GEO-SEQ

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Barry Freifeld

Earth Sciences Division

Lawrence Berkeley National Laboratory

U.S. Department of Energy

National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Building the Infrastructure for CO_2 Storage

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Presentation Outline

- Goals and objectives
- Success criteria
- Technical Status
- Accomplishments to date
- Summary of key findings and lessons learned
- Future plans

Benefit to the Program – Goals and Objectives

- GEO-SEQ is a broad program supporting the Carbon Storage Program's major storage goals
  - Develop technologies that will support industries' ability to predict CO_2 storage capacity in geologic formations to within ± 30%
  - Develop technologies to demonstrate that 99 percent of injected CO_2 remains in the injection zones
- The GEO-SEQ project leverages scientific understanding and technology development through collaboration with highly visible, ongoing, world-class projects including the Otway Project and In Salah JIP. In Fy12 GEO-SEQ initiated a new collaboration with the PTRC's-managed Aquistore Project.
- GEO-SEQ investigates fundamental geochemical and petrophysical processes that underpin GCS merging laboratory research to address field-scale issues

Project Overview: Success Criteria

- Fundamental Studies process and response studies – success criteria is the petrophysical measurement of reservoir and cap rock using the resonant bar system at frequencies relevant to field scale
- CO2CRC Otway Project collaboration – success criteria is the collection of field-scale data and interpretation to establish a single-well residual saturation test
- In Salah JIP – success criteria is presentation of unique data collected in collaboration with InSalah researchers of the Joint Industry Partnership (JIP)
- Geochemical Assessment – the success criteria is development of a methodology for assessing the suitability of saline aquifers and depleted oil reservoirs for carbon sequestration

Technical Status

- International collaboration – field demonstrations
  - Australia's CO2CRC Otway Project (since 2005)
  - In Salah JIP Project (since 2006)
  - Aquistore Project (new collaboration started in 2012)
- Fundamental Studies (since 2009)
  - Laboratory Petrophysics
  - Laboratory Tracer Testing Studies
  - Coupled Reservoir Modeling and Field Monitoring
  - Monitoring Technology Development
- Geochemical Assessment (since 2010)

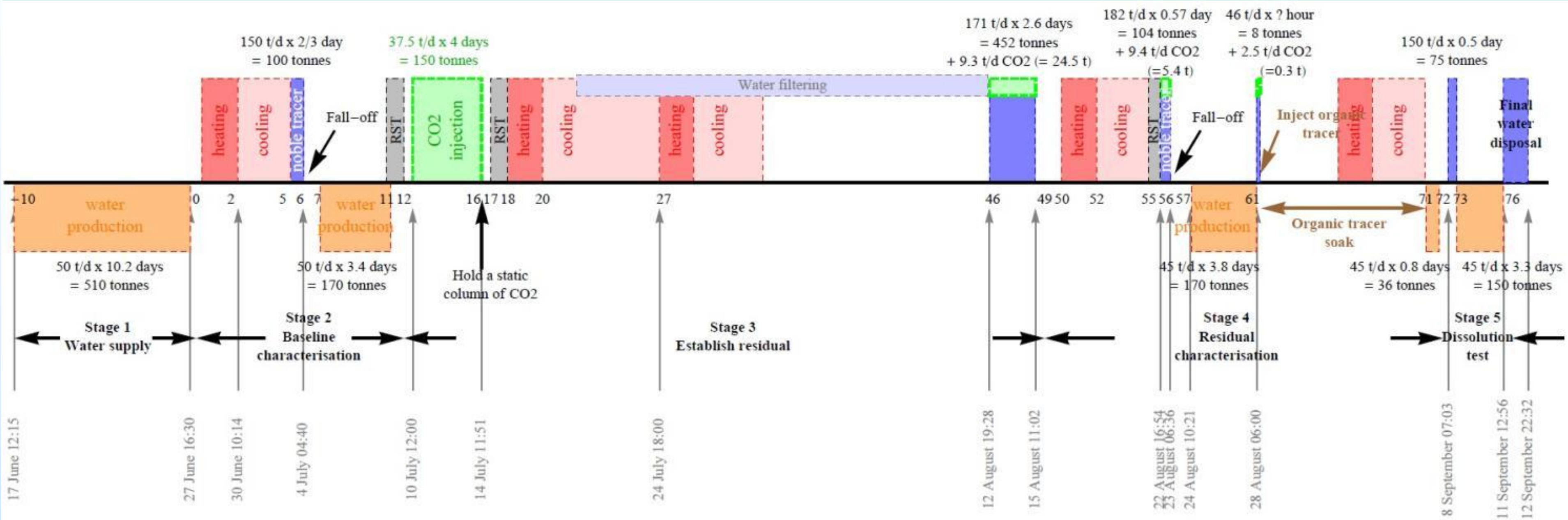
Otway Project Stage 2c

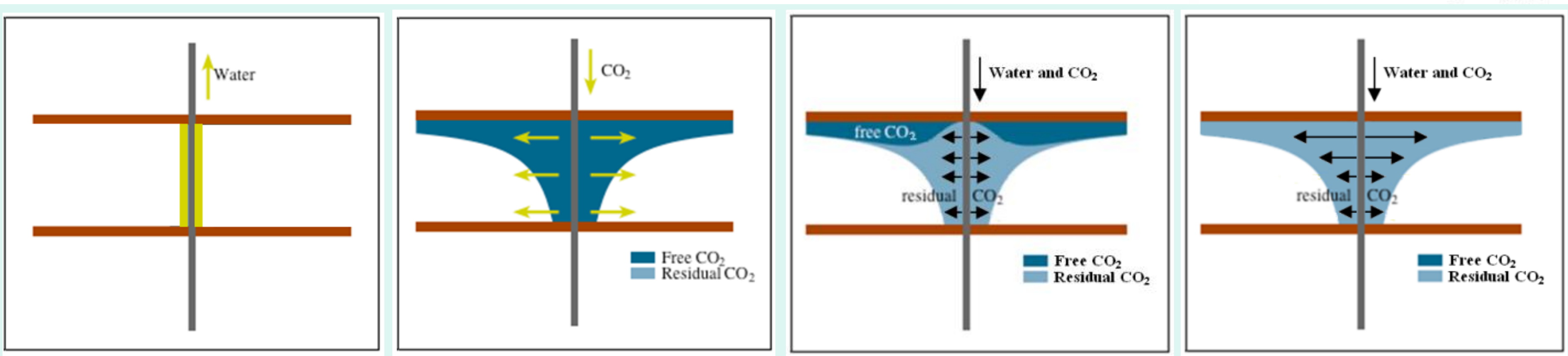
Leveraging $15M Australian Program –

- •LBNL Supplied CRC-2 monitoring equipment
- •Performed successful completion
- •Participated in 75 day field campaign to measure residual gas saturation

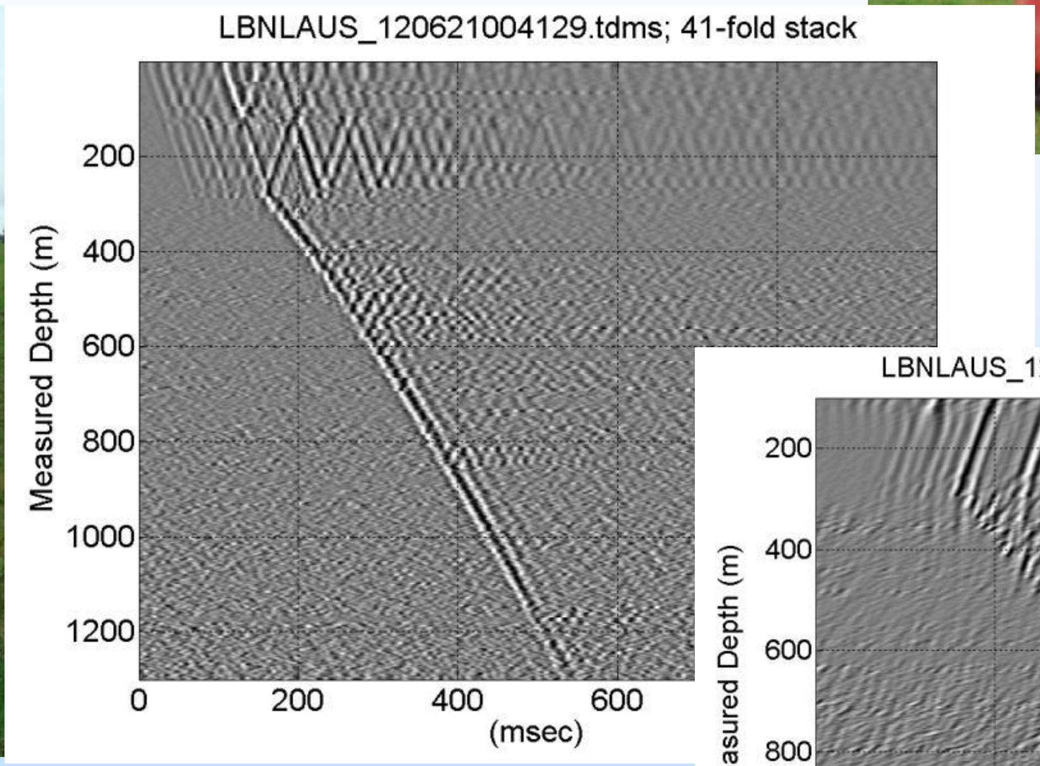
FY12 Accomplishment:

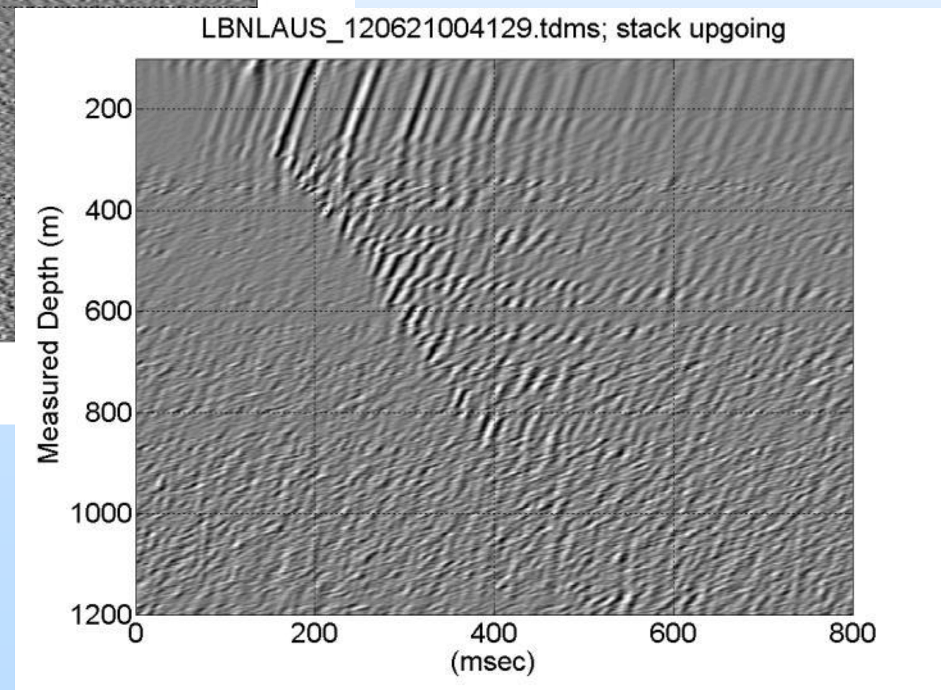
Otway Stage 2b: Residual Gas Saturation Test





Otway Project – May 2012
FO Seismic acquisition

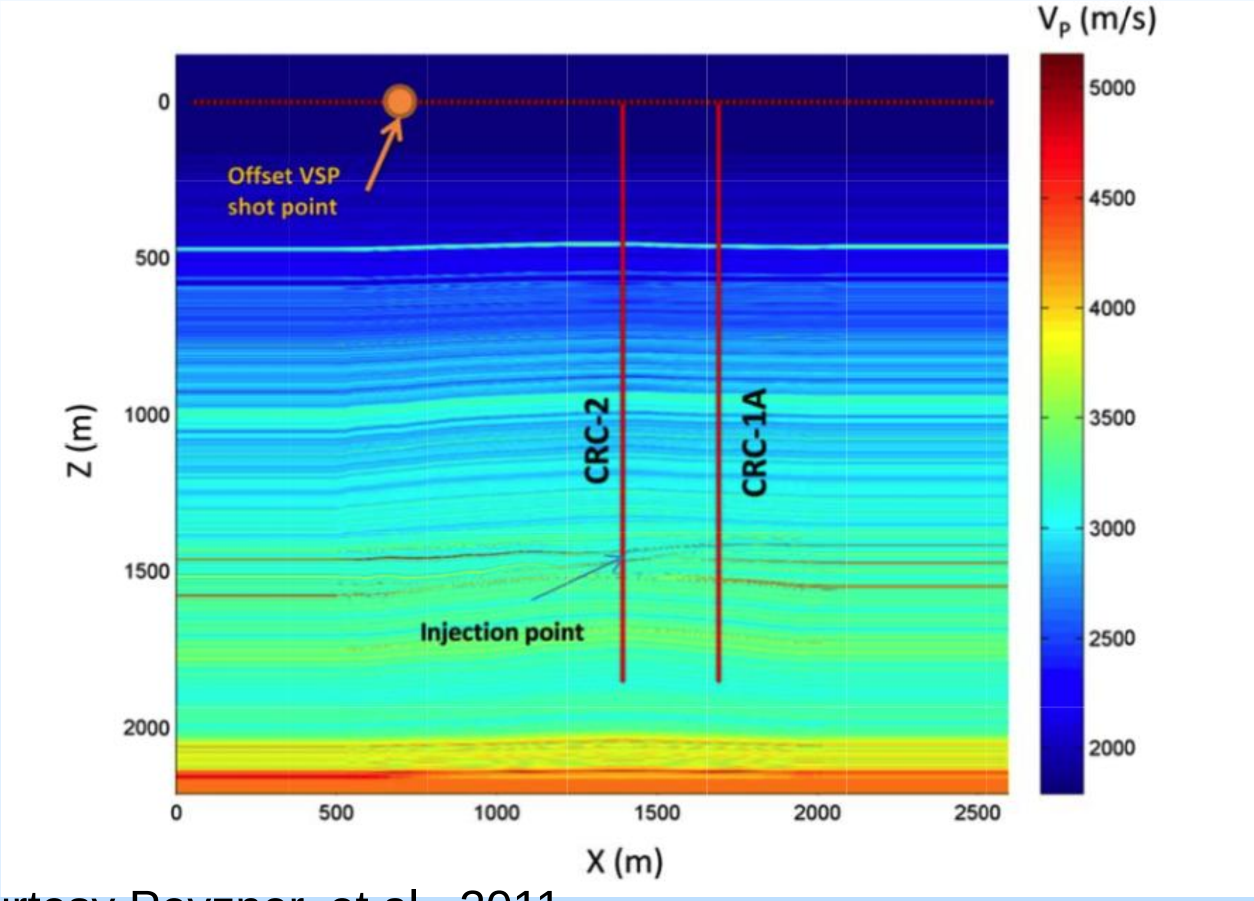




Otway FY13 Planning for Stage 2c 10,000 – 30,000 T injection

Addition of Crosswell to Seismic Monitoring Plan

Permanent seismic monitoring array

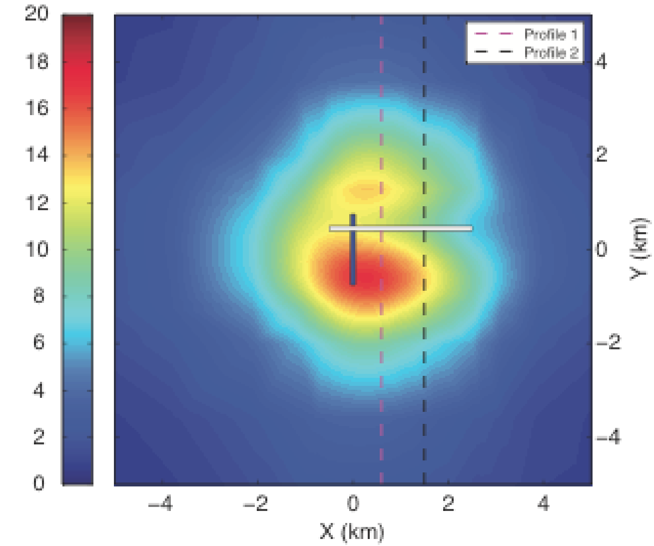


Courtesy Pevzner, et al., 2011

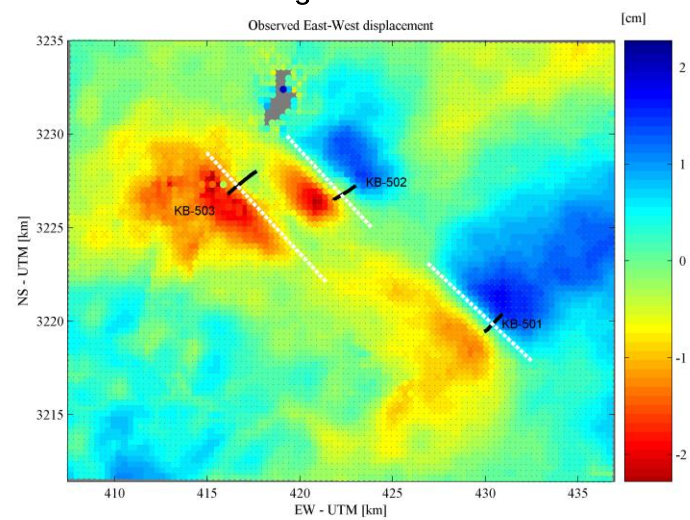
LBNL Orbital Vibrator Seismic Source

In Salah Project FY12

- **Simulation of Large Scale Deformation and Stress Changes via Coupled Modeling**
  - Constraining fracture zone height; Induced seismicity with cooling effects; New models for stress and multiphase flow in fractured reservoirs
- **Inverse Modeling**
  - Well scale model (Initial forward model); Reservoir scale model (Leverage with NRAP-ARRA)
- **Analysis of Ground Surface Deformations from InSAR**
  - Horizontal and vertical components
- **Microseismic Monitoring and Analysis**
- **Fracture Based Seismic Analysis**
  - 3D seismic being reprocessed and analyzed for fractures

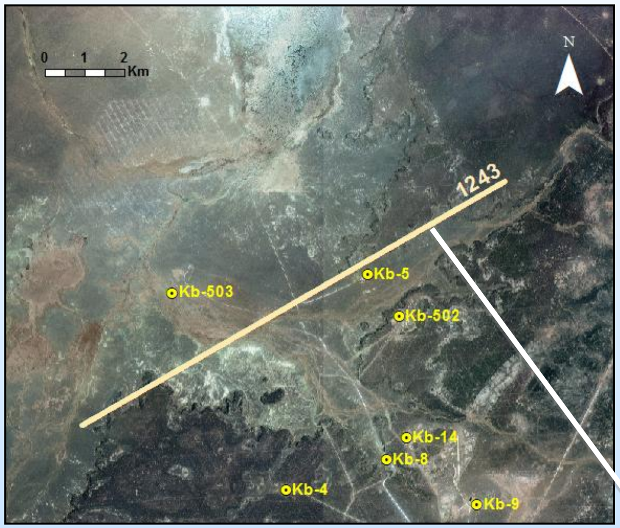


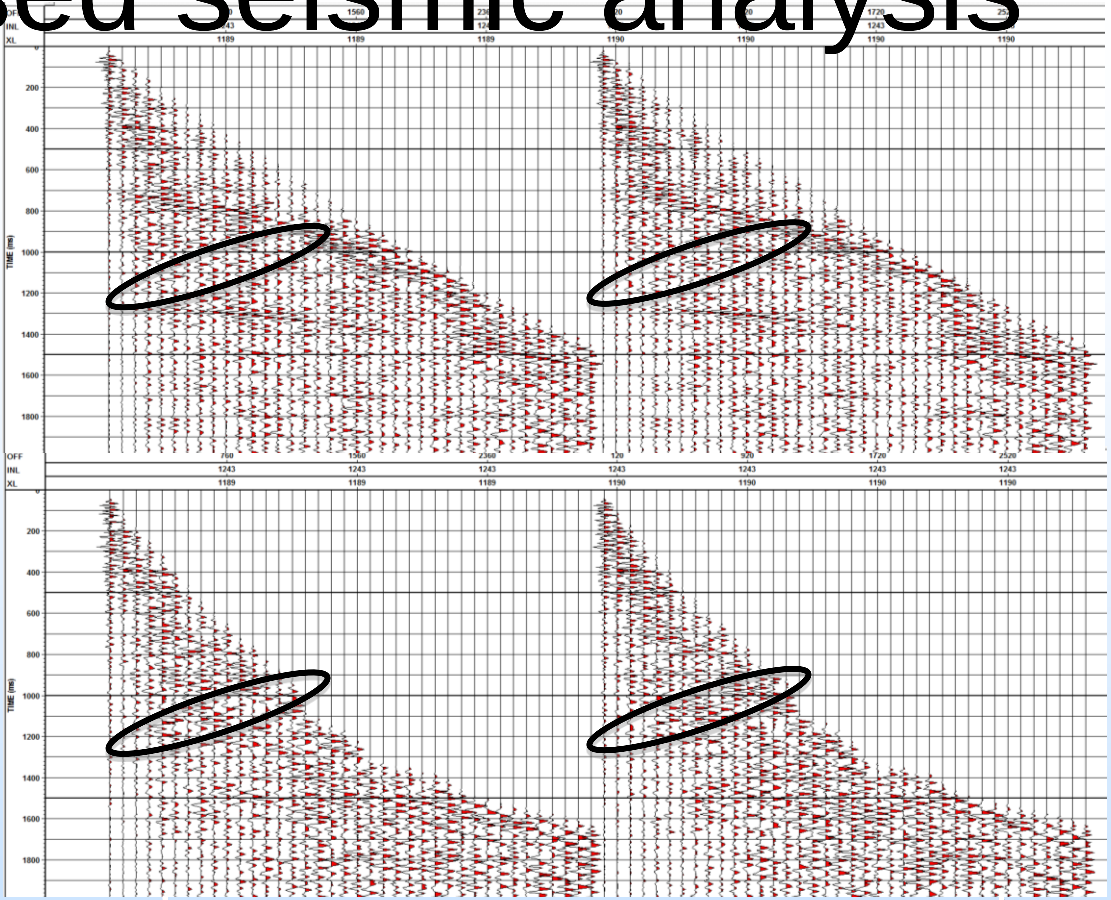
Coupled flow and geomechanics to constrain height of fracture zone

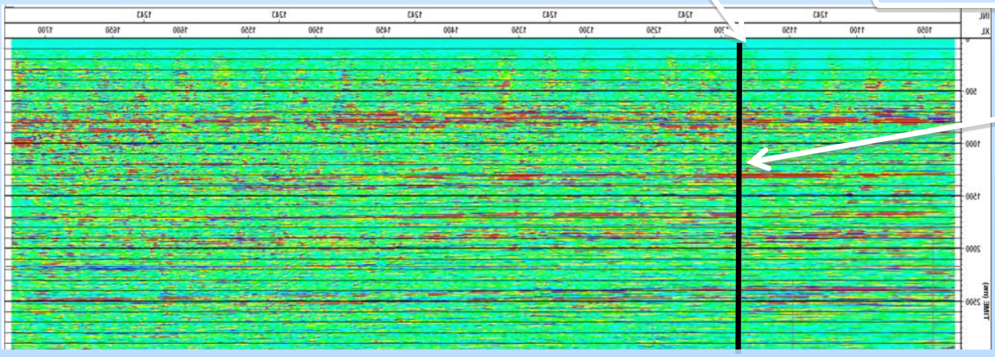


InSAR Horizontal component

Fracture-based seismic analysis



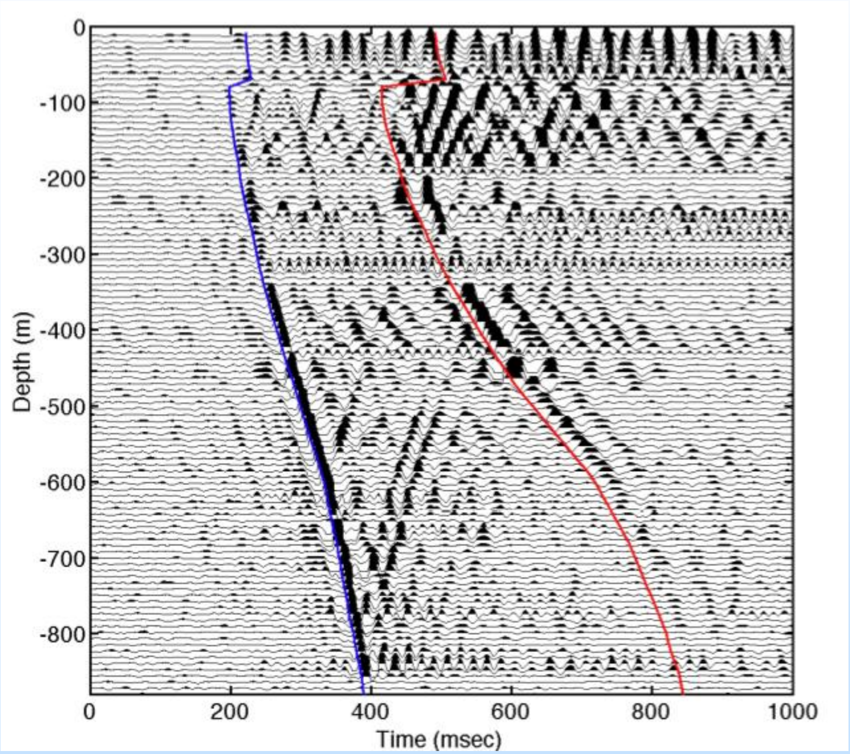




In collaboration with Dr. Harbert of the Univ. of Pittsburgh

Subtask 2.4: Aquistore Project

VSP Data from Borehole Fiber



Miller, et al., EAGE, 2012

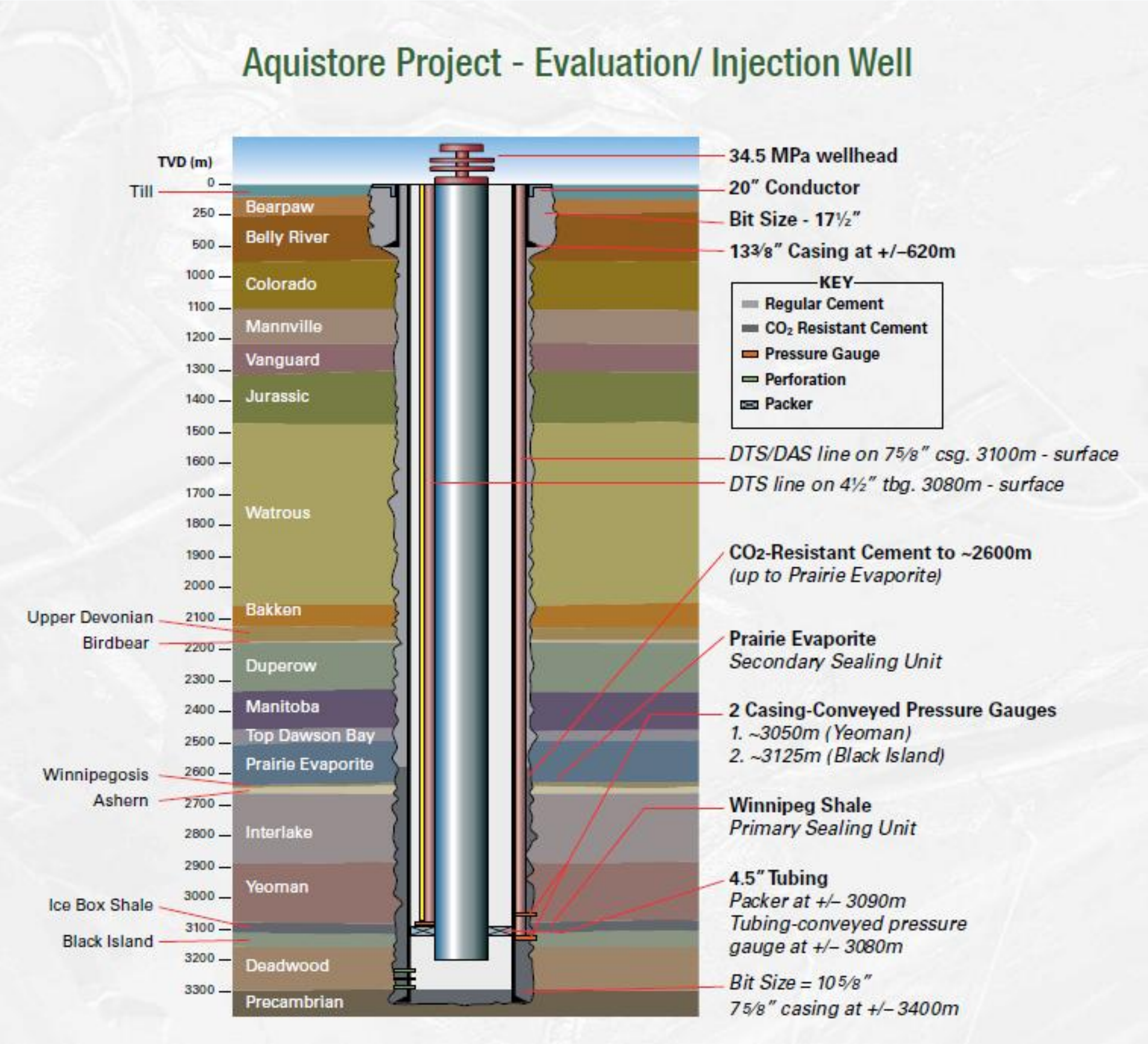
Fiber Optic Distributed Seismic

- Field testing and analysis of new fiber-optic monitoring technology
- LBNL collaborating with PTRC-led project to install a fiber-optic cable for performing acoustic and DTS monitoring of the Aquistore's injection well

Subtask 2.4: Aquistore Project

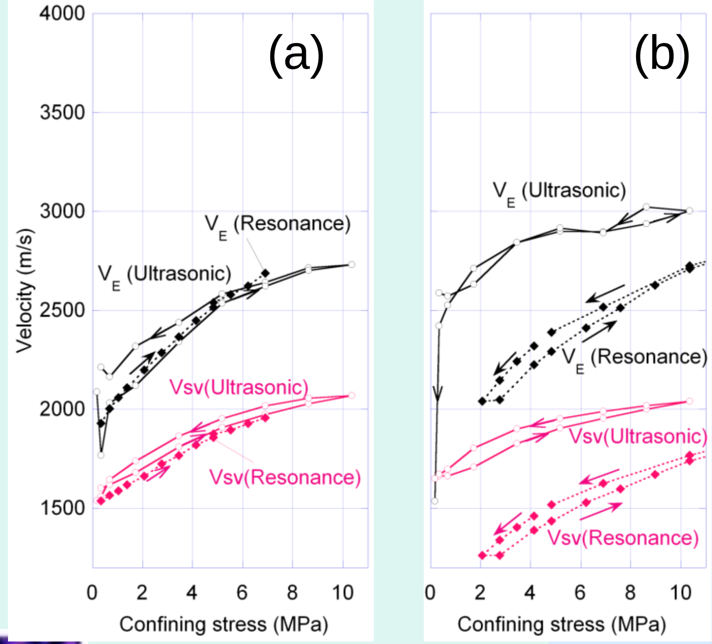
Highly leveraged research –

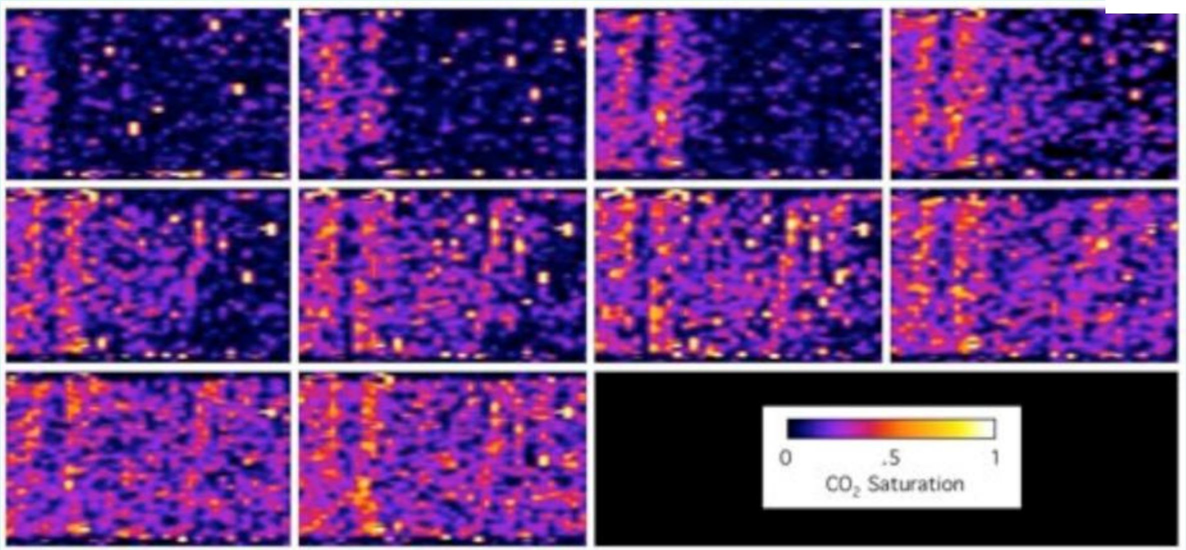
Using the large investment in the Aquistore project, perform a direct comparison of fiber-optic DAS and conventional geophone technology



Subtask 3.1: Petrophysics

Lab measurement of seismic velocity vs CO_2 saturation – Tuscaloosa (Cranfield)





CO_2 Injection into core

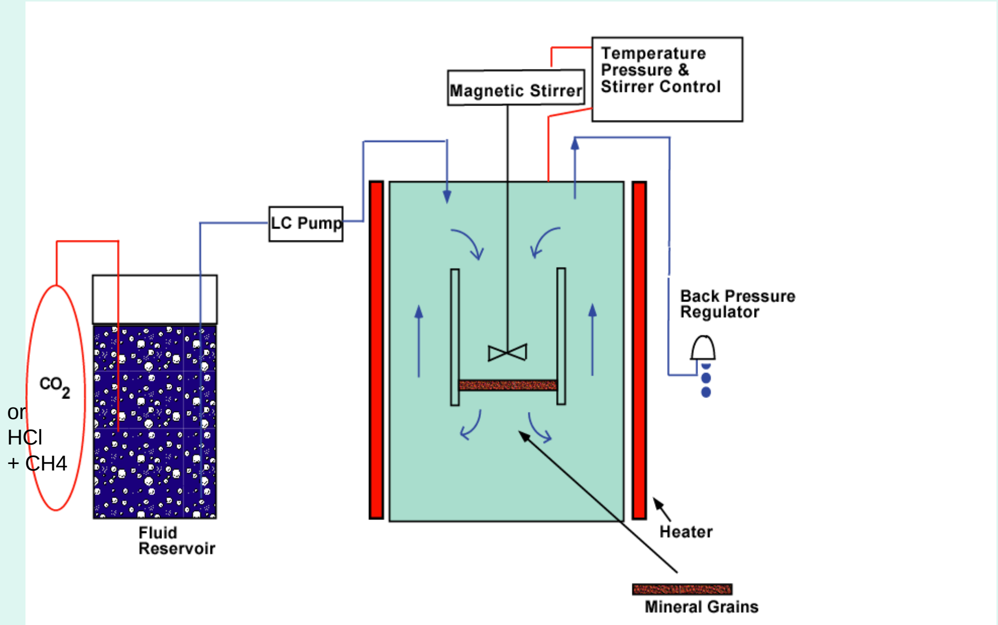
Velocity Measurement comparing ultrasonic and resonant bar
(a) Dry
(b) Brine saturated

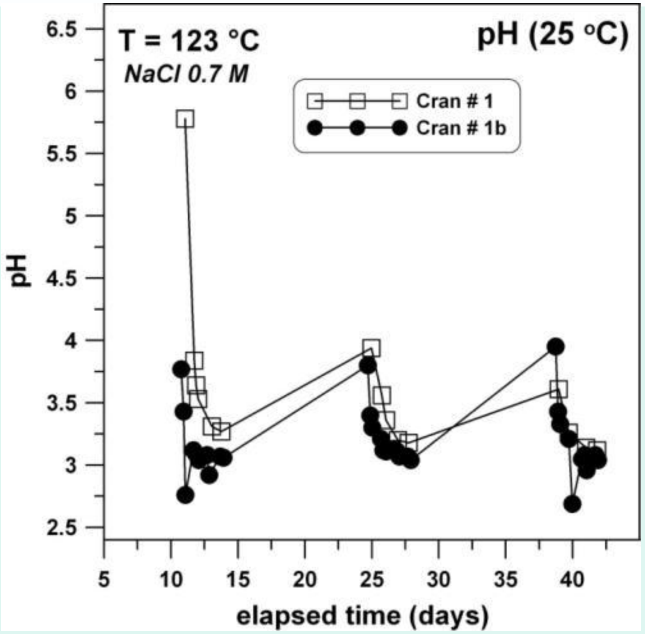
Drs. Nakagawa & Kneafsey, LBNL

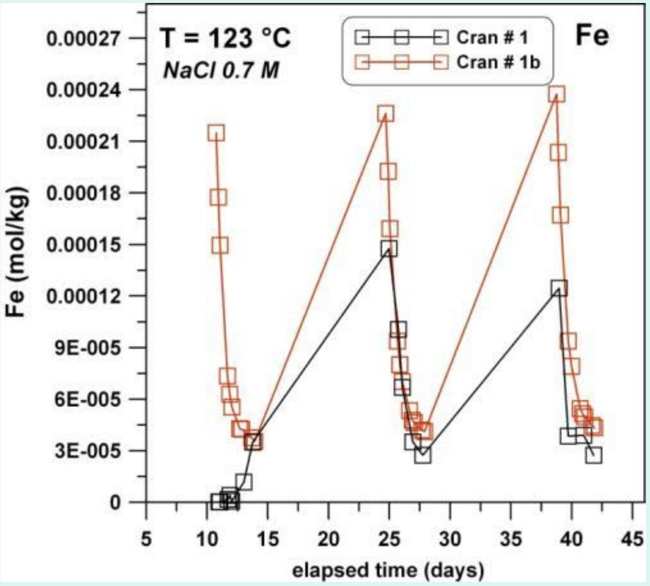
Geochemical Assessment

Cranfield Mixed Flow Reactor Experiments

- Cran#1 w/o O_2 control
- Cran#1b O_2 controlled by methane fugacity
  - Little impact on chlorite dissolution rate or pH
  - Strong impact on metal release rate and concentration







Accomplishments to Date

- Fundamental Studies
  - Development of monitoring tools using leveraged field opportunities
    - U-tube fluid sampler and the piezo-tube seismic source
  - Laboratory Phase-Partitioning Tracer Studies (Krypton completed)
  - Conducted Petrophysical Laboratory Measurements using resonant bar apparatus
- Otway Project
  - Successfully installed multifunction monitoring system in CRC-2
  - Completed 75 day residual saturation test program
  - Performed a walk-away VSP using a fiber-optic acoustic monitoring system

Accomplishments to Date

- In Salah JIP Project
  - Performed Simulation of Large Scale Deformation and Stress Changes via Coupled Modeling (1) Constraining fracture zone height; (2) Induced seismicity with cooling effects; (3)New models for stress and multiphase flow in fractured reservoirs
  - Inverse Modeling using both Well scale model (Initial forward model); Reservoir scale model (Leverage with NRAP-ARRA)
  - Analysis of Ground Surface Deformations from InSAR with both horizontal and vertical components
  - Microseismic Monitoring and Analysis
  - Fracture Based Seismic Analysis with 3D seismic being reprocessed and analyzed for fractures
- Geochemical Asessment
  - Completed all phases for clean sand, dirty sand and altered sand
  - Participated in GaMin’11 international calibration exercise
  - Developed CO_2 sequestration research experimental protocols

Summary – Key findings & lessons learned

Task 1 Fundamental studies

Tom Daley (PI)

- Key findings
  - The resonant bar technique has proven valuable in understanding wave propagation at field relevant frequencies
  - measurement of saturation vs velocity for Cranfield (Tuscaloosa) using resonant bar showed effects of "patchy" saturation and strong anisotropy
- Lessons learned
  - Commencement of testing of orbital vibrator seismic source for CO_2 monitoring revealed need for significant engineering investment before future field deployment.

Task 2 Otway Project

Barry Freifeld (PI)

- Key findings
  - Otway Project Stage 1 demonstrated safe secure storage of CO_2 in a depleted gas reservoir (PNAS publication)
  - Otway Project Stage 2 Residual Gas Saturation test shows both the potential and difficulties in the single-well approach
- Lessons learned
  - Careful planning and simplified engineering can result in a fully operational well-based monitoring system

Task 3 In Salah JIP

Jonny Rutqvist (PI)

- Key findings
  - The use of ground surface monitoring by InSAR has exceeded all expectations, enabling monitoring of the underground injection performance and detection fluid movements and fluid pressure propagation through underground geological structures.
  - Potential injection-induced opening of deep fracture zones at the lower part of the caprock have been identified and analyzed in terms of coupled geomechanical processes and fracture zone geometry.
  - A 3D seismic survey has been very valuable to independently identify such fracture zones at depth in the lower part of the capock.
  - The combined monitoring of InSAR and mircroseismicity, complemented by 3D seismic survey have proven to be useful for monitoring and early detection of unwanted geomechanical changes, and preventative actions could be taken, such a lowering injection pressure. .
- Lessons learned
  - Micro-seismic monitoring shows a correlation between number of events and injection rates, but more comprehensive seismic network would be needed and should have been deployed before the start of the injection for optimum utilization as a monitoring tool.

Task 4 Geochemical Assessment

Kevin Knauss (PI)

- Key findings
  - Metals are released from all reservoir rock types by acidification by CO_2, but as the solution is neutralized by continued interaction, the metals largely re-associate with the rock. Specific details depend upon reservoir rock type.
- Lessons learned
  - The redox state is important in understanding metal release and ultimate fate of mobilized metals.

Future Plans (FY13)

- Fundamental processes
  - Continue to use resonant bar system to investigate seismic propagation
  - Investigate use of fiber-optic acoustic technology and further engineer borehole orbital vibrator
- Otway Project
  - Continue analysis of Stage 2b data
  - Participate in Stage 2c injection test and geophysical monitoring (cross-hole orbital vibrator)
- InSalah JIP
  - Continue detailed coupled process model analysis
  - Investigate fracture propagation in caprock
  - Continue interpretation of InSAR data
- Aquistore
  - Use fiber-optic methods, participating in initial 1600 T injection experiment followed by much larger injection
- Geochemical Assessment
  - Complete carbonate case experiments
  - Complete “real” brines experiments
  - Design simplified tests specific to rock type

Appendix

Organization Chart

Project Coordination and management: Barry Freifeld and Tom Daley

Task PIs				
	Task 1: Fundamental Processes Tom Daley	Task 2: Otway Project Barry Freifeld	Task 3: In Salah JIP Jonny Rutqvist	Task 4: Geochem Assess Studies Kevin Knauss

LBNL Scientists and Technical Staff

Brian Bonner, Paul Cook, Christine Doughty, Stefan Finsterle, Jonathan Ajo-Franklin, Karl Kappler, Burton Mack Kennedy, Timothy Kneafsey, Jennifer Lewicki, Hui-Hai Liu, Ernie Majer, Alejandro Morales, Seiji Nakagawa, Curt Oldenburg, John Peterson, Karsten Pruess, Tian-Fu Xu, Donald Vasco, Yingqi Zhang

Collaborating Organizations – primary contacts

Australian CO2CRC – Richard Aldous, Matthias Raab, Rajindar Singh

Texas Bureau Economic Geology – Susan Hovorka, Tip Meckel

In Salah JIP (BP, Sonatrach, Statoil) – Alan Mathieson, Iain Wright

USGS Menlo Park – Yousif Kharaka

ORNL – Tommy Phelps

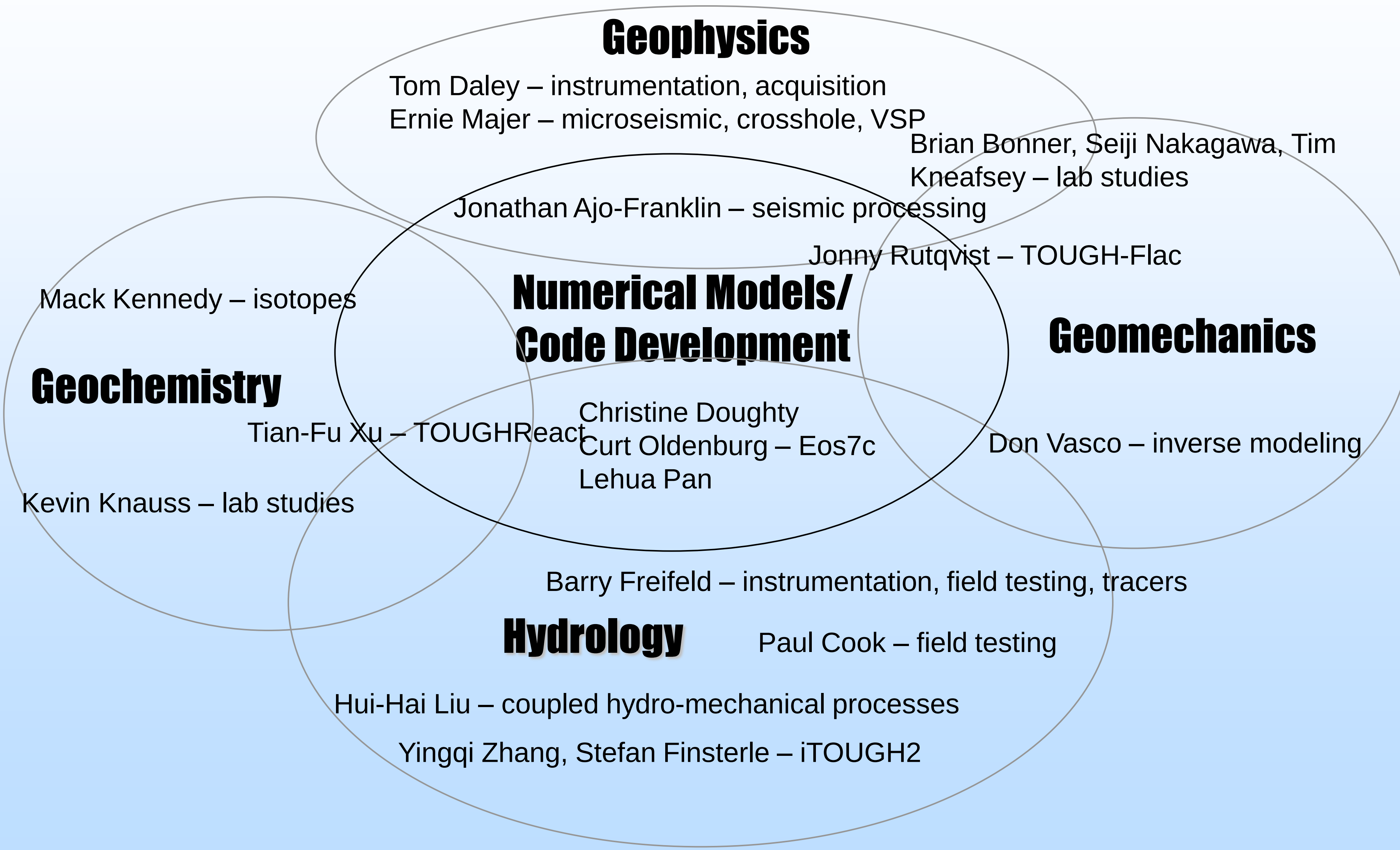
Alberta Innovates – Ernie Perkins

Simon Fraser University – Dirke Kirste

CSIRO Petroleum – Linda Stalker

Geosciences Australia – Chris Boreham

Multidisciplinary Team Capabilities



Task 1. Fundamental Processes Milestones

	FY10	FY11	FY12
Task 1 Fundamental processes and response studies			
1.1 Petrophysical laboratory measurements			
3.2 Laboratory phase-partitioning tracers			
3.3 Coupled reservoir model and field data			
3.4 Monitoring technology development			
Milestones			
FY10 Q4 Completion of documentation in support of commercializing CASSM technology			
FY11 Q2 Report on initial resonant bar measurement of seismic velocity and attenuation as a function of CO2 saturation for standard core sample			
FY12 Q2 Report on initial resonant bar measurement of seismic velocity and attenuation as a function of CO2 saturation for reservoir core sample.			

Task 2. Otway Project

	FY10	FY11	FY12
2.1 Field testing			
2.2 Laboratory measurements			
2.3 Modeling and simulation			
2.4 Planning and coordination			
Milestones			
FY10 Q1 Preliminary design of a Single-Well Huff-N-Puff test for Otway Stage II			
FY11 Q1 Description of instrumentation for monitoring the Single-Well Huff-N-Puff test for Otway Stage II			
FY12 Q3 Otway Stage 2c experiment design report			
FY12 Q1 Preliminary interpretation and data report from the Otway Project Stage 2b test			

Task 3. In Salah JIP

	FY07		FY08		FY09	
3.1 Reservoir data collection						
3.2 InSAR data analysis						
3.3 Simulation of injection						
3.4 Deployment of surface seismic network						
3.5 Simulation of stress change						
Milestones						
FY10 Q3 InSalah microseismic monitoring: Documentation of the instrument design and the as-built, as-installed, field instrumentation						
FY11 Q3 Interim assessment of surface deformation for the In Salah demonstration project using acquired satellite-based interferometry (InSAR) data						
FY11 Q3 InSalah microseismic monitoring: Report on data acquisition using the microseismic array.						
FY12 Q2 Interim assessment of Algerian In Salah storage project time lapse surface changes intergrated with geomechanical models						

Task 4. Geochemical Assessment

	FY10	FY11	FY12
Task 3. In Salah JIP Gas Project			
3.1 Site Data and Sample Acquisition			
3.2 Experiment Simulation and Design			
3.3 Reaction Progress Experiments			
3.4 Assessment Methodology or SOP			
Milestones			
FY10			
FY11			
FY12			

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