Core Carbon Storage and Monitoring Research: Task 2: Field Testing of Emerging Technologies

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U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Transforming Technology through Integration and Collaboration
August 18-20, 2015

Presentation Outline

- Field testing – benefits of leveraged research to mature emergent technologies
- International Collaborations
  - CO2CRC Otway Project (Australia)
  - Carbon Management Canada
  - PTRC Aquistore Project (Canada)
  - Mont Terri Underground Research Lab (Switzerland)
- Conclusions

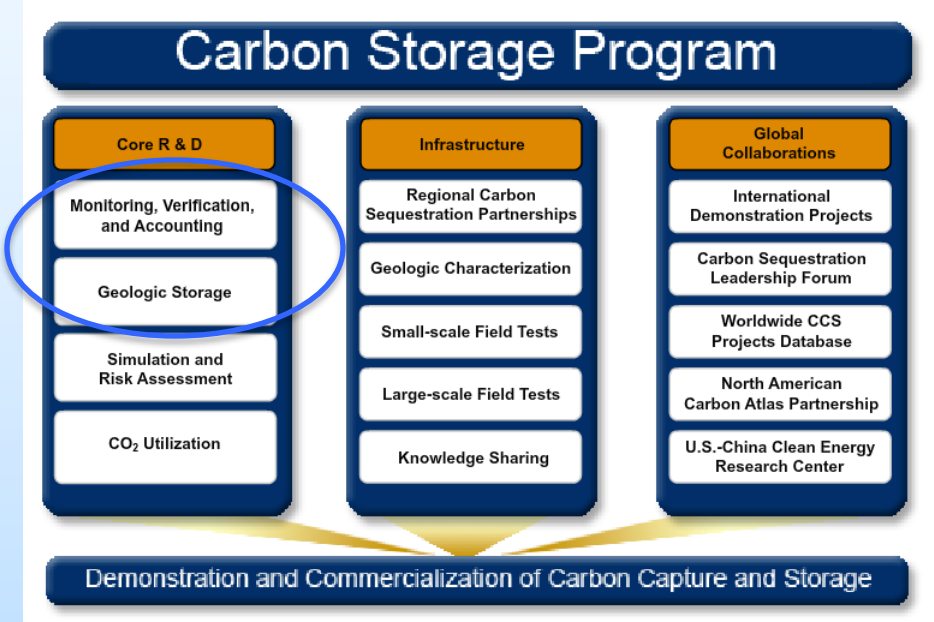
Benefit to the Program

- 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
- Project benefits:
  - Deployment and testing of new monitoring technologies and methodologies.
  - Broader learnings from leveraged research opportunities
  - Rapid transfer of knowledge to domestic programs

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: Goals and Objectives

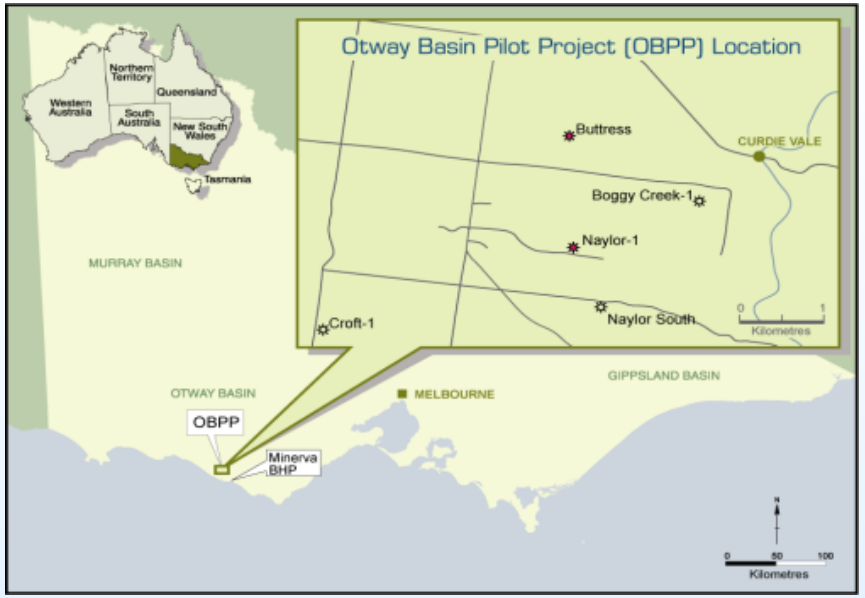
- The Core Carbon Storage and Monitoring Research Program (CCSMR) aims to advance emergent monitoring and field operations technologies that can be used in commercial carbon storage projects. This effort aligns with program goals:
  - Improve estimates of storage capacity and sweep efficiency
  - Develop new monitoring tools and technologies to achieve 99% storage confirmation
- Success criteria is if we are able to advance the TRL of targeted technologies from a level of TRL 3 – 5 up to 6 – 7 through leveraged field testing opportunities.

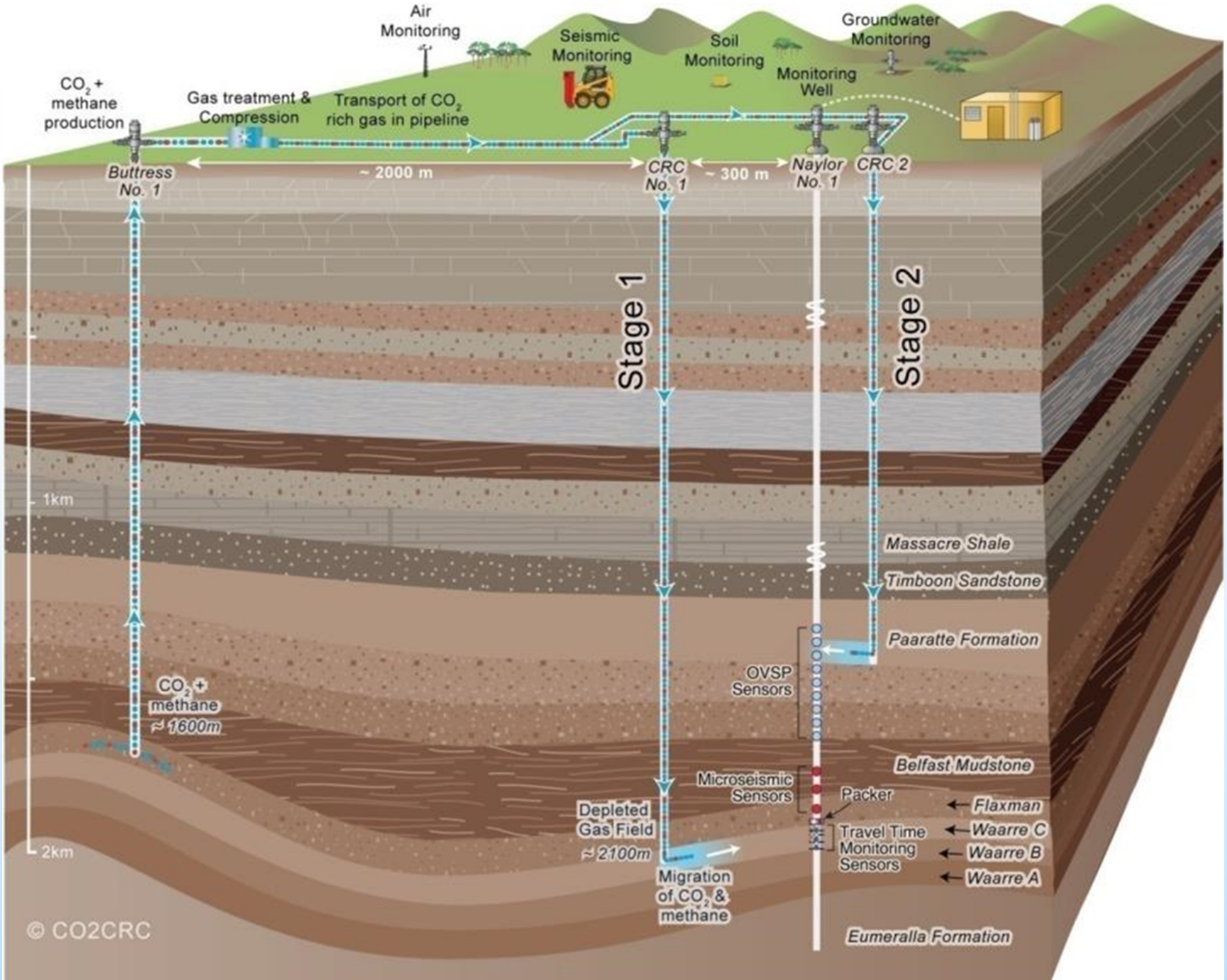
Technical Status

- Update of the current status of our various collaborations and the emerging technologies that are being demonstrated for the following projects:
  - CO2CRC Otway Project (Australia)
  - Carbon Management Canada
  - PTRC Aquistore Project (Canada)
  - Mont Terri Underground Research Lab (Switzerland)
- Benefit of leveraged international research opportunities
  - Able to stretch limited research $$$ by using infrastructure of host projects
  - Fill technological niche by providing additional expertise and technology not already within host project team
  - Acquire learnings from the broader program that can enrich our domestic program

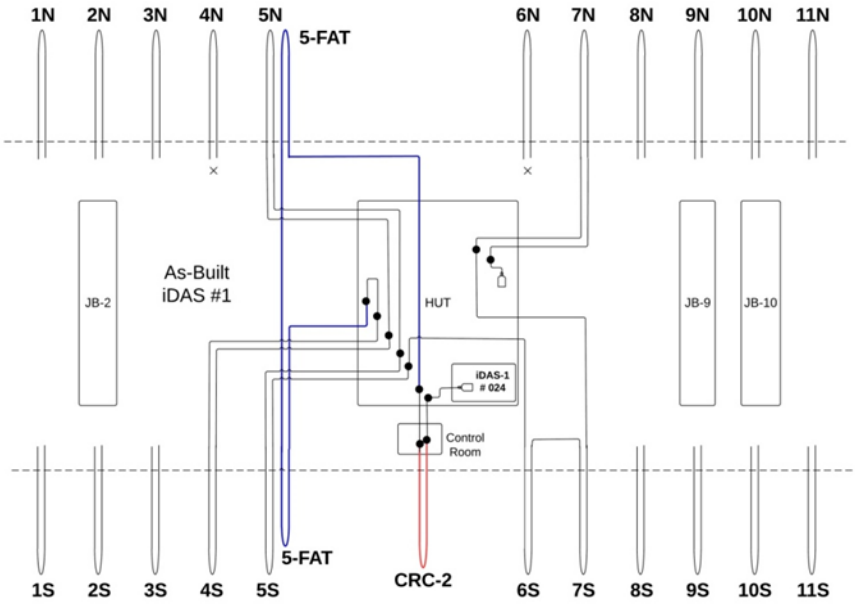
Otway Project

- Completed Otway Project Stage 2b co-contaminant injection test
- Recompletion of CRC-2 well using novel two-zone completion
- Installed fiber-optic DAS network
- Acquired baseline data (first ever 3D reflection seismic survey using DAS!)
- Preparing to install rotary seismic sources September 2015

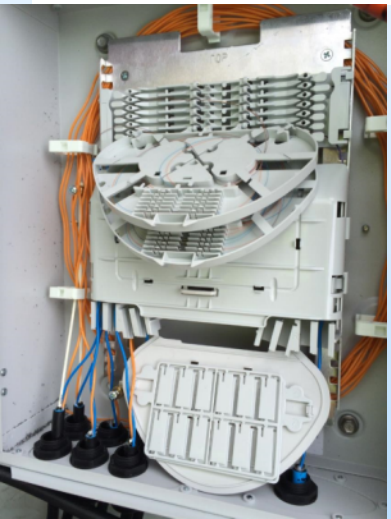


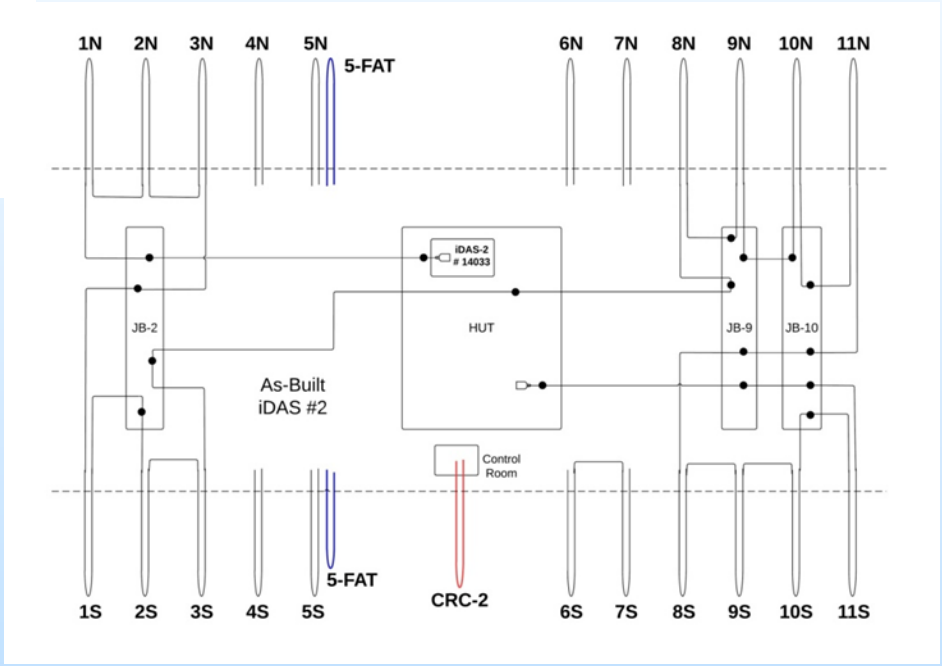

Air Monitoring
Seismic Monitoring
Soil Monitoring
Groundwater Monitoring
Monitoring Well
CO_2 + methane production
Gas treatment & Compression
Transport of CO_2 rich gas in pipeline
Buttress No. 1
~ 2000 m
CRC No. 1
~ 300 m
Naylor No. 1
CRC 2
Stage 1
Stage 2
1km
2km
Massacre Shale
Timboon Sandstone
Paaratte Formation
OVSP Sensors
CO_2 + methane ≈ 1600m
Belfast Mudstone
Microseismic Sensors
Packer
Depleted Gas Field ≈ 2100m
Travel Time Monitoring Sensors
Flaxman
Waarre C
Waarre B
Waarre A
Migration of CO_2 & methane
Eumeralla Formation
© CO2CRC

Fiber-Optic DAS Network

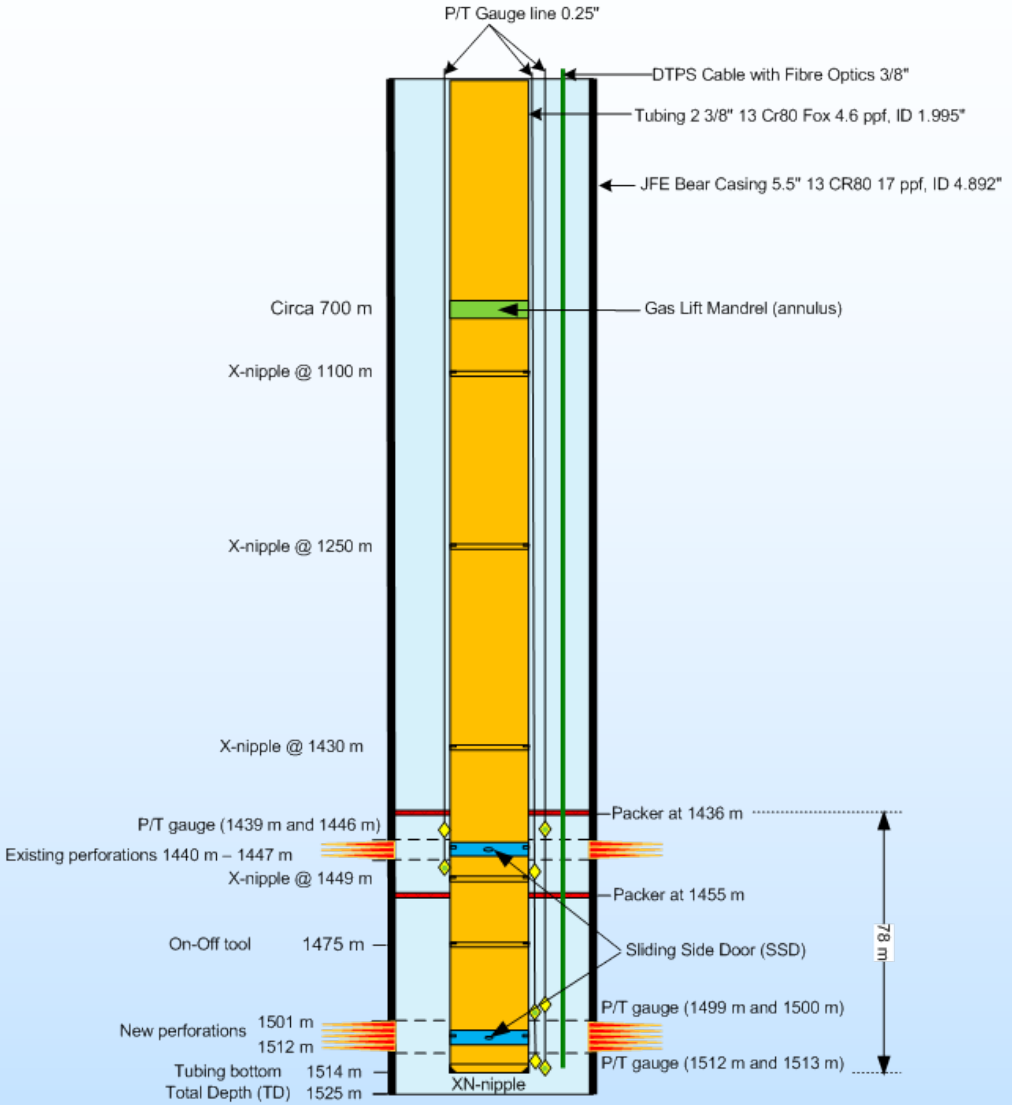


Red dots – vibroseis points
White dots – geophones and FO network.



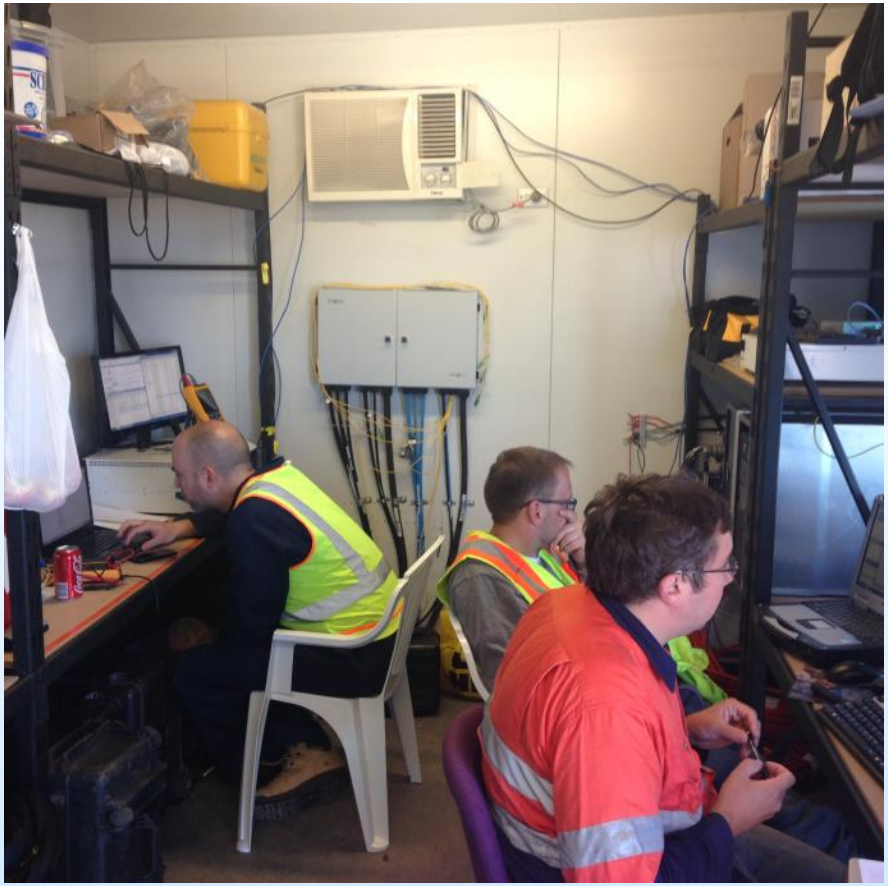


Two zone completion – Fiber-optic cable penetrates through reservoir



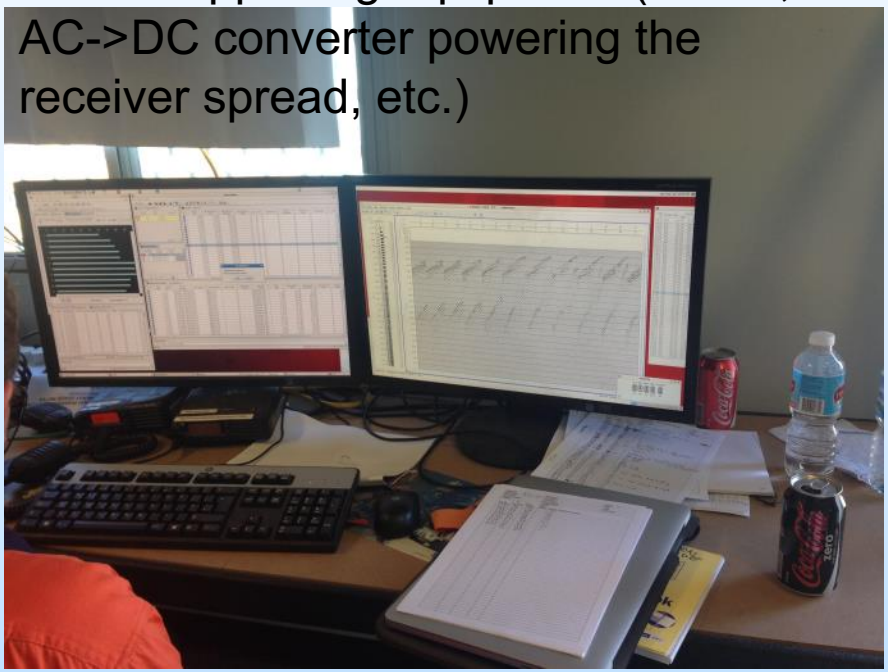
Hydraulic set packers with feedthroughs
On/Off tool used to eliminate rotation

Seismic Data Recording



2 DAS Units – one for each fiber-optic loop

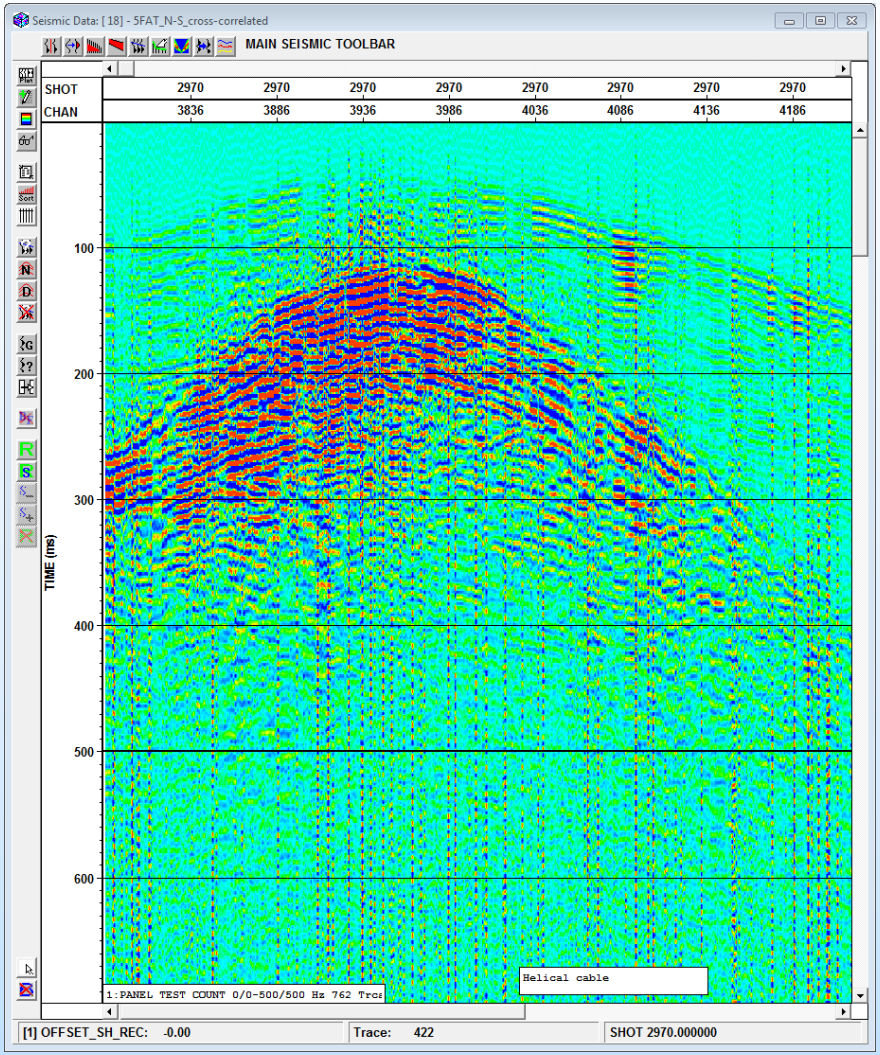
2 x PC Linux workstations (one running Sercel 428 server the other client software)
LCI-428
NAS storage
Some supporting equipment (radios, AC->DC converter powering the receiver spread, etc.)



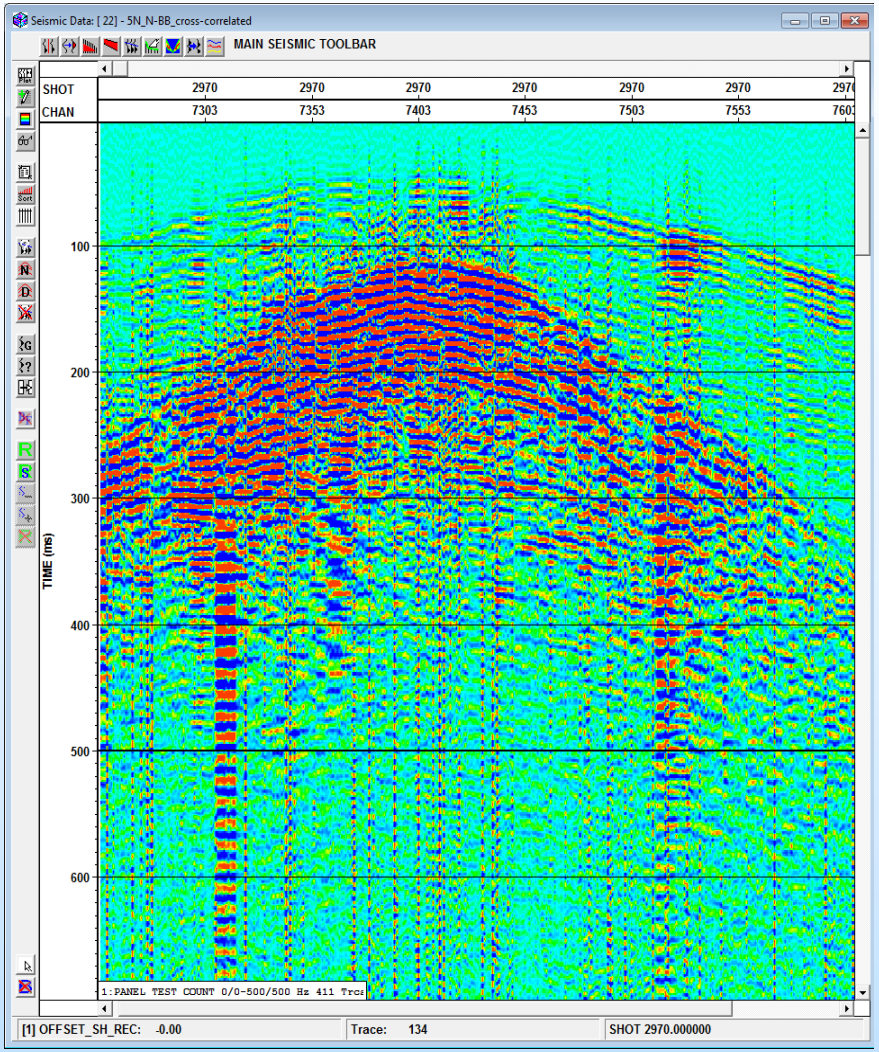
Comparison crosscorrelated shot gathers at S29VP70

Bandpass filtering: 30 – 150 Hz, t^2 gain applied,
true amplitude comparison.

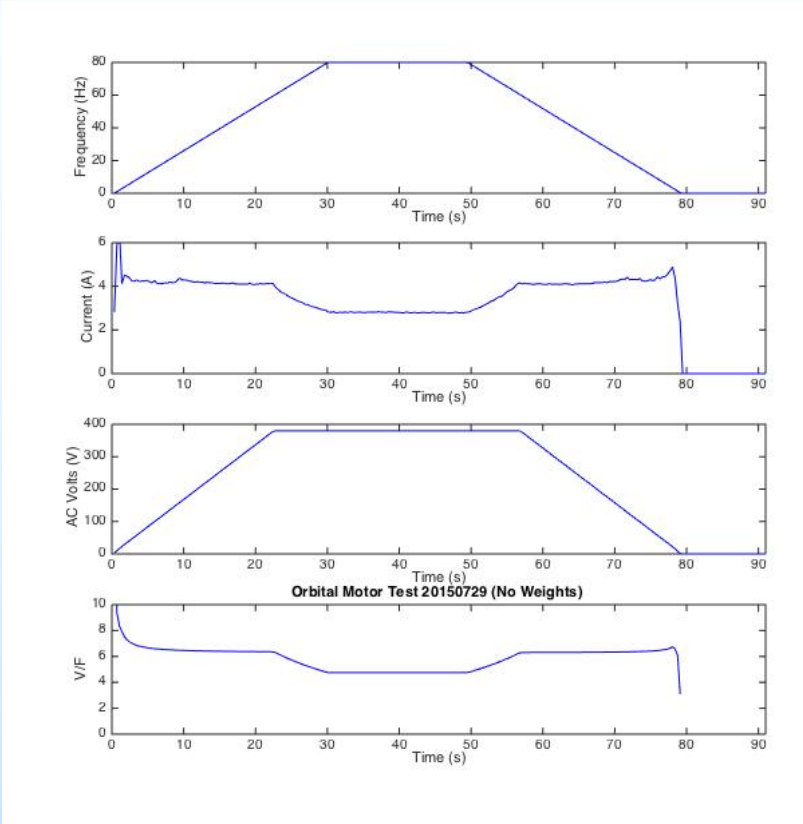
5-FAT



5-N



Rotary Orbital Permanent Seismic Source for 4D Monitoring



Swept frequency fixed rotary source –

- Design for extended periodic seismic excitation (e.g. 1 hr/day)
- 20 to 80 Hz sweep
- Reverse motor direction each sweep
- F_{peak} = 10 T-f

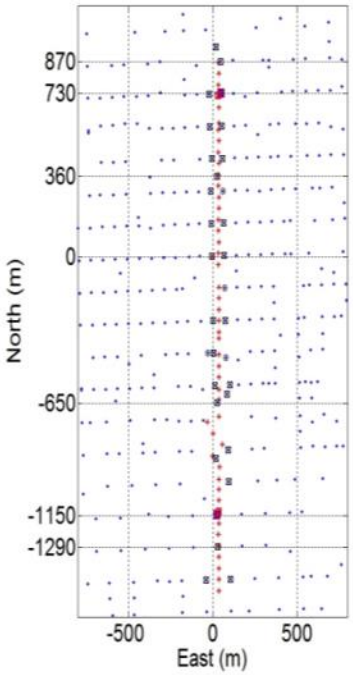
Aquistore Accomplishments

- Leveraged multiple funding streams for augmented geophysics program (PTRC, NRC, DOE, and Chevron)
- DAS VSP, crosswell and passive monitoring
  - Comparison of dynamite and vibroseis
  - Comparison of single mode and multimode fiber recording
  - Recording of JOGMEC ACROSS source into fiber-optic array
  - 20+ days continuous passive recording using DAS array in 2015

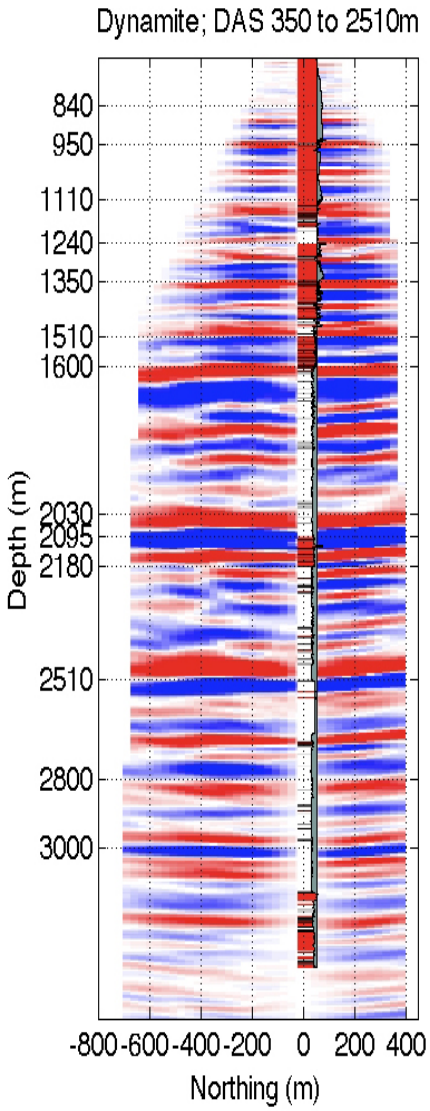
Aquistore DAS 2D Walkaway: Dynamite vs Vibroseis Comparison

- Started with denoised data as recently delivered
- Processed Walkaway & comparable dynamite lines using chain specified
- Sensors 350 - 2510 m
- Generally good quality
  - some differences due to geometry differences

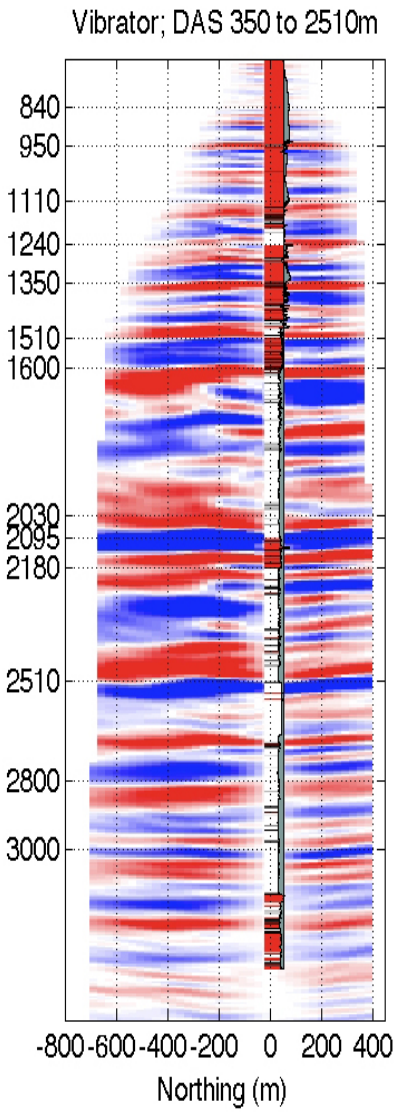
Vib and Exp Shot Points



Explosive

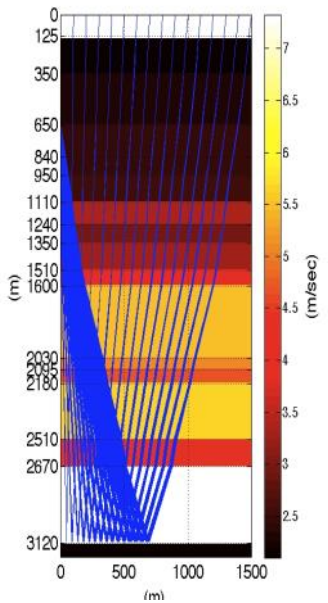


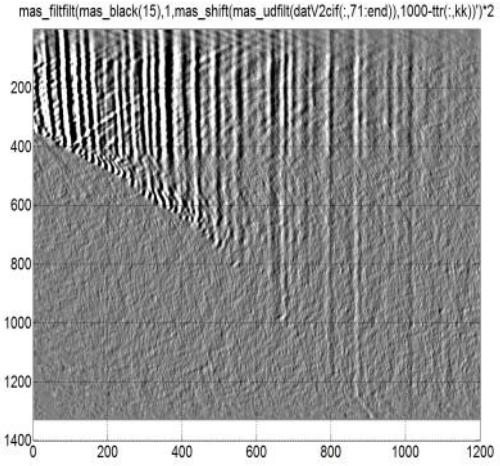
Vibroseis

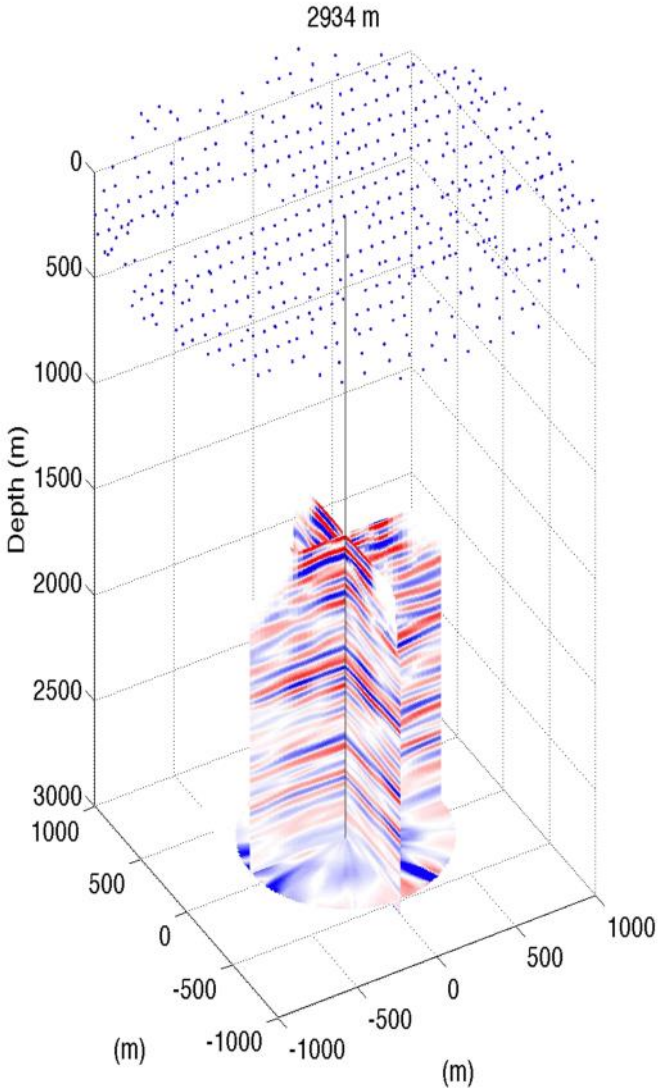


Aquistore DAS VSP Imaging: Migration Test

- 512 Dynamite Sources
- 71 SM receiver channels from good cement zone (650:4:930m)
- TIV anisotropic model fits picked times
- 2D GRT migration of shot gathers + 3D merge of images







Mont Terri Fault Slip Experiment

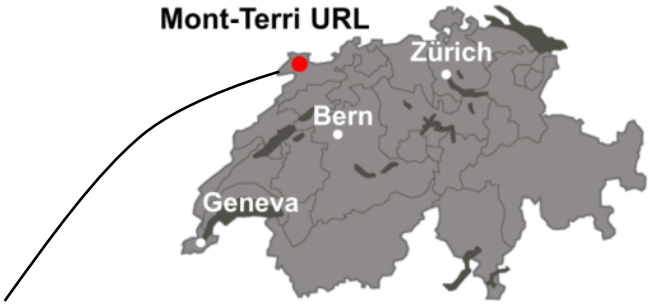
Mont Terri Project

swisstopo ENSI JAEA

Objectives:

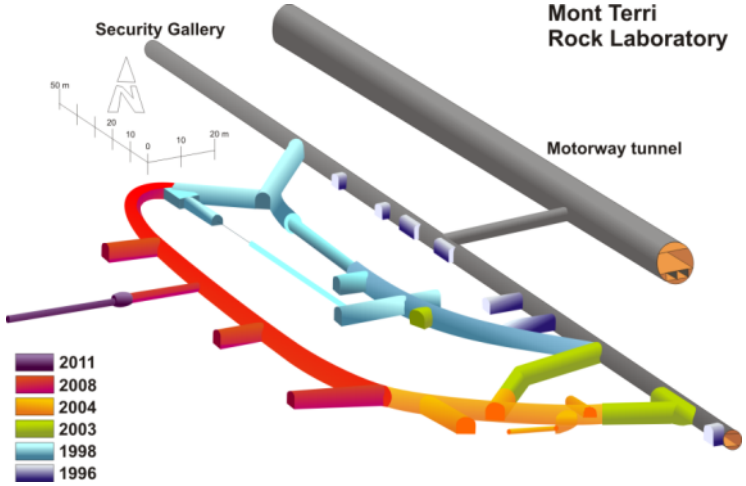
- Potential for leakage along faults that intersect a sealing formation
- Risk of induced seismicity

Mont Terri URL operated and under the lead of swisstopo



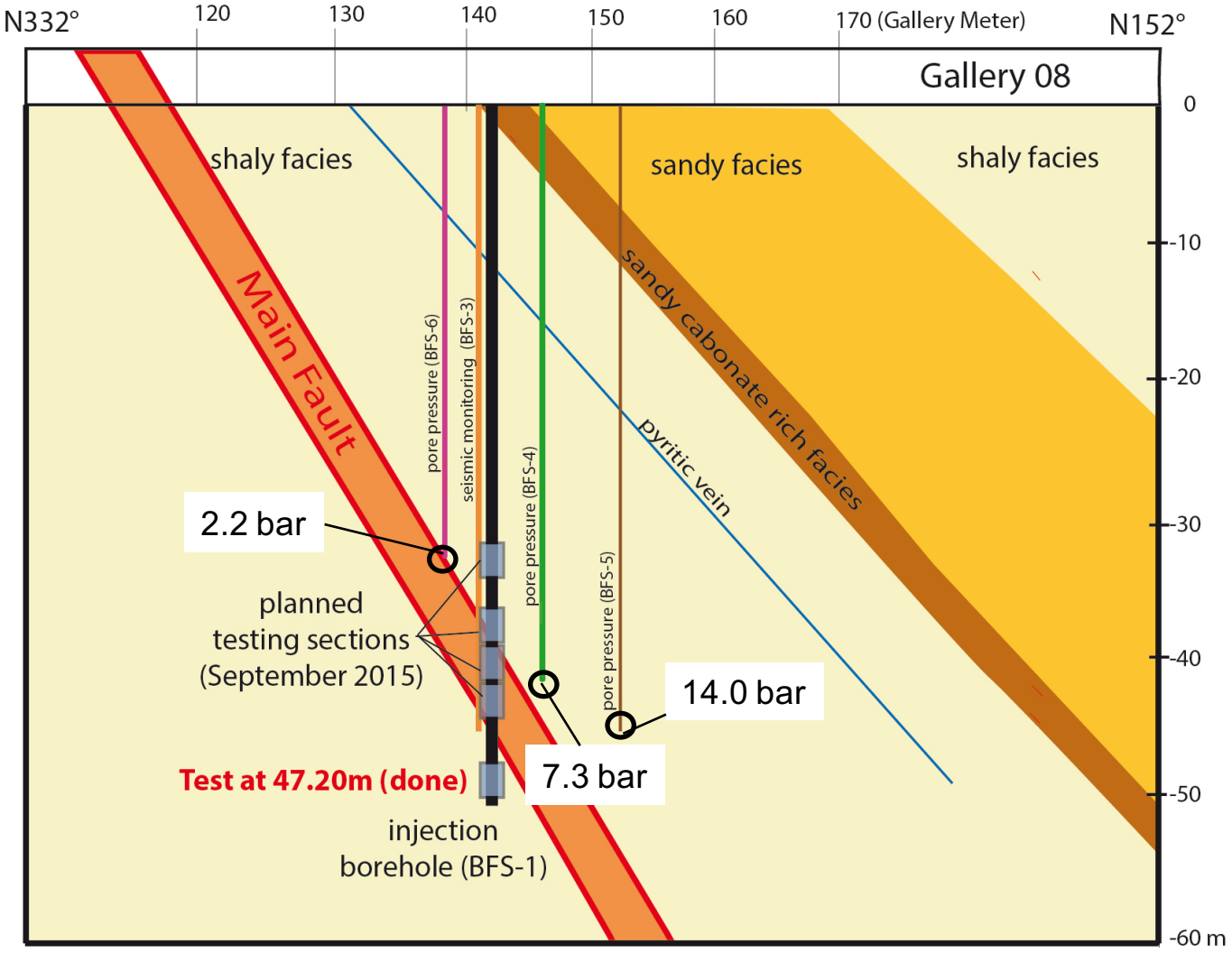
Concept:

- Increase water pressure in different testing sections
- Trigger fault slip
- Monitoring fault permeability, stress and strain tensors evolution, and induced seismicity



Experimental set-up of the FS expriment

Mont Terri Project

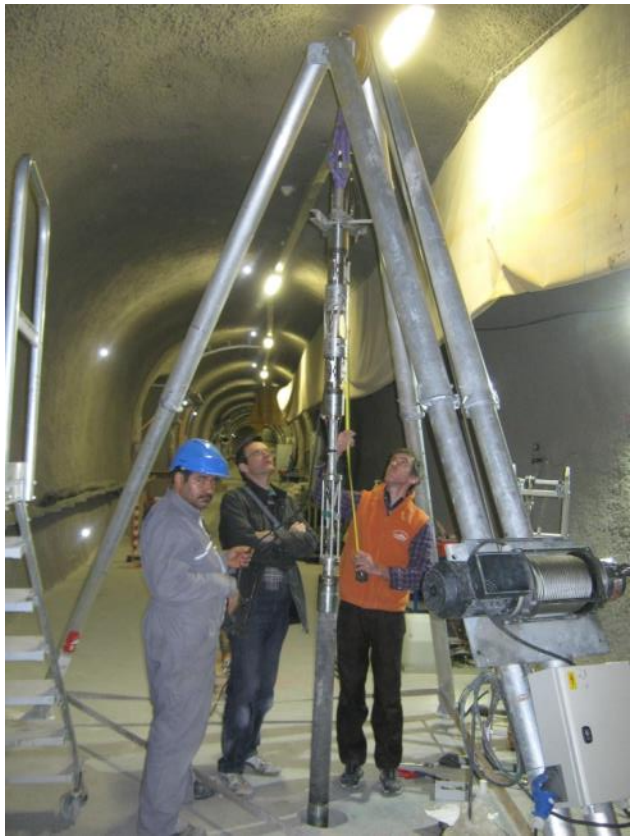


Test at 47.20 m: in-situ installation

Mont Terri Project

Passive seismic monitoring:
2 accelerometers and two geophones

Step-Rate Injection Method for Fracture In-Situ Properties (SIMFIP)
Using a 3-component borehole deformation sensor



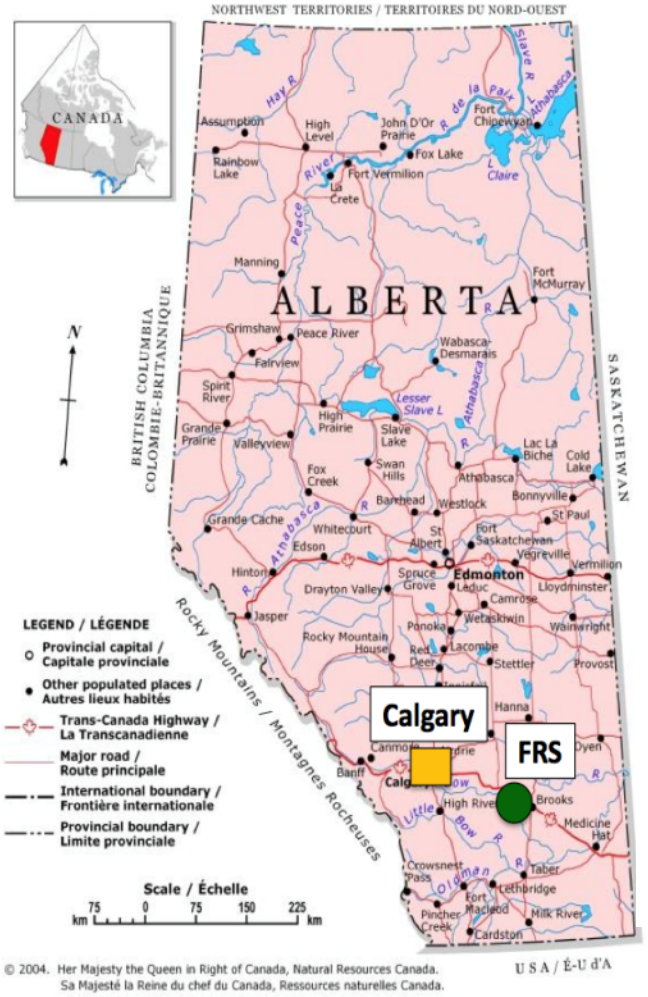
LBNL Collaboration on Mont Terri Status

Mont Terri Project

- An initial fault slip experiment was conducted in June resulting in 80 μm of slip but was terminated early due to equipment issues
- A second test will be conducted in September 2015
- LBNL is currently building a 3D geomechanical model for the site and will be involved in analyzing the data collected

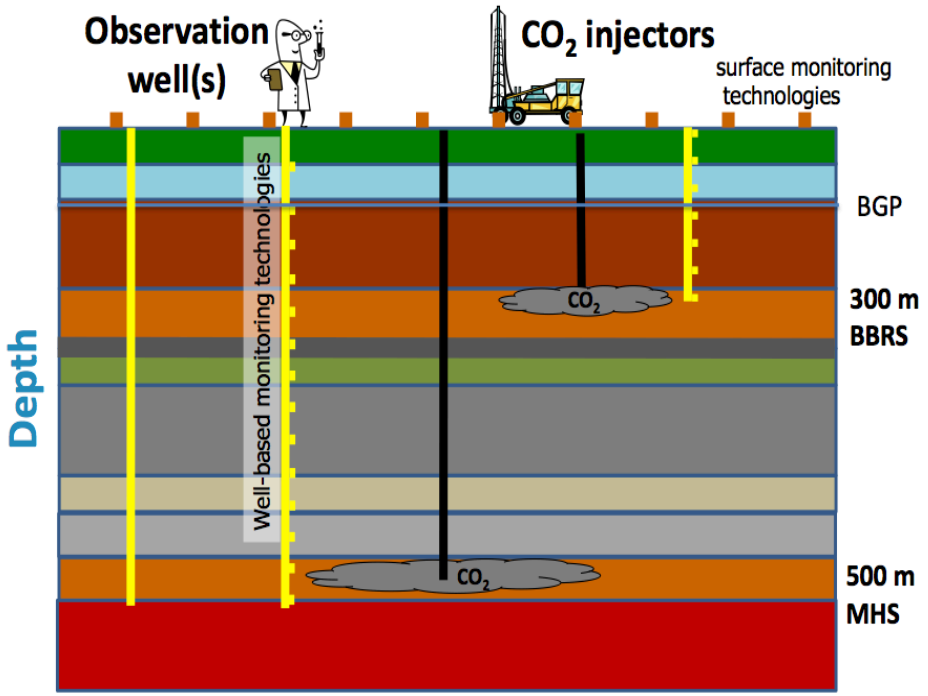
CMC Canada Collaboration

CMC
Containment & Monitoring Institute



CMC
Containment & Monitoring Institute

FRS schematic

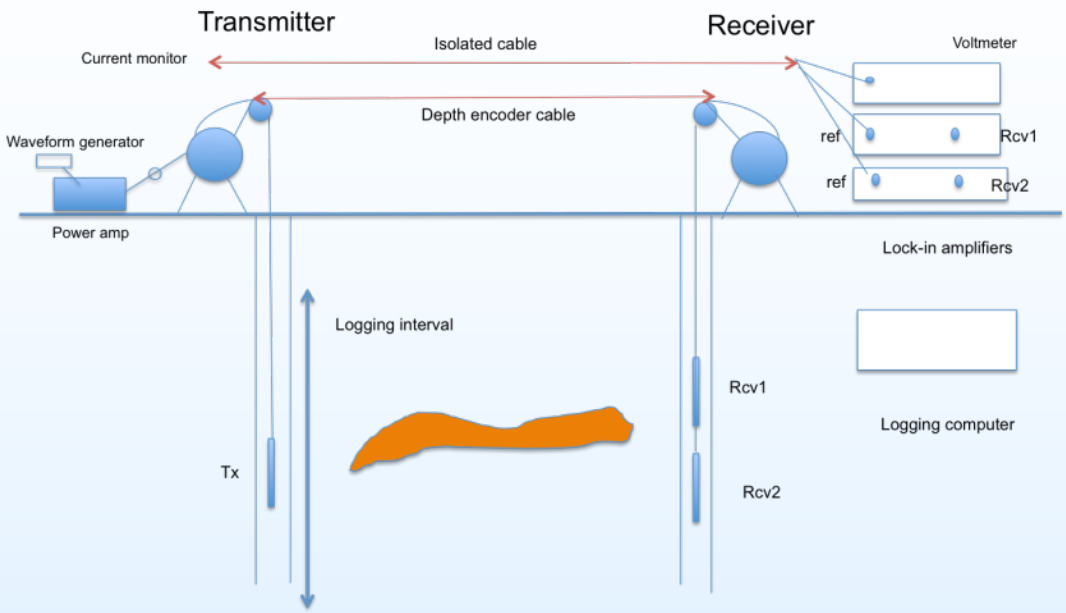


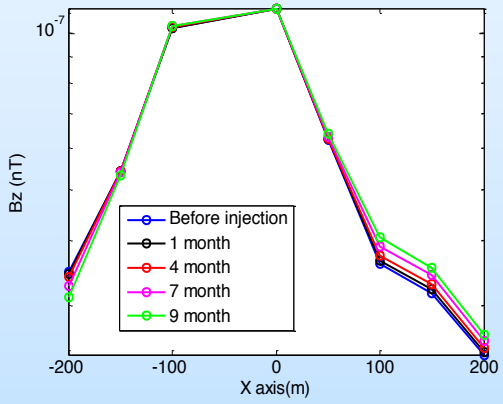
CMC Collaboration

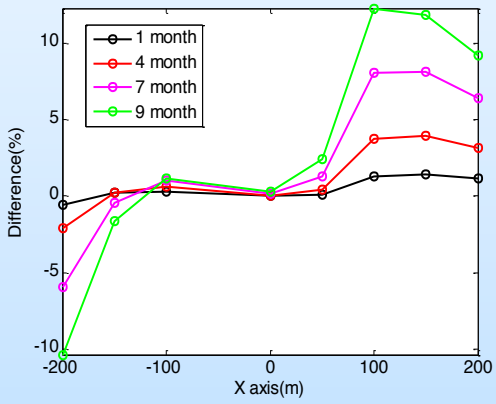
LBNL is participating in design, deployment and testing of emerging monitoring technologies at FRS. Technologies being considered in the planning phase include:

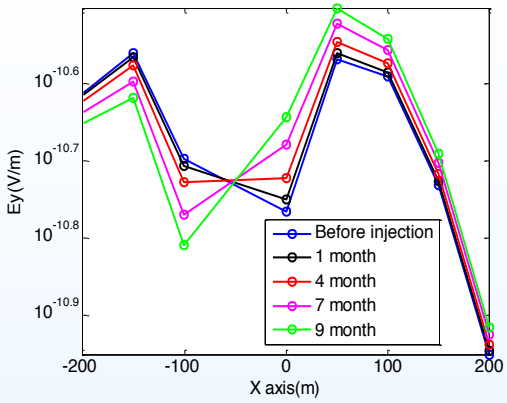
1. Electrical Resistivity Monitoring
2. EM crosswell monitoring
3. Crosswell Seismic and/or Continuous Active Source Seismic Monitoring (CASSM) deployment and operation
4. Geochemical Sampling (Behind Casing U-tube)
5. DTS/heat pulse

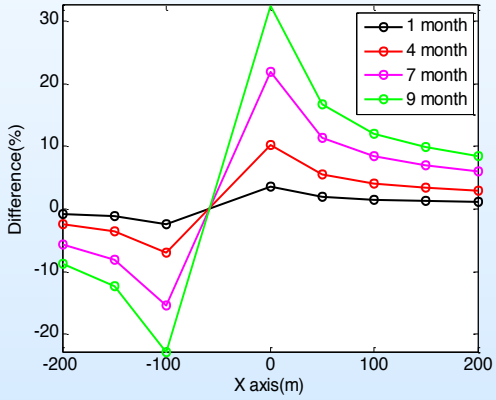
EM Imaging Forward Modeling











Differences in magnetic and electrical field before and after injection.

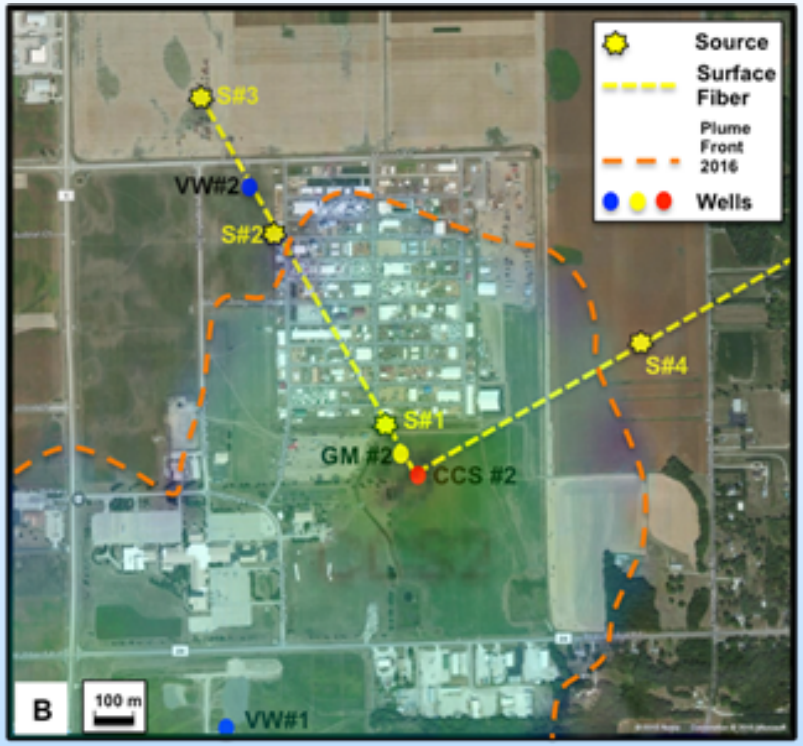
Accomplishments to Date

(In collaboration with our international partners)

- Conducted co-contaminant field test at the Otway Site using SO_2, NO_2 and O_2 in the CO_2 injection stream. Data interpretation is ongoing
- Recompletion of CRC-2 well successfully carried out using two zone design.
- Installed fiber-optic seismic network at Otway Project Site. Baseline data collection complete.
- Conducted a series of seismic acquisitions in collaboration with the PTRC at Aquistore Site using conventional and fiber-optic technology
- At Mont Terri the first of a series of fault activation studies conducted
- Planning activities and design for EM and Seismic acquisition at CMC site have progressed
- See Tom Daley's talk "Advanced Monitoring Technologies" during Thursday's *Real-Time Monitoring* Session for more details on the technologies we are working on advancing. (10:05 am Ellwood I&II)

Synergy Opportunities

- We are always looking for high value collaborative opportunities to demonstrate and trial the technologies we are working to advance.
- Key example is the Illinois Industrial Carbon Capture and Storage Project through FOA-1240 will make use of technologies being tested now at Aquistore and Otway including FO DAS, rotary seismic sources, and 4D data interpretation methods.



Summary

- International projects have been fruitful opportunities for advancing emergent monitoring technologies. Our goal is to move technologies from a TRL 3 – 5 up to TRL 6 – 7.
- Lessons Learned include that maturing technology is a non-linear process. Often field trials indicate gaps that need to be addressed through more focused “small scale” research
- Future plans are to continue leveraging existing opportunities while identifying commercial scale projects that can benefit from new approaches

Acknowledgments

- Funding for LBNL was provided by the Carbon Storage Program, U.S. Department of Energy, Assistant Secretary for Fossil Energy, Office of Clean Coal and Carbon Management through the National Energy Technology Laboratory under contract No. DE-AC02-05CH11231.
- Our international collaborations have been supported by the generous efforts of numerous colleagues and diverse funding streams. An incomplete includes:
  - The Australian Federal and State Government of Victoria through the CO2CRC along with their industry and academic partners. Particular acknowledgment to Matthias Raab and Rajindar Singh for support of the Otway Project.
  - The Canadian PTRC and NRC for the support of the Aquistore Project with thanks to Don White and Kyle Worth for inviting LBNL to participate. Additional funding by Chevron and Silixa Ltd field support.
  - The CMC CaMI Field Research Site and Don Lawton.
  - The swisstopo research group for Mont Terri and Yves Guglielmi, Pierre Henry (CEREGE, Aix-Marseille University)

Appendix

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

Organization Chart

- CCSMR Task Leads
  - Barry Freifeld (Field Testing Emerging Technologies)
  - Tom Daley (Advancing Monitoring Technology)
  - Jens Birkholzer (Optimization Framework)
- Key Staff
  - Michelle Robertson, Paul Cook, Todd Wood (Field testing and support)
  - Abdullah Cihan, Jonathan Ajo-Franklin, Kevin Knauss, Valeri Korneev, John Peterson, Jonny Rutqvist, Nic Spycher, Don Vasco, Qualin Zhou (Scientific support)

Gantt Chart

	Q1 FY15			Q2 FY15			Q3 FY15			Q4 FY15		
Subtask Description	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**
Task 1 Project Management and Planning												
Task 2 Field Testing of Emerging Technologies												
Subtask 2.1 Aquistore Project												
Subtask 2.2 Otway co-contaminant injection				**B**								
Subtask 2.3 Carbon Management Canada										**A***		
Subtask 2.4 Mont Terri URL							**C**					
Subtask 2.5 Industry and international field site development												
Task 3 Advancing Monitoring Technology												
Subtask 3.1 Continuous monitoring				**D***								**E**
Subtask 3.2 Instrumentation Development										**F**		
Task 4 Optimization Framework							**G**					**H**

Milestone 2-1 (A)	Report on current monitoring design and proposed LBNL supplement for Carbon Management Canada Field Research Station
Milestone 2-2 (B)	Report on Installation plan for CO2CRC Otway Stage 2c fiber-optic monitoring system and integration into continuous network.
Milestone 2-3 (C)	Review of coupled-models for application to the Mont Teri geomechanical investigation
Milestone 3-1 (D)	Test results of a prototype helical wound fiber-optic cable for improved broadside sensitivity
Milestone 3-2 (E)	Design and testing plan for coupled U-tube and Gas Membrane fluid sampler
Milestone 3-3 (F)	Application of Stoneley-wave and P-wave data for well integrity monitoring using distributed acoustic sensing
Milestone 4-1 (G)	Identify suitable field sites/partners for demonstration of optimization toolset
Milestone 4-2 (H)	Develop methodology for adaptive CO2 storage management with dynamic model updating based on continuously measured field data

Bibliography

- New Project start in 2015. No peer reviewed publications yet.

Invited talks:

- Daley, T.M., 2015, (invited) Comparison of Fiber Optic Monitoring with Conventional Geophone Detection Systems at Aquistore, 10th Monitoring Network Meeting, International Energy Agency Greenhouse Gas Program, Berkeley, CA, June 10-12, 2015.
- Daley, T.M., 2015, (invited) Induced seismicity from CO_2 storage: monitoring and risk assessment, Stanford Center for Carbon Storage Annual Meeting, Workshop on "Induced Seismicity due to CO_2 injection", Palo Alto, Ca, May 27-28.
- Freifeld, B.M., 2015 (invited) Engineering Aspects of Pressure Monitoring, A Review of State-of-the-Art, 10th Monitoring Network Meeting, International Energy Agency Greenhouse Gas Program, Berkeley, CA, June 10-12, 2015.
- Freifeld, B.M., 2015 (invited) Field Demonstration of CO_2 Geothermal at the SECARB Cranfield Site, Cranfield, Mississippi, International Energy Agency Greenhouse Gas Program, Berkeley, CA, June 10-12, 2015.
- Rutqvist J. (invited) Modeling Fault Reactivation and Induced Seismicity during Underground CO_2 Injection. Stanford Center for Carbon Storage (SCCS) Annual Meeting, Workshop on "Induced Seismicity due to CO_2 injection", Stanford, California, May 28, 2015.