Geophysical Monitoring of Seals and Plumes

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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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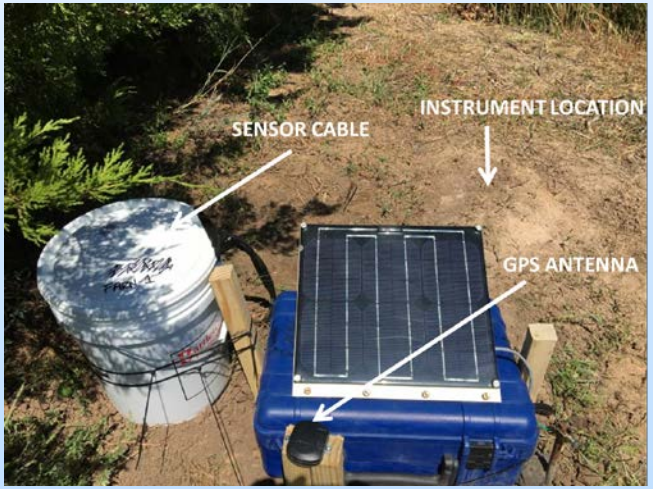
Technical Status

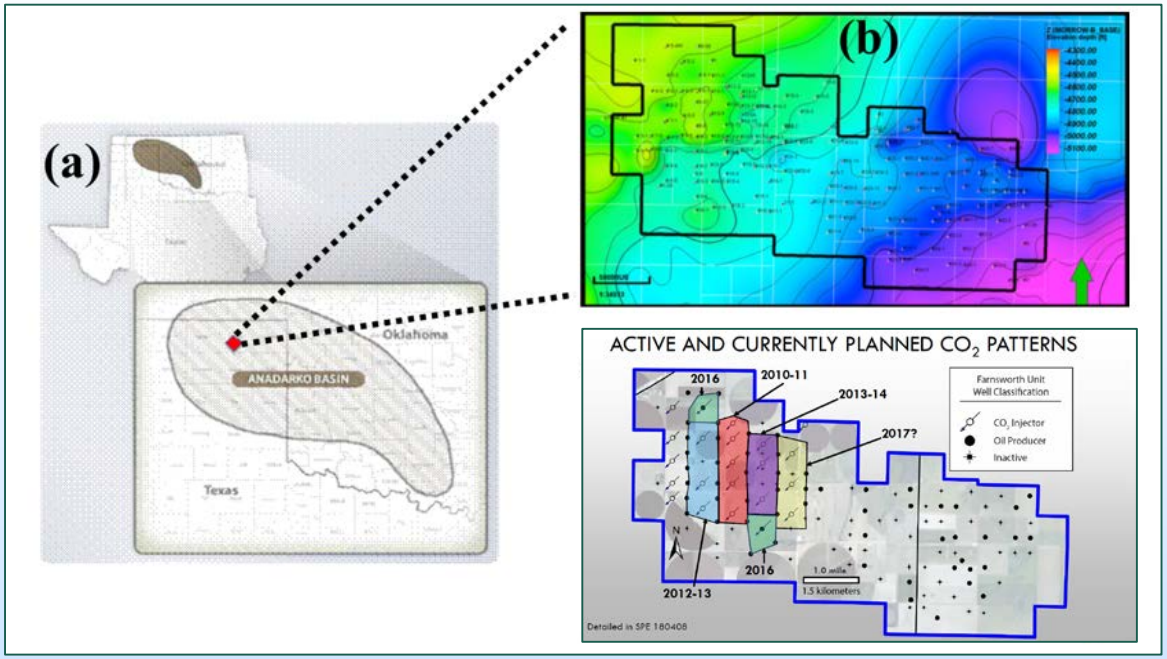
- Overarching Goal- To develop a suite of non-wellbore-based technologies for monitoring seals and plumes.
  - Inexpensive
  - Small Physical and Environmental Footprint
    - Landowner Tolerated
    - Ease of Permitting
  - Suitable for Long-Term Monitoring (50 years)
    - Remote, Unattended Operation
    - Automatic Data Interpretation and Alert Notifications

Technical Status

- Current Objective- To evaluate passive seismic monitoring using a network of solar-powered, broadband seismometers deployed on the surface.



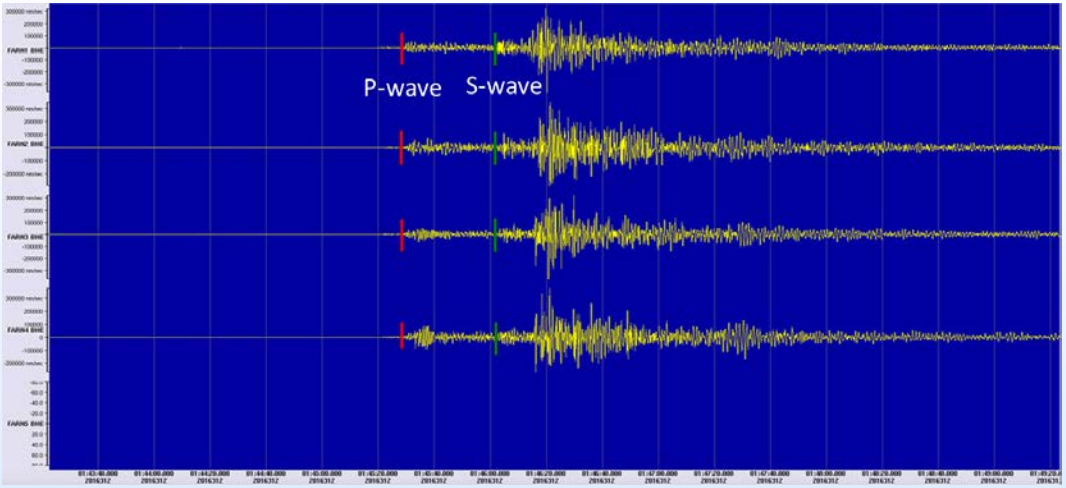
Field Deployment-Farnsworth EOR



New Mexico Tech
Robert Balch and
Leonard Garcia

Seismometer Network at Farnsworth EOR

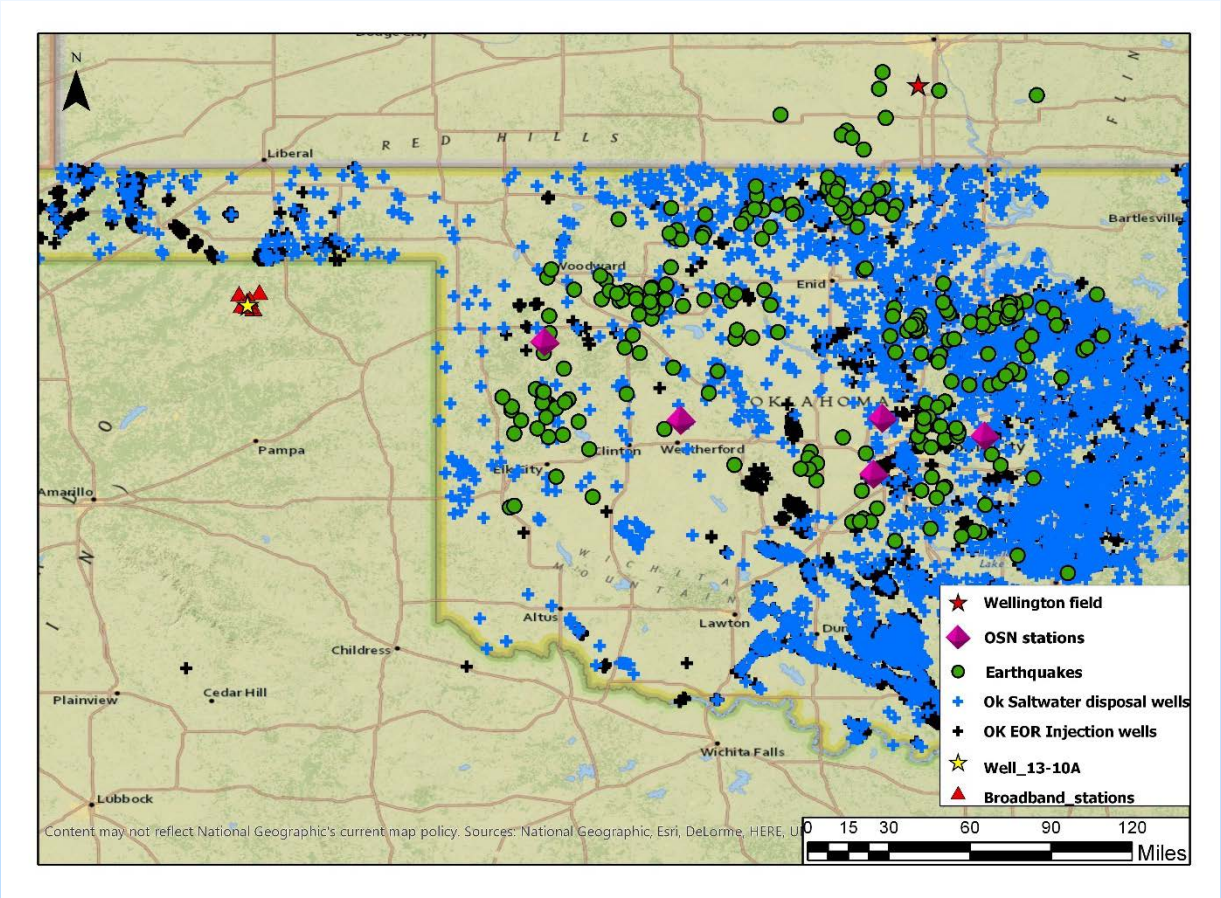
Seismometer Network at Farnsworth EOR



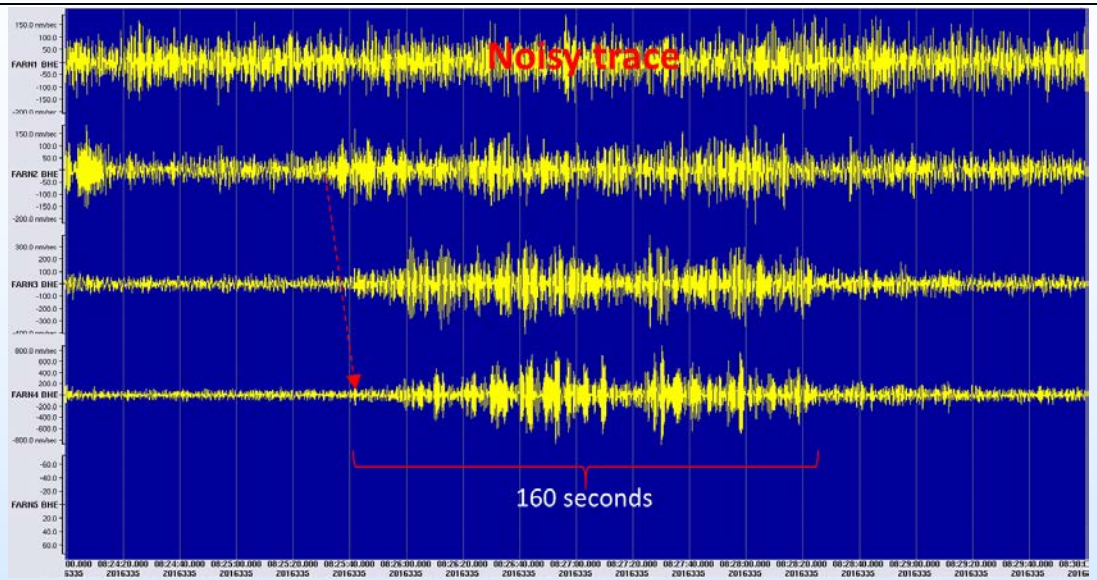
- 441 Earthquakes (Mw > 0) in 3 months
  - All but 12 earthquakes were also recorded in one or more national/regional seismic catalogs including:
    1. Advanced National Seismic System (ANSS)
    2. USGS's National Earthquake Information Center (USGS-NEIC)
    3. New Madrid Earthquake Catalog
    4. International Seismological Centre (ISC)
    5. Oklahoma Seismic Network (ONC)

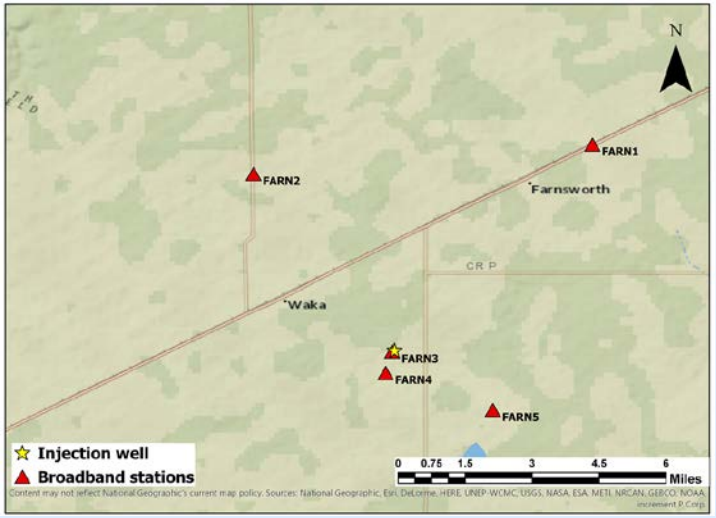
Seismometer Network at Farnsworth EOR

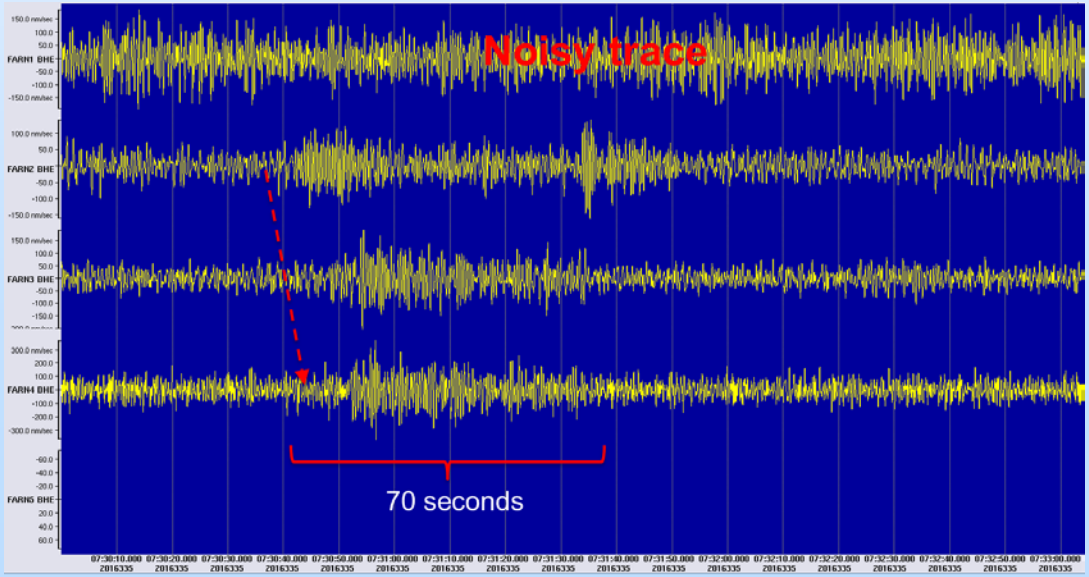
- 441 Earthquakes (Mw > 0)
- Located 330 earthquakes (280 locations after QA/QC)
- **No earthquakes within 90 miles of EOR Site**

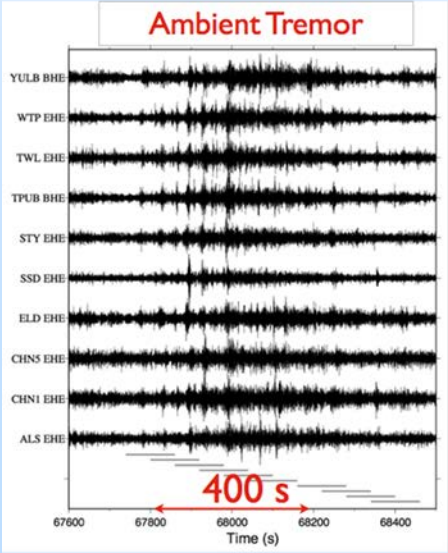


Seismometer Network at Farnsworth EOR





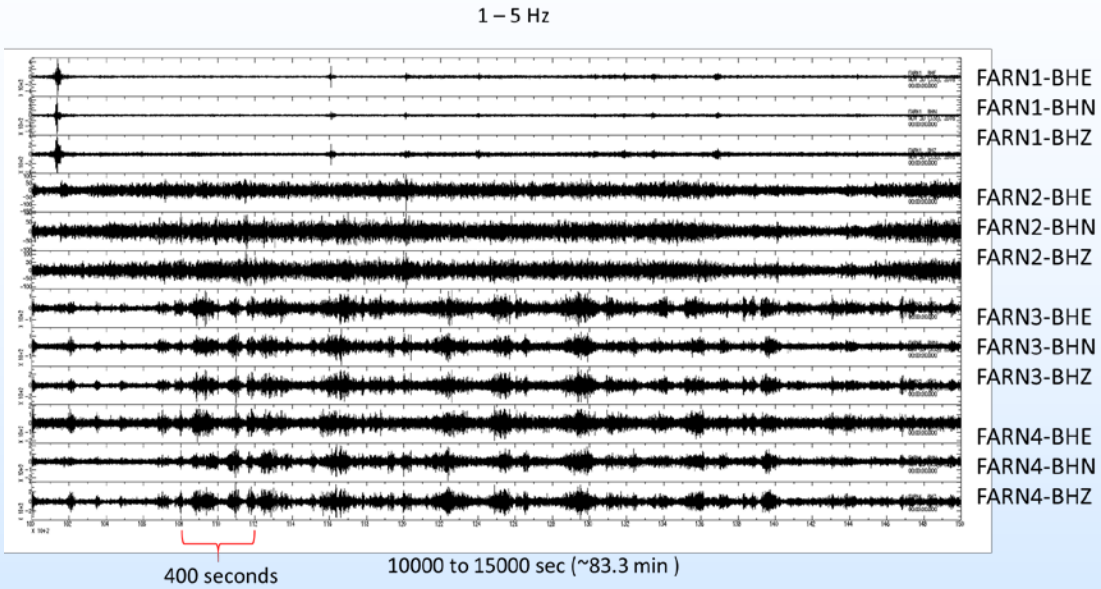


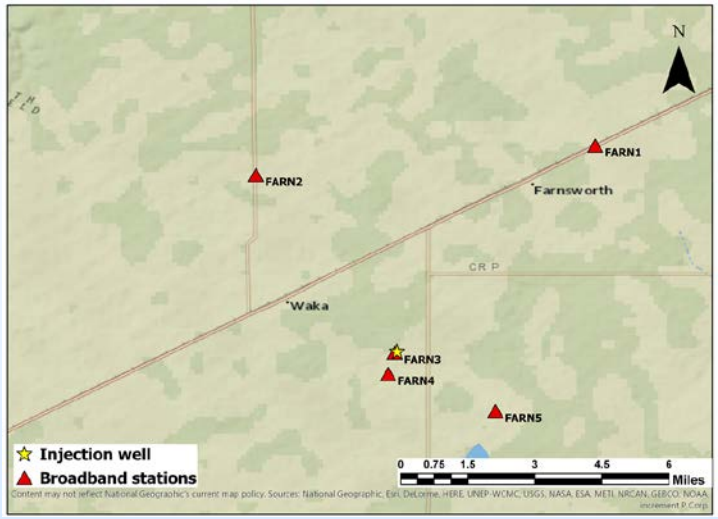


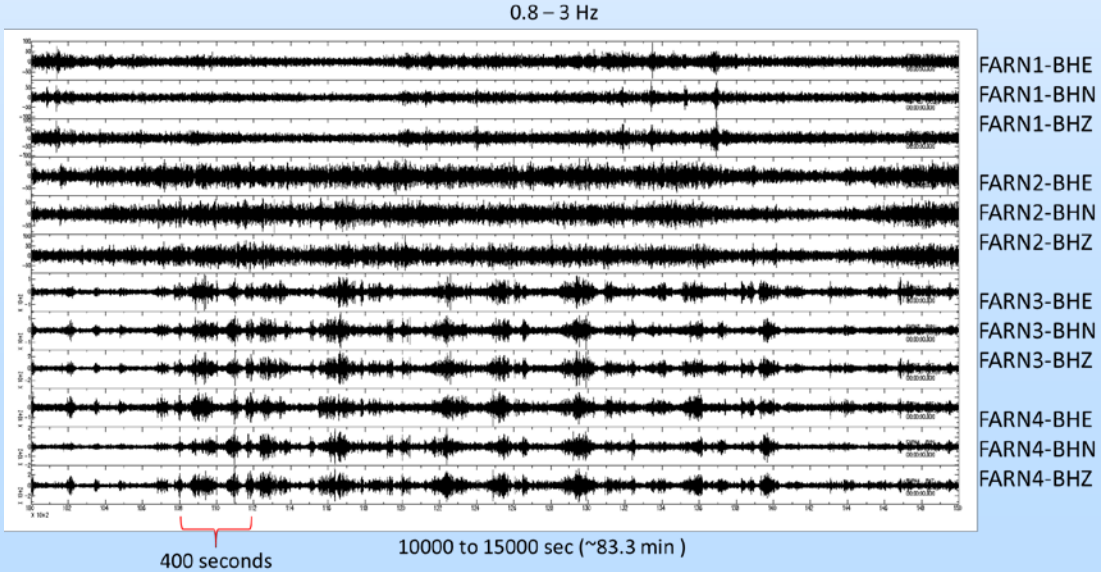
Example of typical tectonic tremor
2-8 Hz
Example shown in Taiwan

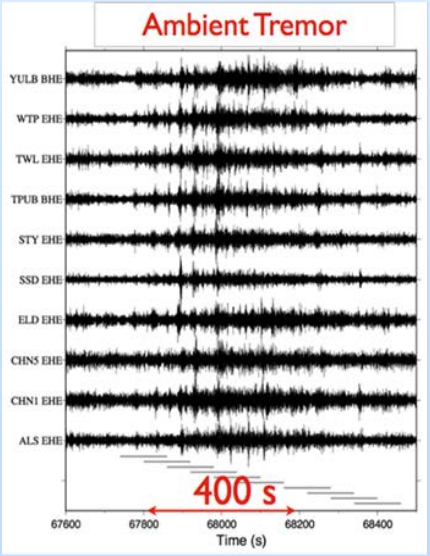
Ref: Chao et al., JGR, 2017, in revision

Seismometer Network at Farnsworth EOR









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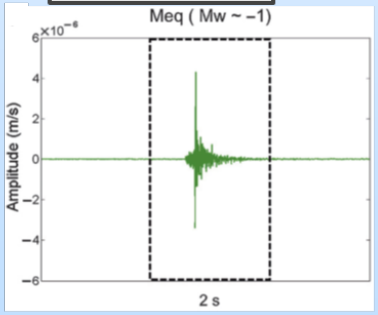
Origin of Tremor at Farnsworth EOR

1. Volcanic Tremor
2. Tectonic Tremor
3. Tremor Associated with Hydraulic Fracturing
4. Tremor Associated with $scCO_2$ injection

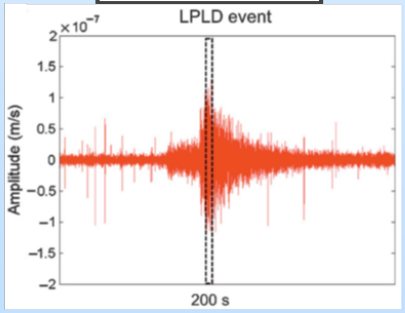
Types of Failure and Deformation Mechanisms

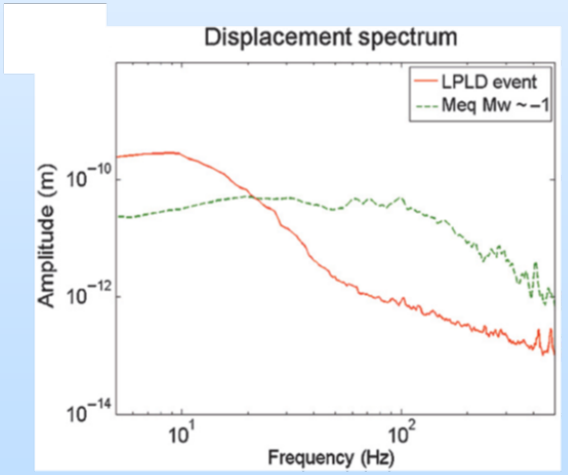
Brittle
(50-150 HZ)



Courtesy: Das and Zoback, 2013

Non-brittle
(1-30 HZ)

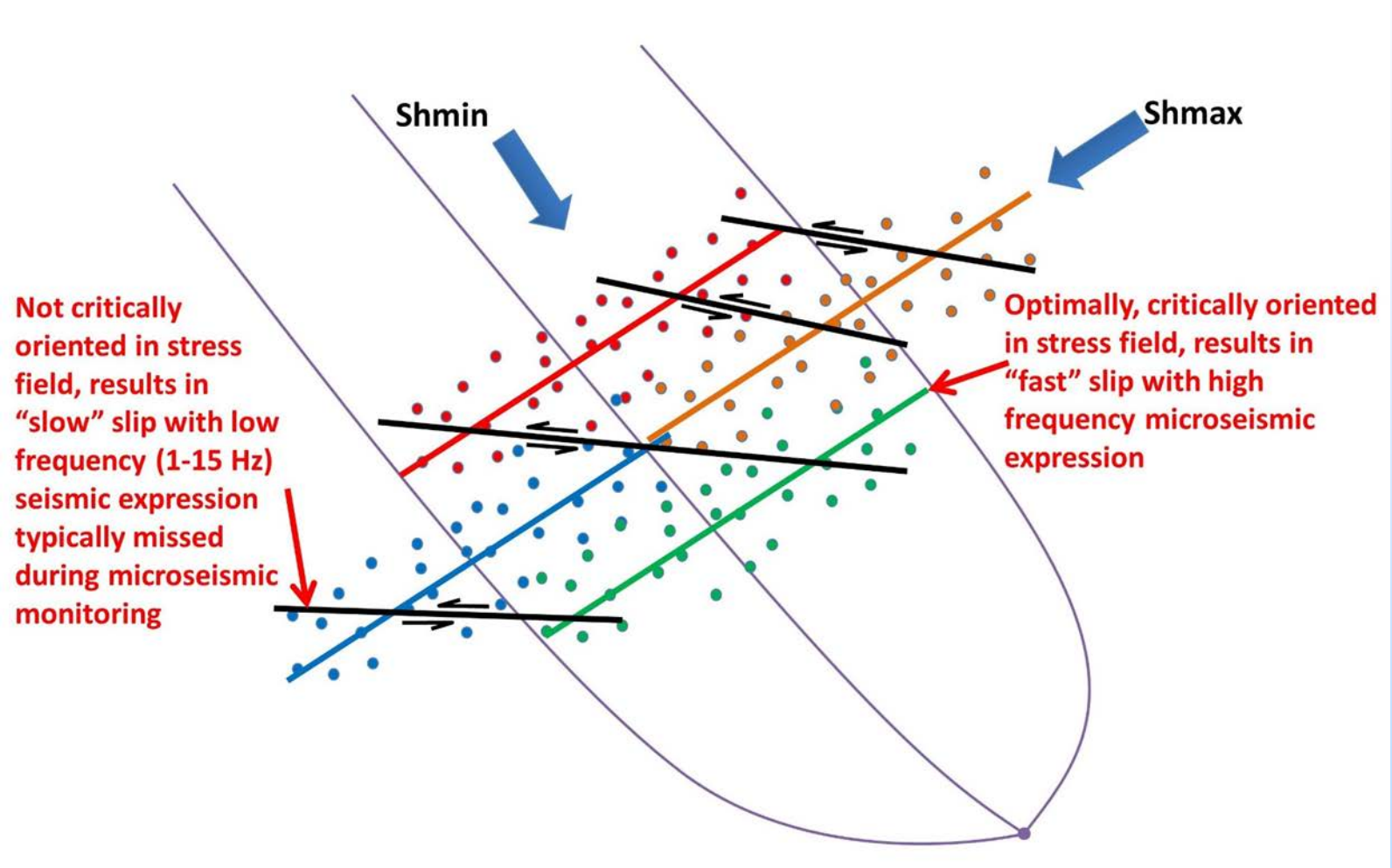




Courtesy: Das and Zoback, 2013

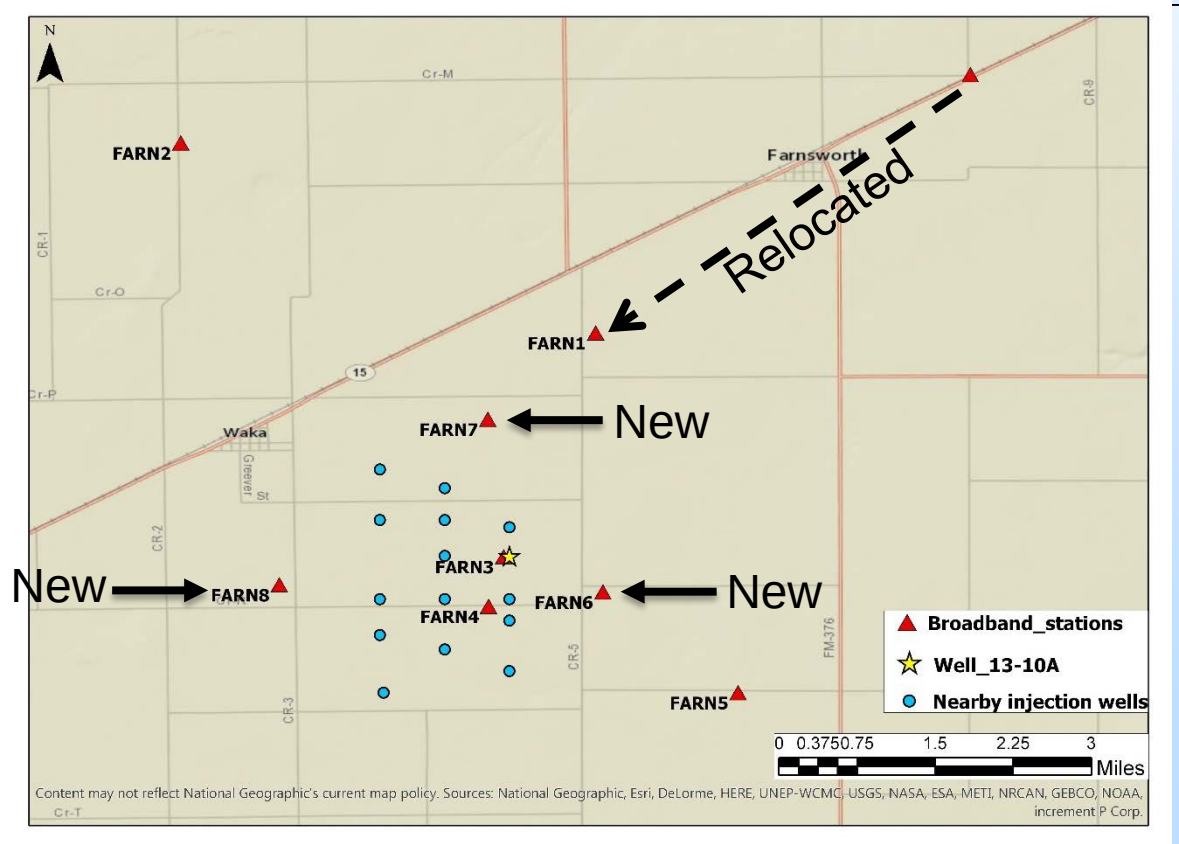
- Low amplitude
- Absence of clear arrival
- Noise-like appearance

Origin of Tremor at Farnsworth EOR



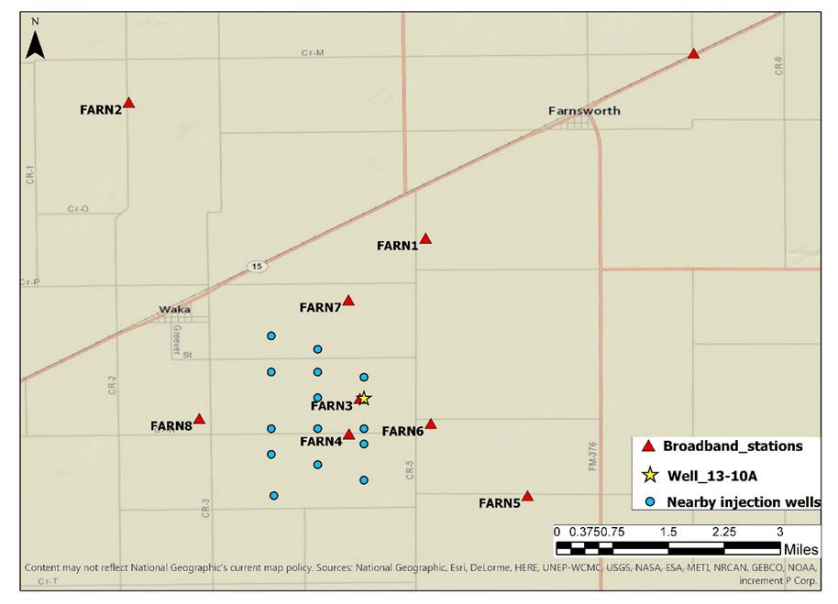
Origin of Tremor at Farnsworth EOR

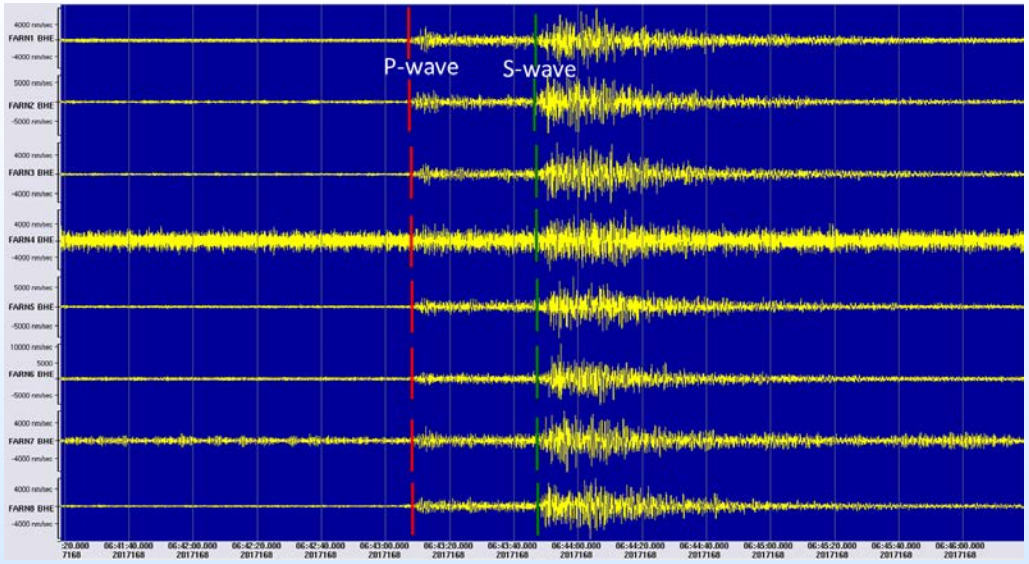
- Long-Period Long Duration Events (LPLD) cannot be located using traditional seismology (lack clear P and S arrivals)
- Cross–Correlation with many stations needed
- Three new stations added in June 2017 (total 8 stations)

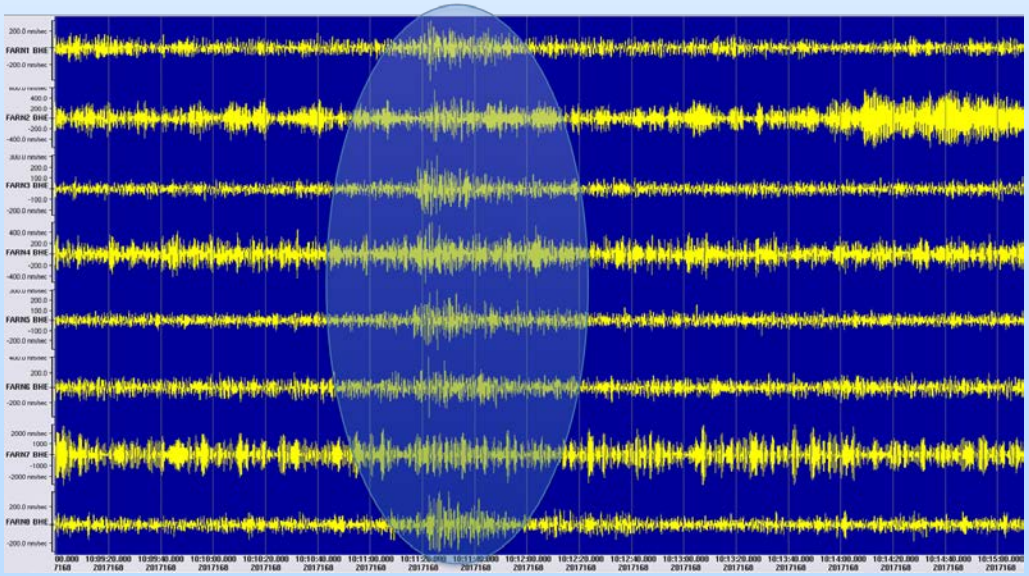


Seismometer Network at Farnsworth EOR

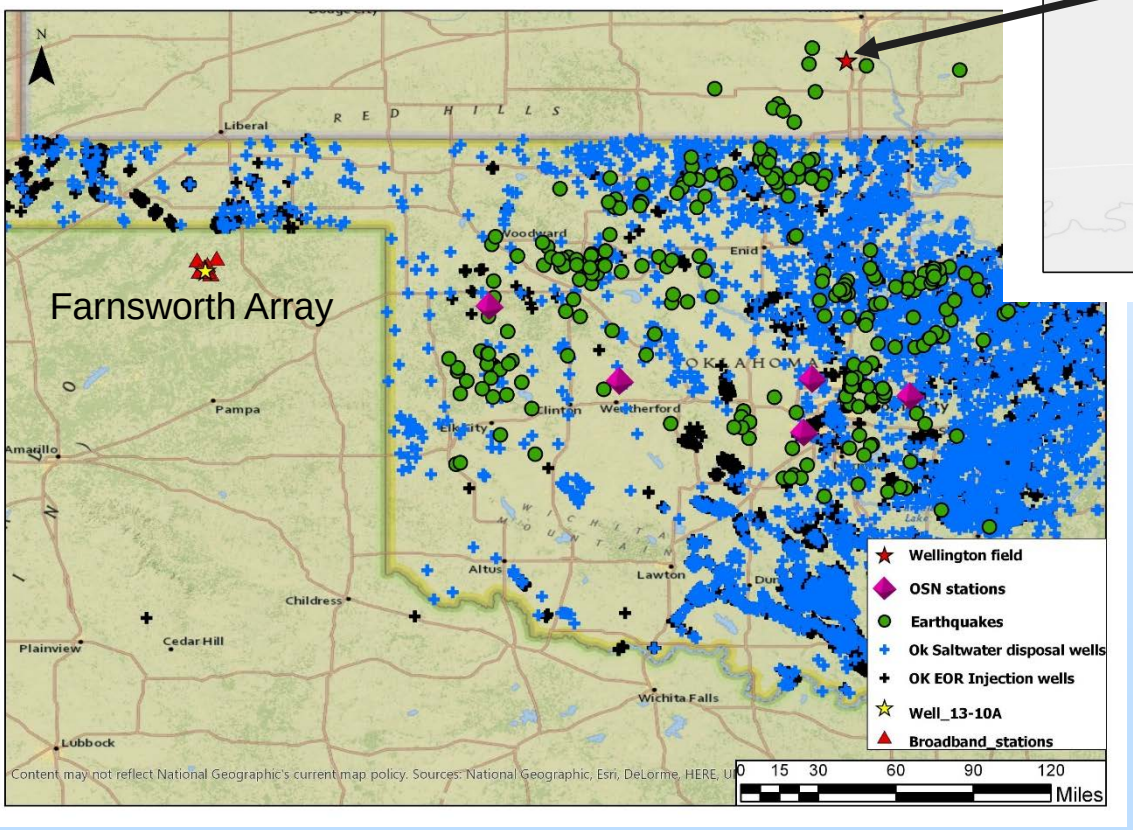
Recent Results

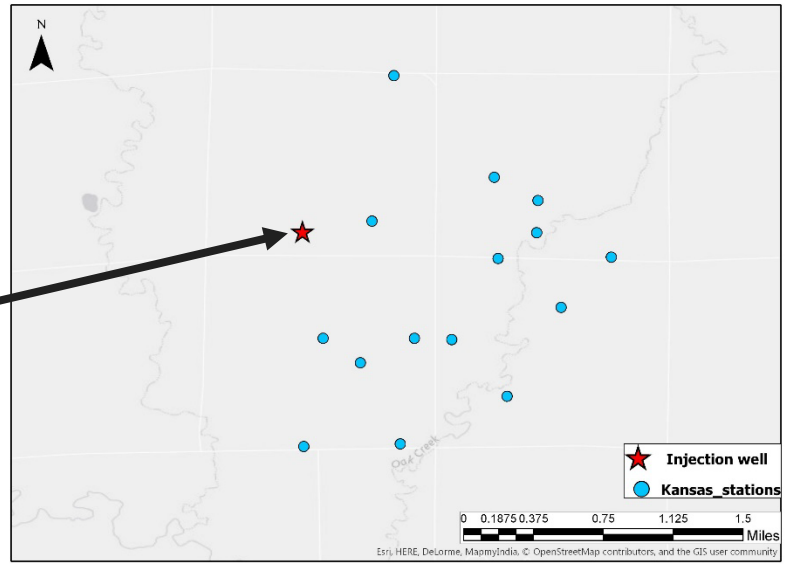






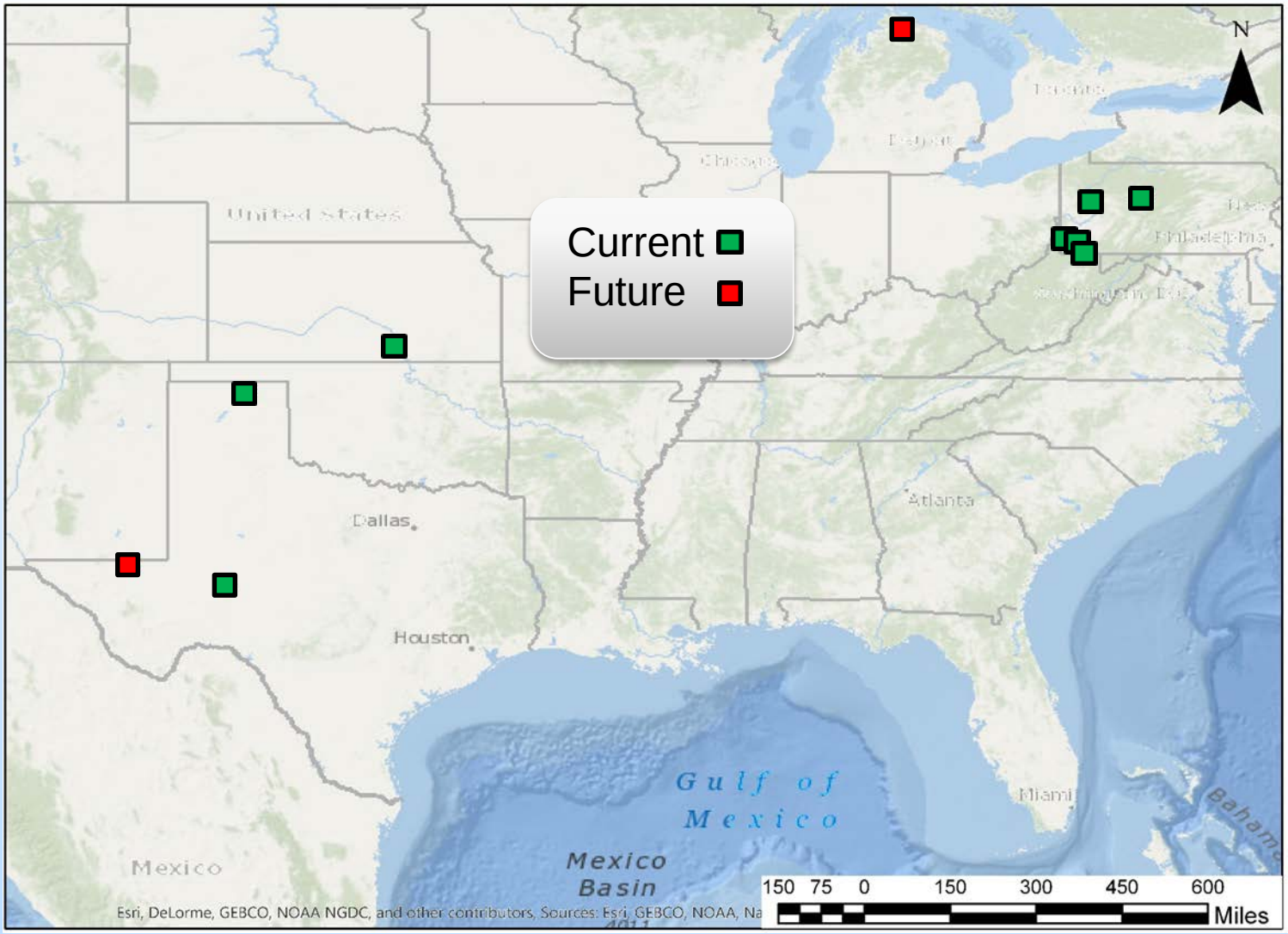
Wellington Field





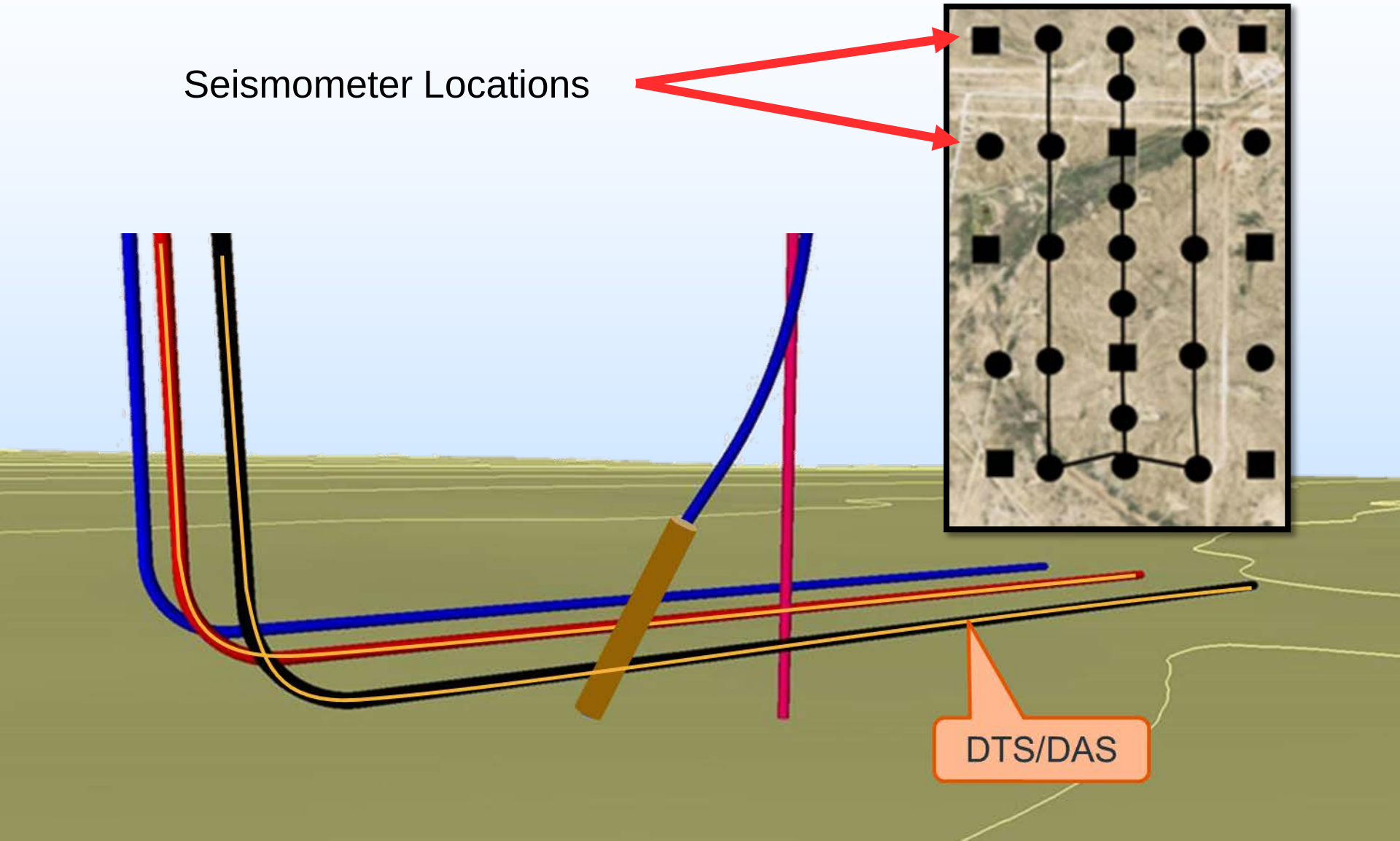
Kansas Geological Survey
Alex Nolte

Seismic Datasets - Screening for Low-Frequency Tremor



Mother Of All Networks (MOAN)

GTI - Hydraulic Fracturing Test Site #2



Accomplishments to Date

- Established a network of five-broadband-seismometers at Farnsworth EOR
- Continuous monitoring for 10 months
- Detected no earthquakes>Mw 0 within 90 miles of location
- First(?) to detect LPLD tremor at EOR site
- Added 3 seismometers to network (total 8 seismometers)

Lessons Learned

- Research gaps/challenges.
  - Inability to locate sources of LPLD tremor
  - Source mechanism unknown
- Unanticipated research difficulties.
  - Impact of rodents on seismometer wiring
  - Noisy seismometer location
- Technical disappointments.
  - None
- Changes that should be made next time.
  - More seismometers

Synergy Opportunities

- Collaborations
  - Southwest Partnership (New Mexico Tech)
  - Kansas Geological Survey
  - Battelle (MRCSP)

Project Summary

- Key Findings
  - No earthquakes (Mw>0) within 90 miles
  - Detected LPLD (low frequency tremor) near injection well
- Next Steps
  - Continued monitoring at Farnsworth EOR
  - Determine location and mechanism of low frequency tremor.

Appendix

Benefit to the Program

1. Develop and validate technologies to ensure for 99 percent storage permanence.
2. Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness.
3. Develop Best Practice Manuals (BPMs) for monitoring, verification, accounting (MVA), and assessment; site screening, selection, and initial characterization; public outreach; well management activities; and risk analysis and simulation.

Benefit to the Program

- Geophysical Monitoring of Seals and Plumes – The objective of this task is to support DOE's large-scale field activities by developing and demonstrating non-borehole-based methods for detecting the plume and pressure front in the storage formation. In addition, methods will be explored to provide an early warning of deformation within overlying seals. The drivers for seeking non-borehole-based methods are: (1) the increasing difficulty and cost of locating, permitting, drilling, instrumenting, and abandoning monitoring wells and (2) the possibility that plume fingering might bypass a monitoring well network without detection.

Project Overview
Goals and Objectives

Brief Description	Planned Completion Date
Task 9.0 Geophysical Monitoring of Seals and Plumes	
Interpreted seismic monitoring results from an incrementally expanding network of broadband seismometers deployed on the surface above a large CO_2 injection site that will: • Permit the distinction between induced seismicity due to the CO_2 injection and seismicity from natural or outside sources. • Provide more accurate locations for seismic events. • Provide insight into focal mechanisms for observed seismic events. • Identify areas of the storage formation with abnormally high pore pressure. • Provide early warning of seal deformation.	12/29/2017

Organization Chart

- Project Team
  - PI-Rick Hammack (Physical Scientist)
  - Seismologist-Abhash Kumar (AECOM)
  - Geophysicist- Bill Harbert (ORISE)

Gantt Chart

Task 9.0 Geophysical Monitoring of Seals and Plumes		2017			
9.1	Passive Seismicity at CO_2 Injection Locations				
	M1 Milestone (M1.17.9.A) – An array of 5-8 solar-powered, broadband seismometers will be installed at Farnsworth EOR location.				

Bibliography

– Kumar, A., Zorn, E., Hammack, R., and Harbert, W., 2017, Passive seismic monitoring of an active CO2-EOR operation in Farnsworth, Texas. Proceedings-Society of Exploration Geophysicists Annual Meeting, Houston, TX