GEO-SEQ

LBNL's Consolidated Sequestration Research Program (CSRP)

Project Number FWP ESD09-056

Barry Freifeld

Lawrence Berkeley National Laboratory

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 GEO-SEQ
- Technical Status
  - Otway Project (CO2CRC)
  - In Salah (BP, Sonatrach and Statoil)
  - Ketzin Project (GFZ, Potsdam)
  - Aquistore (PTRC)
- Accomplishments and Summary
- Future Plans

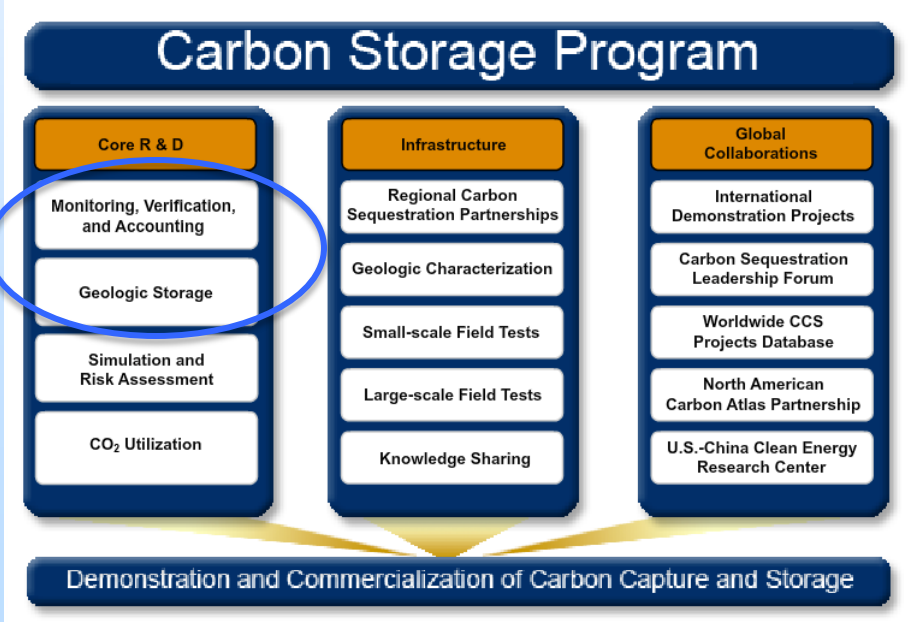
Benefit to the Program

- Program goals being addressed:
  - Develop technologies to improve reservoir storage capacity estimation
  - Develop and validate technologies to ensure 99 percent storage permanence.
- This research addresses these goals through active collaborations with significant international demonstration programs. Research is varied and includes:
    - **Storage Process Monitoring**
    - **Deployment and testing of new monitoring strategies, technologies and tools**

Benefit to the Program

- 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 DOE infrastructure programs
  - publications and presentations made available to all parties interested in removing barriers to commercial-scale geologic carbon sequestration.

Core R&D:
MVA and Geologic Storage



Project Overview: Objectives

- LBNL's Consolidated Sequestration Research Project 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
- Other CSRP talks:
  - Task 3. Fundamental Studies (Tom Daley) after this talk
  - Task 4. Simulation Studies (Jens Birkholzer) 4:45 Wednesday in Simulation/Risk Assessment

Project Overview: Goals

- Improve understanding of storage processes and monitoring through leveraging international research opportunities
  - Improve estimates of storage capacity and sweep efficiency
  - Develop new monitoring tools and technologies to achieve 99% storage confirmation
- Iterative research with Task 3.0 Fundamental Studies
  - Results from Fundamental Studies applied to the field and field observations used to direct future laboratory research

Technical Status

- CSRP restructured in FY12 – explicit separation into more fundamental research and field demonstration in Task 2 & 3
- In FY13 GEO-SEQ focused on collaborations with significant international storage demonstration programs.

CSRP FY 13

Task1.0: Management

Task 2.0: GEO-SEQ

- ***2.1 CO2CRC Otway Project (Australia)***
- ***2.2 In Salah JIP (Algeria)***
- ***2.3 Ketzin Project (Germany)***
- ***2.4 Aquistore (Canada)***

Task 3.0: Fundamental Studies

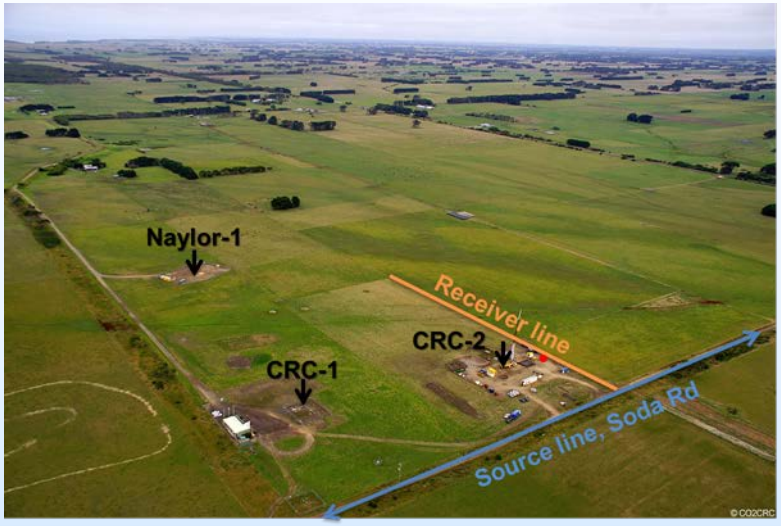
- Petrophysics
- Geochemical Assessment
- Monitoring Instrumentation Development

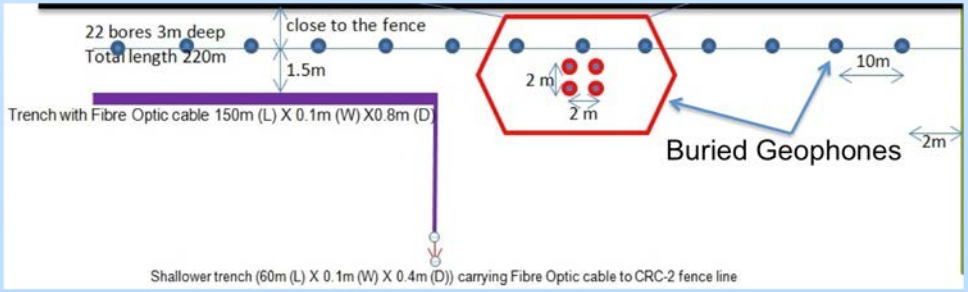
Task 4.0: Simulation Studies

- Large-Scale Impacts
- Sim-SEQ
- CF CO_2-EOR simulation
- Stochastic Inversion

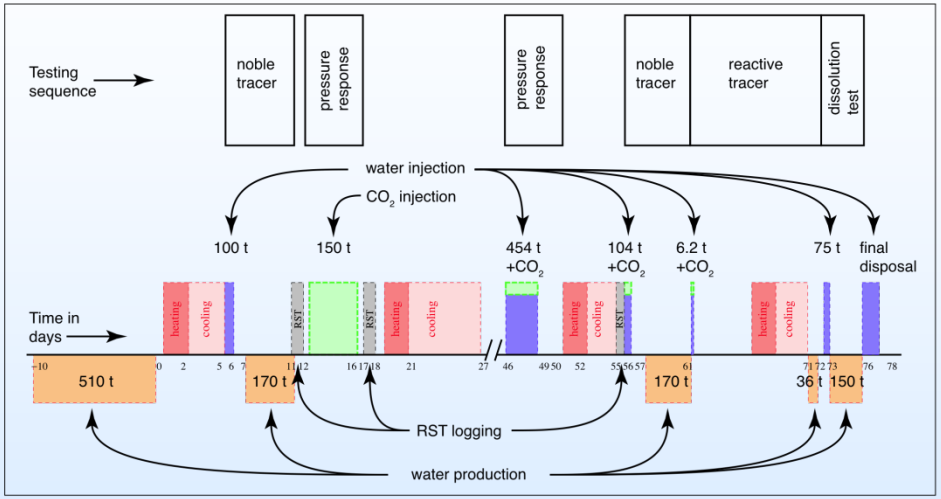
CO2CRC Otway Project

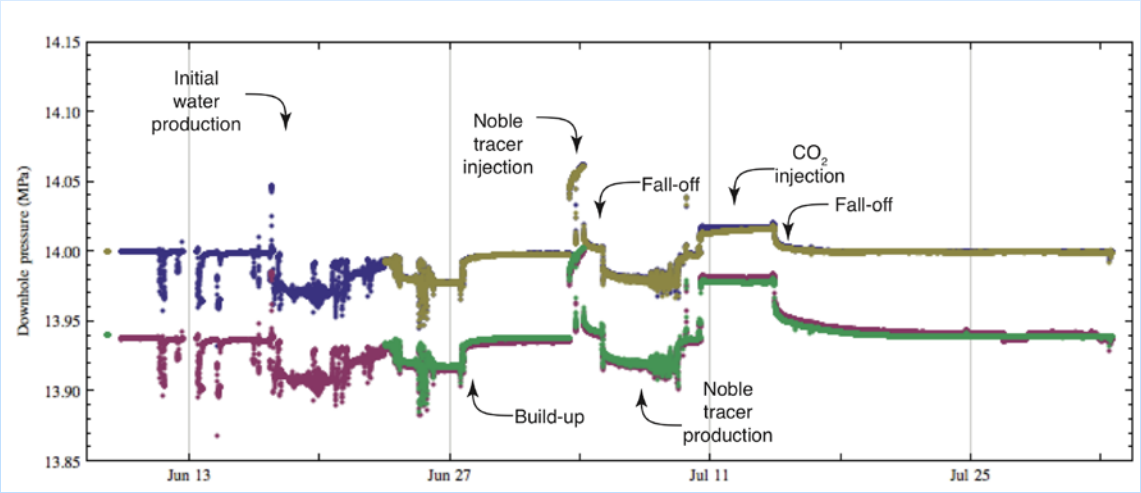
- Stage 2b Residual Saturation Test results presented at GHGT-11
- Fiber-optic/conventional geophone WVSP. Published in The Leading Edge (Daley et al. , 2013)
- Planning ongoing for the Stage 2c injection





Otway Residual Gas Test Results



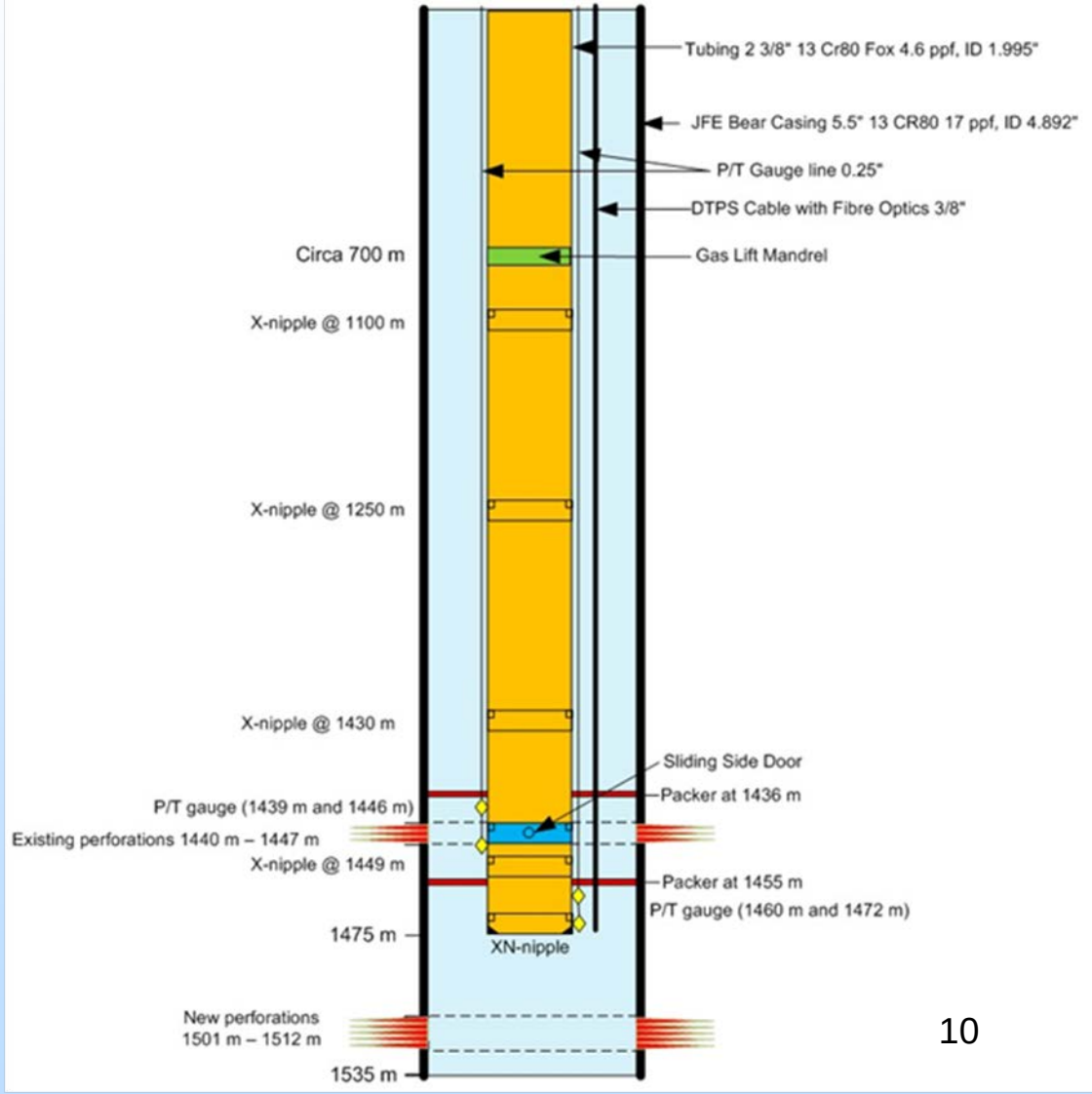


Residual Gas Saturation Estimates

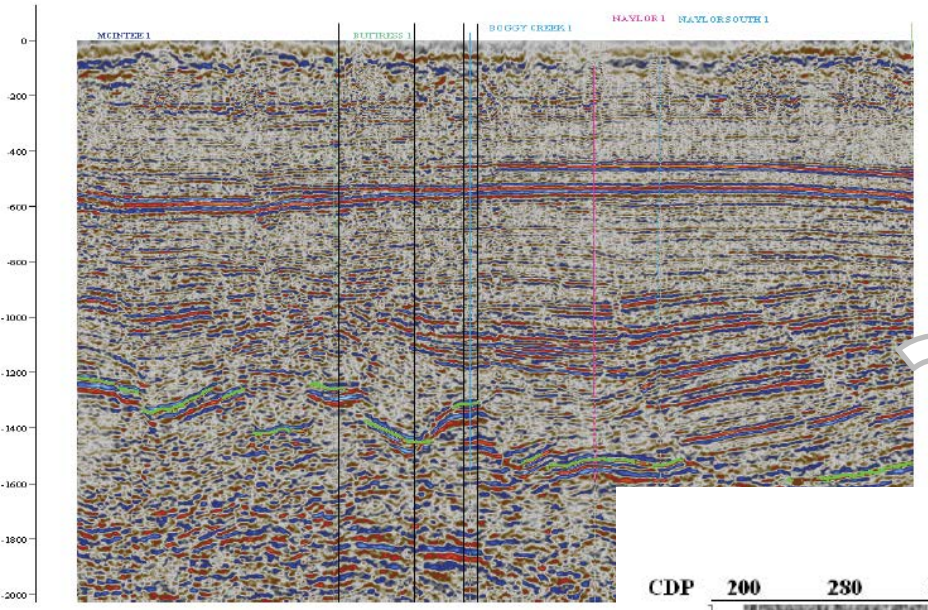
- Pressure transients
- Pulsed-Neutron (RST)
- Tracer analysis
- Dissolution test
- FO Heat-pulse

CO2CRC Otway Project

- Stage 2c – inject 10,000 T and monitor using a permanent buried geophone network
- New technologies
  - Surface CASSM rotary source
  - FO surface and well-based monitoring



Stage 2c – awaiting FID



Existing seismic data used to create synthetic models to test detection sensitivity

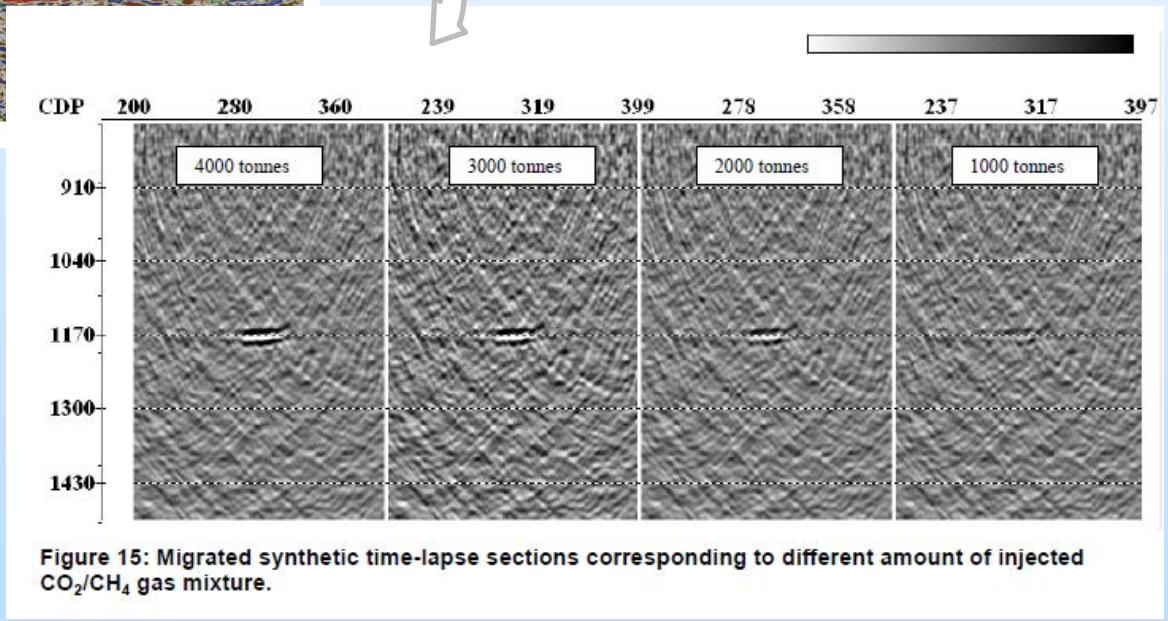


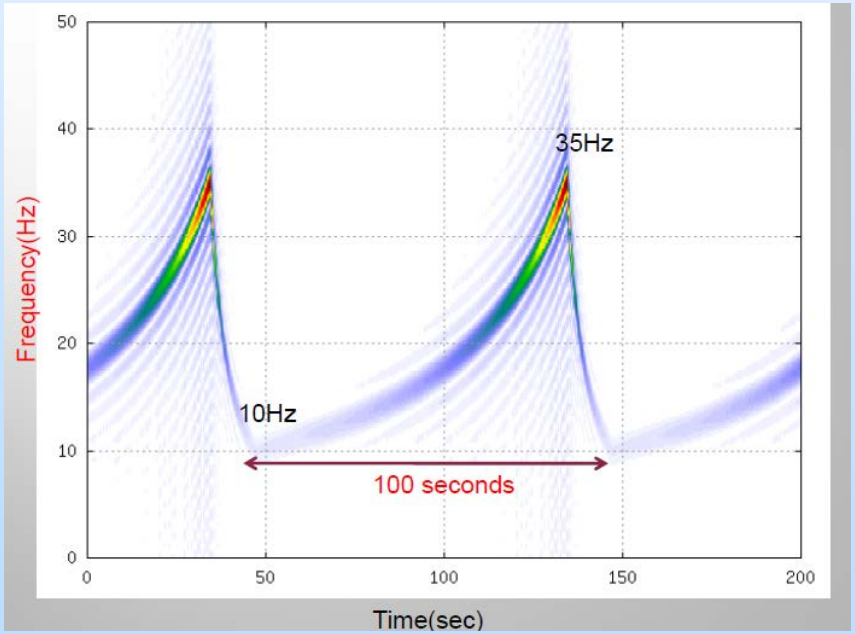
Figure 15: Migrated synthetic time-lapse sections corresponding to different amount of injected CO_2/CH_4 gas mixture.

Synthetic studies: Roman Pevzner, Curtin University

FO ideal for new modalities of data acquisition

LBNL Planned contribution to Stage 2c

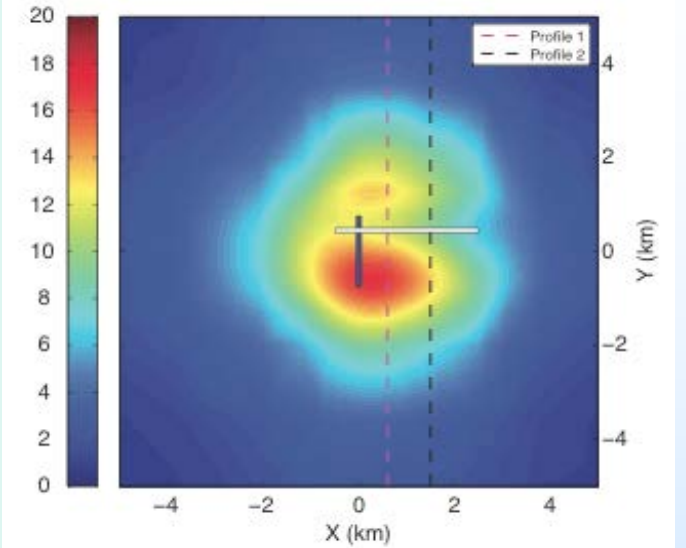
- Borehole orbital vibrator for crosswell imaging
- New design surface CASSM
- Fiber-optic monitoring in parallel with Australian deployed conventional geophones



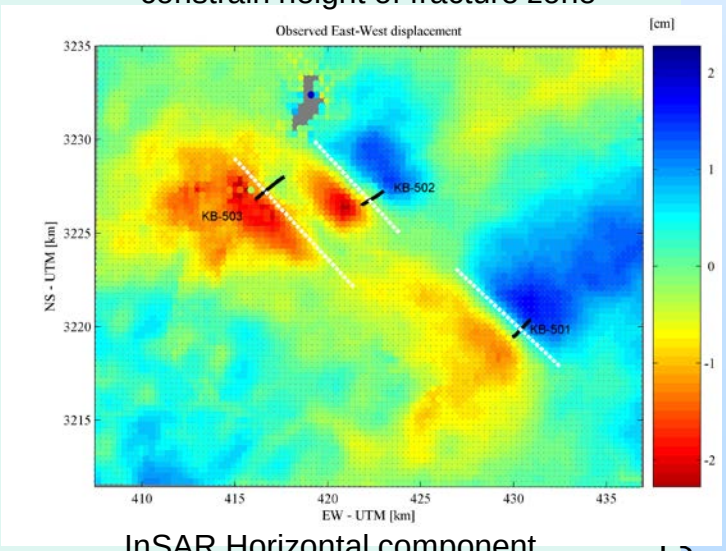
JOGMEC – ACROSS Source
Image: Junzo Kasahara, U. Tokyo

In Salah Project FY13 (LBNL PI: Jonny Rutqvist)

- **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

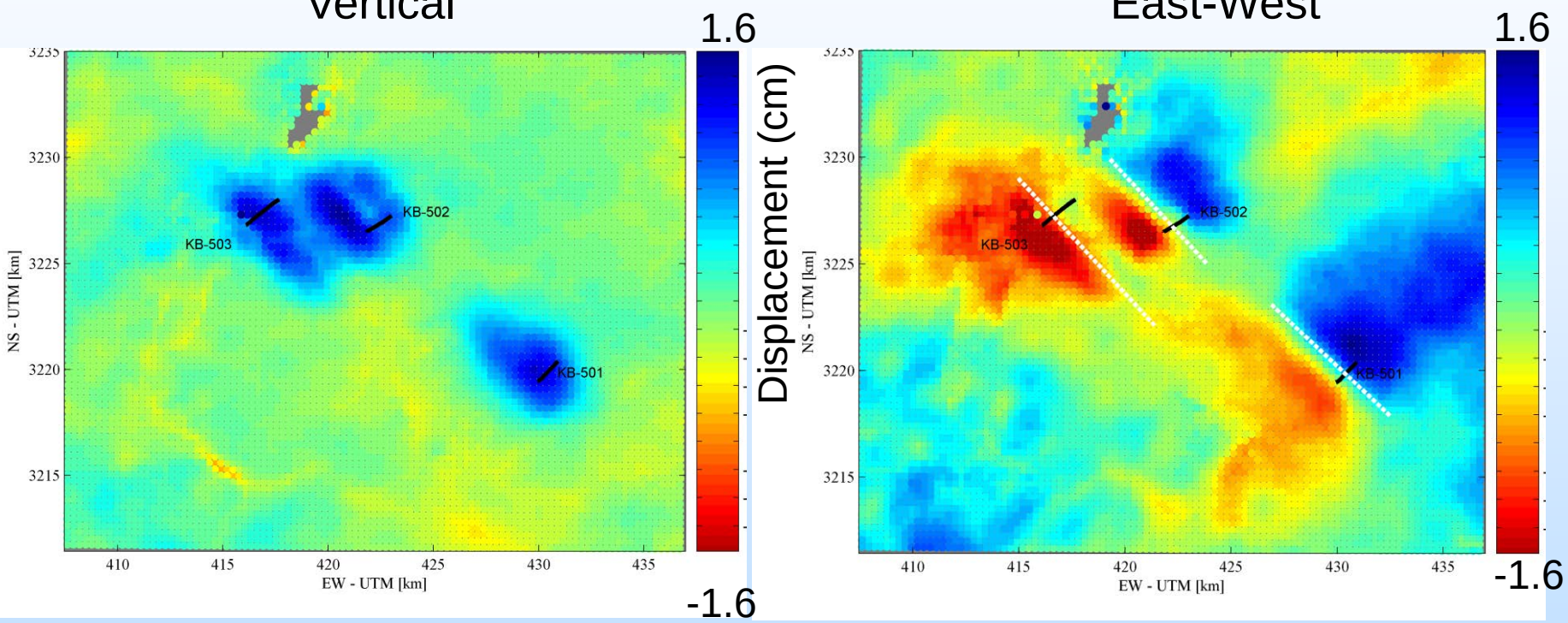


InSAR Horizontal component

2004-2008

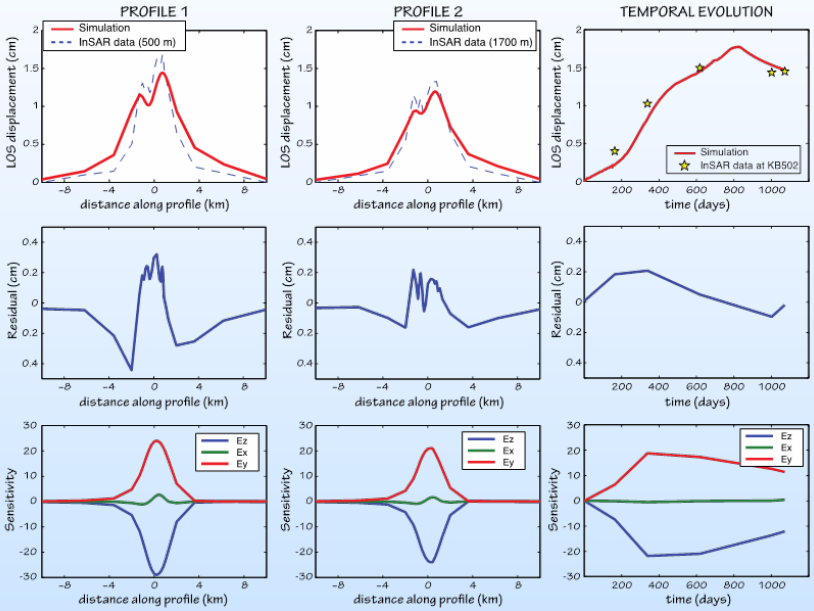
Vertical

East-West



InSAR Analysis using TOUGH2-FLAC

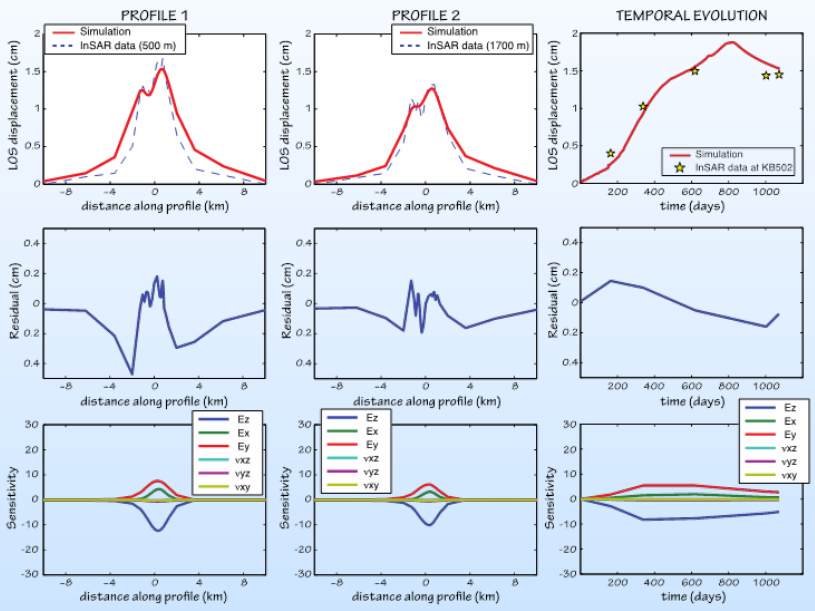
3-parameter model



$E_x = 10^{8.77\pm0.03}$ GPa (0.58 GPa)
$E_y = 10^{8.08\pm0.05}$ GPa (0.12 GPa)
$E_z = 10^{9.03\pm0.04}$ GPa (1.1 GPa)

Rinaldi & Rutqvist, 2012 Fall AGU)

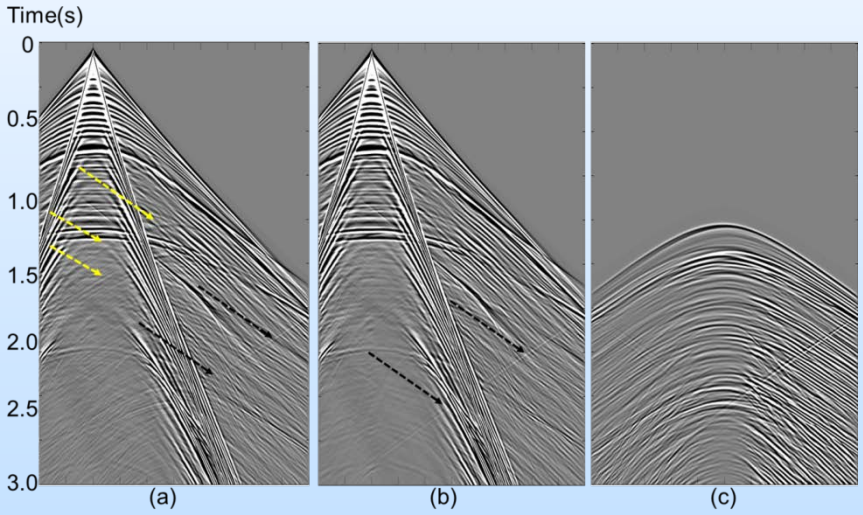
6-parameter model



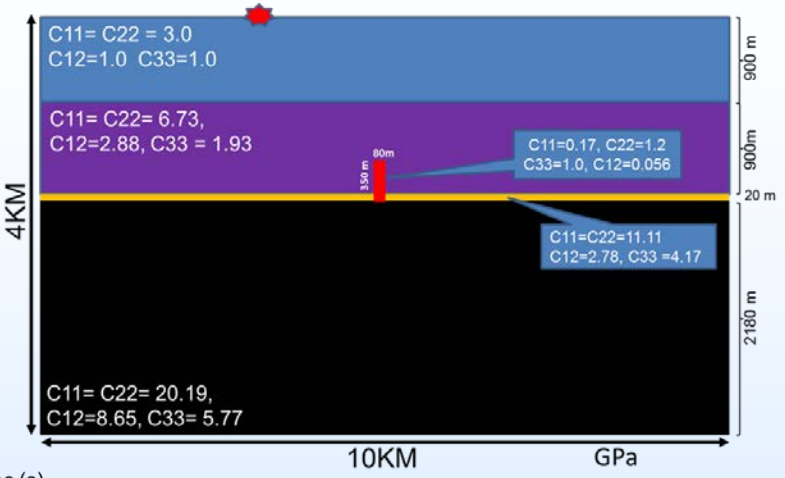
$\mathbf{E}_x = 10^{8.9\pm0.7}$ GPa (0.97 GPa)
$\mathbf{E}_y = 10^{8.7\pm0.6}$ GPa (0.53 GPa)
$\mathbf{E}_z = 10^{9.4\pm1.0}$ GPa (2.43 GPa)
$\mathbf{v}_{xy} = 0.19\pm0.53$
$\mathbf{v}_{xz} = 0.28\pm0.58$
$\mathbf{v}_{yz} = 0.28\pm0.66$

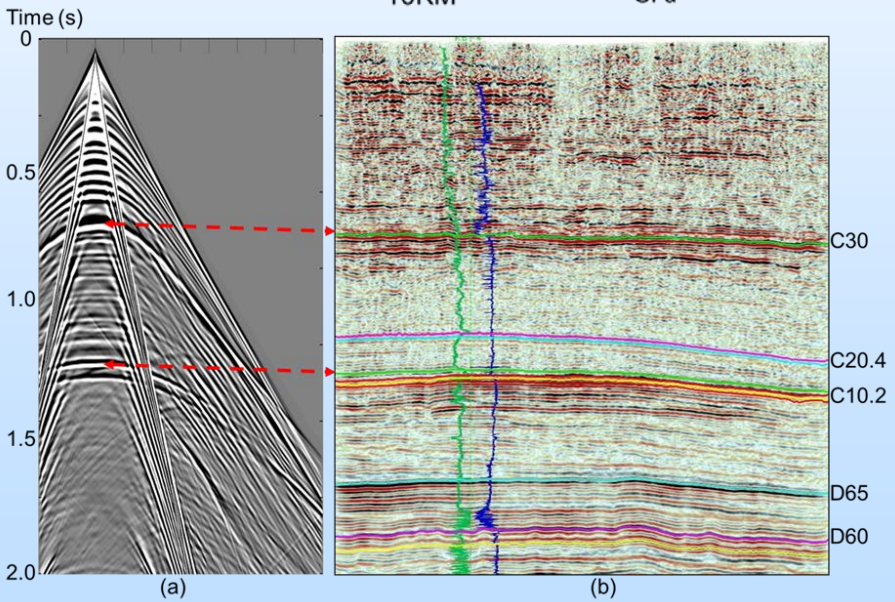
Fracture Based Seismic Analysis

Perform forward seismic wave propagation analysis to confirm the presence of fracture zone scattered events in the raw shot gathers



Modelled surface recorded seismograms, (a) with fracture zone embedded, (b) without fracture zone, and (c) their difference.



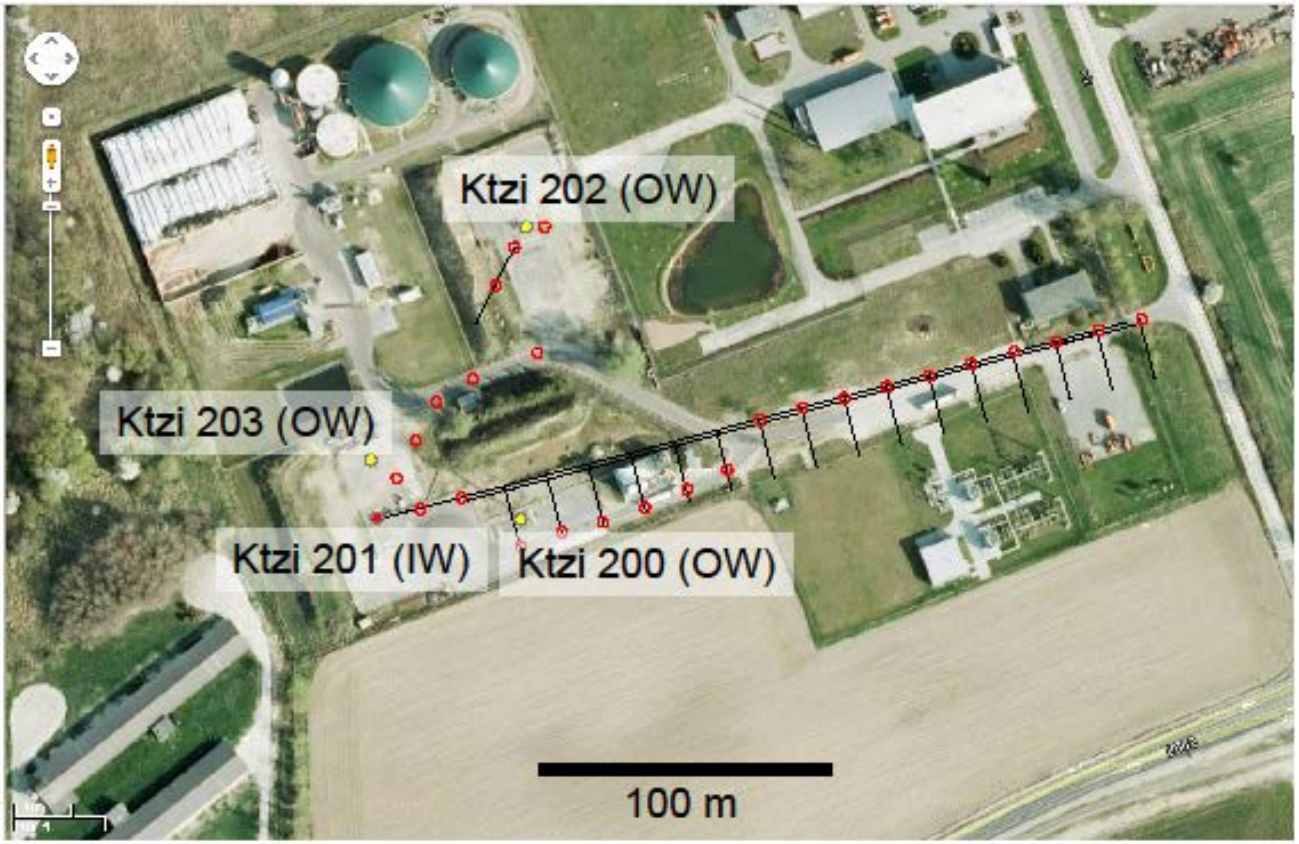


(a) shows a window of 0 to 2 seconds of modeling seismogram with fracture, (b) real seismic section.

Ketzin Project FY13 Activities

- Performed three heat-pulse tests in Ktzi 203
- May 2013 WVSP using fiber-optic DAS
  - Silixa Ltd. recording contracted through GFZ, Potsdam
  - FOTECH DAS used in collaboration with Baker Hughes

Ketzin Pilot Site: Surface Map of Wells and Vibro-Points



Scheduled experiment:

Vibro source activated on each source point.

Data recording in four wells using fibre optic iDAS.

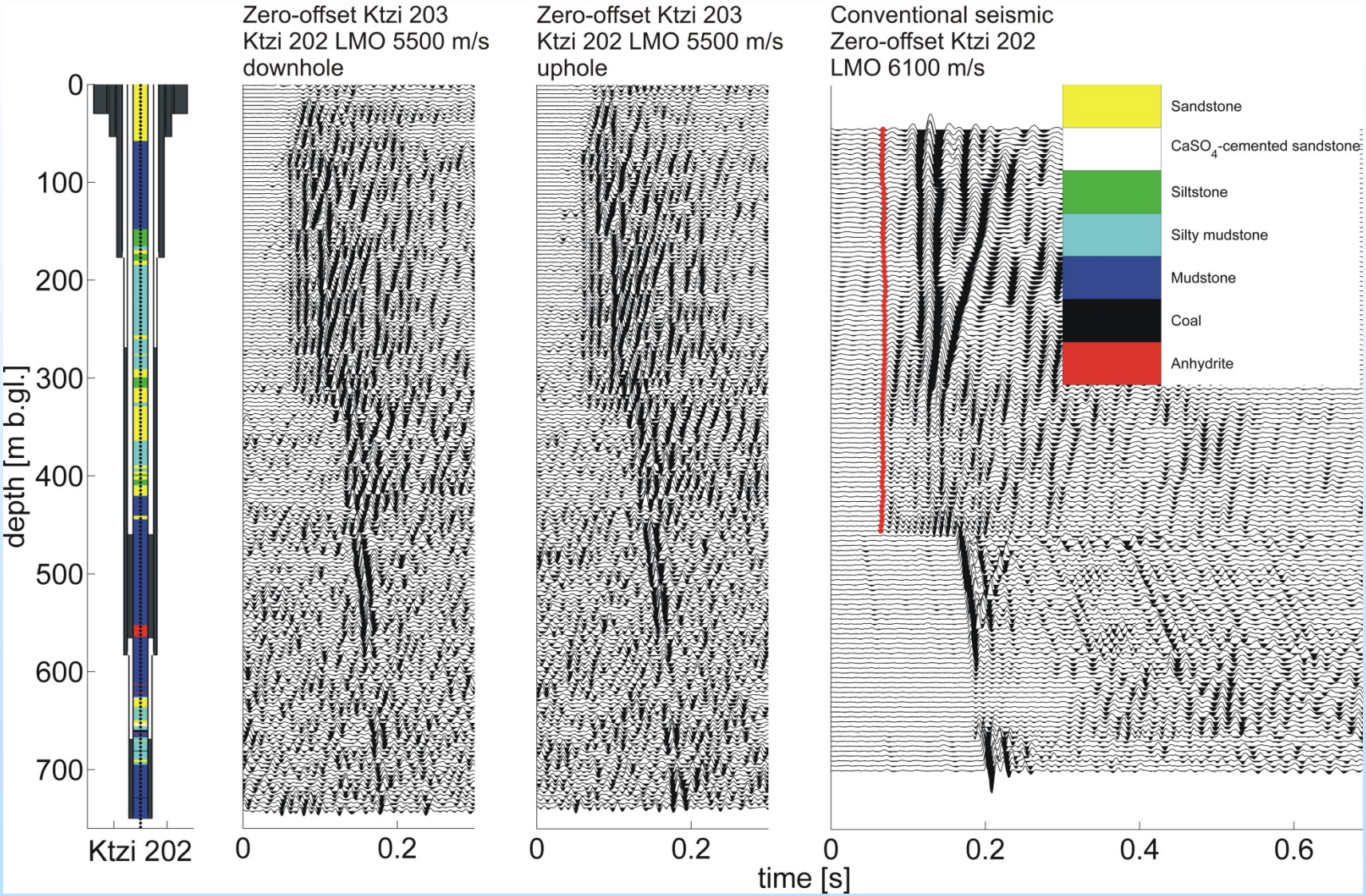
Date: week 20 of 2013

- Injection well
- Monitoring well
- Vibro point

Four wells and surface cable linked using a single fiber
Equivalent to ~6000 channels of data

DAS Data from Ketzin CO2 Pilot

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



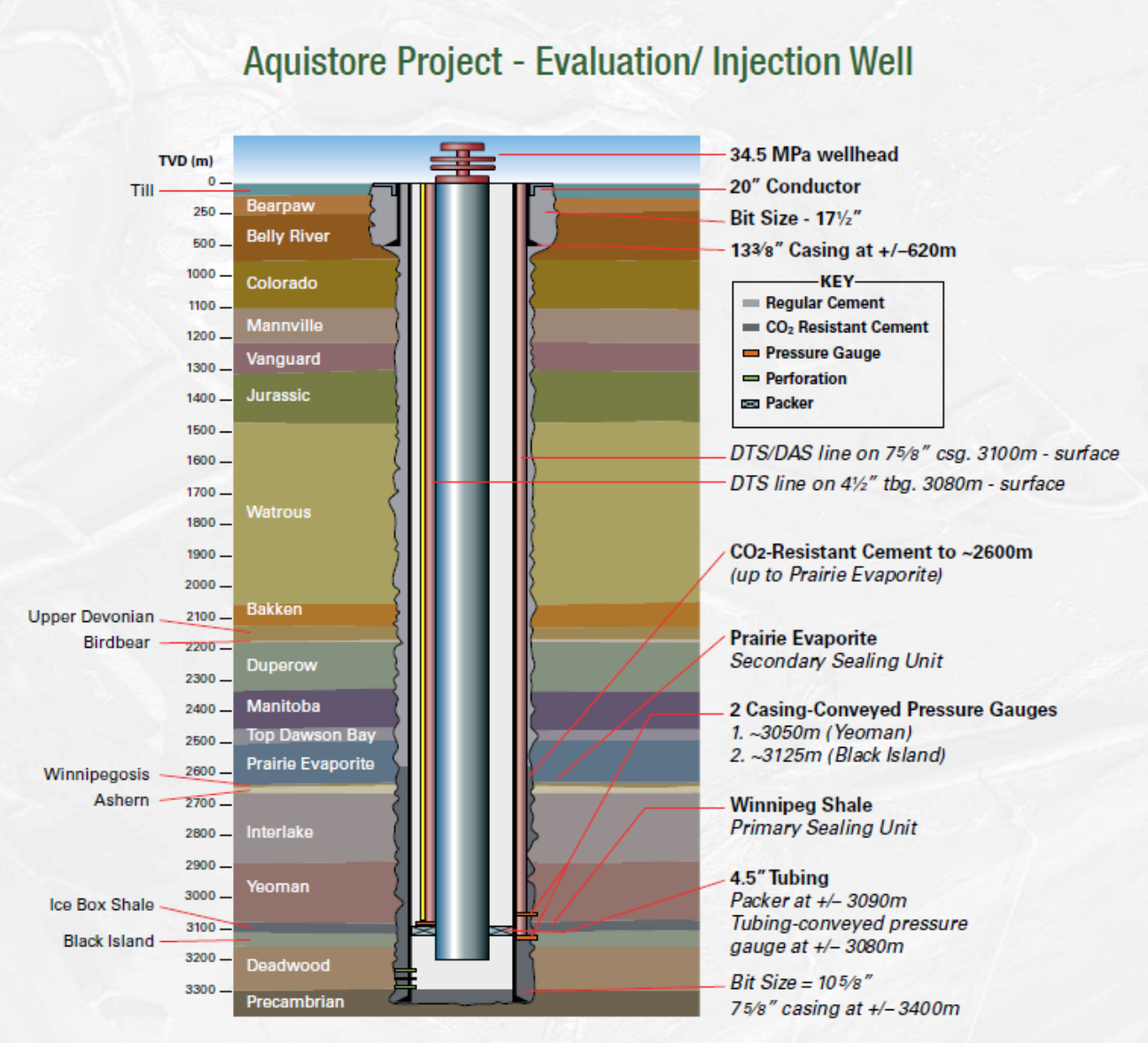
From Daley, et al, Leading Edge, 2013
Analysis courtesy GFZ, Potsdam

Subtask 2.4: Aquistore Project

Highly leveraged research –

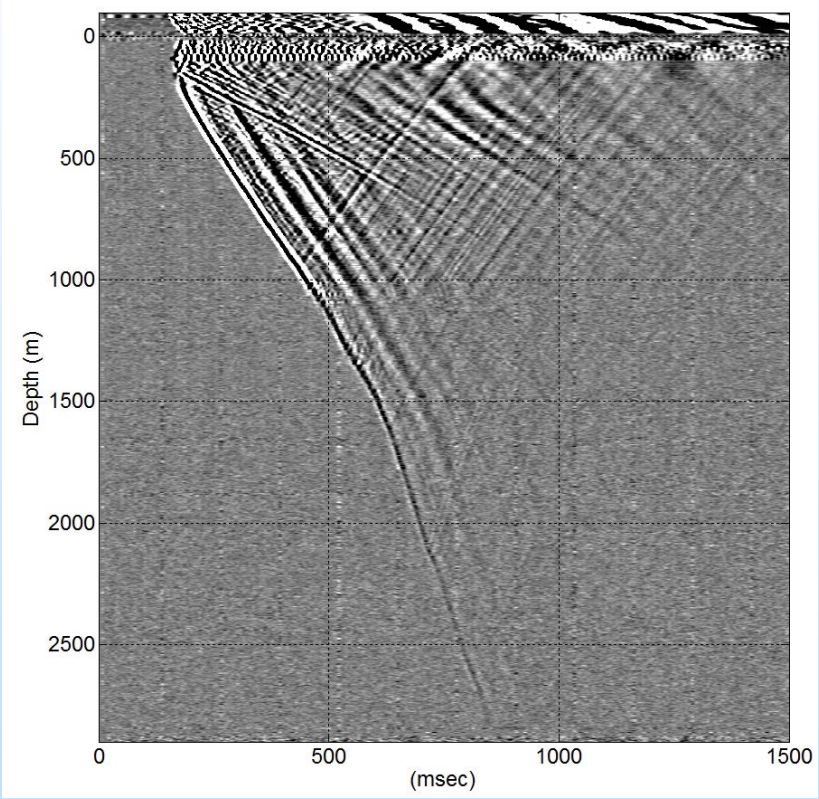
In collaboration with the PTRC Aquistore project, perform a direct comparison of fiber-optic DAS and conventional geophone technology

May 2013 – FO DAS VSP performed in conjunction with 3D surface reflection survey



Aquistore Project: DAS Vertical Seismic Profile

- Behind Casing, cemented, 3 km, 220 explosive shots



Raw data, May 2013

Accomplishments to Date

- Otway Project
  - Stage 2b Residual Saturation Test demonstrated methods to estimate residual CO2 saturation
  - Fiber-optic WVSP analyzed and demonstrated potential for FO methods and also surface monitoring with buried cables
- In Salah JIP
  - InSAR data has shown opening or volume change along vertical features at the depth of the injection and extending a few hundred meters up from the injection zone – conclude several hundred meters of apparently undisturbed (intact) caprock protects against migration of the injected CO_2.
  - Using seismic data analysis, fracture zone identified as above the injection interval (about 350 meters high, 3000 meters long and 80 meters thick)
- Ketzin Project
  - Deployed new FO heat-pulse system using DC power
  - Conducted two FO seismic acquisitions. ZOVSP and WVSP using outside casing cables
- Aquistore
  - In conjunction with a surface reflection survey using permanently installed geophones, recorded DAS data

Summary

- Key Findings
  - Seismic monitoring important but constrained by limitations in resolution and sensitivity
  - Well-based monitoring provides robust diverse data but limited to fixed well locations
- Lessons Learned
  - No silver bullet for monitoring technology. A multiple methods approach is required

Future Plans

- Continue field studies incorporating integrated monitoring solutions including U-tube, permanent gauges, and fiber-optic DAS, DTS, heat-pulse
- Seek out new opportunities: distributed FO chemical, ERT & EM, new seismic sources – surface CASSM
- FY14 Focus – fiber-optic technologies and behind casing instrumentation deployments

Appendix

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

Organization Chart

- GEO-SEQ is one of LBNL's Consolidated Sequestration Research Program Tasks lead by Barry Freifeld
- Closely linked to Fundamental Studies lead by Tom Daley
- GEO-SEQ has four subtasks with principal investigators (PI)
    - Otway Project PI: Barry Freifeld
        - Participants: Tom Daley, Yingqi Zhang, John Peterson, P. Cook
    - In Salah PI: Jonny Rutqvist
        - Participants: Tom Daley, Don Vasco, Hui-Hai Liu, Antonio Rinaldi
    - Ketzin Project PI: Barry Freifeld
        - Participants: Barry Freifeld, Tom Daley, Michelle Robertson
    - Aquistore Project PI: Tom Daley
        - Participants: Barry Freifeld, Michelle Robertson

Fundamental Studies	Title	Role in Task/Subtask
B. Freifeld	PI and Mechanical Engineer	Lead scientist for Otway Project and Ketzin
T. Daley	PI and Research Scientist	Lead scientist for Aquistore
J. Rutqvist	PI and Research Scientist	Lead scientist for In Salah JIP
M. Robertson	Project Scientist	Coordinator of field projects and oversees geophysical measurement facility support
P. Cook	Scientific Engineering Associate	Mechanical engineering and project support
D. Vasco	Senior Scientist	Data processing and In SAR analysis
H.H. Liu	Research Scientist	Hydrogeologist working on In Salah
A.	Postdoc	Geomechanical specialist working on In Salah

Gantt Chart

- GEO-SEQ Task began in FY00 with a focus on domestic field programs. After the Frio Brine Pilot in FY04 GEO-SEQ transitioned by FY06 to a focus on international collaborations
- 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 2: GEO-SEQ												
Subtask 2.1 Otway Project						**A**			**C**			
Subtask 2.2 In Salah JIP			**B**									
Subtask 2.3 Ketzin Project												
Subtask 2.4 Aquistore			**D**									

Milestones: A. Data report and preliminary interpretation of Otway Project fiber-optic seismic acquisition

B. Report on analysis of InSalah surface seismic mid-point gathers for potential fracture scattered events

C. Design and specifications for well-based monitoring for the Otway Project Stage 2c 10,000 T CO_2 storage demonstration

D. Design and deployment specifications for combined distributed temperature sensing (DTS) and distributed acoustic sensor (DAS) cable for Aquistore project

Bibliography

- Daley, TM, Freifeld, BM, Ajo-Franklin, J, Dou, S, Pevzner, R, Shulakova, V, Kashikar, S, Miller, DE, Goetz, J, Henninges, J, and Lueth, S (2013). Field testing of fiber-optic distributed acoustic sensing (DAS) for subsurface seismic monitoring, The Leading Edge 32, 6, pp. 699-706, http://dx.doi.org/10.1190/tle32060699.1
- Jenkins, C.R., P.J. Cook, J. Ennis-King, J. Undershultz, C. Boreham, T. Dance, P. de Caritat, D.M. Etheridge, B.M. Freifeld, A. Hortle, D. Kirste, L. Paterson, R. Pevzner, U. Schacht, S. Sharma, L. Stalker and M. Urosevic, 2012, Safe storage and effective monitoring of CO2 in depleted gas fields, *Proc. National Acad. Sci.* 2012 109:E35-E41; doi:10.1073/pnas.1107255108.
- Boreham, C., Underschultz, J., Stalker, L., Kirste, D., Freifeld, B., Jenkins, C., Ennis-King, J., (2011) Monitoring of CO2 storage in a depleted natural gas reservoir: gas geochemistry from the CO2CRC Otway Project, Victoria. *Int. J. Greenhouse Gas Contr.,* 5:1039–1054.
- Underschultz, J., Boreham, C., Stalker, L., Freifeld, B., Xu, J., Kirste, D., Dance, T., 2011. Geochemical and hydrogeological monitoring and verification of carbon storage in a depleted gas reservoir: examples from the Otway Project, Australia. *Int.l J. of Greenhouse Gas Control, doi:10.1016/j.ijggc.2011.02.009.*
- Rinaldi A.P. and Rutqvist J. Modeling of deep fracture zone opening and transient ground surface uplift at KB-502 CO_2 injection well, In Salah, Algeria. International Journal of Greenhouse Gas Control 12, 155–167 (2013)
- Liu, H.H. and Rutqvist J. Coupled hydro-mechanical processes associated with multiphase flow in a dual-continuum system: Formulations and a sensitivity study. *Rock Mechanics and Rock Engineering*, (online October, 2012).
- Liu H.-H., Wei M.-Y. and Rutqvist J. Normal-stress dependence of fracture hydraulic properties including two-phase flow properties. Hydrogeology Journal, 21, 371–382 (2013).