FWP-ESD14095

CCSMR Task 4: Hybrid Seismic Sensing for High-Repeatability Imaging of CO2 Storage in the Illinois Basin

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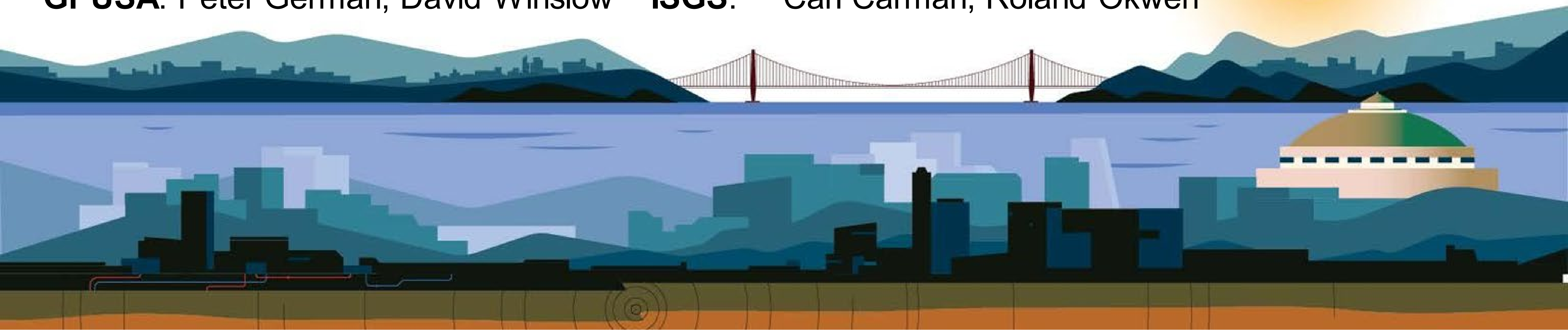
GPUSA: Peter German, David Winslow **ISGS**: Carl Carman, Roland Okwen



Challenge: sparse seismic monitoring beyond 3D VSP

0. Cost-effective = cheap and good illumination

1. How useful?

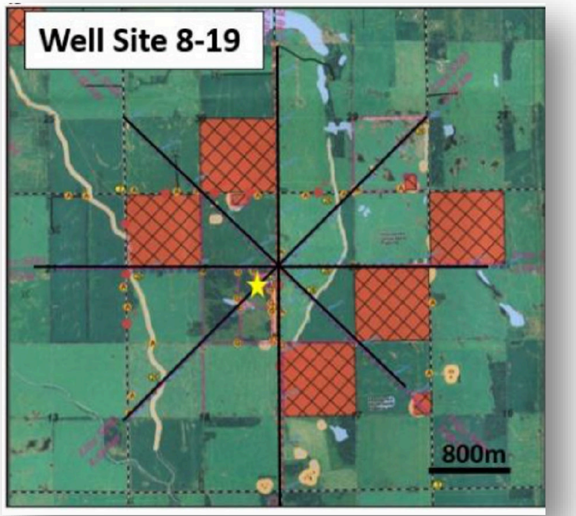
2. How effective?

Walkaway VSP using DAS in deep boreholes: Quest CCS examples

DAS VSP is the biggest thing for the site operators to reduce cost and satisfy EPA

Permeability: 1000 mD (k_V/k_H~.01)
Porosity: 17%
Thickness: 30 m
Amount: ~2.5 Mt over 5 years (will be ~10 Mt at least)

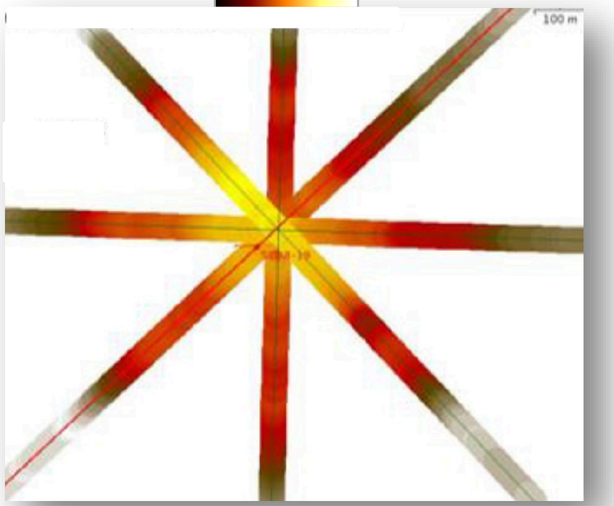
Acquisition geometry



Coverage is limited:

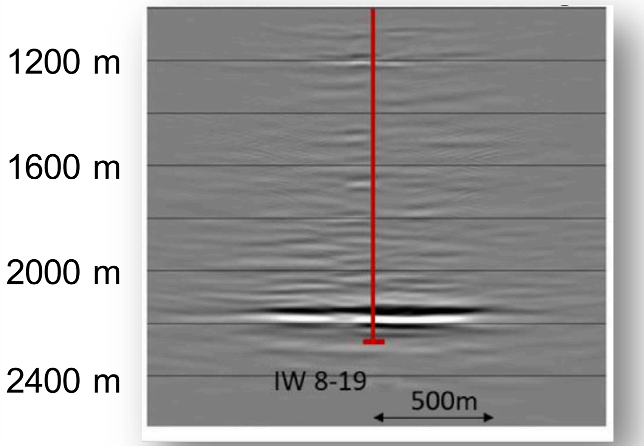
- Permitting (invasiveness)
- Acquisition cost
- Focused around the known plume
- **DAS directivity**
- **Magnitude of completion is compromised**

RMS difference



500 m

Seismic Diff - +



Solution: multiple shallow seismic boreholes

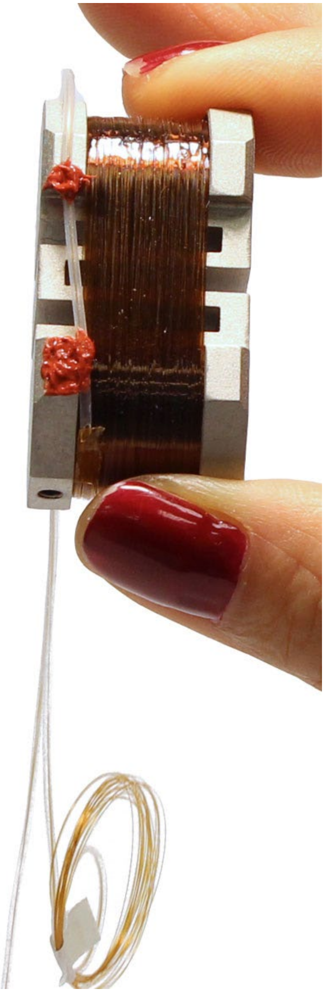
0. DAS + 3C sensors in multiple shallow boreholes

1. Detection of the plume instead of imaging

2. Cheaper and Effective?

Instrumentation: High-Sensitivity Vector Optical System (HS-VOS)

Seismic sensing system for high-precision tracking of injected CO_2/pressure

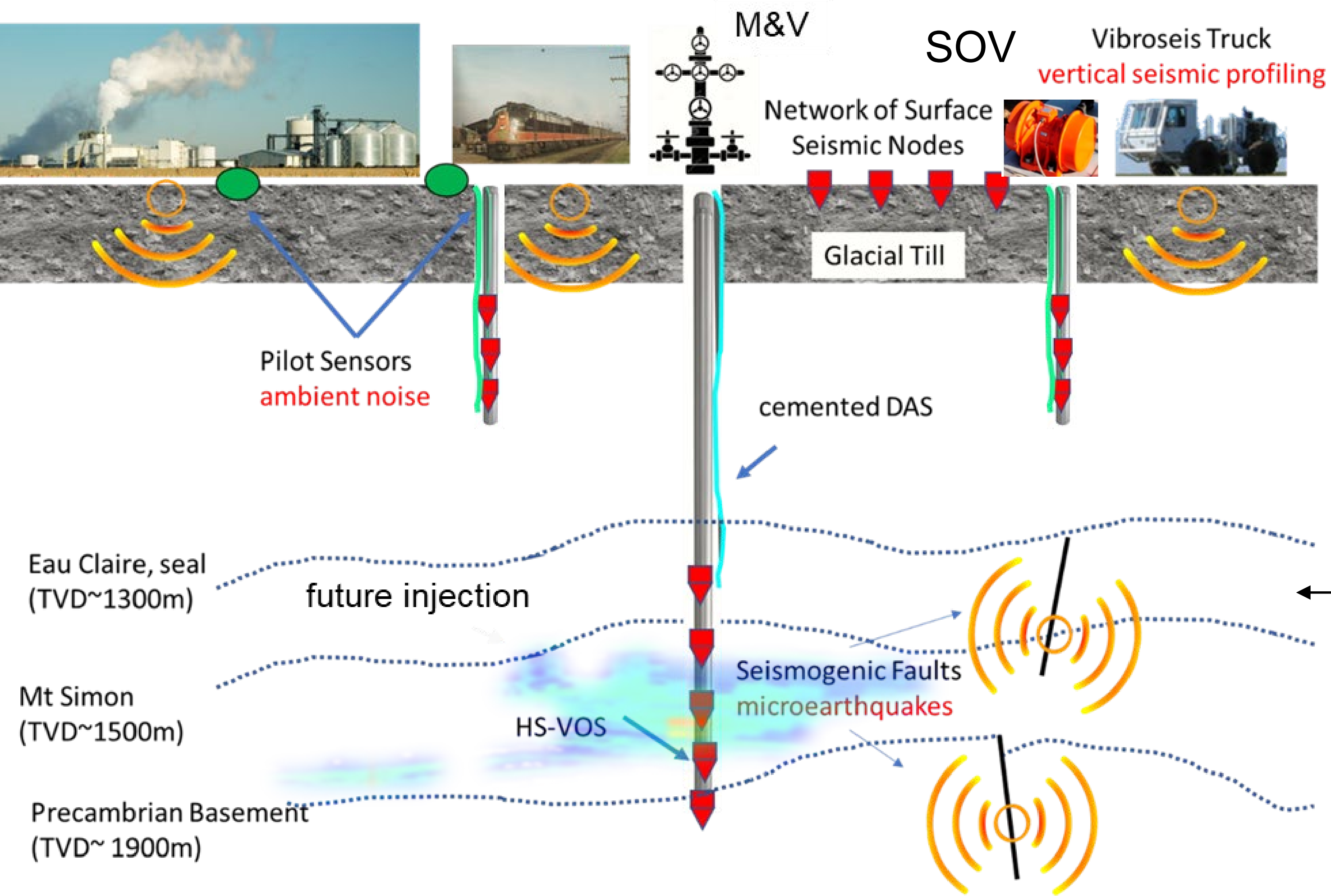


- Refining and applying a system of resilient high-fidelity seismometers
  - On hybrid wireline cable (4x copper and 18x single-mode fiber)
  - Electronics: 9-laser interrogator/demodulator recording system, w/GPS
  - Passive optical sensing, no power downhole, for up to ~3.5km depth / 200^{o}C

- A few semi-successful field deployments in the past
- Preparing the system for deployment at a Carbon SAFE III site

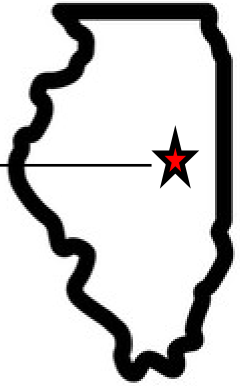
Acquisition: Field deployment at a Carbon SAFE III site

Support FWP: a comprehensive borehole seismic characterization using shallow and deep boreholes



1. Walkaway VSP - optimize 4D seismic
2. Natural seismicity and ambient noise
3. Development of high-repeatability µ–VSP
4. Benchmarking seismic sensors

One Earth Sequestration,
near Gibson city, IL



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The real challenge

One of the shallow seismic boreholes requires a new access road…delay 4 months

Now in place

Deployment on August 19^{th}

Accomplished tasks

1. Prepared for the field deployment

2. Refined/benchmarked seismometers

3. Analyzed legacy seismic data

Instrumentation

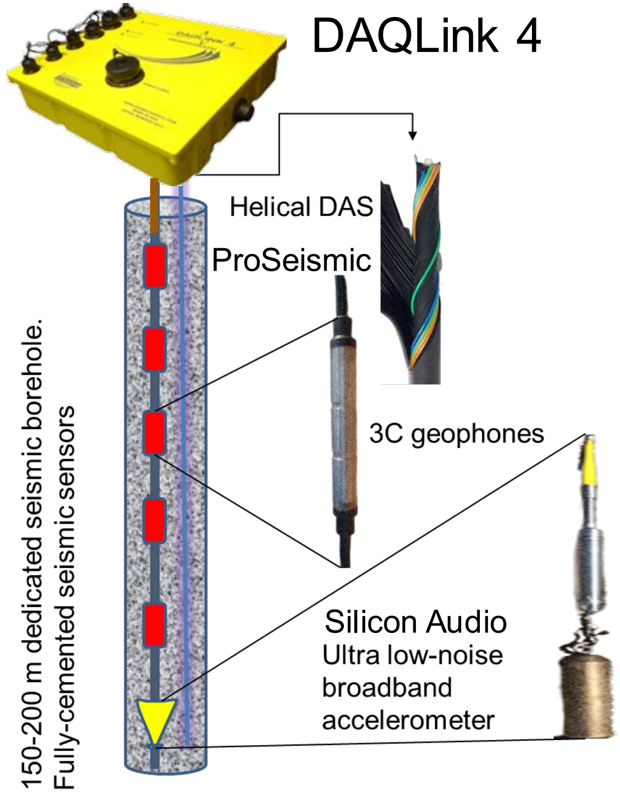
Acquisition design

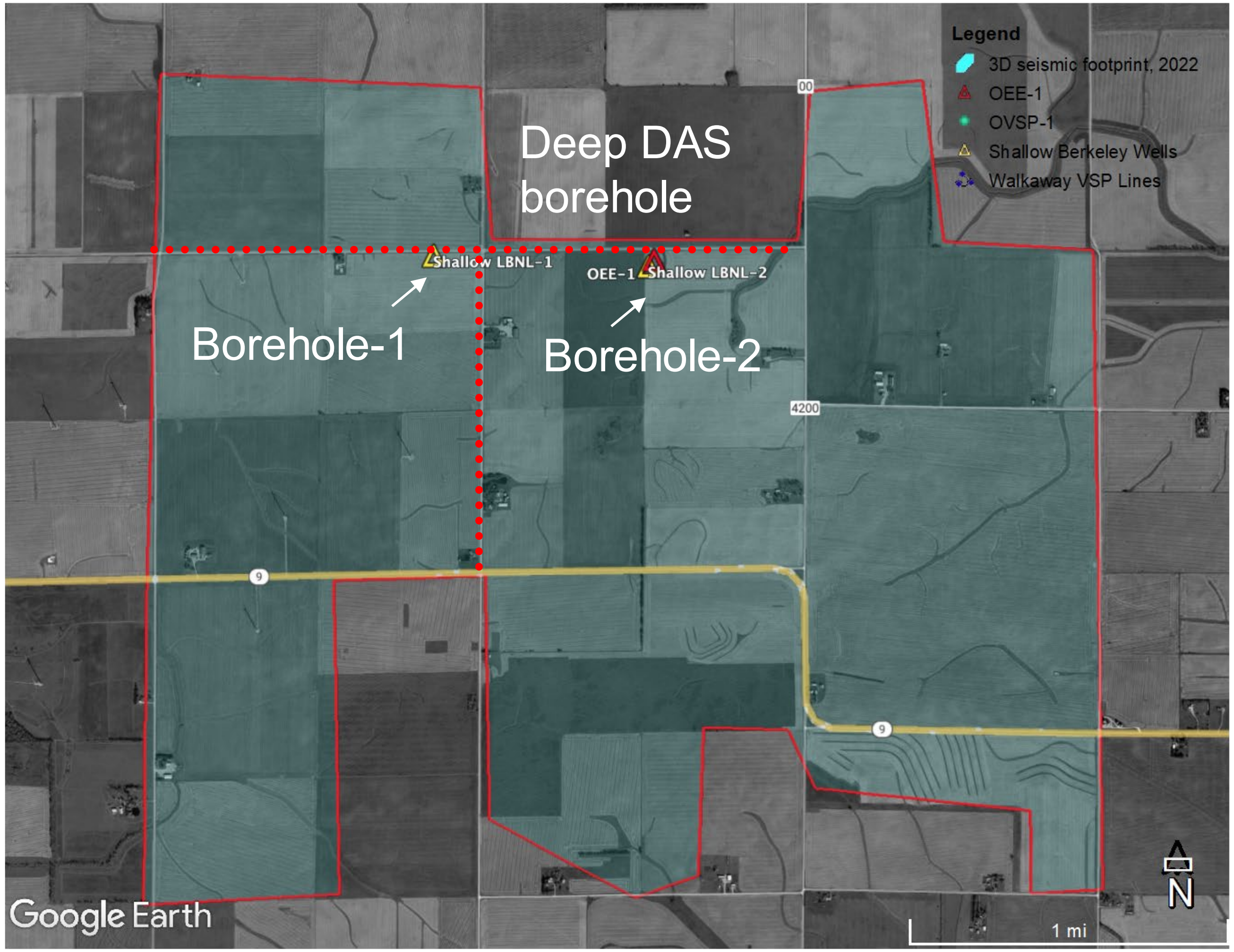
Data streaming

Preparation for the field deployment at the One Earth Sequestration

Designed the seismic acquisition system including the instrumentation and survey design

Nodal stations





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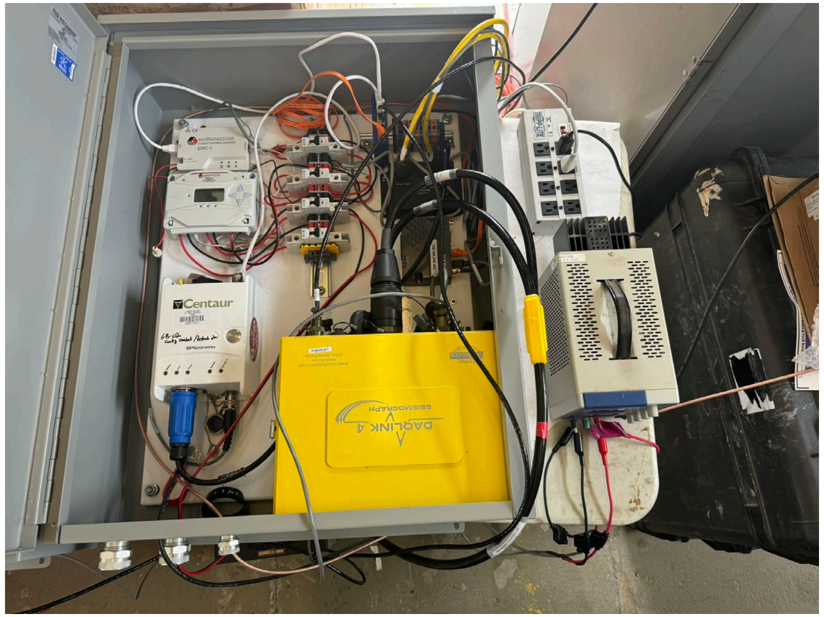
Preparation for the field deployment at the One Earth Sequestration

The instrumentation is fully set up for remote operation/continuous recording



Fully prepared Hoffman boxes x 2

Shallow and deep ultra-low noise optical accelerometers

High-sensitivity/resolution DAS

Accomplished tasks

1. Prepared for the field deployment

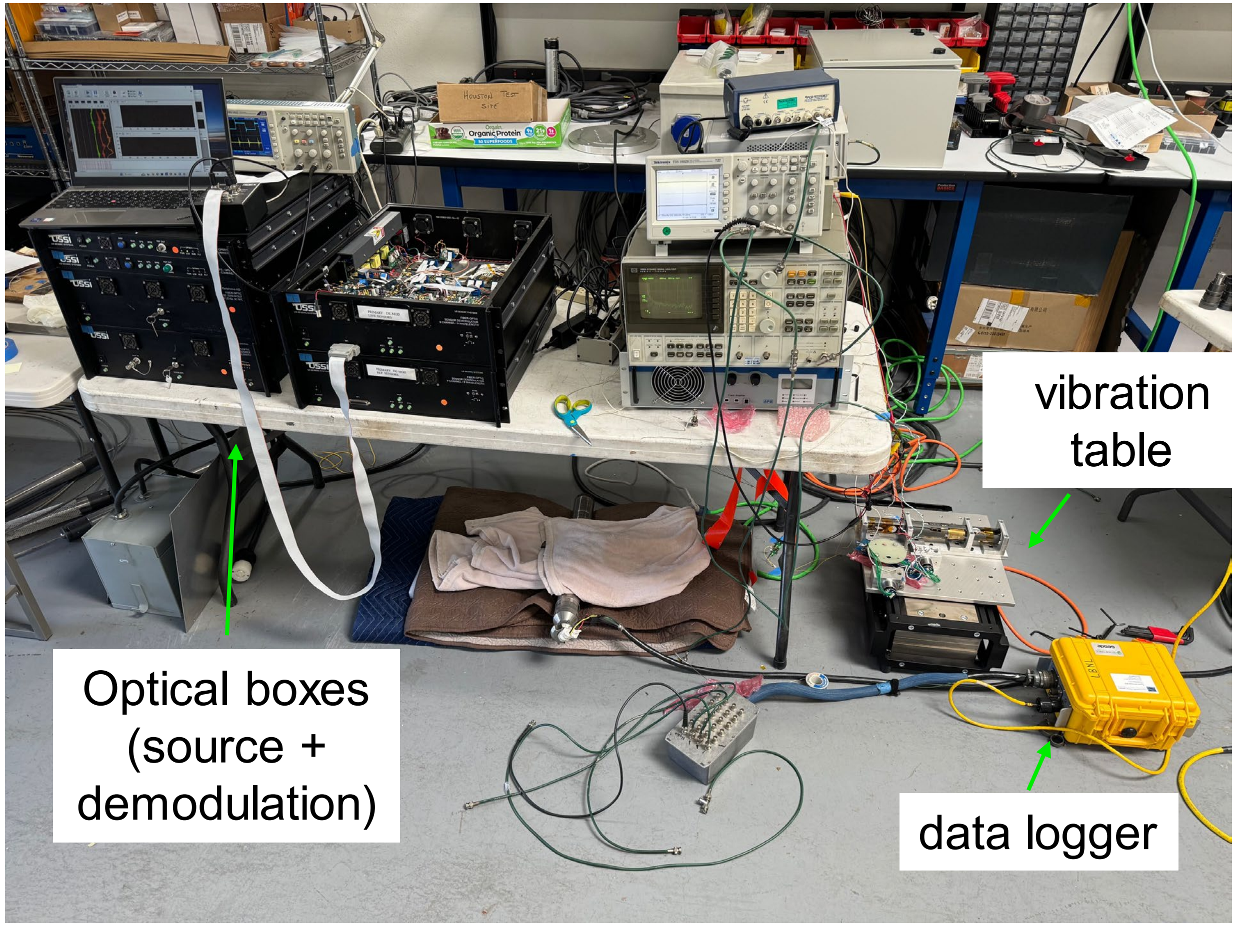
2. Refined/benchmarked seismometers

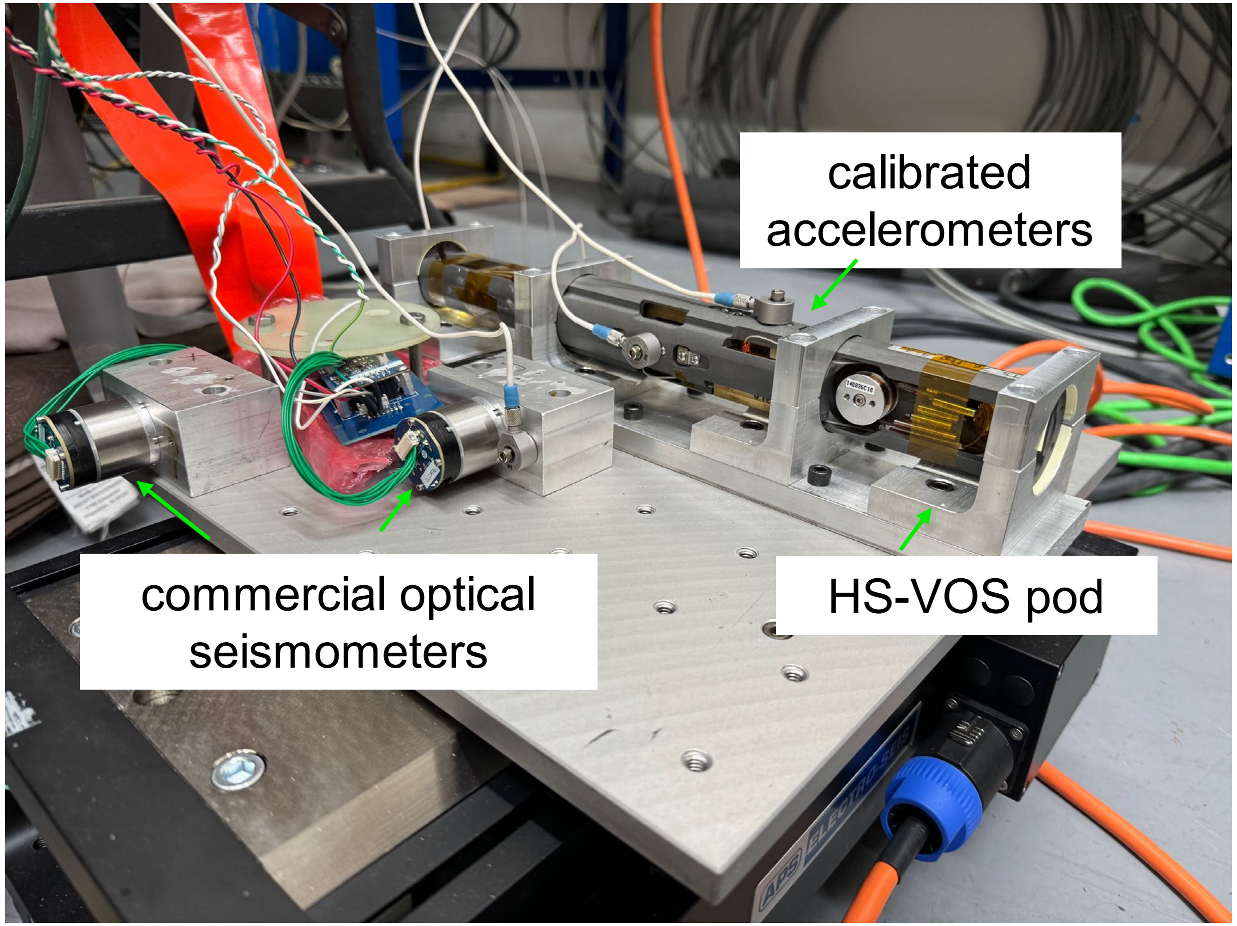
- Sensitive?
- Stable?
- Vector fidelity?

3. Analyzed legacy seismic data

Calibration of the sensors sensitivity

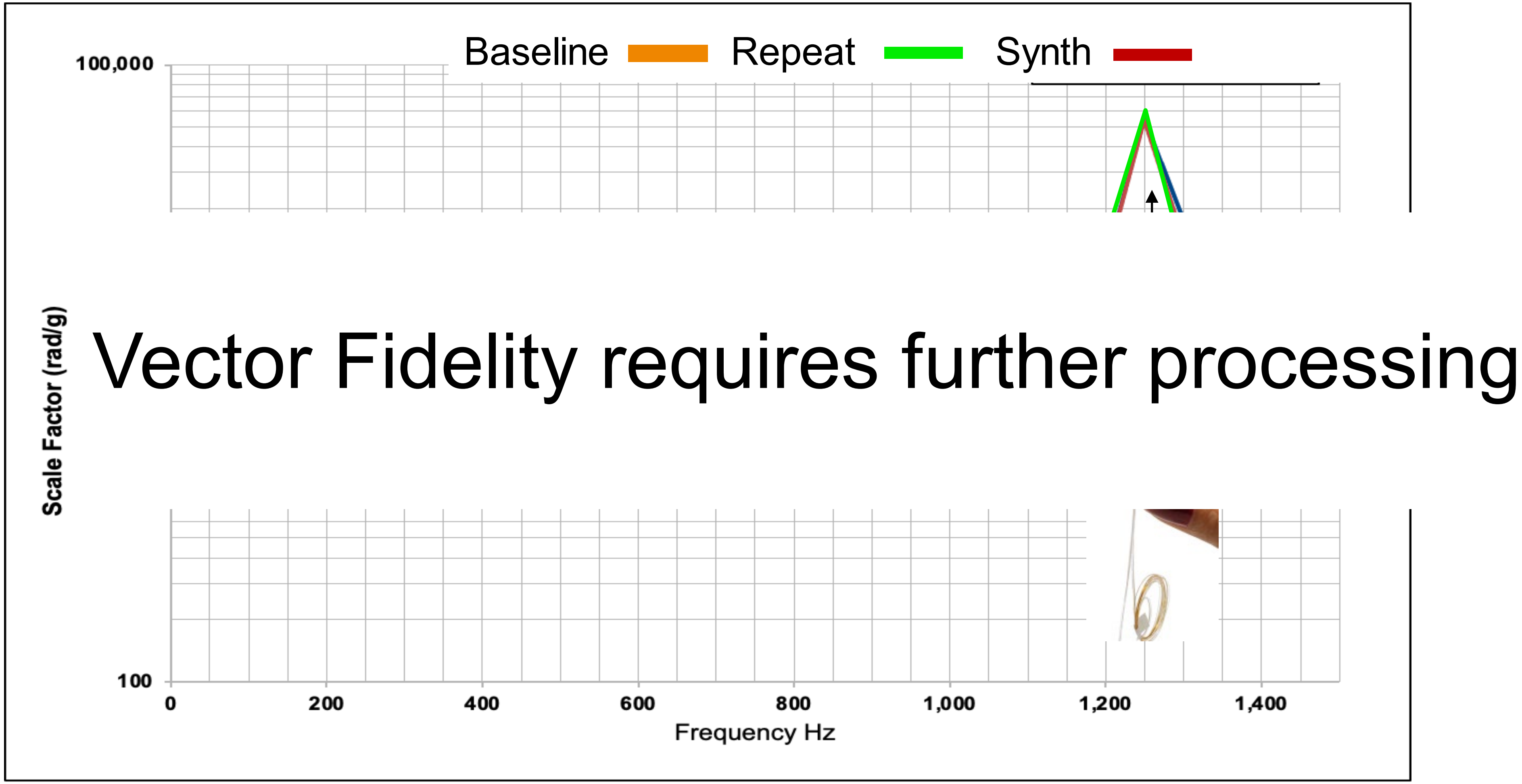
Vibration calibration system and benchmarking





Sensitivity and Stability of the X-component

Low noise; High sensitivity; Great repeatability; Vector fidelity underway



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Accomplished tasks

1. Prepared for the field deployment

2. Refined/benchmarked seismometers

3. Analyzed legacy seismic data

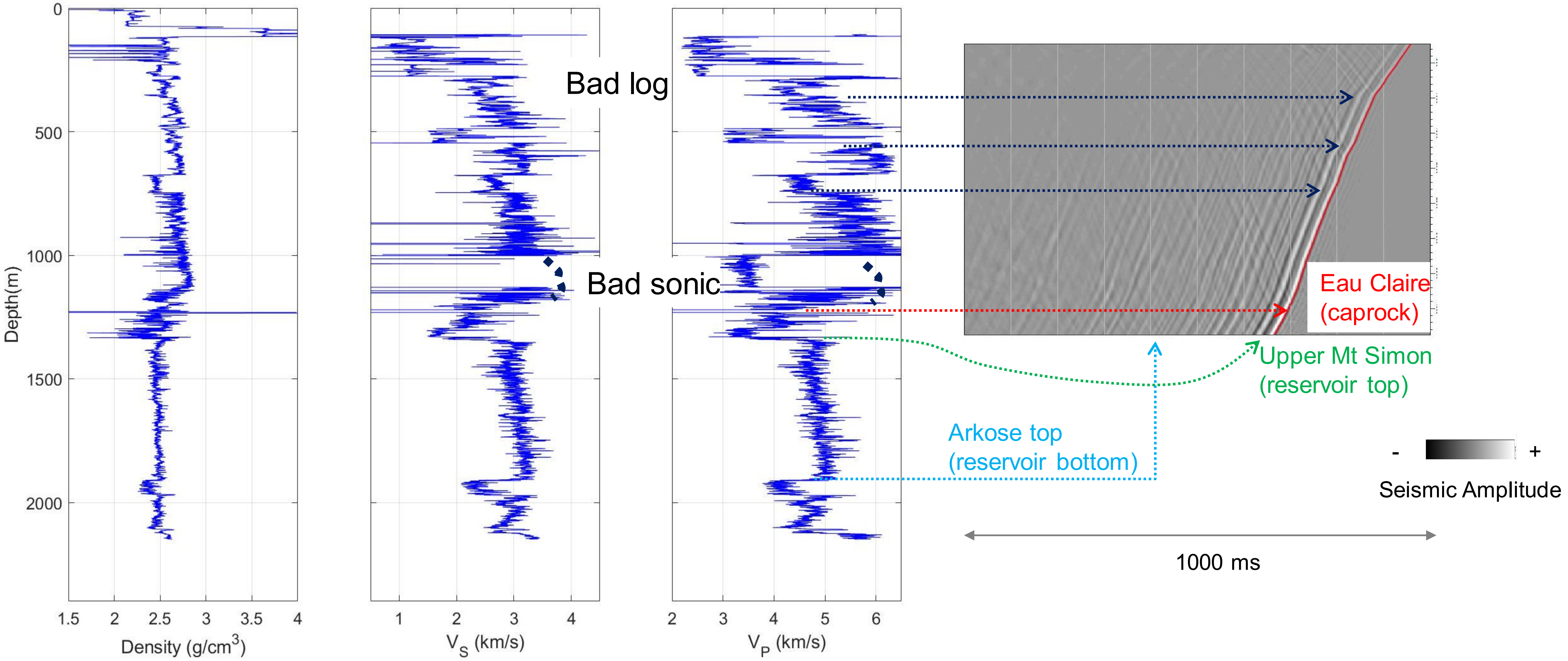
Signal strength

Near-surface effect

Clean-up the noise?

Zero-offset VSP: strength of the target reflections

We can see the injection interval close to it (at 1200 m)...with 32 stacked shots



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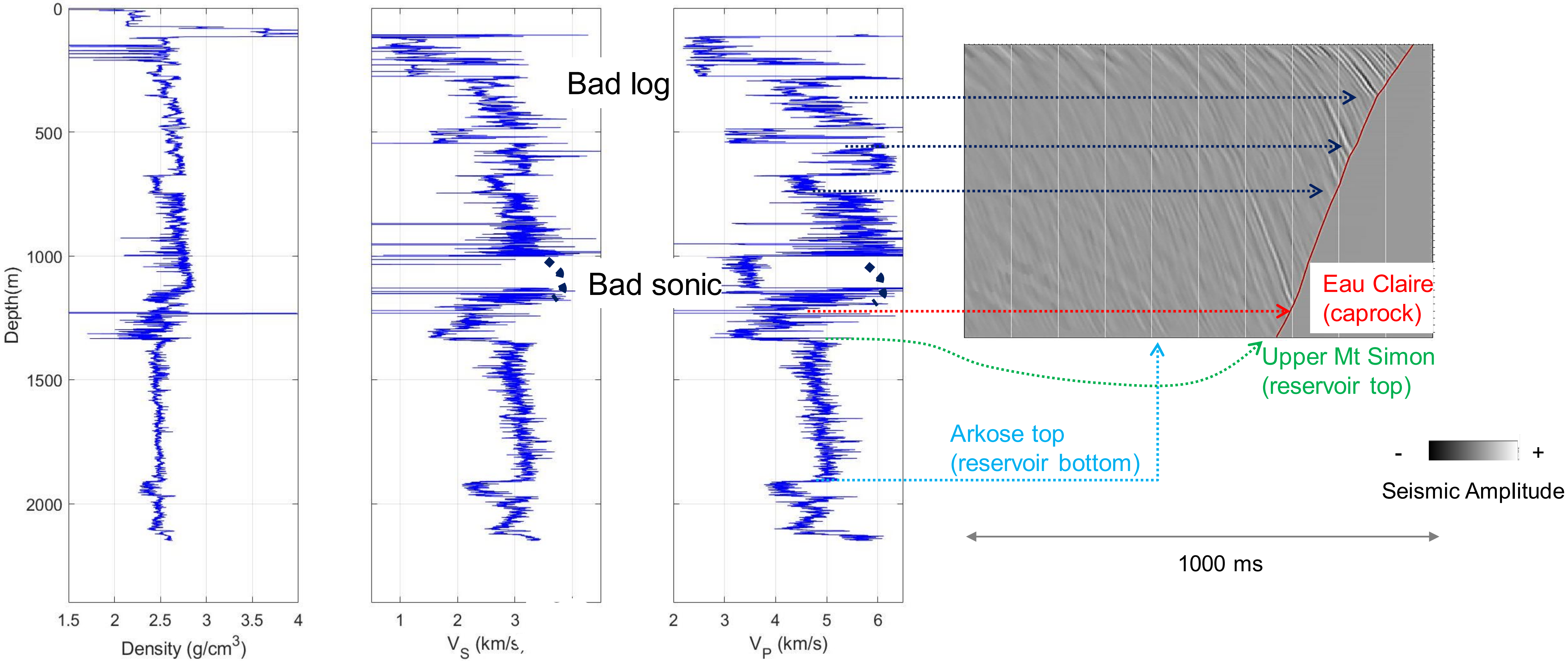
Zero-offset VSP: strength of the target reflections

We can clean the wavefield to see the injection interval close at 200 m



Zero-offset VSP: strength of the target reflections

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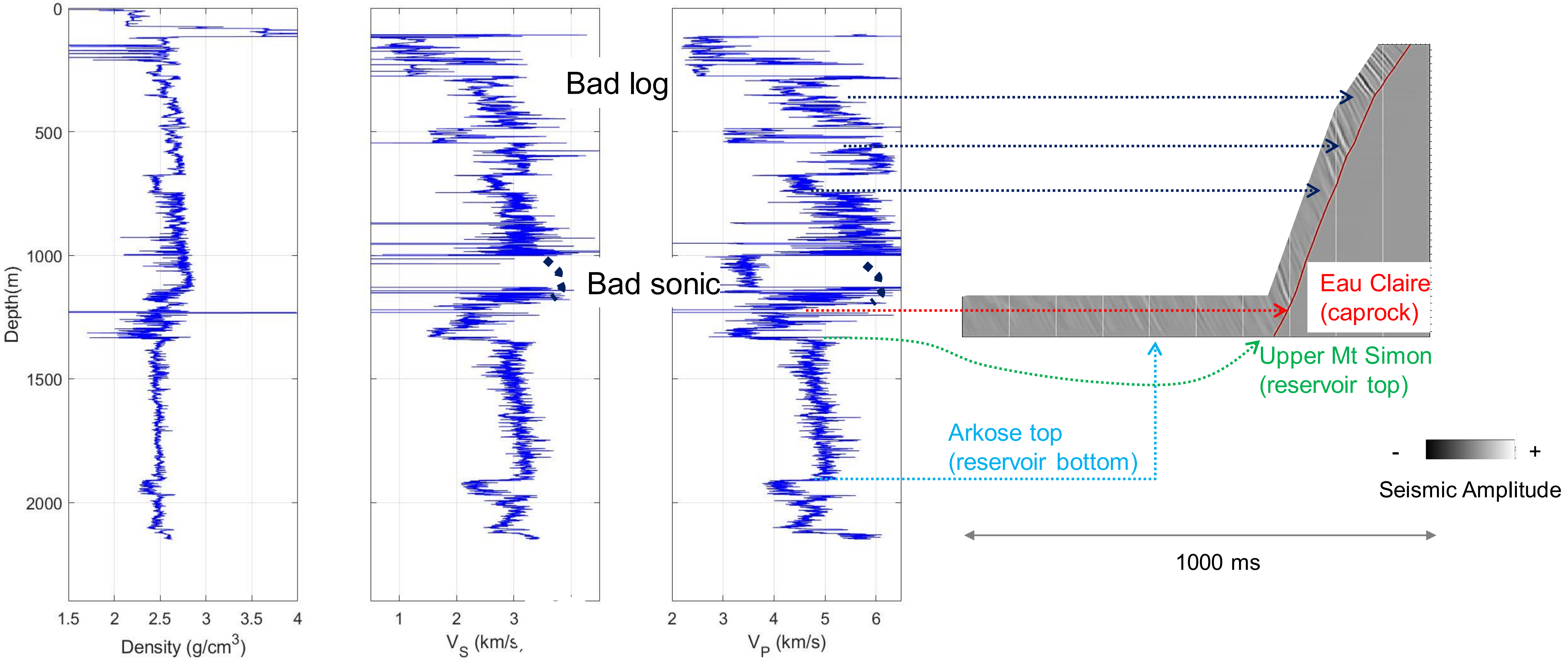
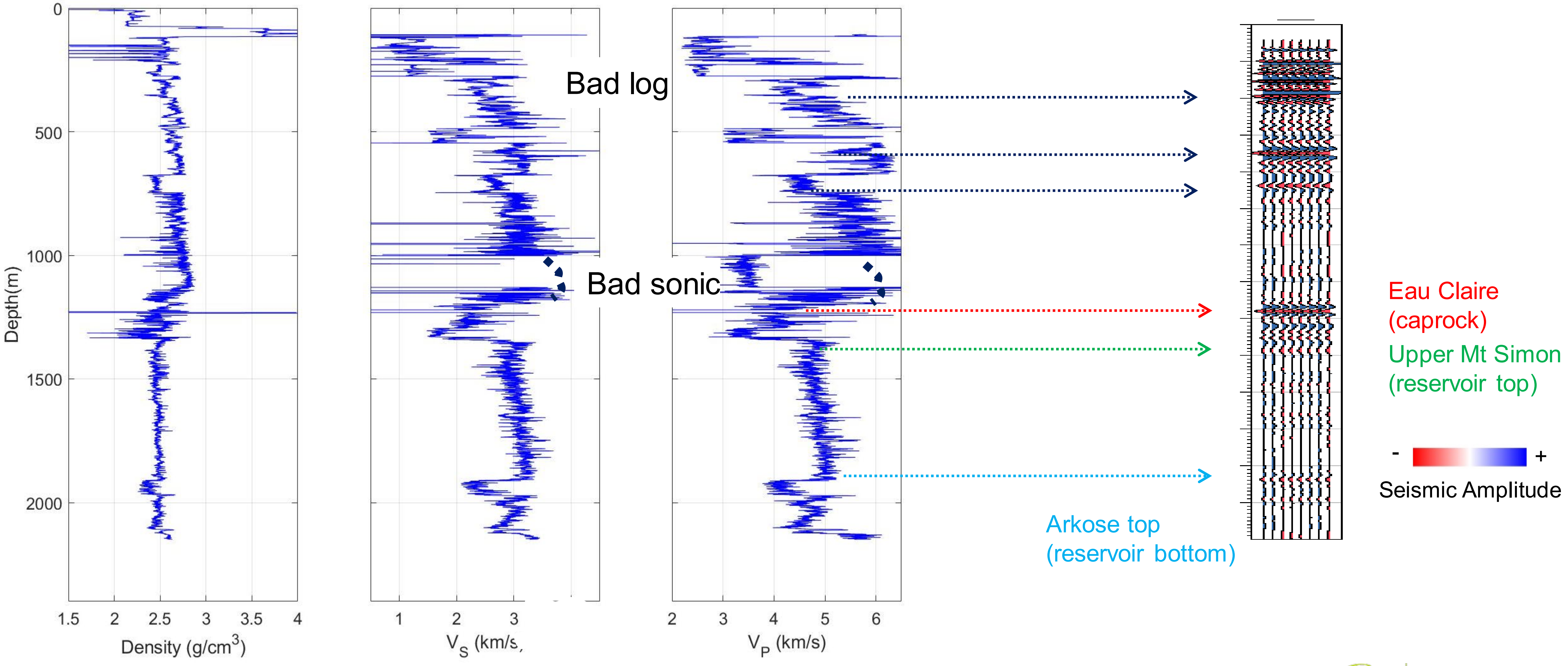


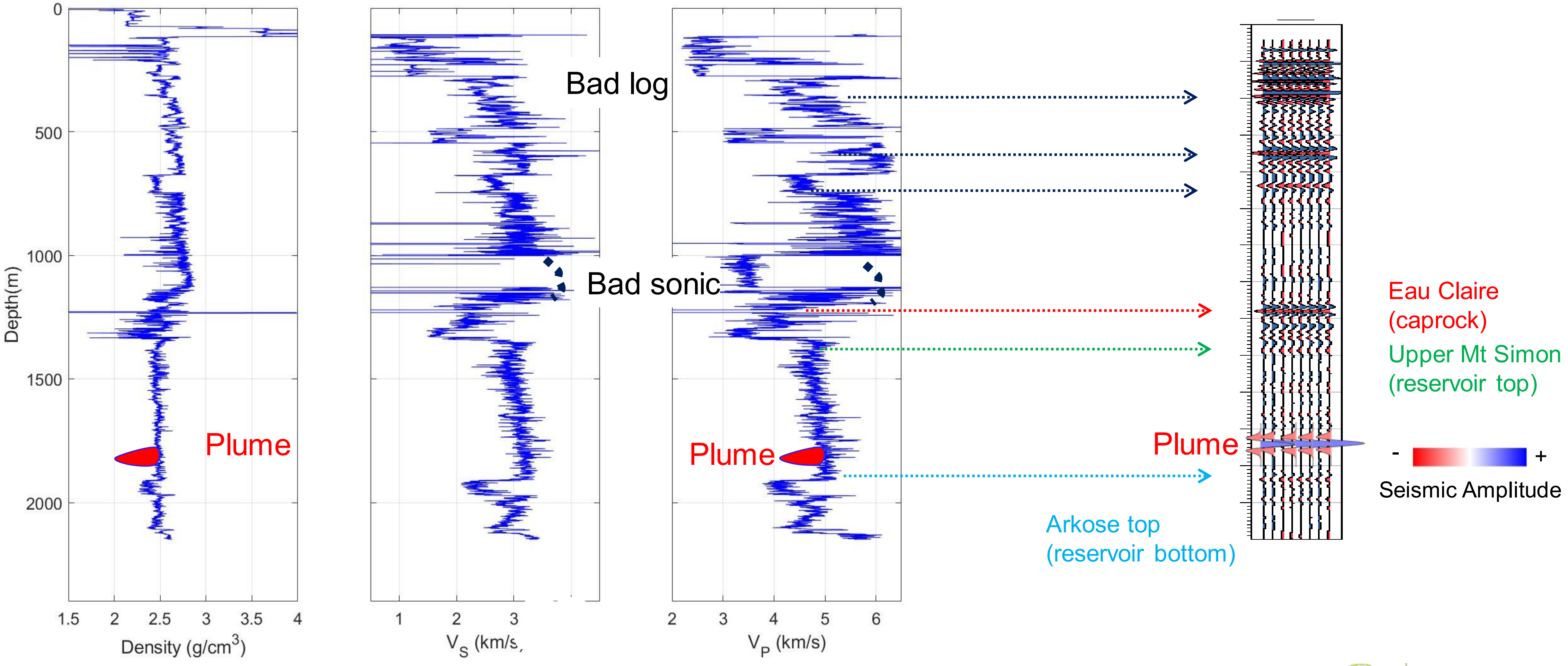
Zero-offset VSP: strength of the target reflections

A simple corridor stack can track the seismic contrasts in the injection interval



Zero-offset VSP: plume detectability

A simple corridor stack can track the reflections from plume (or slow-downs)

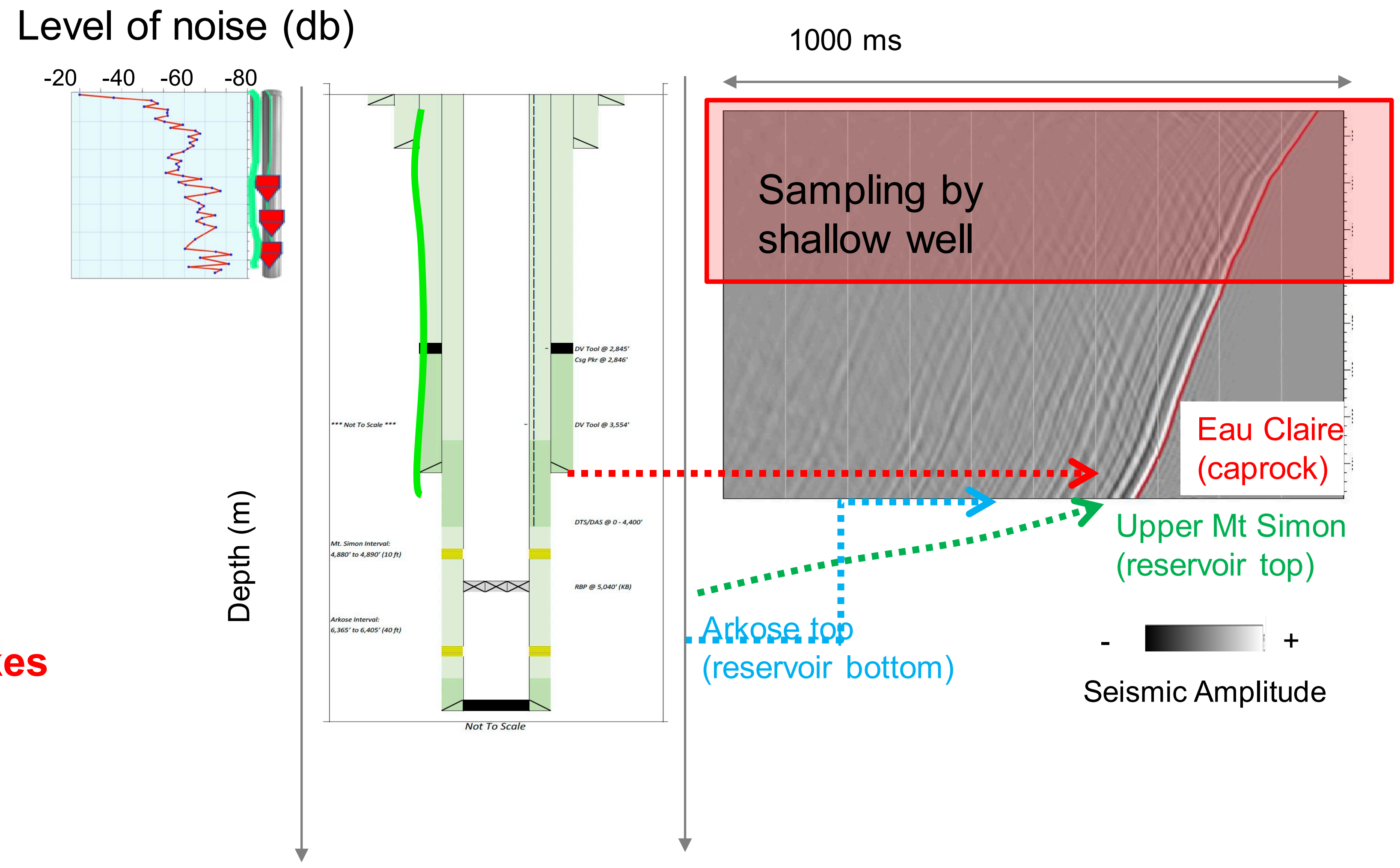


Zero-offset VSP: the use of micro-hole VSP

Shallow wells still have…high SNR + higher repeatability + Wavefield separation

Wavefield is limited, but we can:

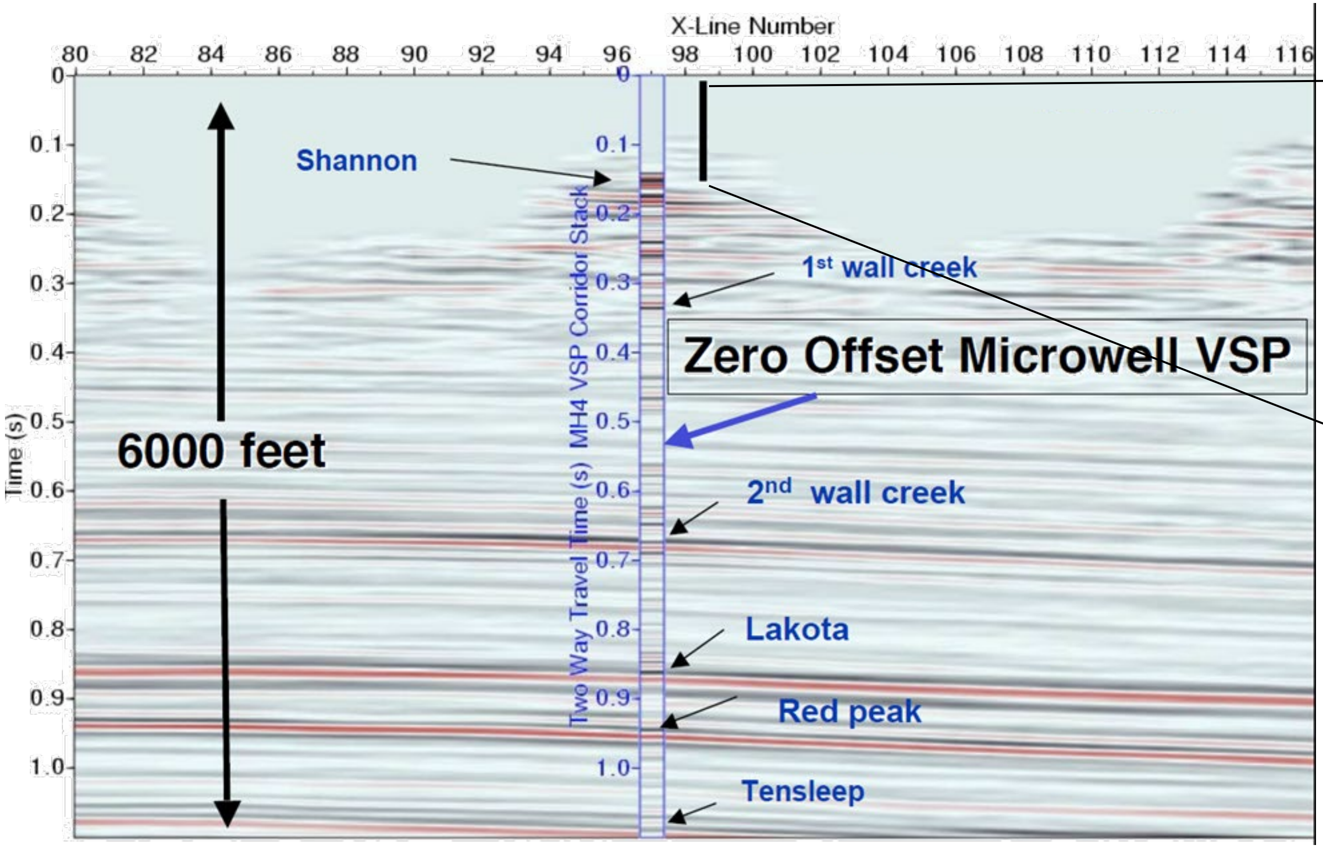
- Separate wavefields
- Filter by polarizations
- Train on the deeper well
- **Sufficient detection coverage**
- **Higher-sensitivity to earthquakes**

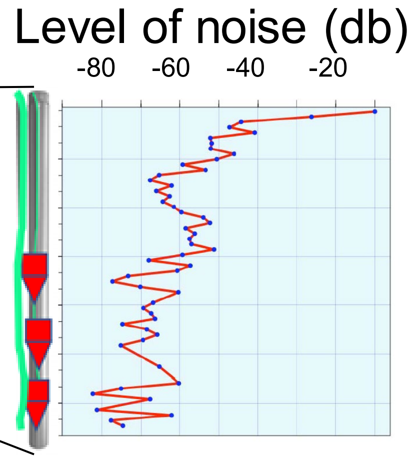


Zero-offset VSP: the use of micro-hole VSP

Case study in West Texas: Majer, Daley et al. 2008

150 m deep well images the entire section





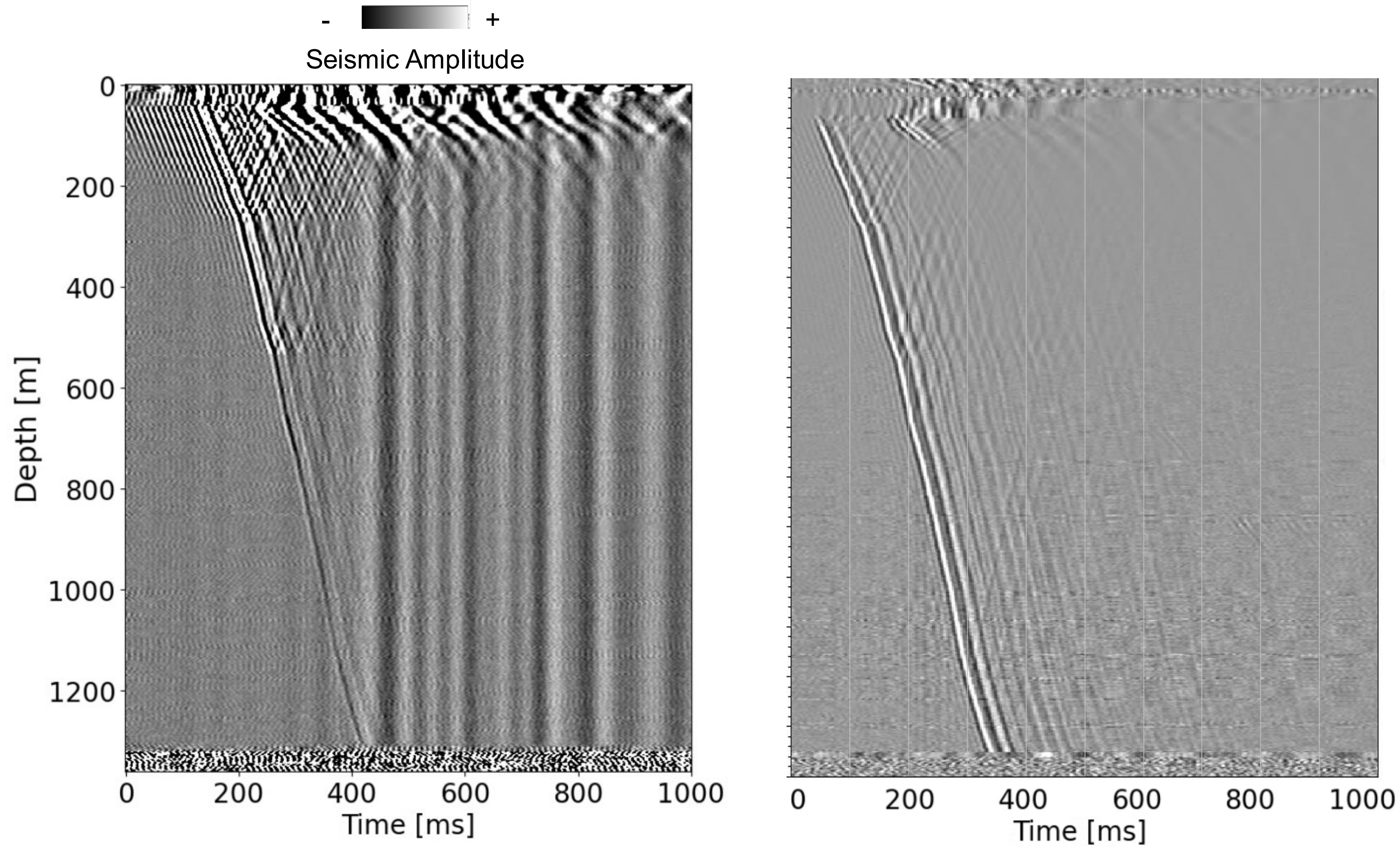
Illumination of micro-VSP: legacy DAS walk-away VSP

0. Might significantly increase the illumination

1. Signal-to-noise is too bad…

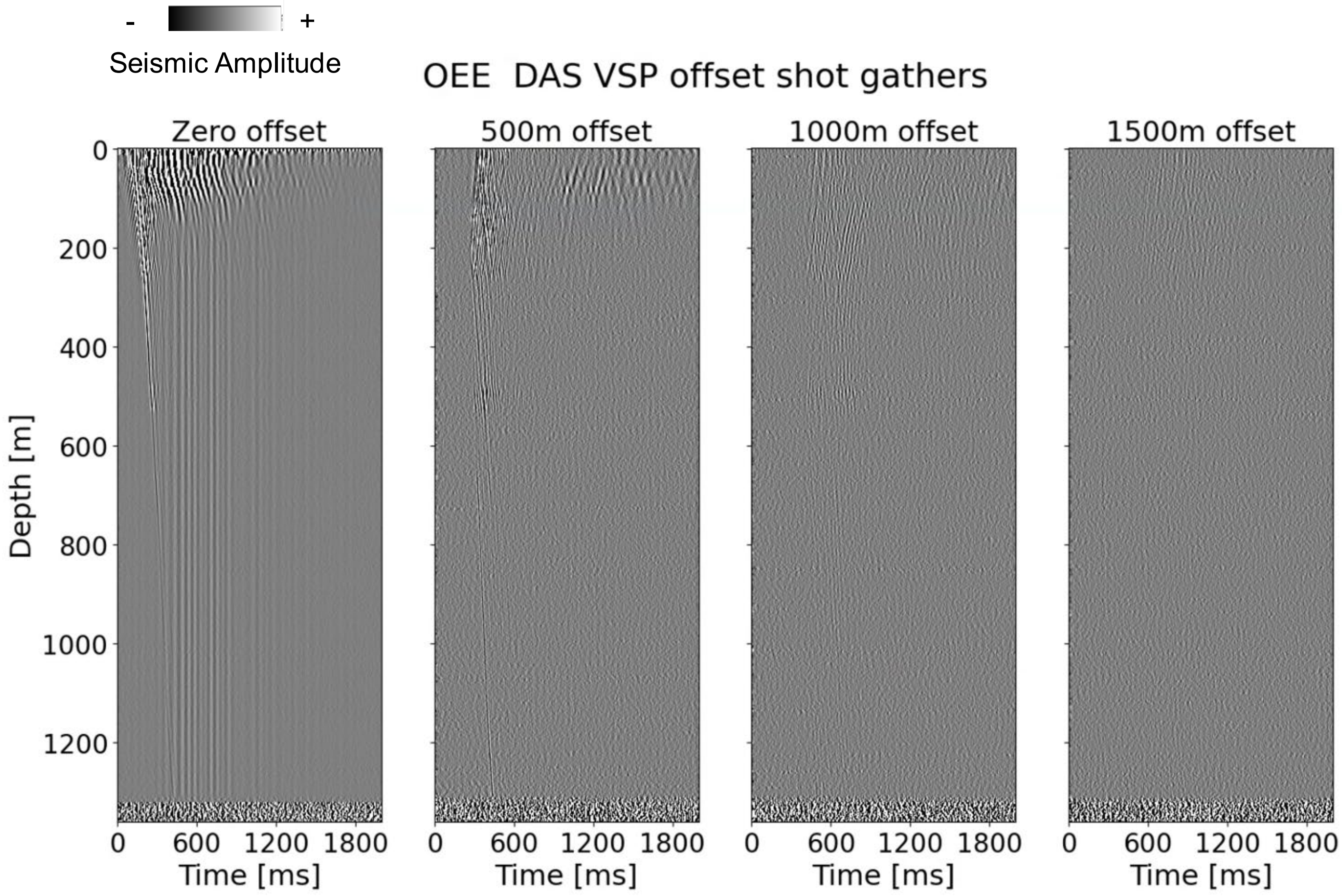
Non-triggered VSP data has a much worse signal-to-noise ratio

Compared to zero-offset VSP (32 shots stacked) the piggy-backed data is useless



Non-triggered VSP data has a much worse signal-to-noise ratio

With increased offset the piggy-backed seismic data is useless



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Earthquake monitoring: legacy passive seismic data analysis

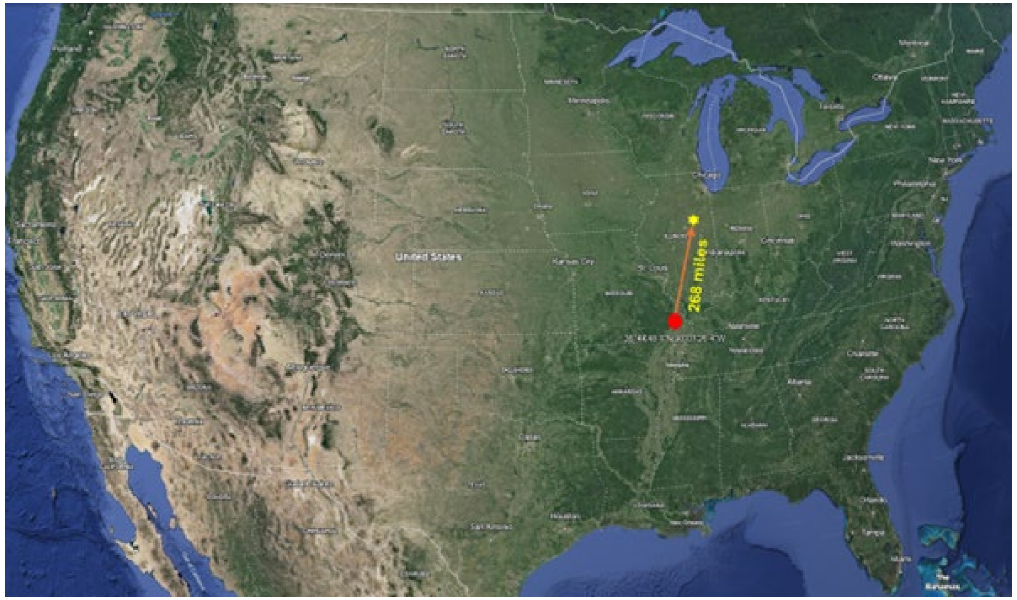
0. Basin-wide seismicity in the basement

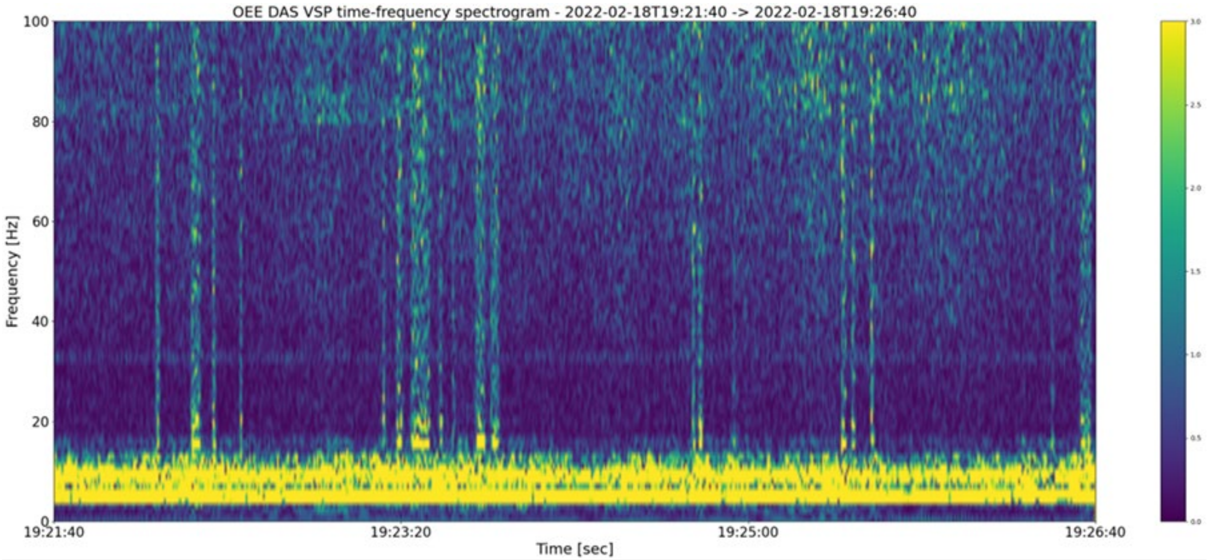
1. Signal-to-noise is too bad…

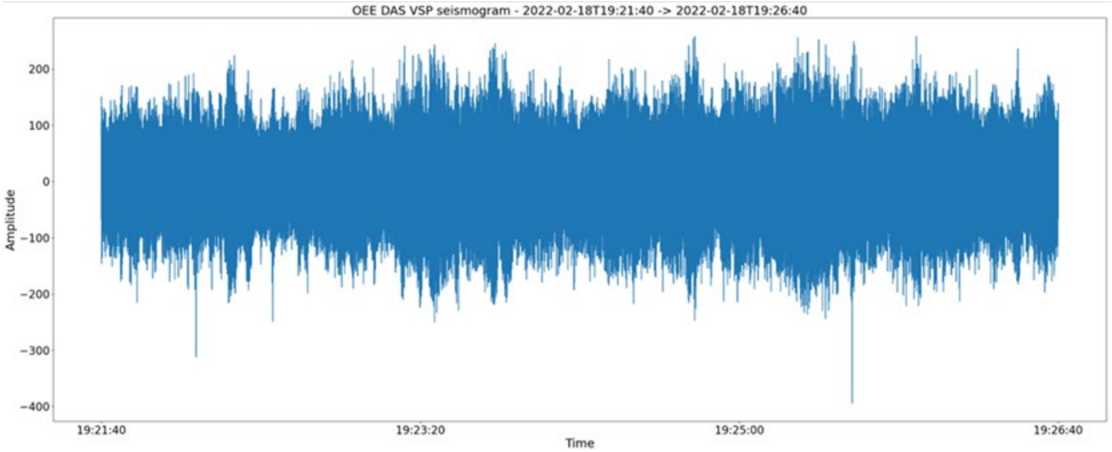
The main challenge

One of the shallow seismic boreholes requires a new access road…delay 5 months

Missouri, M_L2.3, 268 miles



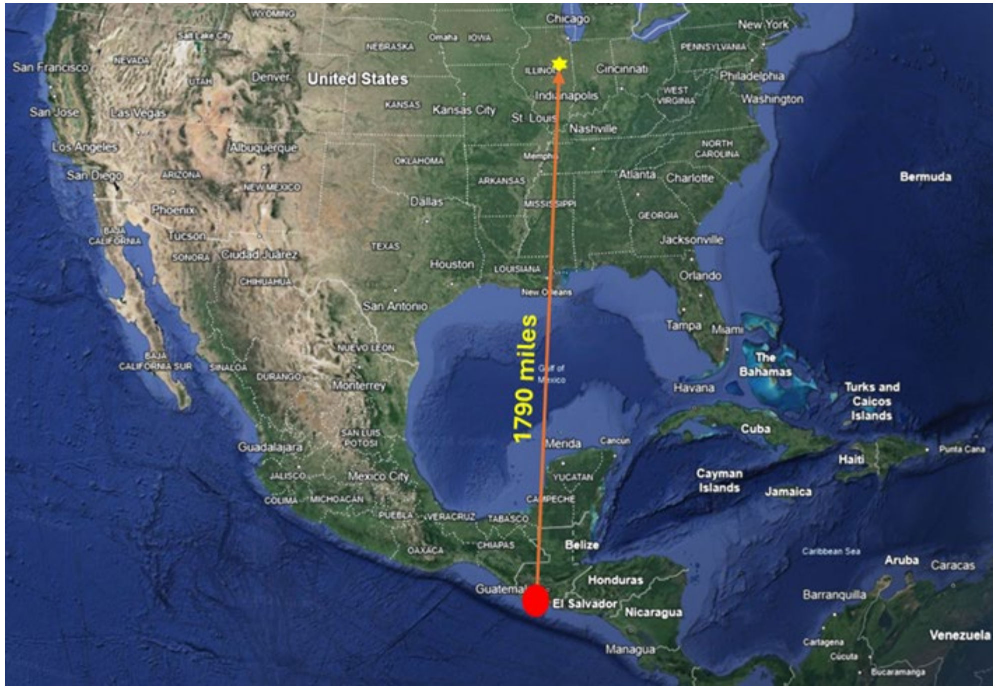


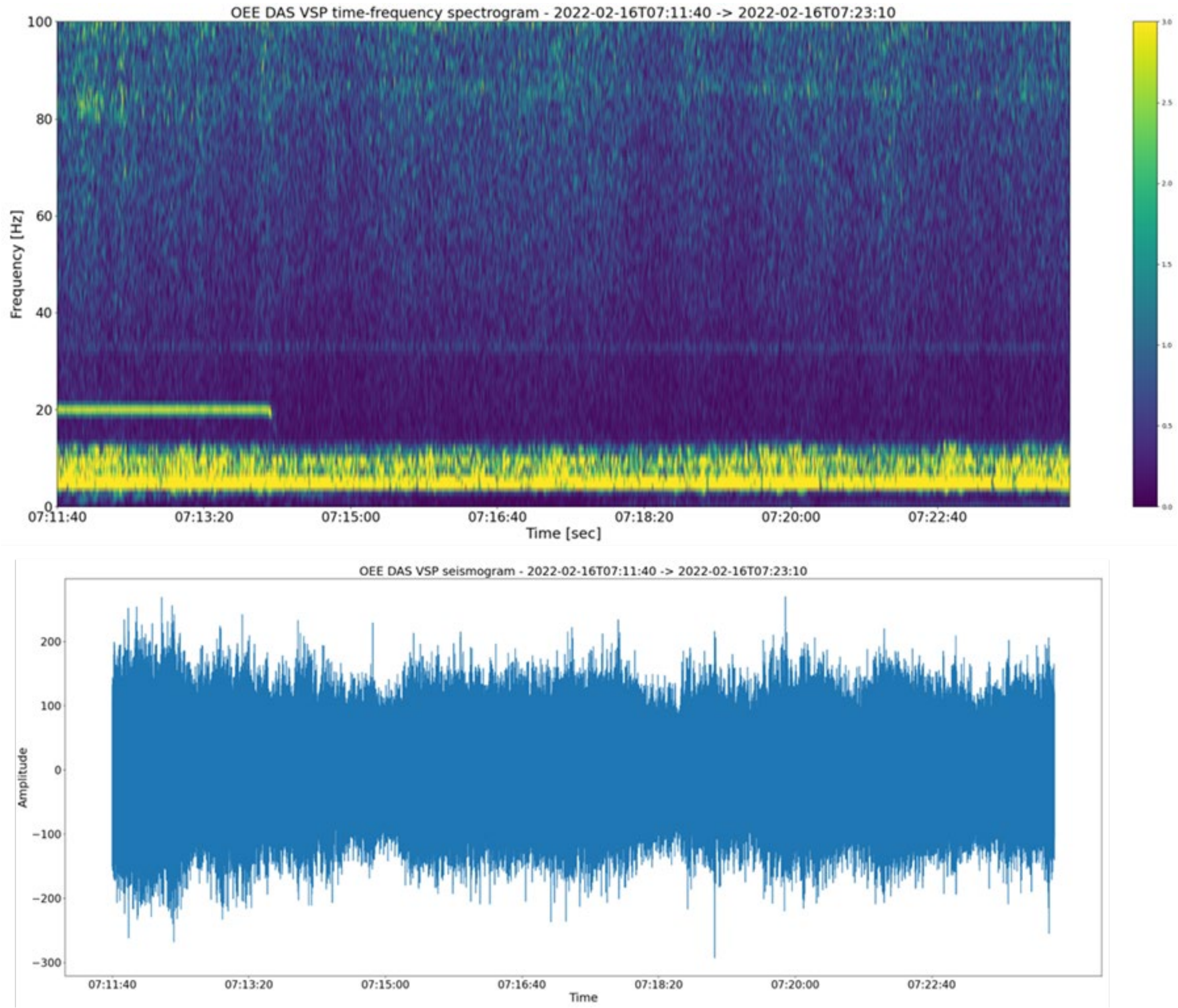


The main challenge

One of the shallow seismic boreholes requires a new access road…delay 5 months

Guatemala, M6.2, 1790 miles





Future work

Full-on field test at the One Earth Sequestration site (Carbon SAFE III)

- Drill and instrument the shallow boreholes in August
- DAS (enhanced) + 3C optical seismometers in the deep well
- Acquire walk-away vibroseis VSP
- Use the signal and noise for a synthetic monitorability study
- Testbed for the next phase of CCSMR:
  - CSEM
  - SOV
  - rock physics analysis of Mt Simon samples

Project Summary

Full-on field test at the One Earth Sequestration site (Carbon SAFE III)

- Preparation to the seismic surveying is completed:
  - The equipment tested
  - Data recording/streaming is set up
  - Drillers and other field contractors are subcontracted

- Feasibility Study for the micro-hole VSP is underway
  - Legacy DAS VSP is of questionable quality
  - But dedicated zero-offset VSP is high quality

- HS-VOS system is operational as confirmed by:
  - Tests in the workshop
  - Deployment in the shallow boreholes

Potential Synergies

- Other Carbon Storage and monitoring projects in the US and abroad
  - Dry Fork CarbonSAFE Phase III (Wyoming)?
- Passive/active monitoring using shallow boreholes:
  - Full proposal submitted to DOE for a long-term monitoring at a commercial storage site in the Bay Area
- Induced seismicity monitoring and/or crosshole seismic at hot injection similar to CarbFIX 2 (Iceland)
  - Our 200C sondes are interchangeable with the 200C test sondes

Organization Chart

- **Lawrence Berkeley National Laboratory:**
  - Task PI, Data Lead: Stanislav Glubokovskikh
  - Field Lead: Michelle Robertson
  - Senior Engineer: Paul Cook
  - Seismic Postdoc: Bin Lyu
- **Illinois State Geological Survey:**
  - Illinois Storage Corridor PI: Roland Okwen
  - POC: Carl Carman
- **One Earth Energy**
  - VP for Sequestration: Curt Blakley
- **GPUSA:**
  - Seismologist: Peter German
  - Optical Engineer: David Winslow

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 at an operational CarbonSAFE sites
  - Broader learnings from leveraged international research opportunities
  - Rapid transfer of knowledge to domestic programs