Fundamental Studies in Support of GEO-SEQ

LBNL's Consolidated Sequestration Research Program (CSRP)

Project Number FWP ESD09-056

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U.S. Department of Energy

National Energy Technology Laboratory

Carbon Storage R&D Project Review Meeting

Developing the Technologies and

Infrastructure for CCS

August 20-22, 2013

Presentation Outline

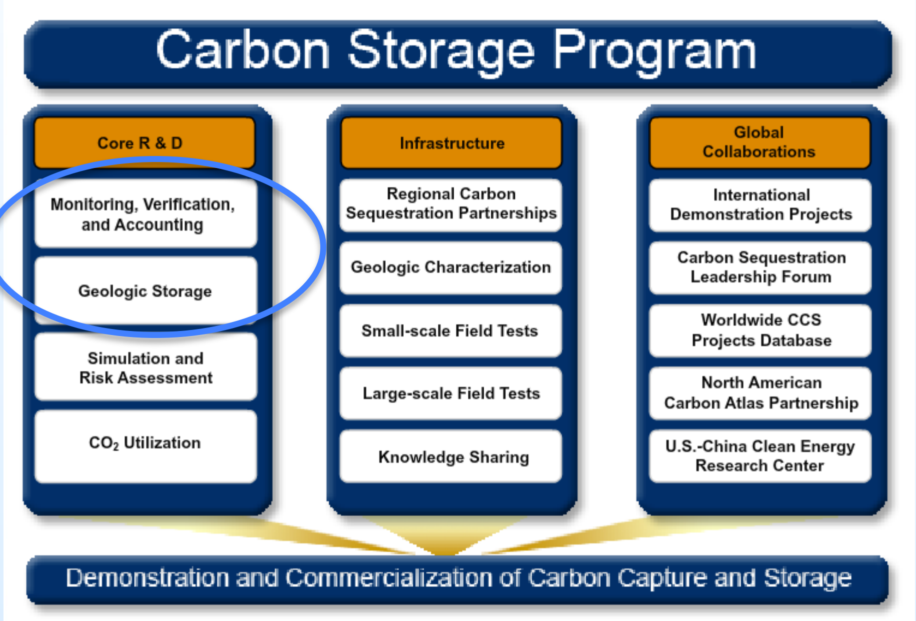
- Benefits and Goals of Fundamental Studies
- Technical Status
  - Petrophysical Relationships
  - Geochemical Processes
  - Monitoring Instrumentation
- Accomplishments and Summary

Benefit to the Program

- Program goals being addressed:
  - Develop and validate technologies to ensure 99 percent storage permanence.
  - Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness
- This research addresses these goals by supporting GEO-SEQ and GCS field studies using investigation of fundamental processes affecting storage and monitoring, including
    - **Petrophysical relationships**
    - **Geochemical processes**
    - **Development of monitoring technology and tools**

Benefit to the Program

Core R&D:
MVA and Geologic Storage



- DOE and the carbon sequestration community will benefit from:
  - a close working relationship with numerous domestic and foreign industrial and academic teams
  - interactions with and assistance given to other regional projects
  - publications and presentations made available to all parties interested in removing barriers to commercial-scale geologic carbon sequestration.

Project Overview:
Goals

- Improve understanding of processes seen in field studies through use of laboratory scale work
  - petrophysical measurement
  - geochemical assessments.
- Develop field monitoring instrumentation
  - use demonstration scale pilots as R&D testing facilities while contributing to pilot goals

Project Overview: Objectives

- LBNL's Consolidated Sequestration Research Project (CSRP) aims to provides knowledge and lessons learned from performing distinct tasks with common overall goals:
  - Developing the knowledge base to enable commercialization of geologic carbon sequestration (GCS)
  - Identifying and removing barriers to sequestration through targeted research.
  - Understanding processes and developing improved tools
    - improve quantitative interpretation of monitoring data to ensure 99 percent storage permanence.
    - ensure containment effectiveness.

Project Overview: Objectives

- Success Criteria (FY13)
  - Demonstration of petrophysical measurements using a resonant bar system on reservoir and/or cap rock materials
  - Perform geochemical assessments for GCS reservoir rock types
  - Contribution of new and/or improved instrumentation for application to GCS

Technical Status

- Fundamental Studies began in FY13 by bringing together existing work to investigate monitoring technologies and fundamental geochemical and petrophysical processes that underpin GCS.
- The work was motivated by GEO-SEQ field projects, and their use as testing facilities to scale up from laboratory to field scale.
- Reorganization within CSRP for FY13

FY12

Task 1.0: Project Management

Task 2.0: GEO-SEQ
- Otway
- In Salah
- *Fundamental Studies*
  - *Petrophysics*
  - *Monitoring Instrumentation*
  - Partitioning Tracers
- *Geochemical Assessment*
- Certification Framework

Task 3.0: Sim-SEQ

Task 4.0: Large-Scale Hydrological Impacts of CO_2 Geological Storage

Task 5.0: CO2SINK Collaboration

FY 13

Task1.0: Management

Task 2.0: GEO-SEQ
- Otway
- In Salah
- CO2SINK
- Aquistore

***Task 3.0**: Fundamental Studies*
- *Petrophysics*
- *Geochemical Assessment*
- *Monitoring Instrumentation Development*

Task 4.0: Simulation Studies
- Large-Scale Impacts
- Sim-SEQ
- CF CO_2-EOR simulation
- Stochastic Inversion

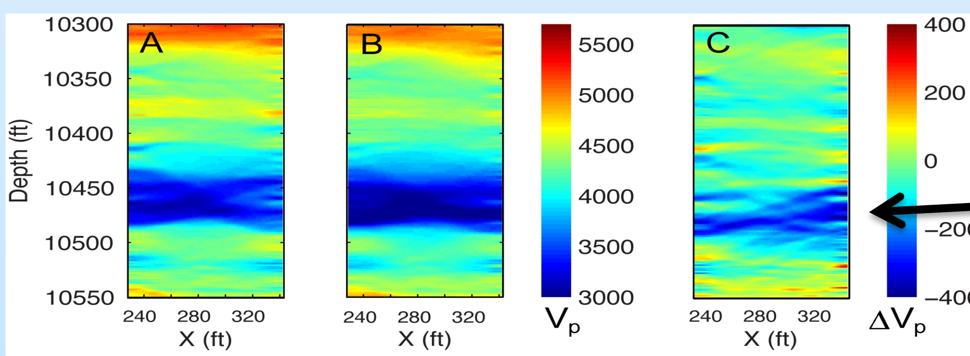
Petrophysical Relationships

PI: Seiji Nakagawa

- Goal: Improve understanding of relationships between measured data and desired information
- Focus on Seismic Velocity as a function of CO_2 Saturation
  - Changes in seismic velocity have provided excellent 'maps' of CO_2 distribution – but what is the true saturation?

Pre Injection   Post Injection   Difference

Cranfield
Tuscaloossa
Reservoir



CO2 Plume

Ajo-Franklin, et al, 2013 IJGCC.

Utilize Modern Petrophysical Models: 'Patchy' Saturation

Analysis of Tuscaloosa D/E (Cranfield Reservoir)

What affects the seismic response calculation?

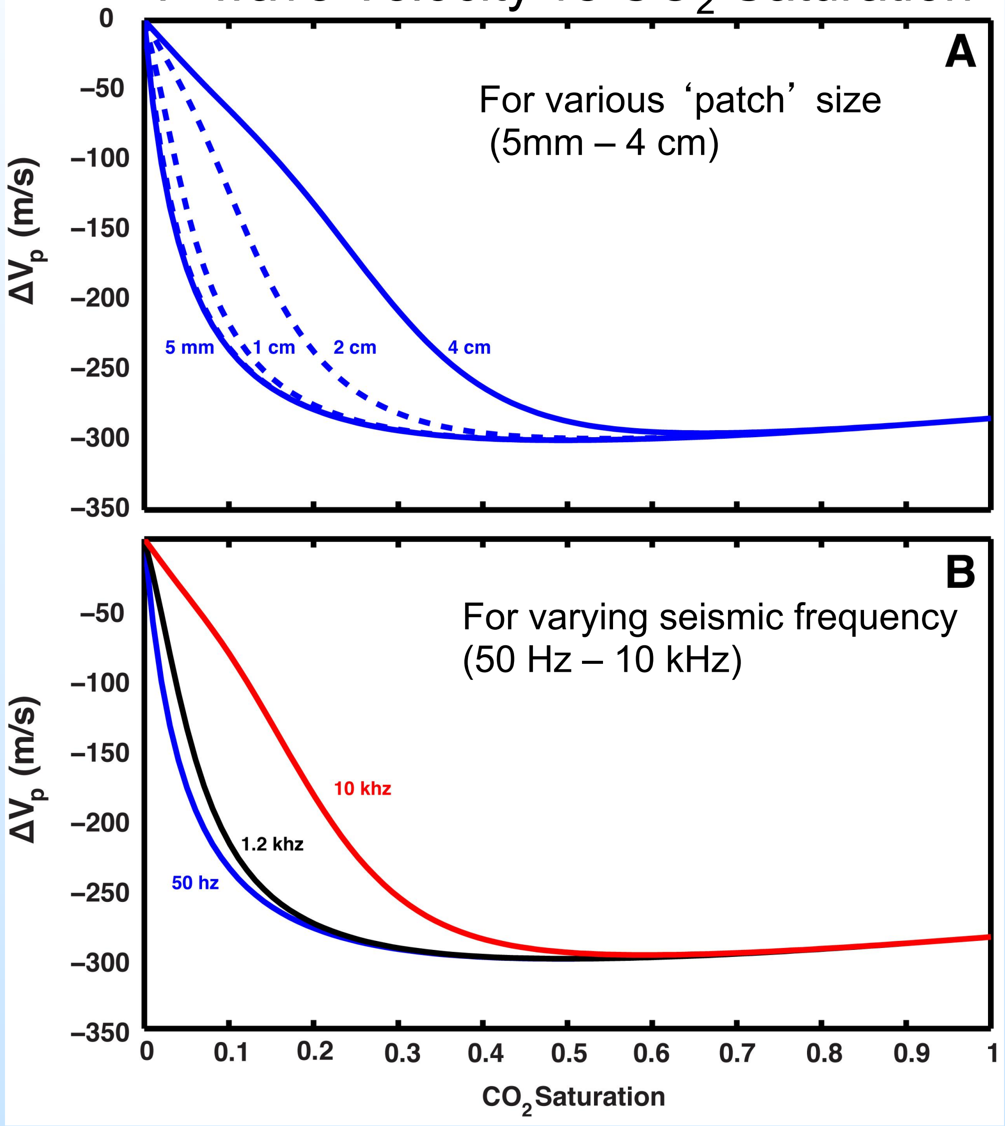
"Patch Size", Frequency,

pressure, temperature, brine properties, matrix properties (density, moduli of grains), clay percentage and clay properties, porosity, CO_2 property model, CH_4 property model

<u>Variation within reservoir:</u>
10470 ft core data predicts larger change than 10465' core.

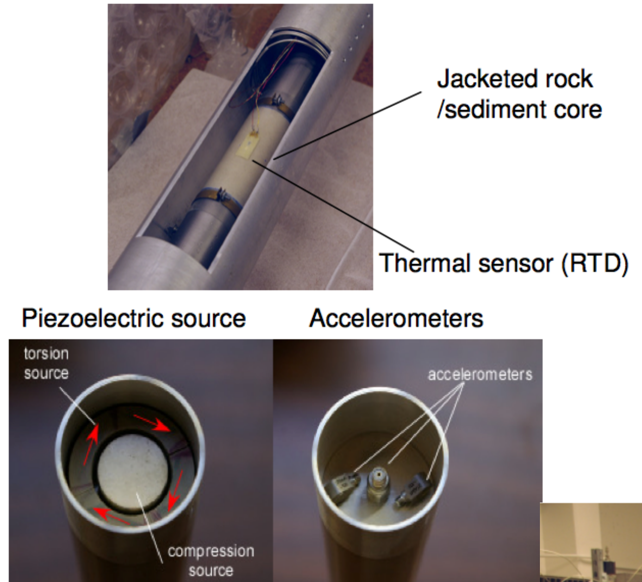
Ajo-Franklin, et al, 2013 IJGCC.

P-wave Velocity vs CO_2 Saturation



Develop Instruments

Split Hopkins Resonant Bar

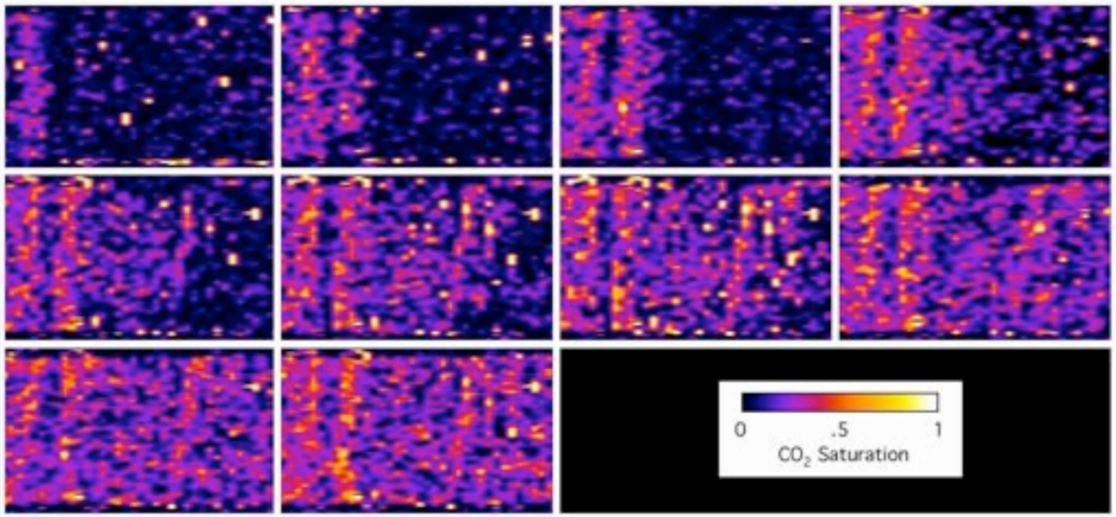


- *Laboratory seismic measurements with concurrent x-ray CT imaging*
  - *LBNL's x-ray CT scanner (GE Lightspeed 16).*
- *In Situ P/T conditions*

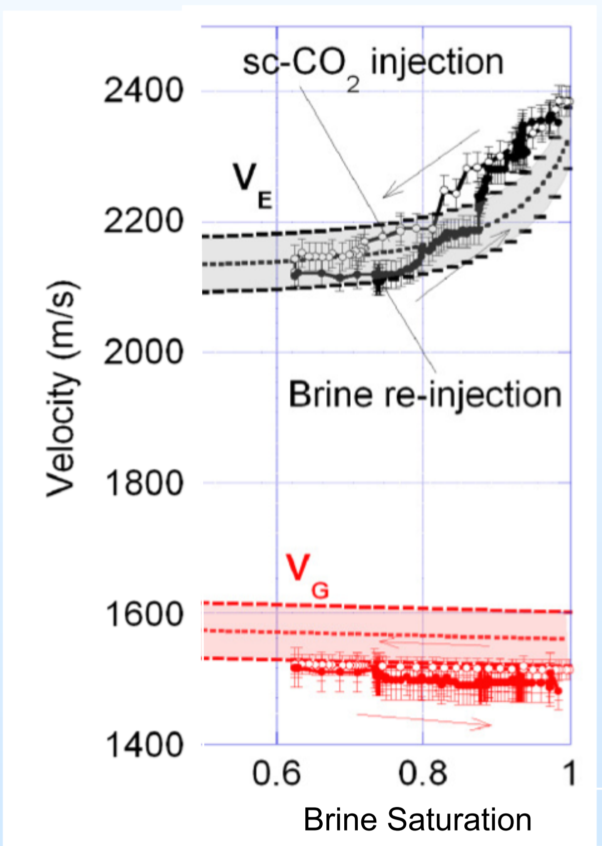
Nakagawa and Kneafsey, LBNL

Petrophysics
Measurement of Fundamental Properties

CT Scan Image of CO_2 in Core



Velocity vs Saturation

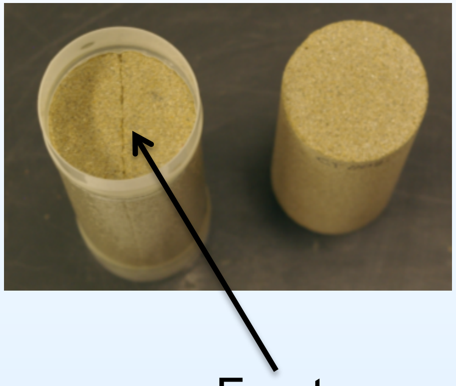


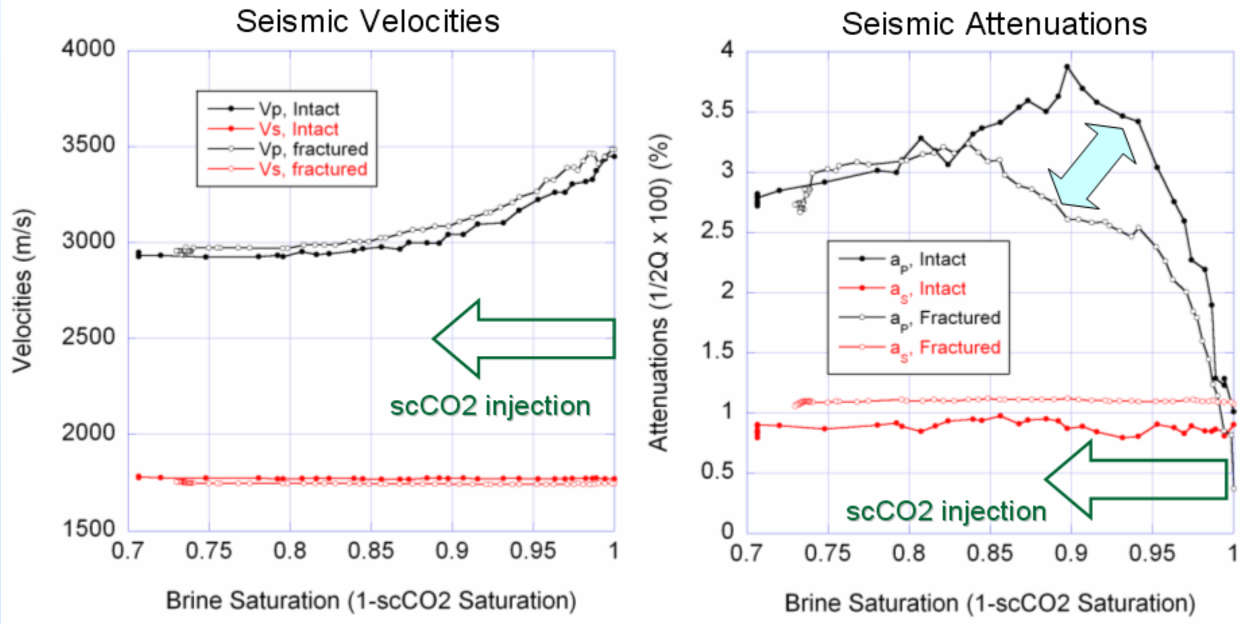
- Results:
- Estimate ~ 300 m/s change in velocity
- Measure seismic velocity vs CO_2 saturation
  - Estimate patch size (~1 cm) limited by core size (~2 cm)
- Strong structural anisotropy of the rock

Nakagawa, et al, 2013, Geophysical Prospecting

New Results:
Intact vs Fractured Reservoir

- Understand how fractures in reservoir influences distribution of CO_2, and impacts the seismic velocity and attenuation
- Initial result – difference in attenuation





Nakagawa and Kneafsey, LBNL

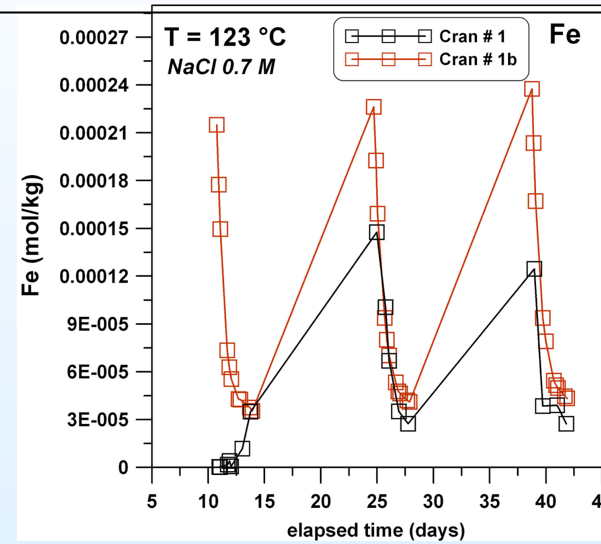
Geochemical Assessment

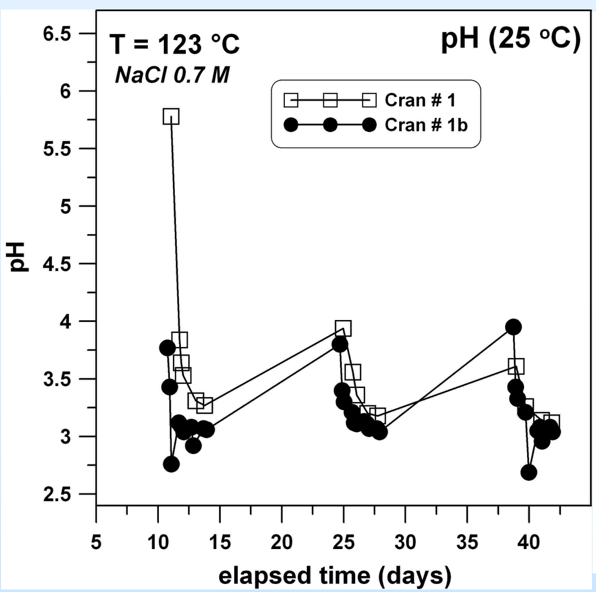
PI: Kevin Knauss, LBNL

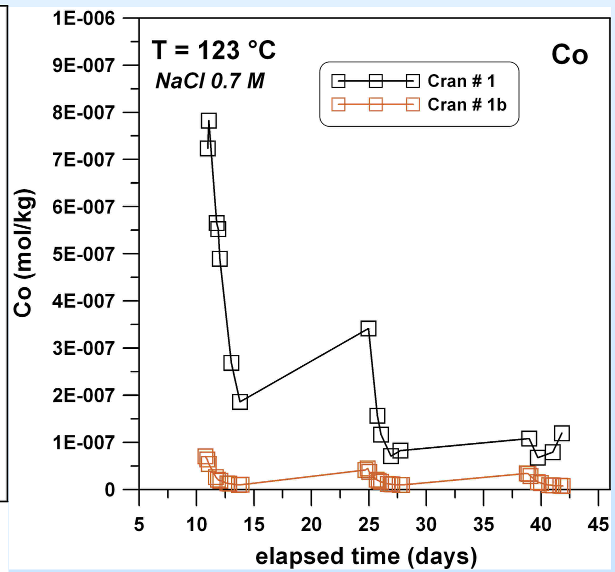
- **Goals**
  - Conduct experiments to understand geochemistry of CO_2 sequestration processes spanning injection, neutralization and long-term phases of storage
    - GCS site core samples span expected rock types
    - Evaluate the fate and longevity of released metals into aqueous solutions
  - Develop simplified screening tests that industry can use to evaluate site suitability and predicted performance

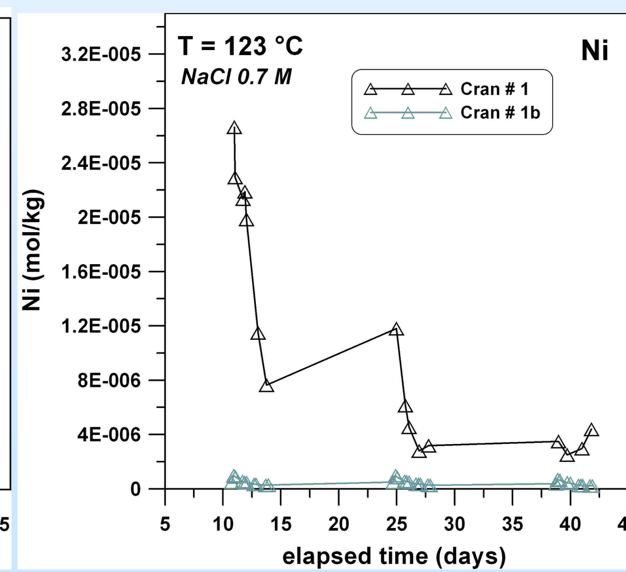
Geochemical Assessment

- "real" brine experiments
  - Synthetic brine matched to field composition
    - Frio C- and Blue sands, Cranfield, Weyburn
- Role of O_2 fugacity
  - Metal release
  - Fate upon neutralization
- Screening protocol
  - Develop simplified test
  - Criteria specific to rock type



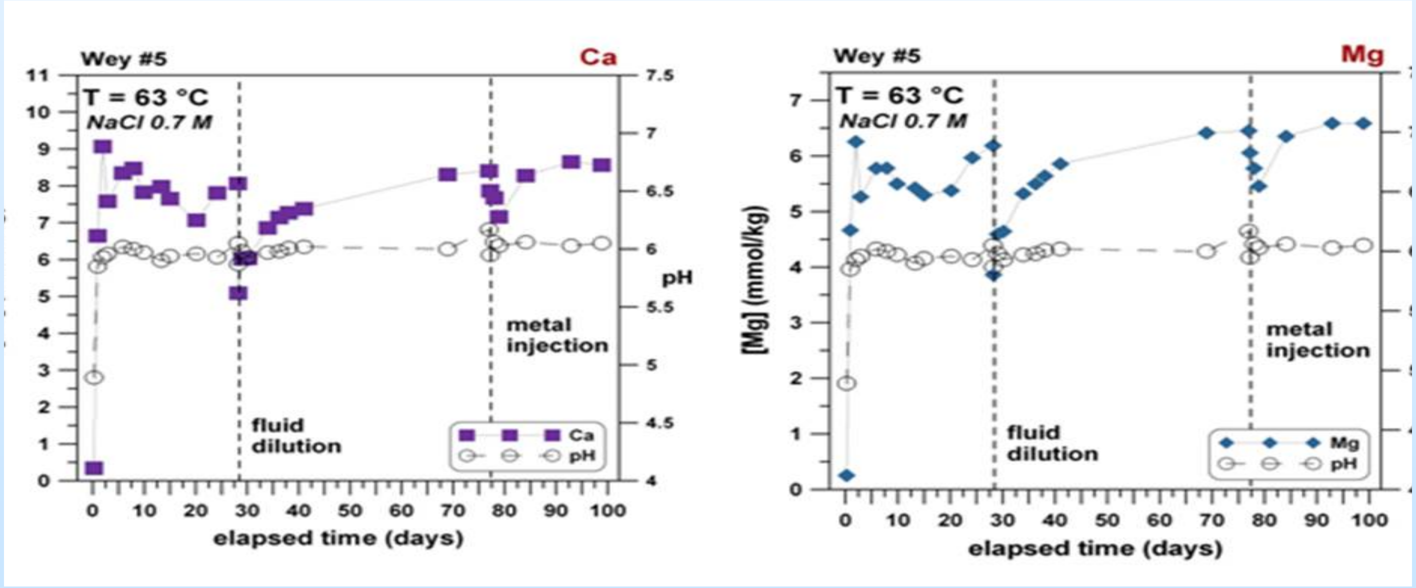






New Results
Weyburn Reservoir

- Completed an experiment using the solid material from the Midale Marly Unit of the Weyburn reservoir rock
- Three different stages over 99 days
  - Stage 1: 28 days – Reaction of Marly dolostone with the CO_2-saturated fluid
  - Stage 2: the reacting fluid was diluted by injection of a CO_2-free NaCl pH = 2.7.
  - Monitored for 49 days
  - Stage 3: 20 days - introduce acidified (pH = 1.7) brine containing elevated levels of metals (Cr, Ni, Zn and Pb)



Monitoring Instrumentation Development

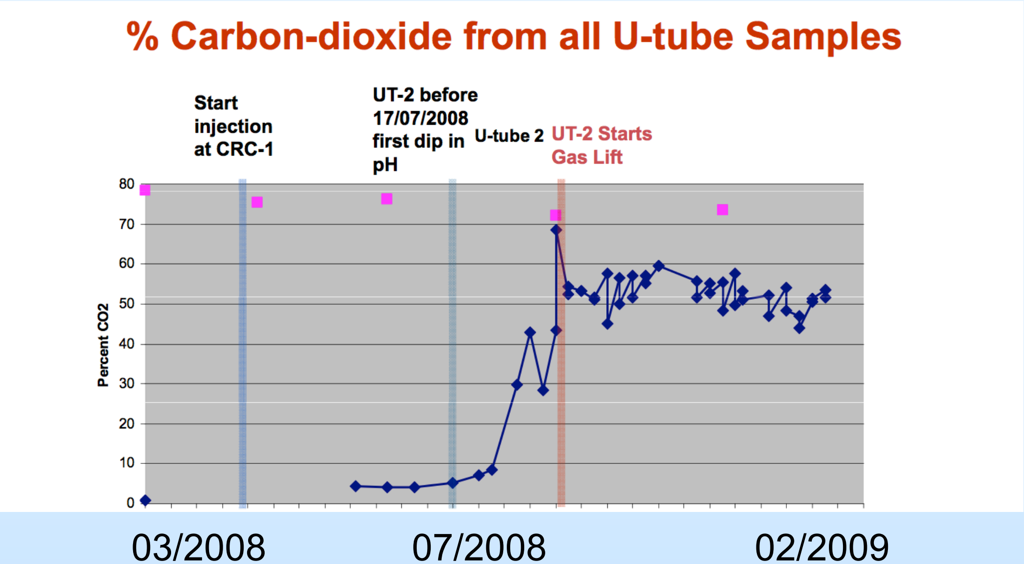
- LBNL's participation in pilot tests via GEO-SEQ led to development and application of novel monitoring tools for GCS
  - U-tube fluid sampling
  - Continuous Seismic Monitoring (CASSM)
  - Borehole shear-wave source (orbital vibrator)
  - Fiber Optic Monitoring
    - Heat-Pulse Thermal Monitoring v
    - Distributed Acoustic Sensing

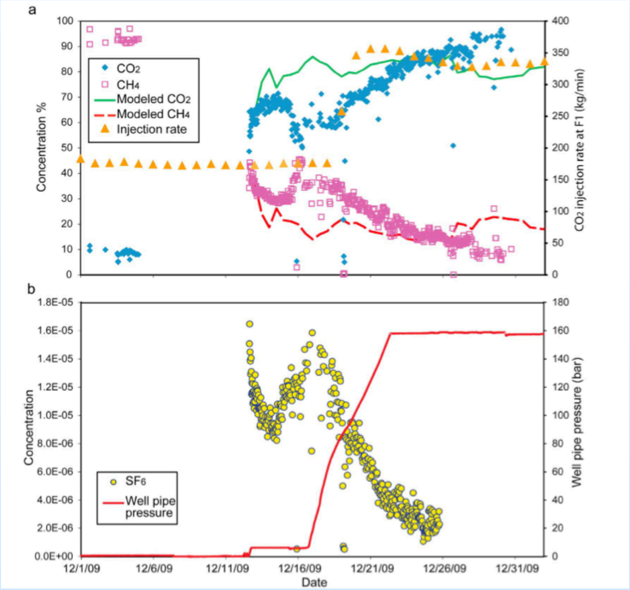
Custom Packer Design for Monitoring

U-Tube Fluid Sampling
Examples from Otway Project

- Goal: Near continuous measurement of aqueous and gas geochemistry
  - Value of U-tube sampling demonstrated at Frio, Otway, Cranfield, and elsewhere

Cranfield: From Lu, et al, 2012, JGR





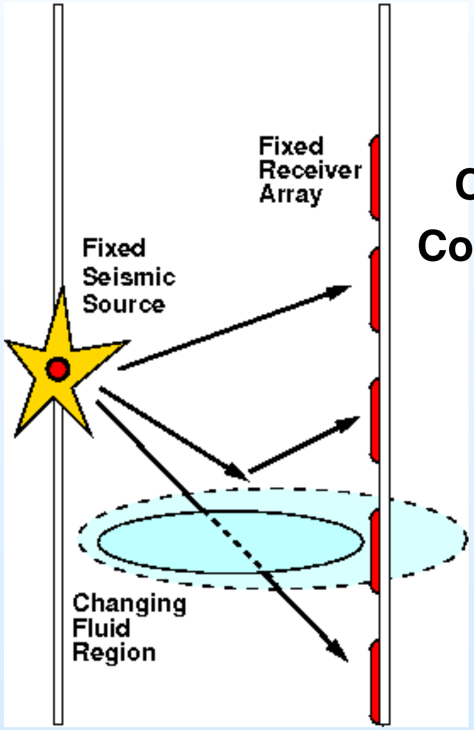
CO_2 and CH_4 (top); SF_6 and wellhead pressure (bottom): Well 31F2

CASSM

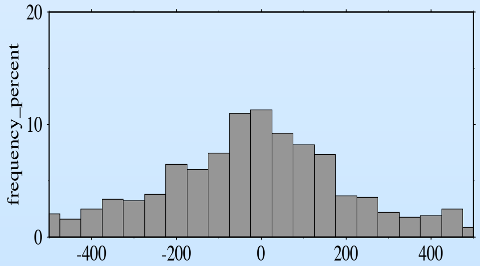
Continuous Active-Source Seismic Monitoring

- Goal: Precision In-situ monitoring of seismic properties
  - Current: crosswell geometery
  - Planned: surface – borehole

- Motivation:
  - Monitoring of In-Situ Processes
    - Reservoir dynamics and petrophysics
      - Velocity/Saturation (fluid effects)
      - Coupled flow/seismic data/models



Crosswell Configuration

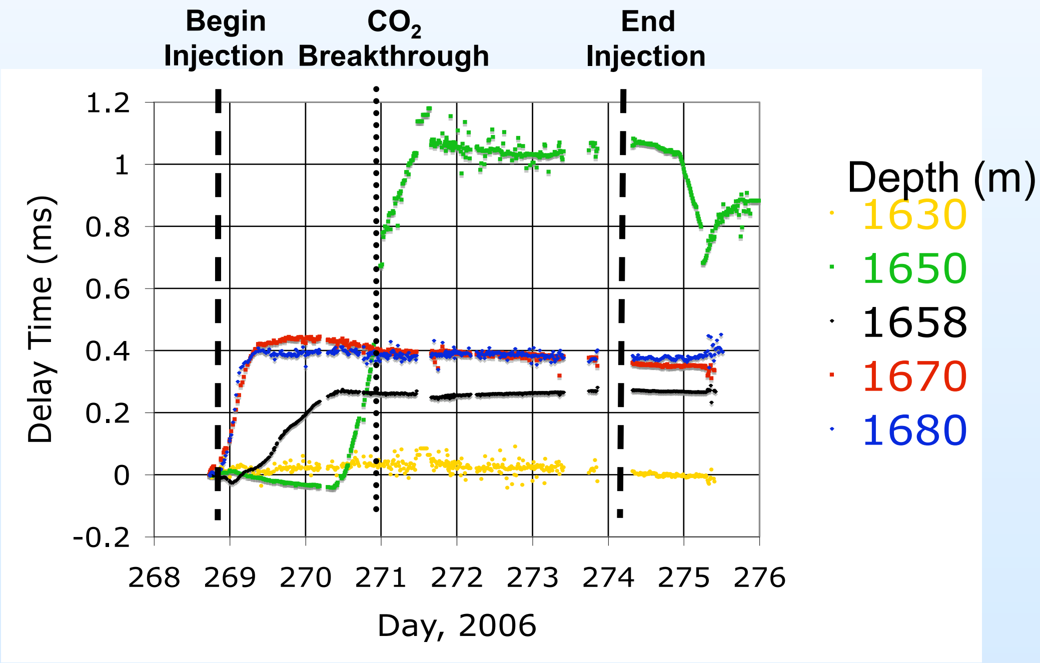


Delay Time (ns)

CASSM Applications

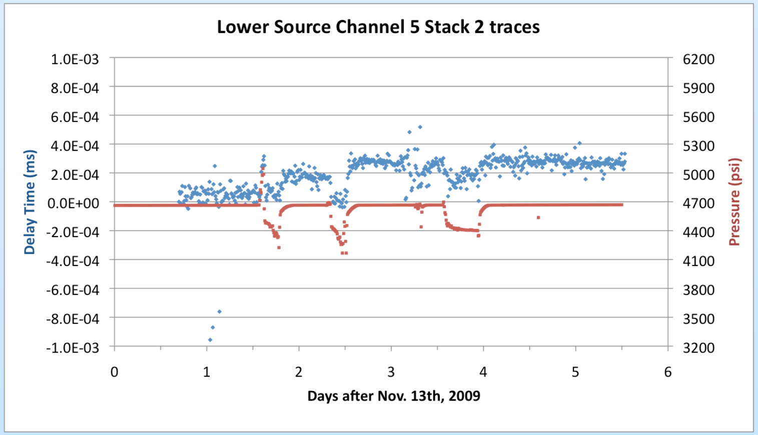
Piezo-Tube Seismic Source

Continuous Seismic Monitoring



Frio-II; Daley, et al, 2008

Velocity-Pore Pressure @ 3.2km



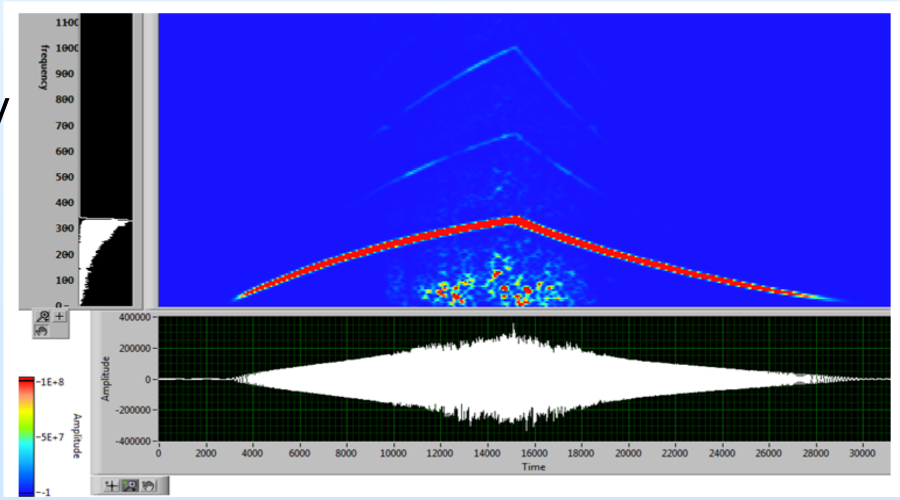
Cranfield 2010; Daley, LBNL

Borehole Seismic Source: Orbital Vibrator

- Unique ability to generate P- and S-Waves in 100-1000 Hz band
- Higher power than piezoelectric

Frequency

Amplitude

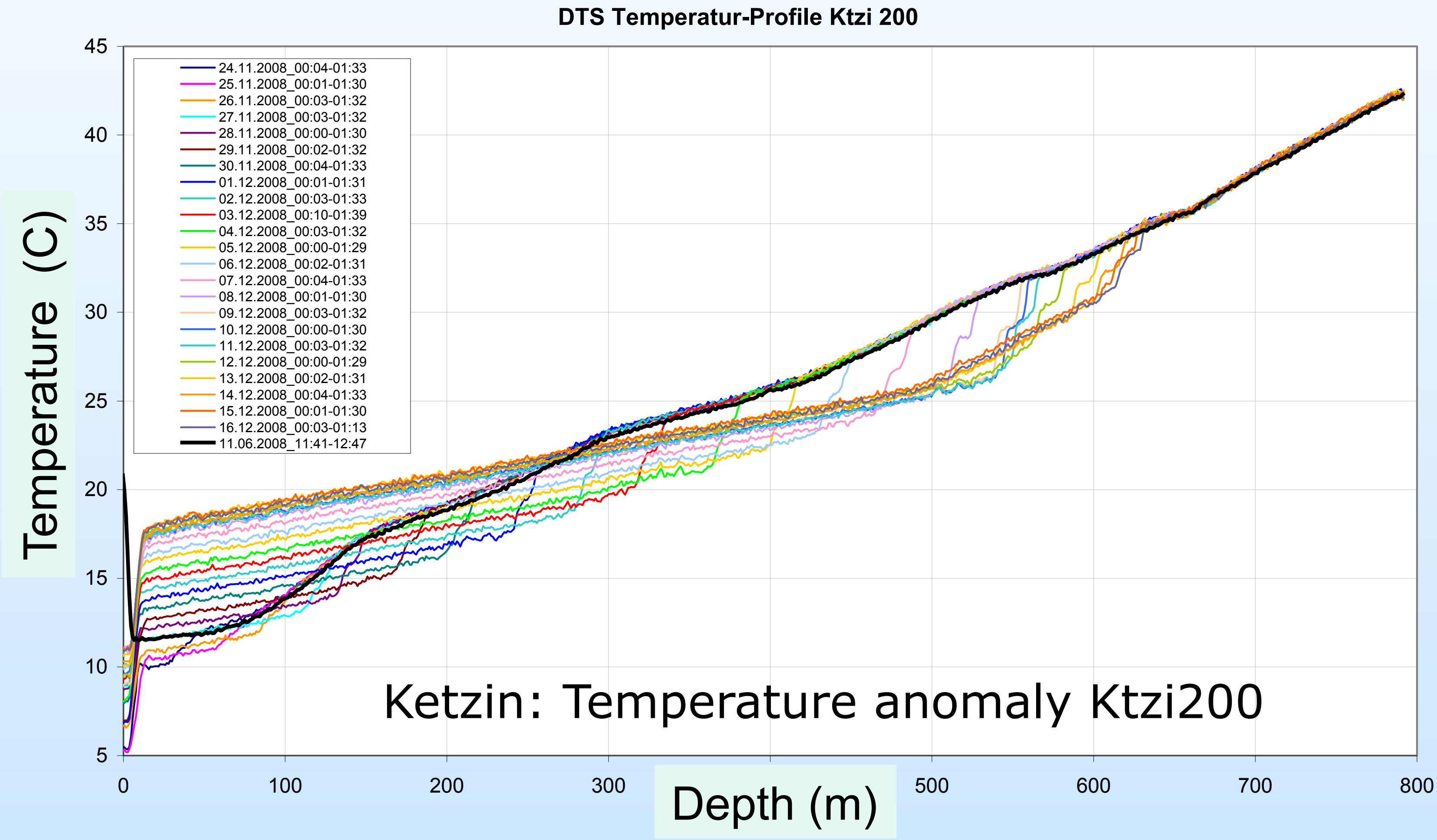


High-Speed Orbital Vibrator

Test Borehole

Fiber Optic Technology

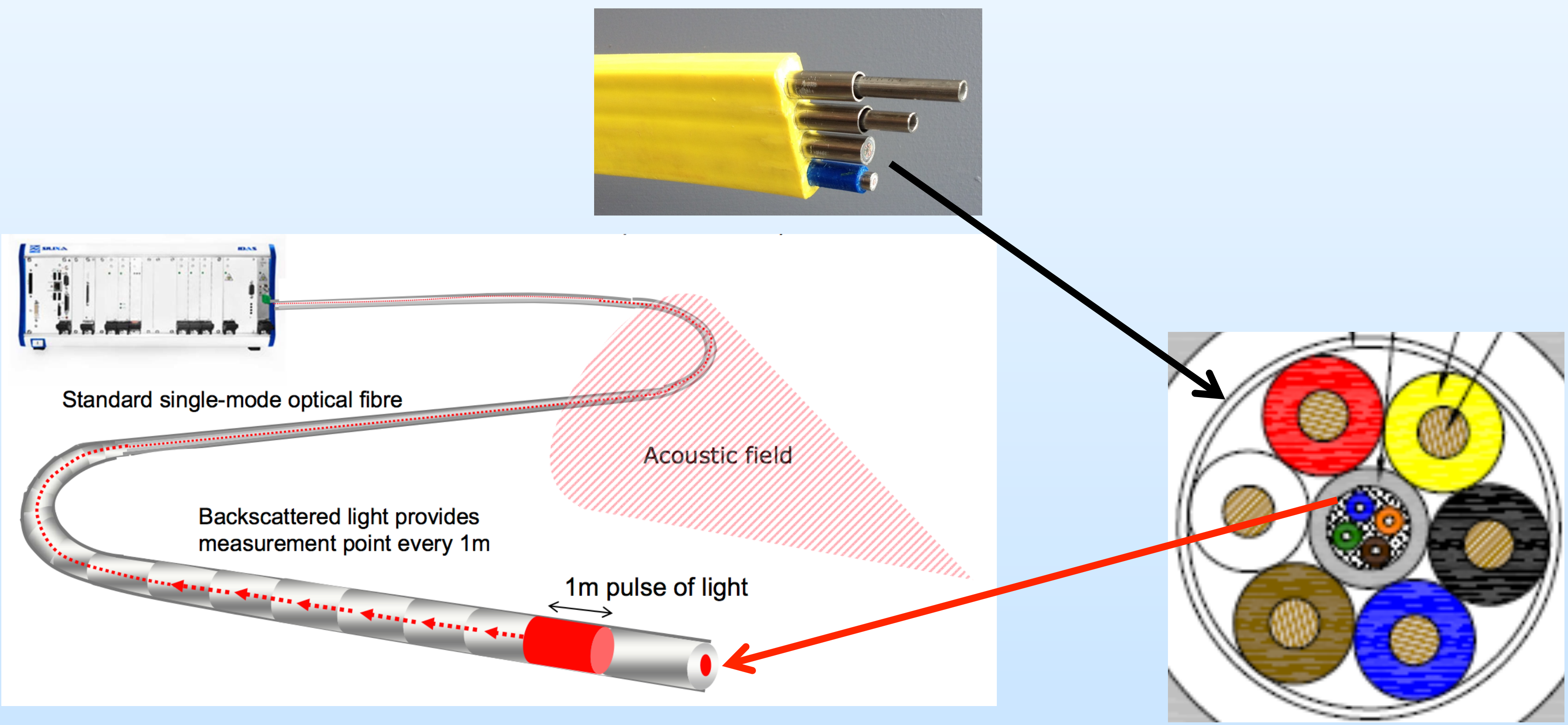
- Distributed Temperature Sensing



Ketzin Data Courtesy Jan Henninges, GFZ

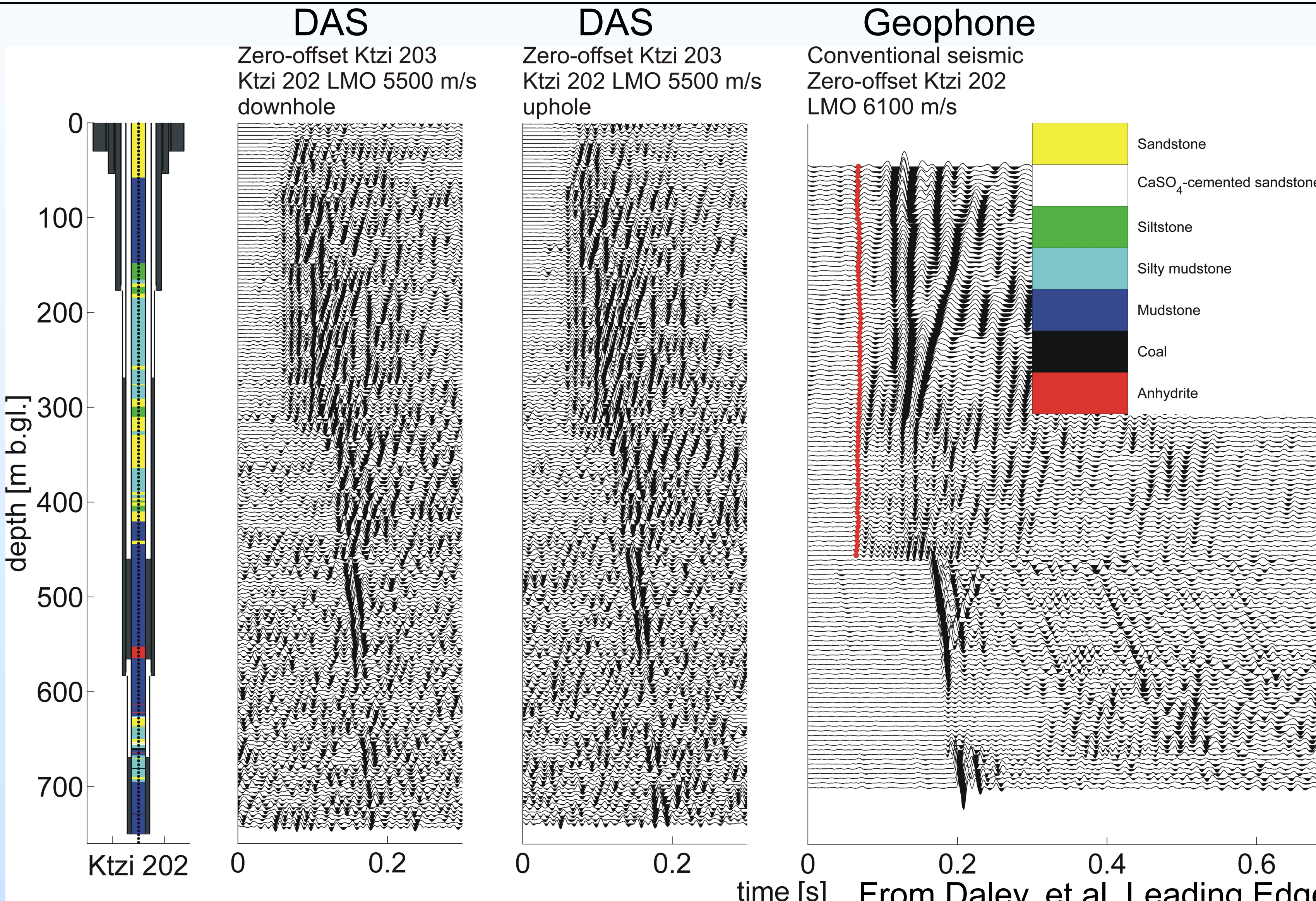
Distributed Acoustic Sensing (DAS)

- Goal: Robust, less expensive, continuous monitoring
- DAS acquisition allows seismic monitoring with fiber optic
  - Sensitivity less than standard geophone, but
  - Spatial sampling and ease of deployment much greater



DAS Data from Ketzin CO2 Pilot

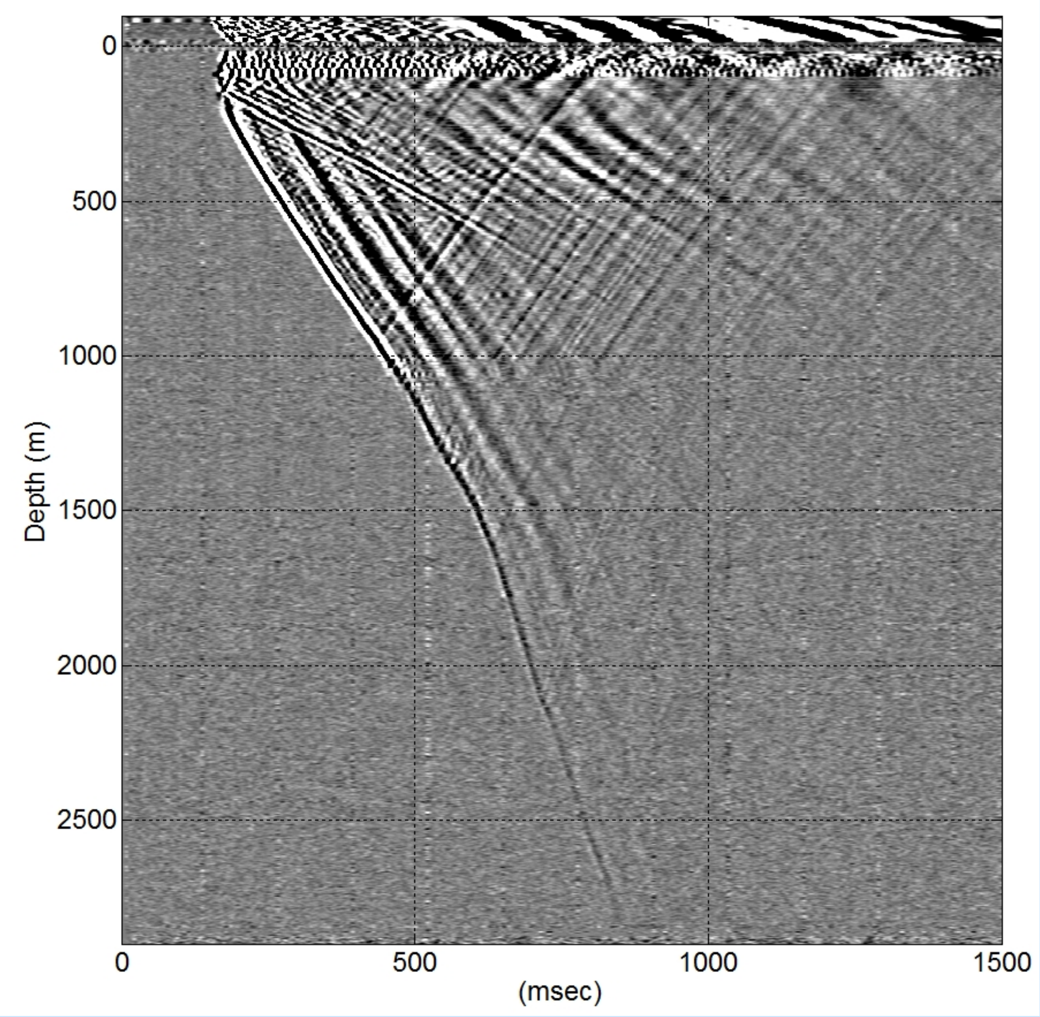
Fiber deployed behind casing (but not cemented at all depths)



From Daley, et al, Leading Edge, 2013
Analysis courtesy GFZ

Aquistore Project: DAS Vertical Seismic Profile

- Behind Casing, cemented, 3 km, explosive shot



Raw data, May 2013

Accomplishments to Date

- Petrophysics
  - Development of Resonant Bar with CT Scanning
  - Seismic theory tested with measurements at field scale (wavelength) on GCS reservoir core
  - Improved estimates of in-situ CO_2 saturation
- Geochemical Processes
  - Analsyis of core samples spanning expected rock types
  - Emphasize metal mobilization and impact of O_2 fugacity
  - Develop simplified screening tests that industry can use to evaluate site suitability and predicted performance
- Instrumentation Development
  - Improved fluid sampling (U-tube)
  - Improved seismic monitoring (CASSM, Orbital Vibrator)
  - Development/Testing of Fiber Optic Technology

Summary

– Key Findings
  - Seismic estimates of saturation need petrophysical measurements and constraints
  - Need simplified screening tests for geochemical effects
  - Fiber optic monitoring has notable potential

– Lessons Learned
  - Fundamental studies are needed and best motivated by field applications

– Future Plans
  - Further analysis and development of
    – petrophysical relationship between seismic velocity and CO_2 saturation
    – Geochemical effects on GCS on reservoir rocks
    – Monitoring technology and tools

Appendix

– These slides will not be discussed during the presentation, but are mandatory

Organization Chart

- Fundamental Studies is a subtask of LBNL's Consolidated Sequestration Research Program lead by Barry Freifeld
- Closely linked to GEO-SEQ also lead by Barry Freifeld
- Fundamental Studies has three tasks with principal investigators (PI) and scientific task leads
  - PI: Tom Daley
    - Petrophysical Relationships PI: Tom Daley
      - Task Leads: Seiji Nakagawa, Tim Kneafsey, Jonathan Ajo-Franklin
    - Geochemical Assessment PI: Kevin Knauss
    - Monitoring Instrumentation PI: Tom Daley
      - Task Leads: Barry Freifeld, Jonathan Ajo-Franklin

Fundamental Studies	Title	Role in Task/Subtask
T. Daley	PI and Research Scientist	Lead scientist for fundamental studies
S. Nakagawa	Research Scientist	Scientist working on rock mechanics using resonant bar apparatus
J. Ajo-Franklin	Research Scientist	Geophysicist supporting laboratory studies and field seismic data processing
M. Robertson	Project Scientist	Coordinator of field projects and oversees geophysical measurement facility support
P. Cook	Scientific Engineering Associate	Mechanical engineering and project support
K.G. Knauss	PI and Research Scientist	Geochemist supervising laboratory studies
J.P. Icenhower	Research Scientist	Geochemist working on CO2 laboratory studies
G.D. Saldi	Postdoc	Geochemist working on CO2 laboratory studies
N.J. Pester	Postdoc	Geochemist working on CO2 laboratory studies

Gantt Chart

- The Fundamental Studies Task began in FY13 with reorganization of LBNL's CSRP. FY13 milestones shown.
- Current planning for FY14 is in progress.

	Q1 FY13			Q2 FY13			Q3 FY13			Q4 FY13		
Subtask Description	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**
Task 3 Fundamental Studies												
Subtask 3.1 Petrophysics										F		
Subtask 3.2 Partioning Tracers												
Subtask 3.3 Fundamental Studies: Geochemical Assessment												
Subtask 3.4 Monitoring Instrumentation Development			E									

Bibliography (FY13)

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Geochemical Assessment

- **Accomplishments**
  - Completed all phases for Cranfield Reservoir
  - clean sand, dirty sand and altered sand
  - Participated in international calibration exercise
    - Develop CO_2 sequestration research experimental protocols
- **Plans**
  - Complete carbonate case experiments
  - Complete “real” brines experiments
  - Design simplified tests specific to rock type