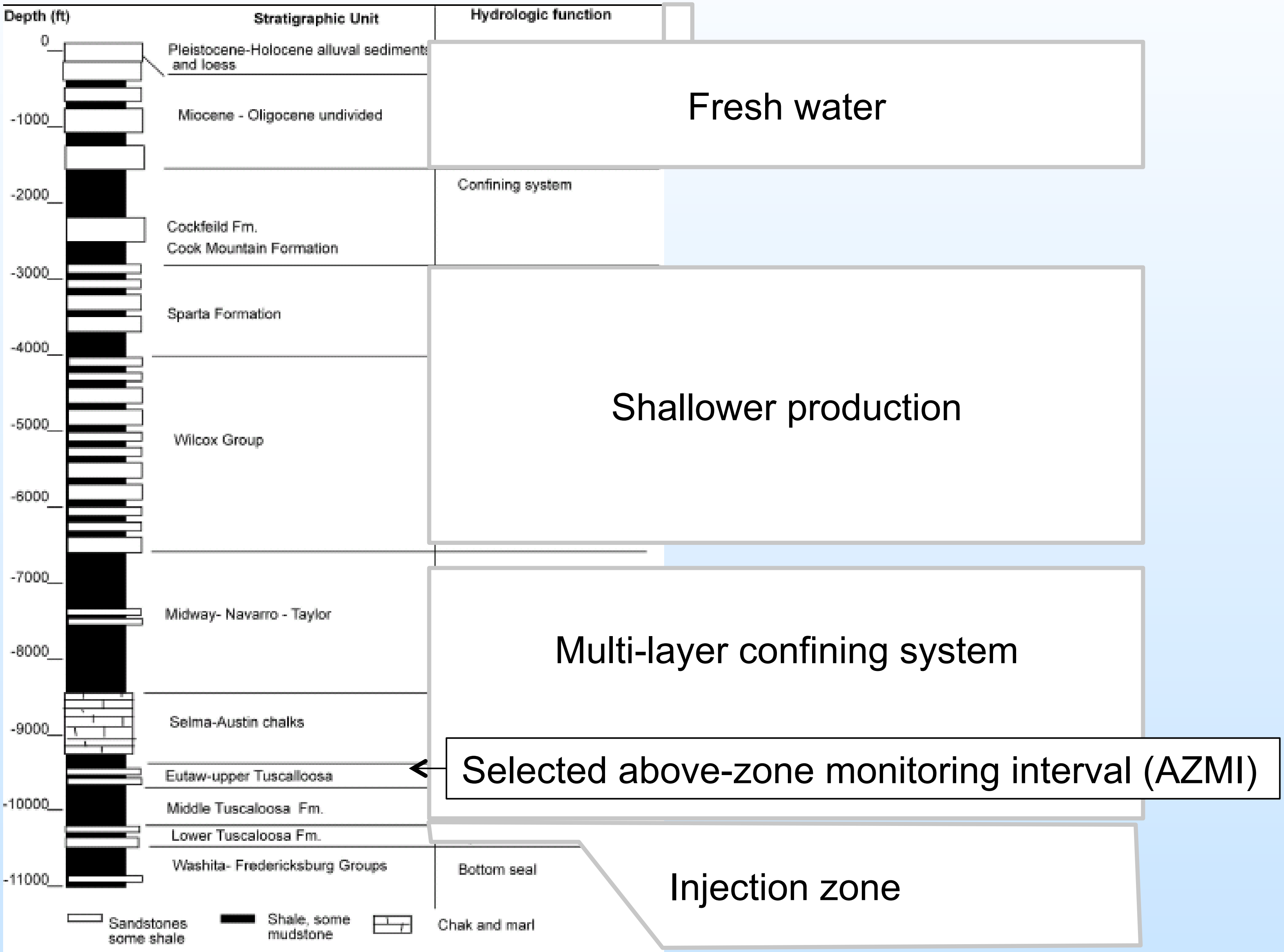
- Simplified AZMI completions
- Improved high temperature and pressure equipment
- Simplified ERT deep installation
- Remote tools for water and soil gas surveillance
- Maturation of monitoring design planning
  - Interaction with international community

Future Plans

- Widespread application of results via publications and applications
- Fluid flow modeling
- Forward modeling of seismic response
- Improved ERT methods
- Public release of technology transfers to PetraNova and Air Products commercial projects
- International Standard for accounting for CO_2 stored in associated with EOR
- Technology transfer and implementation vis Gulf Coast Carbon SAFE

- Questions?

Characterization of Overburden

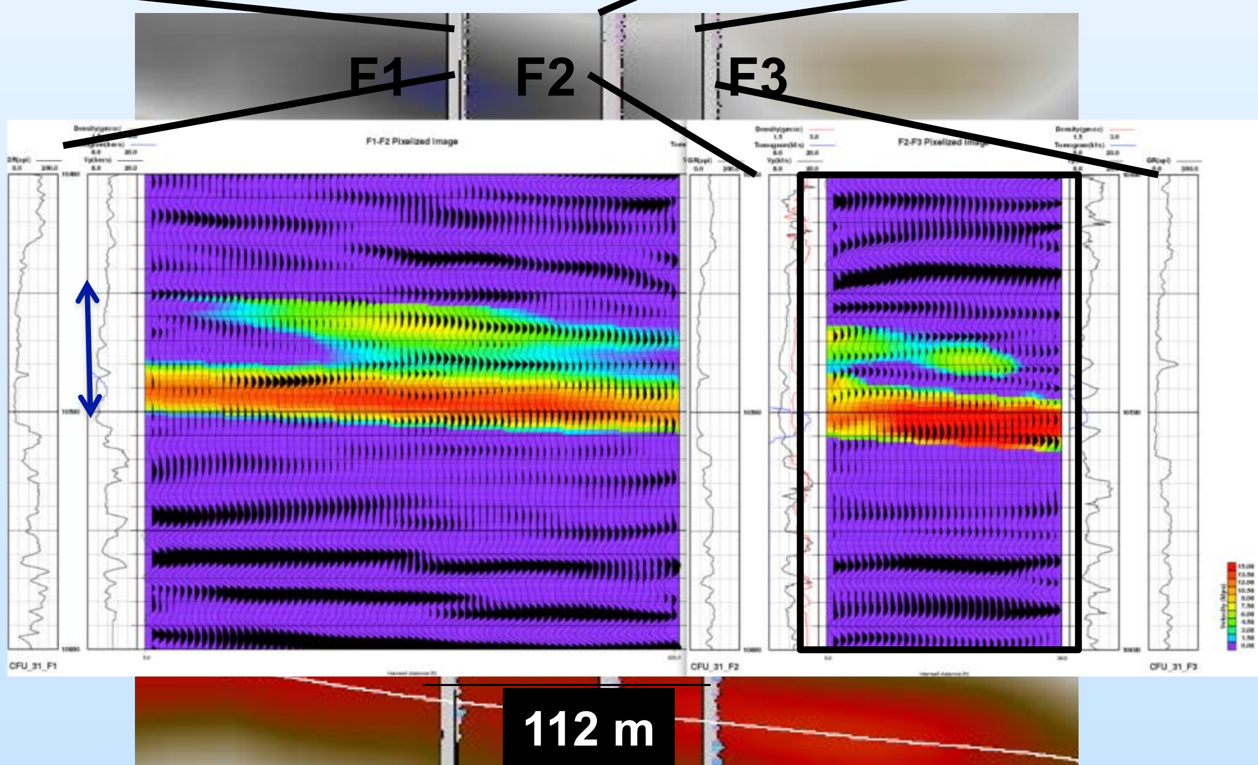


Detailed Area Study (DAS)

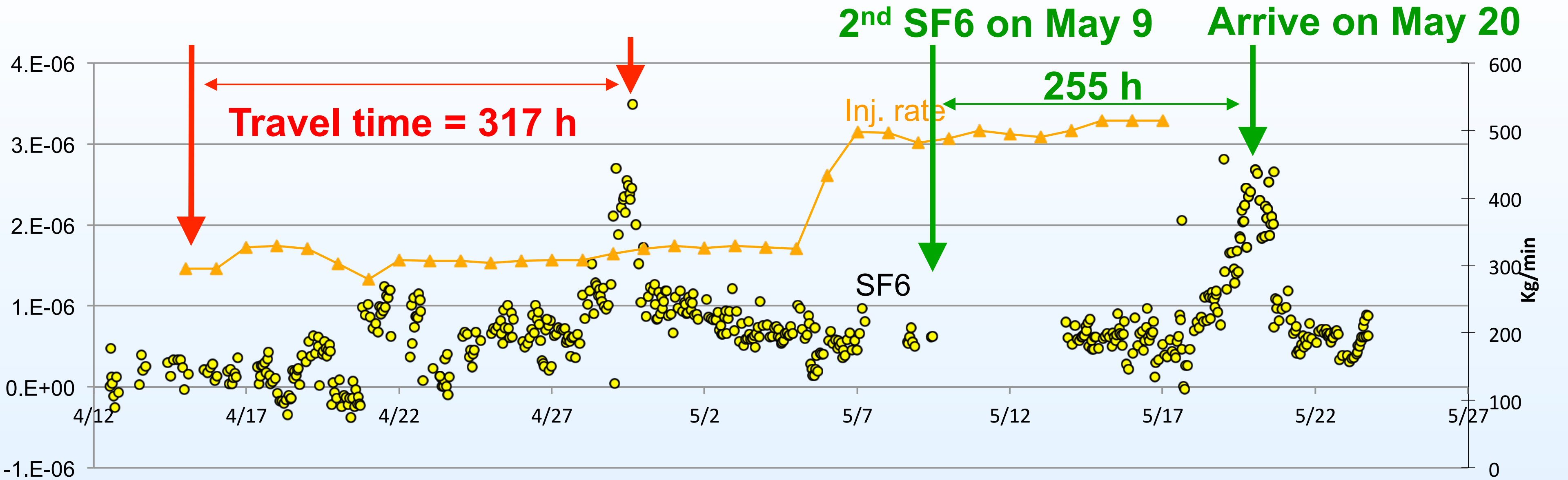
Closely spaced well array to examine flow in complex reservoir

Tuscaloosa D-E reservoir

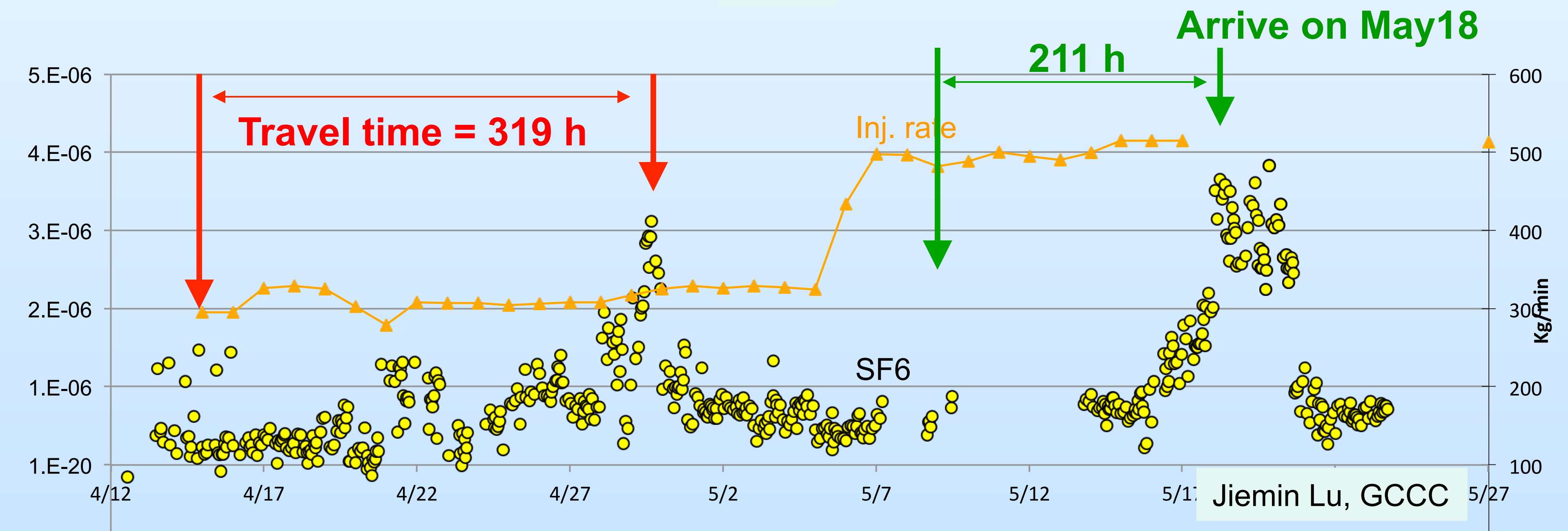
Petrel model Tip Meckel
Time-lapse cross well Schlumberger



CFU31F-2, 68 m away from injector SF6

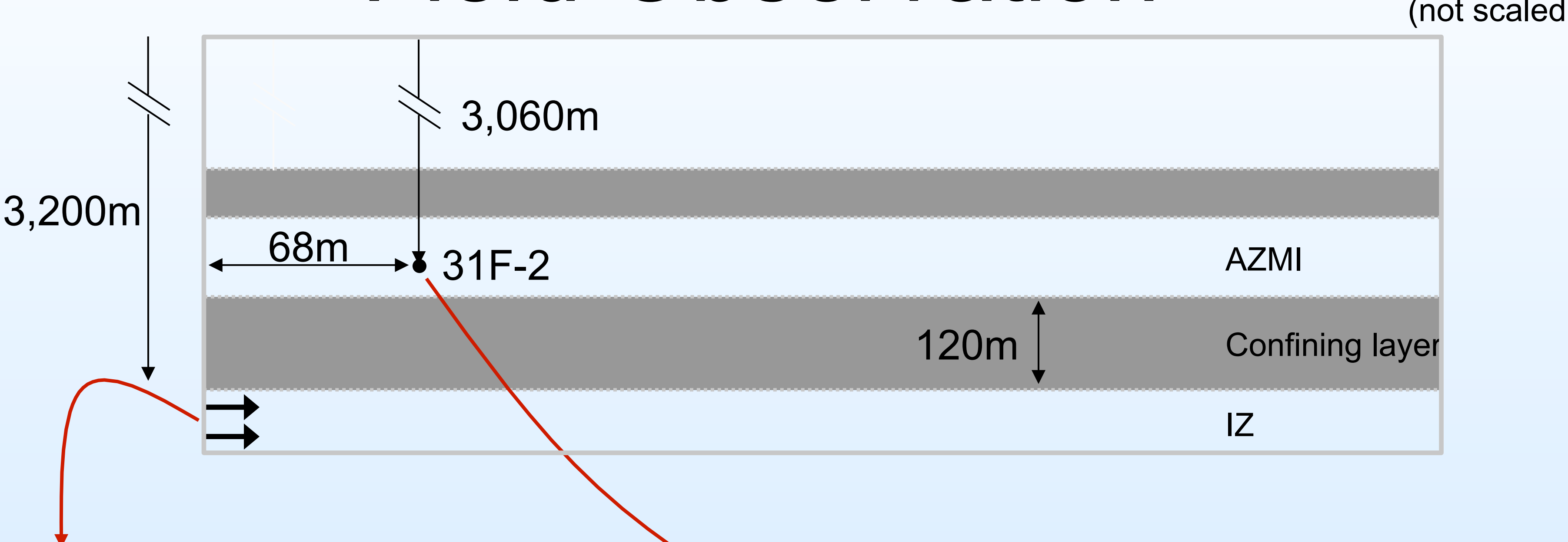


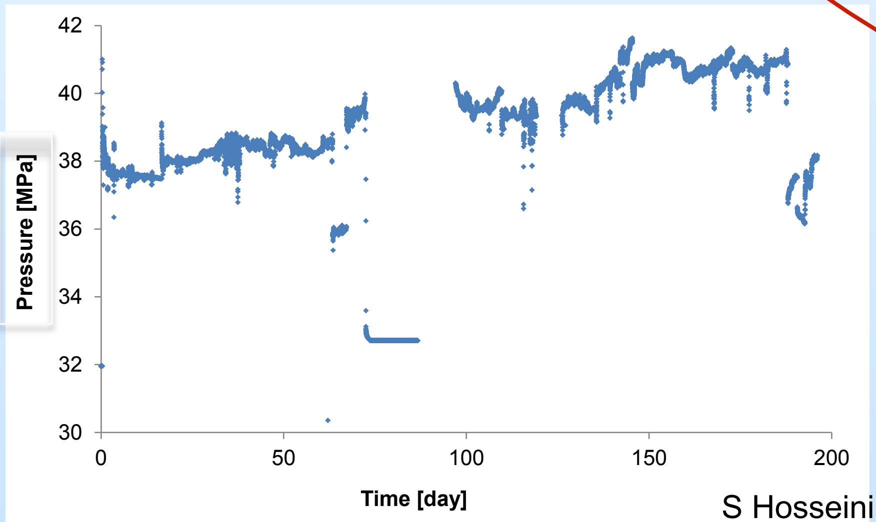
CFU31F-3, 112 m away from injector SF6

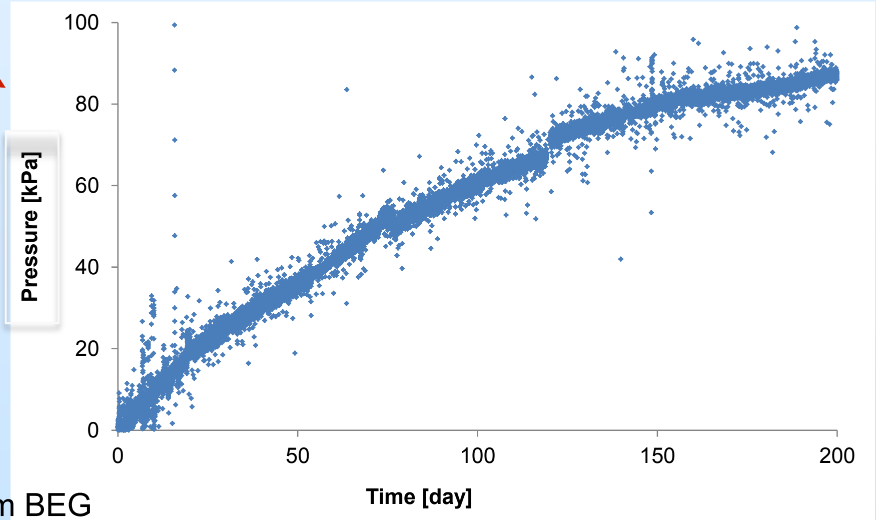


Jiemin Lu, GCCC

Field Observation



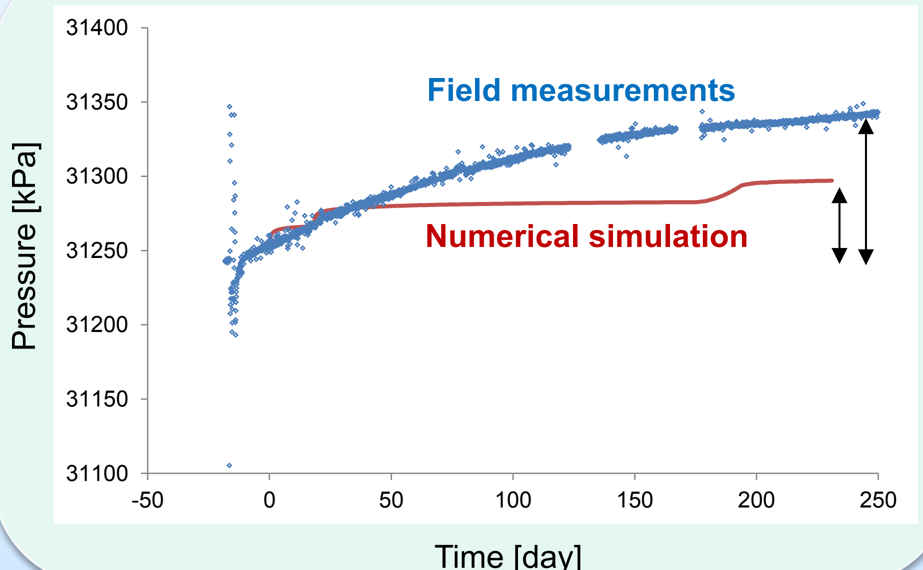




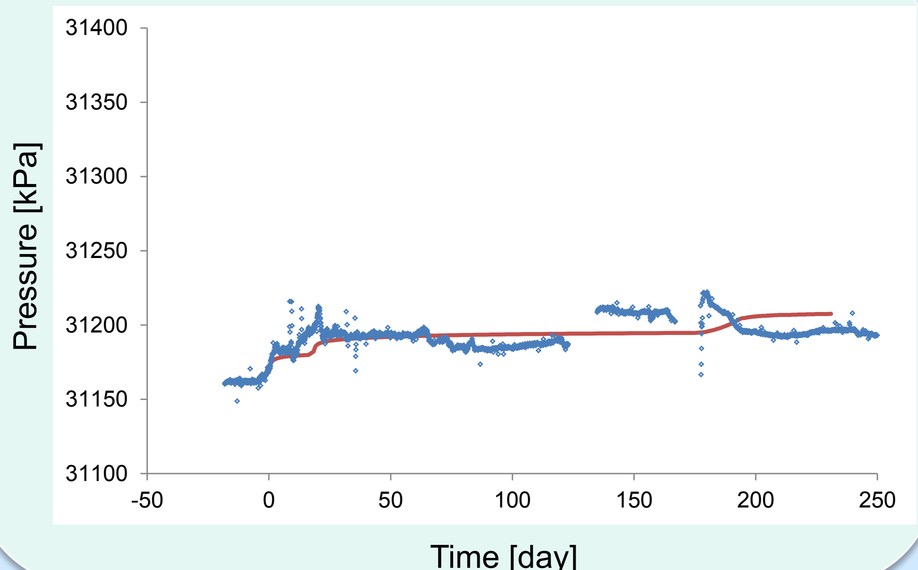
S Hosseini, S. Kim BEG

Matching pressure in AZMI

- 31 F2 Mon. Well: Pressure



- 31 F3 Mon. Well: Pressure



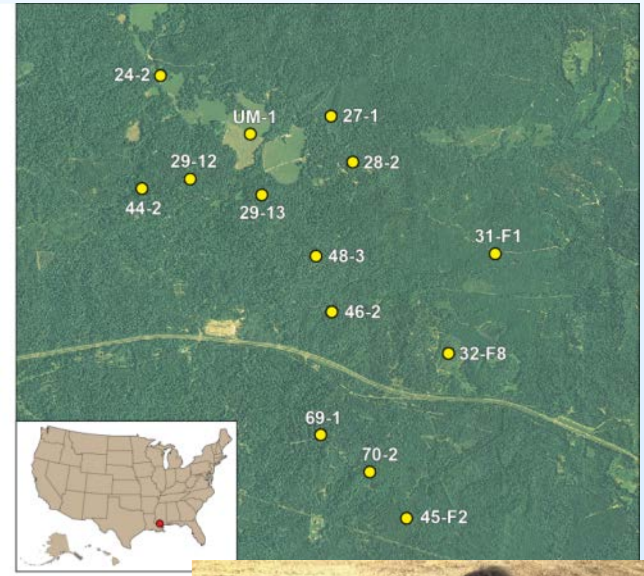
Groundwater at the Cranfield Site: Sampling

- More than 12 field campaigns since 2008
- ~ 130 groundwater samples collected for chemical analysis of

  Cations: Ag, Al, As, Ba, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Pb, Se, Zn
  Anions: F^-, Cl^-, SO_4^{2-}, Br^-, NO_3^-, PO_4^{3-}
  TOC, TIC, pH, Alkalinity, VOC, δC13

  On-site: pH, temperature, alkalinity, water level

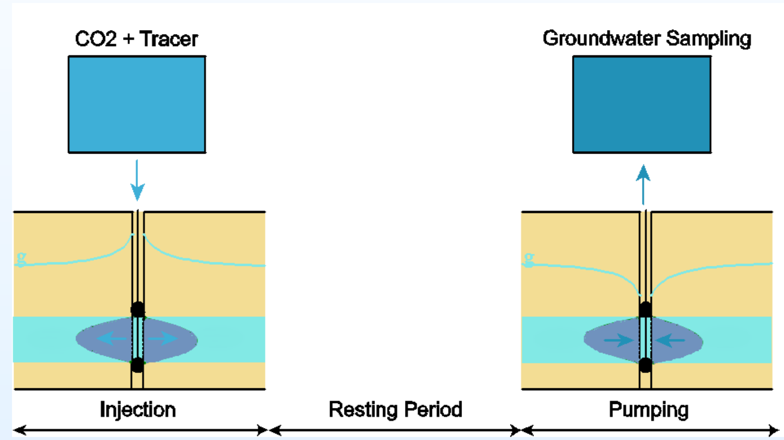
- ~10 samples for noble gases
- ~20 groundwater samples for dissolved CH_4



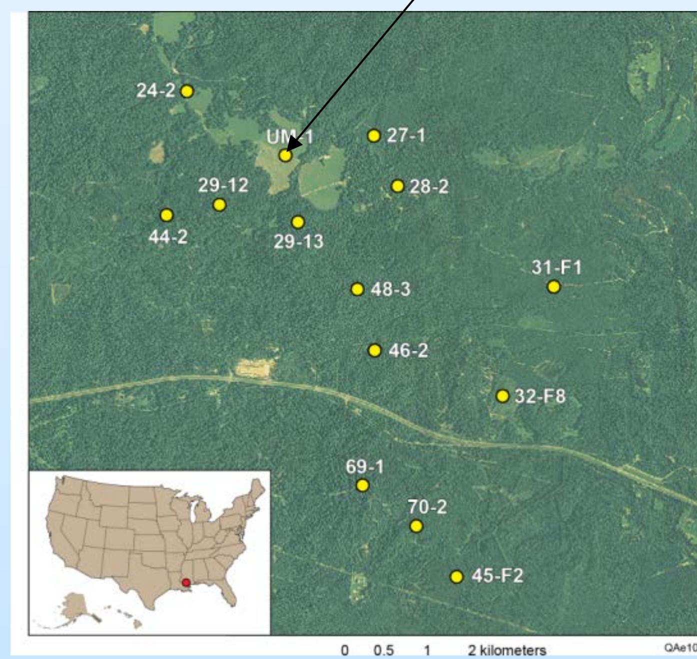
C. Yang, BEG

Groundwater at the Cranfield Site
Single-Well Push-Pull Test

- Maximum concentrations of trace metals observed, such as As and Pb, are much less than the EPA contamination levels;
- Single well push-pull test appears to be a convenient field controlled-release test for assessing potential impacts of CO_2 leakage on drinking groundwater resources;



Testing well



Results were summarized in the following paper

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ELSEVIER

Single-well push–pull test for assessing potential impacts of CO_2 leakage on groundwater quality in a shallow Gulf Coast aquifer in Cranfield, Mississippi

Changbing Yang[a,*], Patrick J. Mickler[a], Robert Reedy[a], Bridget R. Scanlon[a], Katherine D. Romanak[a], Jean-Philippe Nicot[a], Susan D. Hovorka[a], Ramon H. Trevino[a], Toti Larson[b]

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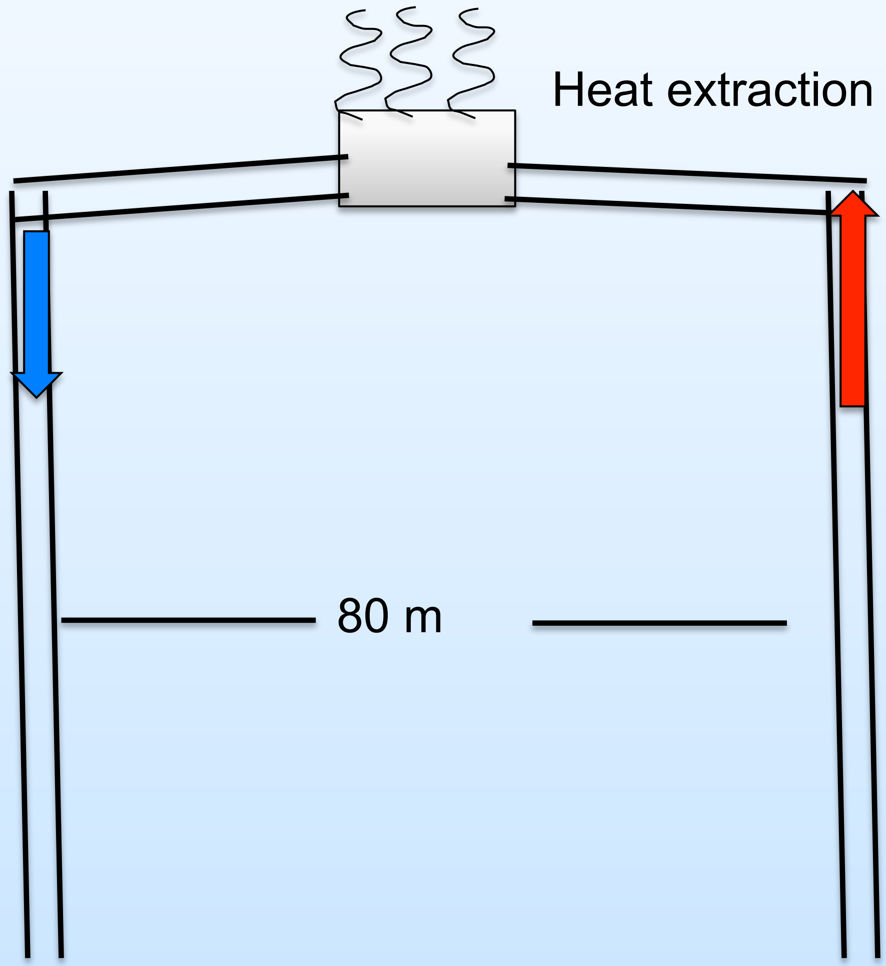
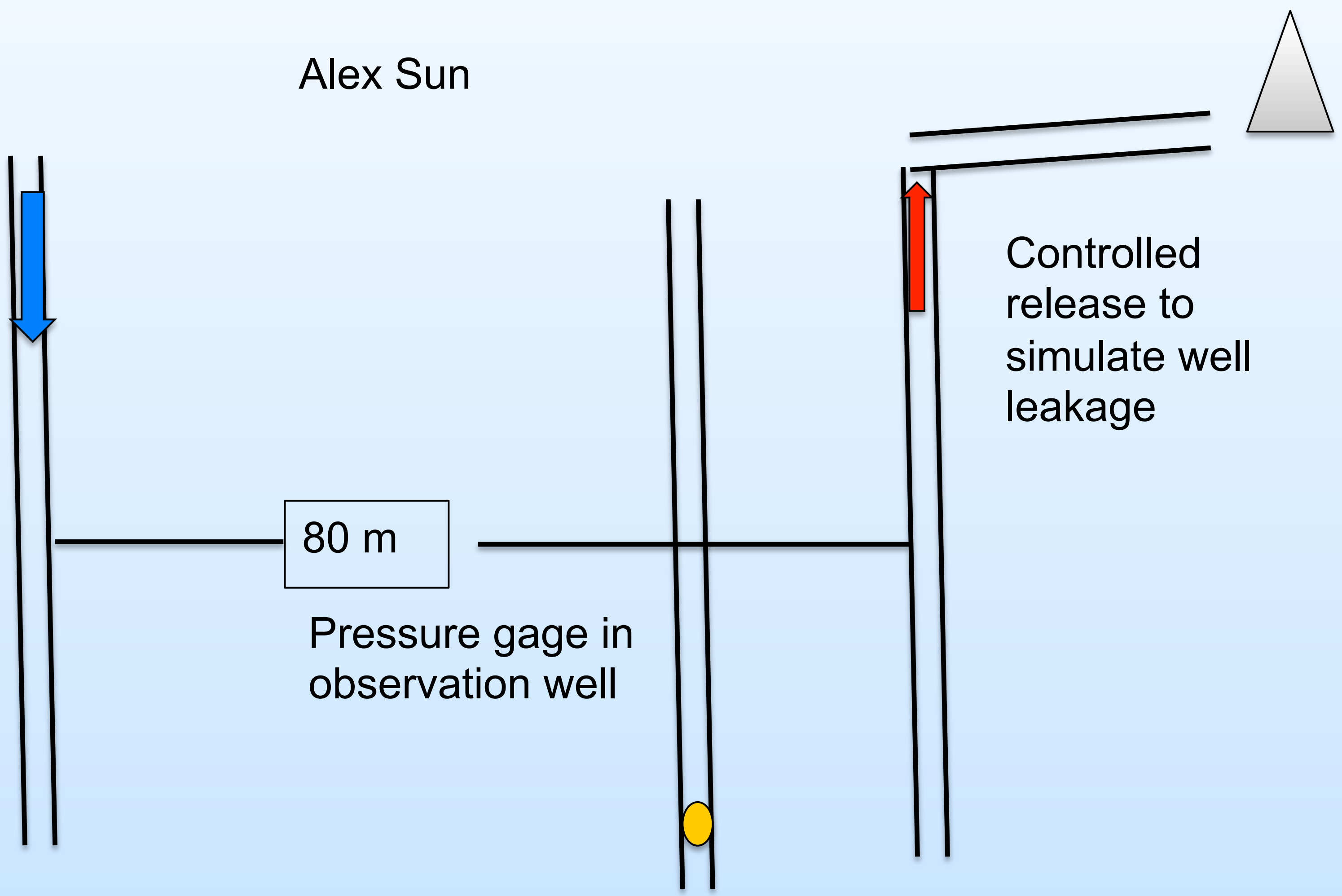
Thermosyphon (Barry Freifeld)



DOE program combining CCSU and geothermal; LBNL lead

Harmonic Pulse testing for Leakage (PIDAS)

Alex Sun



Project Status