Field Testing of Emerging Technologies – The Otway Project

Project Number ESD14-095

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U.S. Department of Energy

National Energy Technology Laboratory

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

August 16-18, 2016

Acknowledgmenets

- The Otway Project is led by the Australian CO2CRC. We would like to acknowledge the funding provided by the Australian government to support this CO2CRC research project.
- We also acknowledge funding from ANLEC R&D and the Victorian Government for the Stage 2C project.
- We thank the National Geosequestration Laboratory (NGL) for providing the seismic sources (INOVA Vibrators) for this project. Funding for NGL was provided by the Australian Federal Government.

- 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 NETL.

Project Team

- The project team consists of participants from the CO2CRC, Curtin University, Lawrence Berkeley National Laboratory, and numerous supporting organizations
- Contributors to the work include Roman Pevzner (Stage 2c Science Lead), Tom Daley, Michelle Robertson, Todd Wood, Shan Dou, Jonathan Ajo-Franklin, Julia Correa, Sinem Yavuz, Konstantin Tertyushnikov, Milovan Urosevic, Dmitry Popik, and Boris Gurevich

Presentation Outline

- Program Benefits
- Objectives
- Background information
- Technical Status
- Accomplishments

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

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.

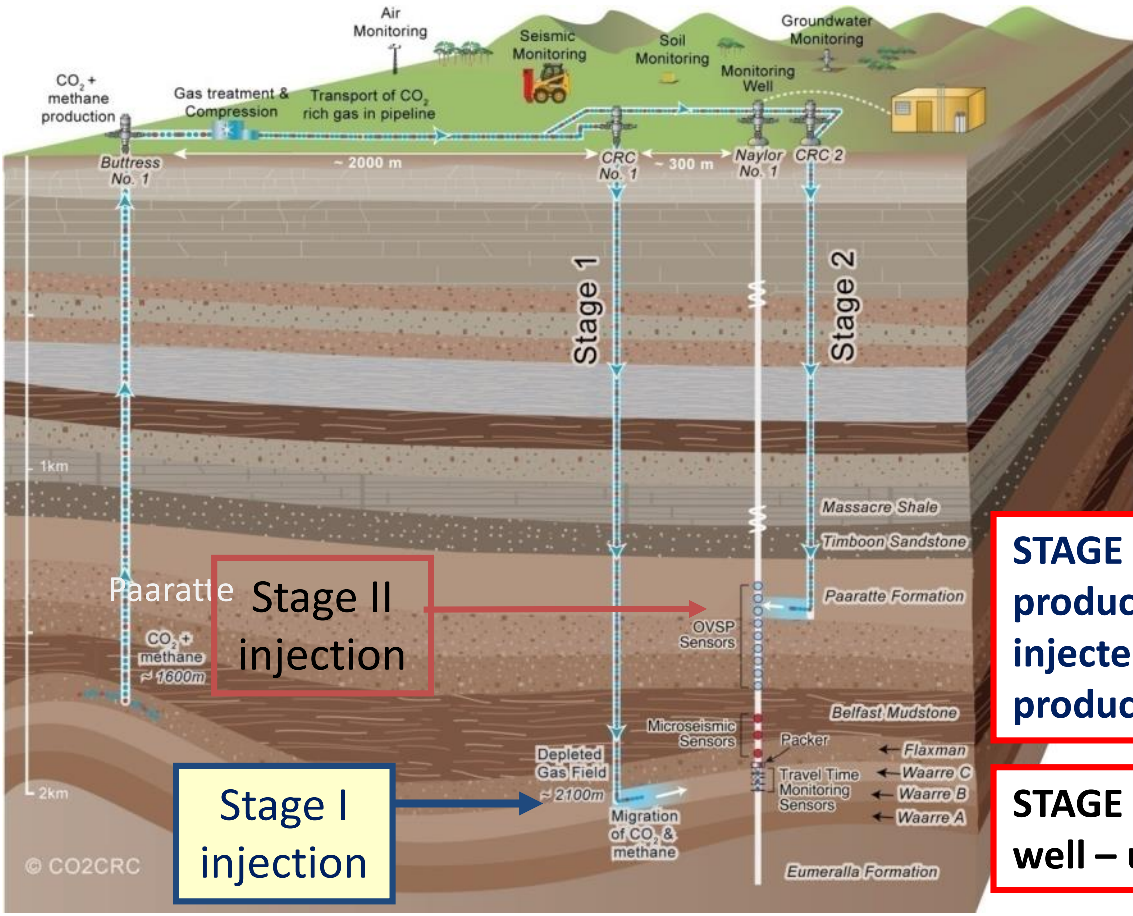
Otway Project FY16 Technology Objectives

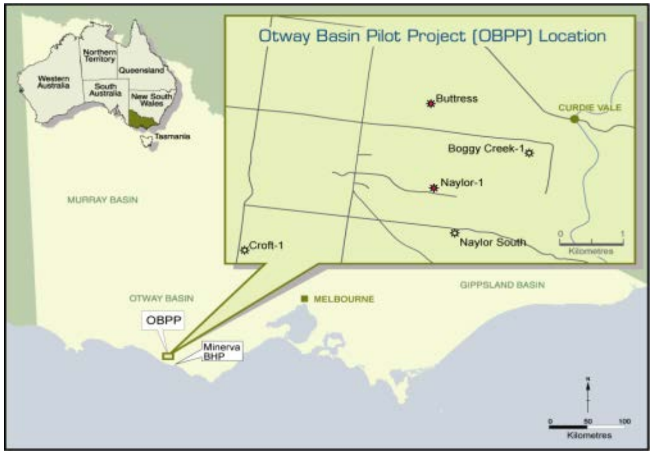
- Perform first ever time-lapse seismic imaging using a DAS areal network consisting of trenched and borehole based fiber
- Operate LBNL designed swept frequency Surface Orbital Vibrators
- Compare performance of DAS technology with conventional geophones

Technical Status

- Completed 15,000 Tonne CO_2 injection
- Performed repeat 3D Vibroseis survey and VSP every 5 kT recorded on DAS and geophones
- Operated on a daily basis newly designed Surface Orbital Vibrators
- Permanence and plume stability monitoring phase has begun

CO2CRC Otway Basin Pilot Project (Victoria, Australia)





STAGE I: An 80/20 % of CO_2/CH_4 stream produced from Buttress, transported and injected into CRC-1 well (previous CH_4 production well) -65 Kt.

STAGE II: CO_2/CH_4 stream injected into CRC-2 well – up to 15 Kt.

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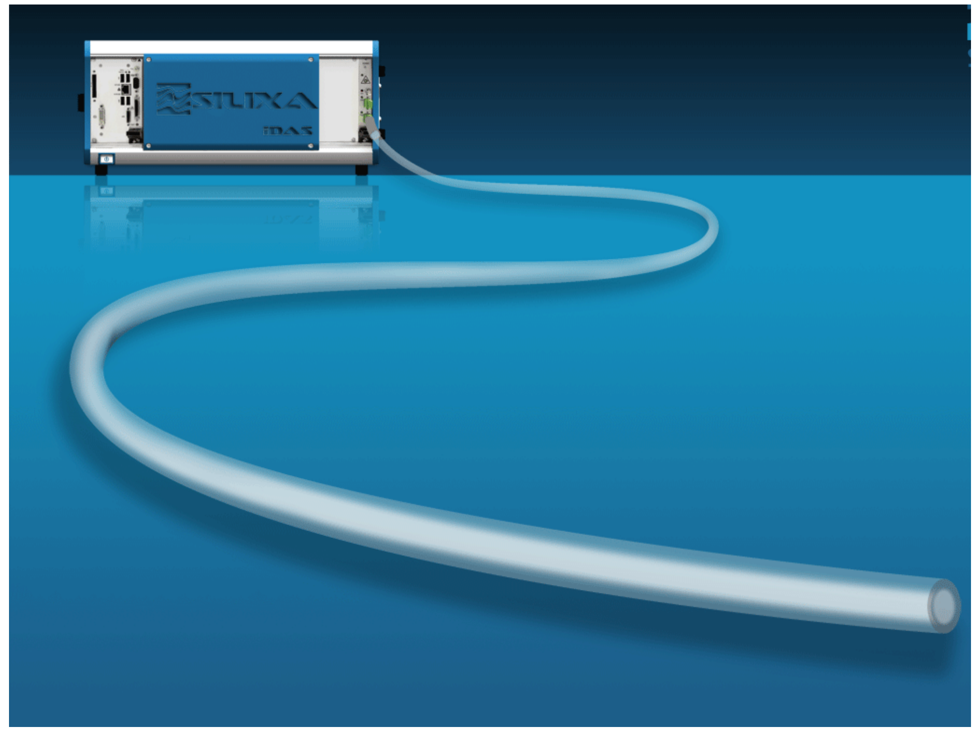
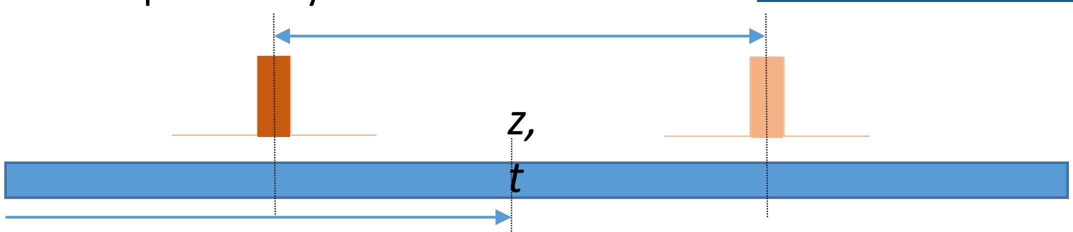
Distributed Acoustic Sensing

- Standard optical fibre acts as the sensor array
  - Typical sampling at 10kHz on 10,000m fibre
  - Standard gauge length of 10m
  - Spatial sampling of 25cm
  - DAS measures change in average elongation per 10m gauge length per 0.1ms acoustic time sample, sampled every 0.25 m in distance





$$\left[u\left(z+\frac{dz}{2},t+dt\right)-u\left(z-\frac{dz}{2},t+dt\right)\right]-\left[u\left(z+\frac{dz}{2},t\right)-u\left(z-\frac{dz}{2},t\right)\right]$$

Parker et al., Distributed Acoustic Sensing – a new tool for seismic applications, *first break* (32), February 2014

Stage 2C Project Overview – monitoring strategy

4D seismic with buried receiver array acquired concurrently with 4D VSP

- Baseline: March 2015
- Monitor surveys: 5 kt, 10kt, 15 kt of injection (January-April 2016), 1&2 years post injection (January 2017&2018)

Offset VSPs

Passive seismic using buried receiver array

LBNL group lead: Trialing 4D seismic with buried DAS array, 4D VSP in CRC-2 (optical fiber on the tubing) and continuous seismic sources

CO2CRC

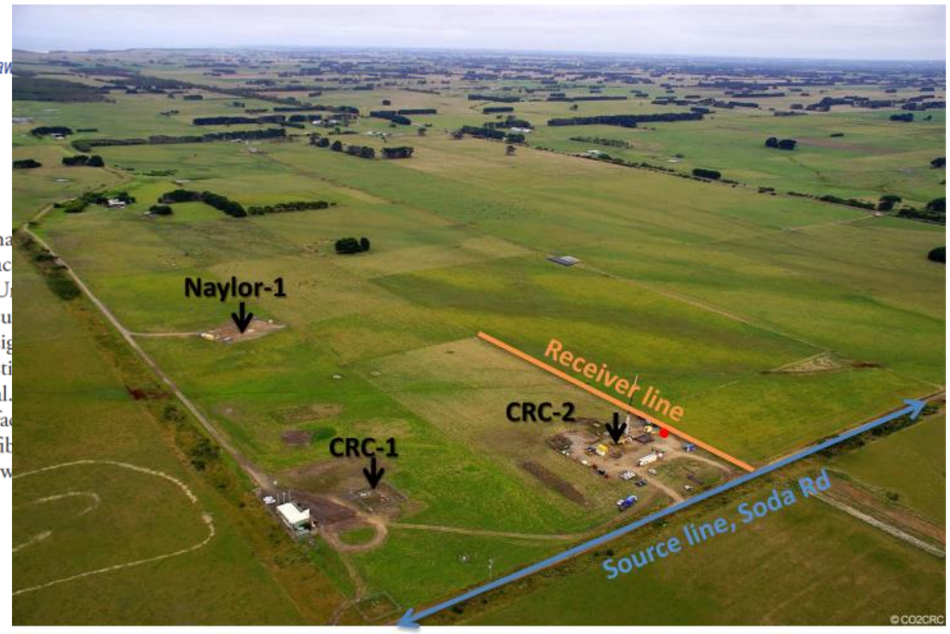
DAS Technology history at CO2CRC Otway Site

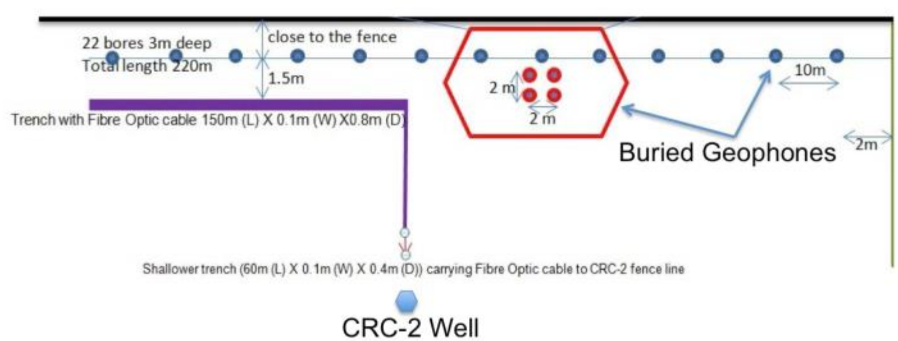
NONREFLECTION SEISMIC AND INVERSION OF SURFACE AND GUIDED WAVES

Field testing of fiber-optic distributed acoustic sensing (DAS) for subsurface seismic monitoring

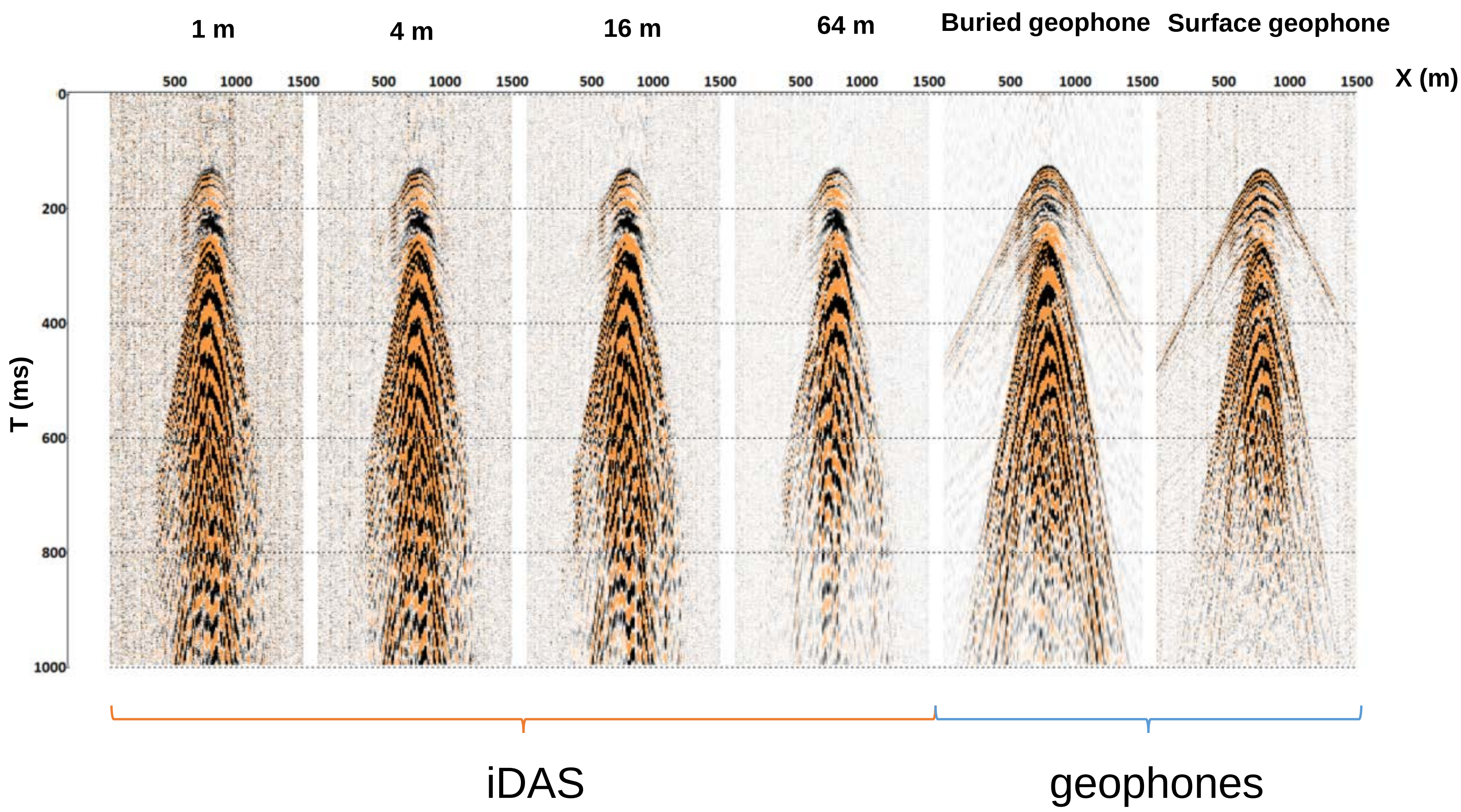
THOMAS M. DALEY, BARRY M. FREIFELD, JONATHAN AJO-FRANKLIN, and SHAN DOU, Law
ROMAN PEVZNER, CO2CRC, Curtin Universty
VALERIYA SHULAKOVA, CO2CRC, CSIRO
SUDHENDU KASHIKAR and DOUGLAS E. MILLER, Silixa
JULIA GOETZ, JAN HENNINGES, and STEFAN LUETH, GFZ

Distributed acoustic sensing (DAS) is a relatively recent development in the use of fiber-optic cable for measurement of ground motion. Discrete fiber-optic sensors, typically using a Bragg diffraction grating, have been in research and development and field testing for more than 15 years with geophysical applications at least 12 years old (Bostick, 2000, and summary in Keul et al., 2005). However, developments in recent years have sought to remove the need for point sensors by using the fiber cable itself as a sensor (Mestayer et al., 2011; Miller et al., 2012).





2012 iDAS trial



Daley et al, 2013, TLE

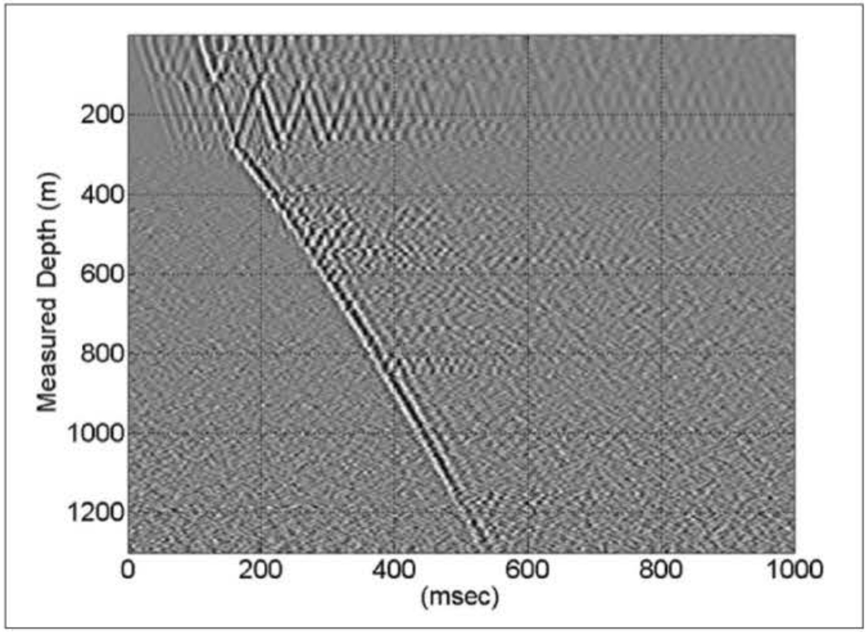


Figure 6. *Shot-gather DAS data from Otway CRC-2 borehole using weight-drop source with 41-fold stack. The top ~300 m of the well experiences multiple reverberations (which had been observed on previous geophone VSP data), but below 300 m the P-wave dominates.*

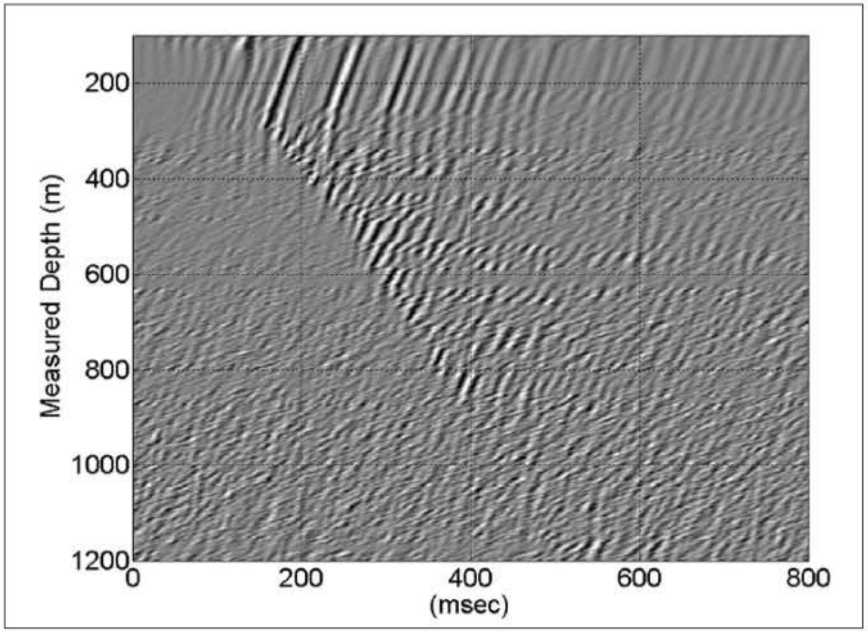


Figure 7. *Upgoing energy for the 41-fold VSP data of Figure 6, using the DAS acquisition in well CRC-2. Reflected energy is observed.*

Daley et al, 2013, TLE

FAT Helical Wound Cable

Anderson and Shapiro – HWC on soft mandrel 1980 US Patent 4375313

Hornman et al. (2013 75^{th} EAGE) introduced a helical wound FO cable

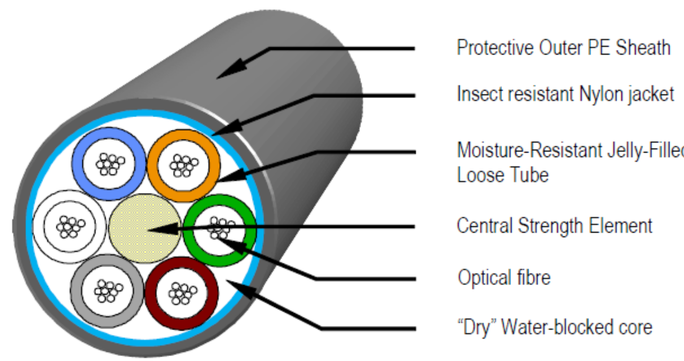
LBNL trialed multiple designs with varying physical properties

Line 5 installed one length of HWC for comparison to straight fiber

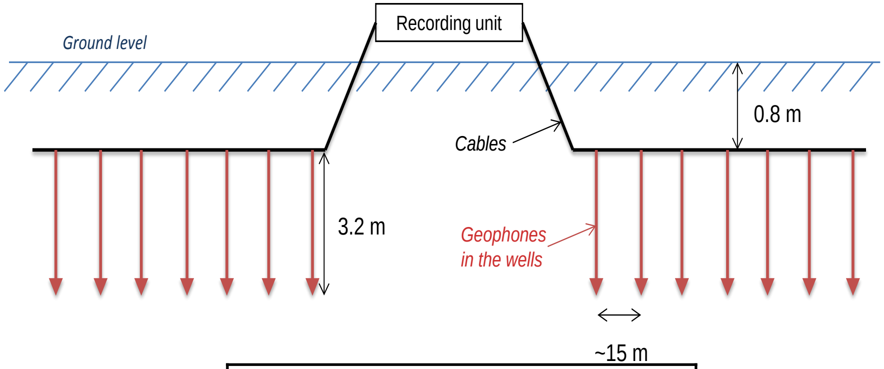
30° spiral wound on 58 Shore A rubber mandrel.

Lessons learned – acoustic impedance of cable and surrounding soil is important

Normal Telecom Cable used in all trenches

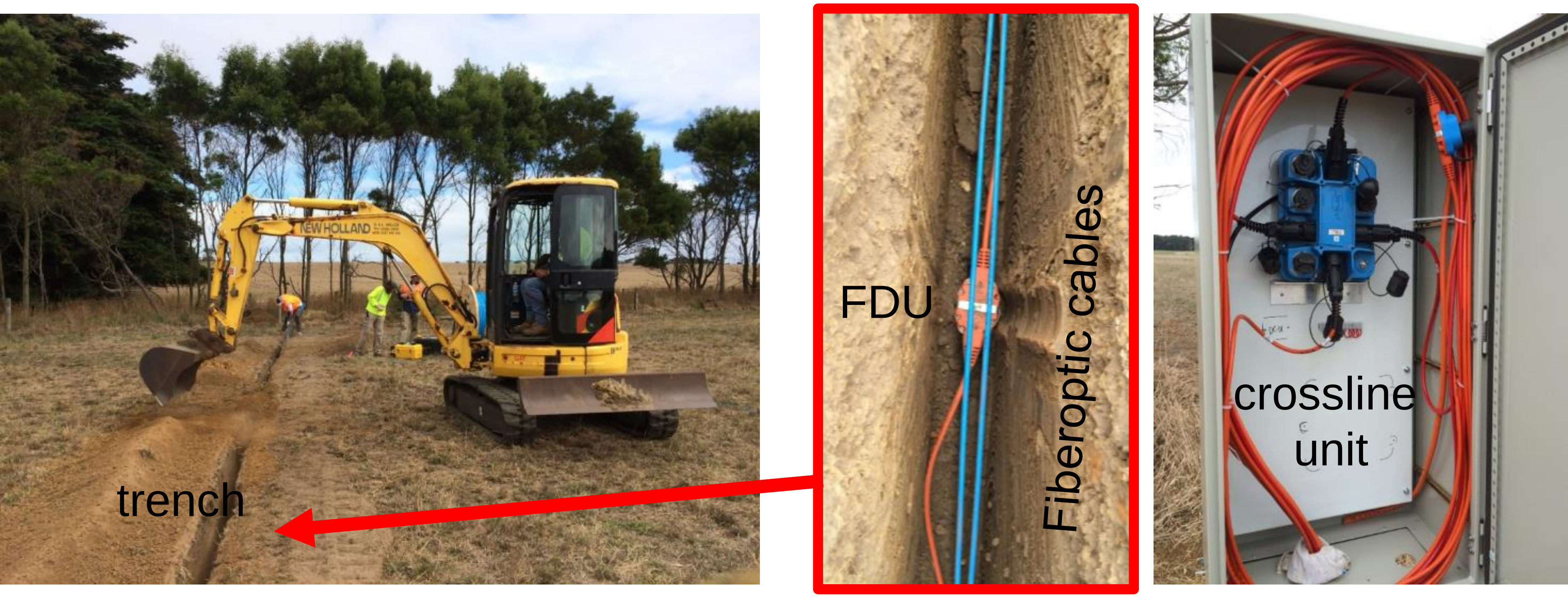


Acquisition design - receivers



RECEIVER PARAMETERS	
Receiver Type	Sercel SG-5
Recording Pattern	Orthogonal cross-spread pattern
Receiver Line Spacing	100 m
Receiver Point Spacing	15 m
Receiver Depth	4 m
Cables Depth	0.8 m

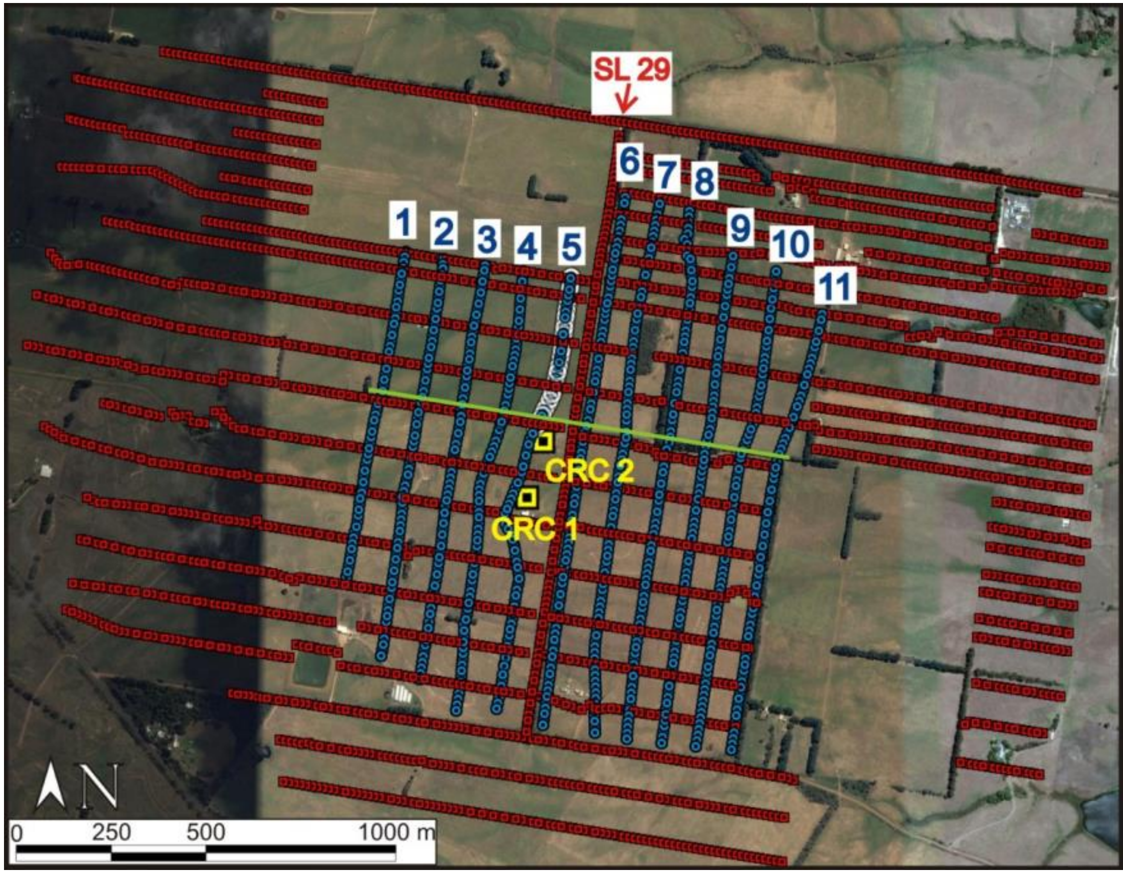
Acquisition design - receivers



Acquisition design - source

SOURCE PARAMETERS	
Source Type	INOVA UniVibe 26000 lbs
Sweep frequency	6-150 Hz
Tapers	0.5 s
Sweep Length	24 s
Listening Time	5 s

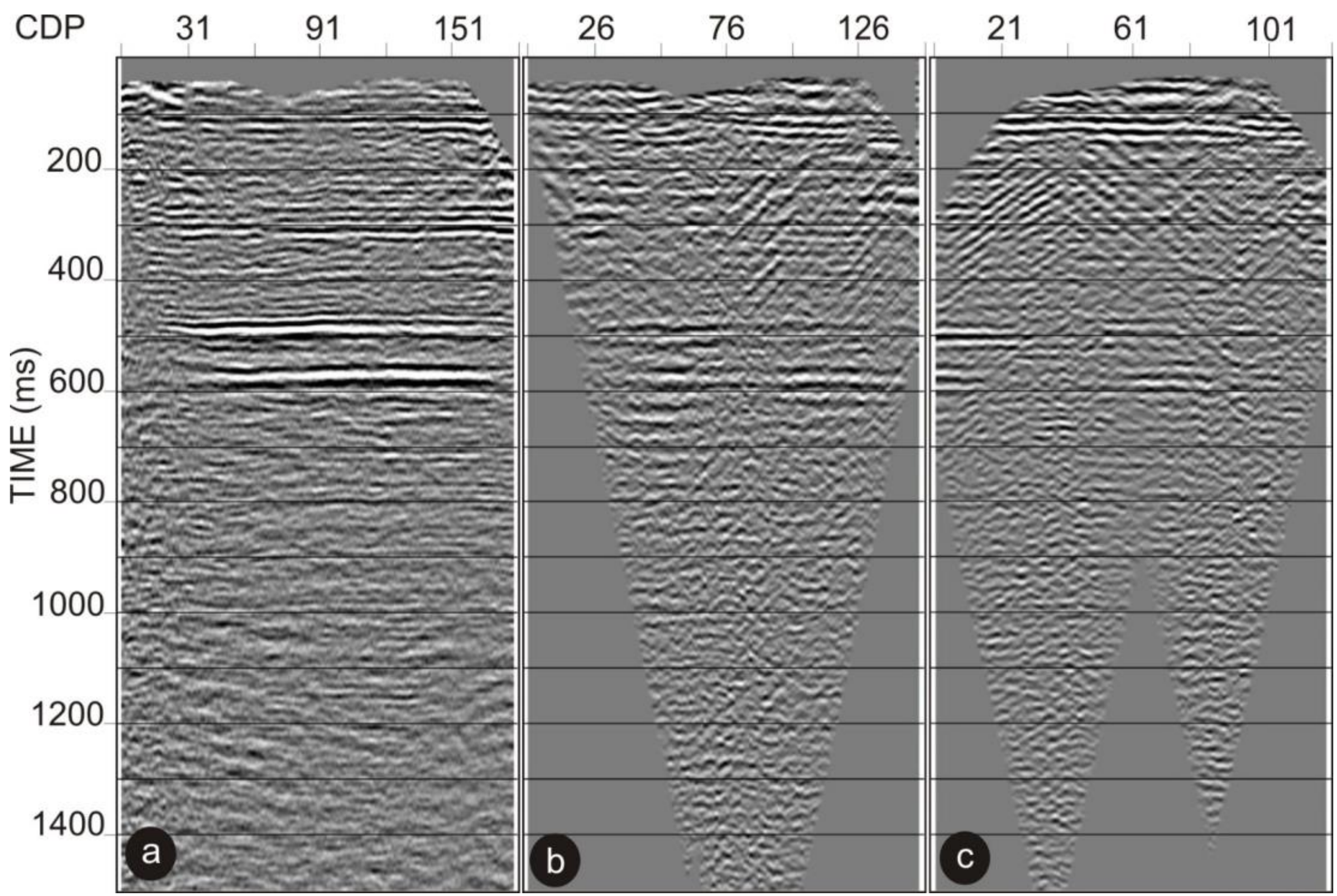
	Geophone	Standard Fibre Optic Cable	HWC
Source Line #	29	29	29
Total # of Sources	107	107	107
Receiver Line #	5	5	5
Total # of Receivers	80	1176	760
Receiver Point Spacing	15 m	1 m	1 m
CDP Bin	10 m	10 m	10 m
Max Fold	101	1559	1010



Map view of the Otway site for the CO2CRC Stage 2C seismic survey, March 2015.

13.5 TB DAS Baseline Data Size!!!

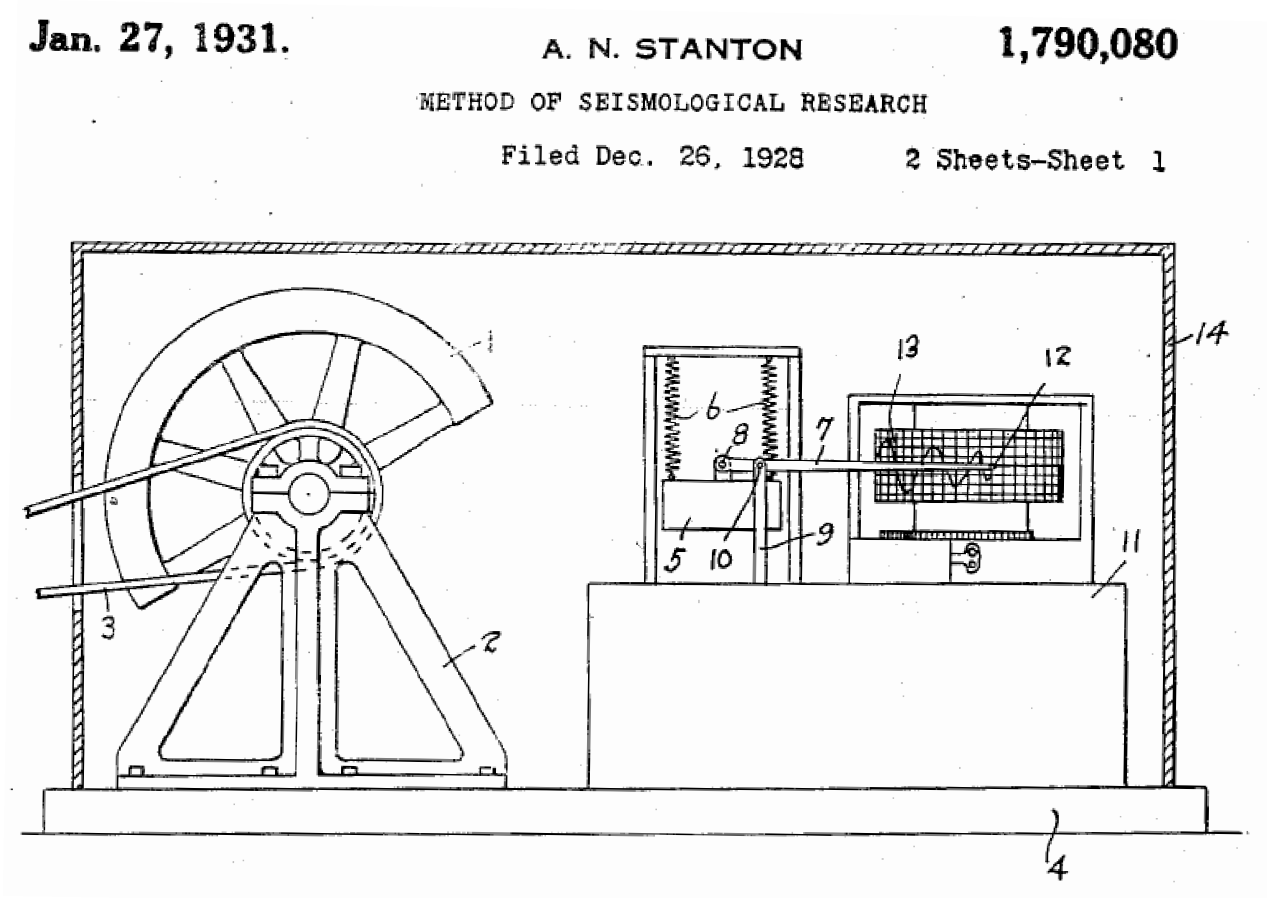
Final stack sections of **a)** geophone, **b)** standard fibre optic DAS and **c)** HWC DAS data.



S. Yavuz et al. 2016 EAGE Vienna Austria

Surface Orbital Vibrators

- US Patent issued for Stanton "Geo-Oscillator" in 1931
- Swept frequency used to identify depth to an interface by means of a "resonance meter" recording amplitude of reflected waves



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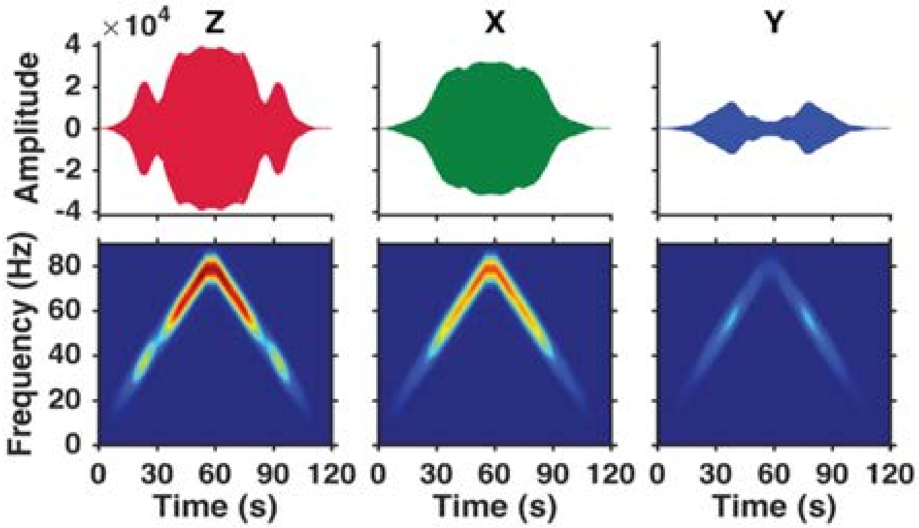
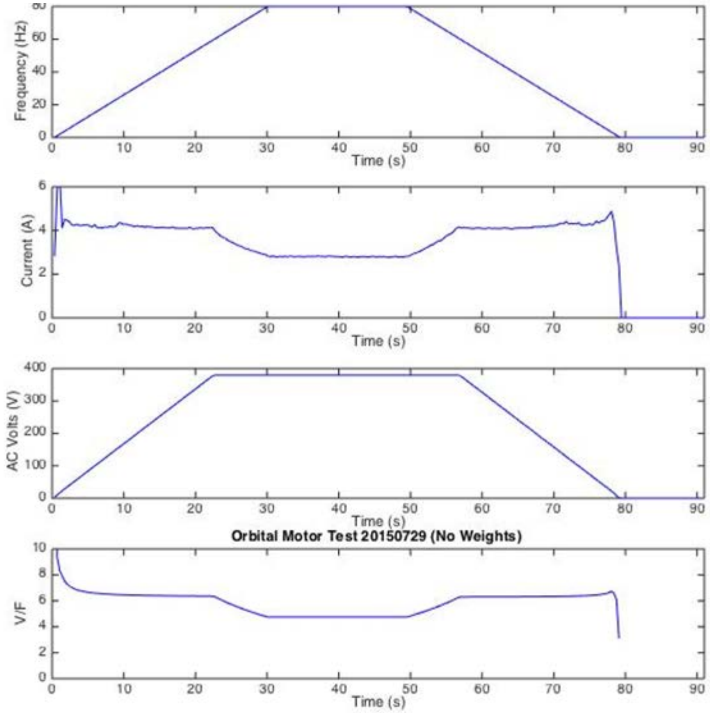
Surface Orbital Vibrator – VFD Controlled AC Induction Motor



Max Frequency 80 Hz, Force (@80Hz) 10 T-f
Phase stability is not maintained. Operate 2.5 hr/d



Force is adjustable

$F = m\omega^2 r$

Lessons learned – Foundation design improved to resist shear

Initial foundations used only threaded rod and rebar to resist forces. Failed within one month

New foundation uses structural steel to improve resistance to shear.

No issues after five months of operation.

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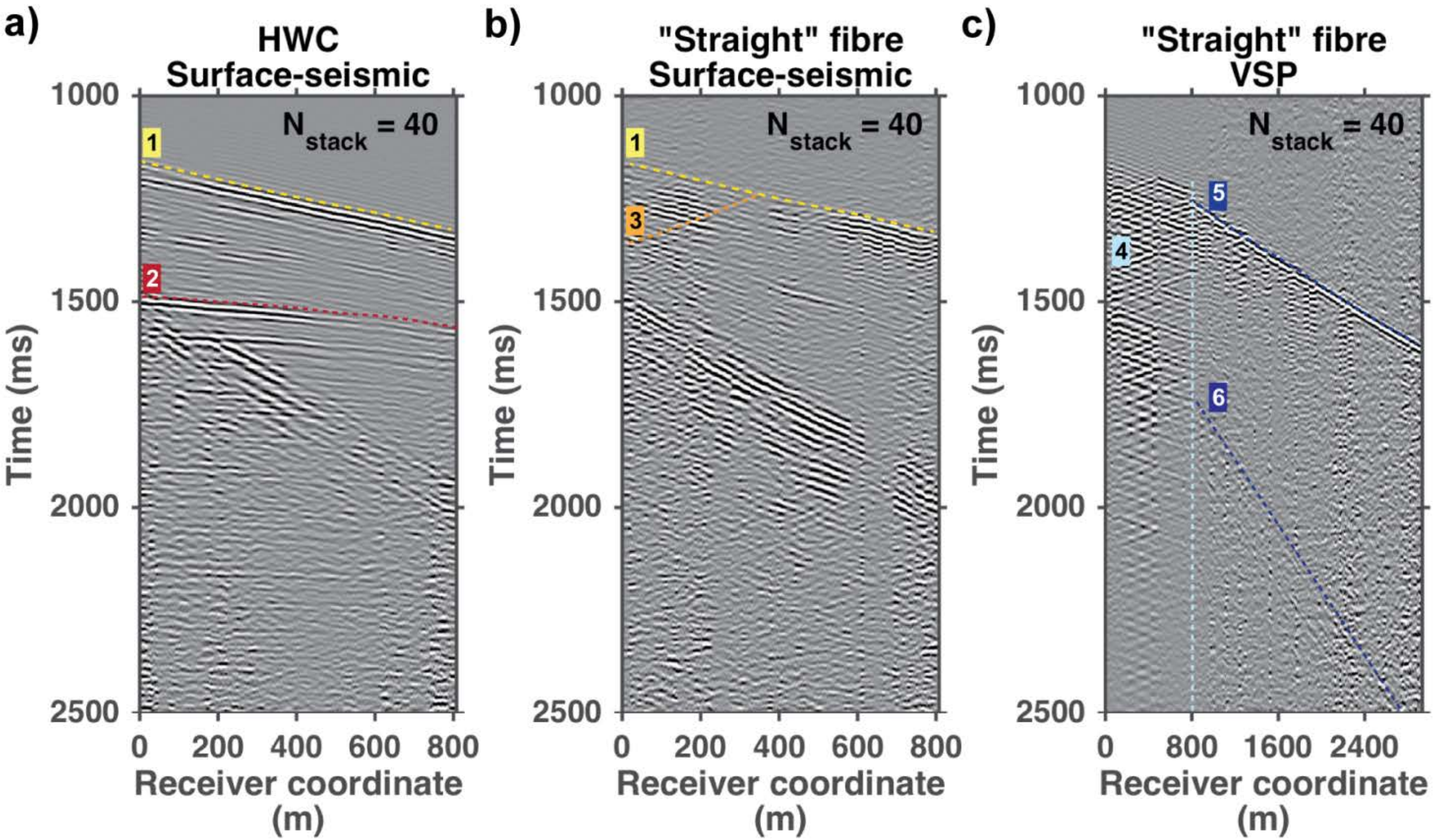
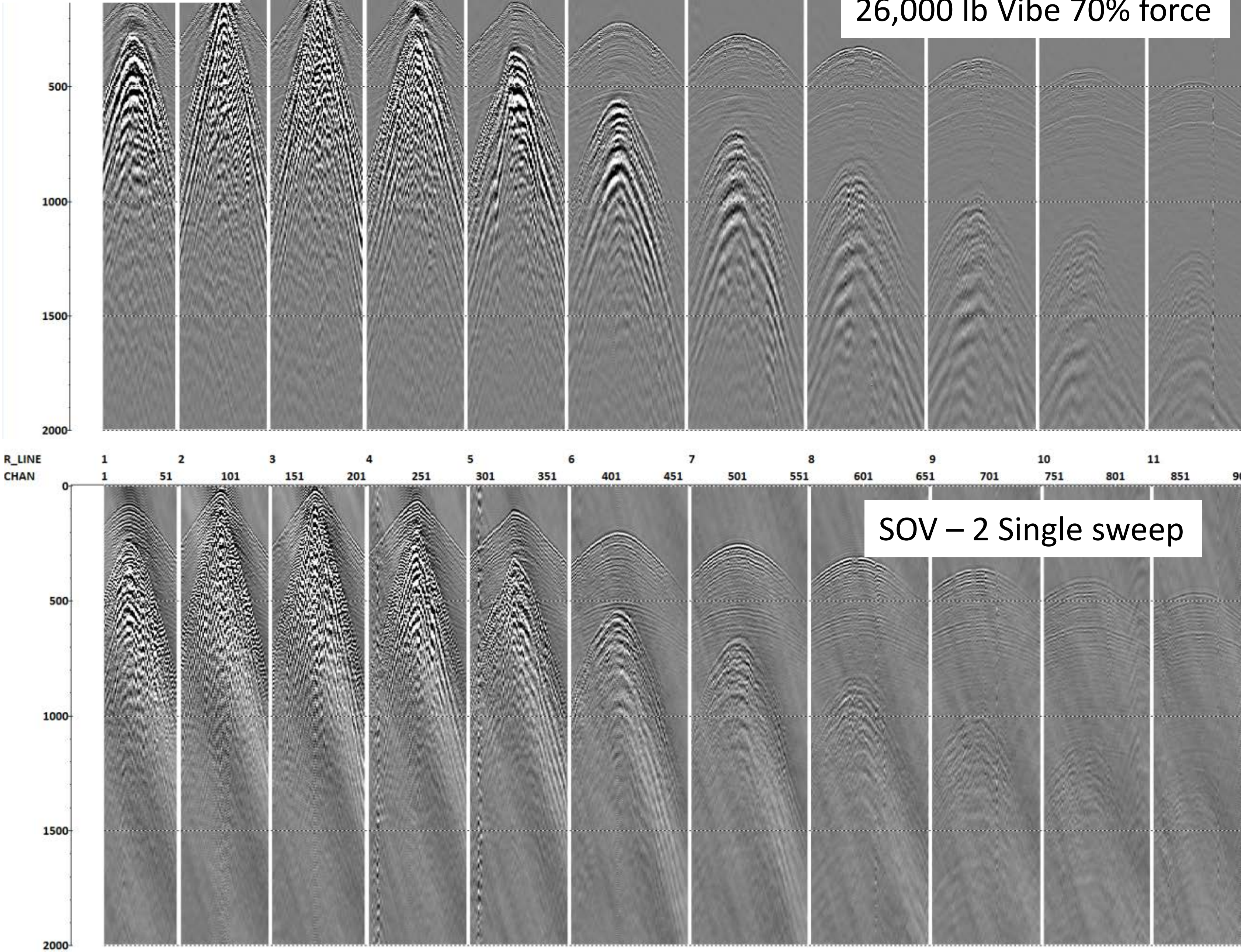
Deconvolved SOV Data

- Helical Cable shows good sensitivity to reflected P.
- Straight telecom less sensitivity



Geophone Data



Accomplishments to Date

- Collaborating with the Otway CO2CRC, monitored the injection of 15,000 Tonnes of CO_2
- Acquired 4 vibroseis surveys using a surface trench based DAS fiber-optic network
- First deployment of a new Surface Orbital Vibrator at the Otway Site for time lapse surveys
- Installed and acquired 3D VSP data using a borehole based fiber-optic
- Presented preliminary results at the 2016 EAGE
- Monitoring of plume stabilization is ongoing

TRL Assessment

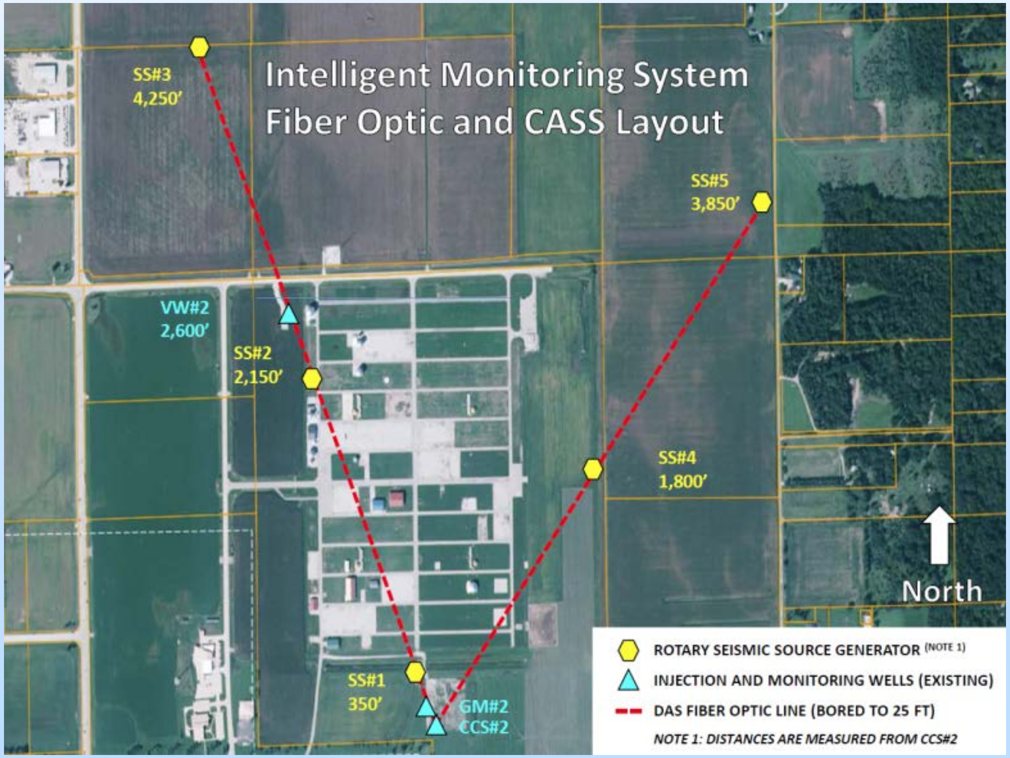
- Surface orbital vibrators and DAS HWC cable started at TRL 4 – 5 in FY15 (early design analysis and engineering performed, testing of primary components performed)
- Otway deployment (FY16) advances technology to TRL 6 (prototype validated in relevant environment)
- FY17 goal of deployment at CaMI Field Research Station and ADM IMS Project goal is to increase to TRL 7 (integrated prototype validated in an operational system)

Synergy Opportunities

CMC CaMI Field Research talk Thursday 1:50 PM

Aquistore Collaboration talk, Wednesday 12:55 PM

ADM Intelligent Monitoring System talk Thursday, 4:35 PM



SubTER Goals Supported

Adaptive Control of Subsurface Fractures and Fluid Flow

Wellbore Integrity	Subsurface Stress & Induced Seismicity	Permeability Manipulation	New Subsurface Signals
Improved well construction materials and techniques	Measurement of stress and induced seismicity	Physicochemical fluid-rock interactions	New sensing approaches
Autonomous completions for well integrity modeling	Manipulation of stress and induced seismicity	Manipulating flowpaths	Integration of multi-scale, multi-type data
New diagnostics for wellbore integrity	Relating stress manipulation and induced seismicity to permeability	Characterizing fractures, dynamics, and flows	Adaptive control processes
Remediation tools and technologies	Applied risk analysis of subsurface manipulation	Novel stimulation methods	Diagnostic signatures and critical thresholds
Fit-for-purpose drilling and completion tools (e.g. anticipative drilling, centralizers, monitoring)			
HT/HP well construction/ completion technologies			

Energy Field Observatories

Fit For Purpose Simulation Capabilities

Lessons Learned

- DAS Technology
  - DAS trenched cable response changed significantly with fluctuating water table.
  - HWC performed significantly better than straight cable for reflected P energy
- Surface Orbital Vibrator
  - Original foundation design inadequate. New design better resisted high shear at base of vibrator
  - Electronics and software completely redesigned during project

Summary

– DAS surface array successfully used to produce migrated images of the subsurface
– Surface Orbital Vibrators fully functional and acquired time-lapsed data set

– Analysis and interpretation of the DAS time-lapse data is ongoing

Appendix

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

Organization Chart

- Project team
  - CO2CRC Ltd., Overall management and coordination of Otway Project
  - Curtin University, Science Lead and performance of geophysical surveys, acquisition of conventional seismic data
  - LBNL, lead on fiber-optic DAS technology and SOV
  - Silixa Ltd. Supported deployment and operation of iDAS technology
- Key participants
  - Roman Pevzner, CO2CRC & Curtin University, Science Lead
  - Rajindar Singh, CO2CRC Program Manager
  - Michelle Robertson, LBNL, Field Support Coordinator
  - Todd Wood, LBNL, SOV Engineer

CCSMR Gantt Chart

Milestone Reporting accompanies Quarterly report	Q1 FY16			Q2 FY16			Q3 FY16			Q4 FY16		
Subtask Description	OCT	NOV	DEC	JAN	FEB	MAR	AP R	MAY	JU N	JUL	AUG	SEP
Task 1 Project Management and Planning												
Task 2 Otway Project			A*									B
Task 3 Aquistore Collaboration			C						D			
Task 4 Carbon Management Canada, FRS						E			F			

Otway Milestones:

A. Preliminary rotary orbital source data report
B. Analysis of time-lapse Stage 2c seismic data

Bibliography

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