Long-Period, Long-Duration (LPLD) Seismic Events Observed at Two CO_2 EOR Locations

RIC Task 25

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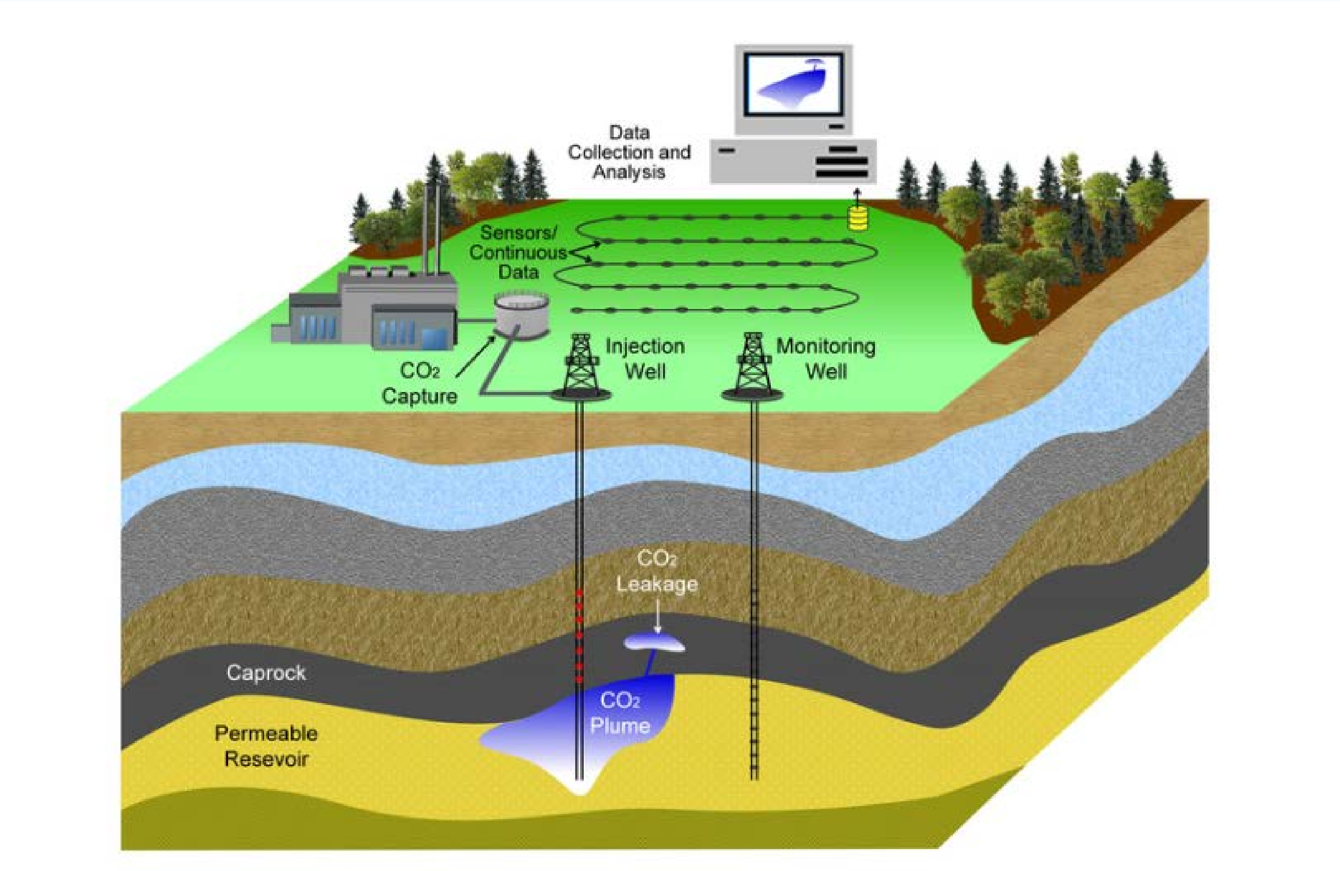
National Energy Technology Laboratory

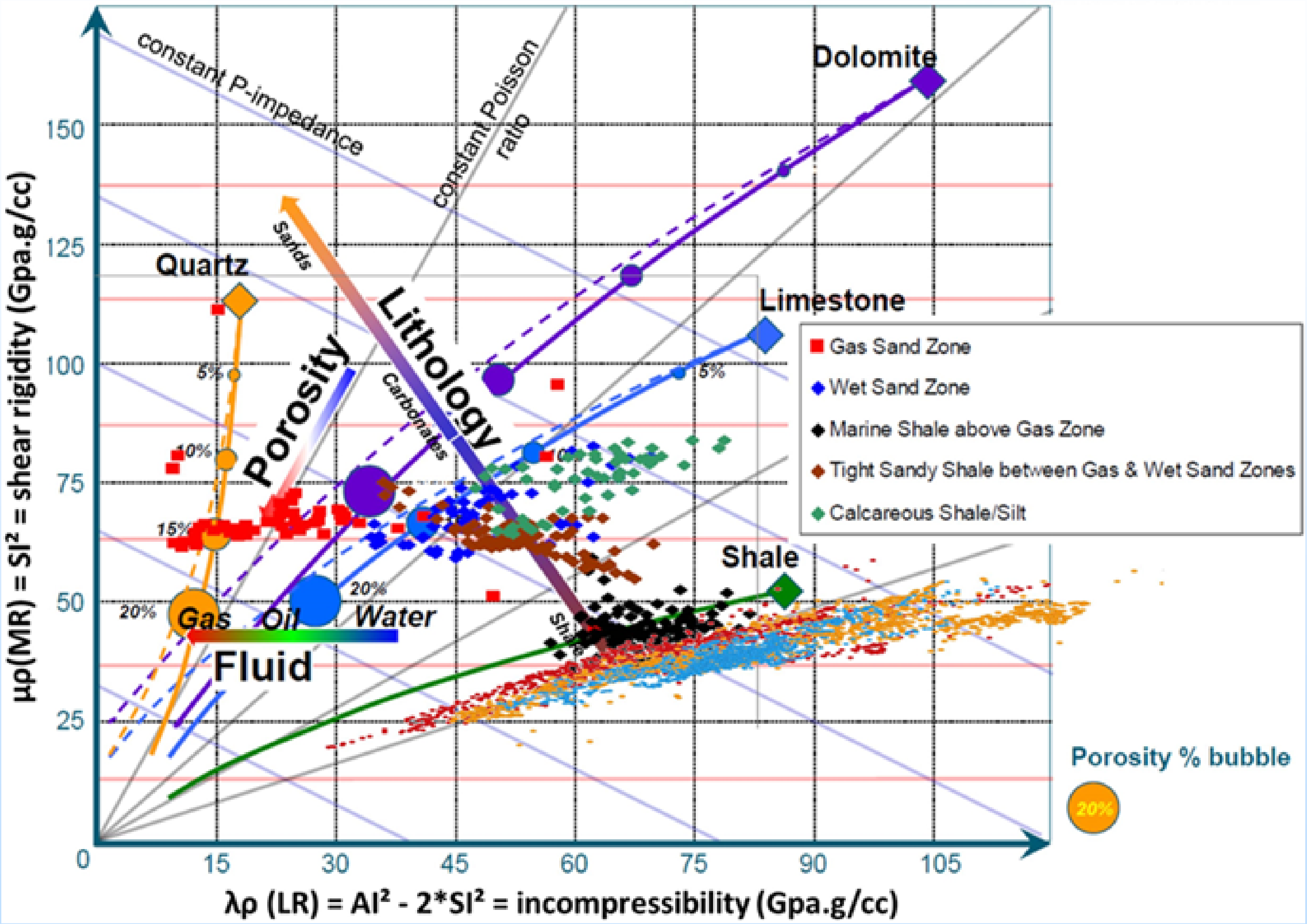
Addressing the Nation's Energy Needs Through Technology Innovation – 2019 Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting

August 26-30, 2019

Microseismic Monitoring may not Detect All Caprock Deformation

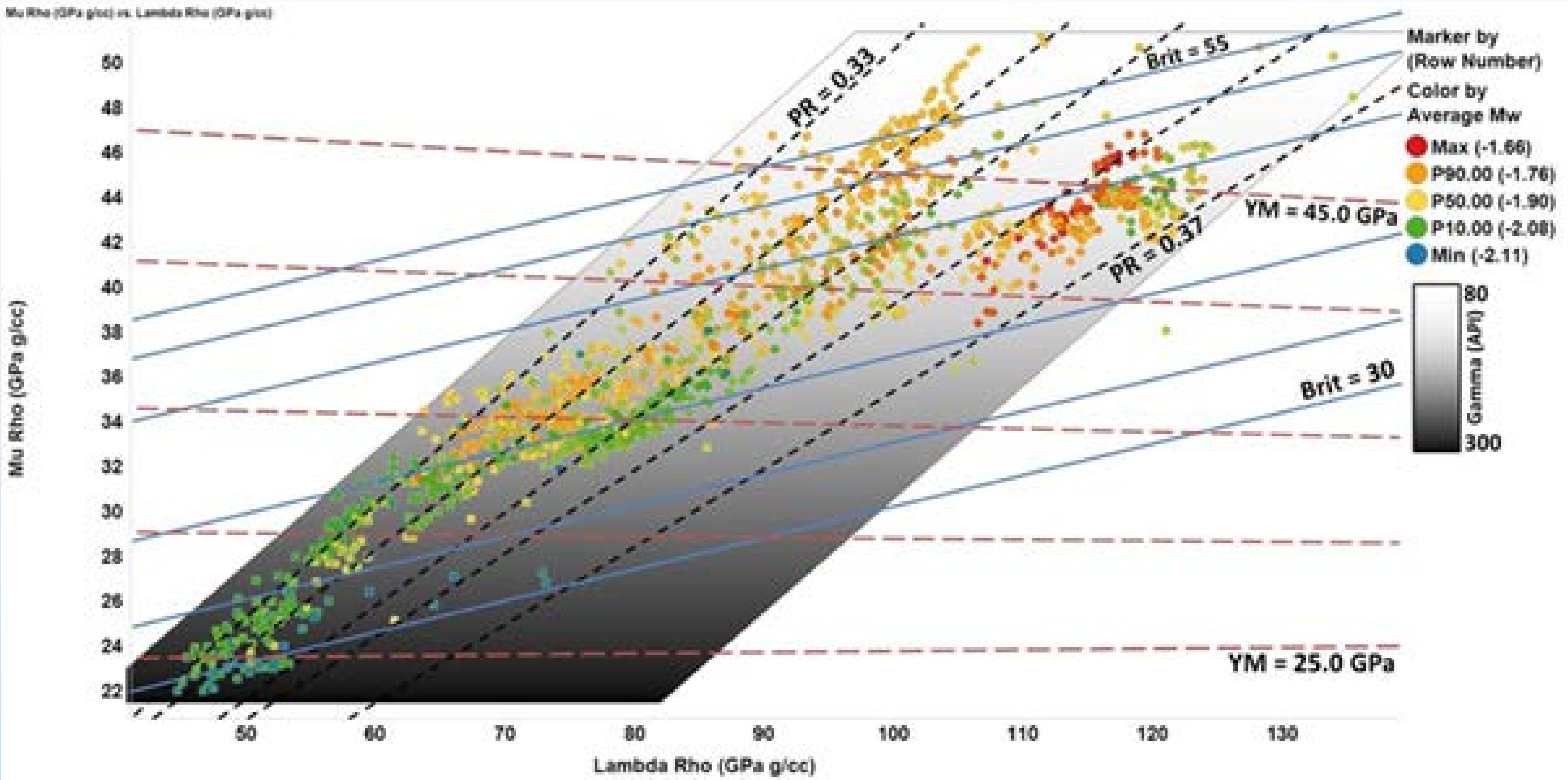


Microseismic Monitoring may not Detect Caprock Deformation

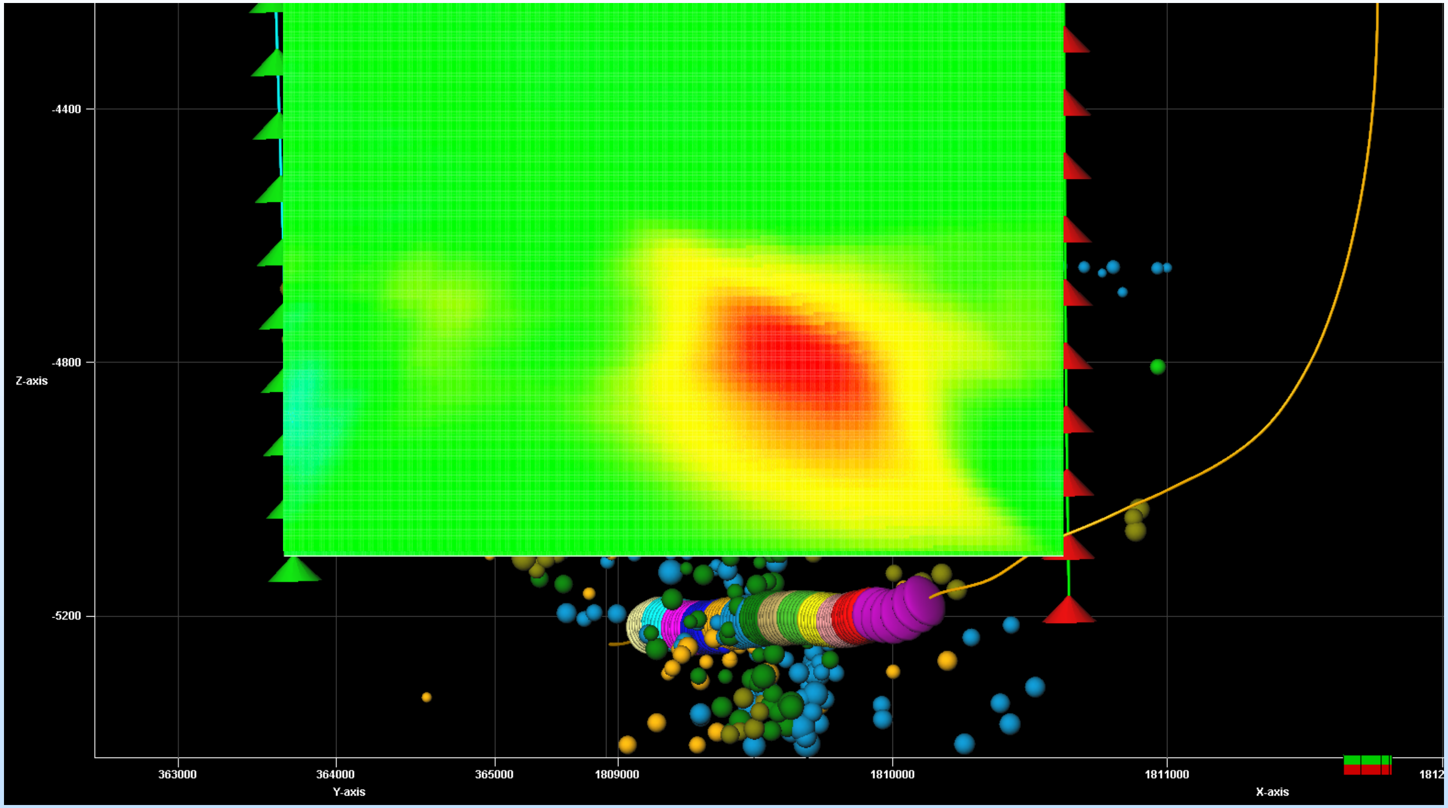


Modified from Goodway (2009)

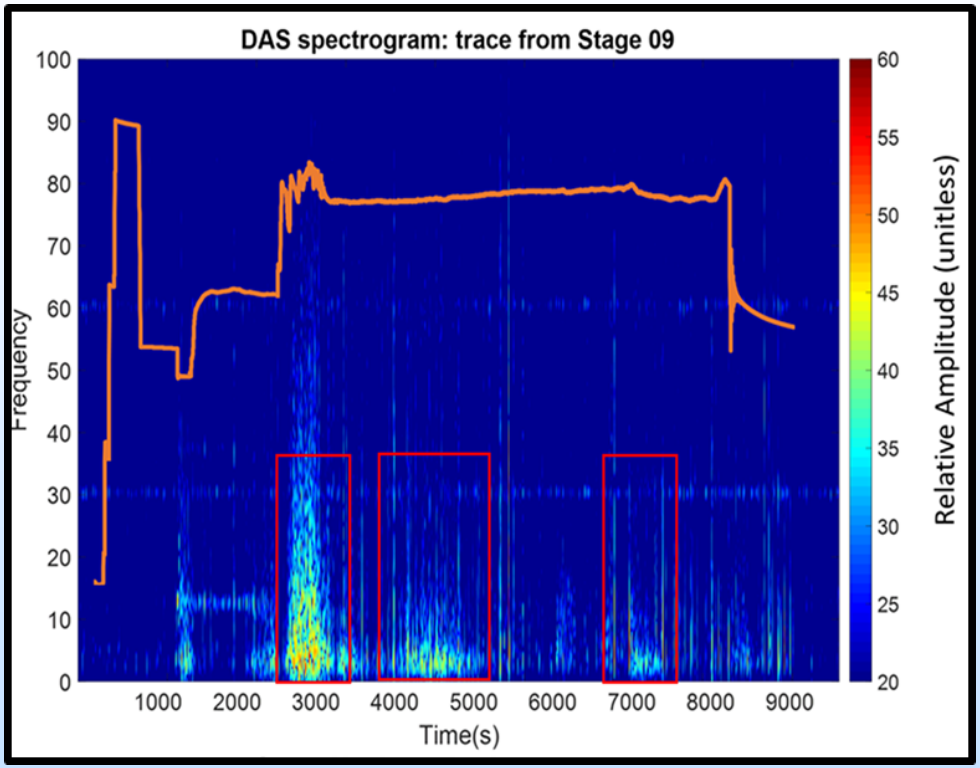
Microseismic Monitoring may not Detect Caprock Deformation

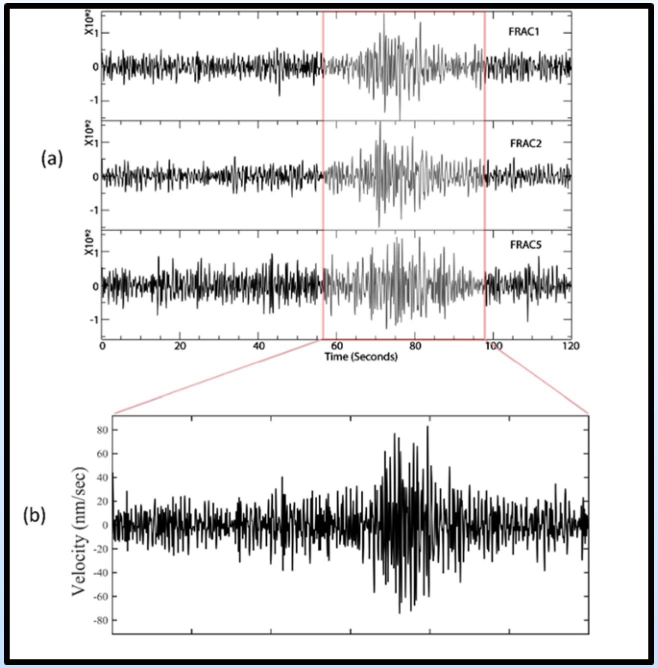


Cross-Well Seismic Tomography – Marcellus Well, Clearfield Co., PA

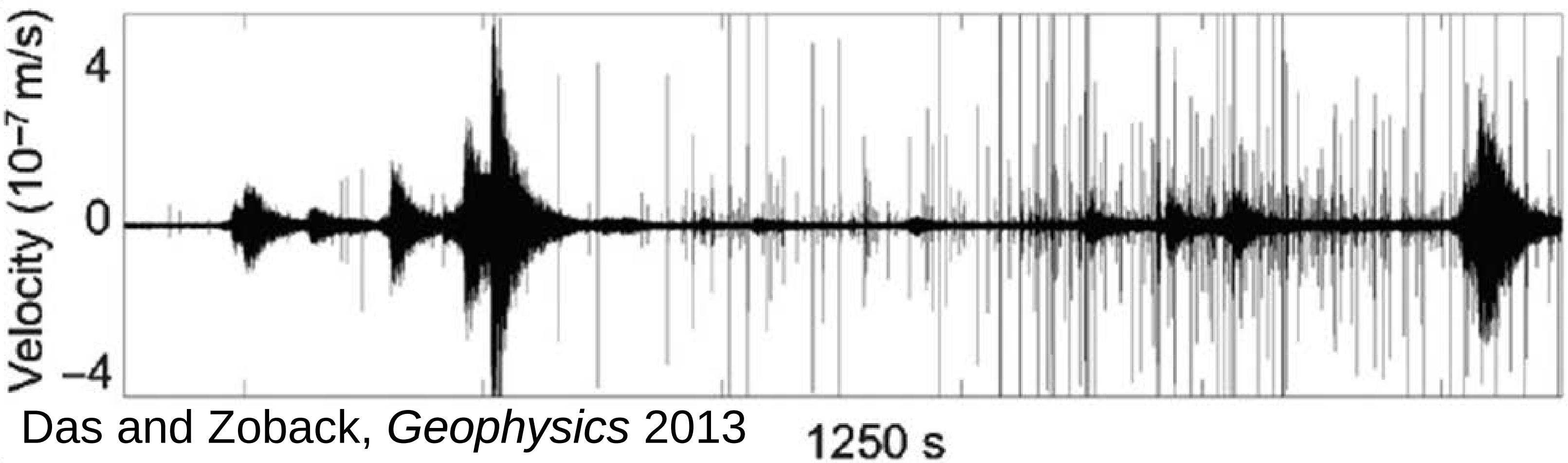


Beyond Microseismic – Long-Period, Long-Duration Events (LPLD)





LPLDs are often confused with M_{eq} (microseismic events)

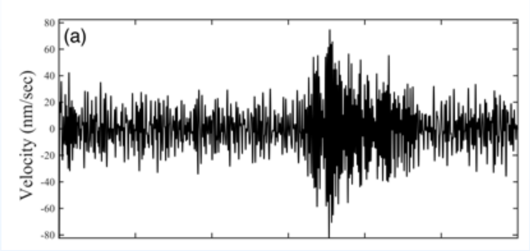


Das and Zoback, *Geophysics* 2013

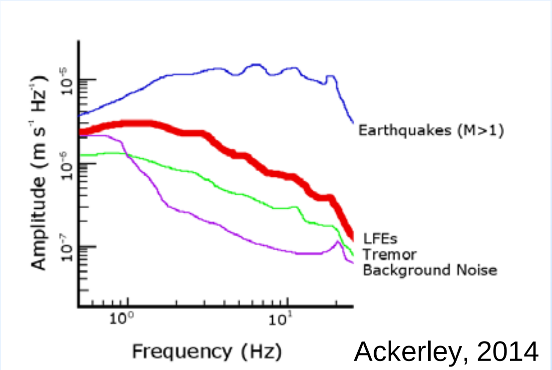
Characteristic	LPLD	Microearthquake
Arrival	Emergent	Impulsive
P and S Picking	No	Yes
Amplitude	Small	Larger
Duration	Long (minutes)	Short (sub-second)
Frequency	0.8 – 80 Hz	> 200 Hz
Locate Source?	Maybe	Yes
Likely Origin	Not Established	Shear Failure

Identifying and Locating LPLD

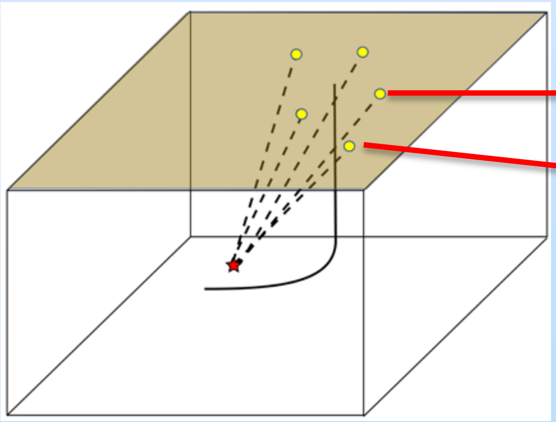
- Focus on low-frequency range (<100 Hz)
- Use cross correlation rather than discrete seismic phase picking for event detection and location
- Make use of public seismic databases to remove distant earthquake sources

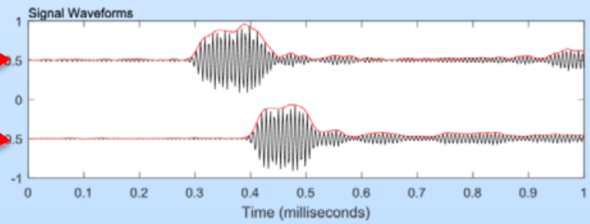


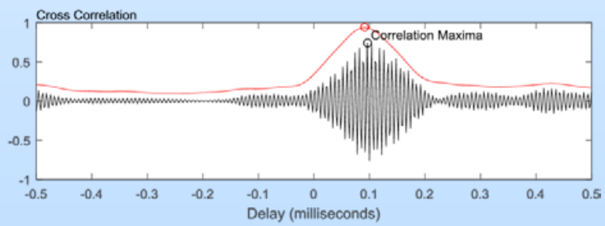
120 sec



Ackerley, 2014





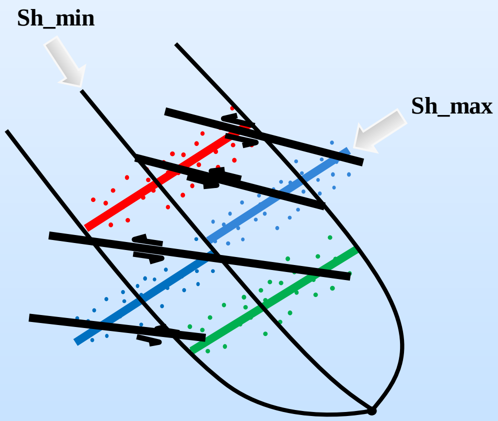


$$M\left(x^{grid}\right)=\sum_{i=1}^{N}\sum_{j=i+1}^{N}\frac{C_{ij}^{\max}-C_{ij}\left(\delta t_{ij}\left(x^{grid}\right)\right)}{\Delta C\left(C_{ij}^{\max}\right)}$$

Proposed Sources of LPLD

Scenario 1

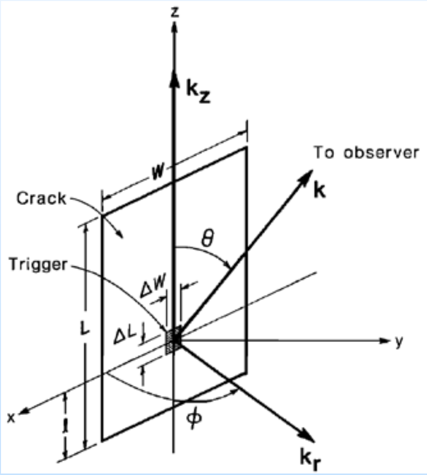
- Stimulation of sub-optimal faults
- High clay content



Adapted from Zoback et al. 2012

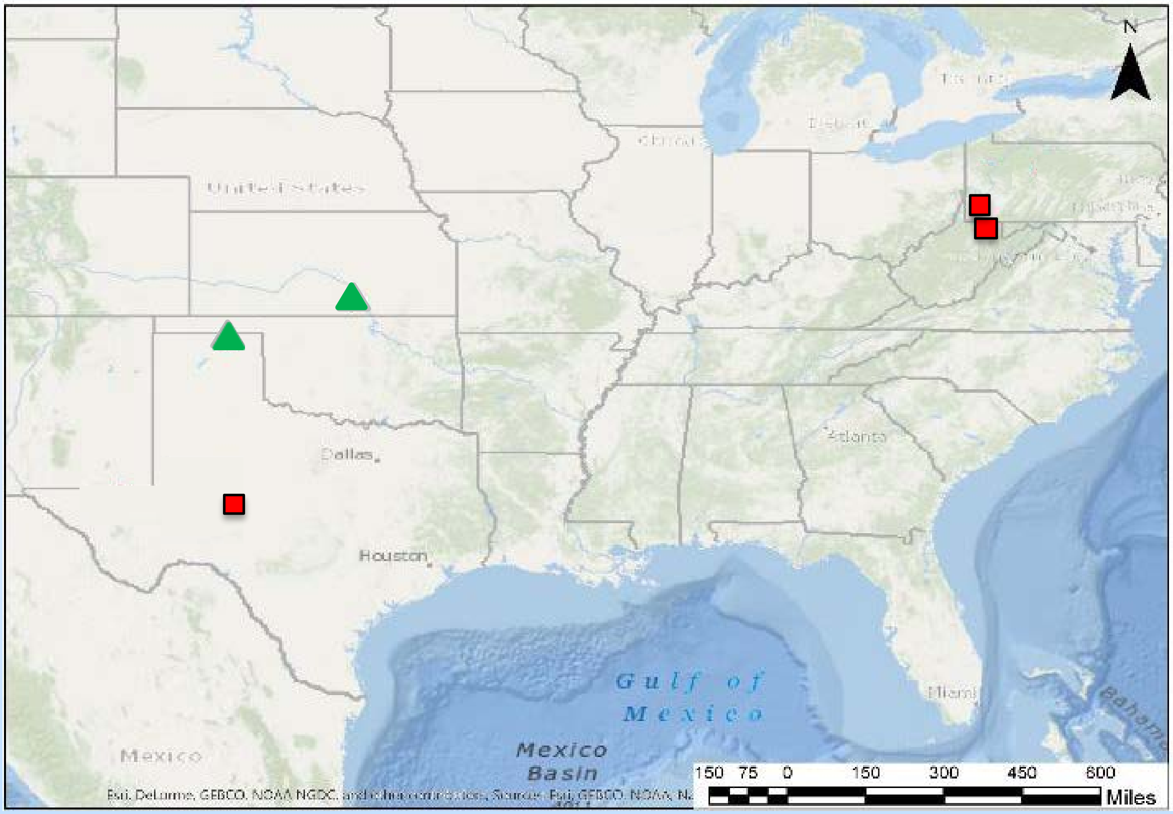
Scenario 2

- Tensile opening of crack
- Resonance of fluid filled cracks



Courtesy: Chouet 1988

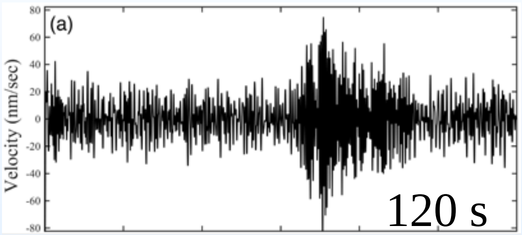
Fluid Injection Sites with LPLDs



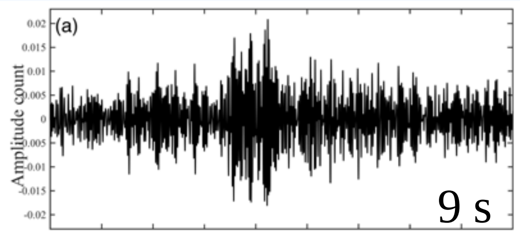
Hydraulic Fracturing

CO_2 EOR

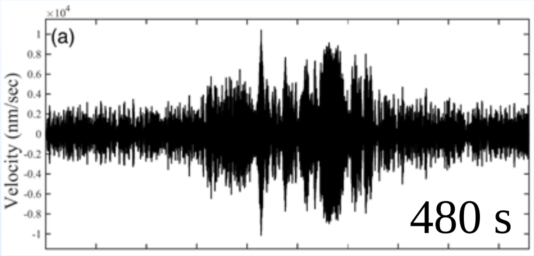
Long Period Long Duration events



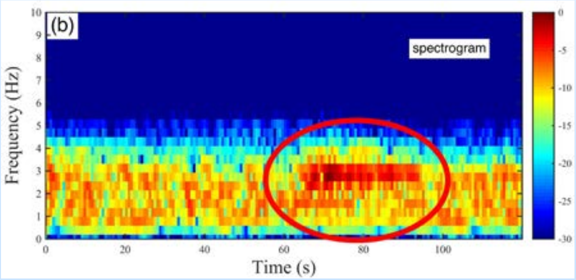
Marcellus Shale



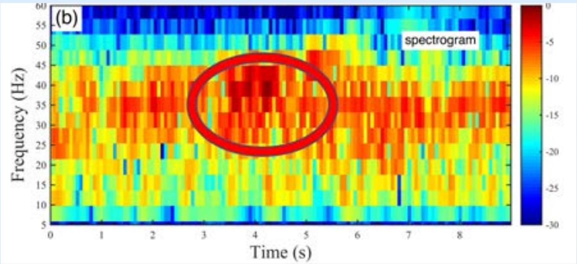
Middle Wolfcamp Shale



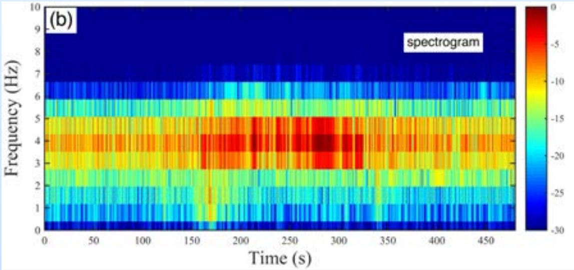
Mississippian Dolomite



West Virginia

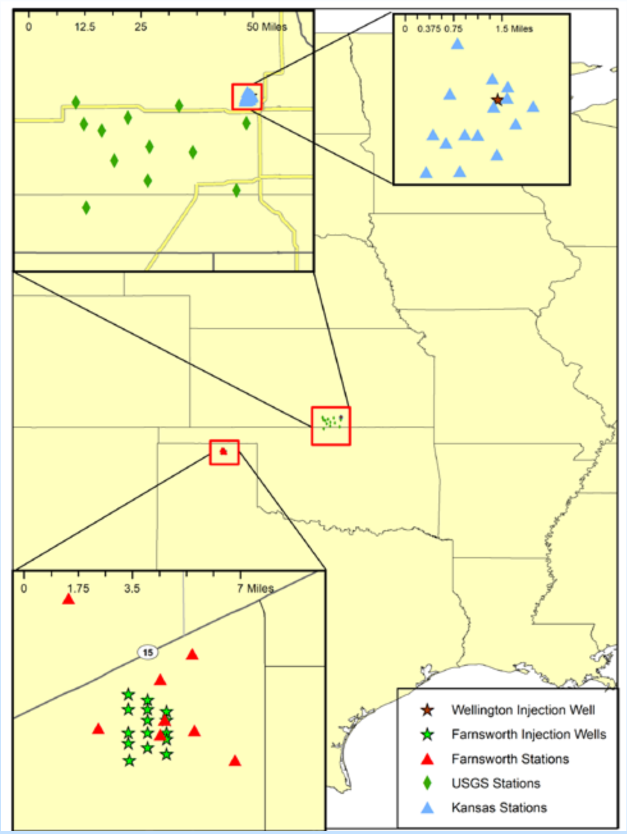


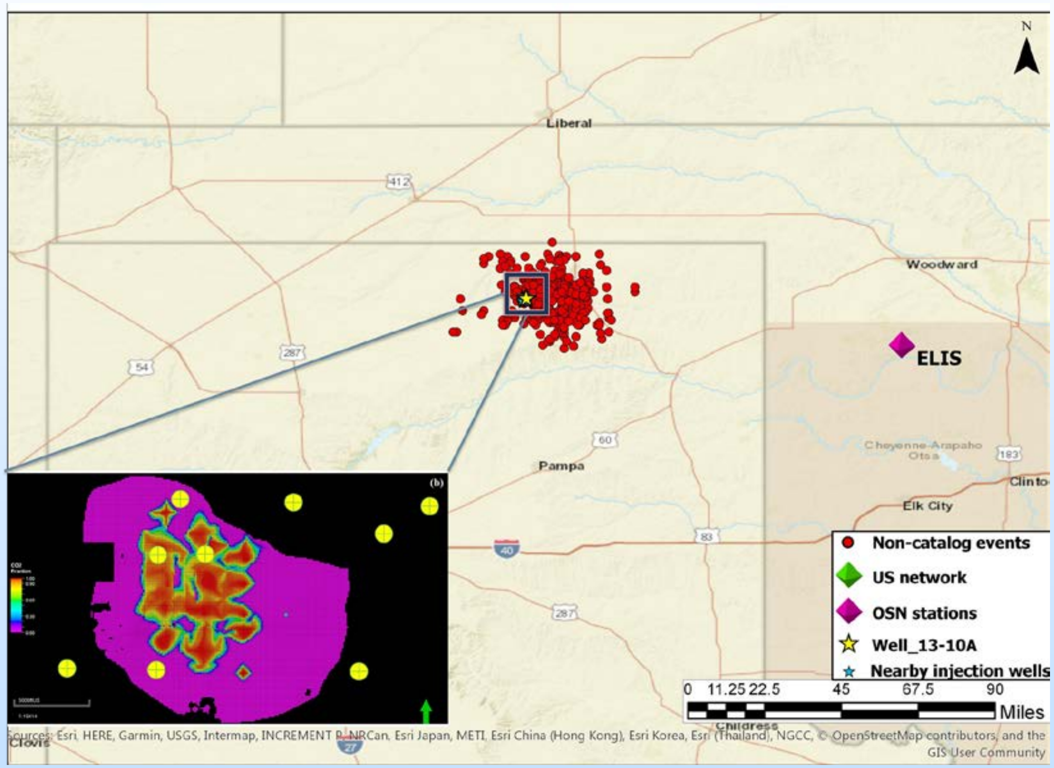
West Texas



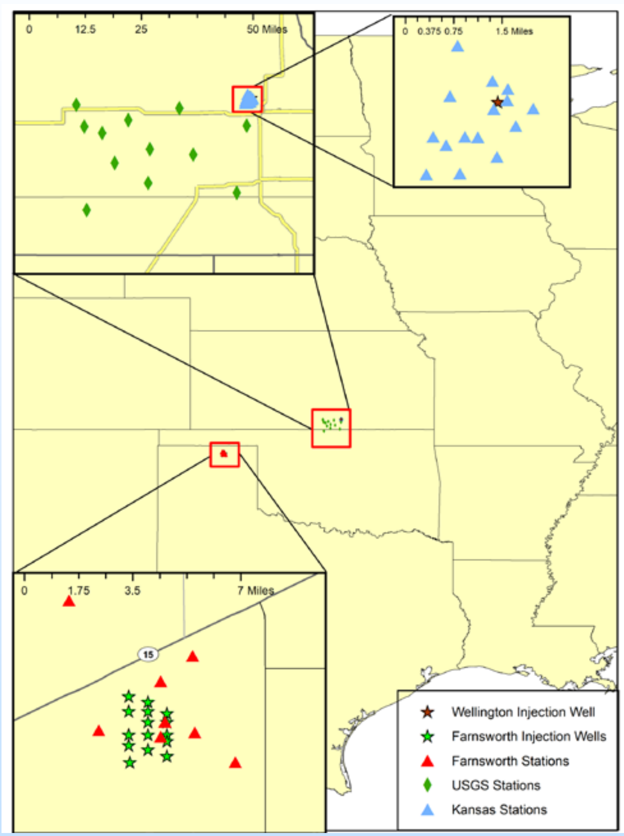
Southern Kansas

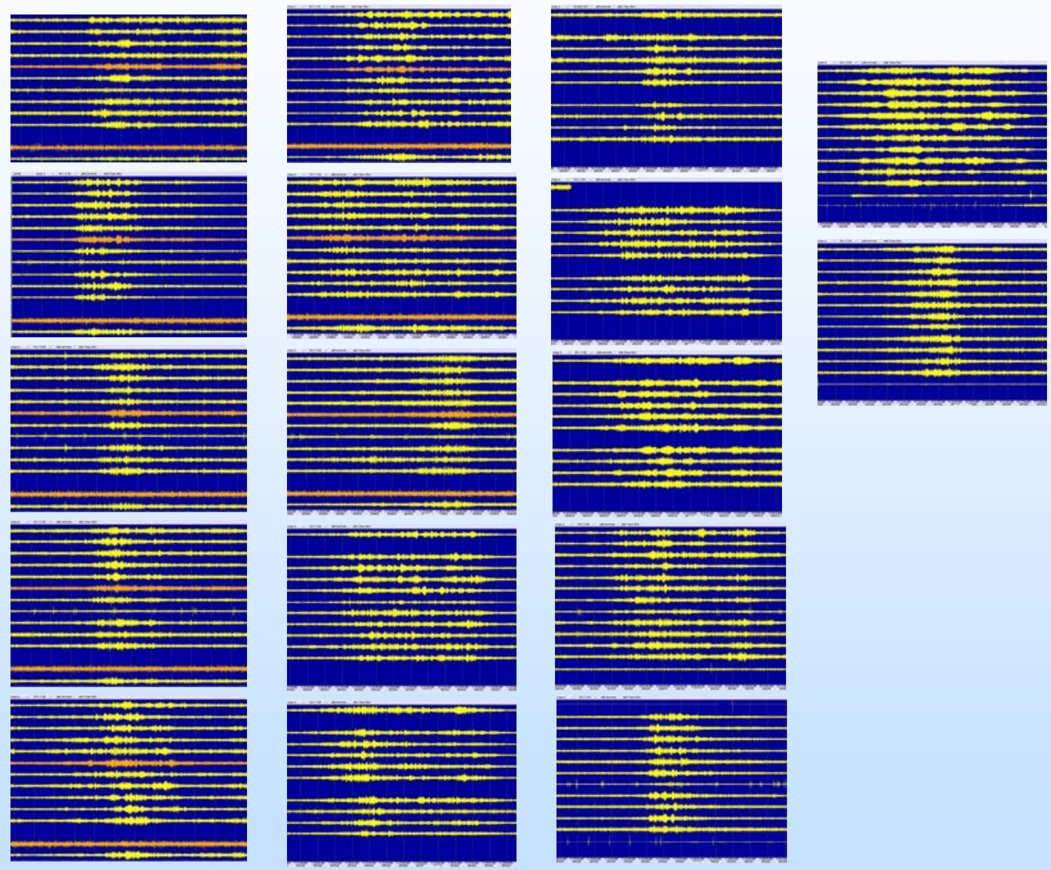
Passive Seismic Monitoring – Farnsworth, TX



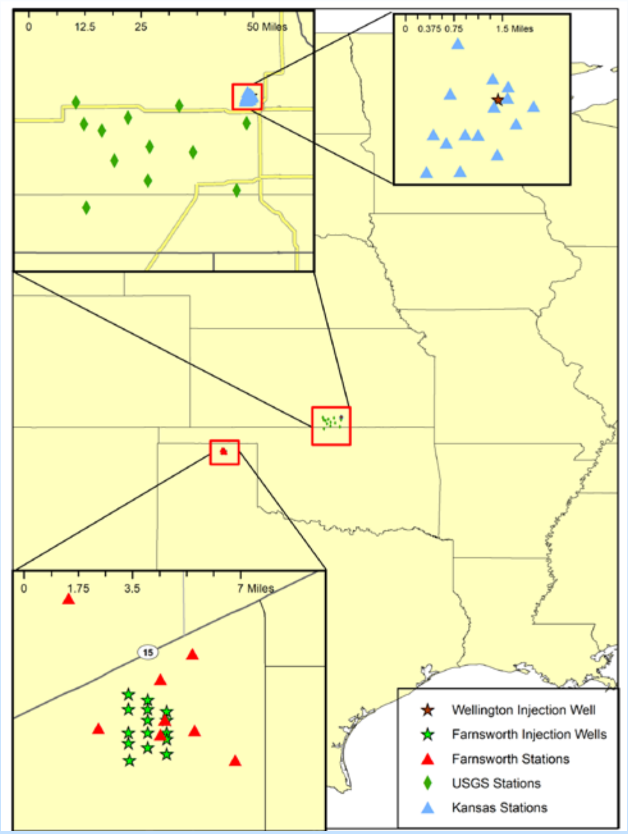


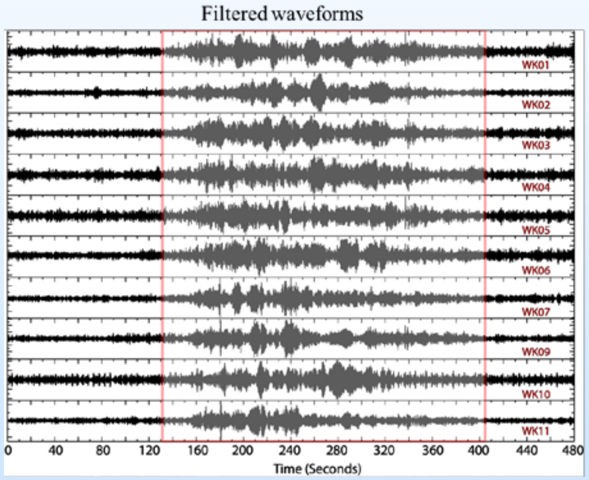
Passive Seismic Monitoring – Wellington, KS

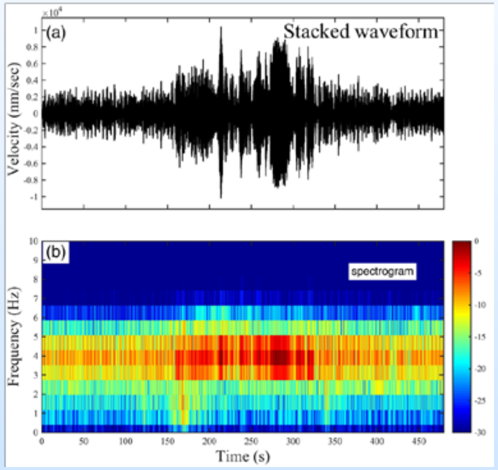




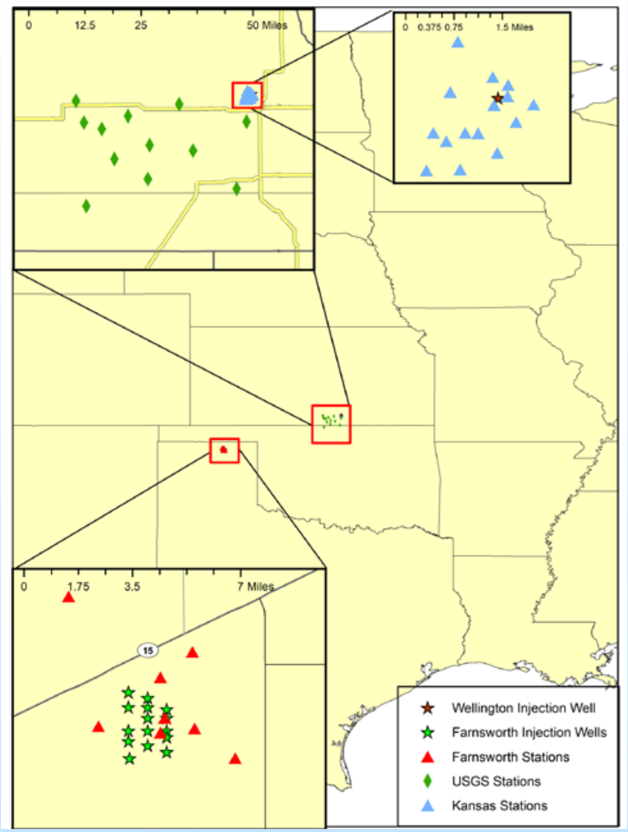
Passive Seismic Monitoring – Wellington, KS

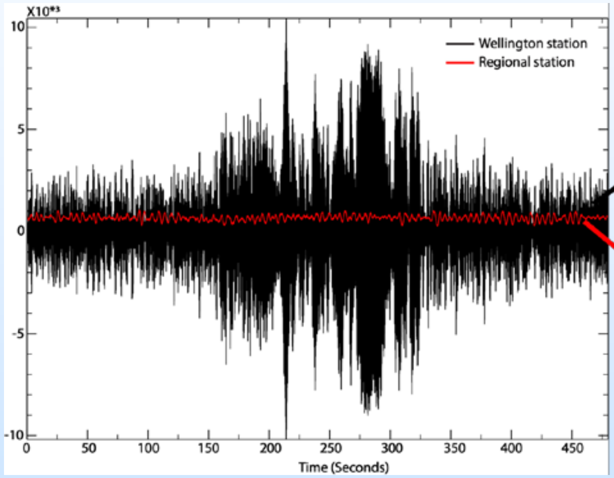


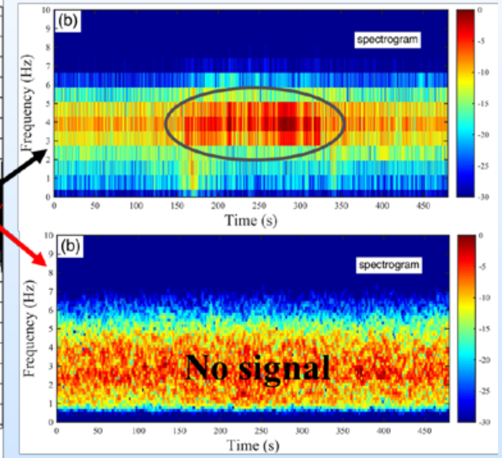




Assurance of Local Seismic Source







Accomplishments to Date

- LPLDs have been identified at 2 CO_2 EOR sites, 3 hydraulic fracturing sites, and 1 produced gas EOR (huff n' puff)
- Waveform envelope cross correlation has been used to locate LPLD events at 1 CO_2 EOR site and 1 hydraulic fracturing site
- Additional seismic data sets have been received from a CO_2 EOR (Battelle) and from a CO_2 enhanced coalbed methane site (Virginia Tech)

Lessons Learned

- Identifying LPLDs still requires a manual examination by an experienced seismologist although progress has been made to automate the screening procedure
- Distant earthquakes have low-frequency waveforms that can be mistaken for local LPLDs. These must be removed from the seismic record prior to LPLD identification

Synergy Opportunities

- LPLD evaluations are complementary to microseismic evaluations that have already been performed at Partnership sites.
- Broadband seismic data has been provided to NETL by:
  - Kansas Geologic Survey/University of Kansas (Wellington CO_2 EOR)
  - Battelle (Pinnacle Reefs CO_2 EOR)
  - Virginia Tech (CO_2 Enhance Coalbed Methane)
- We expect other CO_2 storage partnerships to provide seismic data in the future

Project Summary

- Key Findings
  - LPLDs have been identified at every fluid injection site that we have examined
  - LPLD locations at Farnsworth CO_2 EOR were both inside and outside the modeled CO_2 and pressure extent
  - LPLD locations at a hydraulic fracturing site coincided with areas of microseismic activity
  - LPLDs at CO_2 EOR sites have longer duration than at hydraulic fracturing sites
- Next Steps
  - Examine broadband seismic data from areas without fluid injection
  - Need string shot or perf shot to calibrate waveform envelope cross correlation method

Appendix

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

Benefit to the Program

- By identifying or developing better methods for monitoring caprock integrity, this project helps to ensure permanent storage of CO_2

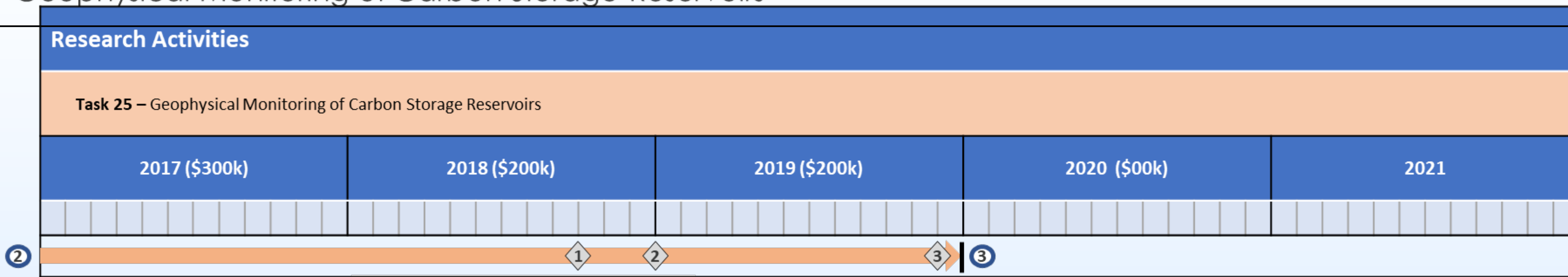
Project Overview

Goals and Objectives

- Project Goal – To identify a cost-effective means to detect deformation in the mechanically weak shale caprock that prevents the upward migration of stored CO_2 into USDWs
  - Objectives
    - Evaluate alternatives to microseismic, which under-represents the amount of deformation in mechanically-weak shale caprock. Success criteria: the method must provide continuous monitoring; identify deformation in plastic shale and movement along pre-existing fractures; be inexpensive to install and maintain; and provide minimal disruption to surface owners.
    - Screen seismicity at CO_2 storage sites, CO_2 EOR sites, and CO_2-enhanced coalbed method sites for the presence of LPLD events. Success criteria: identified LPLD events must be located and temporally/spatially related to fluid injection.

Gantt Chart

Geophysical Monitoring of Carbon Storage Reservoirs



Milestones

1. Complete passive seismic monitoring at Farnsworth EOR and constrain the hypocenter location for observed low-frequency tremor events.
2. Complete review of passive seismic data collected at Wellington EOR (Kansas) and Pinnacle Reefs EOR (Michigan).
3. Determine if low-frequency tremor occurs in a brittle sandstone reservoir undergoing CO_2 injection.

Chart Key

\# TRL Score | Go / No-Go Timeframe | Project Completion

Go / No-Go

Impact

Key Accomplishments/Deliverables	Value Delivered
1. Publish a seismic catalog of low-frequency tremor recorded at Farnsworth EOR during one year of CO_2 injection (12/2018).	• Provide scientific basis for using low-frequency tremor as a new tool to identify areas undergoing non-brittle failure in storage reservoirs; this tool will complement microseismic monitoring which shows where brittle failure is occurring.

Bibliography

– 1. Seismic monitoring of CO_2-EOR operations in the Texas Panhandle and southern Kansas using surface seismometers. 2019 SEG Technical Program Expanded Abstracts, pp. 4903-4907.

– 2. Surface-seismic monitoring of an active CO_2-EOR operation in the Texas Panhandle using broadband seismometers. 2018 SEG Technical Program Expanded Abstracts, pp. 3027-3031.

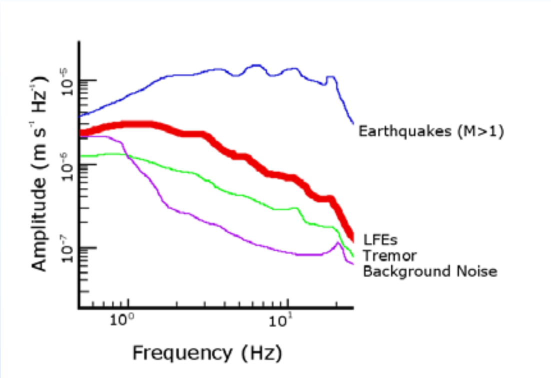
– 3. Passive seismic monitoring of an active CO_2-EOR operation in Farnsworth, Texas. 2017 SEG Technical Program Expanded Abstracts, pp. 2851- 2855.

Technical Status

Manufacturer	Model	Sensitivity [V·s/m]	Clip [mm /s]	Period [s]	Upper corner [Hz]	Power [W]	Weight [kg]	Sensor volume [L]	Shield volume [L]
Geotech	KS-1	2,400	8	360	5	2.4	43	28	–
Streckeisen	STS-1	2,400	8	360	10	10.5	15	14	450
Nanometrics	Trillium 240	1,200	16	240	200	0.65	14	14	60
Nanometrics	Trillium 120	1,200	16	120	175	0.62	7.2	7.2	32
Guralp	CMG-3 T	1,500	13	120	50	0.75	14	8.4	–
Streckeisen	STS-2	1,500	13	120	50	0.8	13	11	72
Geotech	KS-2000	2,000	10	120	50	0.9	11	8.1	–
REF TEK	151B-120	2,000	10	120	50	1.1	12	12	–
Geodevice	BBVS-120	2,000	10	120	50	1.4	14	8.3	–
Nanometrics	Trillium Compact	750	26	120	100	0.16	1.2	0.8	7.8
Guralp	CMG-3ESP	2,000	10	60	50	0.6	9.5	4.7	–
Guralp	CMG-40 T	800	25	30	50	0.46	2.5	3.9	–

Volumes are for three components and are derived from footprint area and height alone

Specifications of broadband seismometers



Encyclopedia of Earthquake Engineering
DOI 10.1007/978-3-642-36197-5_172-1

Principles of Broadband Seismometry

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