Assessment of Leakage Pathways Using Joint EM-Seismic, Borehole and Surface Technologies

Project Number ESD14-095 (Task4)

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U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

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Kirk Osadetz

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Organization Chart

Carbon Management Canada (CMC) organized the Containment and Monitoring Institute (CaMI), led by Don Lawton. Project field site is CaMI Field Research Station (FRS), Newell County, Alberta, Canada

USDOE - LBNL (USA)

- EM: Michael Wilt, Evan Um, Ed Nichols
- Seismic: Pierpaolo Marchesini, Tom Daley

SINTEF (Norway)

GFZ (Germany)

NTNU (Norway)

CMR (Norway)

RITE (Japan)

University of Calgary (Canada)

University of Alberta (Canada)

University of Guelph (Canada)

University of Freiberg (Germany)

INRS (Canada)

Natural Resources Canada

Princeton University (USA)

Imperial College (UK)

University of Bristol (UK)

Edinburgh University (UK)

British Geological Survey

Presentation Outline

- Background on CaMI Field Research Station (FRS)
- Why Joint EM and Seismic Geophysical Monitoring ?
- LBNL Progresses on Data Acquisition and Analysis:
  - Crosswell EM Data
  - Crosswell Seismic Data

  Baseline (pre-injection) for now..
  Injection ongoing.. Time-lapse in 2019
- Introducing Additional EM Methodologies
- Summary and Future Plans

Motivation

2011 - White Paper on Field Testing Needs for Geological Carbon Sequestration (Daley et al., 2011) listed 3 priority field tests:

- A deep (supercritical CO_2) injection into a high permeability, near-vertical fault or fracture zone
- **An intermediate injection simulating secondary accumulation from leakage of gas-phase CO_2**
- A shallow injection studying groundwater impacts from leakage

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Crucial experiment testing monitoring gas-phase CO_2 at intermediate depth as an analog for a leak into a 'thief zone'

Motivation

Crucial experiment testing monitoring gas-phase CO_2 at intermediate depth as an analog for a leak into a 'thief zone'

CaMI/UofC – Field Research Station (FRS)

- A world-leading site for development and demonstration of MMV technologies for fluid containment and conformance
- Undertake controlled CO_2 release at 300 m (Phase 1) & 500 m (Phase 2) depth; up to 1000 t/yr
- Determine CO_2 detection thresholds for different monitoring technologies
- Improve and develop monitoring technologies for tracking the CO_2 plume migration and for cap rock assessment
- Monitor gas migration at shallow to intermediate depths and impacts on intermediate depth groundwater (CO_2 and CH_4)
- Determine fate of CO_2 & CH_4 (trapping/dissolution)
- University & industry field training & research
- Integrating engineering and geoscience
- Public outreach & education

Primary LBNL Focuses

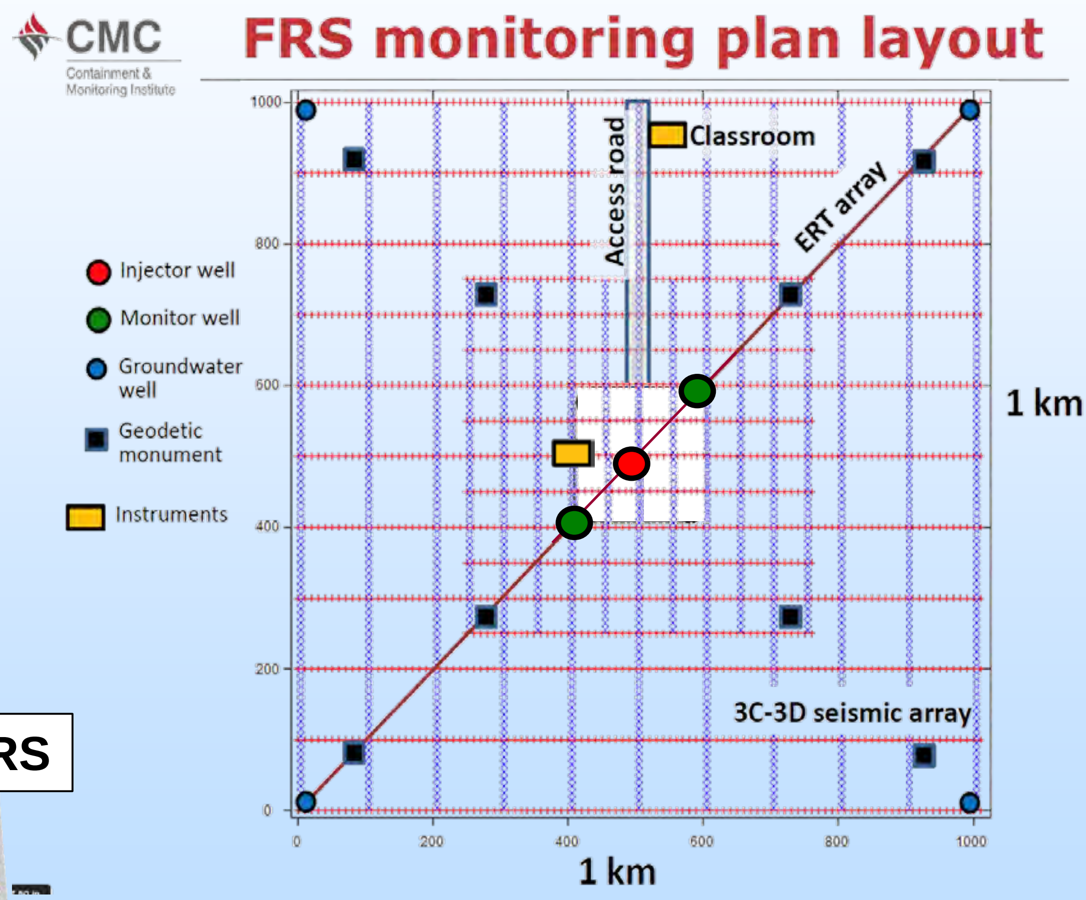
From Lawton, 2016

LBNL's Goal and Objectives

Contribute to a comprehensive monitoring program with:

- Integration and technology maturation of Crosswell EM and Seismic into a multi-physics monitoring approach to improve CO_2 saturation estimates and joint inversion;
- U-Tube fluid sampling;
- Distributed Temperature Sensing (DTS) + heat pulse monitoring;
- Surface and borehole straight + helical Distributed Acoustic Sensing (DAS);
- Distributed Strain Sensing (DSS).

Field Research Station (FRS)



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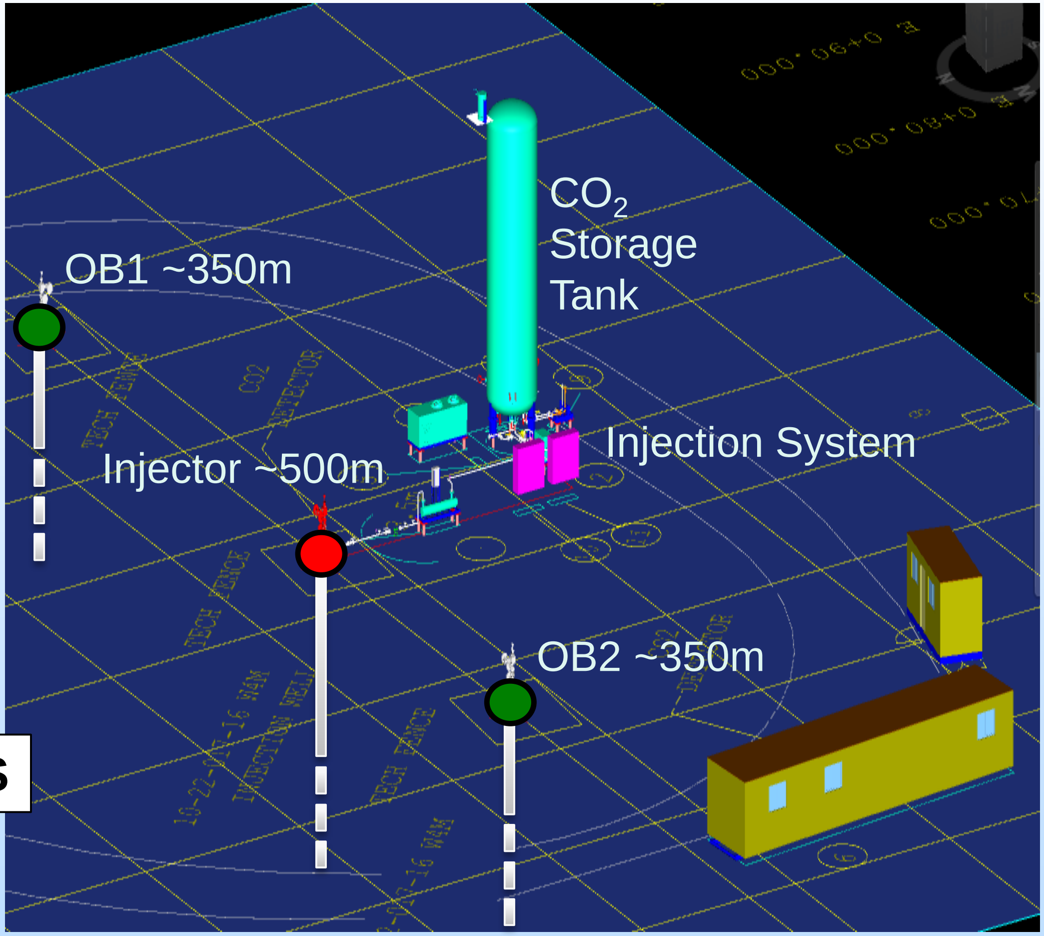

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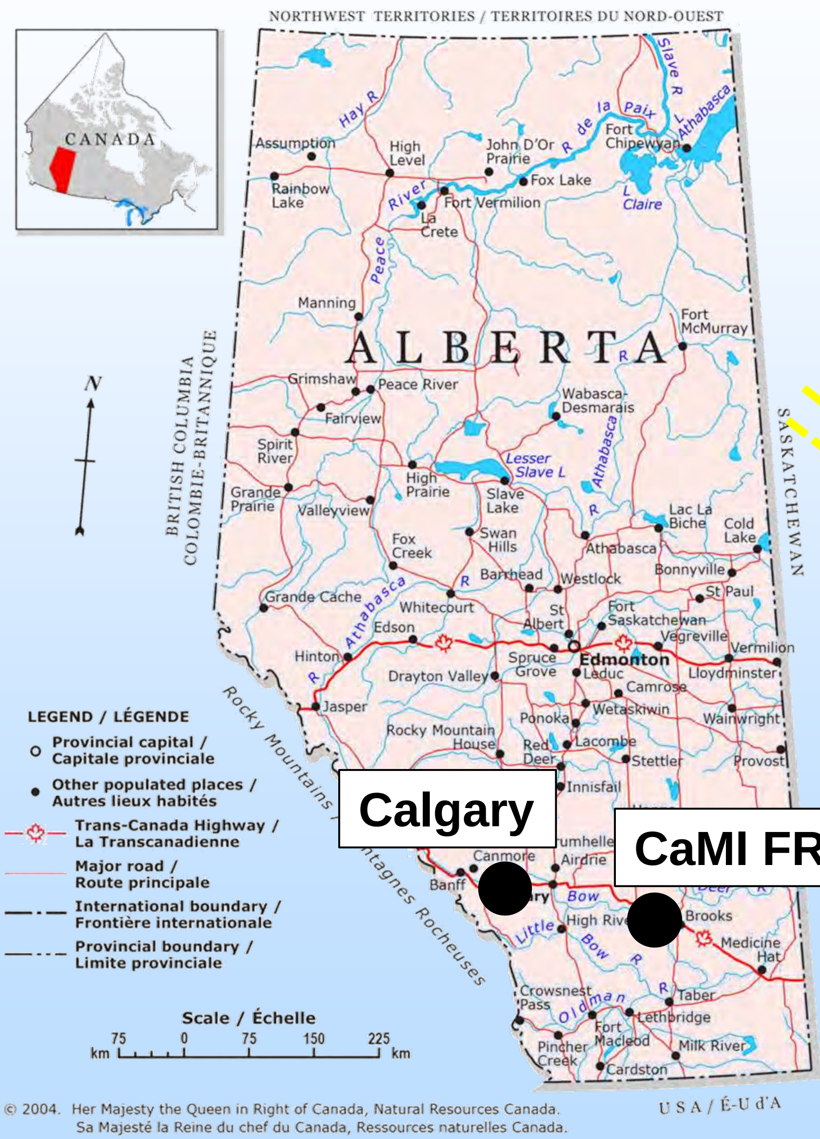

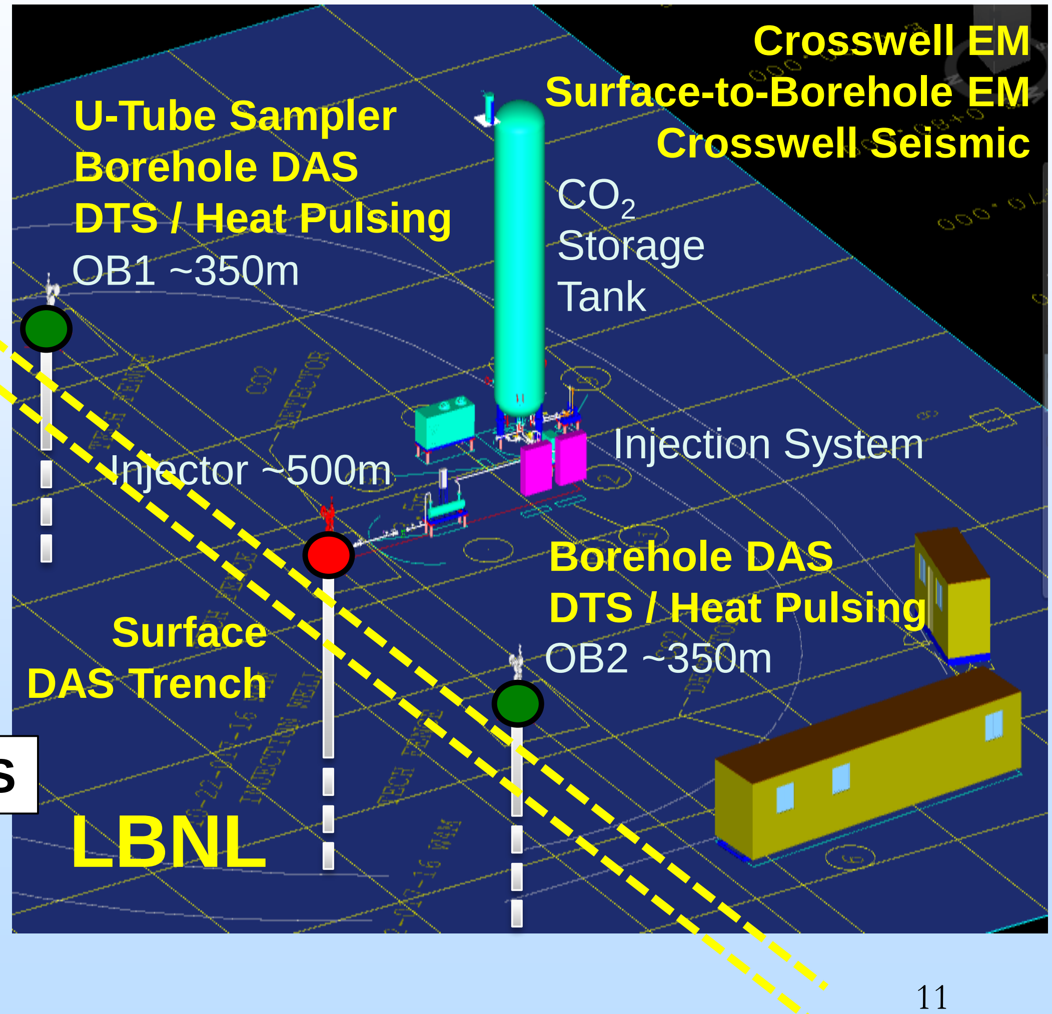

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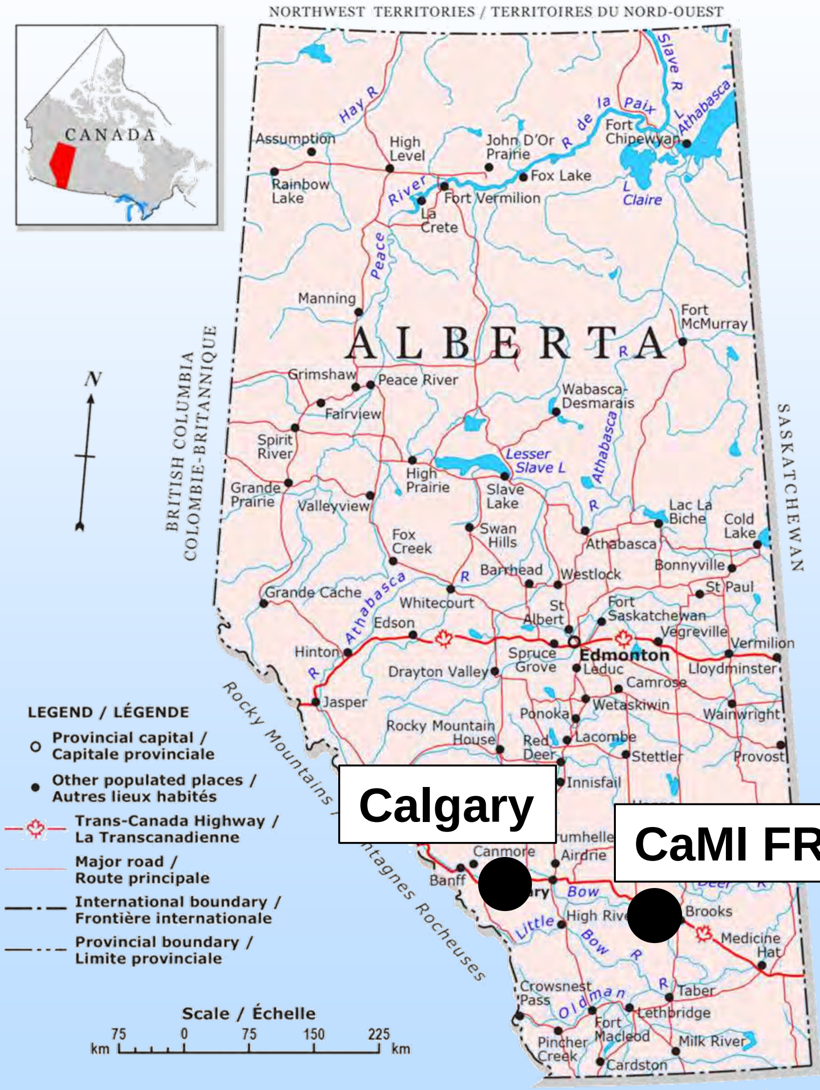

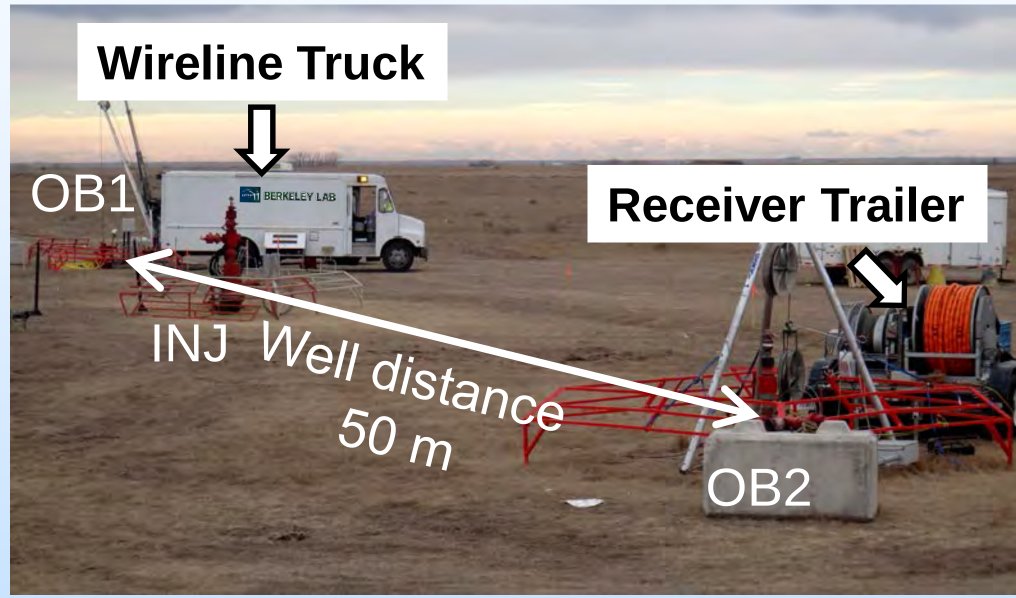

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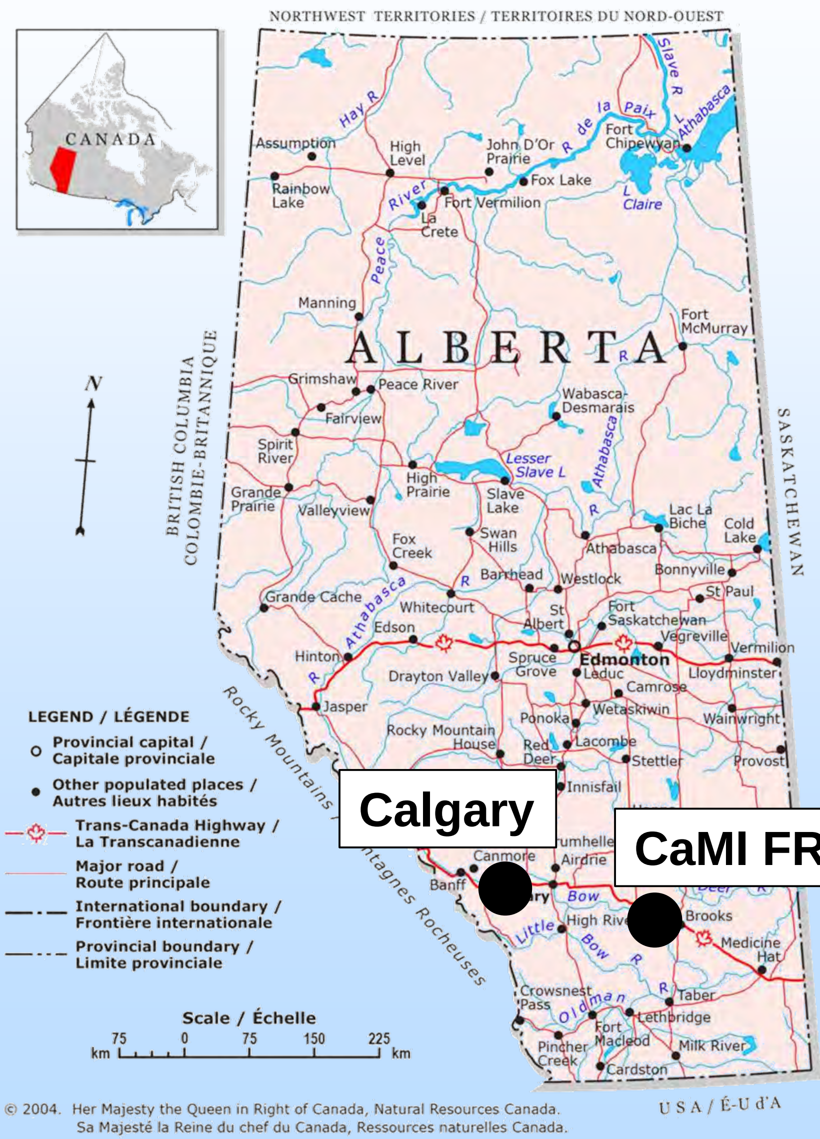
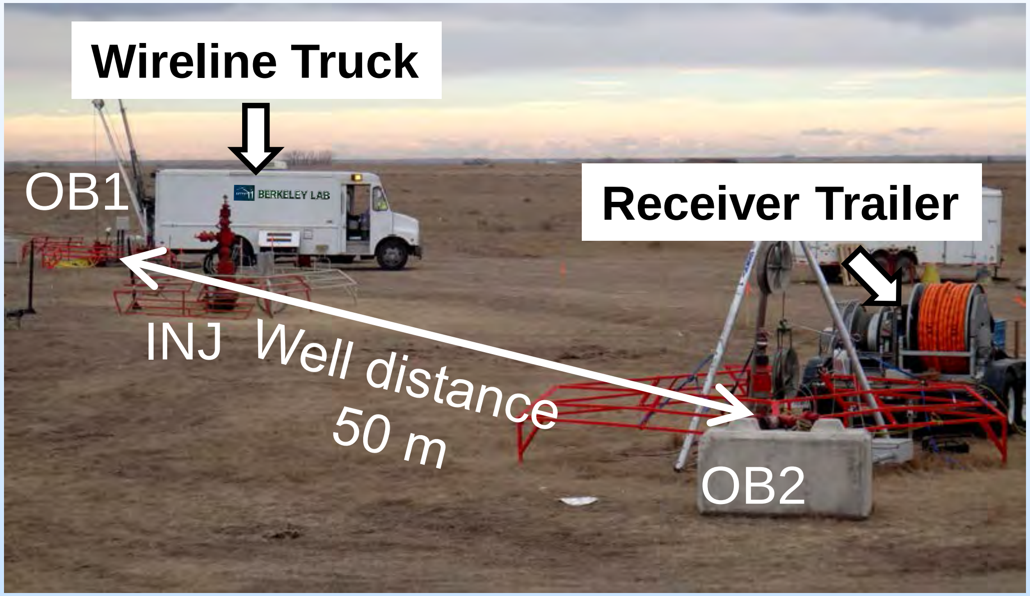
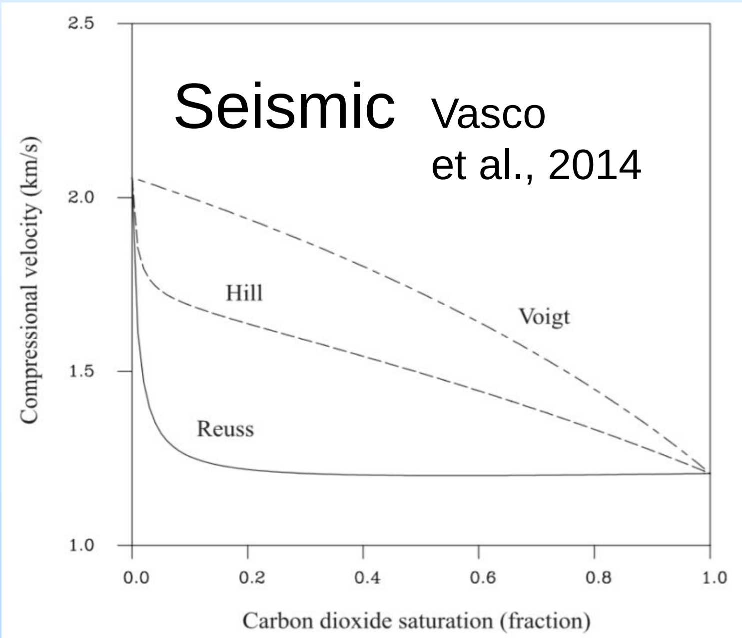


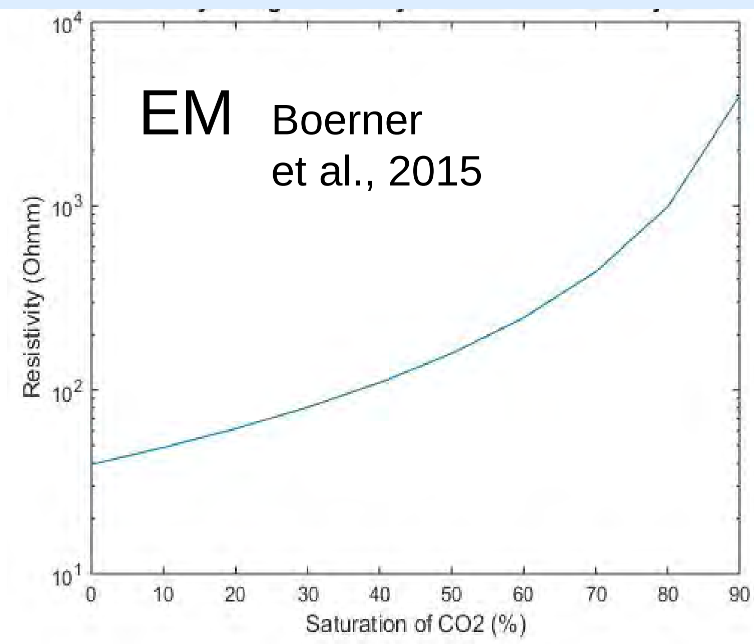


LBNL integrated system:
Constantly raising TRL

Why Joint EM + Seismic?

- Seismic is high-resolution but has uncertainty at high CO_2 saturation and uncertainty in rock physics interpretation
- EM (conductivity) has strong sensitivity at all saturations and a single rock physics model (Archie's relation) and complements seismic for estimating saturation within the injected plume
- Ideally combine EM, seismic, and flow models in joint inversion for CO_2
- Note: Geochemical alterations to rock frame are not currently integrated in either EM or seismic models (but working on that..)





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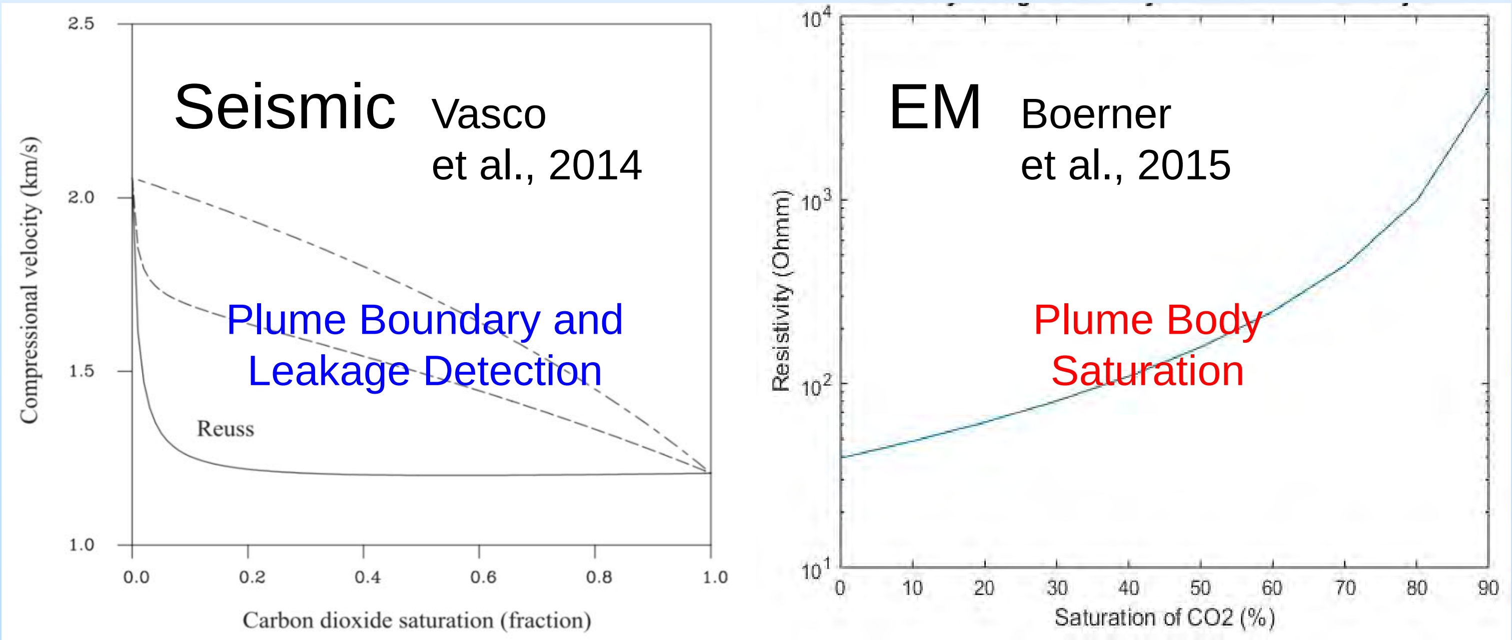
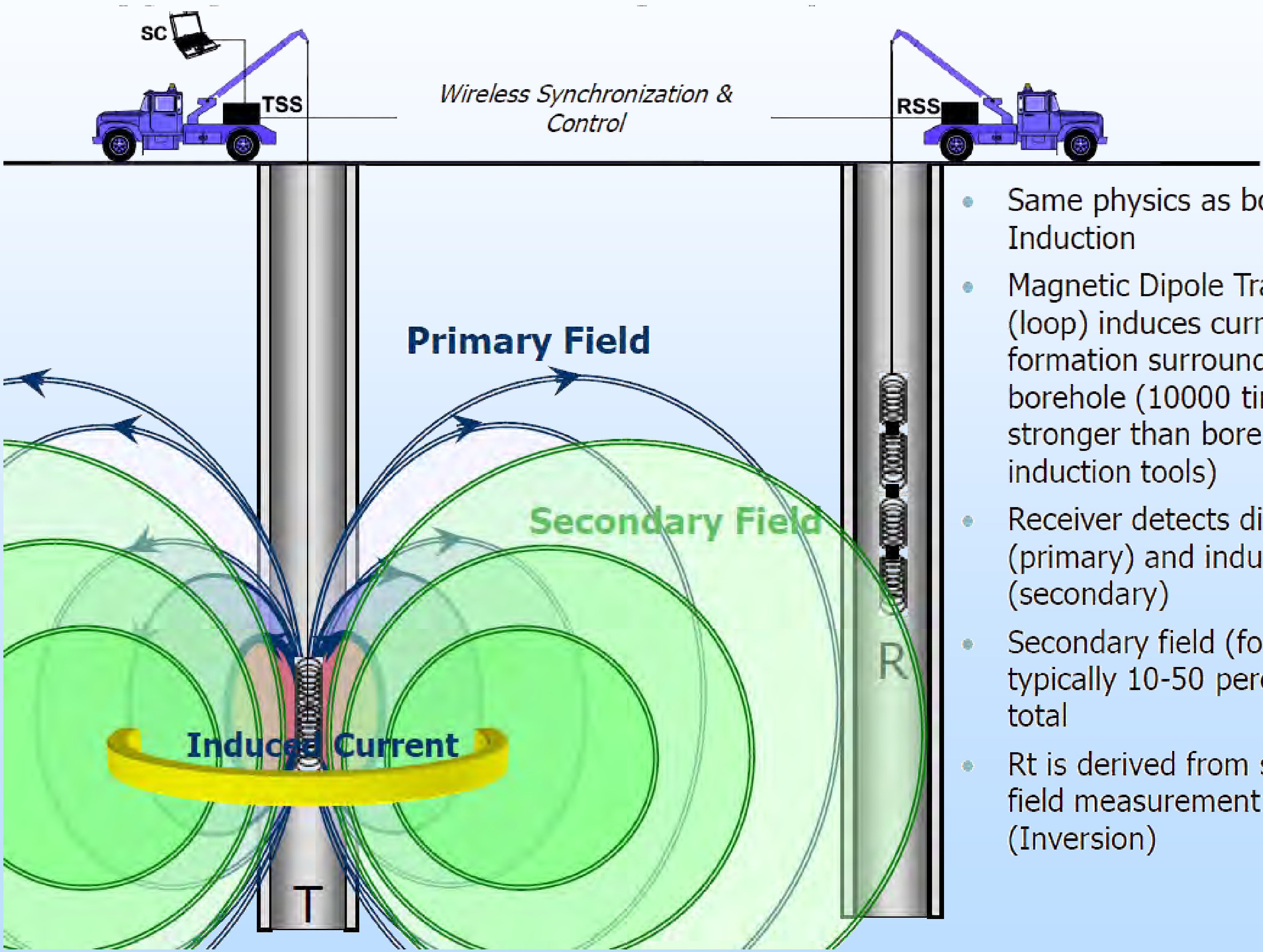


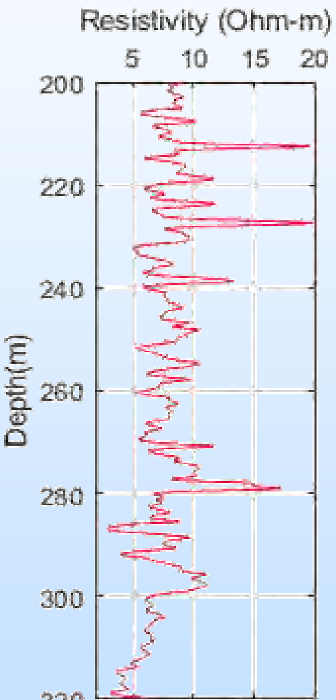
Crosswell EM Method

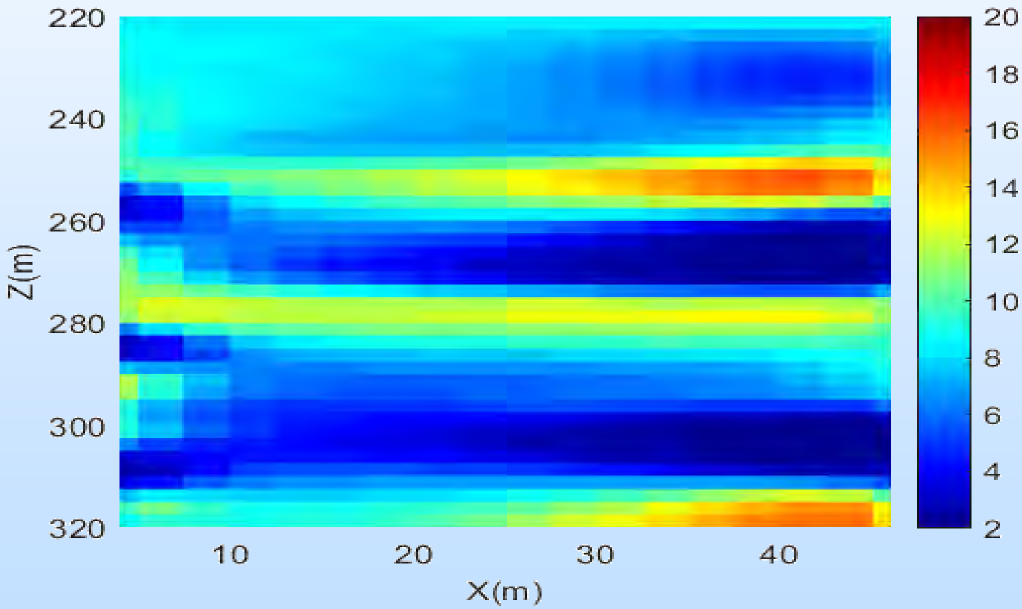


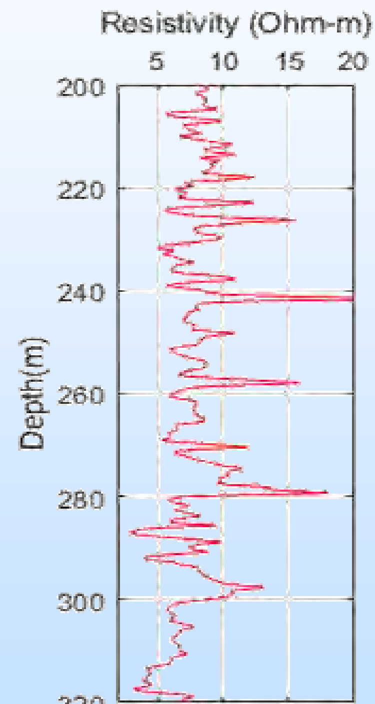
- Same physics as borehole Induction
- Magnetic Dipole Transmitter (loop) induces currents in the formation surrounding the borehole (10000 times stronger than borehole induction tools)
- Receiver detects direct field (primary) and induced field (secondary)
- Secondary field (formation) is typically 10-50 percent of total
- Rt is derived from secondary field measurement (Inversion)

Crosswell EM Method

Log-constrained inversion
200 Hz data

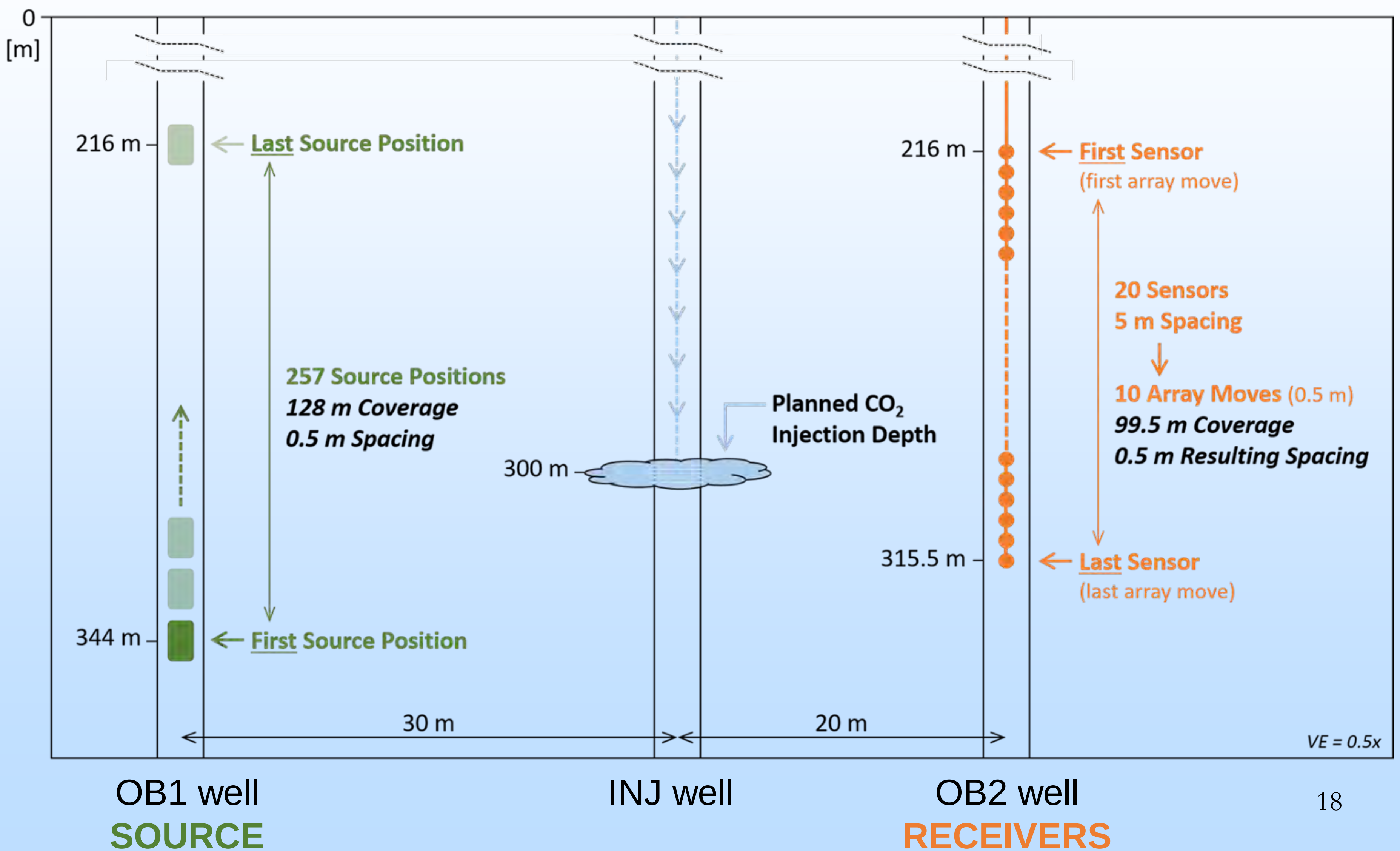






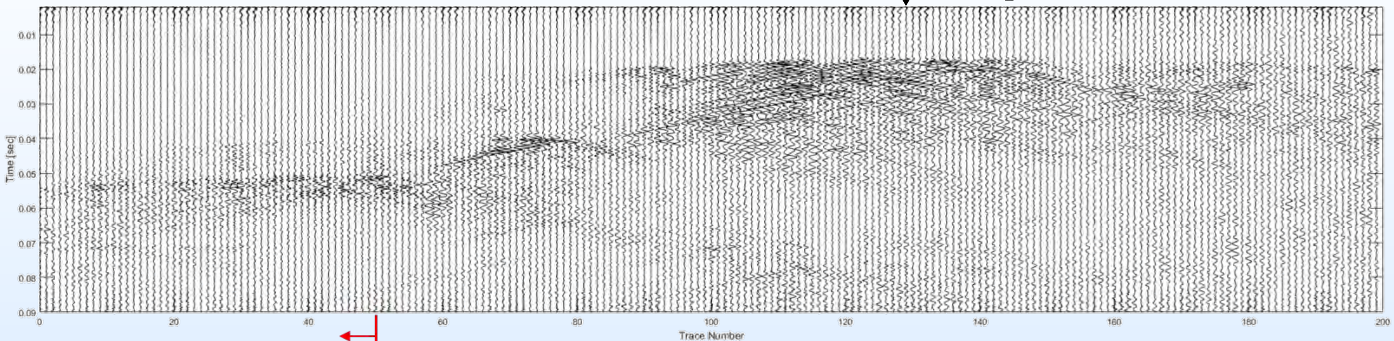
Final Field Data Inversion Misfit ~1.5%

Crosswell Seismic Baseline

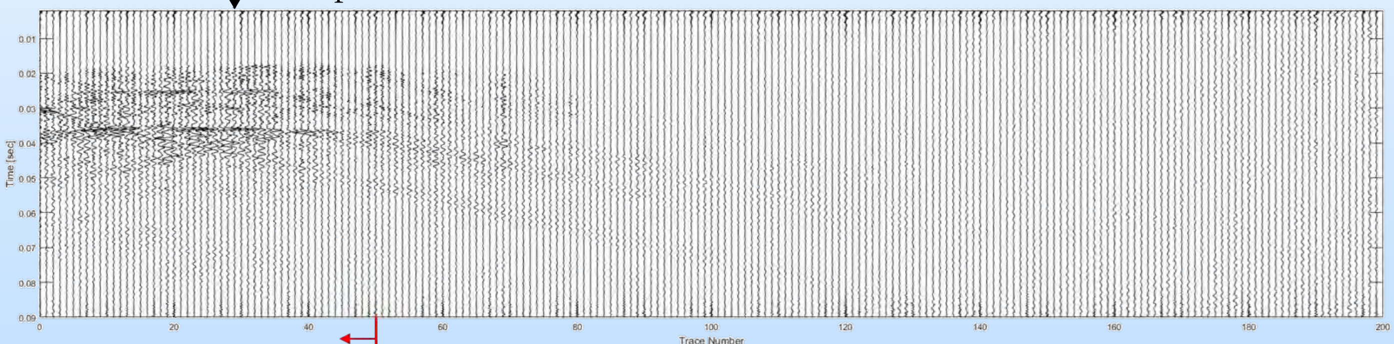


Crosswell Seismic Baseline

0 m ↓ Shot position ~100 m



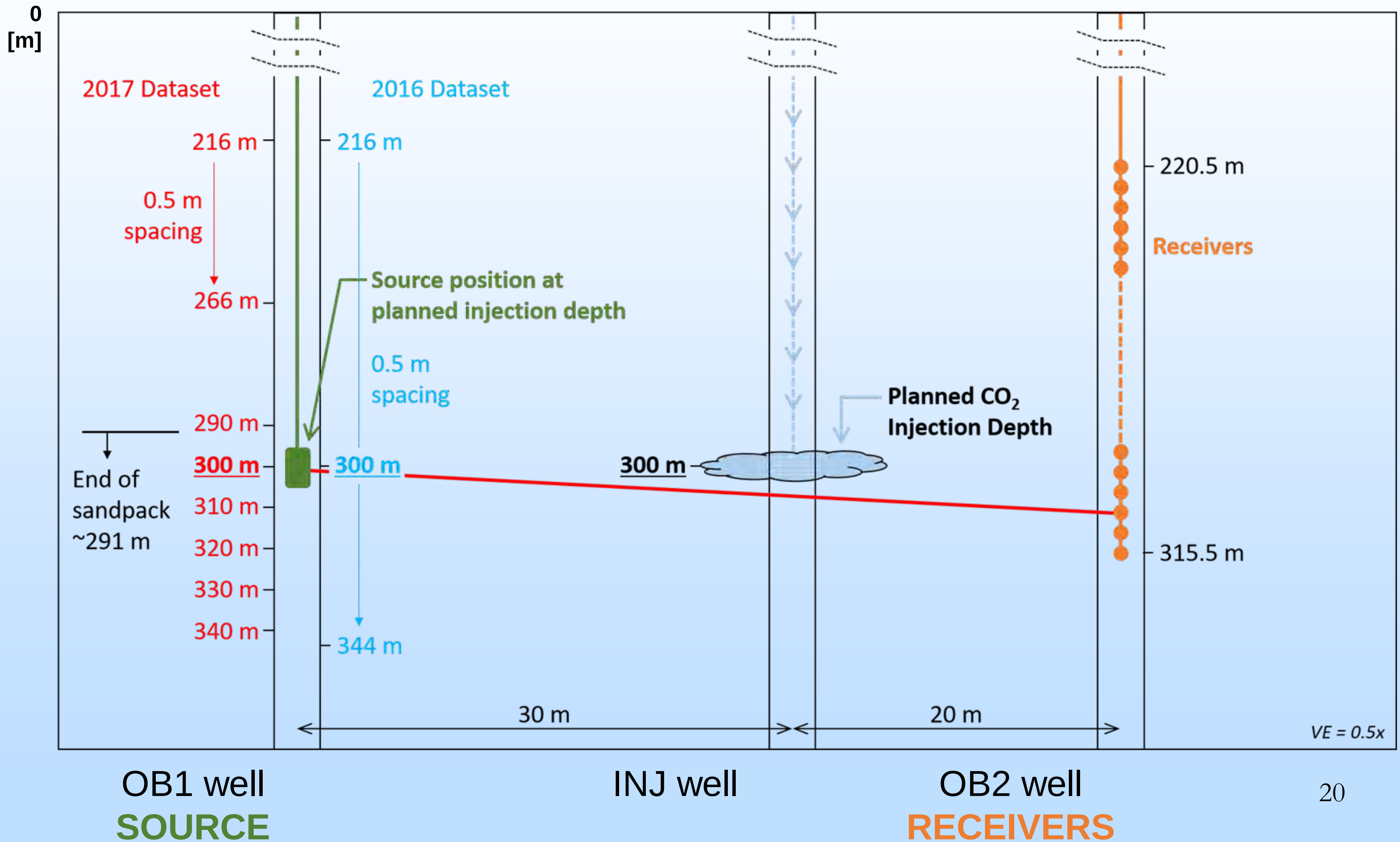
0 m ↓ Shot position ~100 m



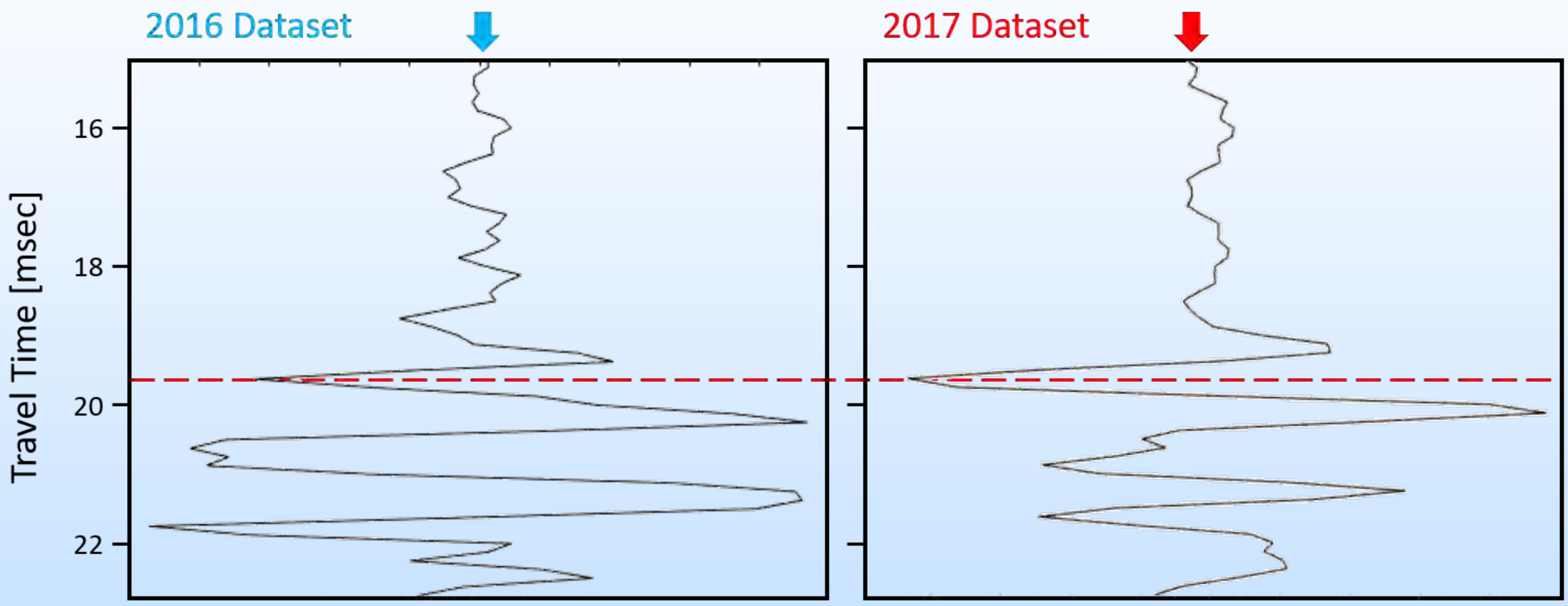
End of Sandpack

- First Arrivals are good for travel time tomography (aperture 1:1)
- Poor transmission near the top of Sandpack completion interval: CH_4 gas in Sandpack

Crosswell Seismic Repeat



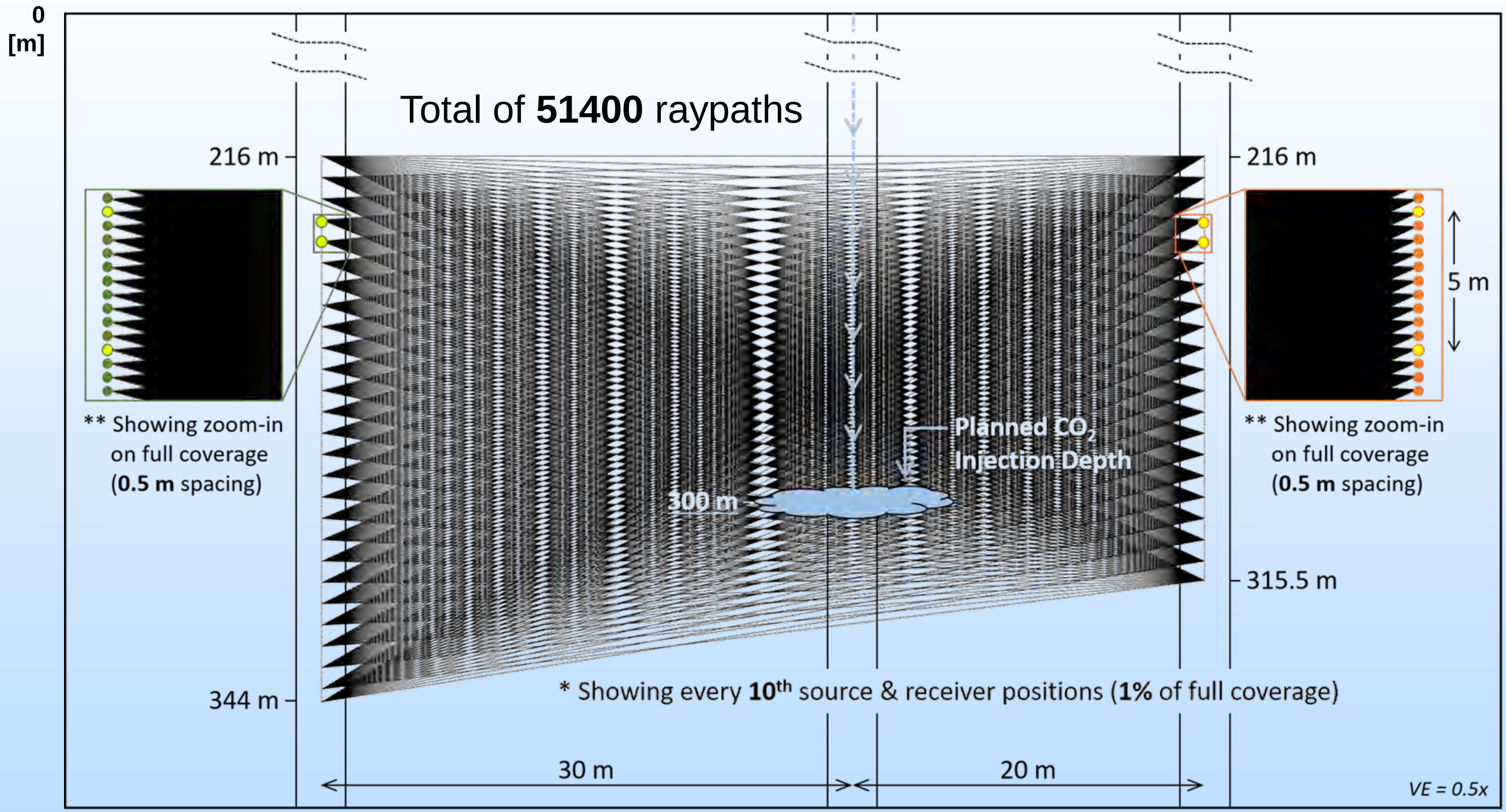
Crosswell Seismic Repeat



Delay error between traces (from crosscorrelation) = **0.024 milliseconds**

Expected time delay due to CO_2: **milliseconds** (orders of magnitude higher)

Crosswell Seismic Coverage

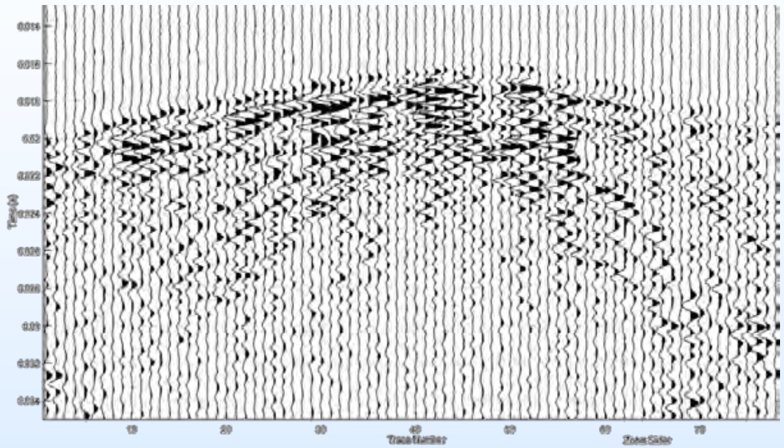


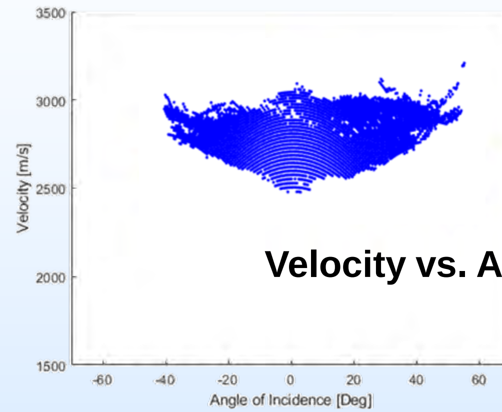
OB1 well
SOURCE

INJ well

OB2 well
RECEIVERS

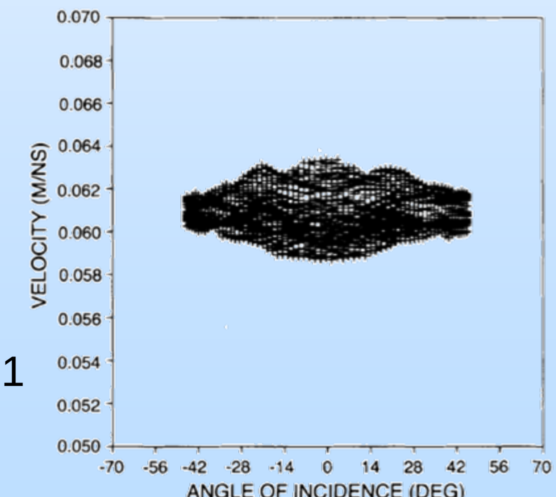
Crosswell Seismic QC





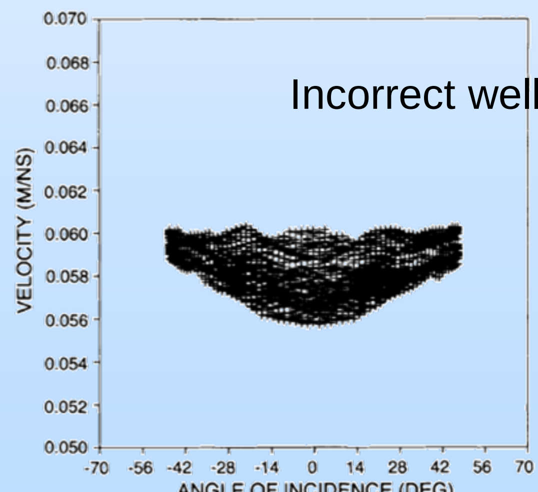
Velocity vs. Angle of Incidence

CORRECT WELL LOCATION



B

INCORRECT WELL SEPARATION

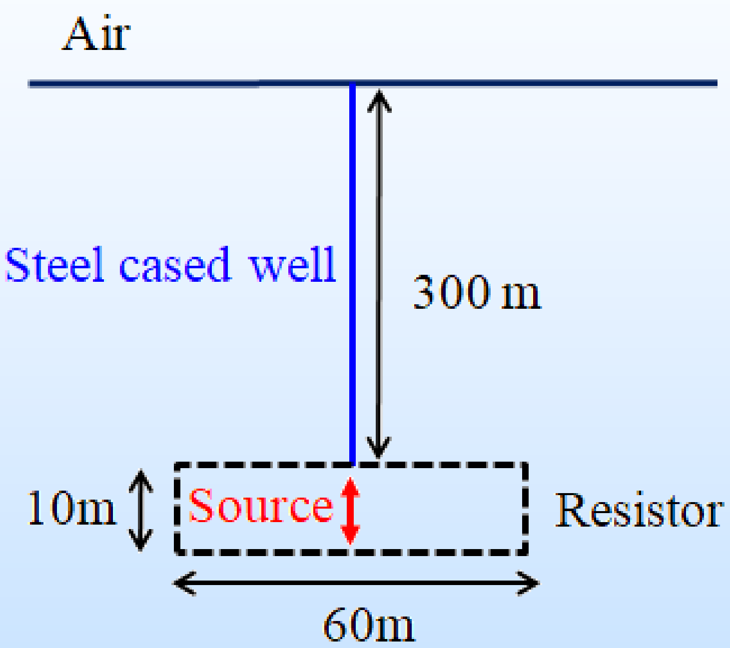


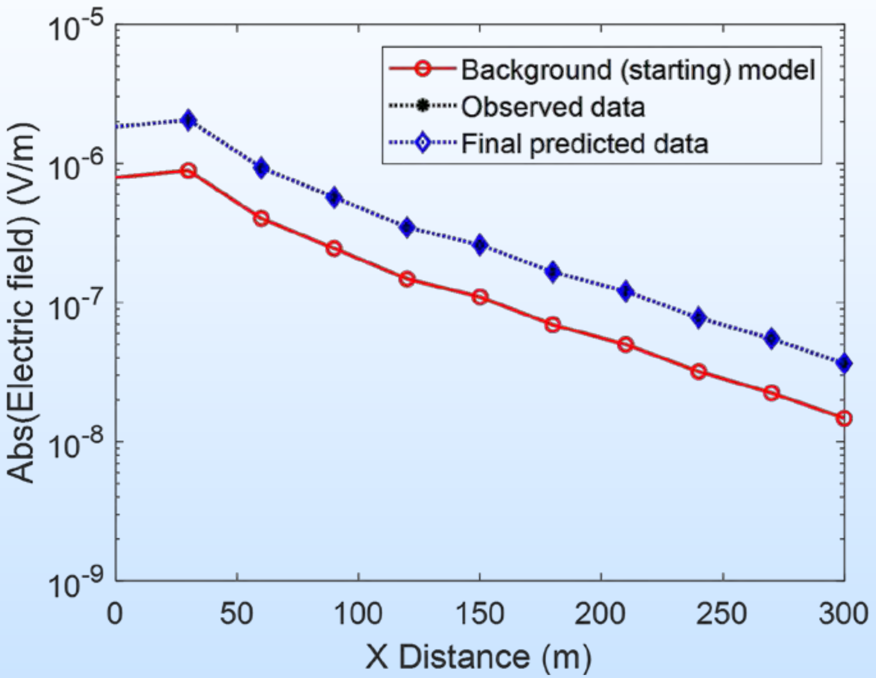
C

Incorrect well separation (?)

From Peterson, 2001

Surface-to-Borehole EM

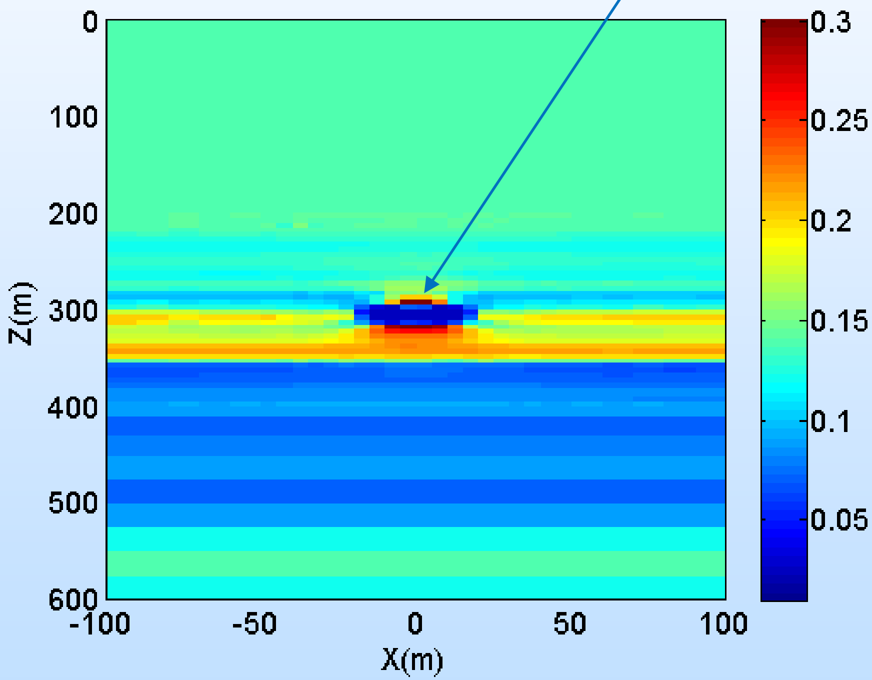


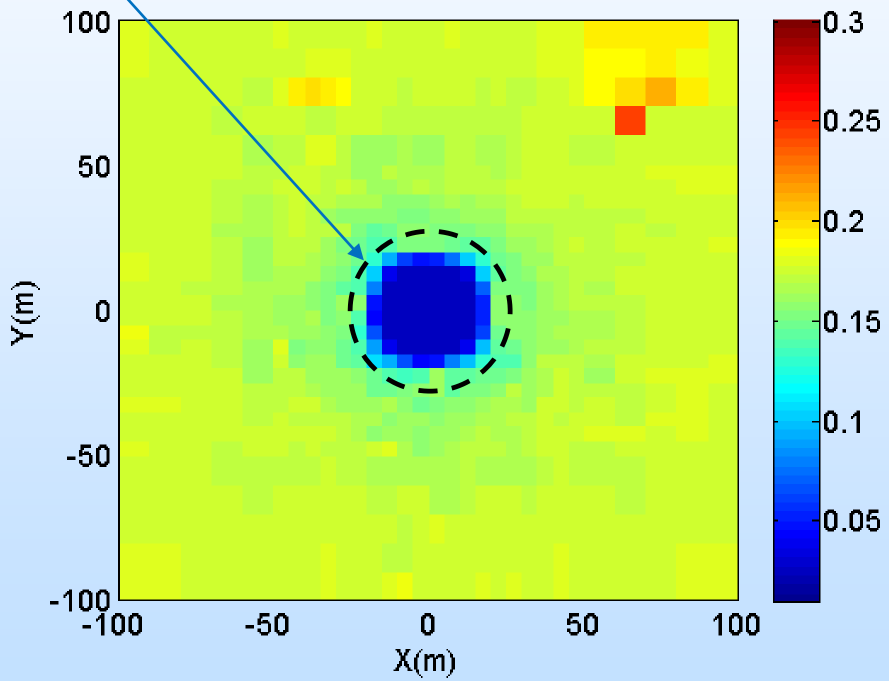


- Electric source below casing shoe energizes the steel cased well.
- About 8 Ohm-m background geology and 30 Ohm-m CO_2 plume
- 200% increase in surface electric field responses

Surface-to-Borehole EM

Recovered CO_2 plume

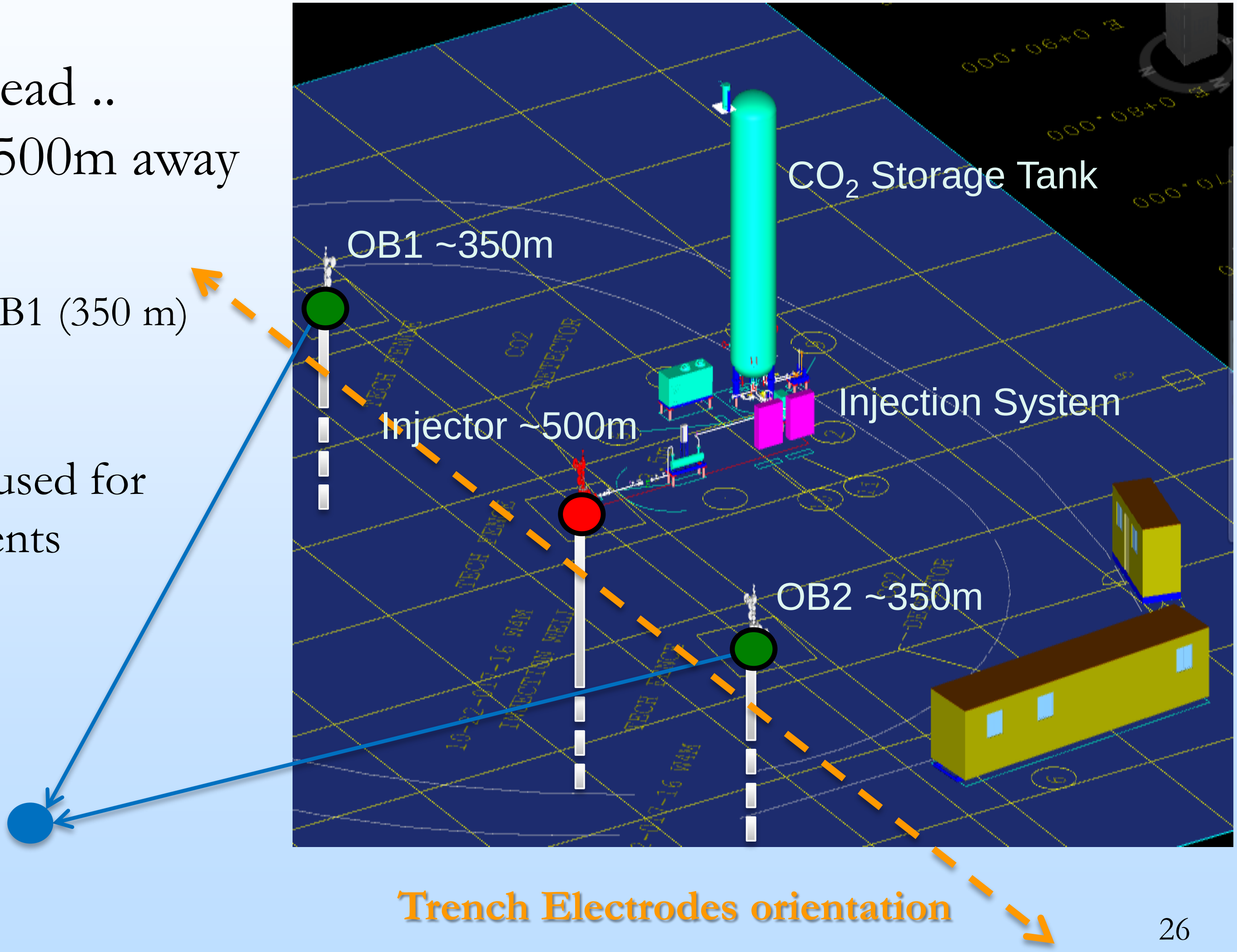




Case Integrity Test

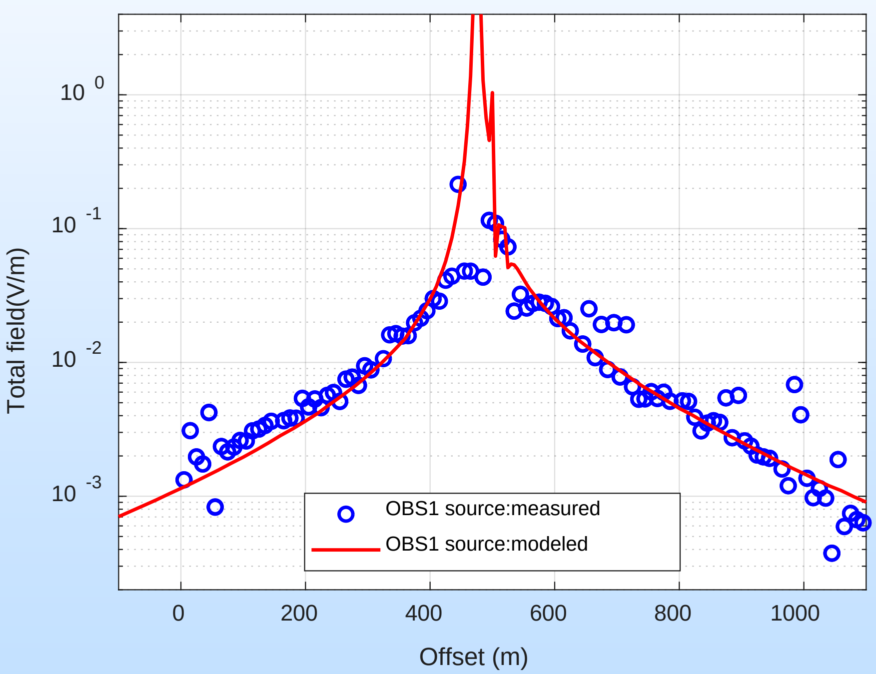
Current on well head ..
Return electrode 500m away

- Two wells used
  - OB2 (60 m) and OB1 (350 m) steel casing depth
- 5 Hz signal used
- Trench electrodes used for voltage measurements

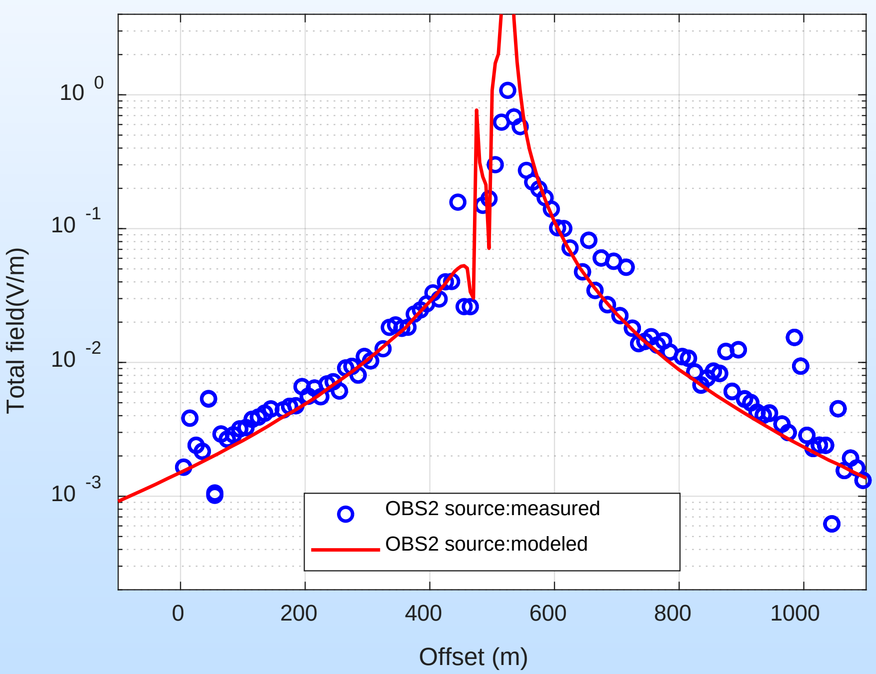


Case Integrity Test

OB1 Well



OB2 Well



Accomplishments to Date

- Collaboration with CMC/CaMI on field site development and monitoring program;
- Progress made towards a fully-integrated EM-Seismic acquisition and recording system (raised TRL);
- <u>EM</u>: preliminary inversion results; steel casing energization as alternative source; case integrity opportunity;
- <u>Seismic</u>: 2017 repeat survey for repeatability assessment; traveltime picking for tomographic inversion; developed automatic tomography acquisition system.

Synergy Opportunities

- EM
  - Crosswell EM tomographic survey within BEST (Brine Extraction and STorage) project in Pensacola, Florida. Michael Wilt, Evan Um, Ed Nichols, LBNL
  - Casing integrity through EERE geothermal program (Casing-Wise, ERT). Yuxin Wu, LBNL
- Seismic
  - Crosswell time-lapse tomography and real-time active monitoring of steam/water injection for EOR, Lost Hills, California. Pierpaolo Marchesini, LBNL and Chevron
    Highlight: new HV amplifier, capable of low frequencies <100 Hz → acquire crosswell DAS (?)

Project Summary

Key Points

- CaMI fills an important need in storage R&D: intermediate depth, gas-phase detect/monitor
- LBNL contributing to a comprehensive monitoring program:

  integration of Crosswell EM and Seismic; U-Tube sampling; heat pulse monitoring; surface and borehole helical DAS; distributed strain;
- Multi-Physics (EM and Seismic) monitoring to improve CO_2 saturation estimates
- Integration of EM and Seismic for joint inversion.

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Lessons Learned

<u>EM:</u> surface-to-borehole; case integrity test;

<u>Seismic:</u> repeatability assessment; well separation information;

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Seismic: repeatability assessment; well separation information;

Future Plans

- Begin injection (CaMI), 700 kg/day planned;
- Wait for sufficient CO_2 injection (breakthrough to at least one OB well?); FW modeling;
- Acquire first repeat data for time-lapse analysis and plume monitoring, ~ Spring 2019;
- EM: surface-to-borehole; system improvement (recording system);
- Seismic: well separation logs (well deviation); new HV amplifier, crosswell DAS (?)

Bibliography

- Daley, T. M., Marchesini, P., Wilt, M., Cook, P., Freifeld, B., Lawton, D.

  Containment and Monitoring Institute (CaMI): Baseline Geophysics for CO_2 Monitoring with Crosswell Seismic and Electromagnetics

  EAGE/SEG Research Workshop on Geophysical Monitoring of CO_2 Injection: CCS and CO_2 - EOR, Trondheim, August 28-31, 2017

- Marchesini, P., Daley, T.M., Wilt, M., Nichols, E., Cook, P.

  Baseline Data for Crosswell Seismic and Electromagnetics at CaMI

  CaMI Research Integration Workshop, Calgary, June 25-26, 2018

- Wilt, M., Marchesini, P., Daley, T.M., Um, E., Cook, P., Nichols, E., Freifeld, B., Lawton, D.

  Crosswell Electromagnetic (EM) and Crosswell Seismic Monitoring of CO_2 Injection: Baseline Field Studies at the CaMI Field Site, Alberta, Canada.

  Greenhouse Gas Control Technologies Conference - GHTT-14, Melbourne, October 21-26, 2018

No Journal Publications, specific to CaMI, as of now

Acknowledgments

- Funding for LBNL was provided through the Carbon Storage Program, U.S. DOE, Assistant Secretary for Fossil Energy, Office of Clean Coal and Carbon Management, through the National Energy Technology Laboratory (NETL), for the project "Core Carbon Storage and Monitoring Research" (CCSMR) under contract No. DE-AC02-05CH11231

- Carbon Management Canada (CMC) Containment and Monitoring Institute (CaMI) Field Research Station (FRS)

- We thank CMC Research Institutes Inc. for access to the CaMI Field Research Station and for logistical support during the field campaigns

Appendix

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 international research opportunities;
  - Rapid transfer of knowledge to domestic programs.

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 technology readiness level (TRL) of targeted technologies from a level of TRL 2 – 3 up to 4 – 5 through leveraged field testing opportunities, with field sites being used as in-situ laboratories.

Energy Geosciences
EARTH & ENVIRONMENTAL SCIENCES AREA

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Gantt Chart

Task	Milestone Description*	Fiscal Year 2016 Q1	Q2	Q3	Q4	Planned Start Date	Planned Completion Date (Reporting Date)**	Actual Start Date	Actual End Date	Comment (notes, explanation of deviation from plan)
Milestone 2-1 (A)	Stage 3 SOV-DAS installation – field architecture and data processing plan		x			1/1/2018	3/31/18 (4/30/18)			AOP Tracked
Milestone 2-2 (B)	Data analysis report for CRC-3 installation SOV data				x	1/1/2018	9/30/18 (10/31/2018)			
Milestone 3-1 (C)	Report on development of a baseline electrical conductivity profile from crosswell inductive EM surveys		x			1/1/2018	3/31/18 (4/30/2018)			
Milestone 3-2 (D)	Report on baseline borehole-to-surface electrical measurements and well casing integrity measurements.			x		1/1/2018	6/30/18 (7/31/2018)			
Milestone 4-1 (E)	Deployment plan for a high sensitivity, wide bandwidth, vector fiber-optical or piezoelectric accelerometer sonde for deep borehole operations		x			1/1/2018	3/31/18 (4/30/2018)			
Milestone 4-2 (F)	Interim report on review of previous DAS data acquired on cemented linear fiber cable for passive micro-seismic monitoring.			x		1/1/2018	6/30/18 (7/31/2018)			
Milestone 5-1 (G)	Analyze, interpretation and simulation of the available strain data			x		1/1/2018	6/30/18 (7/31/2018)			
Milestone 5-2 (H)	In-situ Assessment of the Mechanical coupling between rock-cement-fiber-and-casing				x	1/1/2018	9/30/18 (10/31/2018)			
Milestone 6-1 (I)	Linking the emergence of leakage flowpaths in a fault zone with the characteristics of Static fault displacements and of microseismic signals (Example of the Mont Terri Fault Activation experiment(s) dataset).		x			1/1/2018	3/31/18 (4/30/2018)			
Milestone 6-2 (J)	Preliminary measurements and analyses of long term integrity evolution of a caprock affected by a small natural fault - Understanding why the measured fault leakage behavior upon reactivation is different from one injection test to another?				x	1/1/2018	9/30/18 (10/31/2018)			AOP Tracked
* No fewer than two (2) milestones shall be identified per calendar year per task (per previously separate project)										**Note: Milestone reporting accompanies quarterly report, one month after end of quarter.

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