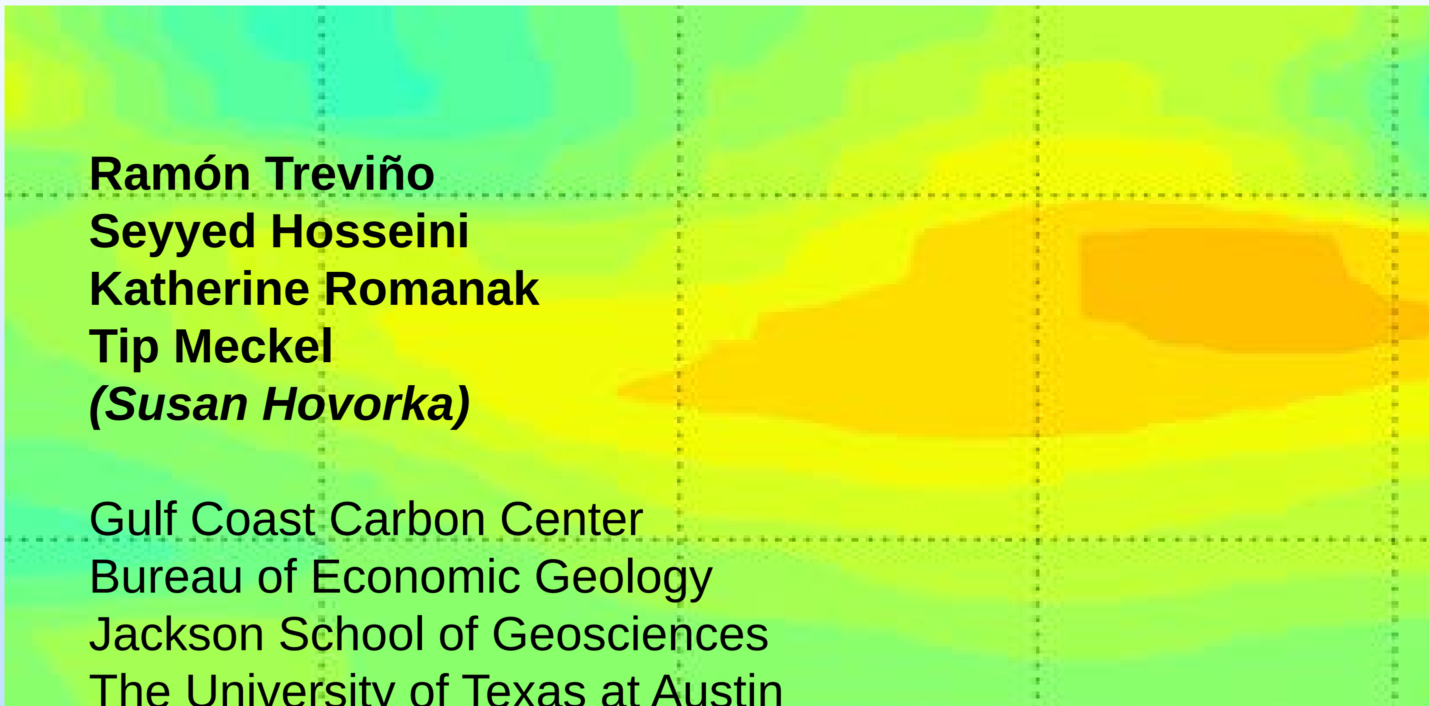
SECARB's Early Test at Cranfield, Mississippi

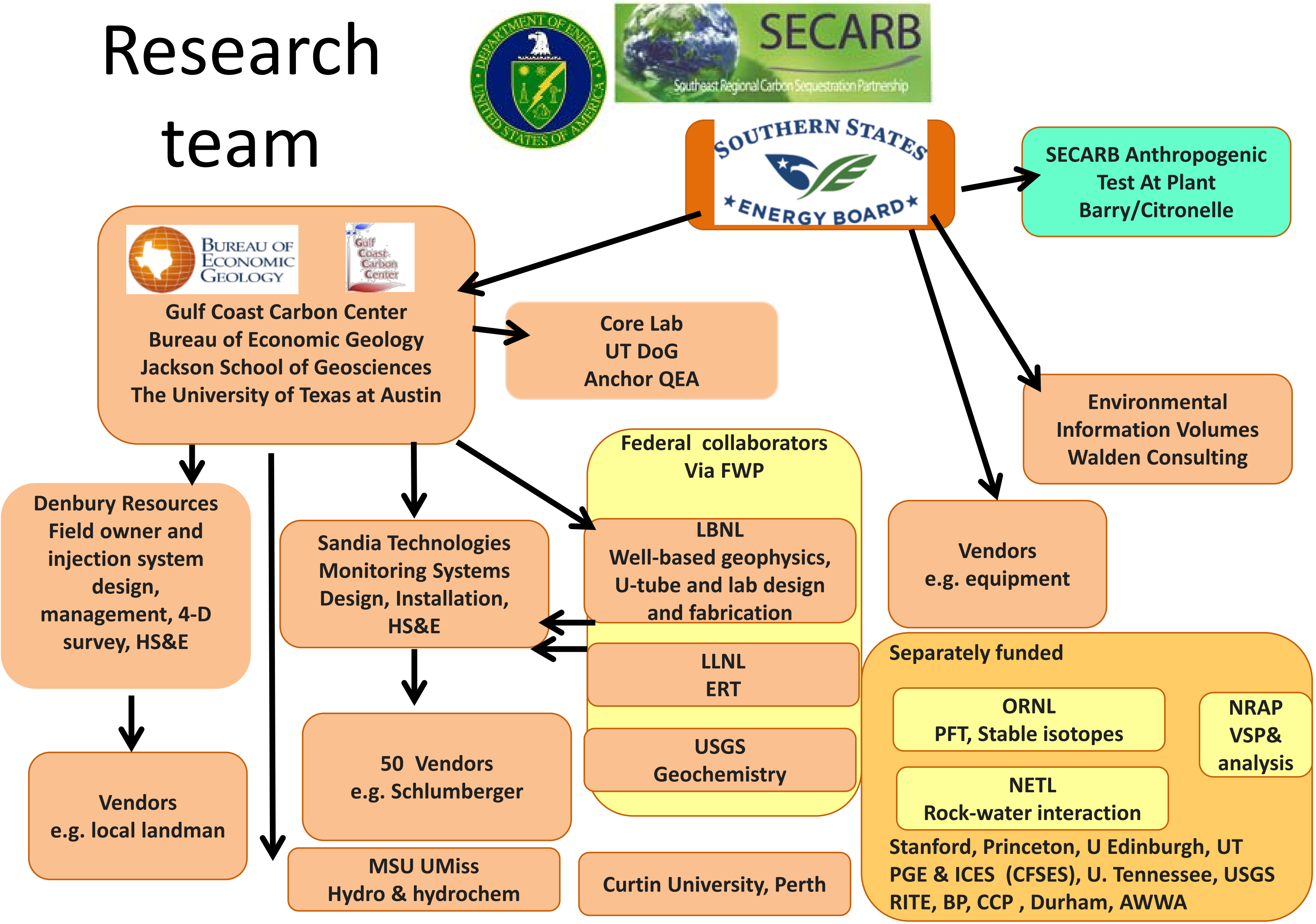


Ramón Treviño
Seyyed Hosseini
Katherine Romanak
Tip Meckel
(Susan Hovorka)

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

ERT Image of CO_2 plume: X Yang LLNL

Early Test Research team



Presentation Outline

- SECARB Early Test Goals
- Site Characterization
- Monitoring and modeling response to injection in the deep subsurface
- Monitoring the shallow subsurface – what would response to leakage or migration look like?
- Remaining work

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Goal: Regional Carbon Sequestration Program goal: Improve prediction of storage capacities

Existing data on reservoir volumetrics

Production history
37,590,000 Stock tank barrels oil
672,472,000 MSCU gas
(Chevron, 1966))

7,754 acres x 90 ft net pay x 25.5% porosity
(Chevron, 1966)

X E [pore volume occupancy (storage efficiency)] = Storage capacity

injection rate – limited by pressure response

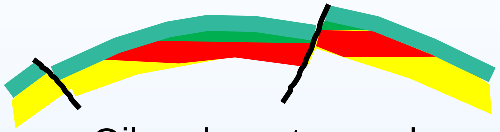
Measure saturation during multiphase plume evolution

Increase predictive capabilities by validating numerical models

Observation: pore volume occupancy was rate and pressure dependent: not a single number

Goal: Regional Carbon Sequestration Partnership program goal: **Evaluate protocols** to demonstrate that CO_2 is retained

High confidence in storage permanence through characterization



Oil and gas trapped over geologic time

Material Impact: failing to retain

Uncertainty and risk assessment → Semi-quantitative assessment via Certification Framework

Research Questions

- P&A well performance in retention?
- Limited analogy between injected and natural fluid retention
- Off structure migration?
- Response to pressure elevation?

Selected assessment approach

shallow

- Well-pad vadose gas
- Ground water chem.
- AZMI pressure
- 4-D Seismic
- 4-D VSP
- IZ pressure
- Microseismic

deep

Protocol Sensitivity & reliability

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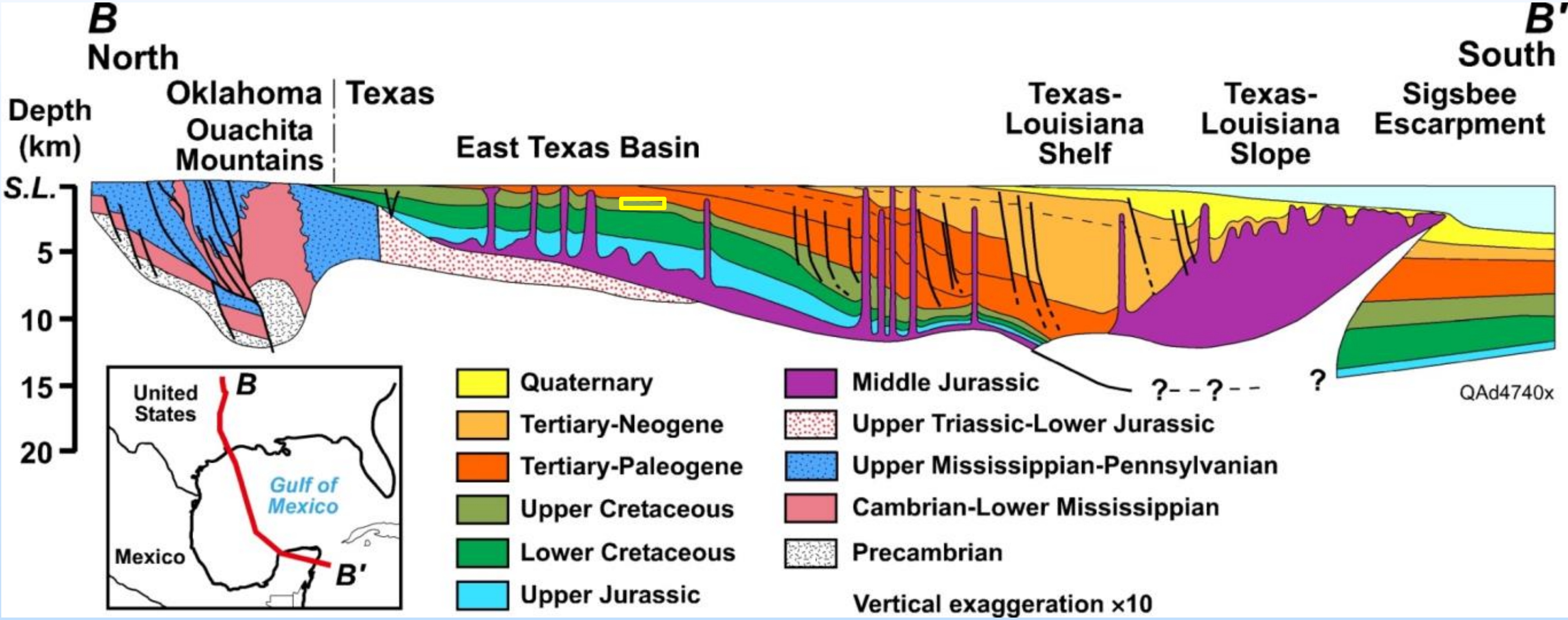
Characterization

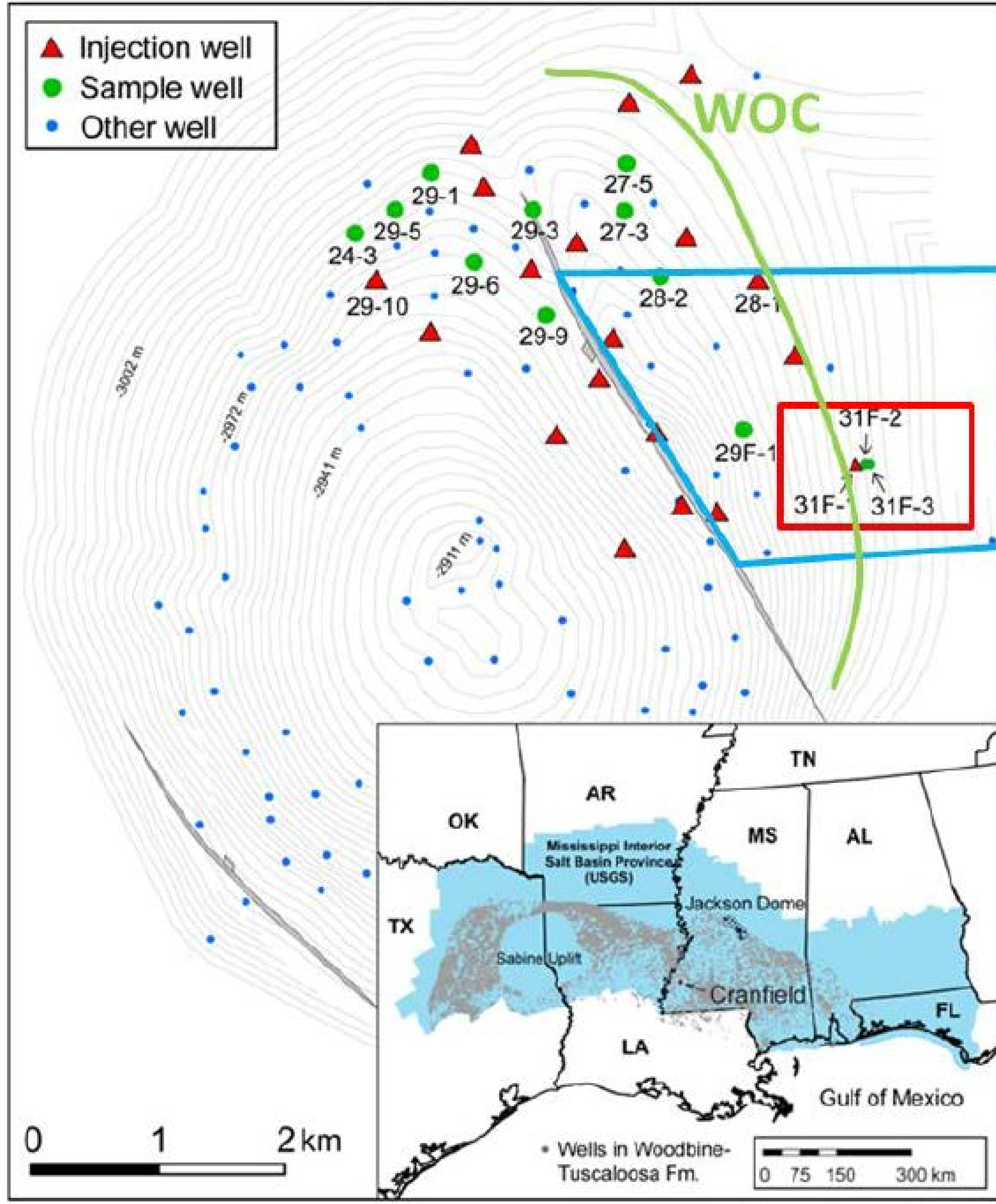
- **Regional setting** (Gulf Coast Wedge)
- **Location**
- **Tuscaloosa Formation** - depositional system
- **Confining system** (overburden)

Gulf Coast Wedge



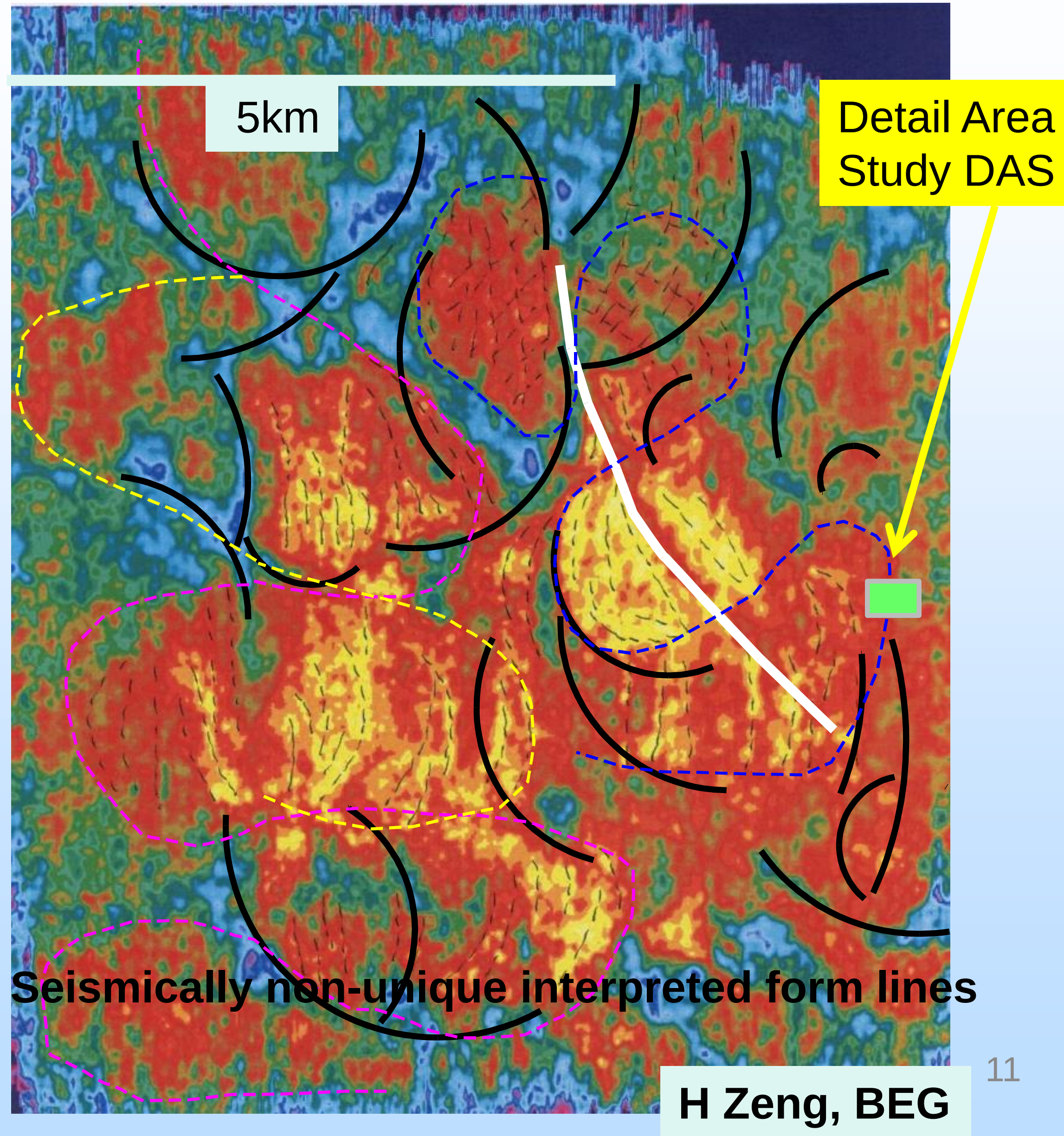
Galloway and others,2000

Location

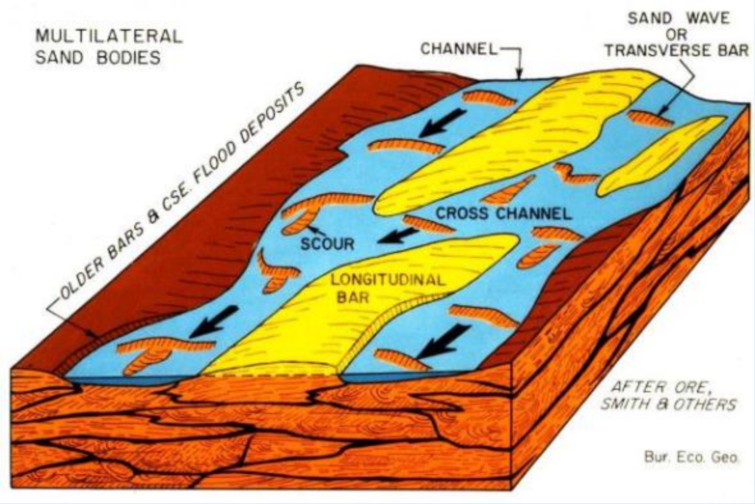


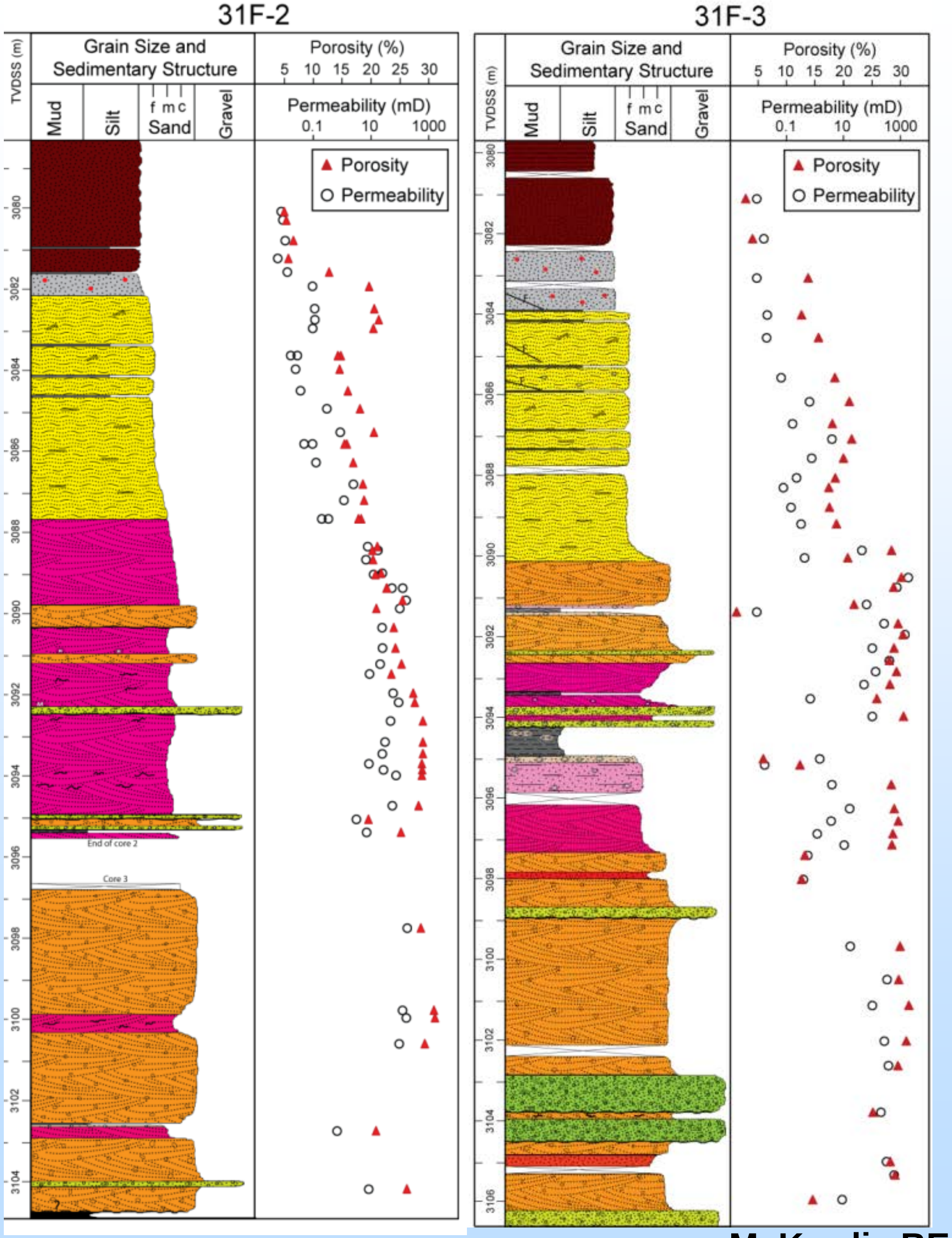
Injection well
Sample well
Other well
WOC
29-1
29-5
24-3
29-10
29-6
29-3
27-5
27-3
28-2
28-1
29-9
29F-1
31F-2
31F-1
31F-3
-3002 m
-2972 m
-2941 m
-2911 m
0
1
2 km
OK
AR
TN
MS
AL
TX
LA
FL
Mississippi Interior Salt Basin Province (USGS)
Jackson Dome
Sabine Uplift
Cranfield
Gulf of Mexico
Wells in Woodbine-Tuscaloosa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

Lower Tuscaloosa sand and conglomerate fluvial depositional environment



Amalgamated Fluvial Channels - Heterogeneity

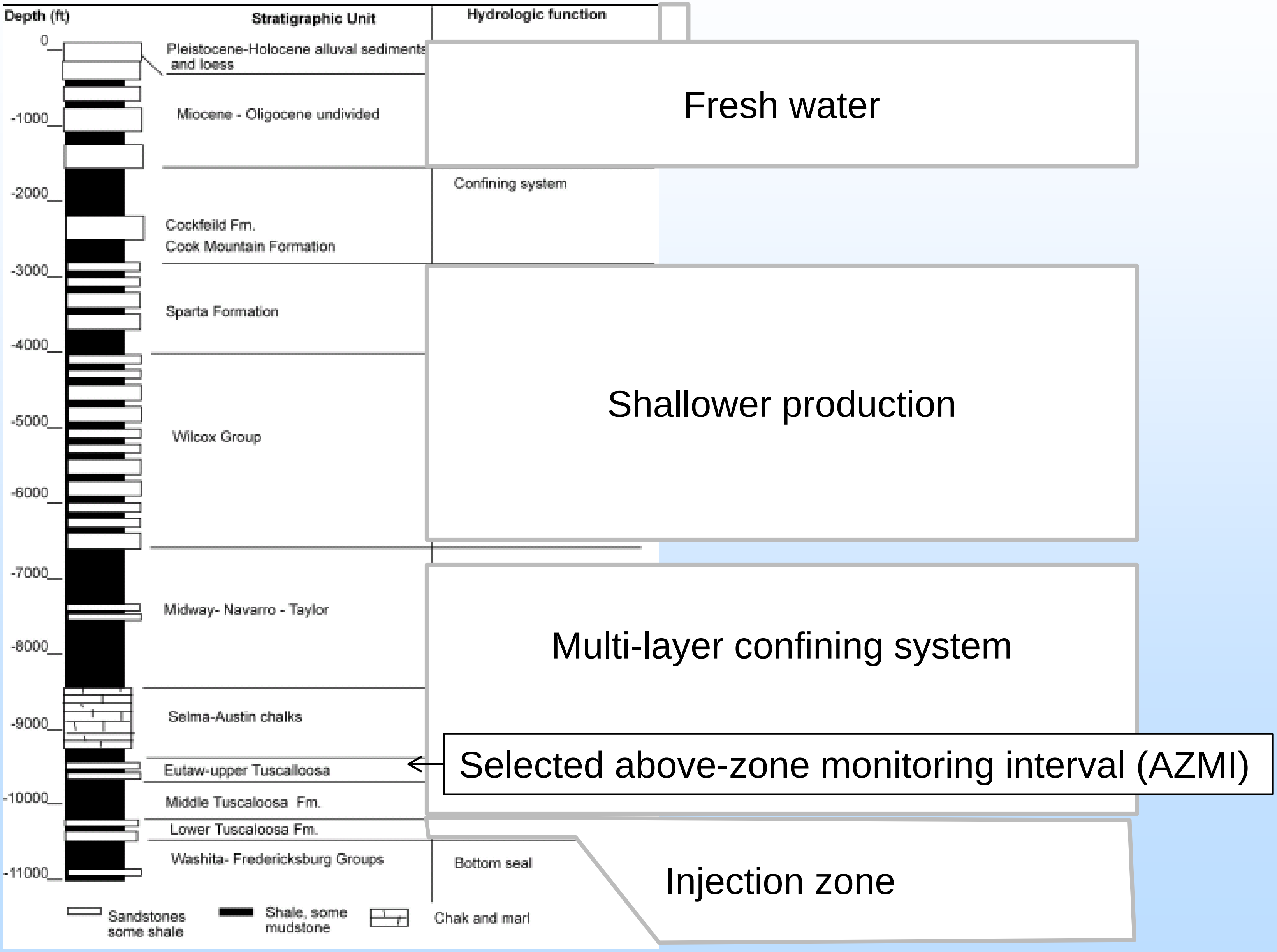




30-m apart

M. Kordi , BEG

Characterization of Overburden



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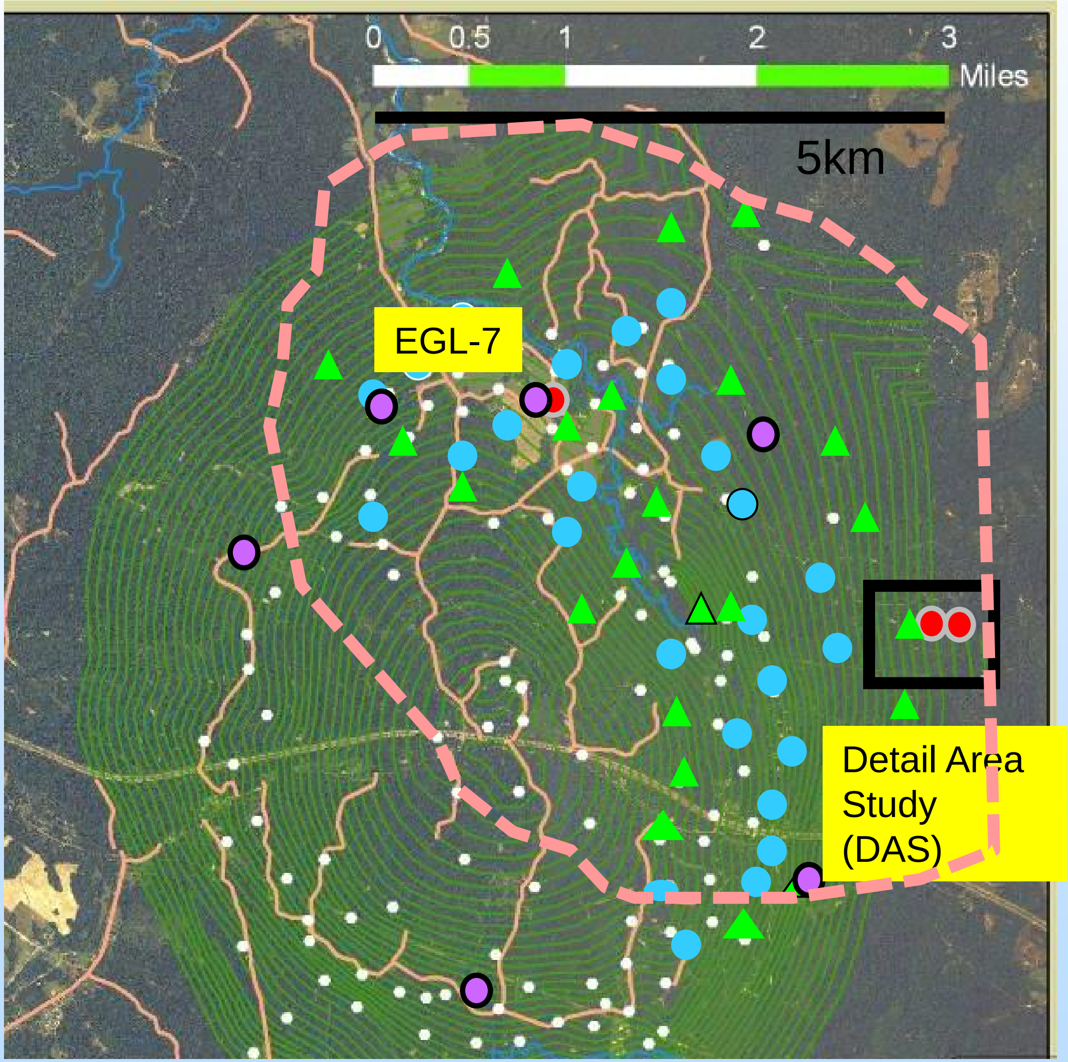
Monitoring response to injection in the deep subsurface



Injector

Producer (monitoring point)

Observation Well

RITE Microseismic

4-D seismic

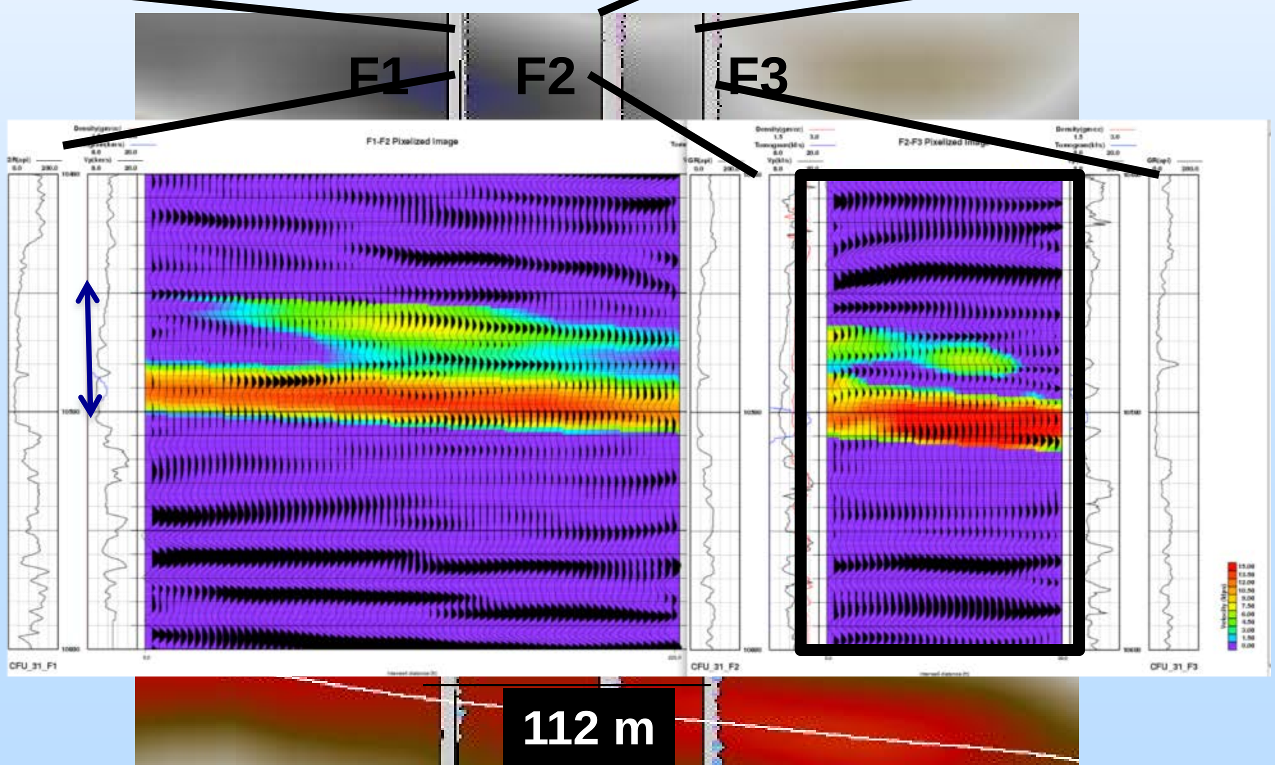
GIS base Tip Meckel, BEG

Detailed Area Study (DAS)

Closely spaced well array to examine flow in complex reservoir

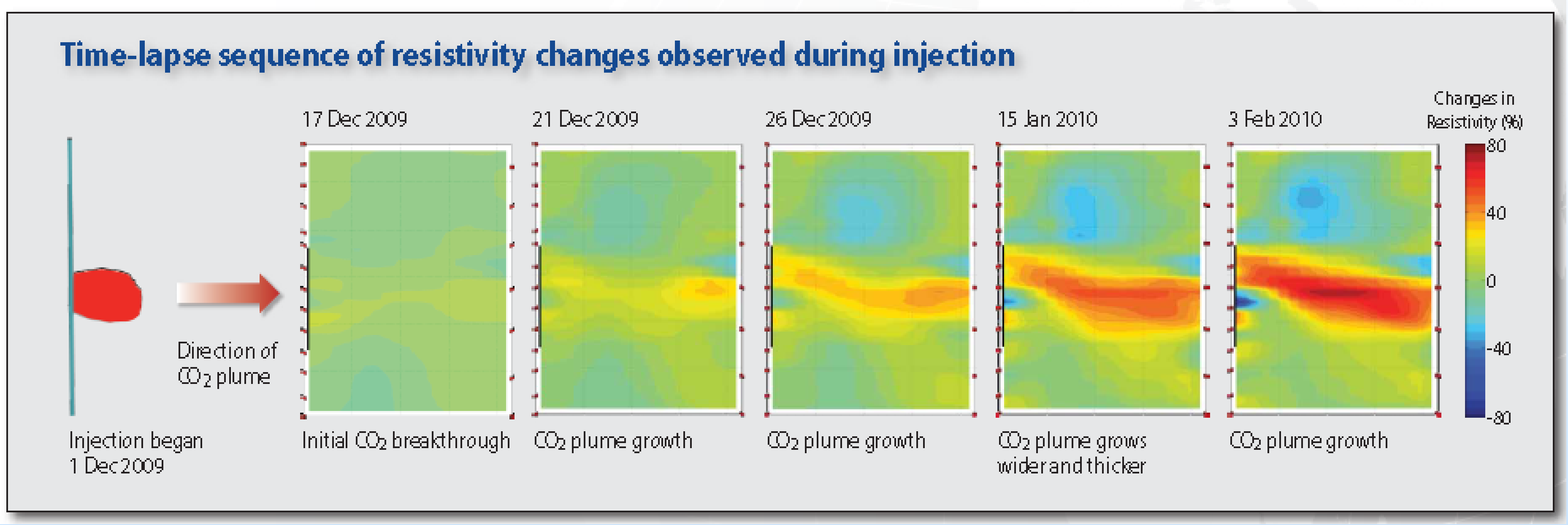
Tuscaloosa D-E reservoir

Petrel model Tip Meckel
Time-lapse cross well Schlumberger



LLNL Electrical Resistance Tomography- changes in response with saturation

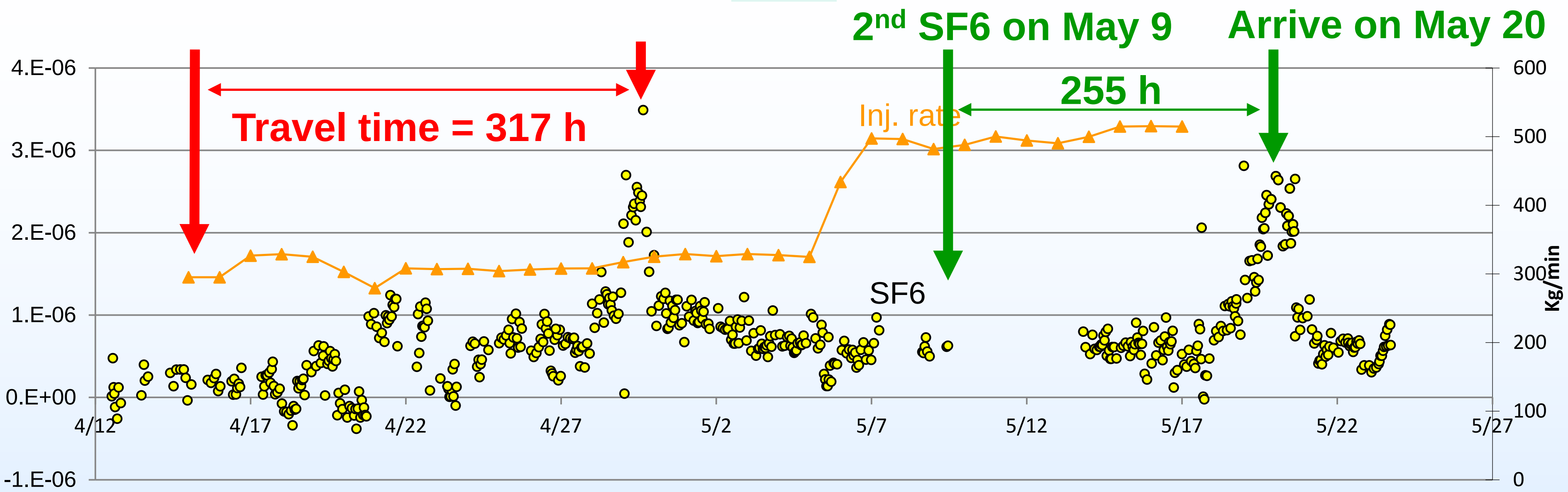
F1 F2 F3



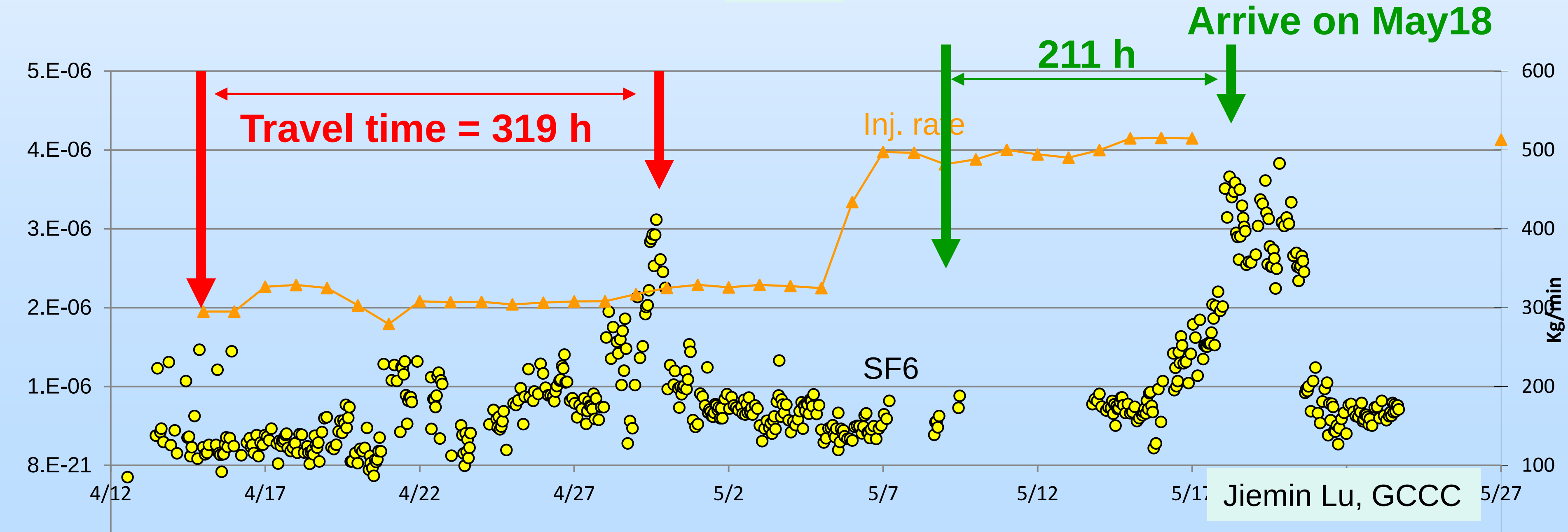
Lawrence Livermore National Laboratory

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

CFU31F-2, 68 m away from injector SF6

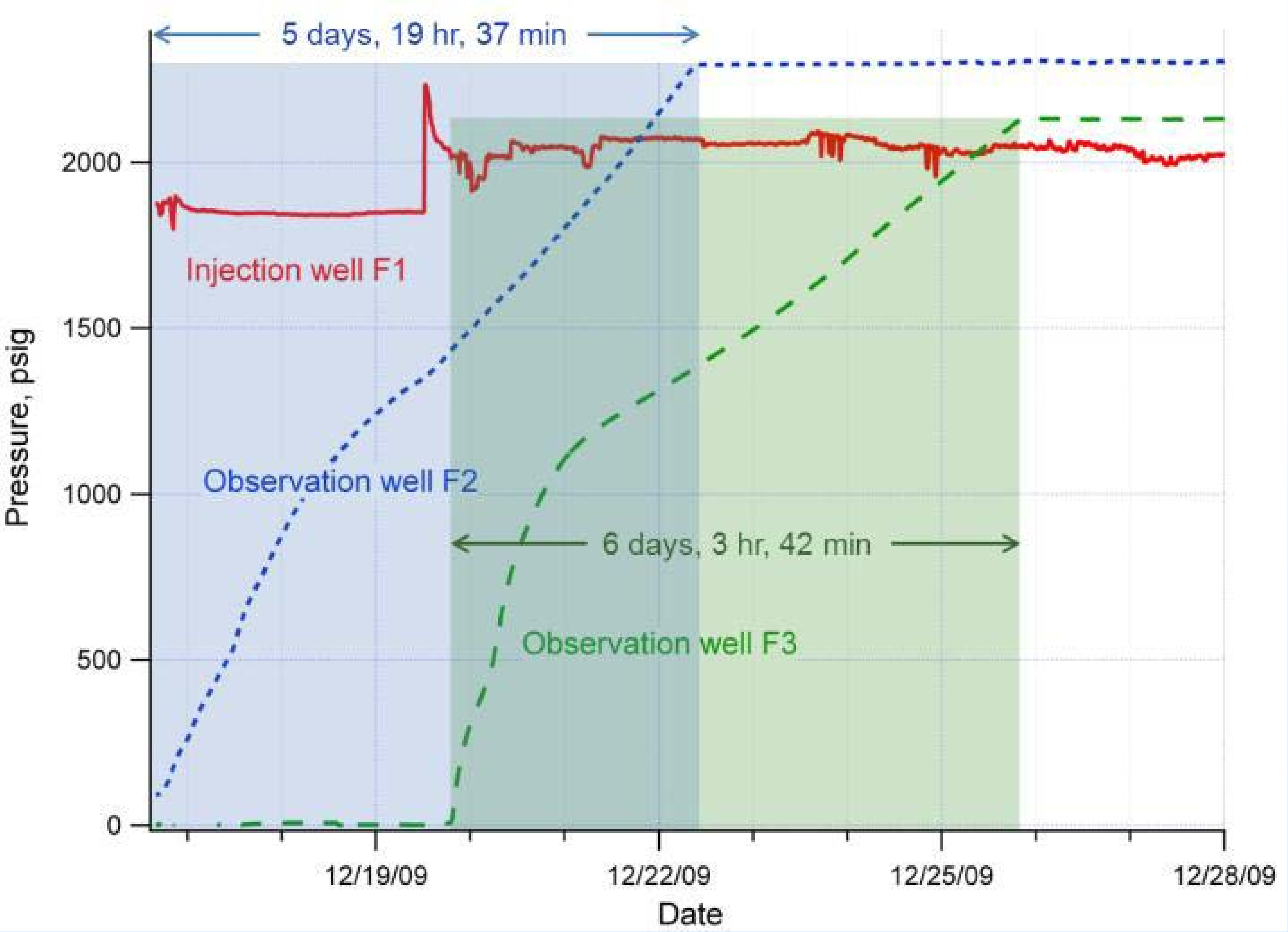


CFU31F-3, 112 m away from injector SF6



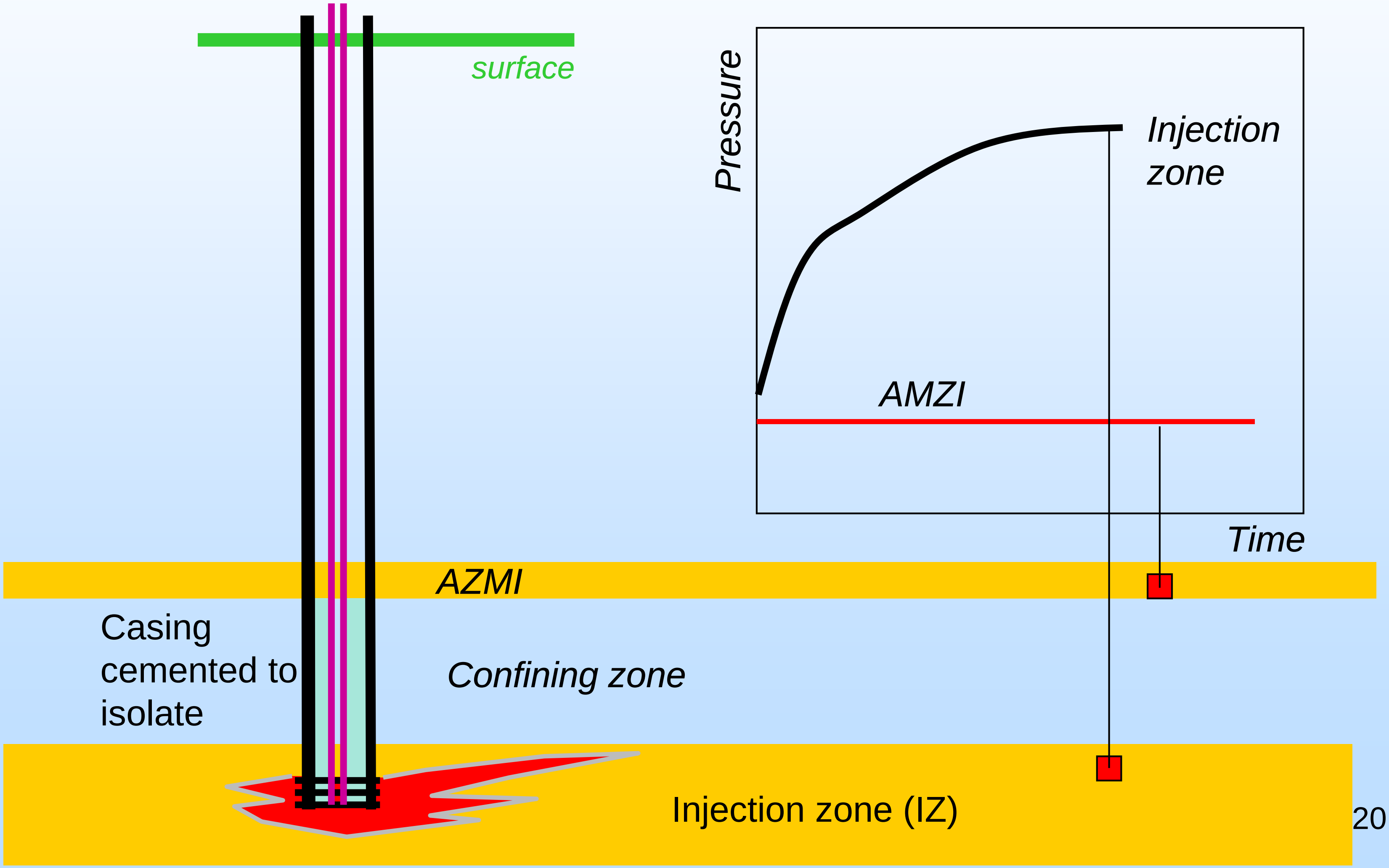
Jiemin Lu, GCCC

Wellhead pressure indicating breakthrough

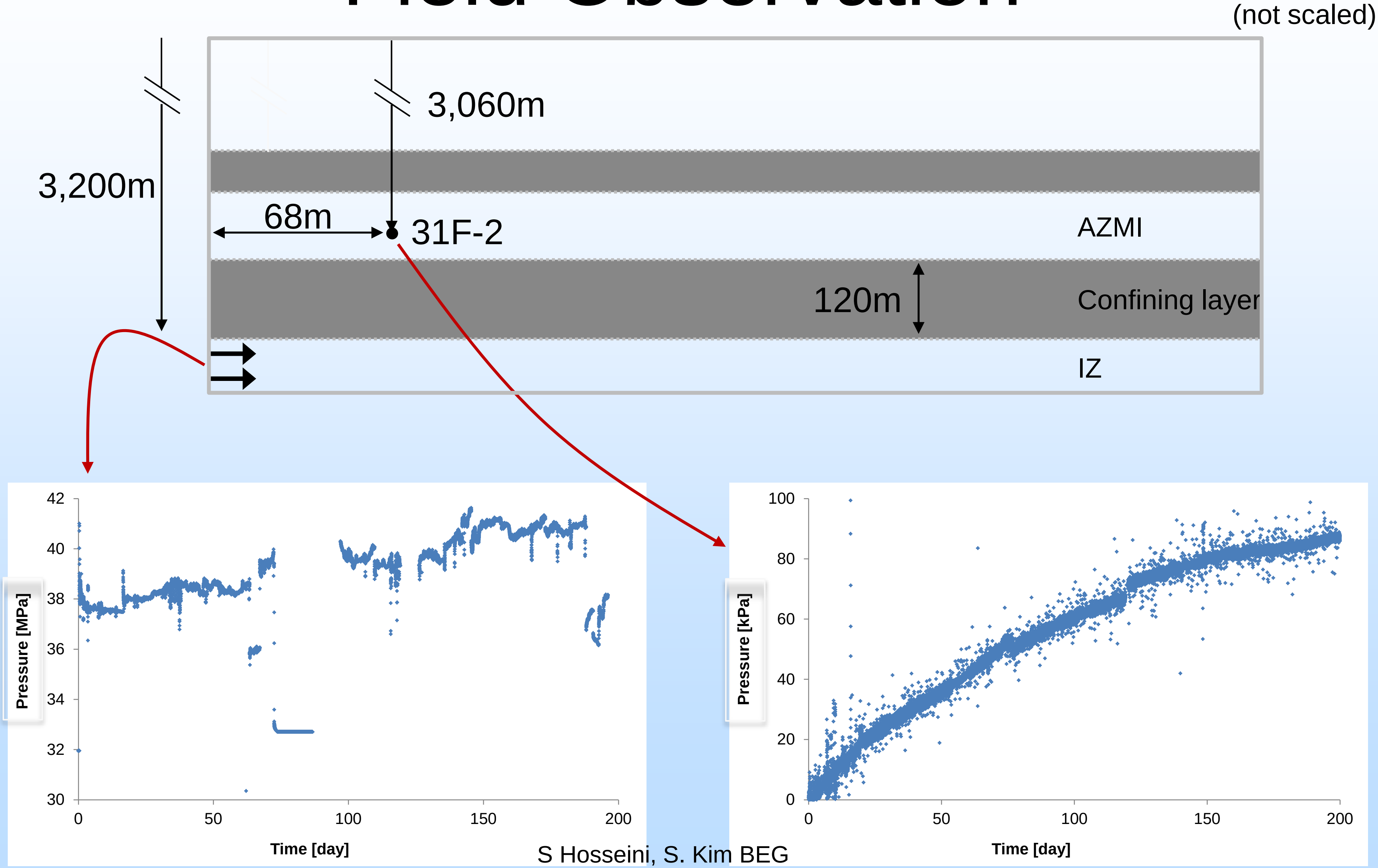


Seyyed Hosseini, BEG, Sandeep Verma Schlumberger

Pressure Monitoring in AZMI (Above zone monitoring interval)

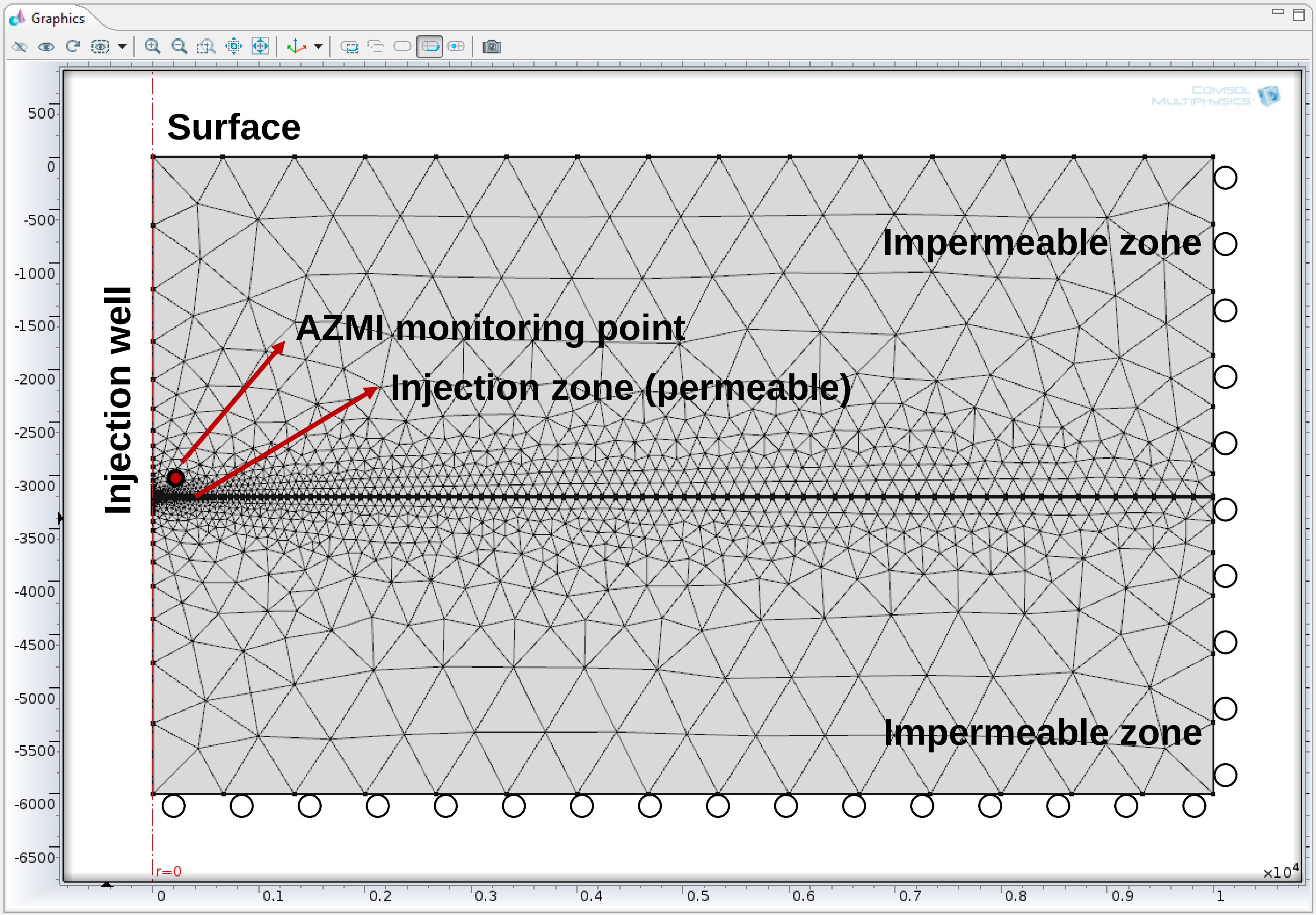


Field Observation



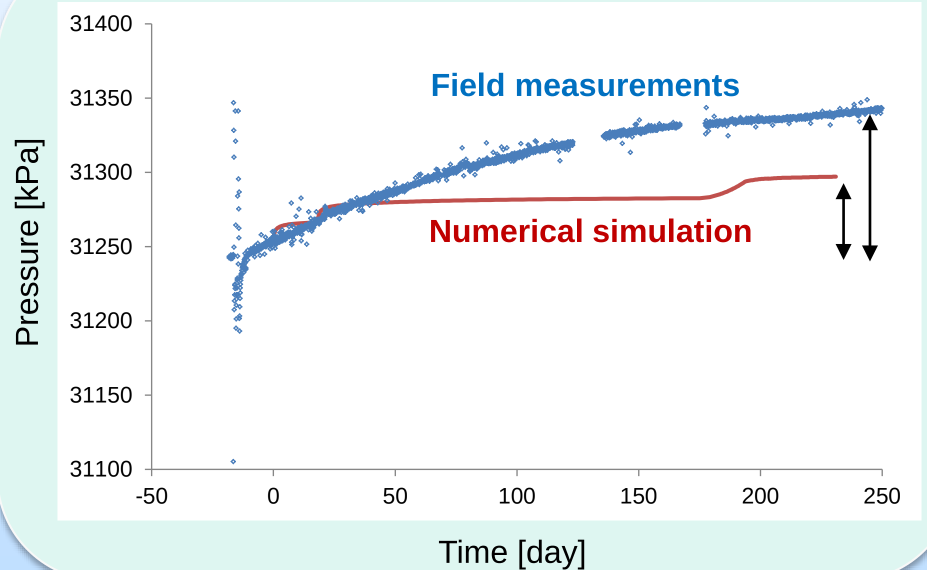
S Hosseini, S. Kim BEG

- COMSOL: simulation model

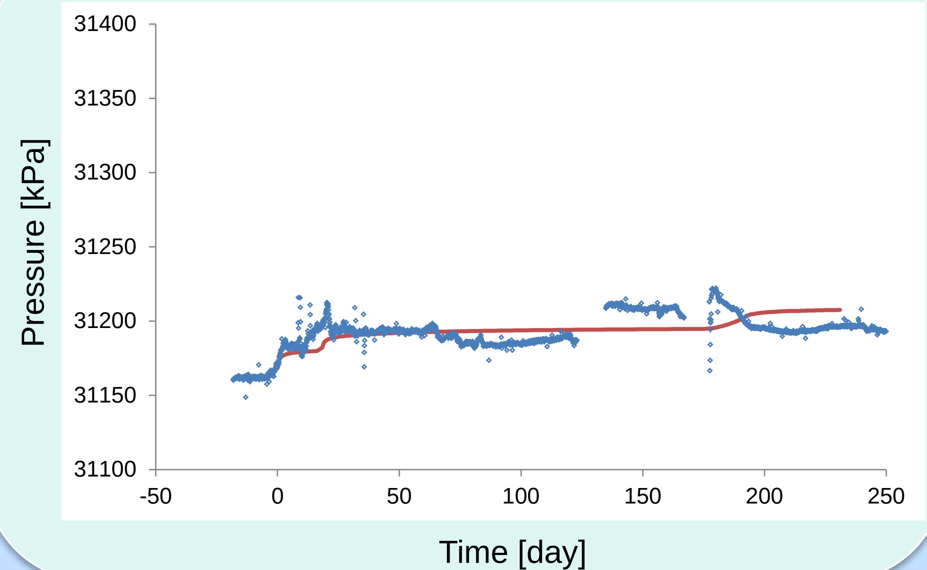


Matching pressure in AZMI

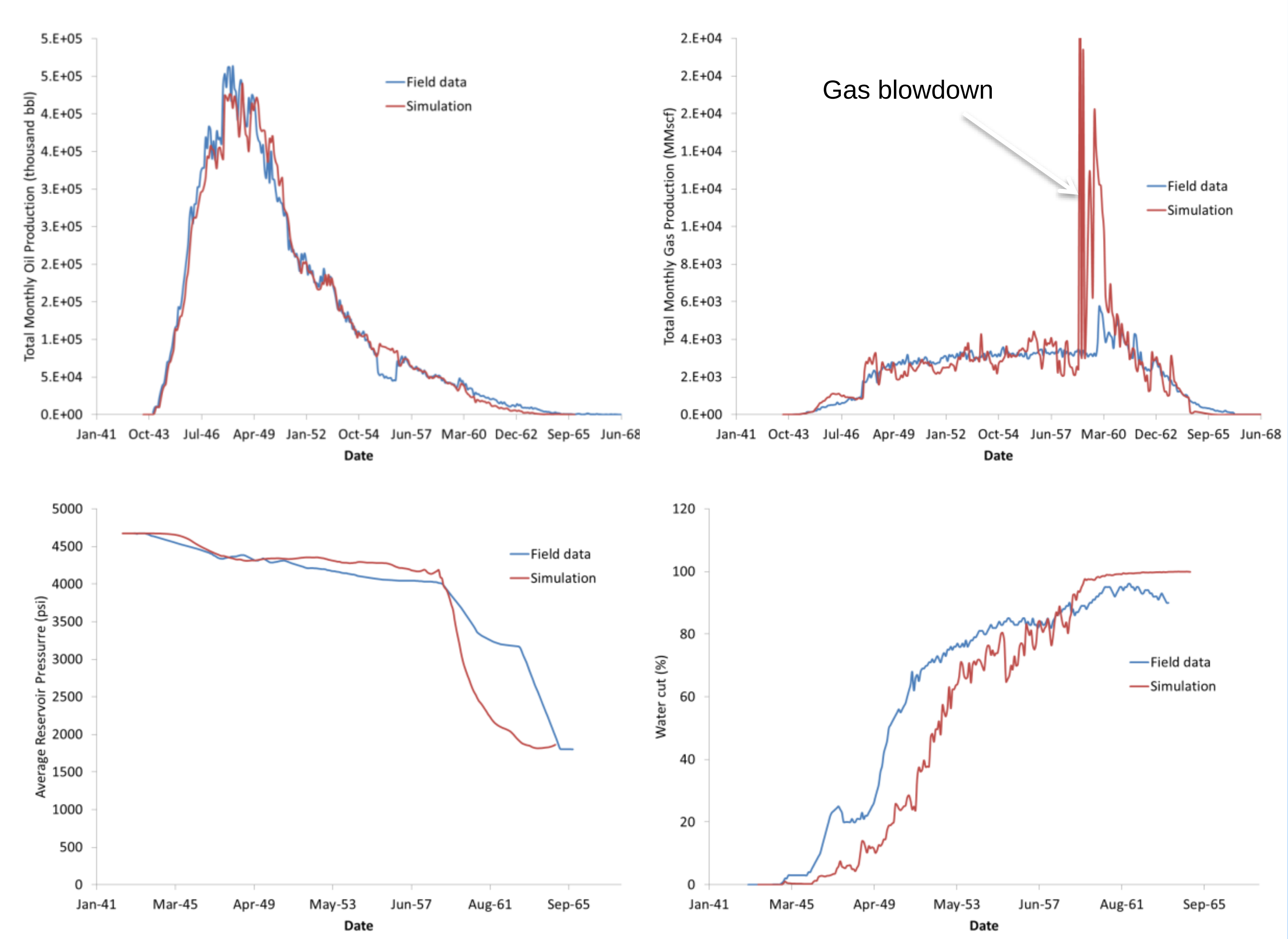
- 31 F2 Mon. Well: Pressure



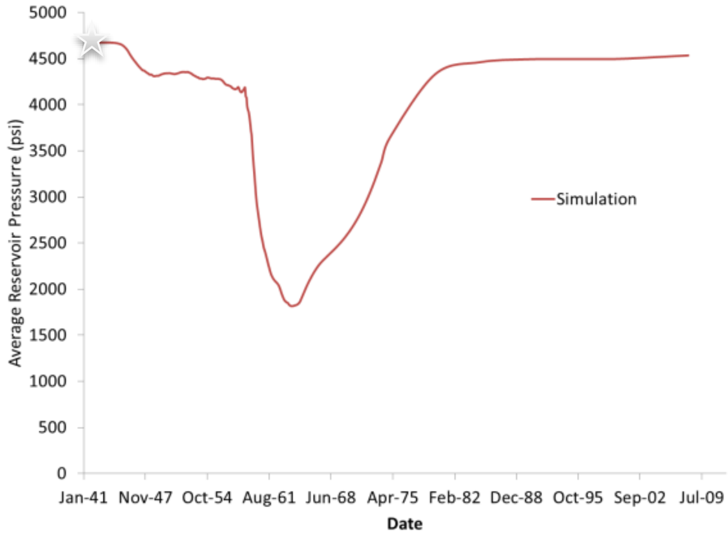
- 31 F3 Mon. Well: Pressure

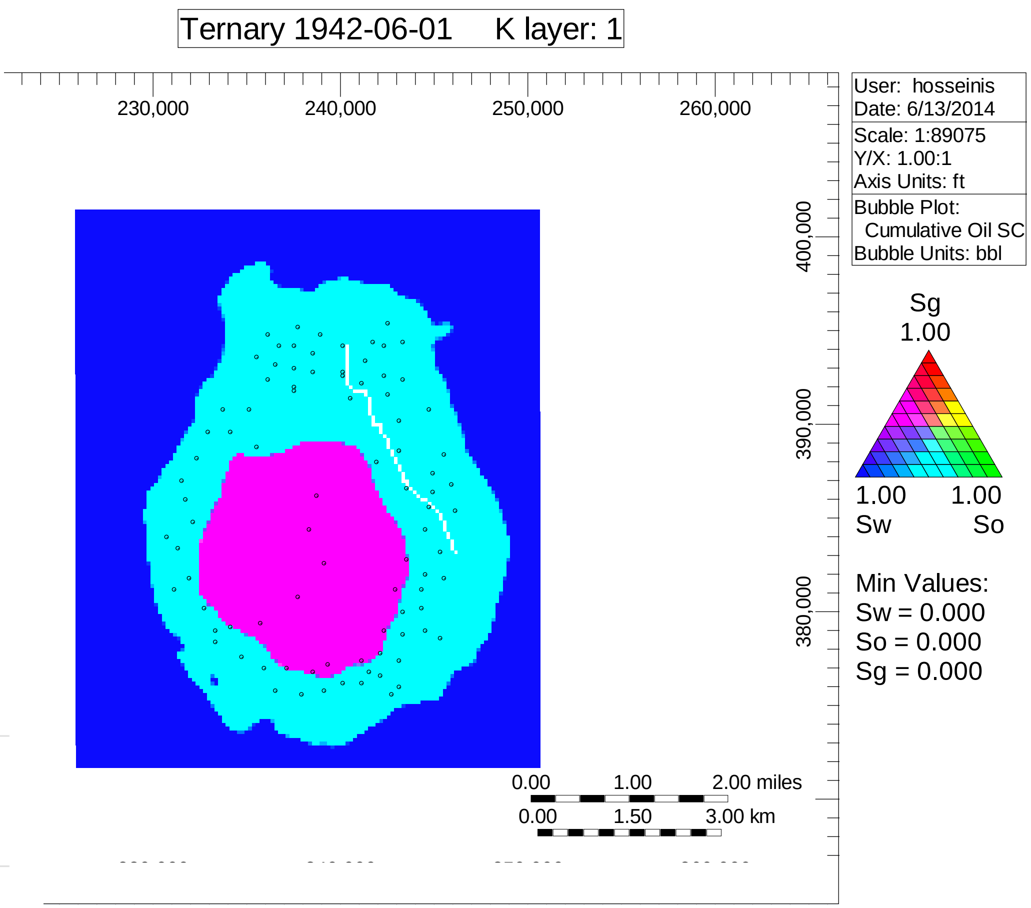


4 D seismic- Historic data history matching (1942-1967)



Ternary saturation map (1942)





ELSEVIER

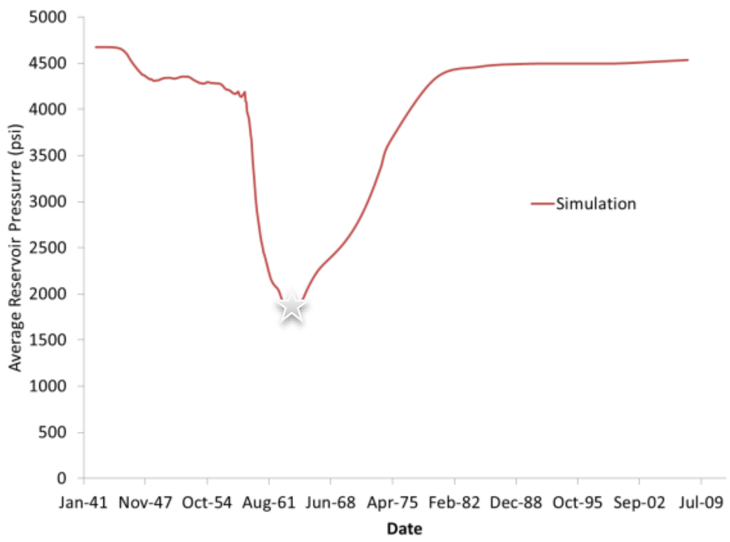
International Journal of Greenhouse Gas Control

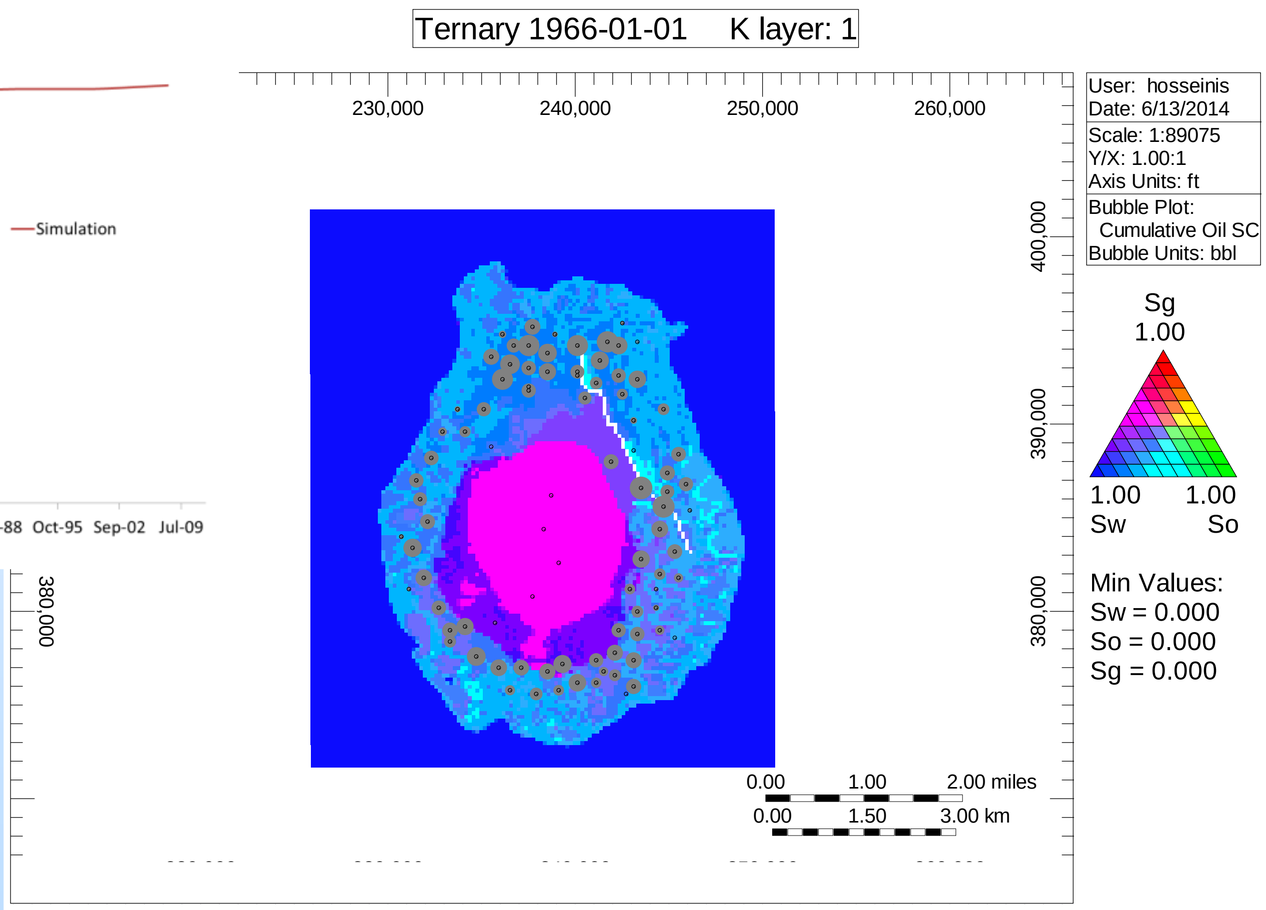
Volume 18, October 2013, Pages 449–462

Static and dynamic reservoir modeling for geological CO_2 sequestration at Cranfield, Mississippi, U.S.A.

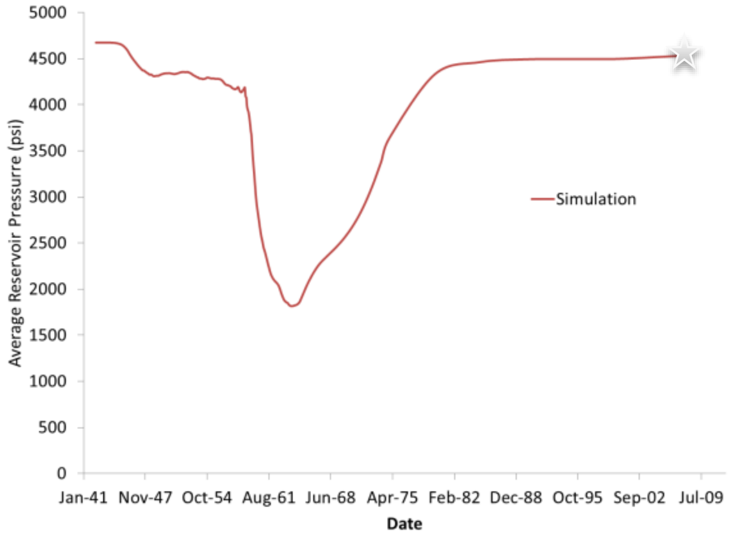
Seyyed Abolfazl Hosseini[a], Hamidreza Lashgari[b], Jong W. Choi[a], Jean-Philippe Nicot[a], Jiemin Lu[a], Susan D. Hovorka[a]

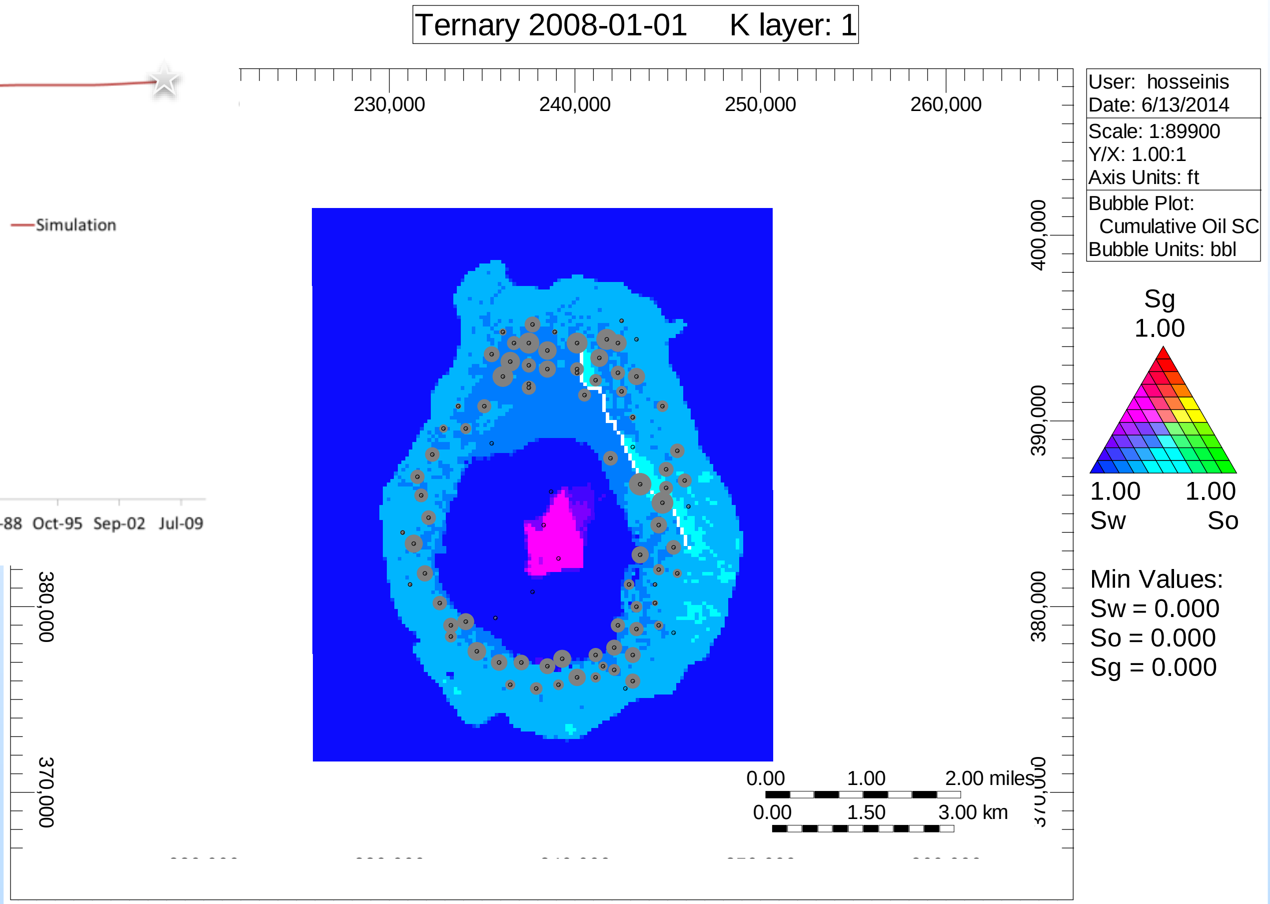
Ternary saturation map (1966)



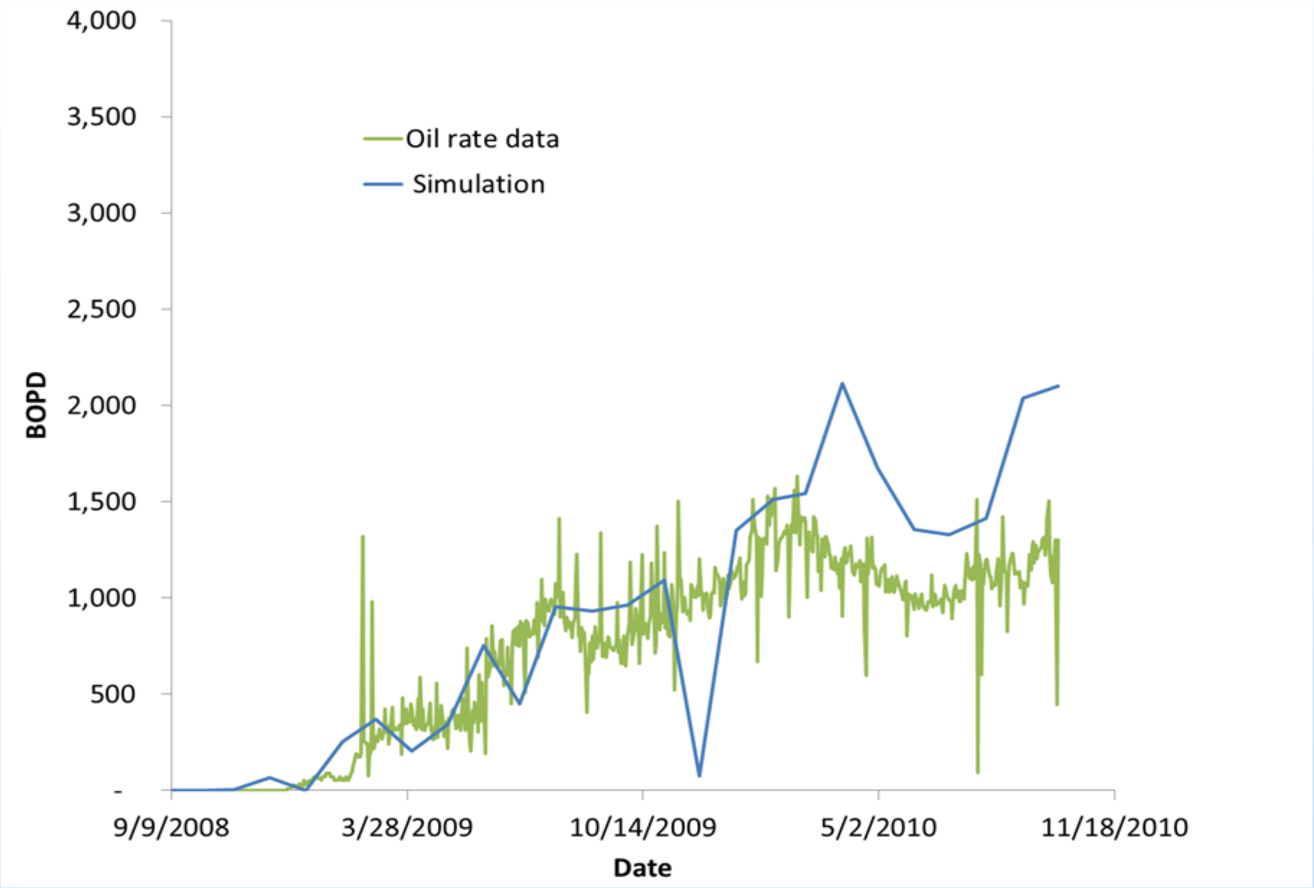


Ternary saturation map (2007)

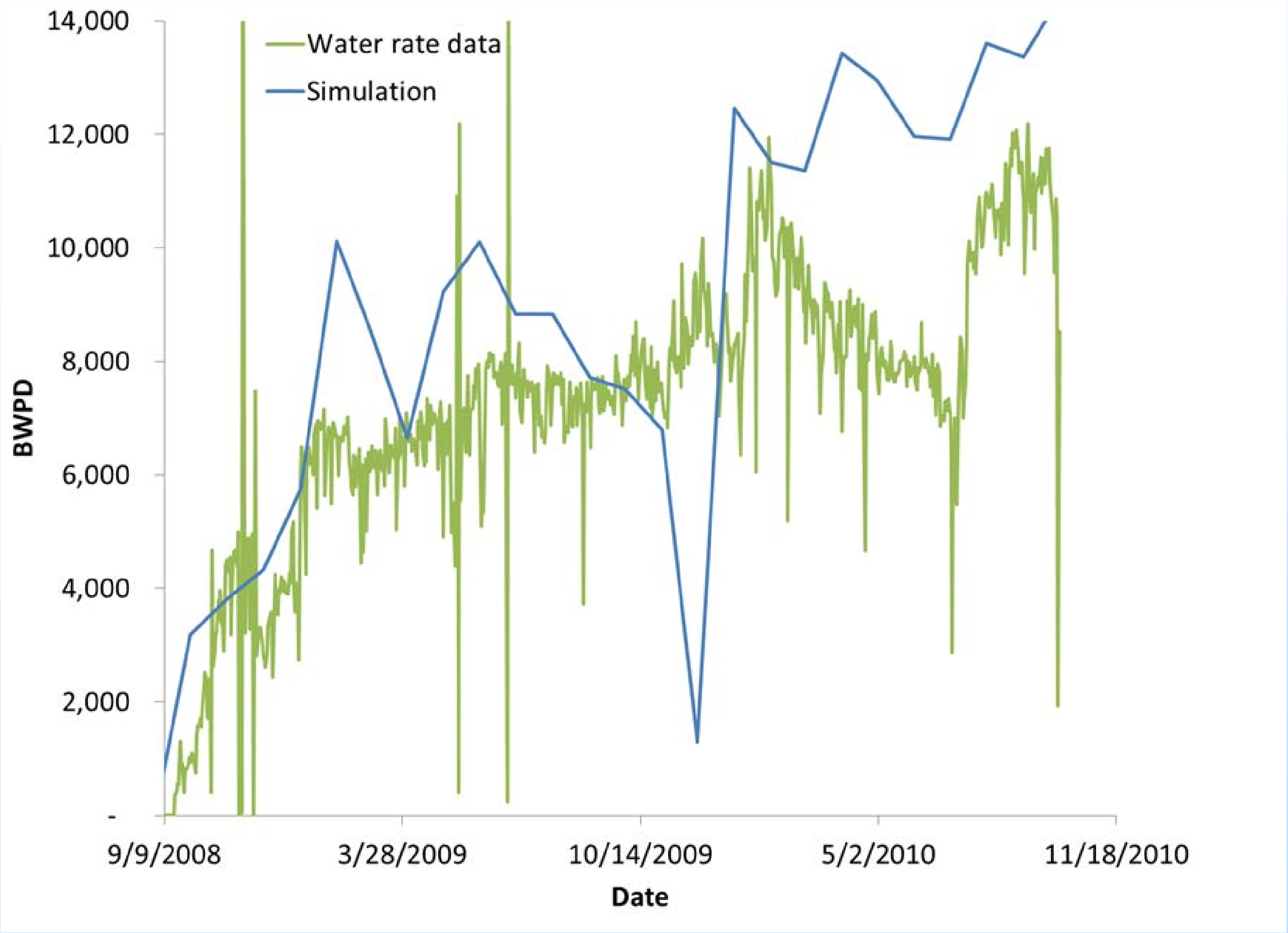




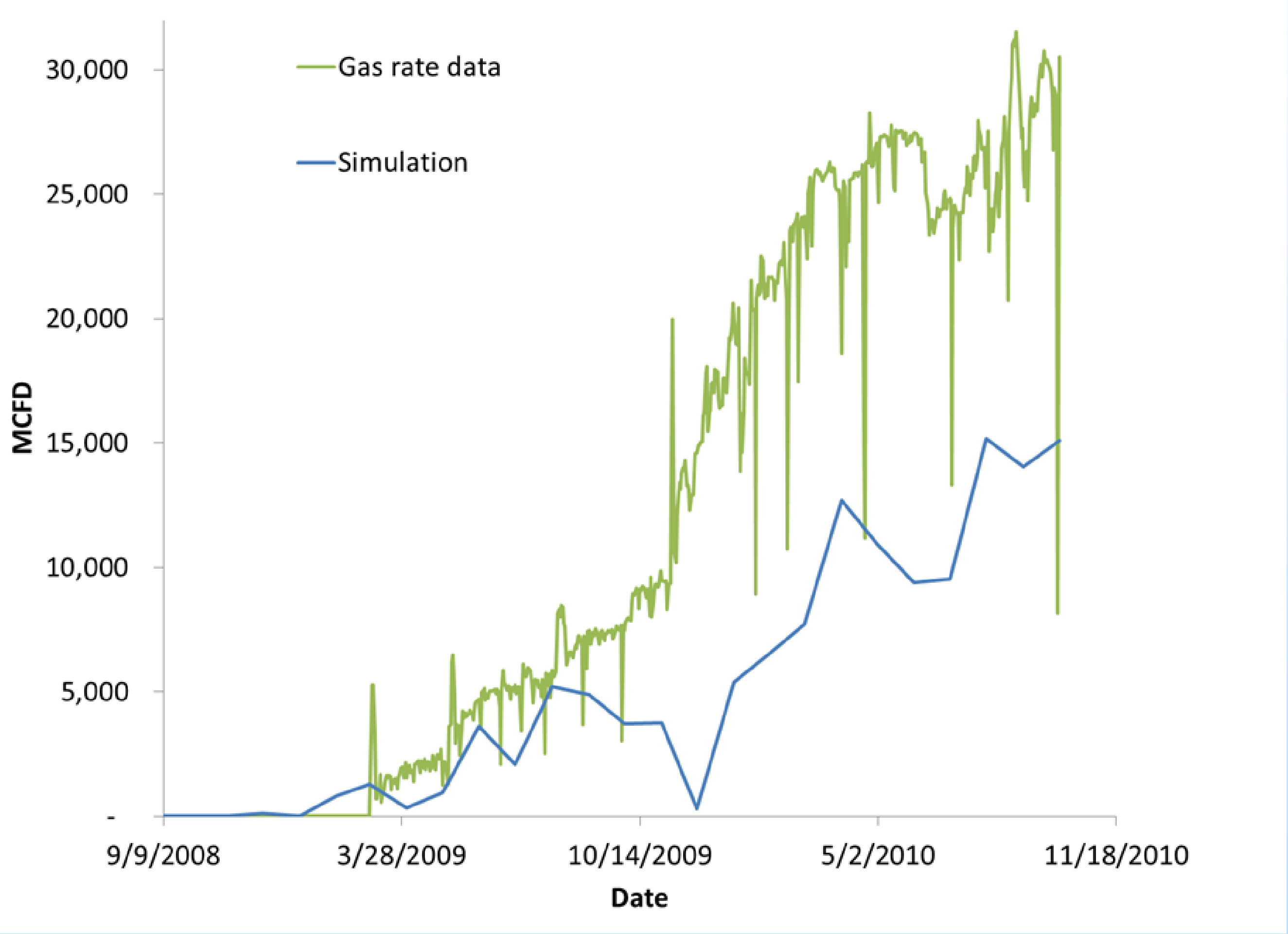
CO_2 Injection Simulation (2007-2010)



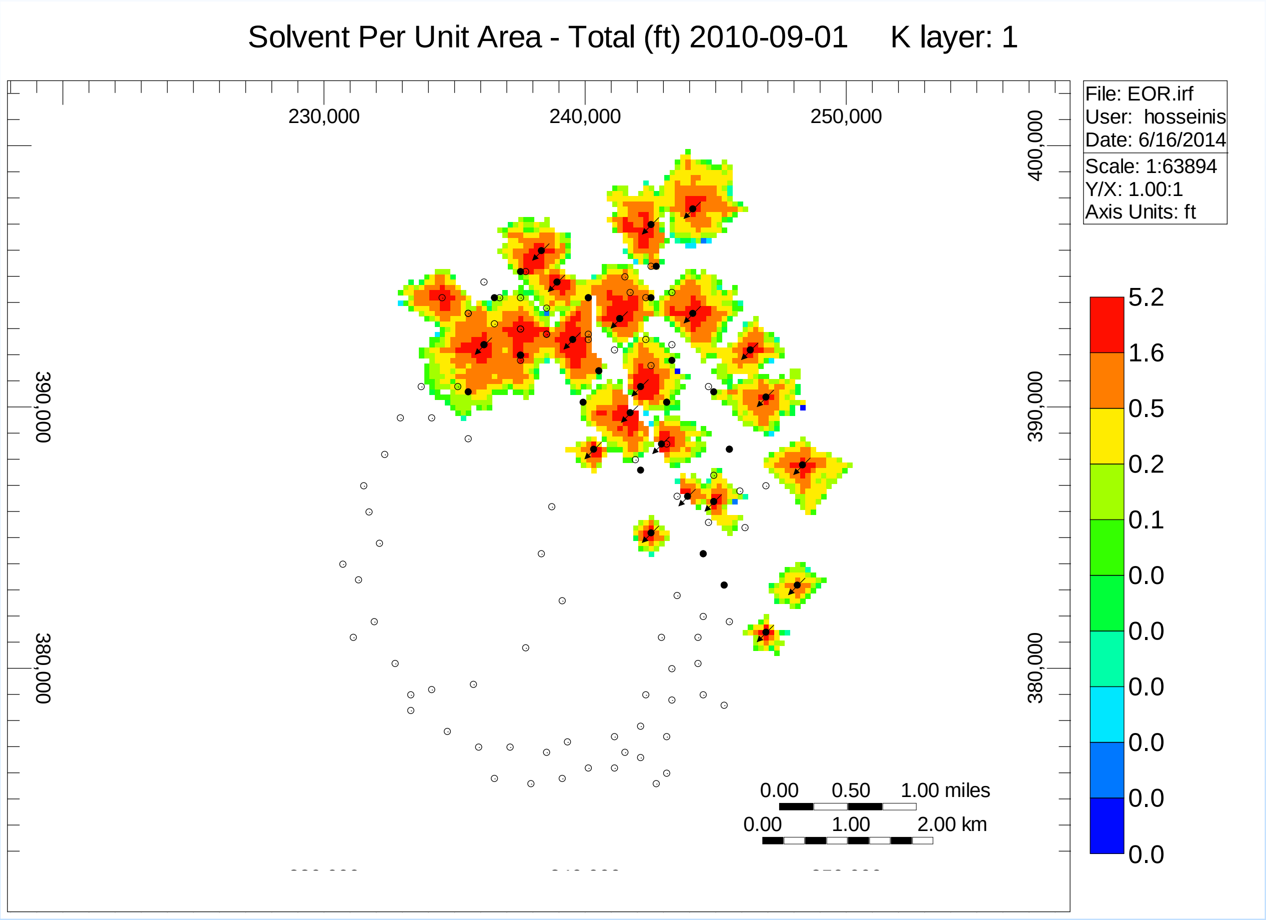
CO_2 Injection Simulation (2007-2010)



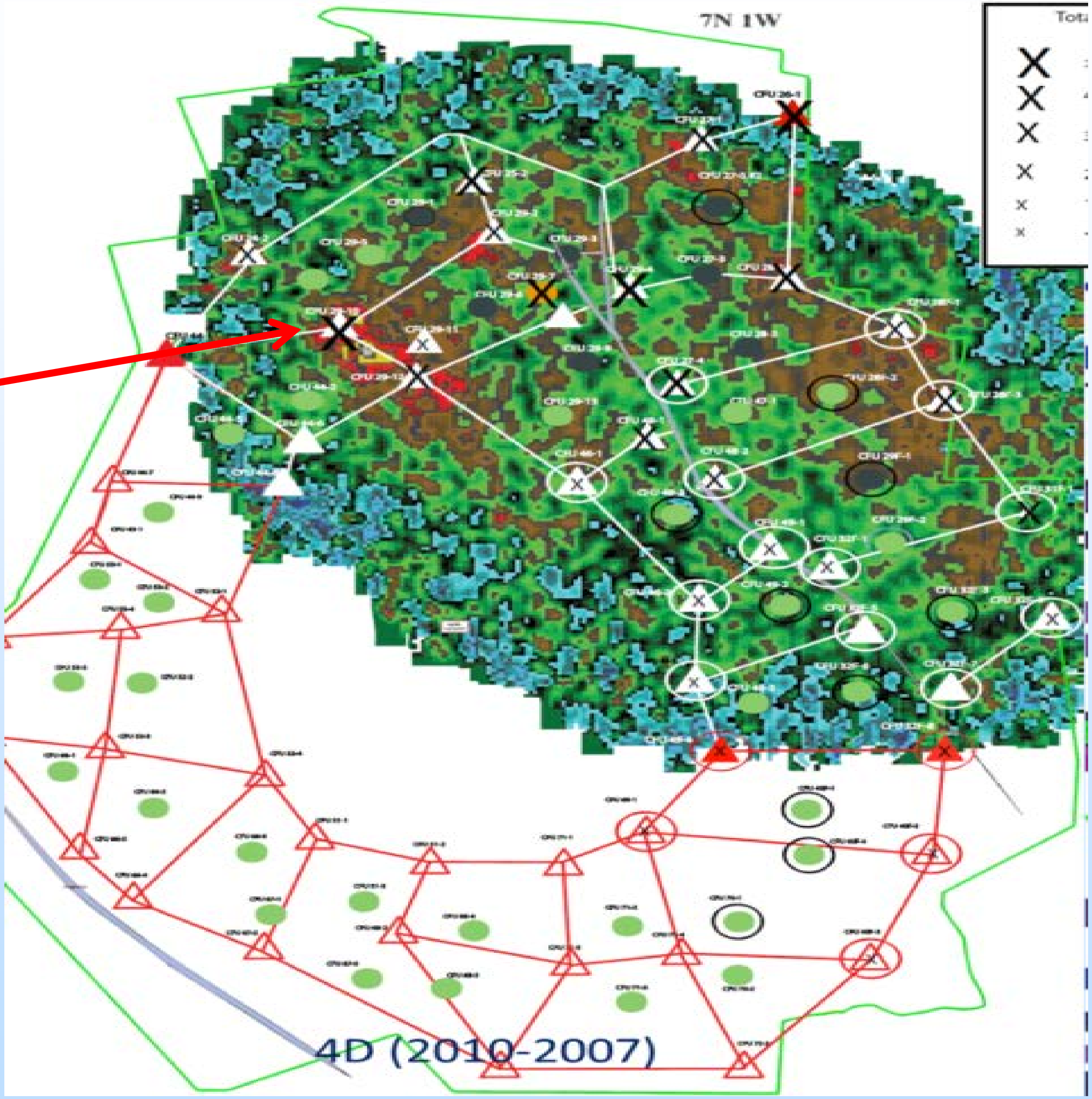
CO_2 Injection Simulation (2007-2010)



CO_2 Injection Simulation (2007-2010)



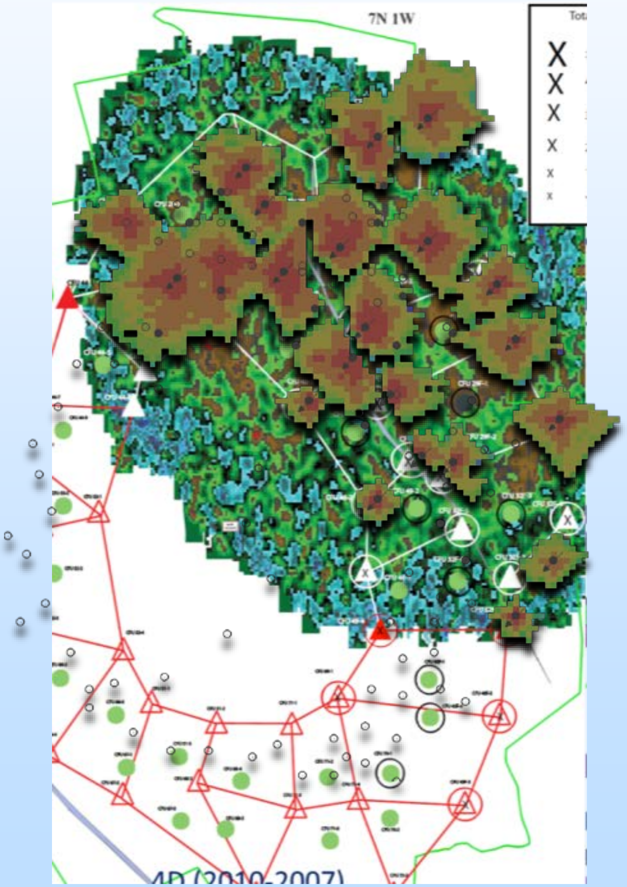
4-D Seismic difference (2010-2007)



Injection began July 15, 2008

Comparison to 4-D Seismic

Red and brown areas are high gas saturation regions



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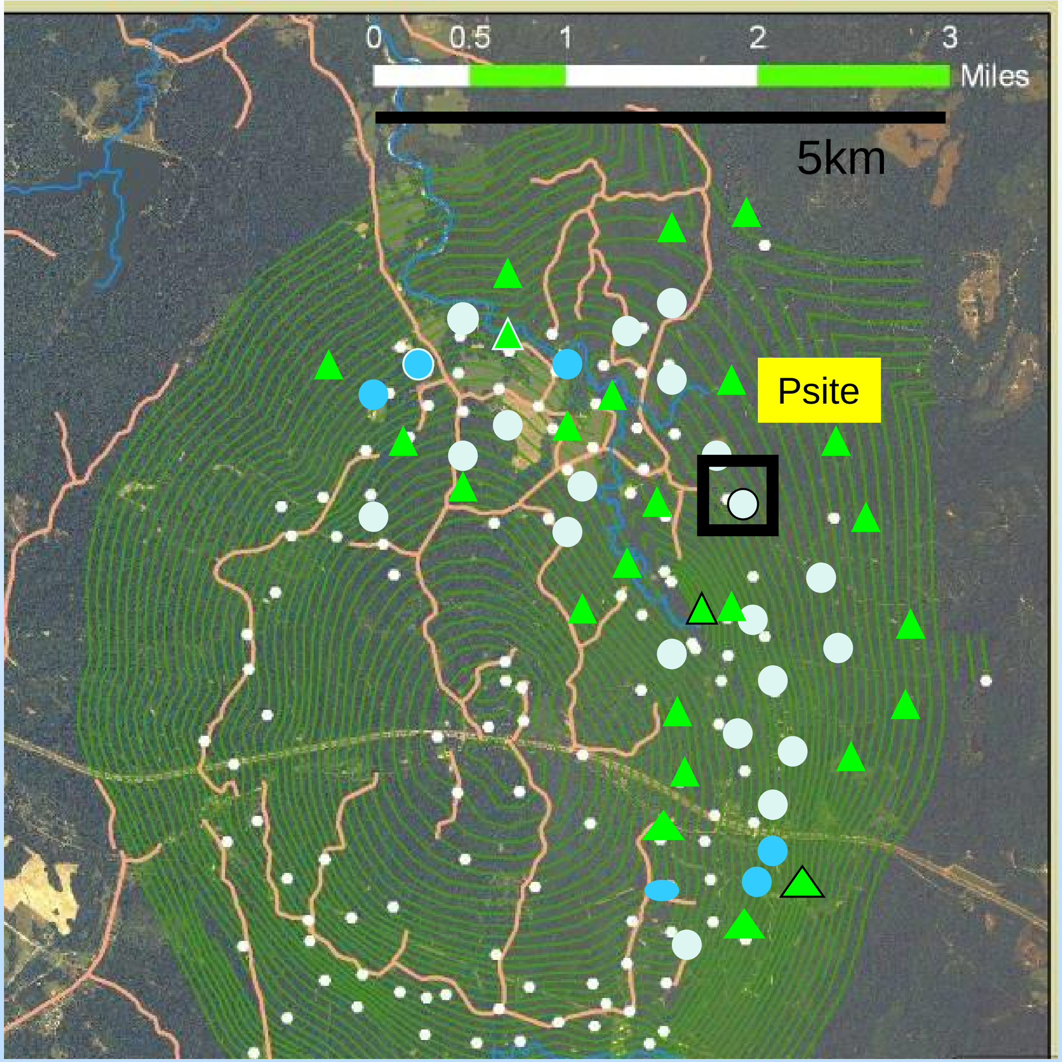


Groundwater sampling point at each Injector

Plugged and abandoned well

Producer

Selected soil gas monitoring points

GIS base Tip Meckel, BE

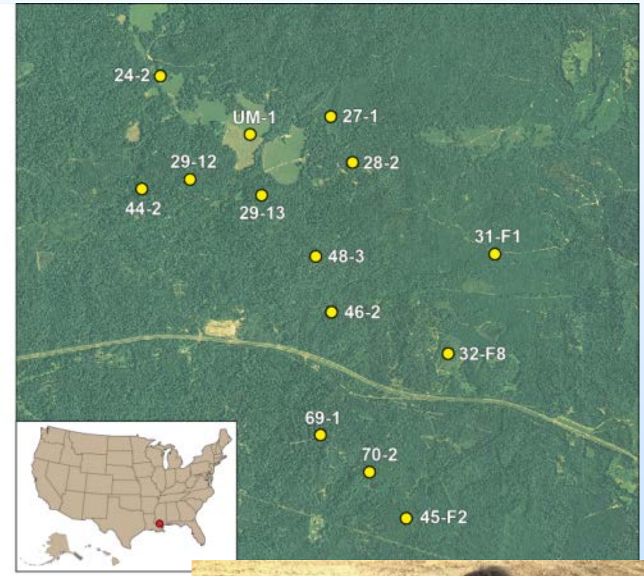
Groundwater at the Cranfield Site: Sampling

- 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

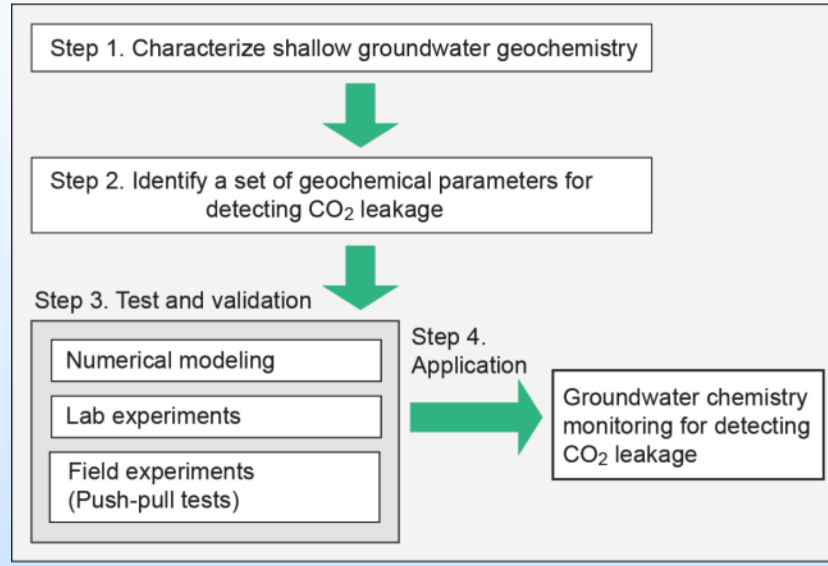
- ~10 samples for noble gases
- ~20 groundwater samples for dissolved CH_4



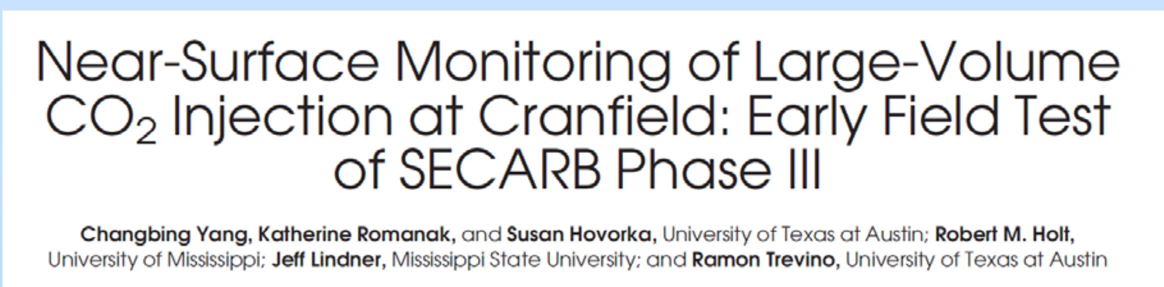
C. Yang, BEG

Groundwater at the Cranfield Site Sampling

- Results (prior to 2013) were summarized in the peer-reviewed paper
- No obvious change in groundwater chemistry was documented
- A step-wise working procedure for groundwater chemistry monitoring was proposed



QAe1189

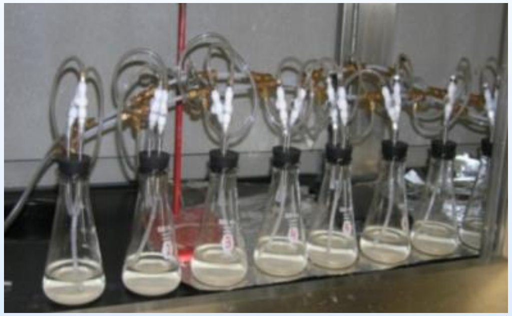


Near-Surface Monitoring of Large-Volume CO_2 Injection at Cranfield: Early Field Test of SECARB Phase III

Changbing Yang, Katherine Romanak, and **Susan Hovorka,** University of Texas at Austin; **Robert M. Holt,** University of Mississippi; **Jeff Lindner,** Mississippi State University; and **Ramon Trevino,** University of Texas at Austin

Groundwater at the Cranfield Site Laboratory and Modelling

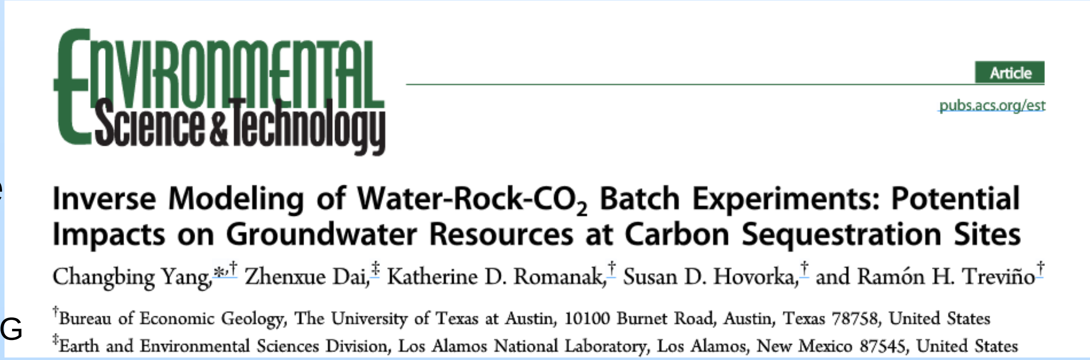
- Test response of groundwater chemistry to CO_2 leakage under laboratory conditions
  - Samples of sediments & groundwater collected
  - Bubbled with Ar for a week, then with CO_2 for ~half year



Pros: easy to do, little cost
Cons: Non-realistic conditions

- Modeled concentrations of major ions showed overall increasing trends, depending on mineralogy of the sediments, especially carbonate content.
- Modeling results suggested that reductions in groundwater pH were more significant in the carbonate-poor aquifers than in the carbonate-rich aquifers, resulting in potential groundwater acidification.
- Mobilization of trace metals was likely caused by mineral dissolution and release of surface complexes on clay mineral surfaces.

C. Yang, BEG


Environmental Science & Technology

Article

pubs.acs.org/est

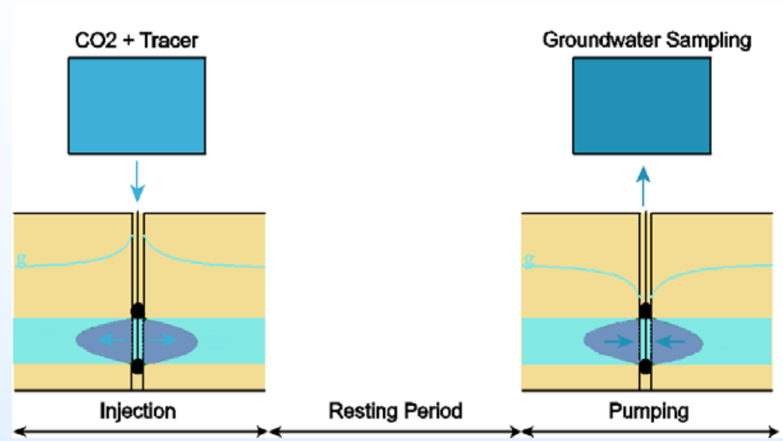
Inverse Modeling of Water-Rock-CO_2 Batch Experiments: Potential Impacts on Groundwater Resources at Carbon Sequestration Sites

Changbing Yang,[*,†] Zhenxue Dai,[‡] Katherine D. Romanak,[†] Susan D. Hovorka,[†] and Ramón H. Treviño[†]

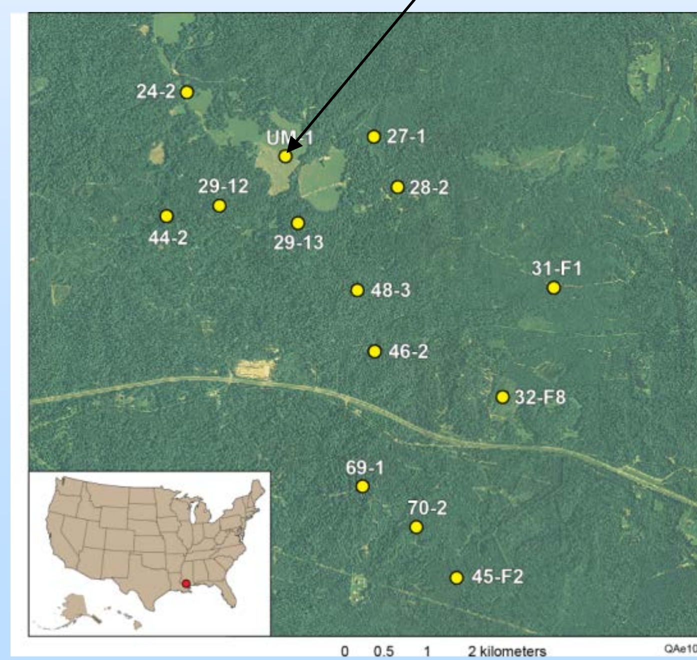
[†]Bureau of Economic Geology, The University of Texas at Austin, 10100 Burnet Road, Austin, Texas 78758, United States
[‡]Earth and Environmental Sciences Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, United States

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

International Journal of Greenhouse Gas Control 18 (2013) 375–387

Contents lists available at ScienceDirect

International Journal of Greenhouse Gas Control

journal homepage: www.elsevier.com/locate/ijggc

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

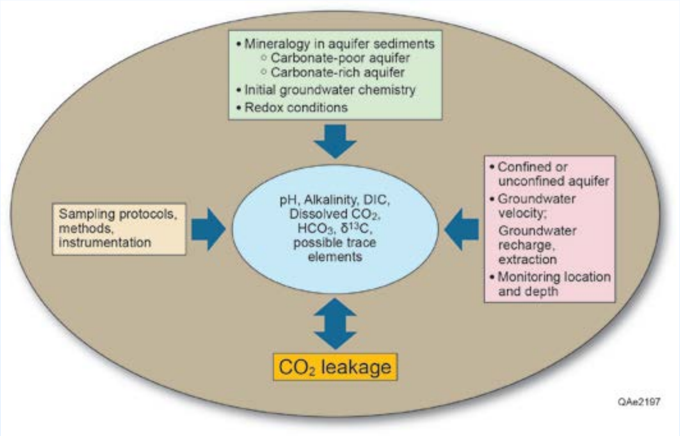
Changbing Yang[a,*], Patrick J. Mickler[a], Robert Reedy[a], Bridget R. Scanlon[a], Katherine D. Romanak[a], Jean-Philippe Nicot[a], Susan D. Hovorka[a], Ramon H. Trevino[a], Toti Larson[b]

[a] Bureau of Economic Geology, The University of Texas at Austin, 10100 Burnet Road, Bldg 130, Austin, TX 78758, United States
[b] Department of Geological Sciences, The University of Texas at Austin, 2275 Speedway Stop C9000, Austin, TX 78712-1722, United States

C. Yang, BEG

Groundwater at the Cranfield Site Numerical Modelling

- To assess sensitivity of geochemical parameters to CO_2 leakage



Preliminary results were summarized in the following paper


Modeling and Analysis

Geochemical sensitivity to CO_2 leakage: detection in potable aquifers at carbon sequestration sites

Changbing Yang*, Susan D. Hovorka, Michael H. Young and Ramon Trevino

Article first published online: 31 JAN 2014

DOI: 10.1002/ghg.1406

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Issue

Greenhouse Gases: Science and Technology

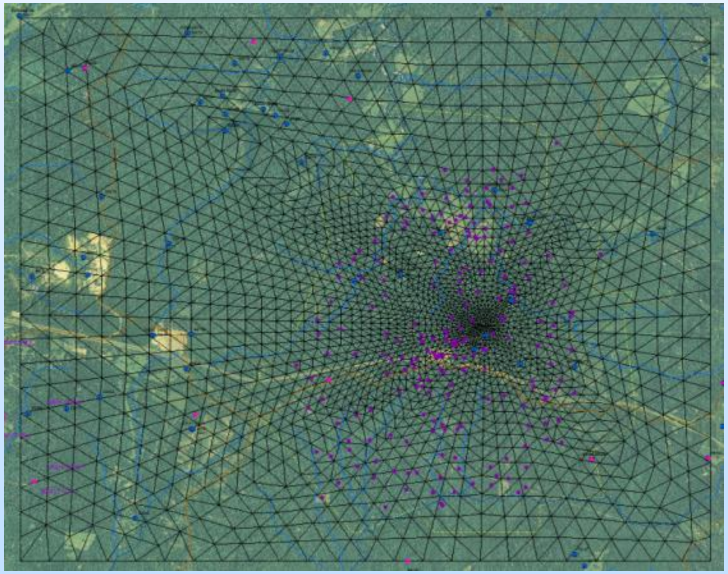
Volume 4, Issue 3, pages 384–399, June 2014

- Dissolved CO_2 & DIC in groundwater are most sensitive to CO_2 leakage
- Alkalinity is moderately sensitive, with the best response in the presence of carbonates in the aquifer sediments while groundwater pH shows best response in the aquifer sediments with little carbonates.
- For monitoring purpose, dissolved CO_2 & DIC are better indicators than pH and alkalinity in potable aquifers at geological carbon sequestration sites.

C. Yang, BEG

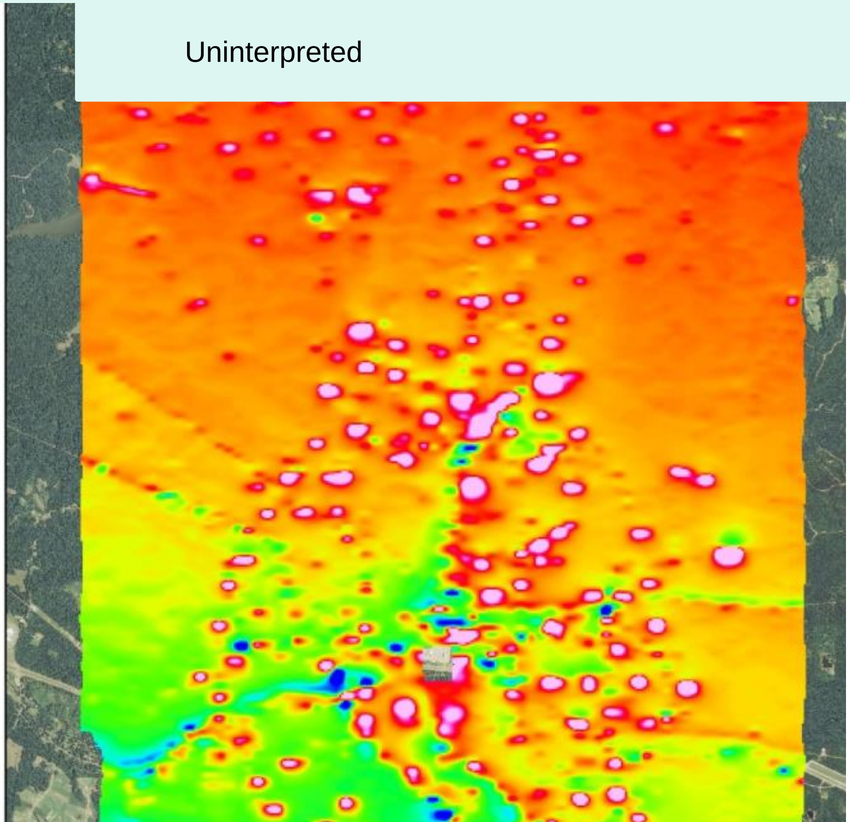
Groundwater at the Cranfield Site Next Steps

- Continue field campaigns for groundwater sampling
- Comprehensively analyze the field results on groundwater
- Compare our groundwater study at the Cranfield site to other sites, such as Weyburn,…
- Conduct reactive transport modeling
  - A preliminary model was completed in 2012 by QEA
  - The new model will focus on assessing
    - Impacts of natural groundwater flow on CO_2 leakage monitoring and change in groundwater quality
    - Heterogeneity
    - Monitoring well spacing

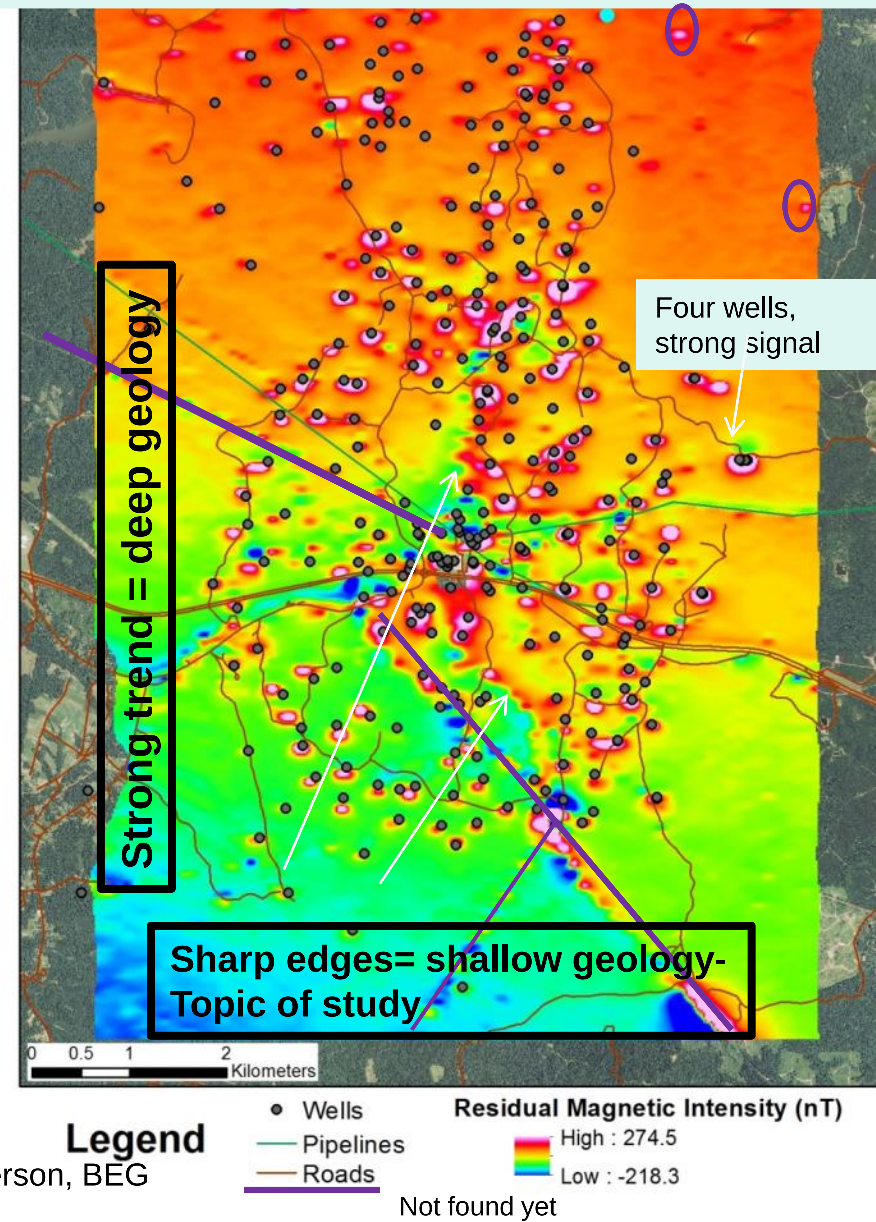


Airborne Magnetics for Characterization

Uninterpreted

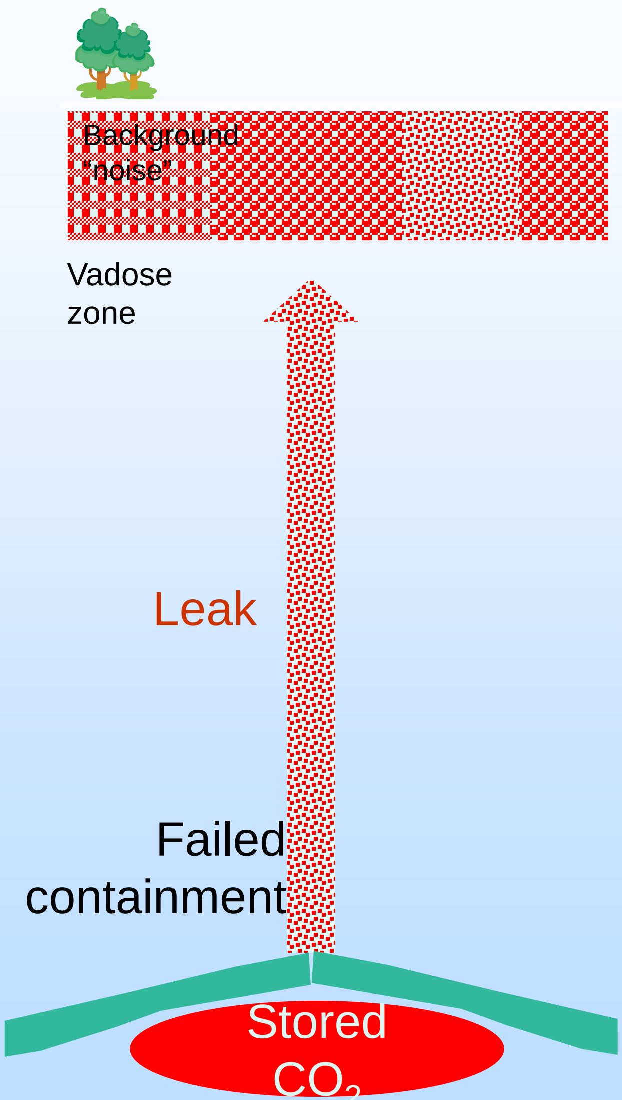


Identification of infrastructure and geologic variatblity



Pine, Hovorka, Anderson, BEG

Process-based Near-Surface Monitoring



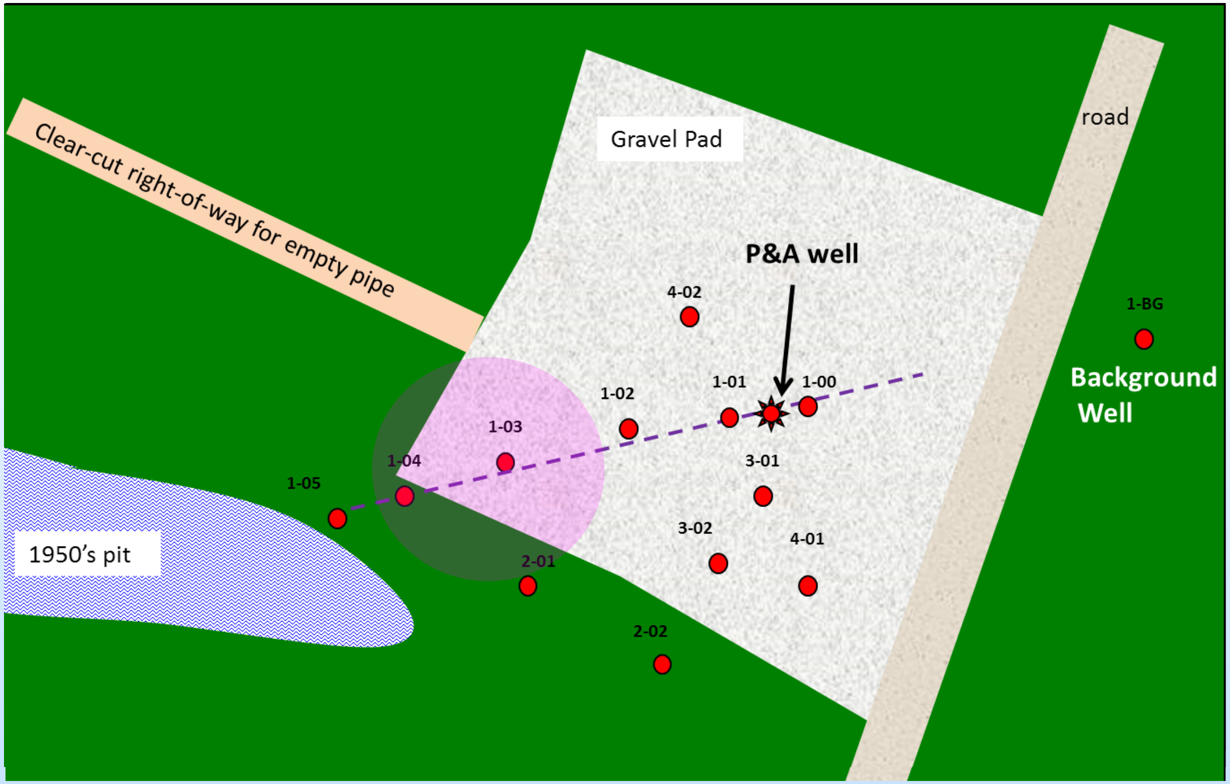
Produce CO_2
Concentrate CO_2
⇒ Mask signal — **False positives**

Consume CO_2
Disperse CO_2
⇒ Dampen signal — **False negatives**

Plant activity
Organics → CO_2
Soil carbonate
Soil moisture
Weather fronts
} Produce, consume, redistribute CO_2

Katherine Romanak BEG

"P-Site"



- Pad, Pit, Plants, P&A well
- Localized monitoring beginning Sept 2009
- 13 multi-depth soil gas sampling stations - 5 m depth
- Localized soil gas anomaly at 1-03
  - **$CH_4 \leq 50$ vol. %**
  - **$CO_2 \leq 45$ vol. %**

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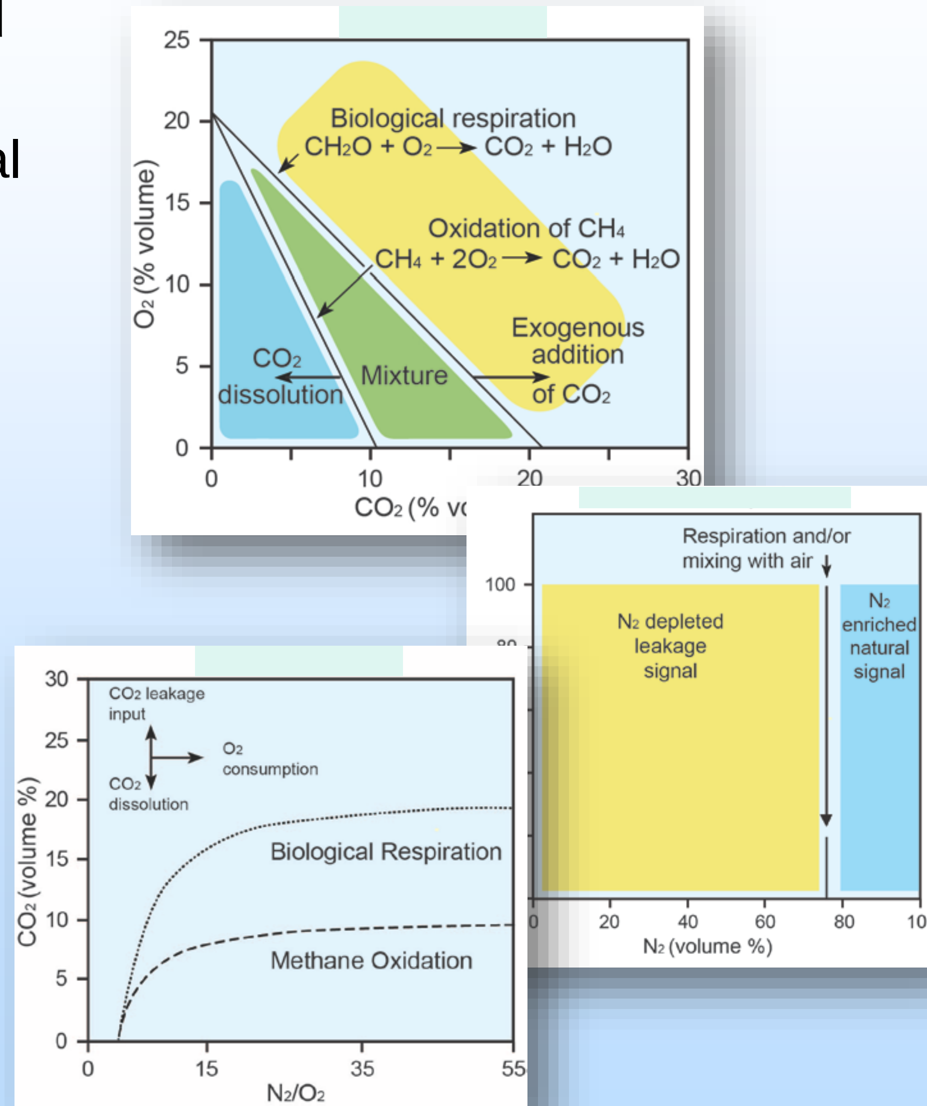
Process-Based Monitoring

- 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



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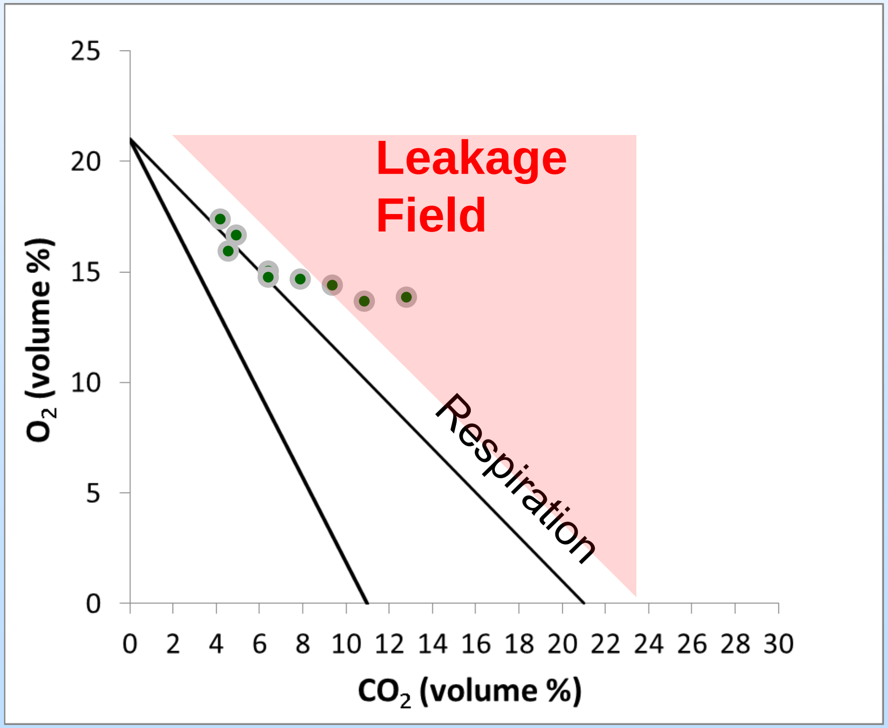
Process-Based Monitoring

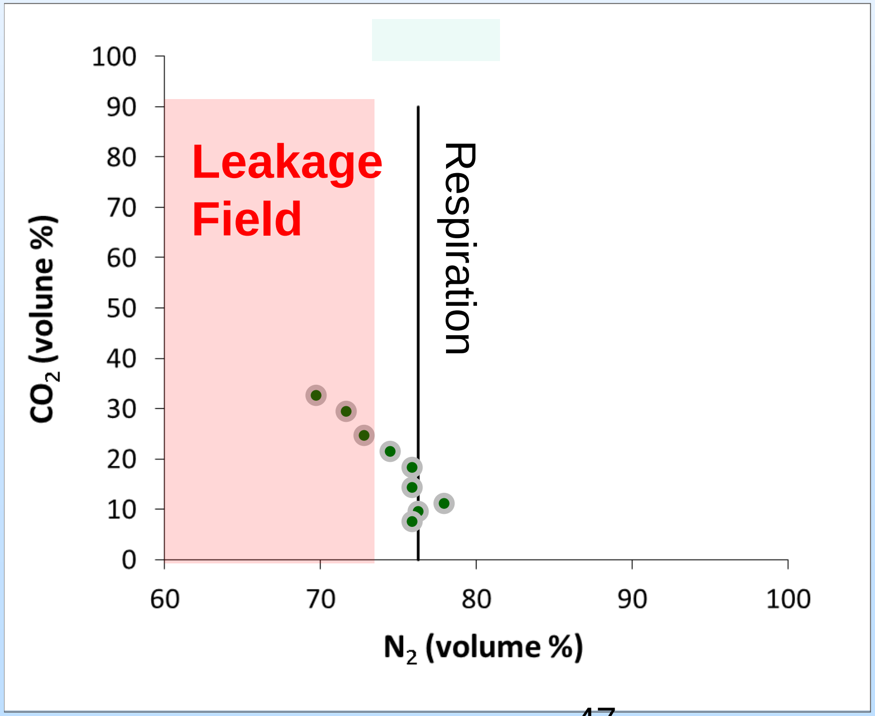
- Developed and tested at Cranfield
- Validated at ZERT Controlled-Release Field Laboratory
- Applied at the Kerr Farm, Weyburn-Midale Oilfield where landowners claimed leakage
- Used at Otway Project, Australia, and considered for use at QUEST and Gorgon
- Being developed for use in offshore marine environments
- Goal to collaborate with Mesa Photonics to develop continuous monitoring capabilities for upscaling

Romanak et al., in press, *Process-based soil gas leakage assessment at the Kerr Farm: comparison of results to leakage proxies at ZERT and Mt. Etna, in press International Journal Greenhouse Gas Control*

“User-Friendly” Data Collection

- Simple data reduction
- No complex correlations with weather
- Graphical analysis can be done instantly
- Continuous monitoring capability will give instant real-time leakage detection information.





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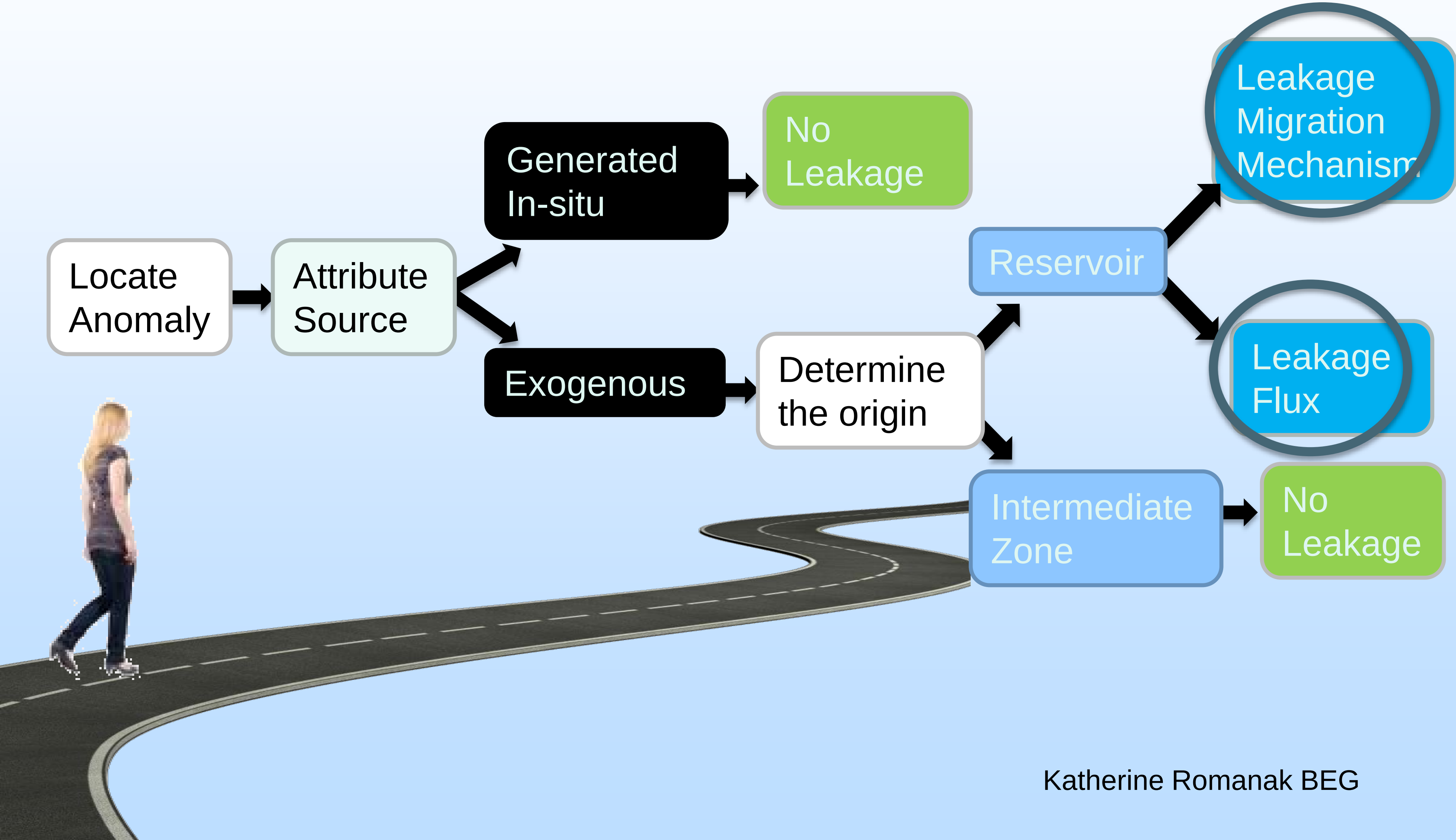
Near-Surface Leakage Assessment



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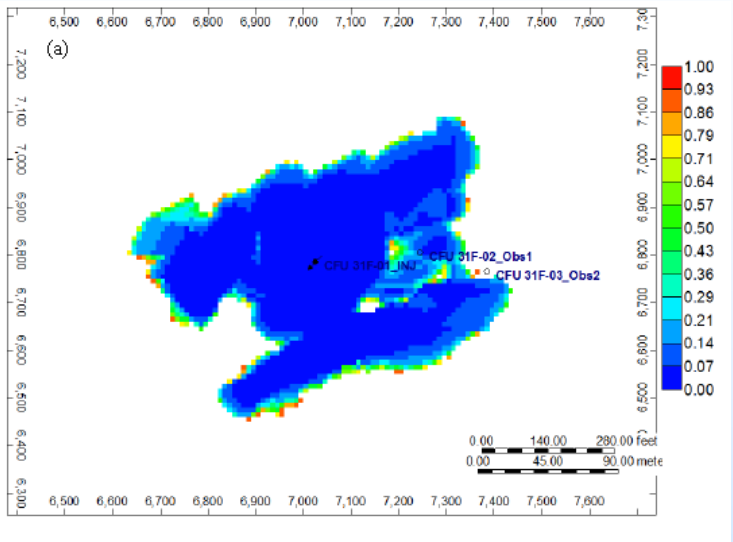
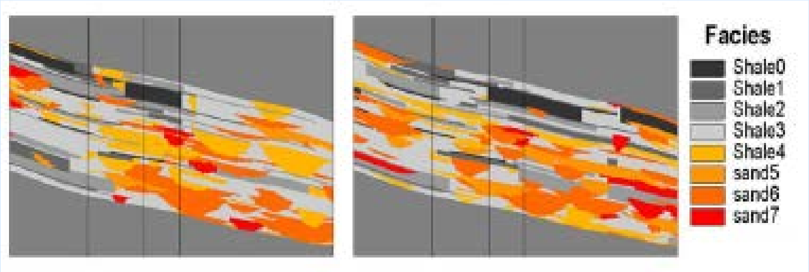
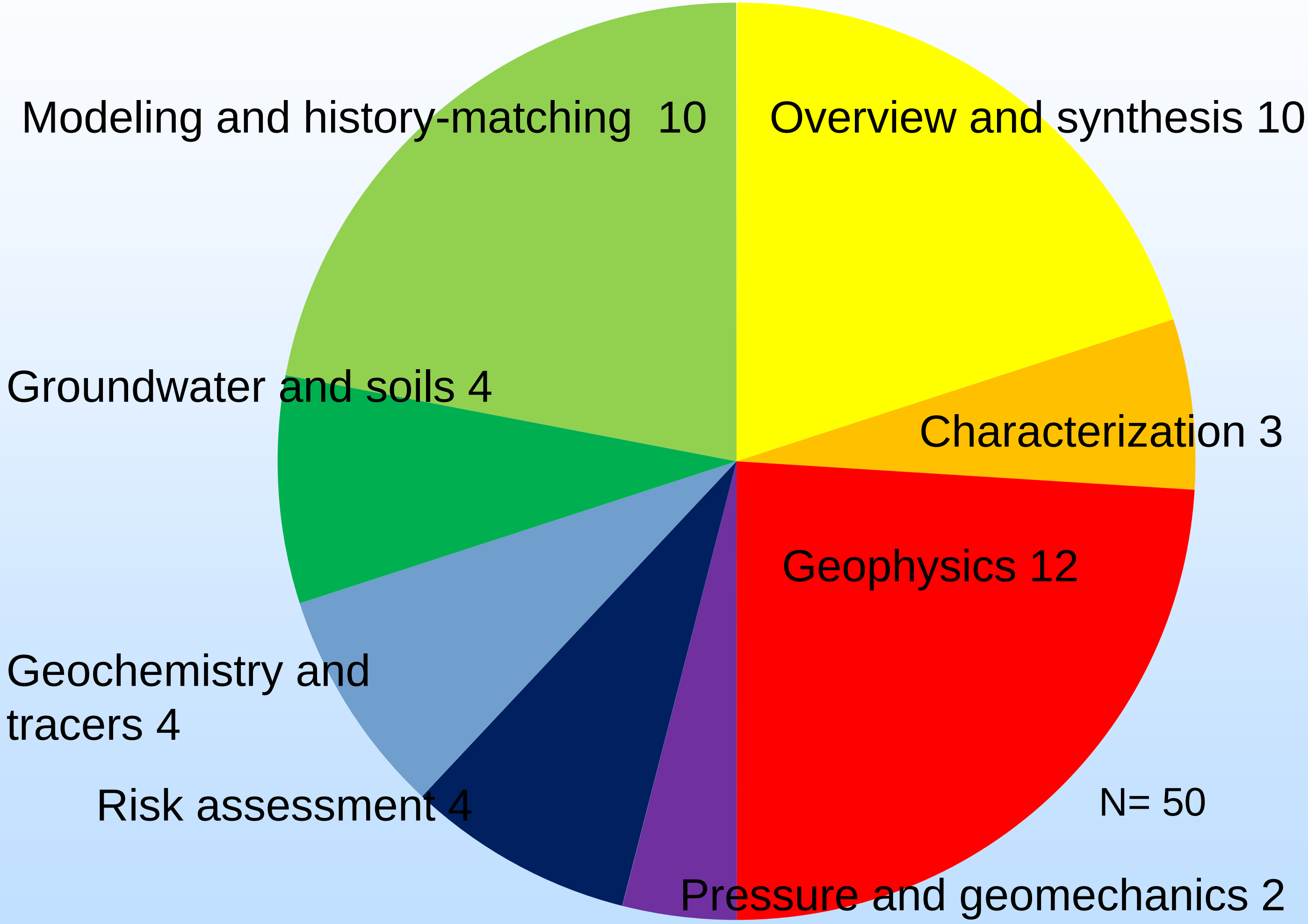
Accomplishments & Key Findings

- **Accomplishments to Date**
  - Monitored CO_2 injection since 2008
  - Injection through 23 wells, cumulative volume over 8 million metric tons
  - First US test of ERT for GS
  - Time lapse plume imaging with cross well seismic, VSP, RST, and surface 3-D
  - RITE microseismic – no detect
  - Groundwater sensitivity assessment push-pull
  - Recognized by Carbon Sequestration Leadership Forum (CSLF) in 2010 for research contributions
  - SIM-Seq inter-partnership model development test
  - Knowledge sharing to Anthropogenic Test and other U.S./International CCS projects
- **Key Findings**
  - Dense data allows assessment of fluid flow measurement and modeling uncertainty
  - Above zone pressure monitoring method viability
  - Process-based method viable





Publications



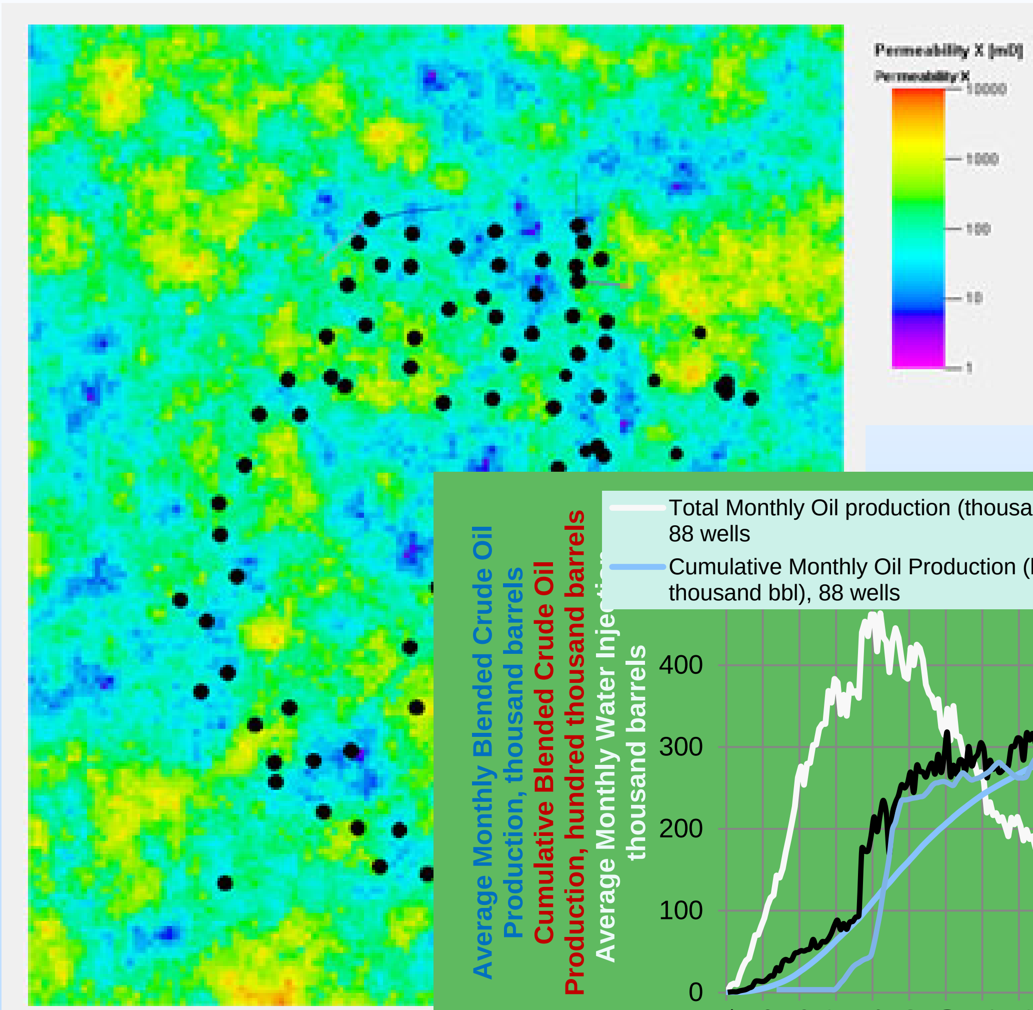
www.gulfcoastcarbon.org bookshelf

Future plans

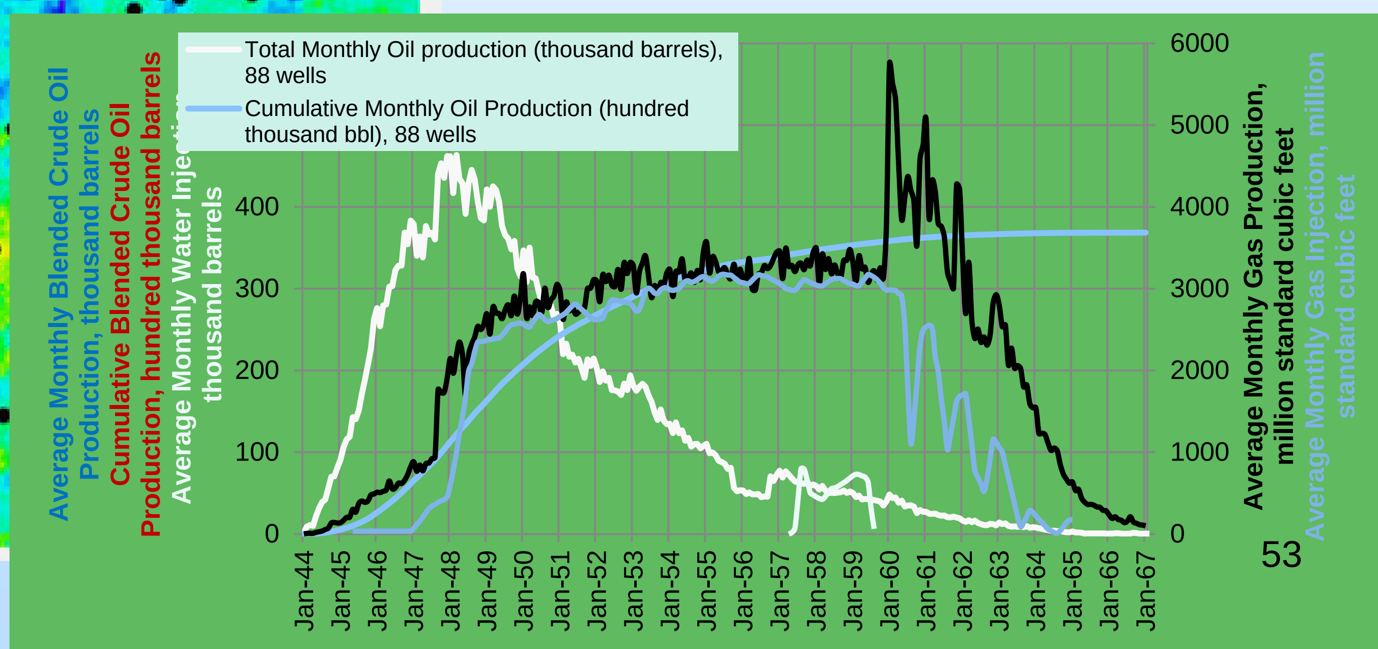
- Knowledge sharing
  - Technical, public and policy
  - Closure issues
  - CCUS concept
- Analysis of data collected
  - Joint/comparative inversions
    - Whole plume inventory
    - Uncertainty methodologies
    - Airborne geophysics
- Continued data collection
  - Continue groundwater and soil gas observation
  - Final use of DAS obs. wells
    - CO_2 geothermal test
    - Pressure interference for leakage detection

extras

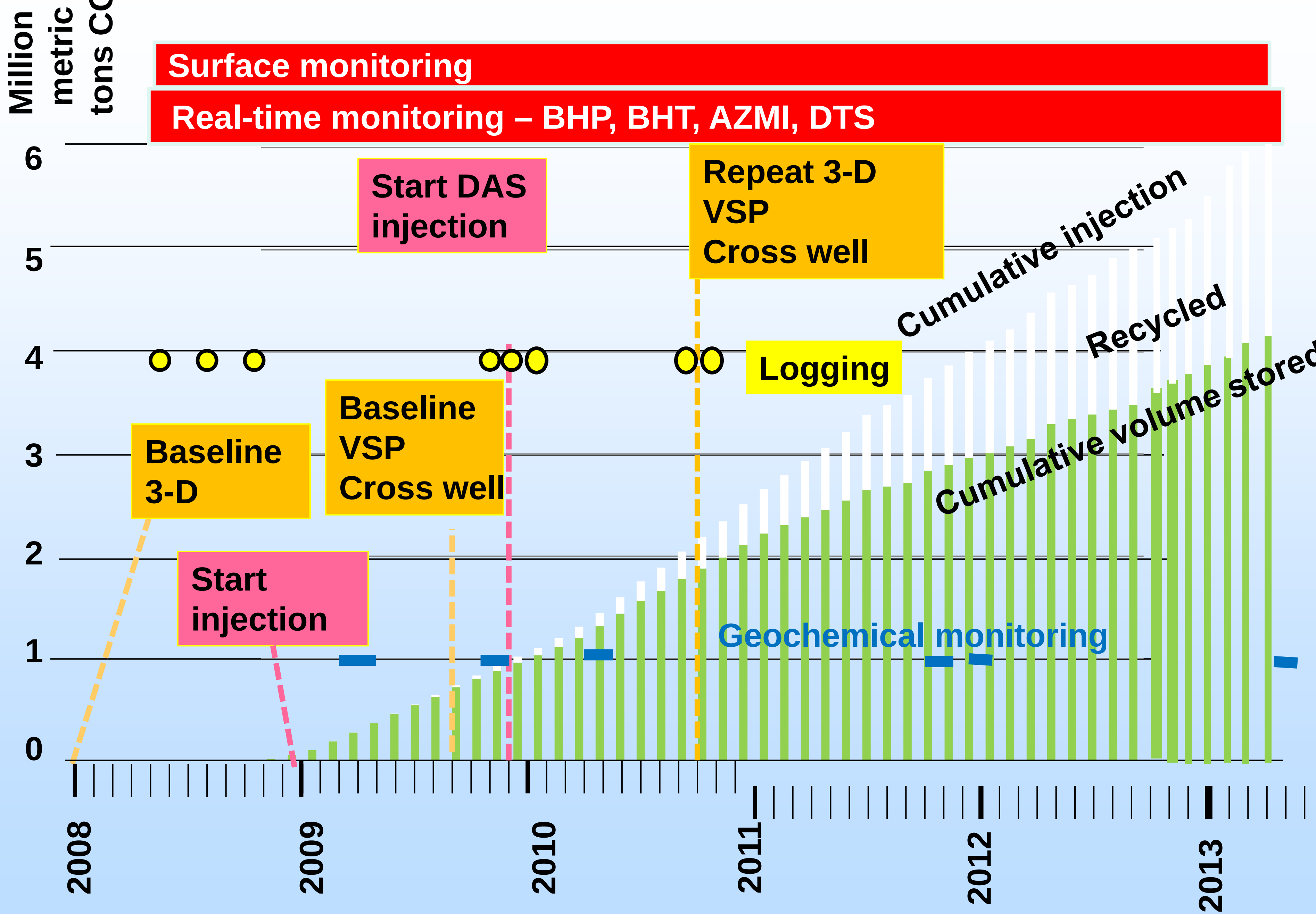
Characterization Using 1943-1966 Production History



Seyyed Hosseini, BEG

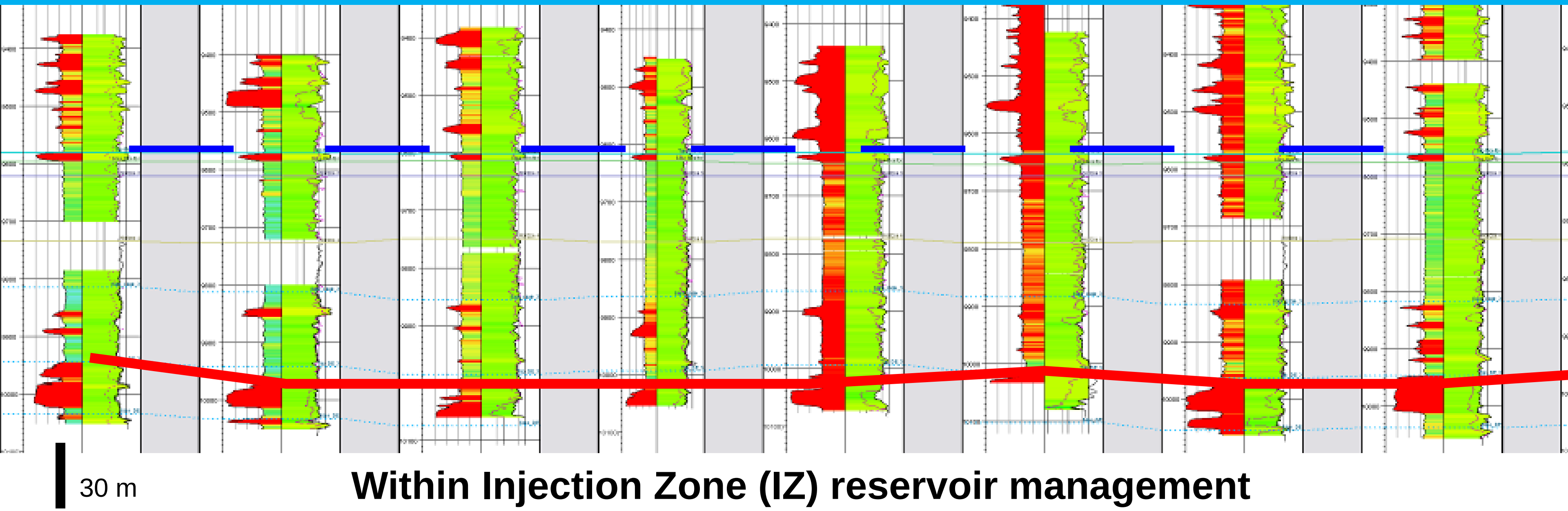


Injection and Monitoring Status (need update to 2014)

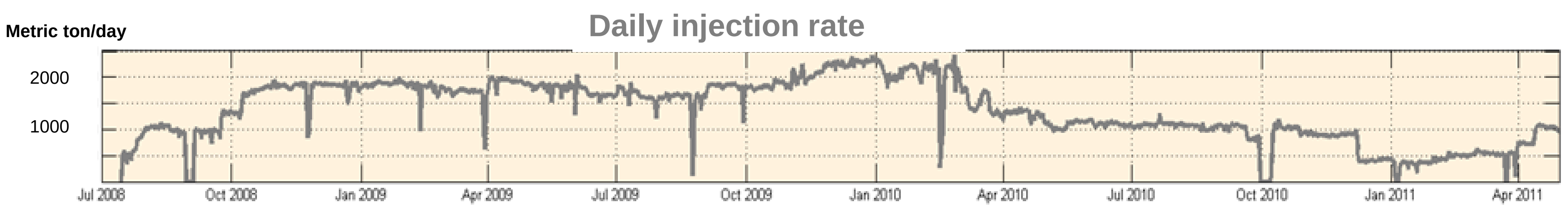


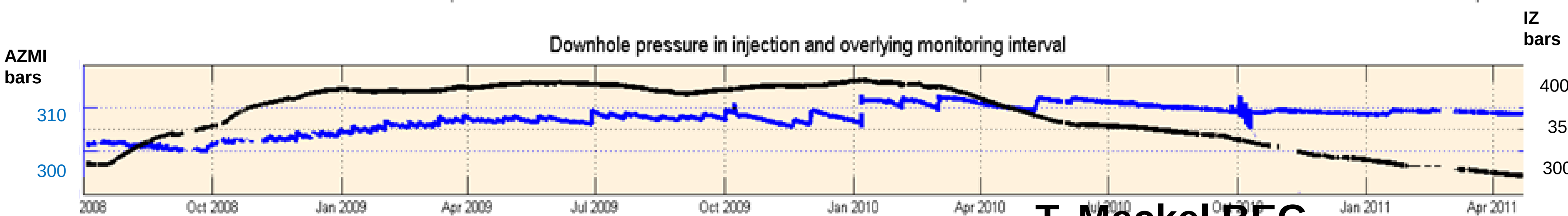
AZMI Pressure Monitoring

Above-Zone Monitoring Interval (AZMI) – leakage detection



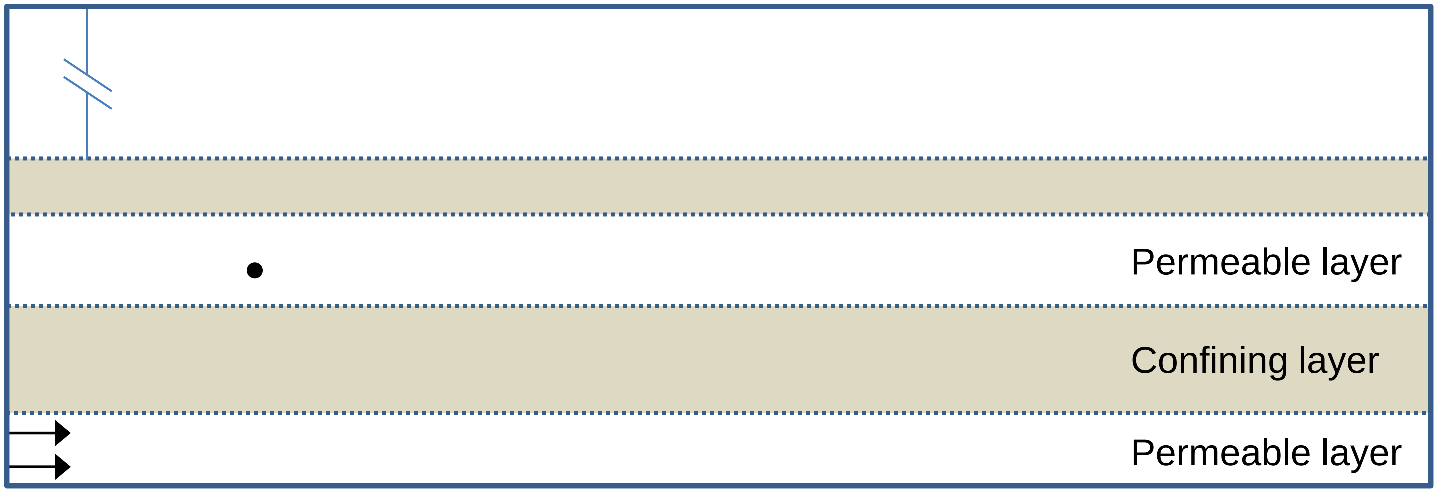
Within Injection Zone (IZ) reservoir management





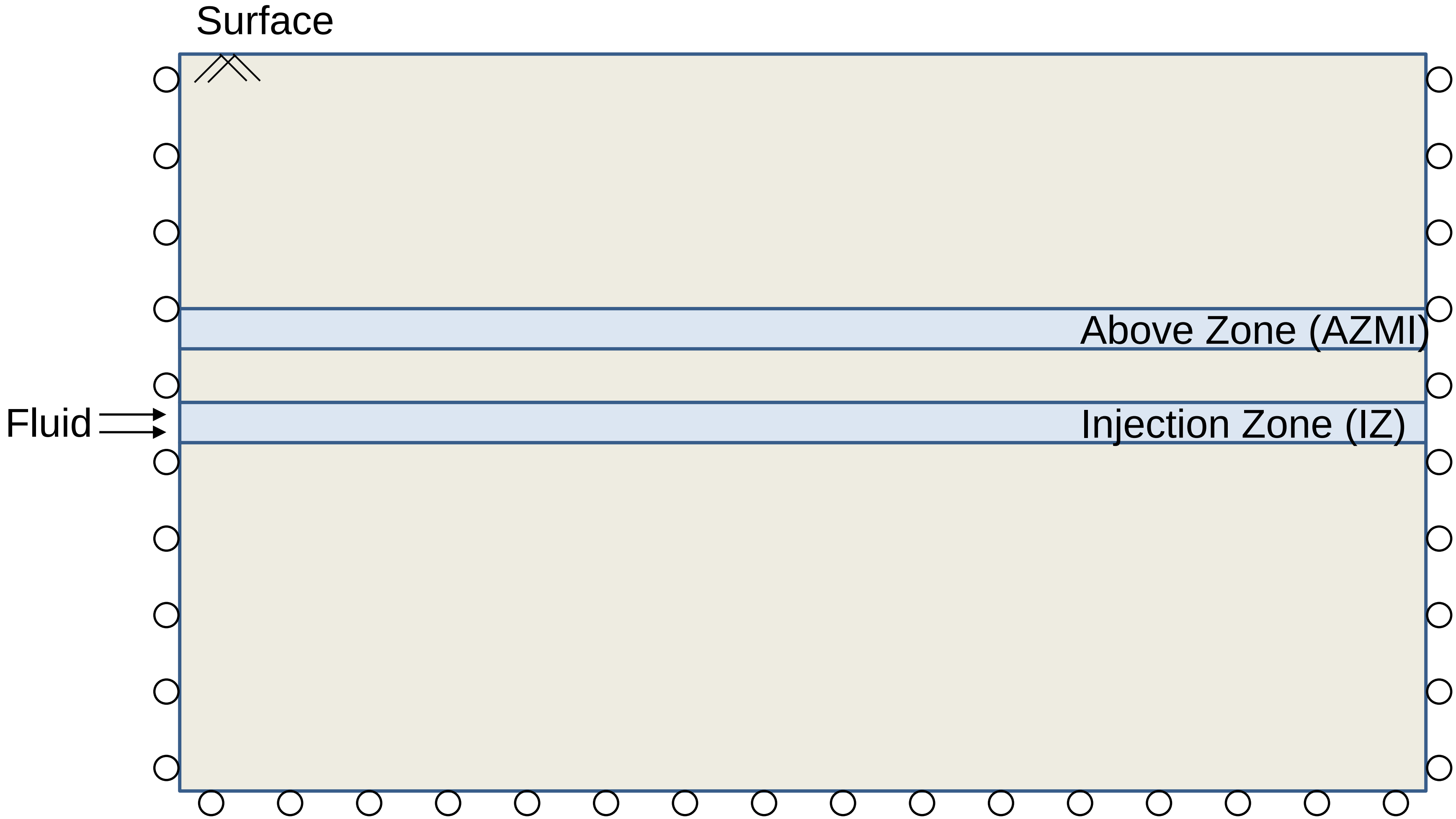
T. Meckel BEG

Theory - Poromechanics



- Conventional geomechanics: pore pressure → stress → strain → displacement
  - Diffusive pressure disturbance penetrates 10-100m in 45 years (Segall, 1985)
- Poroelasticity: displacement → strain → stress → pore pressure
  - Can be used to predict: 1) pore pressure change in AZMI zone, 2) displacement

Simulation Condition

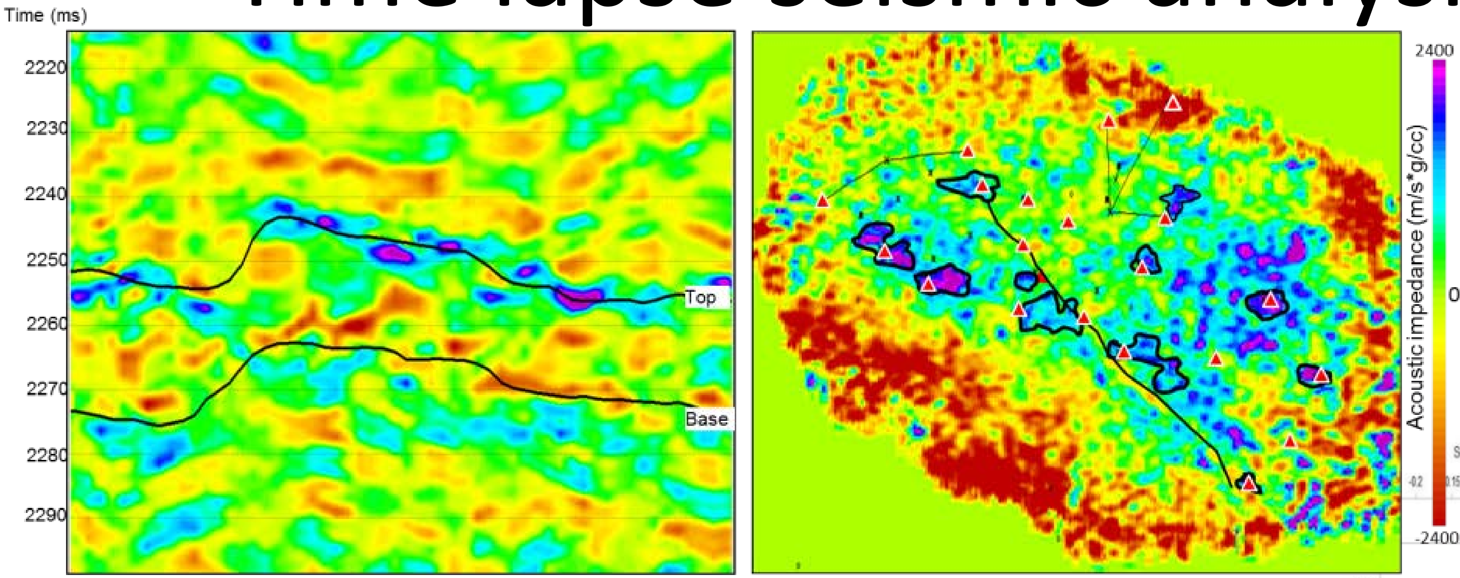


Geometric configuration: 1) 2D plain strain, 2) Axisymmetric

Historic data history matching

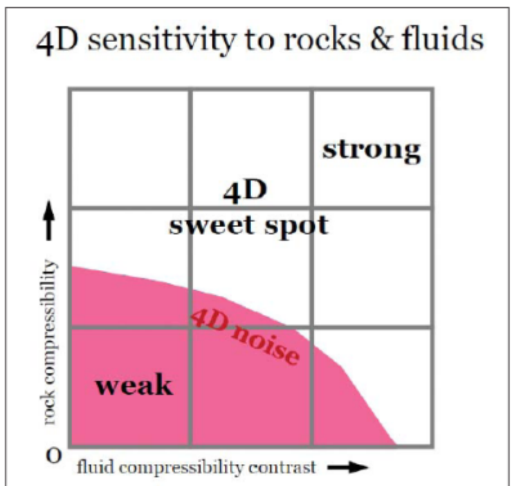
- Operations started in 1943 until 1967 when field abandoned.
- This is important to understand the reservoir condition prior to CO_2 injection specially oil, water and gas saturations.
- Gas saturations could affect 4-D seismic.

Time lapse seismic analysis

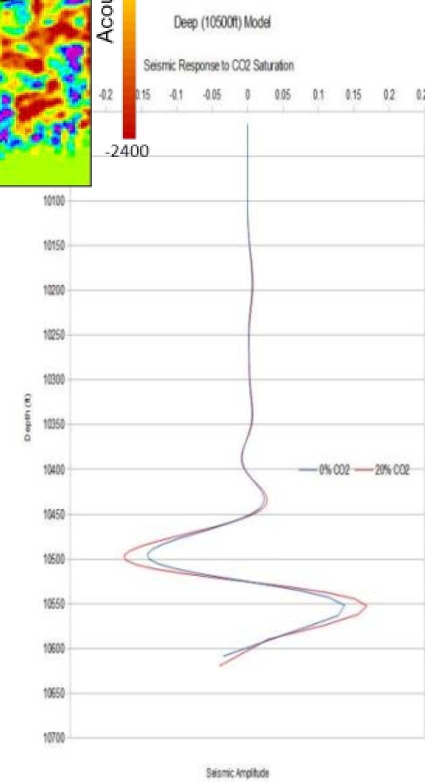


(a) (b)

Rui Zhang, CFSES & UTIG, now LBNL



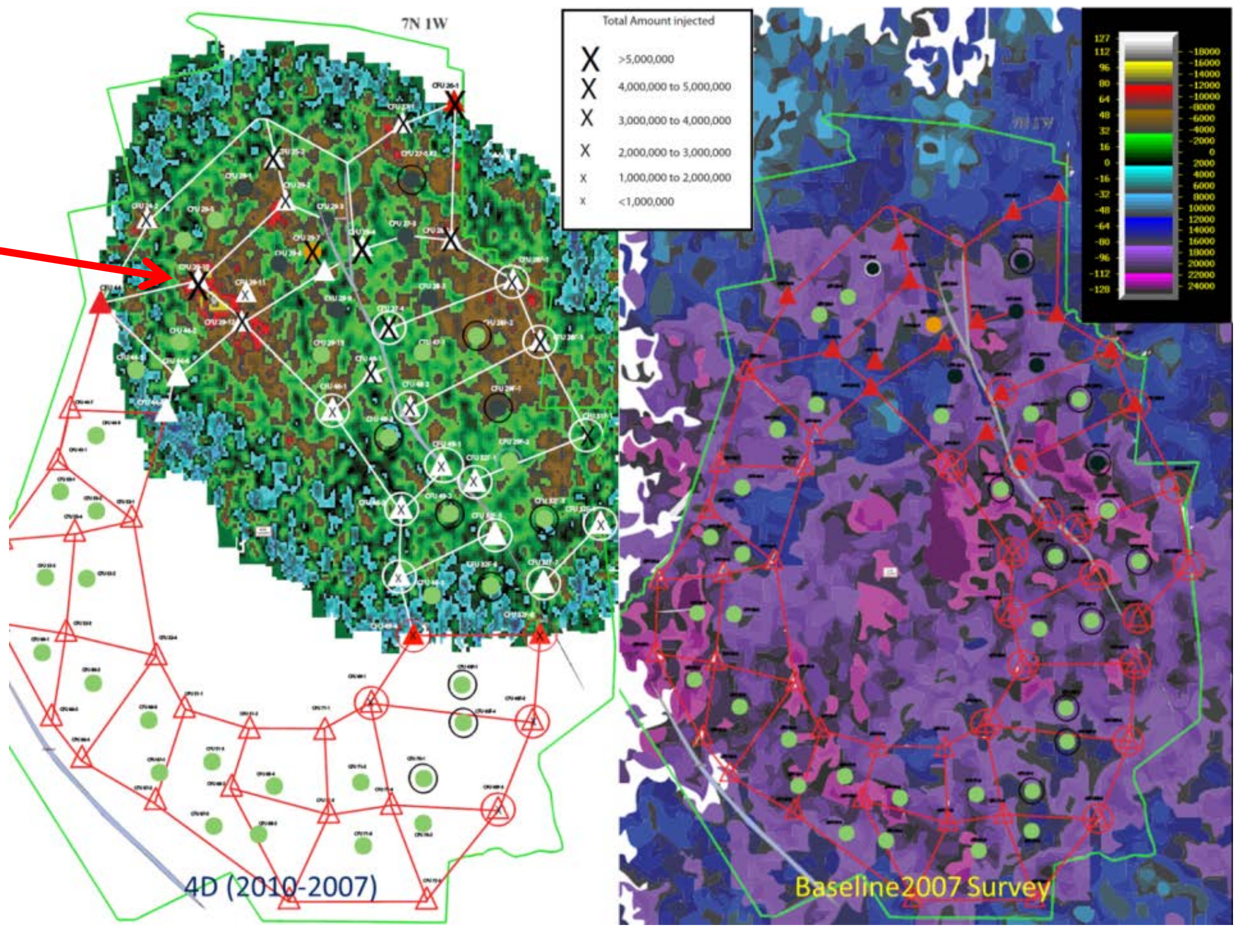
Lumley, 2010



Sava and Remington<BEG

4-D Seismic difference (2010-2007)

Injection began July 15, 2008



No Microseismic response measured

- During injection LBNL surface and downhole study
- Unsuccessful Pinnacle study
- WESTCARB/RITE Microseismic study
  - 12/2011-present
    - 6 3-C sensors in 300 ft boreholes
  - No detection
  - Wind, storm operational noise

Makiko Takagishi, RITE

微小振動観測点（全6点）

Extra slides and extra talking points on Goals FYI

Program Goals – Early Test (1)

Predict storage capacities within +/- 30%

- Well known based upon production history; Early Test advanced the understanding of efficiency of pore-volume occupancy (E factor).
- Success metrics: Measure saturation during multiphase plume evolution (completed). Increase predictive capabilities (modeling underway).

Evaluate protocols to demonstrate that 99% of CO_2 is retained

- Permanence of geologic system well understood prior to test because of retention of large volumes of hydrocarbon.
- Retention uncertainties lie in well performance. Early Test is evaluating methods to assess well performance.
- Success metrics: Measure changes above the injection zone along well, above zone monitoring interval (AZMI), and at surface (P-site) over long times (near complete)

Contribute to development of Best Practices Manuals

- Early Test researchers have contributed to Best Practices Manuals on MVA, characterization, risk and modeling. Assistance has been provided on related protocol development, including IOGCC (U.S.), Pew Center accounting study (U.S.), IPAC-CO_2 (Canada), and CO_2-Care (EU), FutureGen 2 (PNNL) review, BGS, IEAGHG networks, and others.

Program Goals – Early Test (2)

Goal 1 - Injectivity and Capacity

- Advanced understanding of efficiency of pore-volume occupancy (E factor) by measuring saturation during multiphase plume evolution.
- Increase predictive capabilities through modeling.

Goal 2 - Storage Permanence

- Measure changes above the injection zone along well, above zone monitoring interval (AZMI), and at surface (P site) over long times (underway)

Goal 3 - Areal Extent of Plume and Potential Leakage Pathways

- Measured down-dip extent of plume via VSP and 4-D seismic to improve the uncertainty regarding the radial flow (down dip/out of pattern) in the 4-way closure.
- Increase predictive capabilities through modeling

Goal 4 -Risk Assessment

- Saline storage site is located in EOR field with operator owning CO_2.
- Completed certification framework assessment of leakage risk.
- Confirmed well performance as highest uncertainty and focus of monitoring research.
- Geomechanics and RITE/WESTCARB microsiesimic study

Program Goals – Early Test (3)

Goal 5 - Develop Best Practices

- **Participated in developing BPMs for MVA, characterization,**
  risk and reservoir modeling.

Goal 6 - Public Outreach and Education

- **On-site outreach handled by Landmen.**
- **SSEB and Early Team focus on O&E in public and technical arenas.**
- **Hosted site visits, responses to local and trade media, Fact Sheets, and website postings of project information.**

Goal 7 - Improvement of Permitting Requirements

- **Permits obtained by site operator.**
- **Project team focus is on development of regulatory framework for GHG.**
- **Provided experience with monitoring instruments and well performance to decision makers.**