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The SECARB Anthropogenic Test: A Small-Scale, Fully Integrated CCS Demonstration Project

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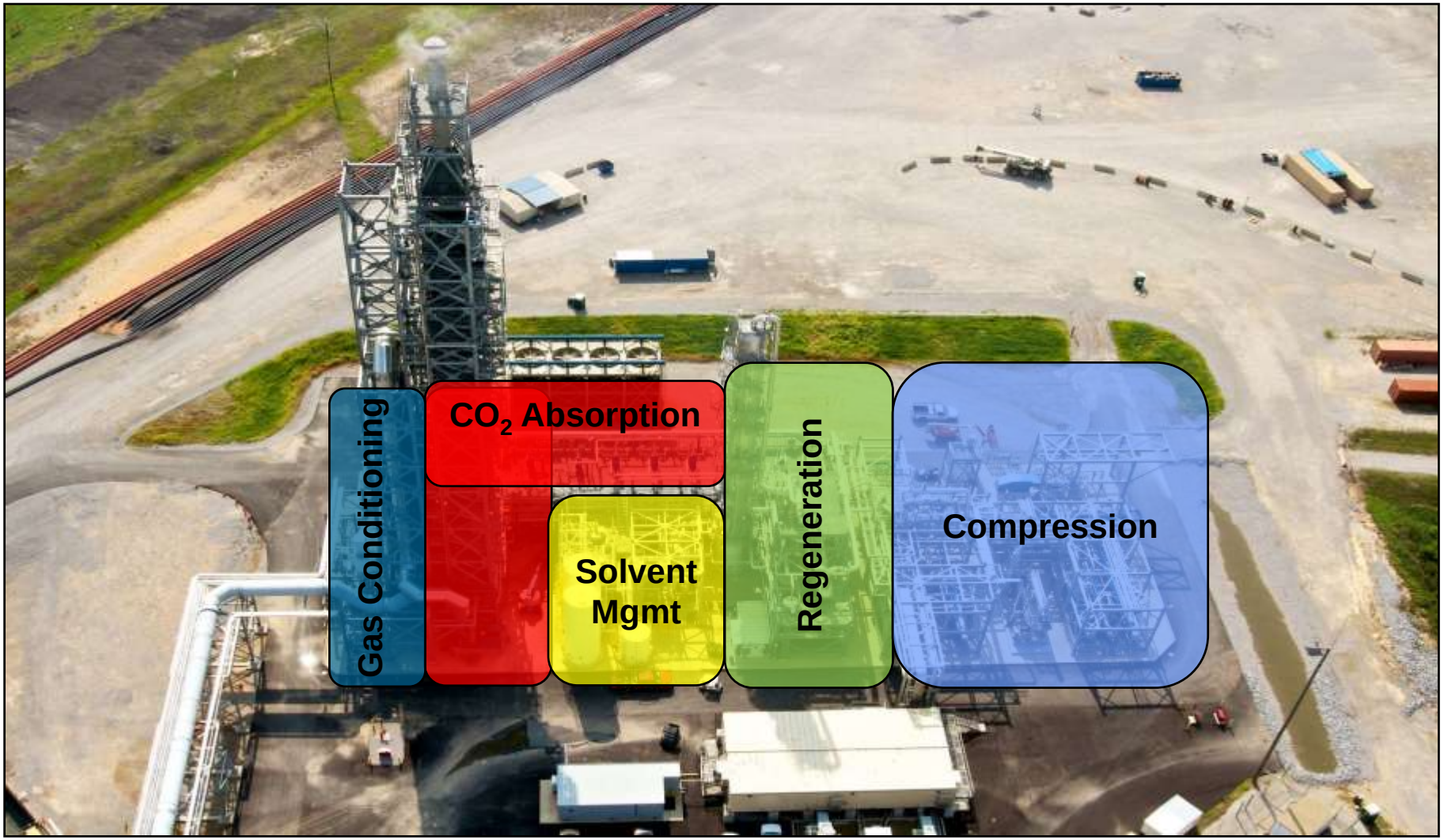
Presentation Outline

- Anthropogenic Test overview
  - Capture
  - Transportation
  - Storage
- Advanced CO_2 monitoring program
  - Fiber optic based distributed sensing
- Challenges and perspective

SECARB Anthropogenic Test Overview

- World's first and largest integrated CO_2 capture, transportation and storage project on a coal-fired power station using advanced amines
- Southern Co. and MHI have captured over 200,000 metric tons of CO_2 since June 2011
- SECARB has transported, injected and stored 100,616 metric tons since August 2012
- Injecting CO_2 into the Paluxy Formation, which has excellent storage capacity of regional significance

MHI Advanced Amine Process
25 MW Equivalent Capture Plant



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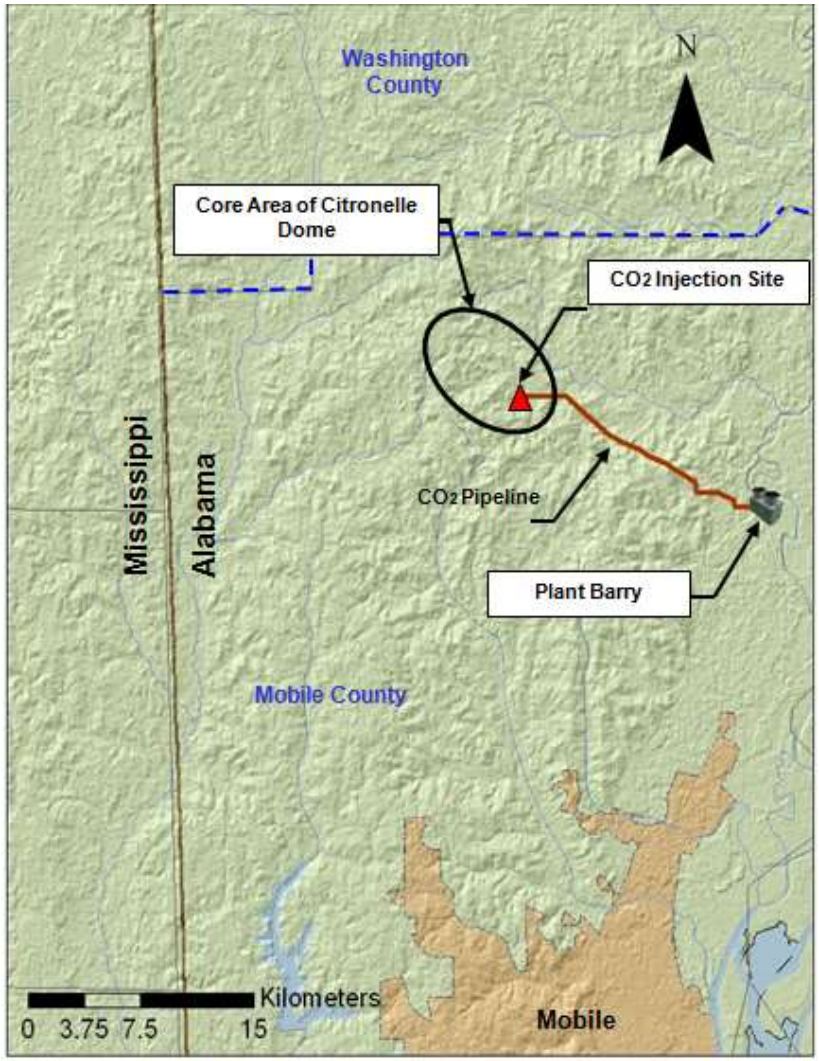
SECARB Transport & Storage Project Overview

- 19 km (12 mile) CO_2 pipeline transports CO_2 from Plant Barry to the Citronelle Dome in Alabama
- Goal is to inject 100,000–300,000 metric tons of CO_2 into the Paluxy Formation (saline)
- Extensive monitoring program: pre-injection (8 months), injection (2 yrs) and post-injection (3 yrs)
- Site closure in 2017



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Pipeline Construction Overview

- 4-inch diameter pipeline
  - ✓ X52 carbon steel pipe
  - ✓ Fusion bonded epoxy coated
- Directional drilled 18 sections under roads, utilities, railroad tracks, tortoise colonies, and wetlands (30 to 60 ft deep)
- Trenched remaining sections
  - ✓ Buried average of 5 ft
- Surface re-vegetation and maintenance
- Corrosion protected

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Geologic Overview

System	Series	Stratigraphic Unit	Major Sub Units	Potential Reservoirs and Confining Zones
Tertiary	Plio-Pliocene		Citronelle Formation	Freshwater Aquifer
	Miocene	Undifferentiated		Freshwater Aquifer
	Oligocene		Chickasawhay Fm.	Base of USDW
		Vicksburg Group	Bucatunna Clay	Local Confining Unit
	Eocene	Jackson Group		Minor Saline Reservoir
		Claiborne Group	Talahatta Fm.	Saline Reservoir
		Wilcox Group	Hatchetigbee Sand	Saline Reservoir
	Paleocene		Bashi Marl	
			Salt Mountain LS	
		Midway Group	Porters Creek Clay	Confining Unit
Cretaceous	Upper	Selma Group		Confining Unit
		Eutaw Formation		Minor Saline Reservoir
		Tuscaloosa Group	Upper Tusc.	Minor Saline Reservoir
			Mid. Tusc. Marine Shale	Confining Unit
			Lower Tusc. Pilot Sand, Massive sand	Saline Reservoir
	Lower	Washita-Fredericksburg	Dantzler sand	Saline Reservoir
			Basal Shale	Primary Confining Unit
		Paluxy Formation	'Upper' 'Middle' 'Lower'	Injection Zone
		Mooringsport Formation		Confining Unit
		Ferry Lake Anhydrite		Confining Unit
		Donovan Sand	Rodessa Fm.	Oil Reservoir
			'Upper'	Minor Saline Reservoir
			'Middle' 'Lower'	Oil Reservoir

- Injecting CO_2 into the Lower Cretaceous Paluxy Formation (9,400–10,500 ft)
- Above the oil reservoir in the Citronelle Oil Field
- Massive 1,100 ft interval of stacked fluvial sands and confining units
- Numerous reservoir seals and confining units above the Paluxy (at least 5)
- Structural dome has proven four-way closure

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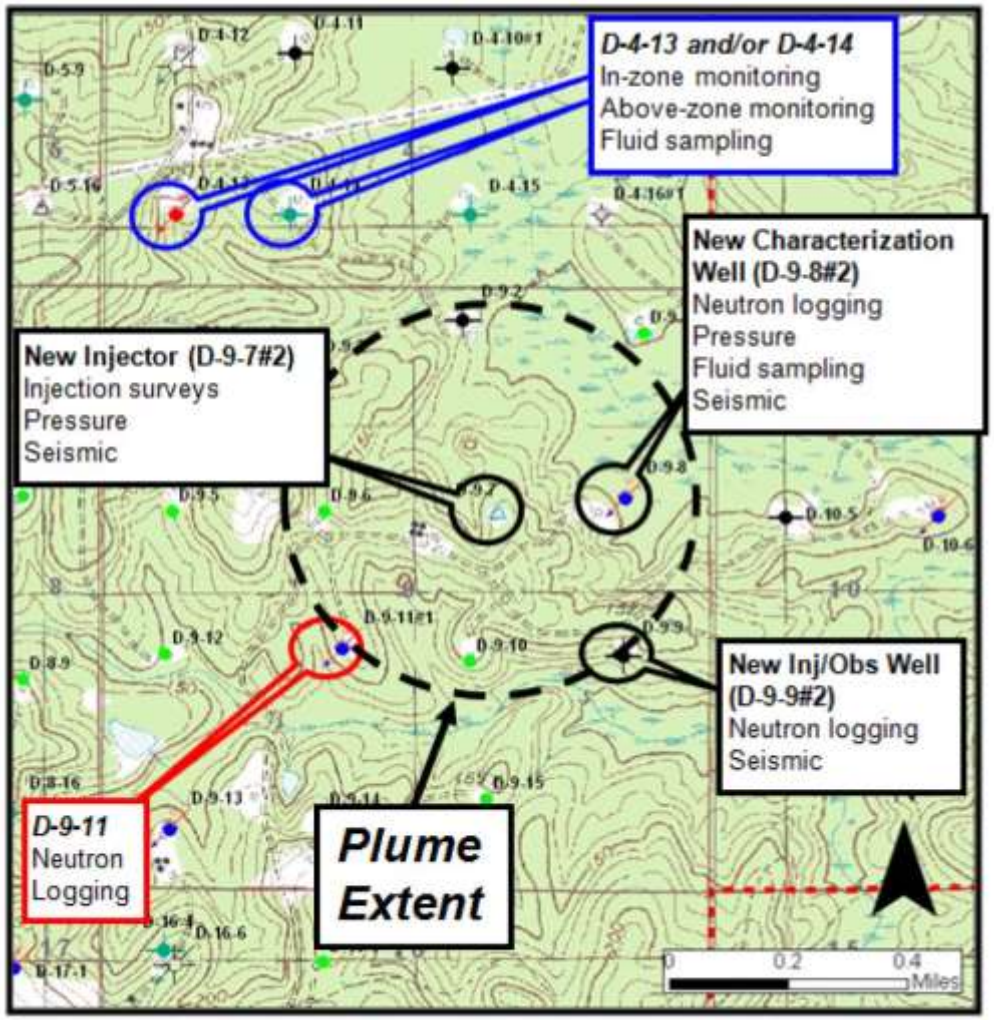
Monitoring, Verification and Accounting Program Overview



- One Injector (D-9-7 #2)
- Two deep Observation wells (D-9-8 #2 & D-9-9 #2)
- Two in-zone & above zone Monitoring wells (D-4-13 & D-4-14)
- One PNC logging well (D-9-11)
- Twelve soil flux monitoring stations
- Four shallow groundwater monitoring wells
- R&D effort is focused on deployment of the Modular Borehole Monitoring (MBM) System in observation well (D9-8#2)

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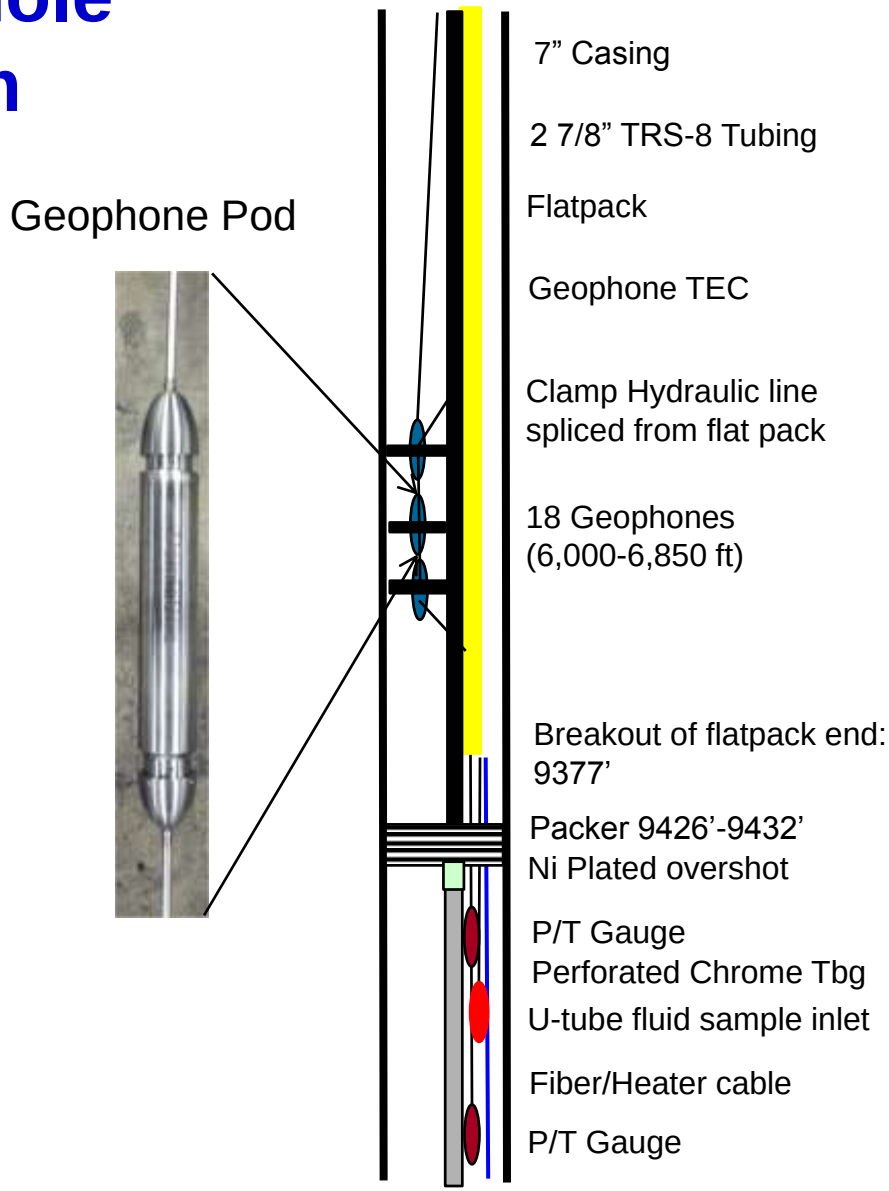
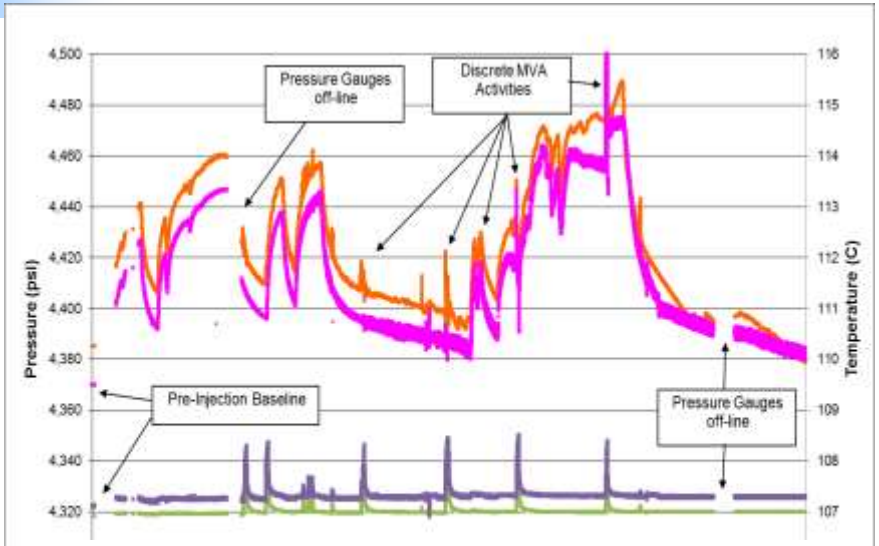
Advanced Modular Borehole Monitoring (MBM) System

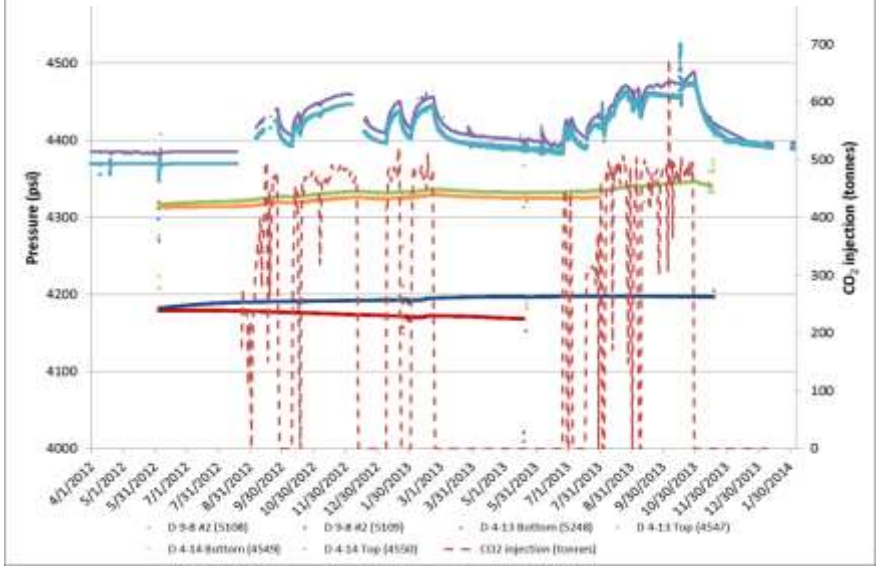
- 18 Level, tubing deployed, clamping geophone array
- Two in-zone quartz pressure/ temperature gauges for reservoir diagnostics
- U-tube for high frequency, in-zone fluid sampling (tube-in-tube design)
- Fiber optic cable for distributed temperature and acoustic measurements
  - Heat-pulse monitoring for CO_2 leak detection
  - Acoustic array for CO_2
- 2 7/8” production tubing open for logging



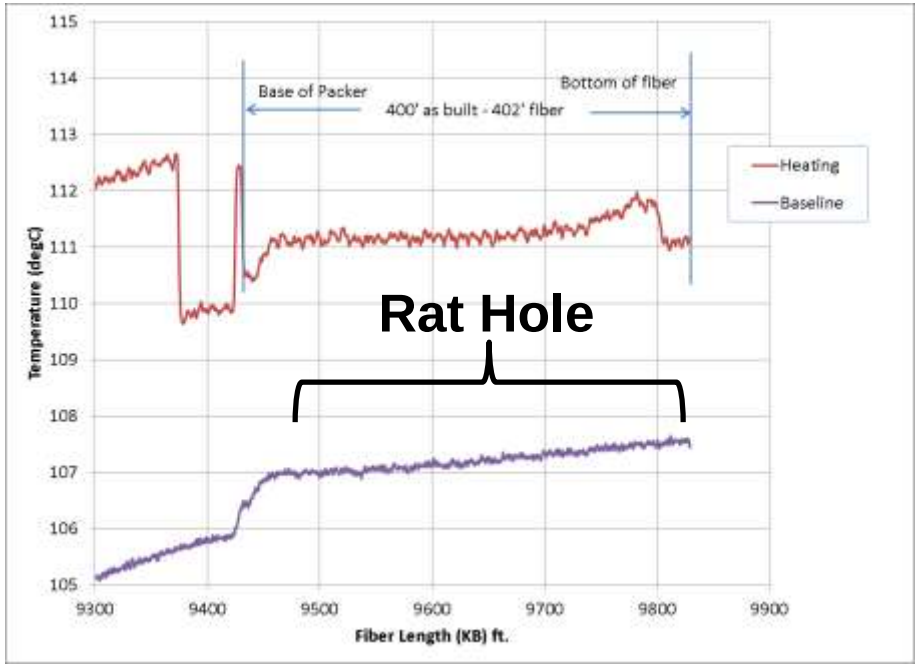
Pressure/Temperature Measurements



Quartz pressure/temperature transducers



Fiber optic based
Distributed Temperature Sensing (DTS)



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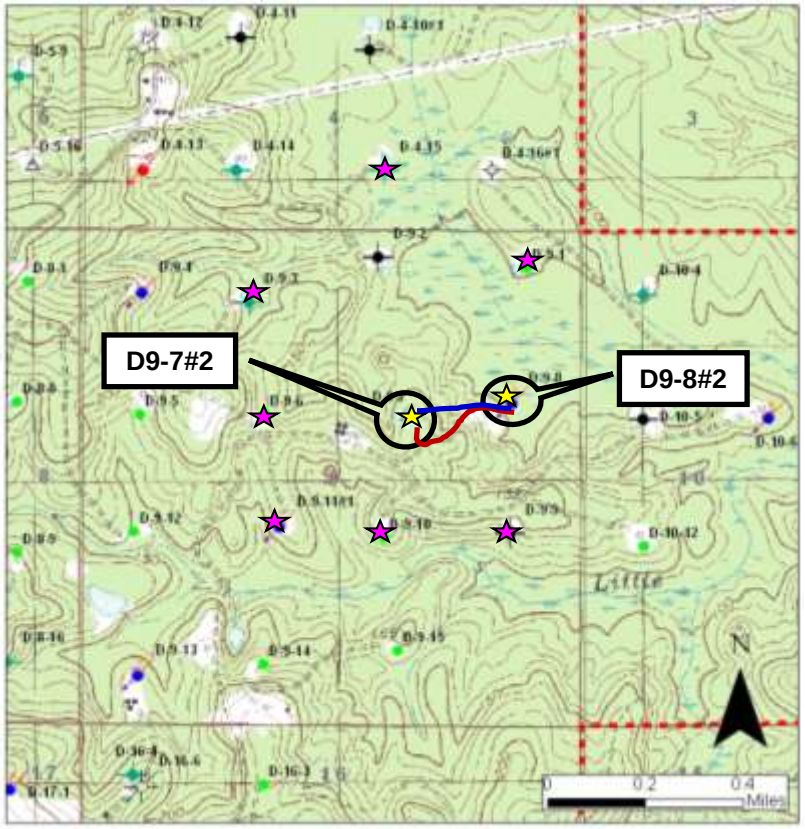
Citronelle Offers a Unique Opportunity to Compare Seismic Methods to Monitor CO_2 Plume Location

- Seismic surveys deployed at Citronelle include:
  - Cross-well seismic surveys
  - Offset vertical seismic profile (VSP) surveys using
  - Walk away VSPs
- Seismic Sources and Receivers
  - 80-level (long) geophone array deployed in the injector (D9-7#2) and observation well (D9-8#2)
  - 18-level (short) geophone MBM array in D9-8#2
  - Fiber-optic distributed acoustic sensor (DAS) array with over 3,100 DAS "receivers"



VSP source offset locations (stars), receiver locations (D9-7#2 and D9-8#2), and walk-away lines (blue and red lines)

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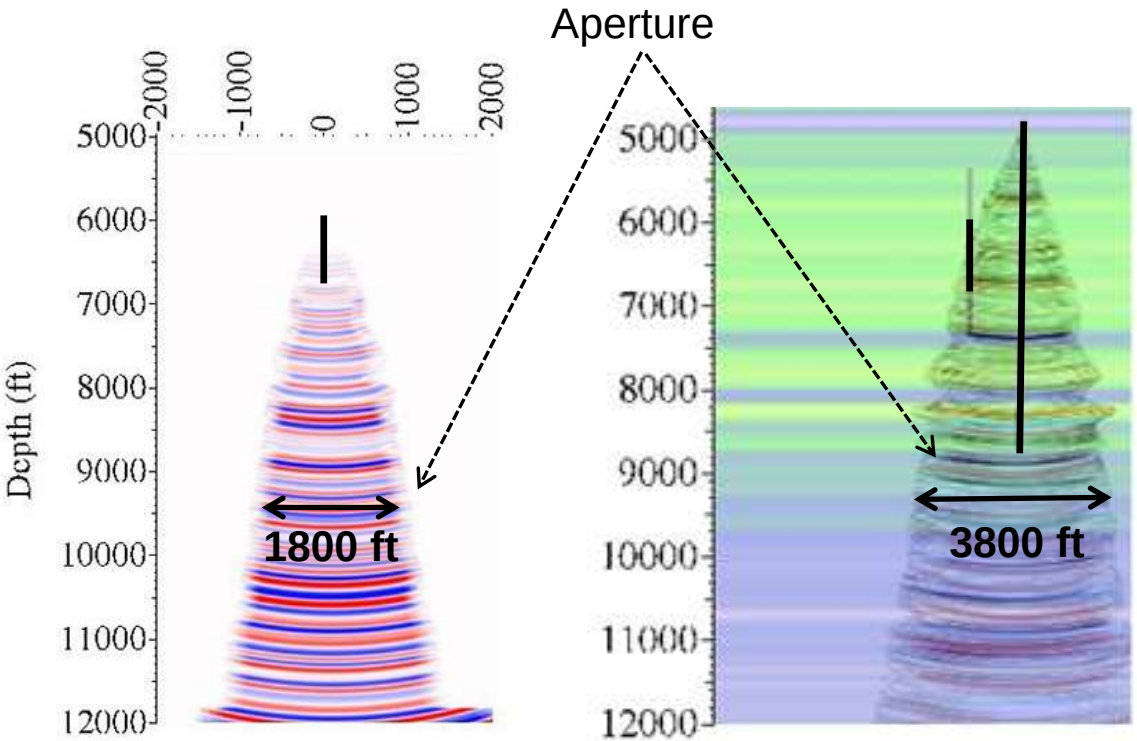
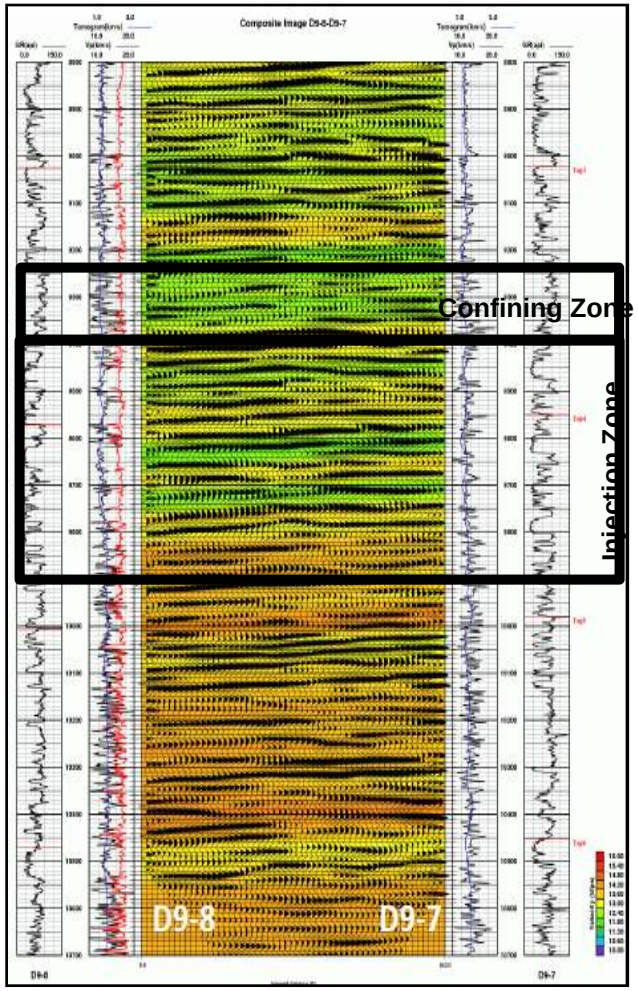
Baseline Seismic Surveys

Semi-permanent short MBM geophone array

Temporary long string geophone array



Cross-well (baseline Jan. 2012)



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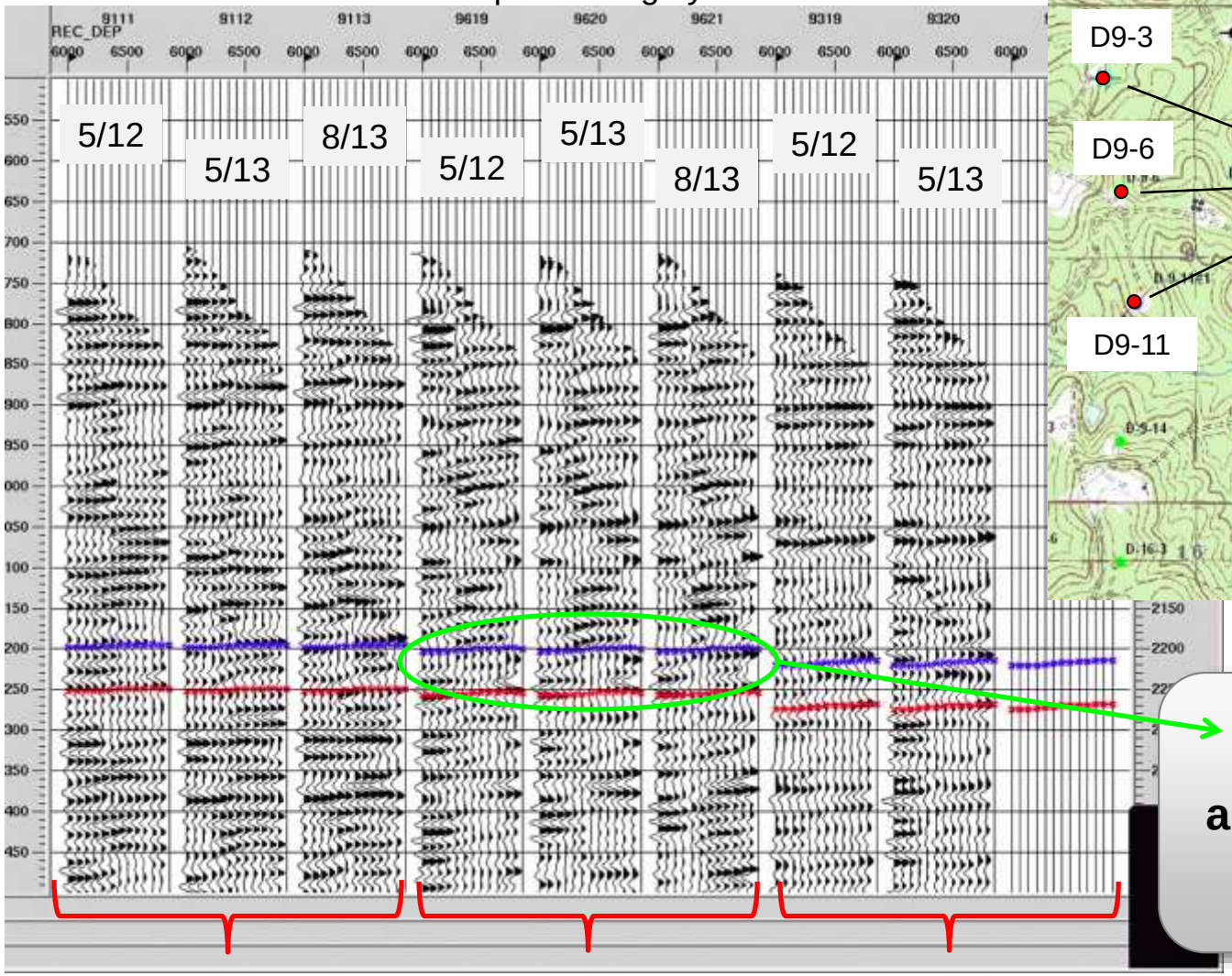
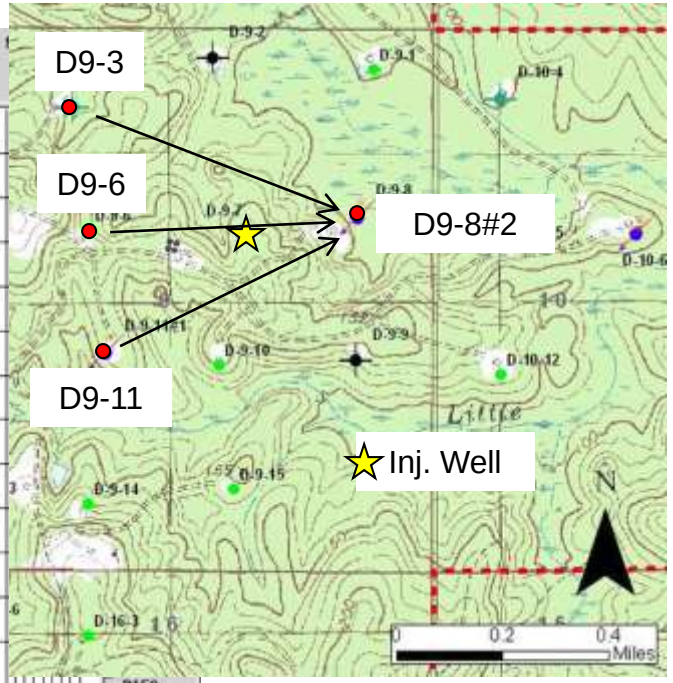
Time Lapse Comparison of Baseline (5-2012) to May and August 2013 VSP Surveys using MBM

Seismic processing by SR2020





Slight change in amplitude at target depth

D9-11 D9-6 D9-3

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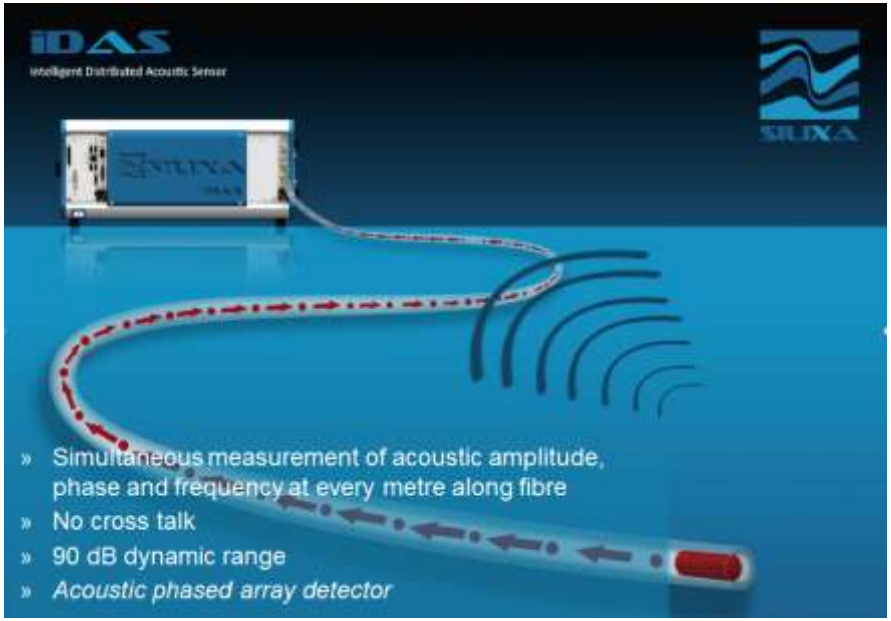
Distributed Acoustic Sensing (DAS)

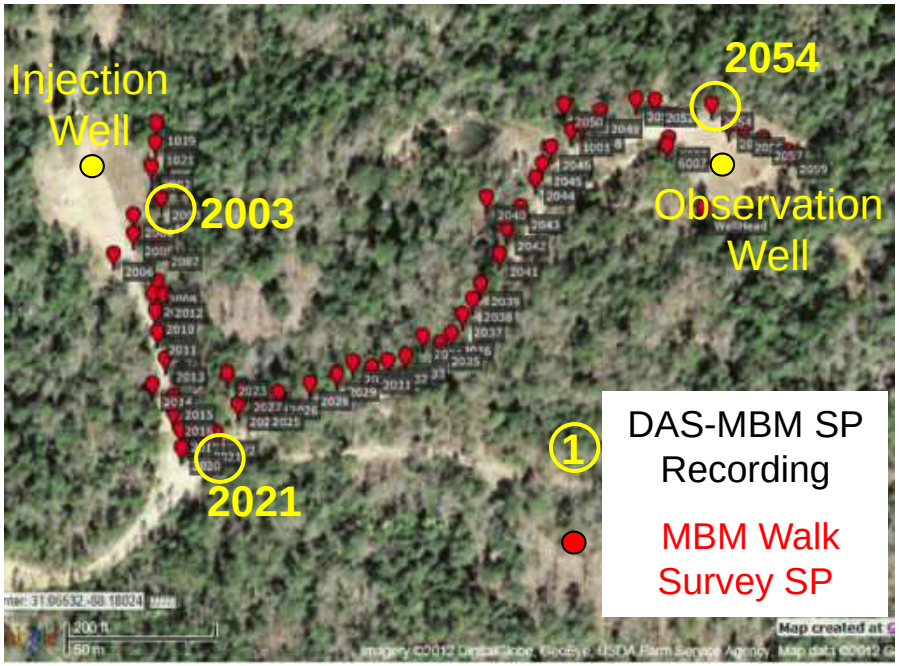
- Light emitted into a fiber is reflected throughout the fiber's length by Rayleigh scattering
- DAS system measures the modulation of the backscattered light
- An acoustic field around the fiber exerts tiny pressure/strain changes on the fiber, resulting in changes to the backscattered light
- The DAS measures these changes by generating a repeated light pulse every 100 µs and continuously processing the returned optical signal, thus interrogating each meter of fiber up to 10 km in length at a 10 kHz sample rate
- Unlike other methods, the system records the full acoustic signal, including amplitude, phase and frequency



A 10 km single mode fiber becomes a high density acoustic array with 10,000 linear sensors with 1 m spatial resolution!

VSP Walkaway Surveys Were Performed in June 2012 and August 2013

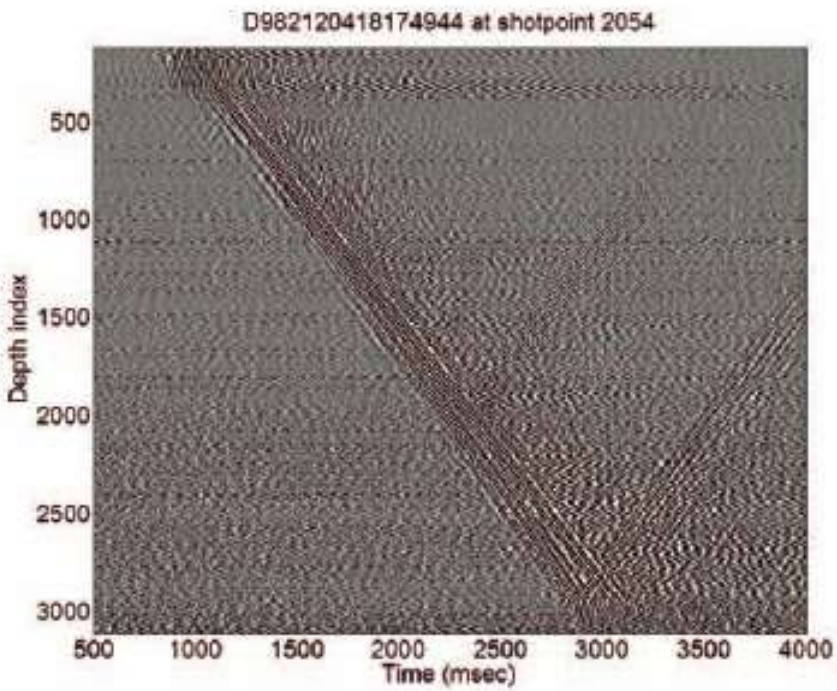
- Walkaway surveys provide detailed coverage between the injection & observation wells
- Source: vibroseis truck
  - ~60 shot points
  - 4–6 sweeps/sht MBM
  - Up to 128 sweeps/sht DAS
  - Sweep duration: 16 s, recording 4 s
  - Sweep frequency range: 10–160 Hz
- Simultaneous recording of receivers:
  - 18-level MBM geophone array in D9-8#2
  - DAS in D9-8#2



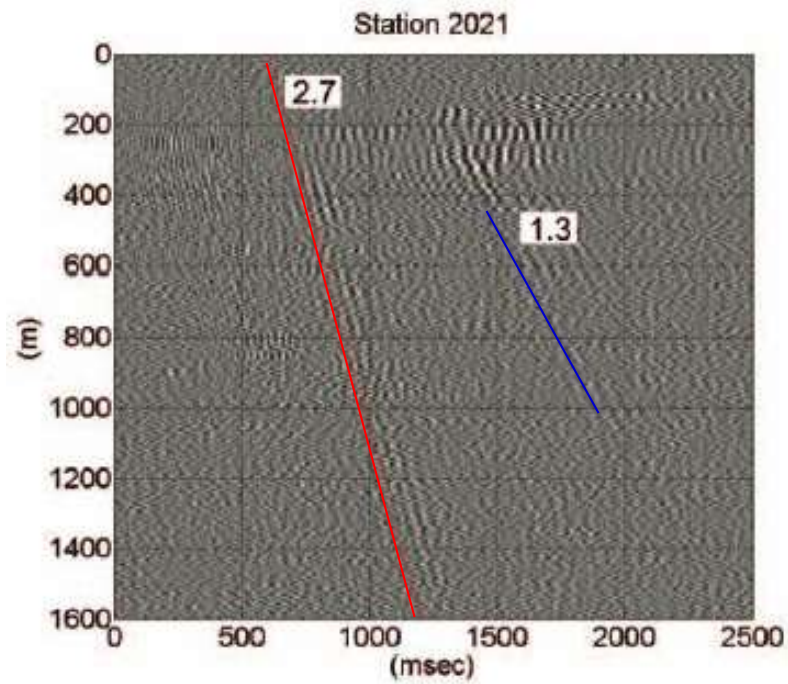
Map showing position of the individual shot points (red dots) for walkaway VSP 2012

June 2012 DAS Results

T. Daley et al., "Field testing of fiber optic acoustic sensing (DAS) for subsurface seismic monitoring," The Leading Edge, June 2013



SP 2054 located ~100 ft offset from the D-9-8 sensor borehole. Observed two tube waves.

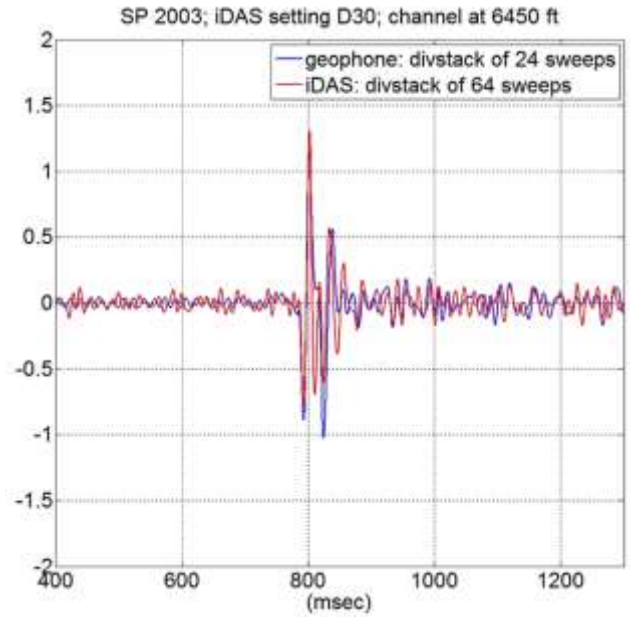


SP 2021 located ~700 ft offset from the D-9-8 sensor borehole. Estimated wave speeds for two events (red and blue lines) are labeled in km/s.

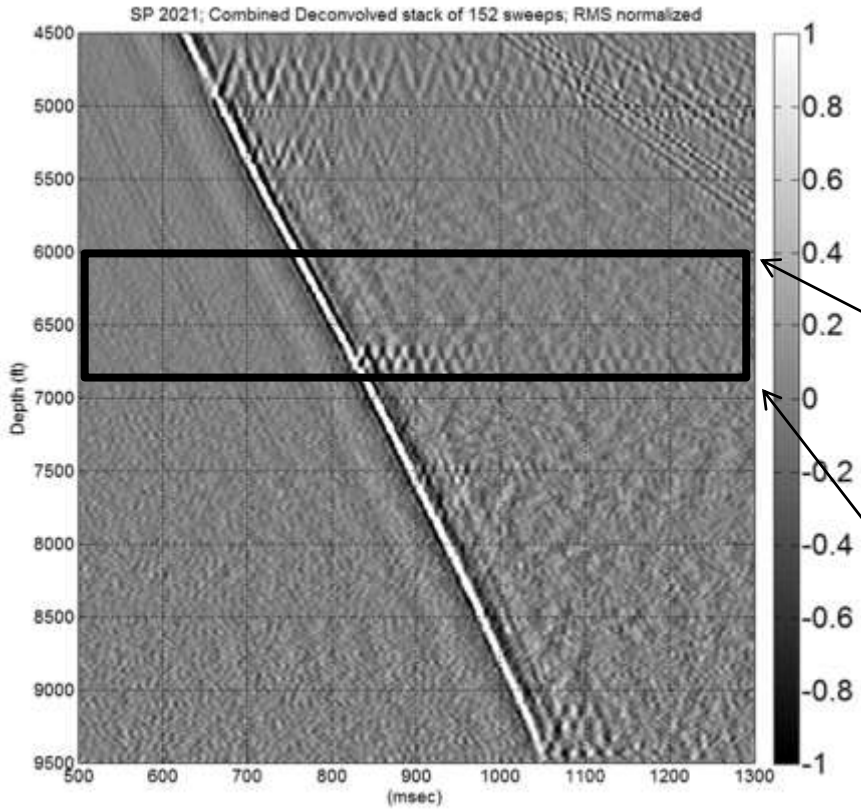
Seismic energy was recorded by DAS but the signal-to-noise ratio (SNR) was not sufficient to observe P-waves below approximately 1600 m (i.e., 2.7 km/s event)

Citronelle DAS-Geophone Comparison from August 2014 Walkaway (up to 128 sweeps)

DAS vs. Geophone

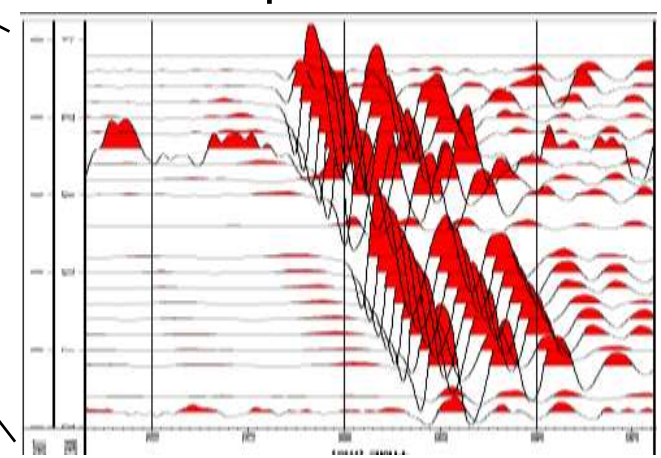


DAS Data



Processed by D. Miller, Silixa

Geophone Data



Acquisition of stacked source sweeps improved DAS data signal to noise ratio, producing traces that match those from more sensitive geophones

Challenges and Perspective

- Reliable, robust sub-surface monitoring equipment and methods are still needed that will last for decades
  - Five out of 18 geophone levels have been killed to date at Citronelle
  - Conventional pressure transducers are experiencing higher noise floor and/or drift
  - FO distributed sensing is innovative and may fill the long-term monitoring gap, but unproven
  - Instrument/method redundancy will be an important component of any monitoring program
- The SECARB Anthropogenic Test represents the largest integrated post-combustion CO_2 capture, transportation and storage project performed to date on a coal fired unit (equiv. to 155,000 t/yr)

Perspective

- Proposed EPA New Source Performance Standards will require EGU to meet 1,100 lb/MW gross emission limit
  - 40% capture on new coal-fired power stations
  - Modest 1,640 MW plant will need to store 5.1 million metric tons/yr for 40 yrs (>200 Mt total!)
  - Compliance with Subpart RR may push utilities into saline storage prematurely eliminating economic incentive associated with CO_2-EOR
- Full scale global saline storage project experience to date is limited to ≤ 1Mt/yr (Sleipner, Snohvit, In Salah)
- Lack of available data on saline reservoirs creates large economic uncertainty
- EPA rules for existing EGUs to be issued in June 2014 (??)

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