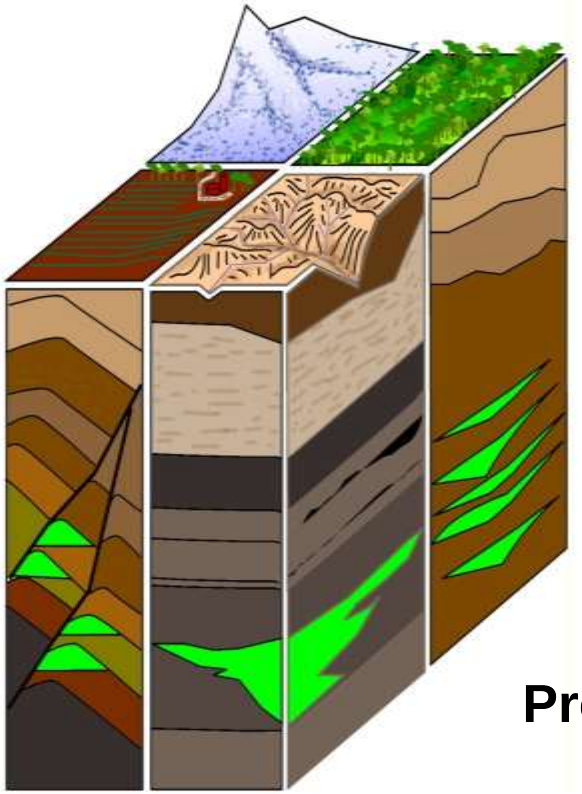

Development of Site-Specific Monitoring Approaches

Presented by Susan Hovorka
Gulf Coast Carbon Center
Bureau of Economic Geology
The University of Texas at Austin

Progress Review of STAR Grant Research on Carbon Sequestration
EPA, Washington DC
January 7th, 2013

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Presentation outline

- Project goals and approaches
- Place of site specific evaluation in monitoring and testing plans
- Update from in-process projects through contact with experts
  - Importance of site-specific noise
- Examples
  - Site-specific controls on sensitivity of groundwater geochemistry for leakage detection
  - Site specific issues on sensitivity of surface 4-D seismic for leakage detection

Site-specific Monitoring and Testing Plan Required

[Class VI] rule also requires owners or operators to submit, with their permit applications, a series of comprehensive ***site-specific plans***: An AoR and corrective action plan, a **monitoring and testing plan**, an injection well plugging plan, a PISC and site closure plan, and an emergency and remedial response plan.

Determine appropriate methods for site-specific geology

- "Today's rule, at § 146.90(g), requires Class VI well owners or operators to use direct methods to monitor for pressure changes in the injection zone and to supplement these direct methods with indirect, geophysical techniques ***unless the Director determines, based on site specific geology***, ***that such methods are not appropriate***."

The study provides support for the Operator to design site specific plan

- The rule enables owners or ***operators to choose from the variety of technologies and methods appropriate to their site specific conditions***.

This study provides data to support Director’s evaluation

- “This requirement for a comprehensive series of **site-specific plans** is new to the UIC program. The Director will evaluate all of the plans in the context of the geologic data, proposed construction information, and proposed operating data submitted as part of the site characterization process, to ensure that planned activities at the facility are **appropriate to the site specific circumstances** and address all risks of endangerment to USDWs.”

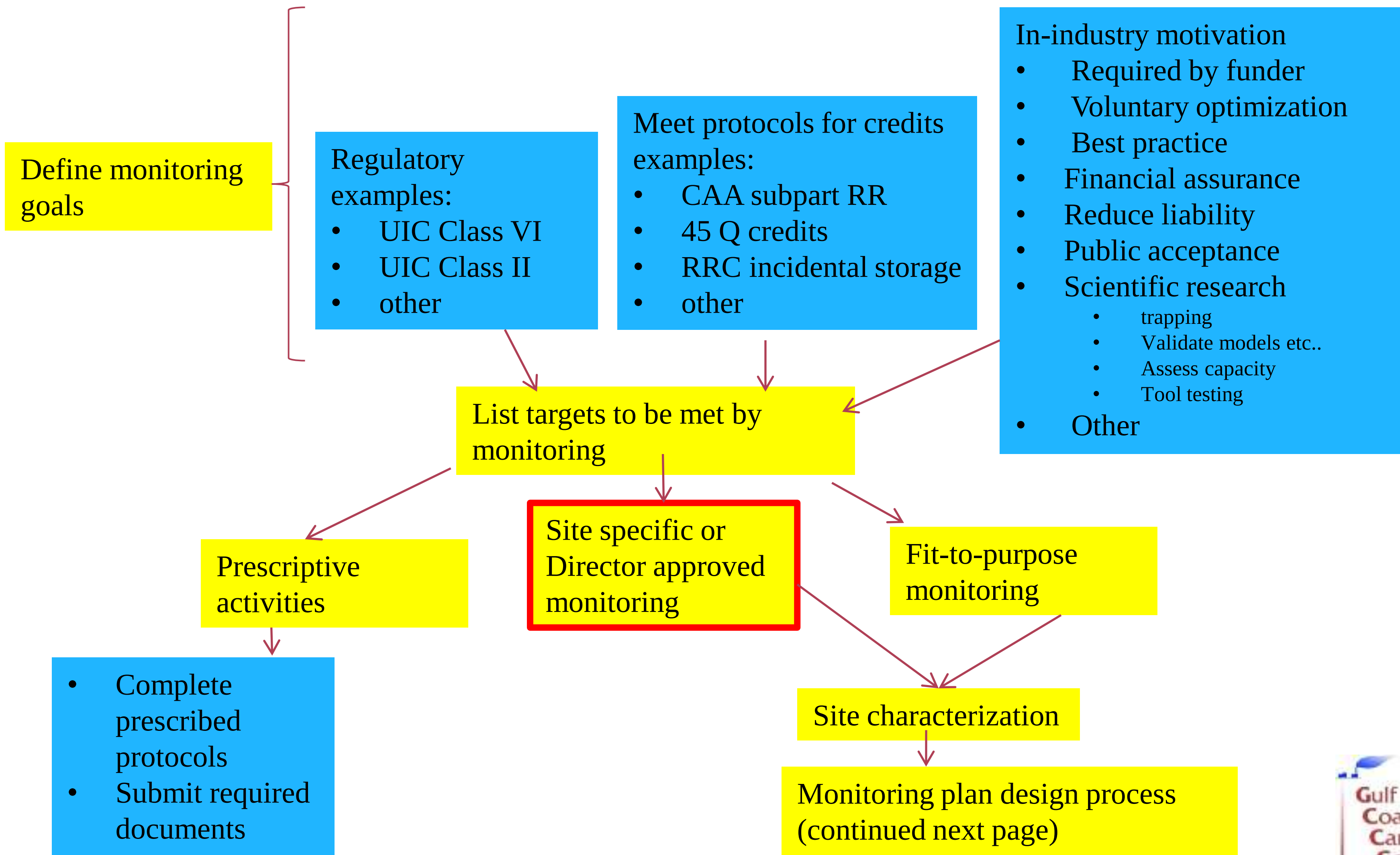
Project goals and approaches

- Develop guidance for site specific monitoring approaches for a CO_2 sequestration site
  - Site specific risk (addressed in other studies)
  - Quantification of site-specific monitoring tool sensitivity
- Expert Panel
  - Data based input
  - Develop wide consensus
- End product
  - Case-based training workbook

Cooperation with CCP-3

- Broaden and deepen assessment of tool sets
- Increased international expertise
  - Data from international projects to increase sample size

Designing a fit-to-purpose(s) Monitoring and test plan (1)



Designing a fit-to-purpose(s) Monitoring strategy continued (2)

Continued from above - Monitoring plan design process

Storage Risk assessment

Identify characterization uncertainties that might lead to material failure to obtain retention and (preferably) identify events preceding failure

Operational actions lead to material failure to obtain retention and (preferably) identify events preceding failure

Model characterization uncertainties that lead to material failure to obtain retention.

- conceptual model
- analytical model,
- geocellular model.

Goal: concrete realization of what failure would look like, trace to early signals that would diagnose condition

Determine what monitoring approaches are sensitive to the possible material failure to obtain retention, or preferably to events preceding failure. Specify spatial and temporal frequency, data collection, data processing, and analysis

Test each mentoring tool sensitivity to detect material failure (or pre-failure) above measurement noise. Design data density and sampling frequency to provide statistically valid measurements of events.

. Continued next page.

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Designing a fit-to-purpose(s) Monitoring strategy continued

Triggers must be set for each tool (otherwise monitoring has no impact).

Trigger: favorable threshold passed → Uncertainty eliminated, reduce monitoring

Trigger: All as predicted → Continue monitoring

Trigger: Tool not sensitive, noise too high → Redesign monitoring

Trigger: Conceptual error discovered → Redesign, starting back at characterization

Trigger: Failure or pre-failure → **Next page**

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Designing a fit-to-purpose(s) Monitoring strategy continued

Tiger: Failure or pre-failure

Triggered test plans are one method to obtain robust determination if a failure or pre-failure event is occurring. If an suspected failure or pre-failure measurement is made, this triggers a pre-designed series of measurements that corroborate and further diagnose failure

Corroborate and further diagnose failure

Finding that failure has not occurred, revise model increase AoR etc.

Revise Monitoring plan, tool sensitivity assumptions etc. to reflect improved characterization

Continue monitoring

Failure in future is predicted

Repair, modify management, including close and abandon site

Revise Monitoring plan, tool sensitivity assumptions etc. to reflect any changed conditions

Failure has occurred

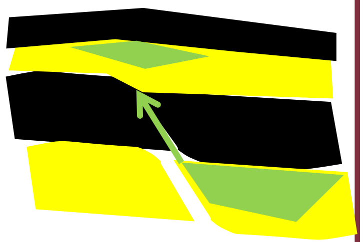
Monitoring to quantify (bound) leakage to the atmosphere and/ or USDW

Reporting, penalties etc..

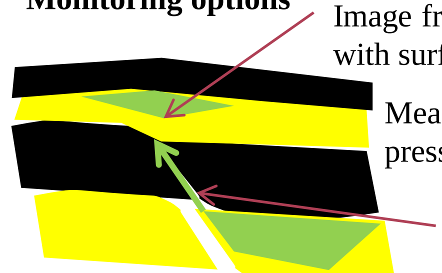
Case example

Characterization Uncertainty: Fault-seal??

Leak path concept



Monitoring options



Test Sensitivity of Monitoring Options

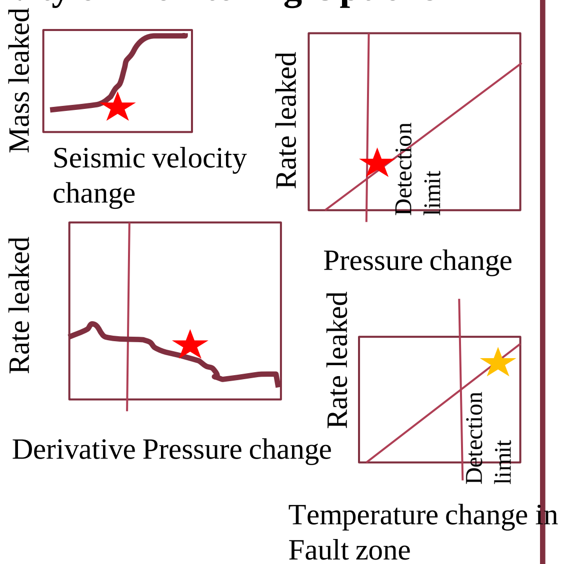
Image free-phase with surface 4-D

Measure change in pressure AZMI

Change in rate pressure increase in reservoir

Microseismic

Temperature change along fault



Set triggers, stage monitoring options

- Select microseismic as pre-failure trigger
- AZMI pressure as most sensitive trigger
- Select Image with surface 4- D and change in rate of pressure change in reservoir as post trigger follow up.
- Decrease analysis of microseismic after pressure peaks and plateaus

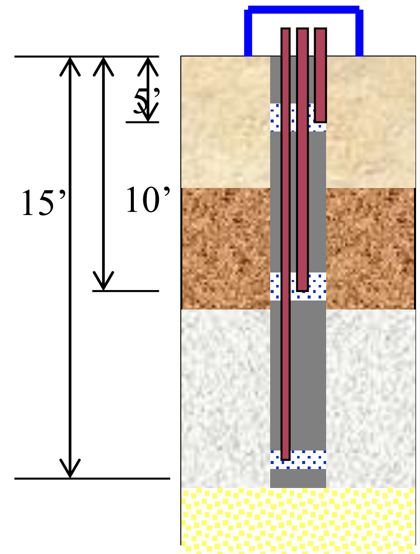
Tool sets under assessment (1)

Near surface

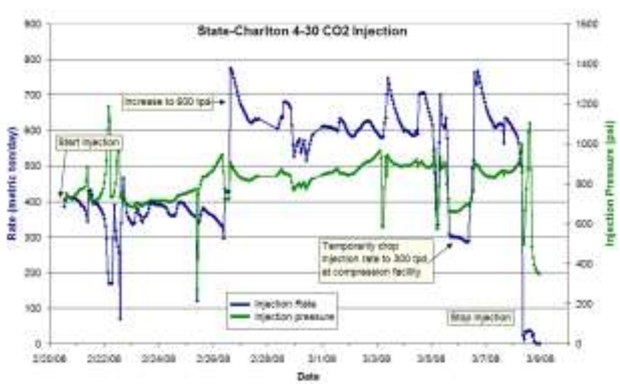
- Soil gas
- USDW – chemistry

Pressure and Temperature

- In Zone
- Above Zone



Soil gas monitoring case from Cranfield



Continuous pressure monitoring case from MRCSP Michigan project

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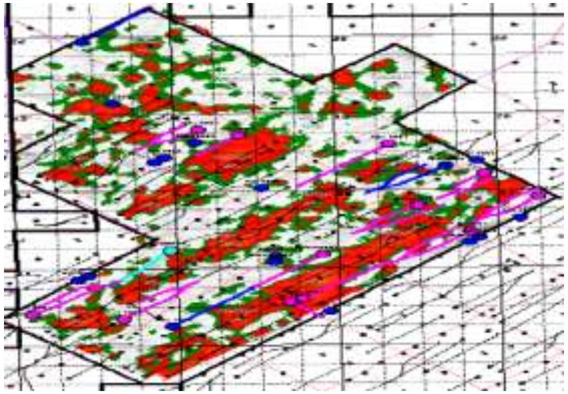
Tool sets to be assessed (2)

Seismic

3D surface seismic repeated after no-CO_2 base line



Weyburn time-lapse seismic
Malcolm Wilson, 2005

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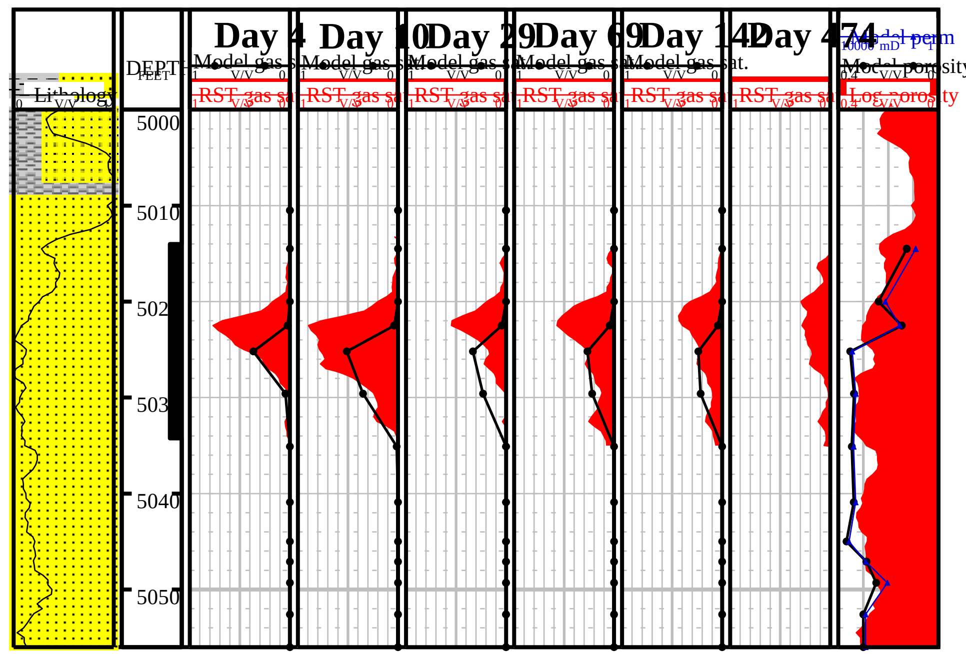
Tool sets to be assessed (3)

Wireline saturation measurements



Frio test
log measurement of change in
saturation

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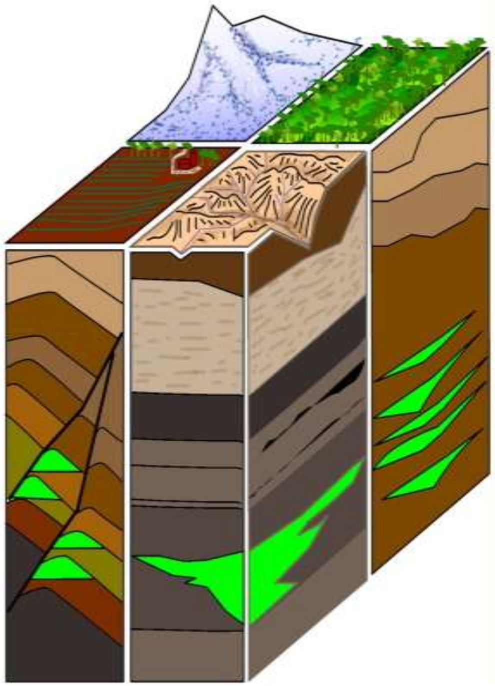
Examples of site-specific parameters



- Soil characteristics, rainfall
- Depth to injection/leakage zone
- Confined/unconfined USDW
- Salinity injection/leakage zone
- Plume thickness injection/leakage zone
- CO_2 saturation in injection/leakage zone
- Contrast ambient with dense/gas phase/ dissolved CO_2
- Background variability in parameter of interest
- Interference with signal

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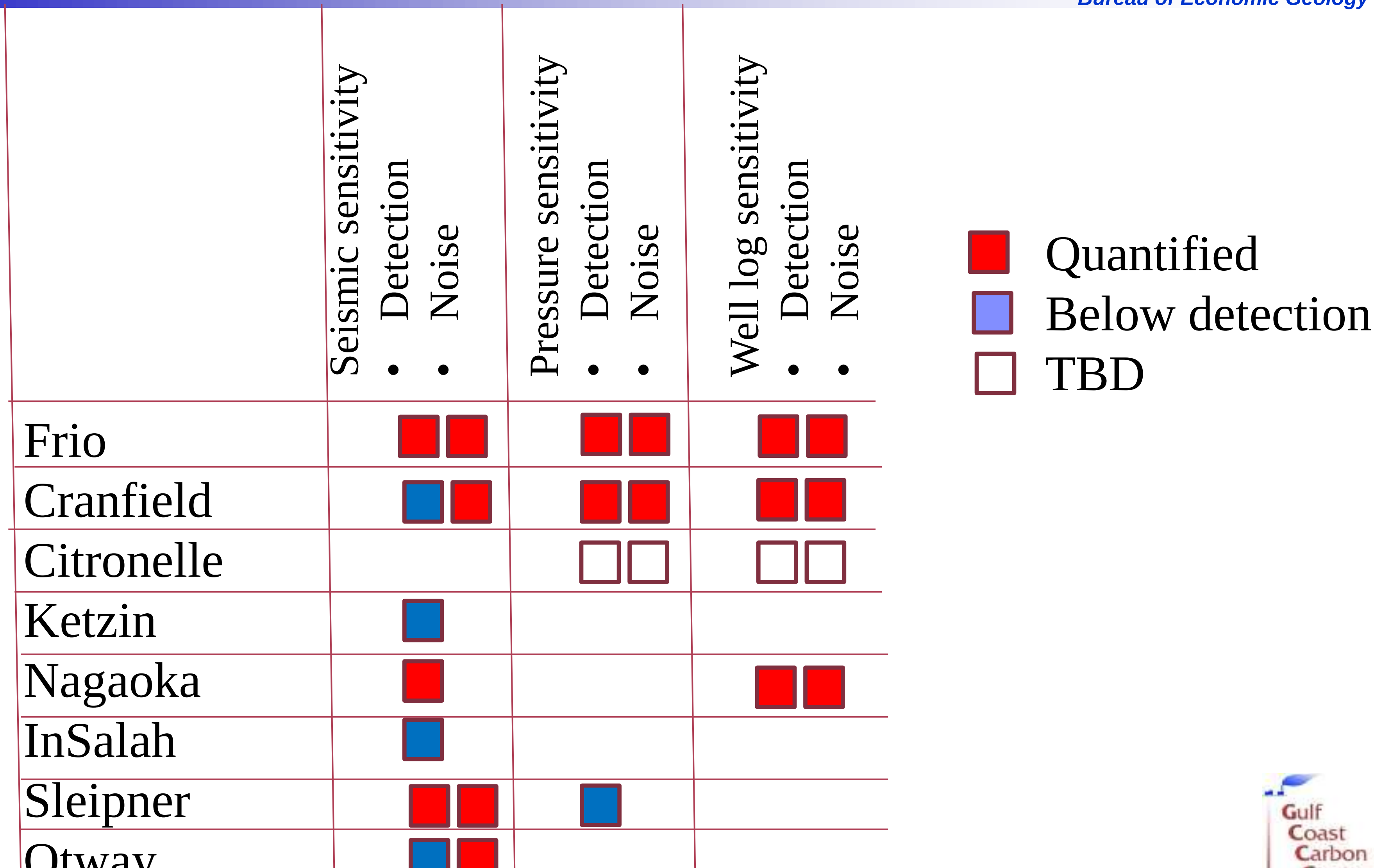
Expectation that field data will be used to guide maturation of EPA's MRV process

The seven RCSPs are conducting pilot and demonstration projects to study site characterization (including injection and confining formation information, core data and site selection information); well construction (well depth, construction materials, and proximity to USDWs); frequency and types of tests and monitoring conducted (on the well and on the project site); modeling and monitoring results; and injection operation (injection rates, pressures, and volumes, CO_2 source and co-injectates)."

Field test results to date: subsurface



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Results to date: surface

	Soil gas sensitivity: Detection	Soil gas sensitivity: Noise	Groundwater sensitivity: Detection	Groundwater sensitivity: Noise	
Otway	Below detection	Quantified	Below detection	Quantified	
SACROC			Below detection	Quantified	
Cranfield	Quantified	Quantified	Quantified	Quantified	P site, controlled release
Weyburn	Below detection	Quantified			
West-Pearl Queen	Quantified				PFT Tracer
ZERT	Quantified	Quantified	Quantified	Quantified	Controlled release
Hastings/W.Ranch	TBD	TBD	TBD	TBD	
Pump Canyon	Quantified				PFT Tracer

- Quantified
- Below detection
- TBD

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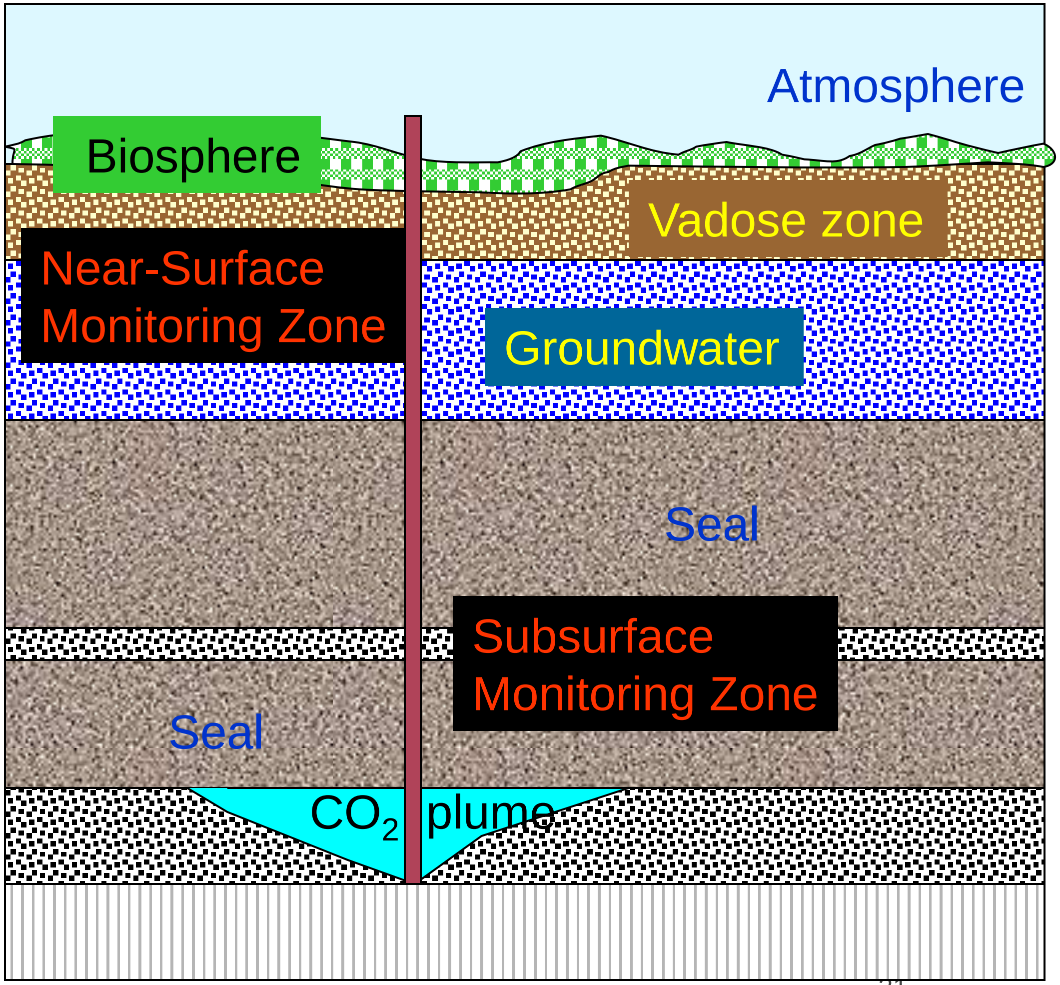
Example sensitivity: Groundwater monitoring (Changbing Yang)



Objectives

- Detecting potential CO_2 leakage signals
- Groundwater quality if CO_2 leakage occurs

Geochemical Parameters for CO_2 Leakage Detection

- Aquifer mineralogy
  - Carbonate-poor aquifer
  - Carbonate-rich aquifer
- Initial groundwater chemistry

Sampling protocols, methods, instrumentation

pH, Alk, Dissolved inorganic carbon, Dissolved CO_2, HCO_3^-, $\delta^{13}C$, + possible trace metals

↔

CO_2 leakage rate

- Confined or unconfined aquifer
- Groundwater velocity
- Groundwater recharge, exploitation
- Monitoring location and depth

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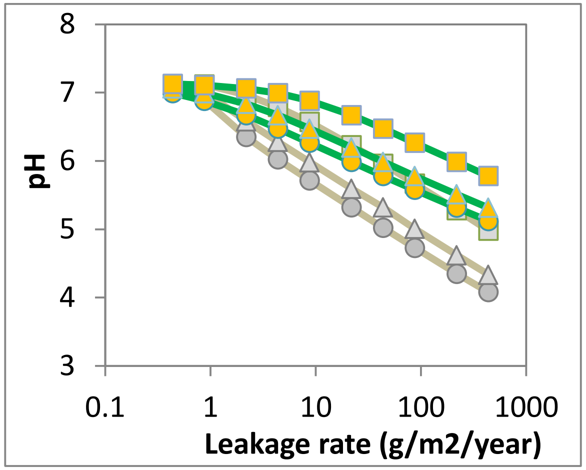
Modeling Approach

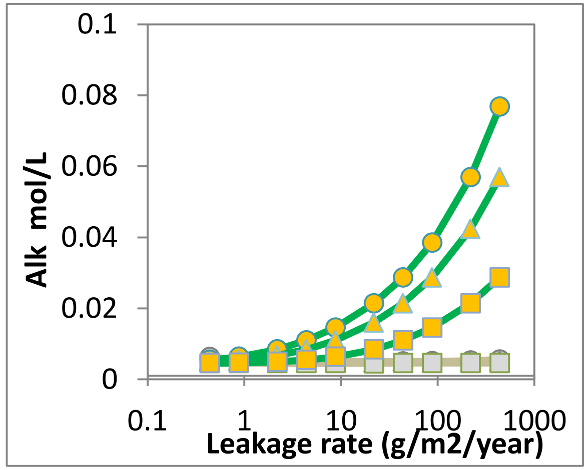
- PHREEQC developed by USGS
  - Batch, no transport
  - Aquifer mineralogy
    - Carbonate poor aquifer: Quartz only and Quartz + albite
    - Carbonate-rich aquifer: Quartz + Calcite
    - Kinetic dissolution
  - Groundwater chemistry
    - GW from Cranfield
    - GW from SACROC
    - GW from Montana in Wilkin and Digiulio, 2010
  - CO_2 leakage rate
    - From 0.44 to 440 g/m^2/year (~3 order magnitudes)
  - Simulation duration
    - 10 years

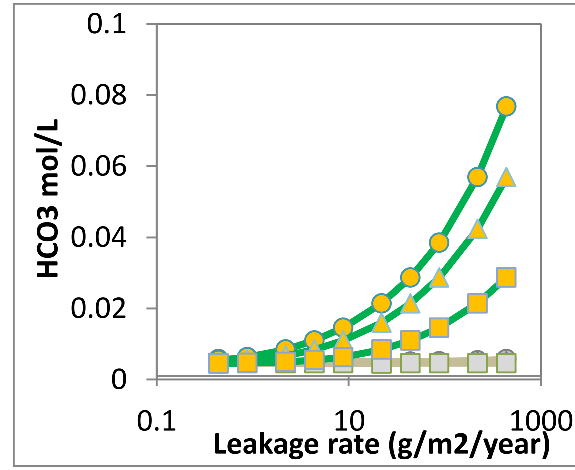
Modeling Results

Impacts of aquifer mineralogy on geochemical parameters

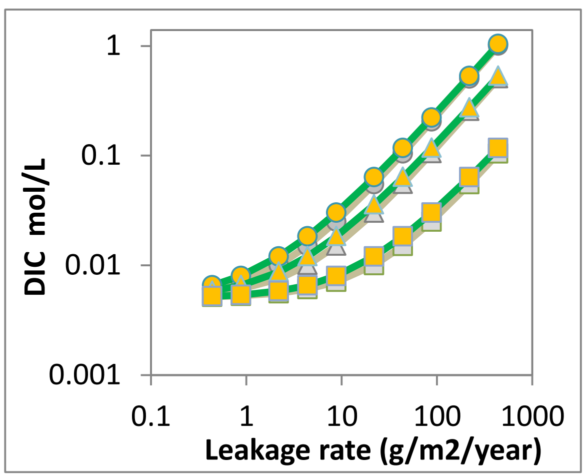
ALK = $[HCO_3^-] + 2\,[CO_3^{2-}]$

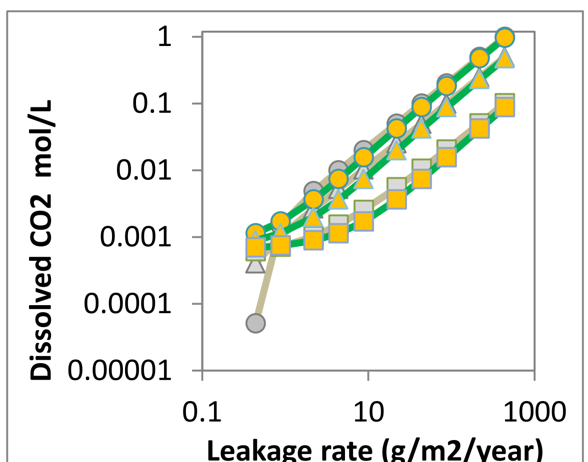


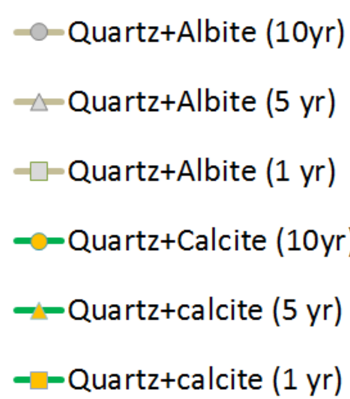




DIC= [Dissolved CO_2] + $[HCO_3^-]$ + $[CO_3^{2-}]$







GW from SACROC

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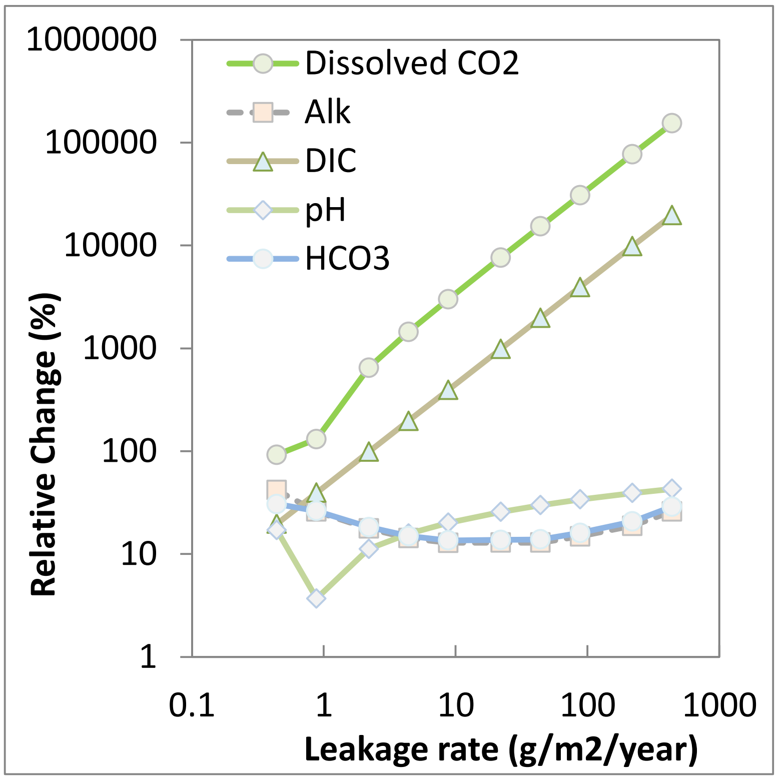
Modeling Results

Impacts of aquifer mineralogy on geochemical parameters

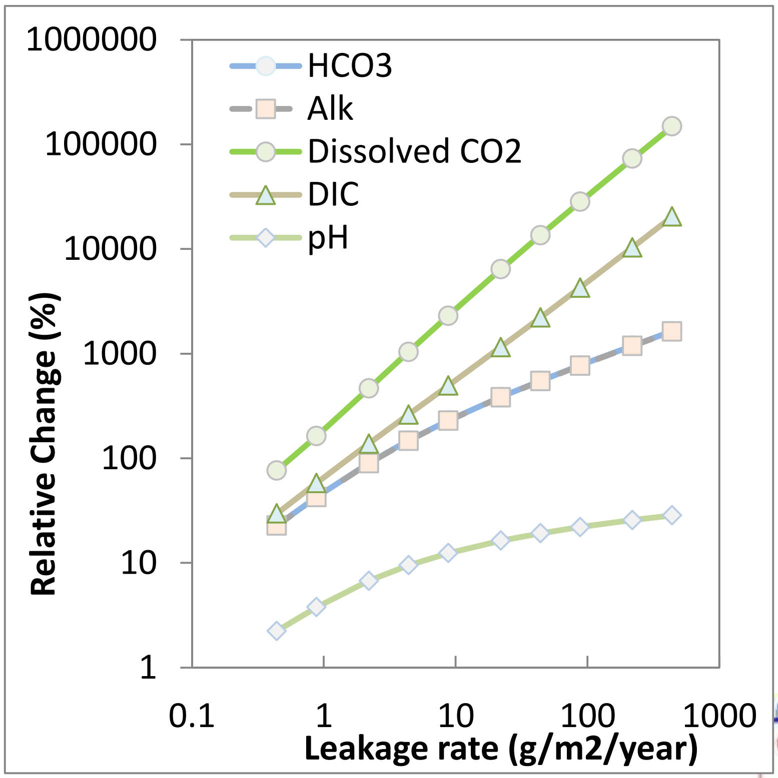
Relative change in geochemical parameters

$$S_p = \frac{|P_t - P_o|}{P_o} \times 100\%$$

Quartz + Albite after 10 yrs



Quartz + Calcite after 10 yrs



GW from SACROC

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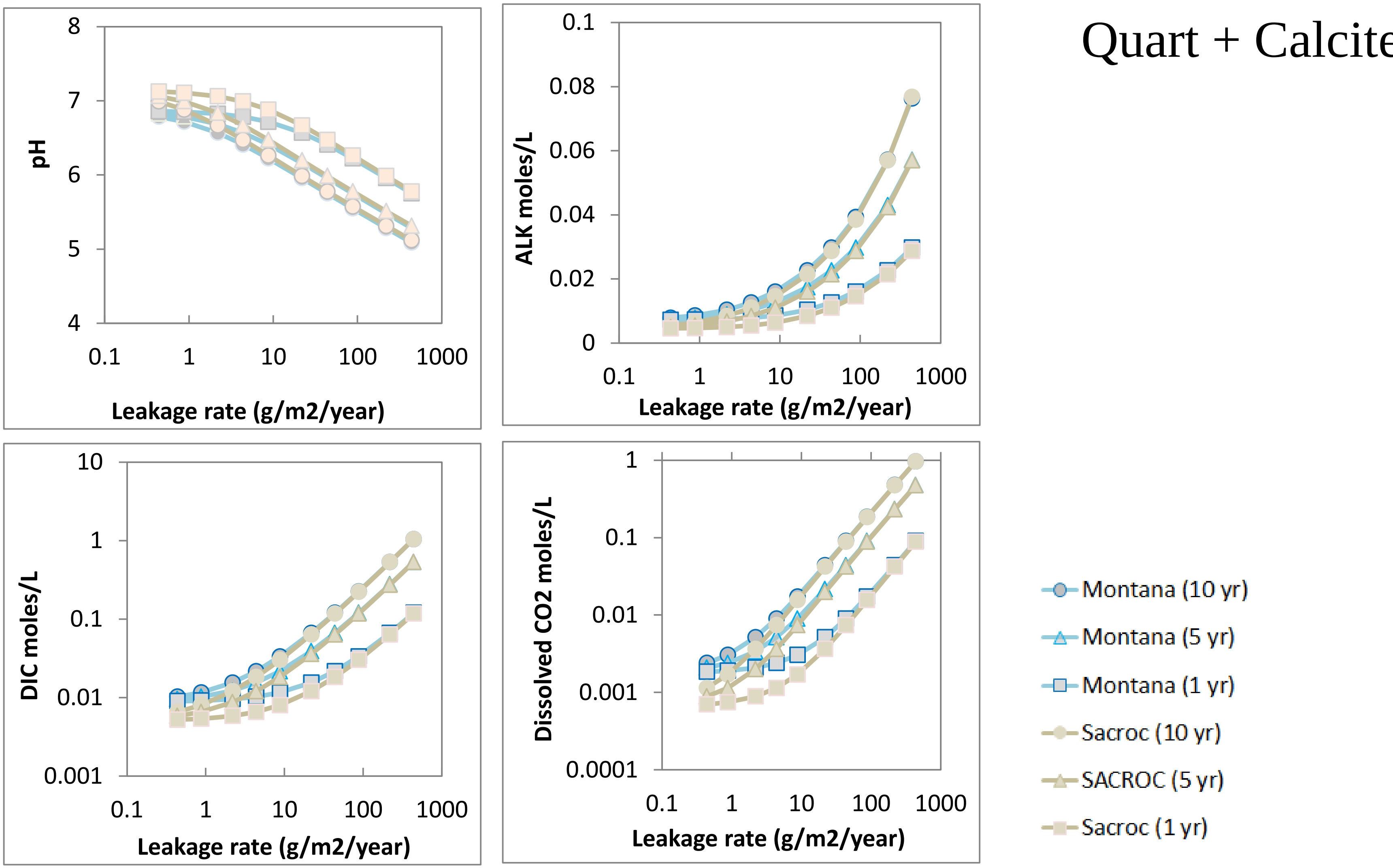
Modeling Results

- Impacts of initial water chemistry on geochemical parameters



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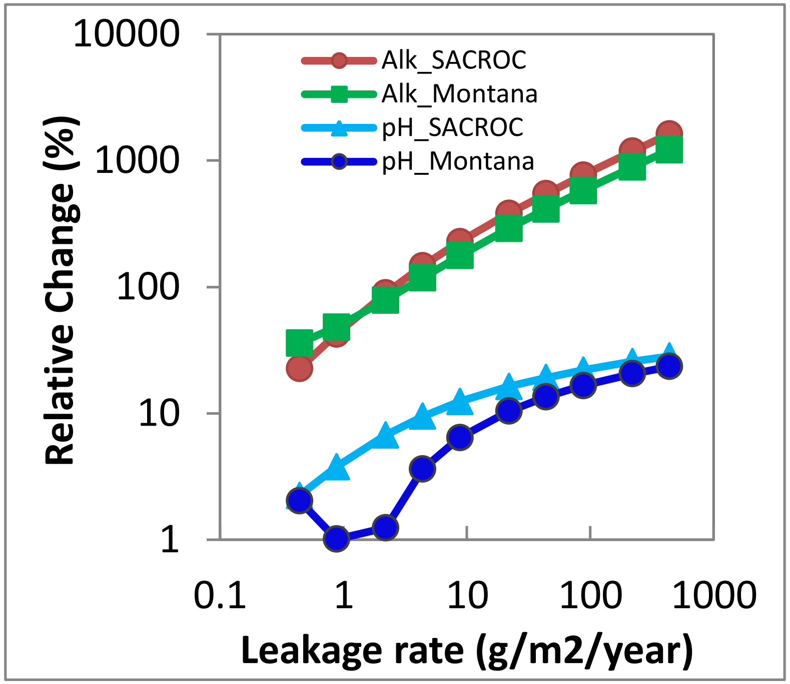
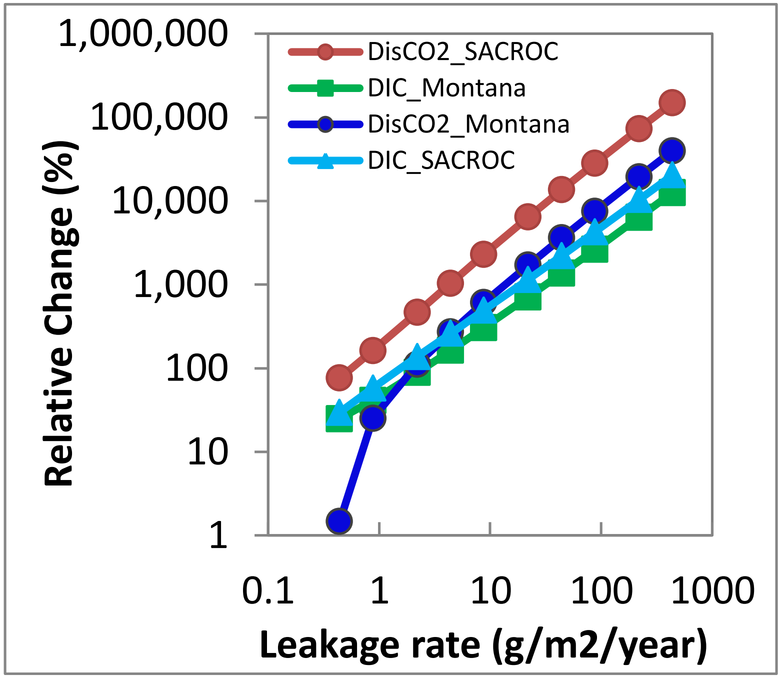
Modeling Results

- Impacts of initial water chemistry on geochemical parameters

Relative change in geochemical parameters

Quartz + Calcite





Difference due to the initial dissolved CO2 in the two ground waters?

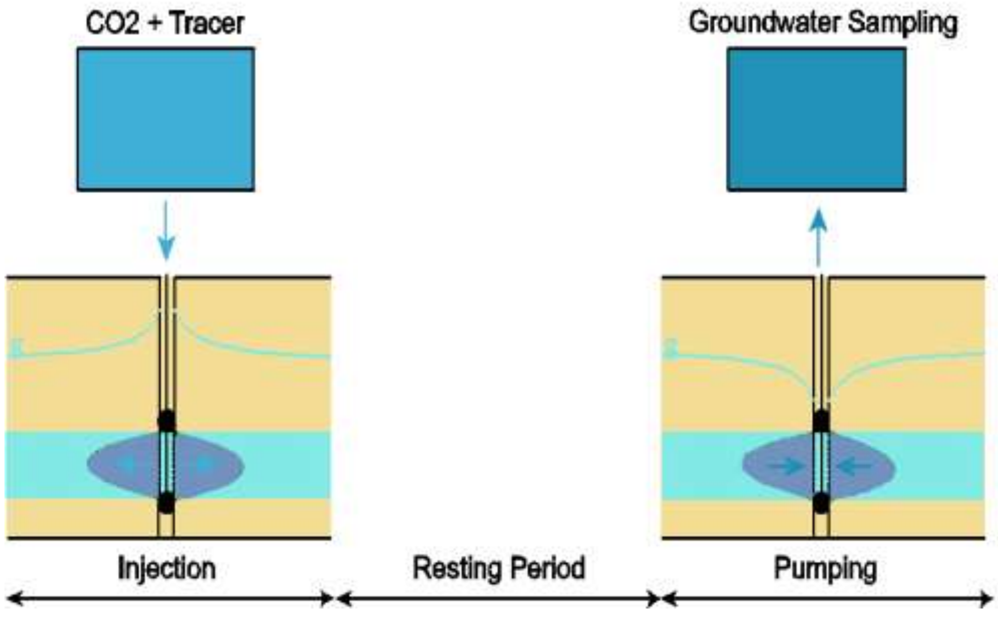
Summary

Aquifer type	Alkalinity	pH	DIC	Dissolved CO2
Carbonate-rich	moderate	mild	strong	strong
Carbonate-poor	weak	moderate	strong	strong

- Impacts of initial groundwater chemistry on responses of geochemical parameters to CO_2 leakage are minor
- DIC and dissolved CO_2 seem to be universal geochemical parameters for detecting CO_2 leakage
- Geochemical parameters may not be able to detect small CO_2 leakage.
- Stable carbon isotope of DIC could be a good indicator for detecting CO_2 leakage. Numerical modeling is underway.

Field validation via Single Well Push-Pull Test funded by AWWA

- The injection phase: inject groundwater saturated with CO_2 into the target aquifer
- The resting phase: let injected water react with aquifer sediments
- The pulling phase: pump groundwater continuously for collecting water samples



Instrumentation

of Economic Geology

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Results

- Potential dissolution of carbonates

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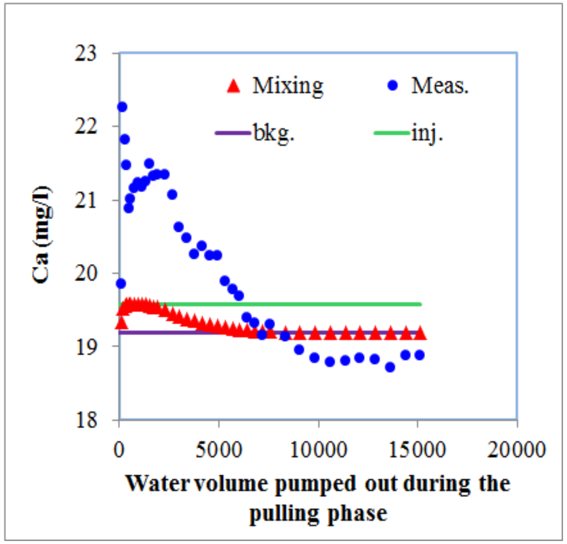

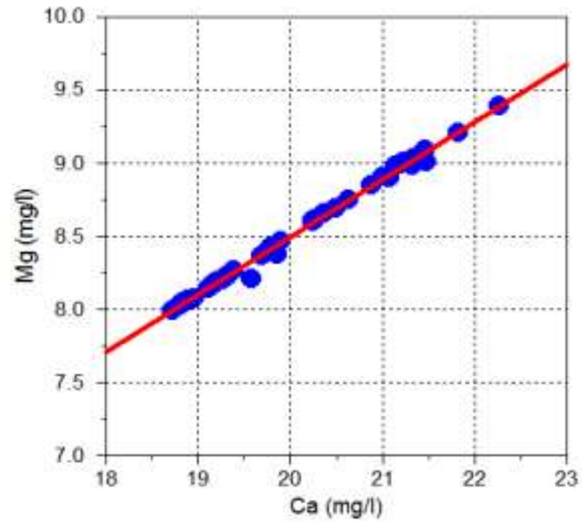

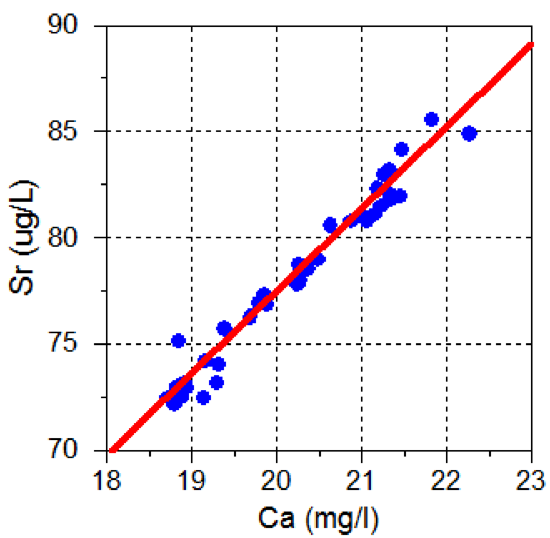

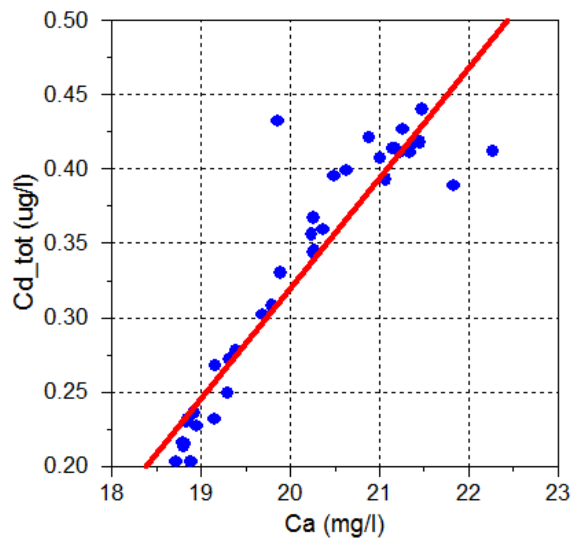

Ba, B, Mo, Cu, Co, Mn

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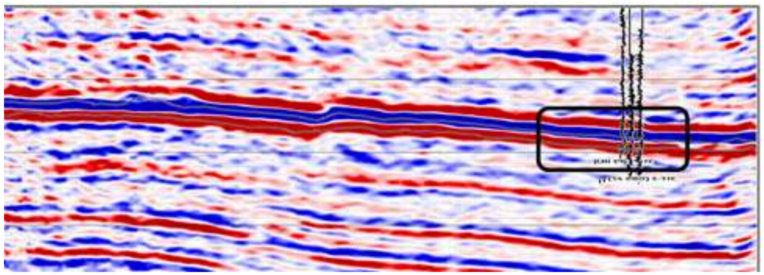
Time lapse seismic analysis –sensitivity to identify the edge of plume

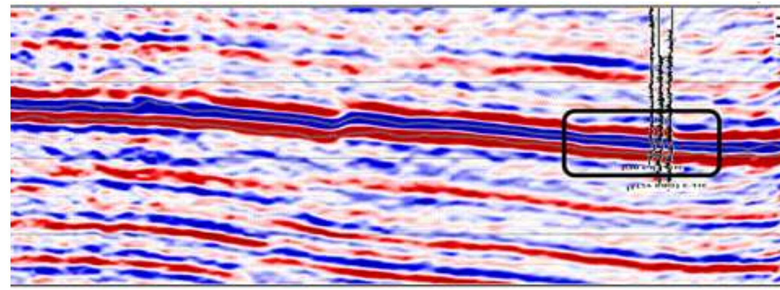
2007 Pre-injection

DAS



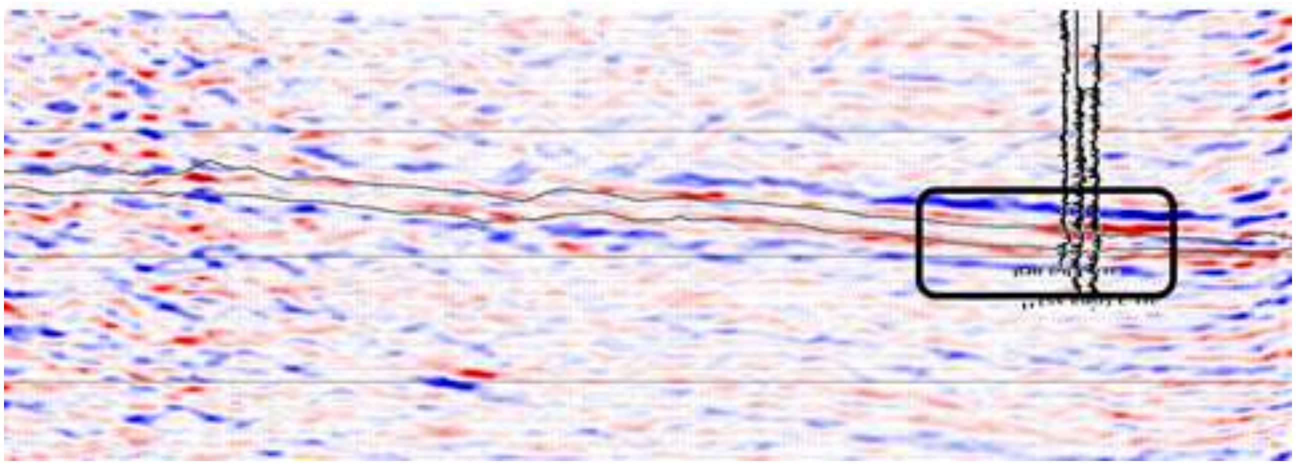
2010 1 year of injection about 1/4 million metric tons this area

DAS



Difference

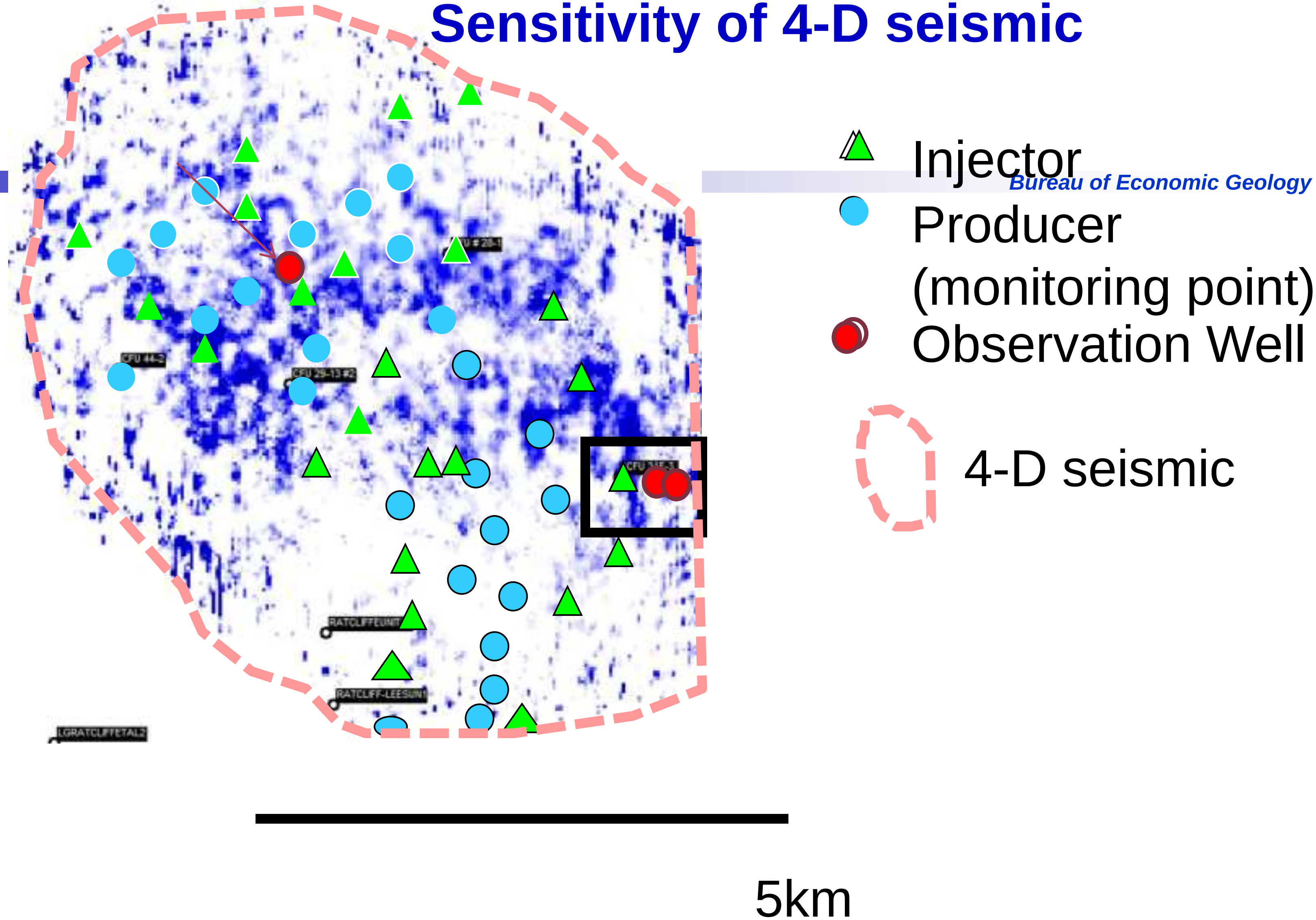
DAS



Rui Zhang, CFSUS & UTIG

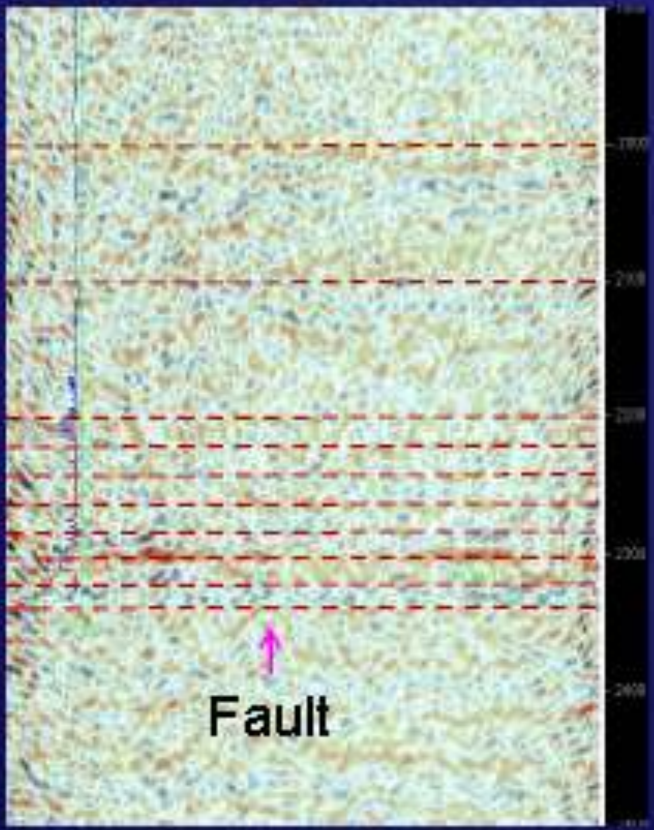
Sensitivity of 4-D seismic

Bureau of Economic Geology

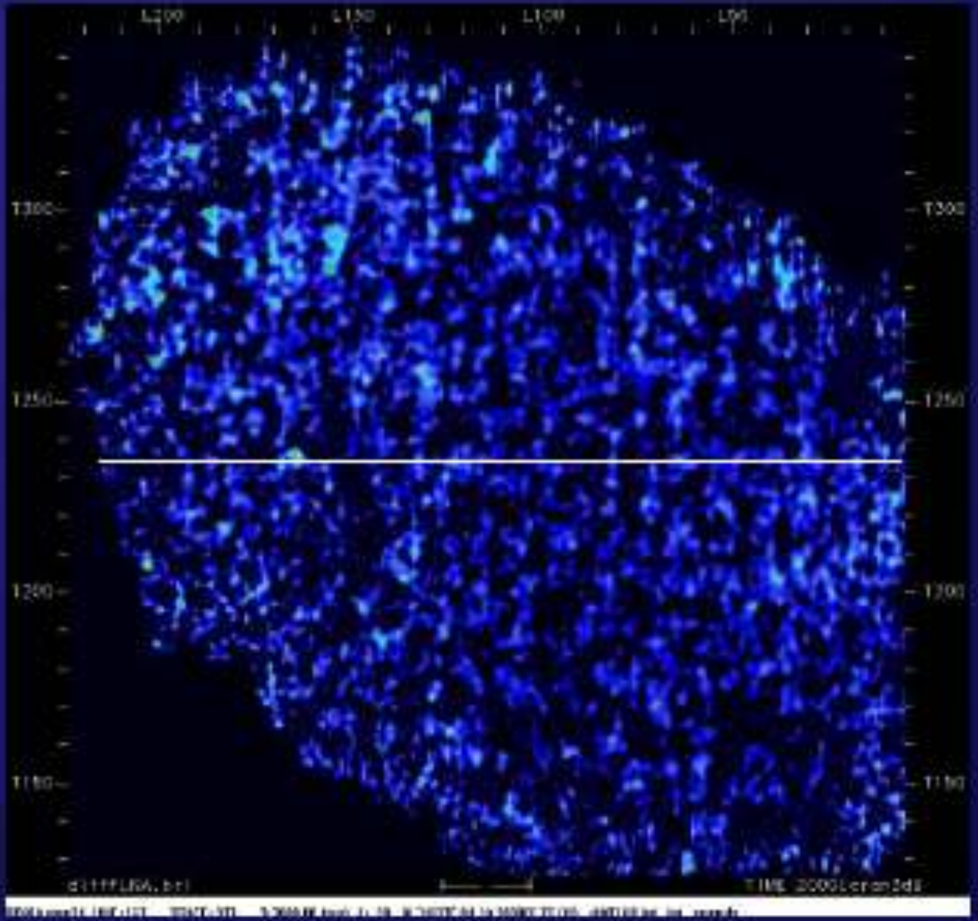


Stratal slices: there is no sign of leaking!

Velocity difference above zone



Cross-section flattened
Velocity difference



Initial result: Hongliu Zeng

Progress Update

- Update from in-process projects through contact with experts
  - Growing list of positive and negative detections
  - Importance of site-specific noise
- Tools reviewed
  - Site-specific controls on sensitivity of groundwater geochemistry for leakage detection
  - Site specific issues on sensitivity of surface 4-D seismic for leakage detection
  - Next talk: Site specific detection with pressure-based AZMI monitoring
- Next:
  - Complete cases
  - Design case-based workbook
  - Peer Review