Microseismics from fiber-optic distributed acoustic sensing: the near-field strain signals and the guided waves

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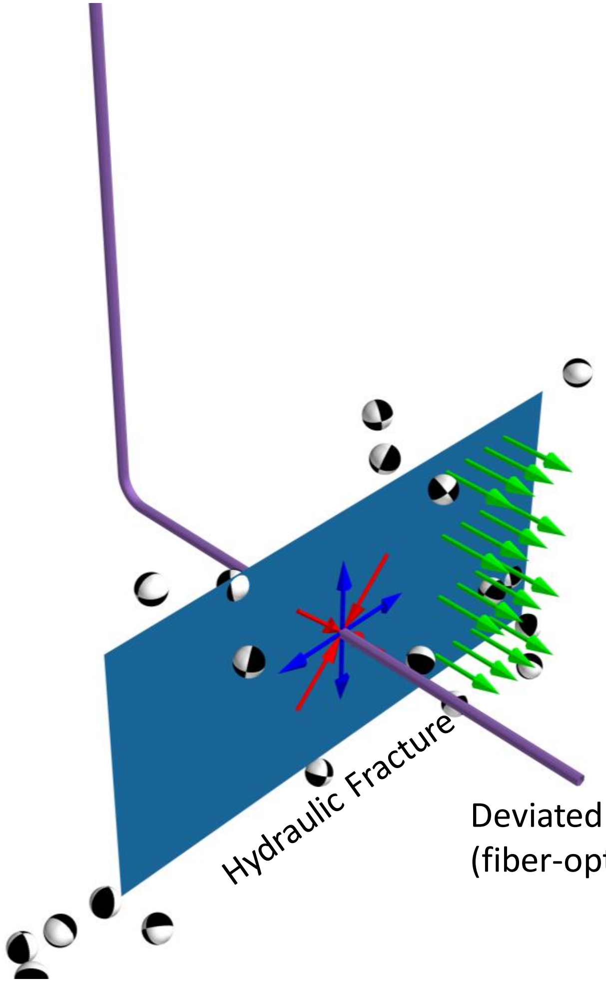
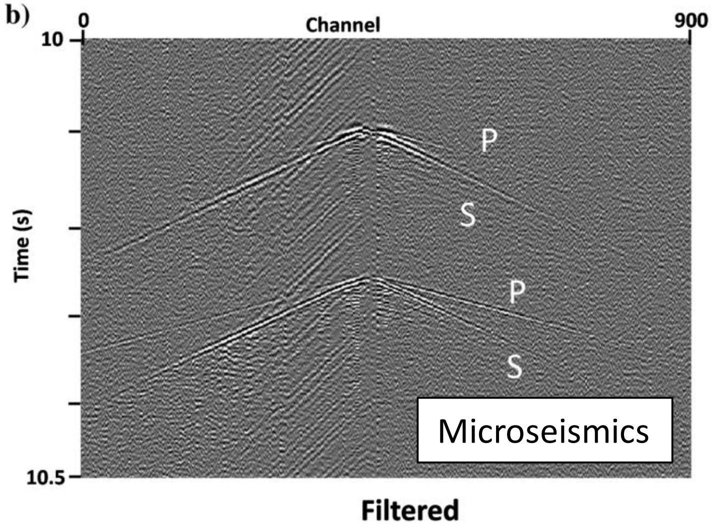
AGU DAS Workshop

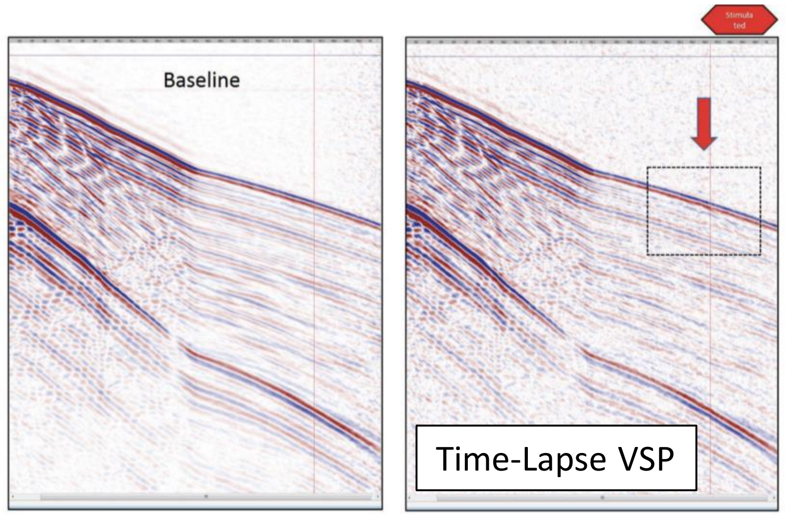
RESERVOIR CHARACTERIZATION PROJECT
COLORADO SCHOOL OF MINES

DAS in Hydraulic Fracturing

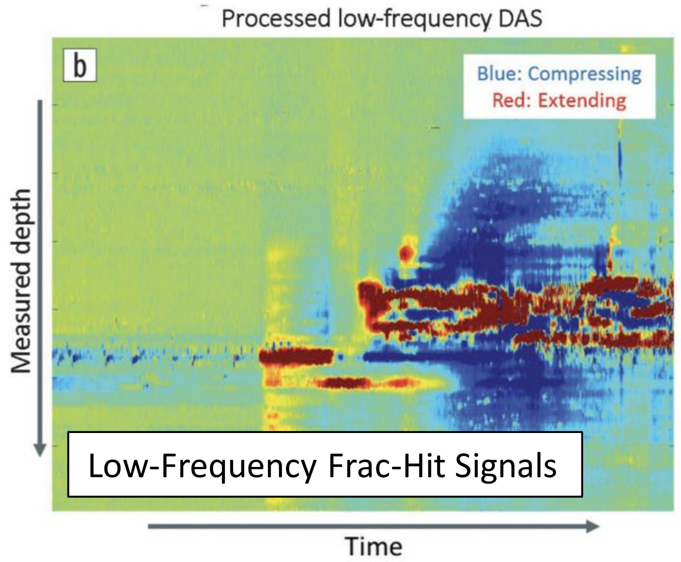




Karrenbach et al. (2019)



Byerley et al. (2018)



Jin and Roy (2017)

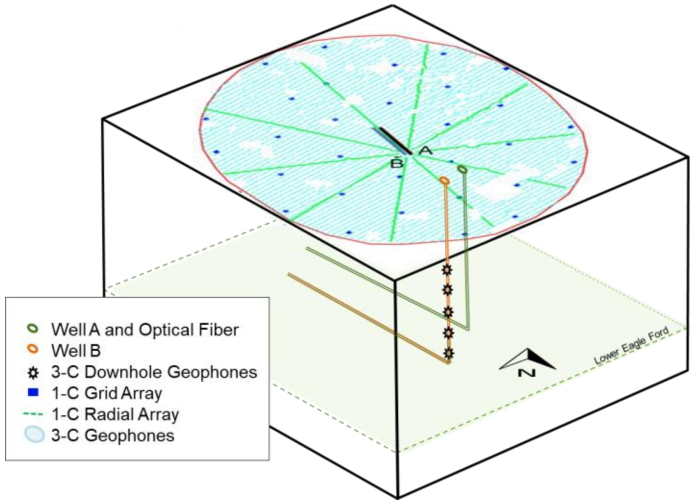
Overview

- Microseismic Guided Waves
  - Guided wave properties
  - Seismic inversion of guided wave dispersion curves*
  - Constraining microseismic event depth*
- Microseismic Near-Field Strain Signals
  - Analytic displacement of a moment tensor point source
  - Synthetic vs. field data*

***Eagle Ford project data provided by Devon Energy Corporation and Penn Virginia Corporation**

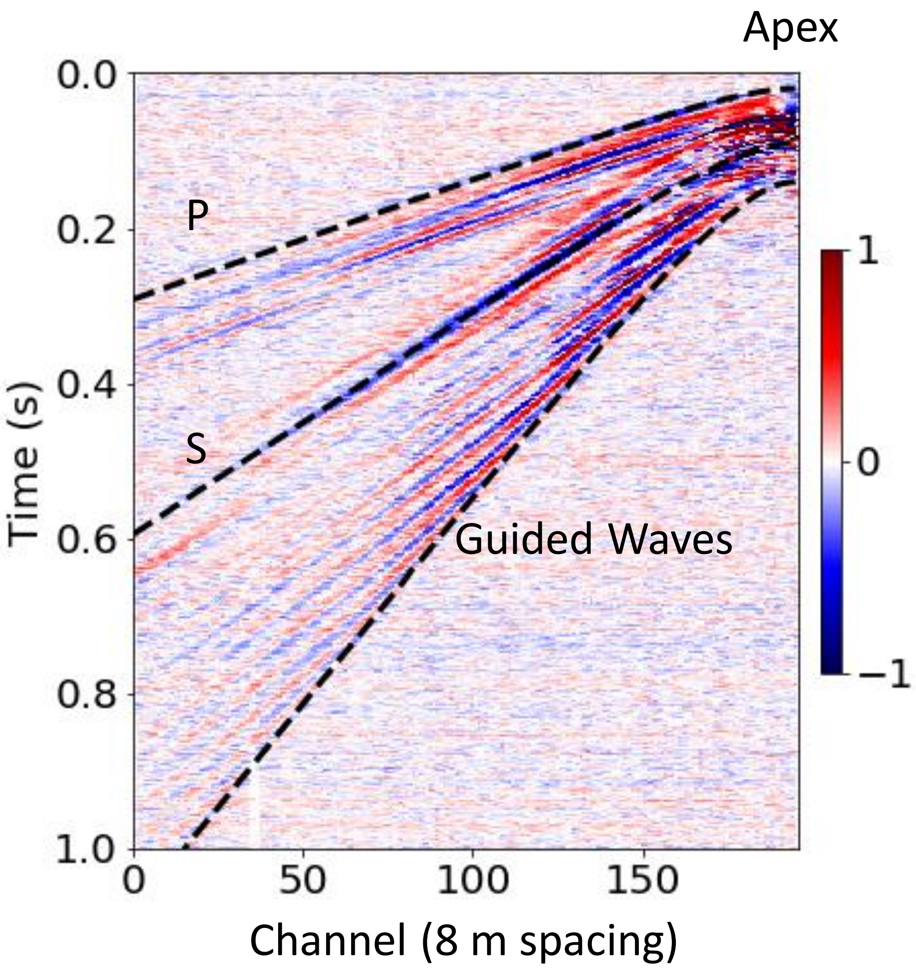
Microseismic Guided Waves

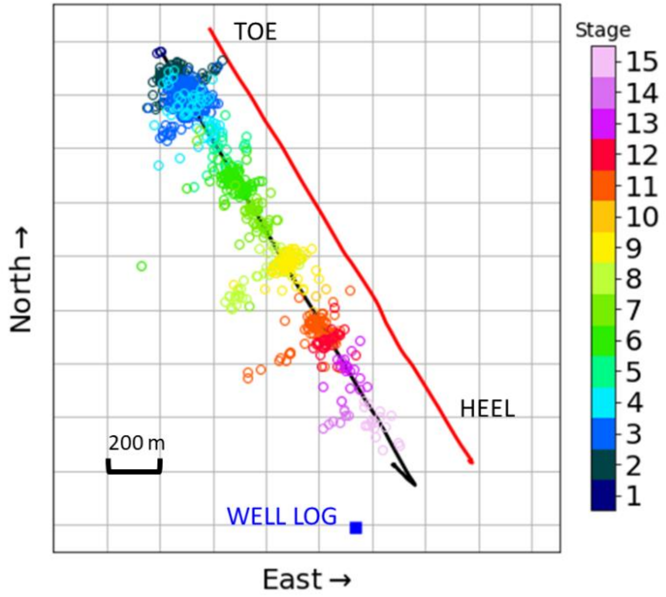
Microseismic Data



Fiber optic distributed acoustic sensing (DAS) in Well A

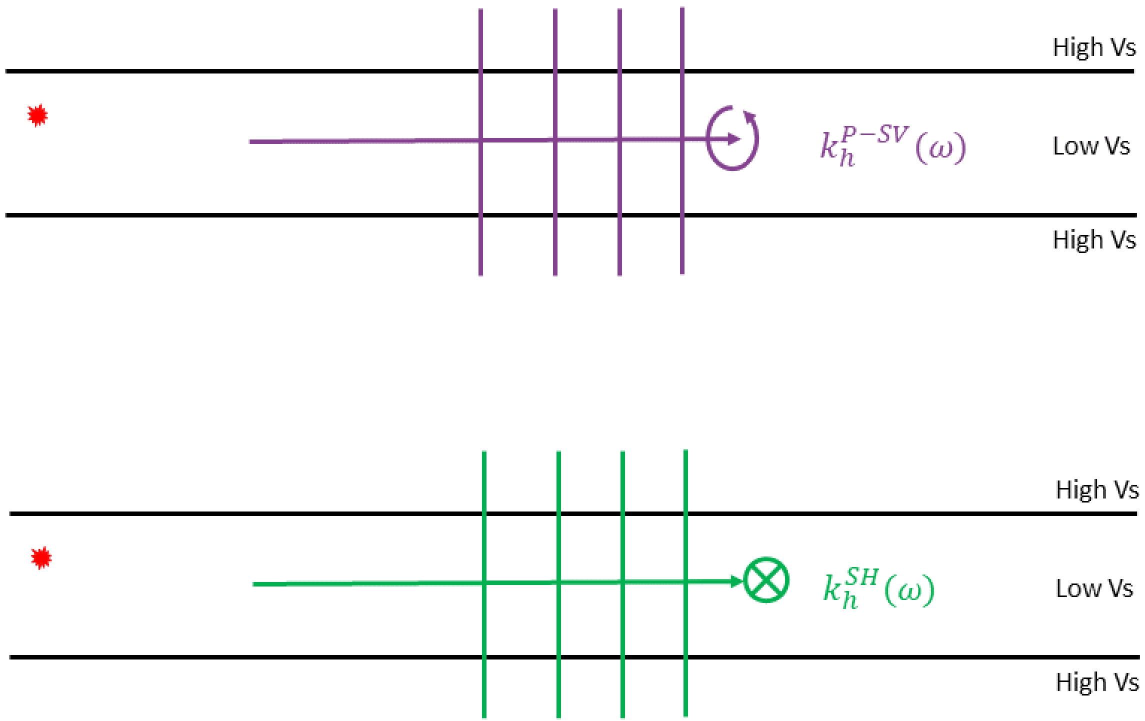
- 14 m gauge length
- 8 m channel spacing
- 2000 Hz sampling rate



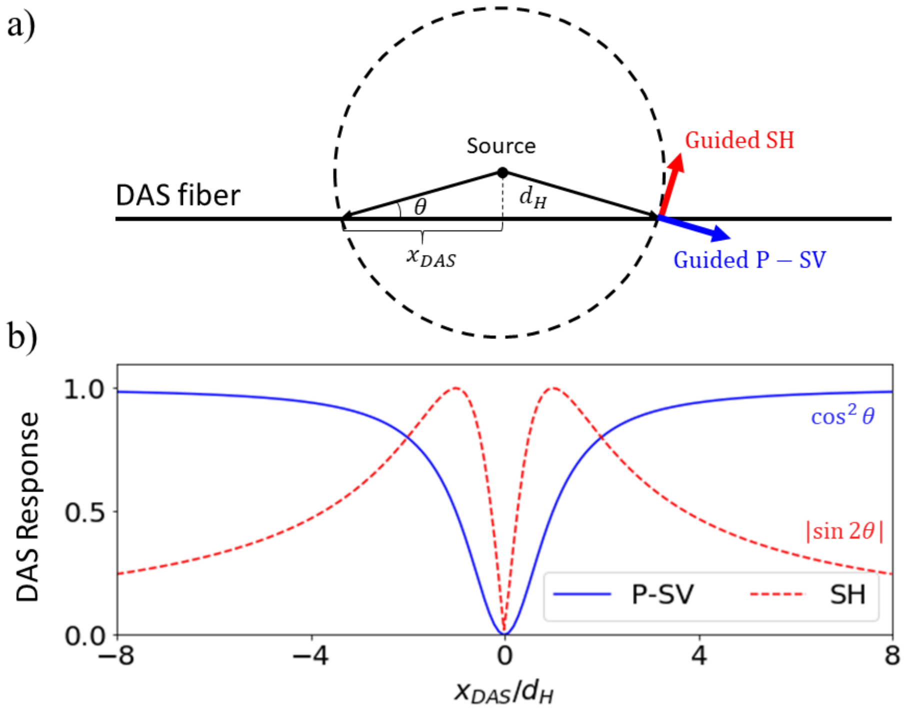


Guided Waves in 3D

Side view



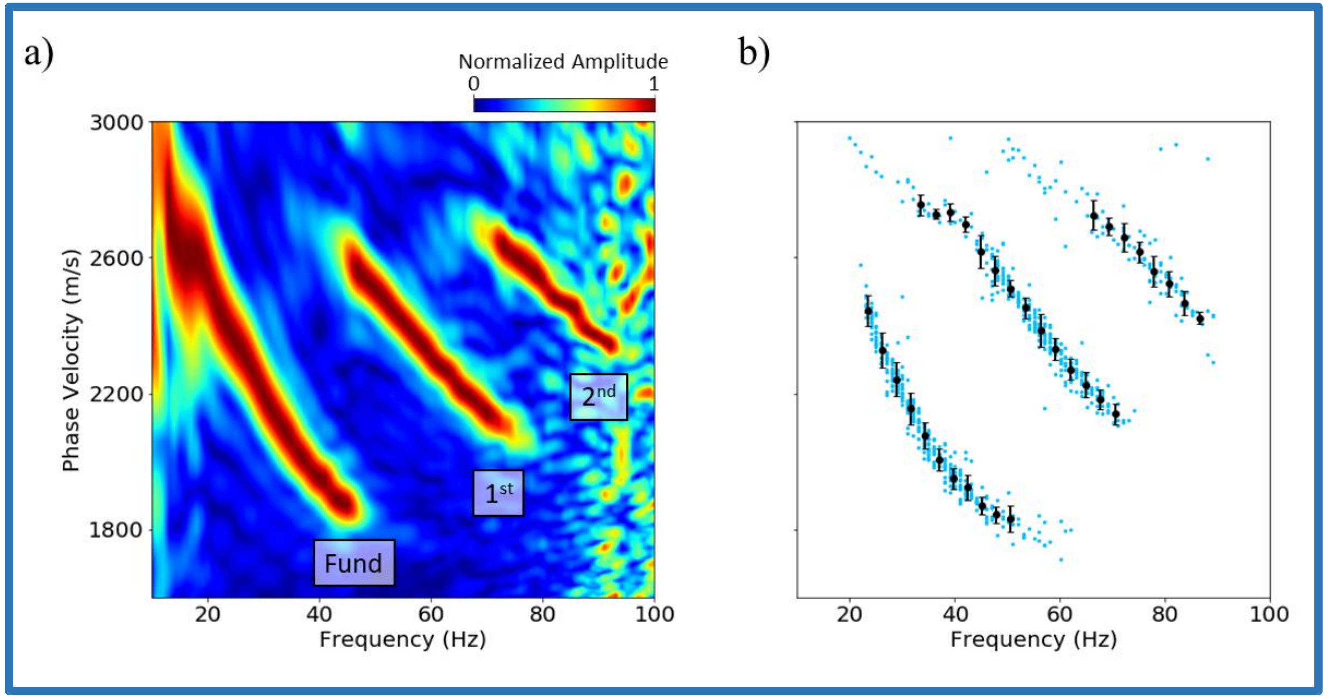
Plan view



Long offset channels -> Dominant guided P-SV waves

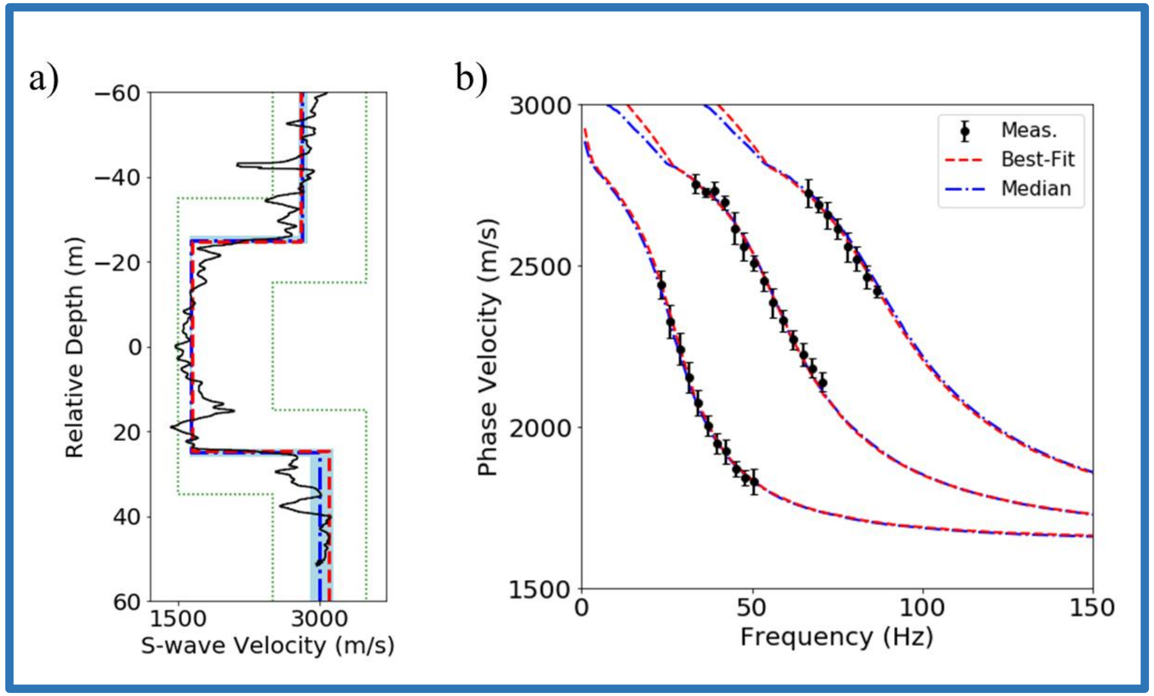
Application 1: Seismic Inversion

Measurement → Inversion



Dispersion Image

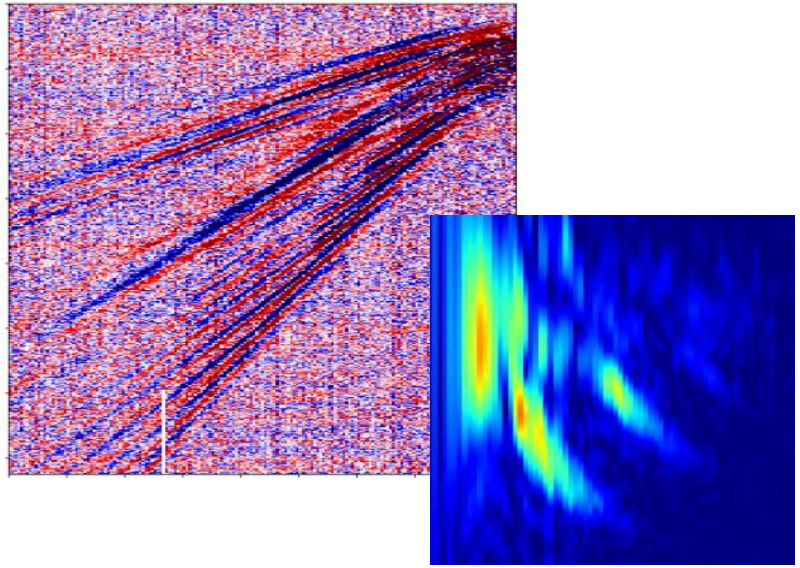
17 events with energetic guided wave signals

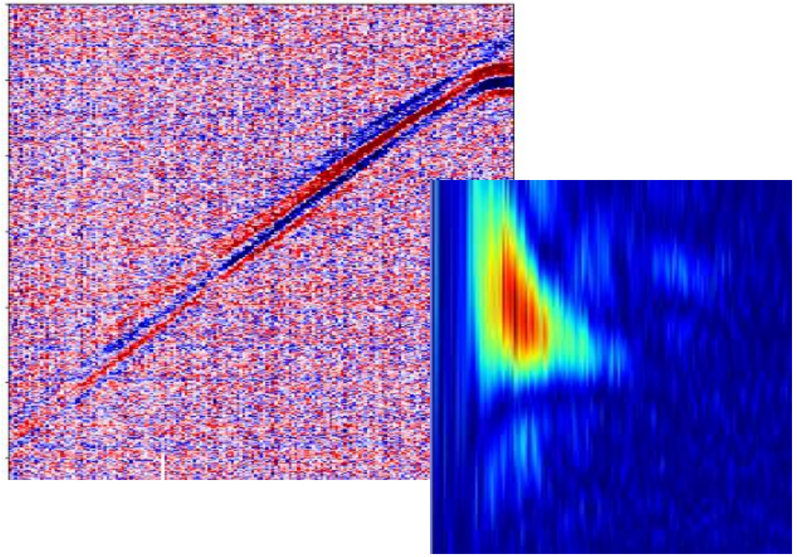


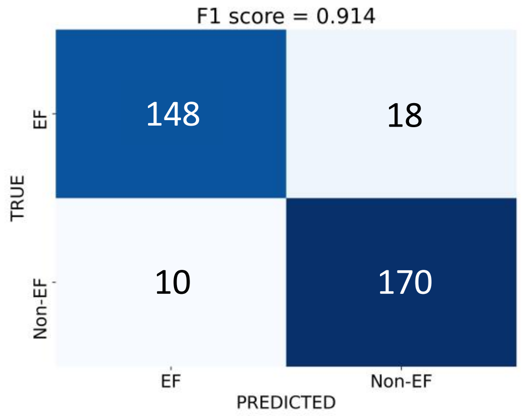
Inversion of guided P-SV with VTI
h = 50.1 m, V_{S0} = 1639 m/s, $\varepsilon - \delta > 0.2$

Luo et al., under review

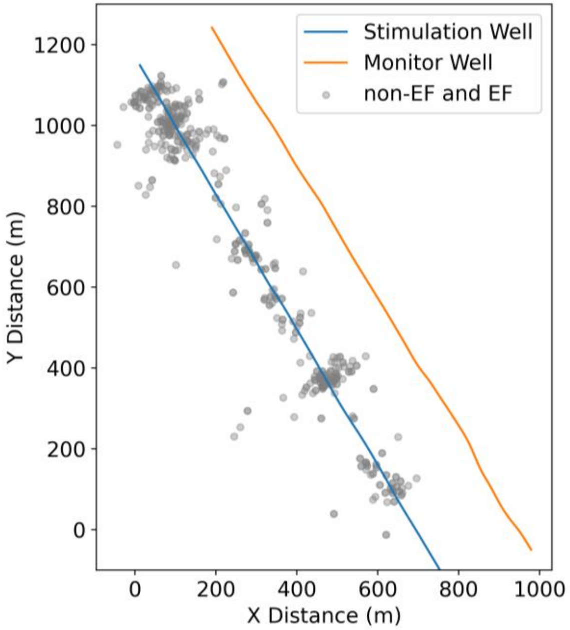
Application 2: Constraining Event Depth



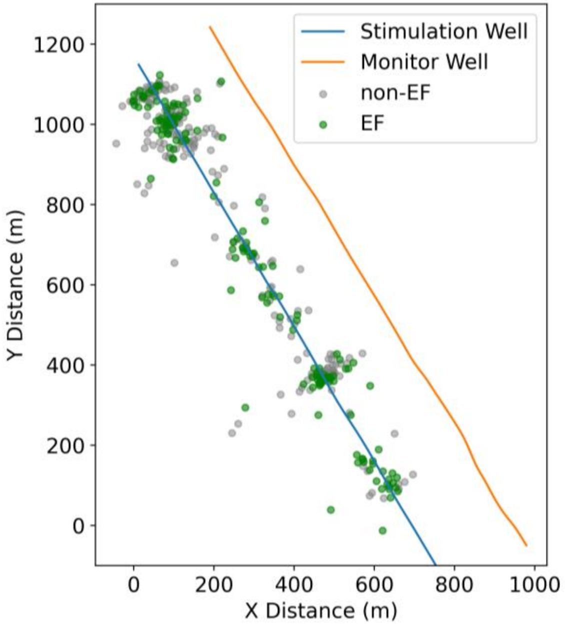




Huff et al. (2020)

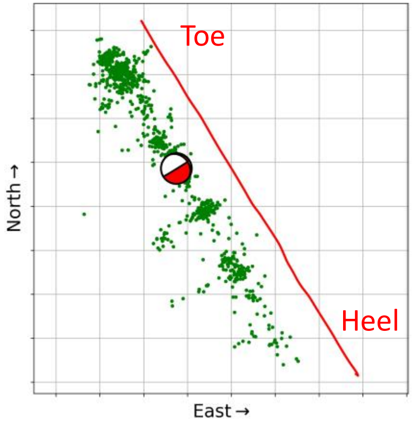


classification

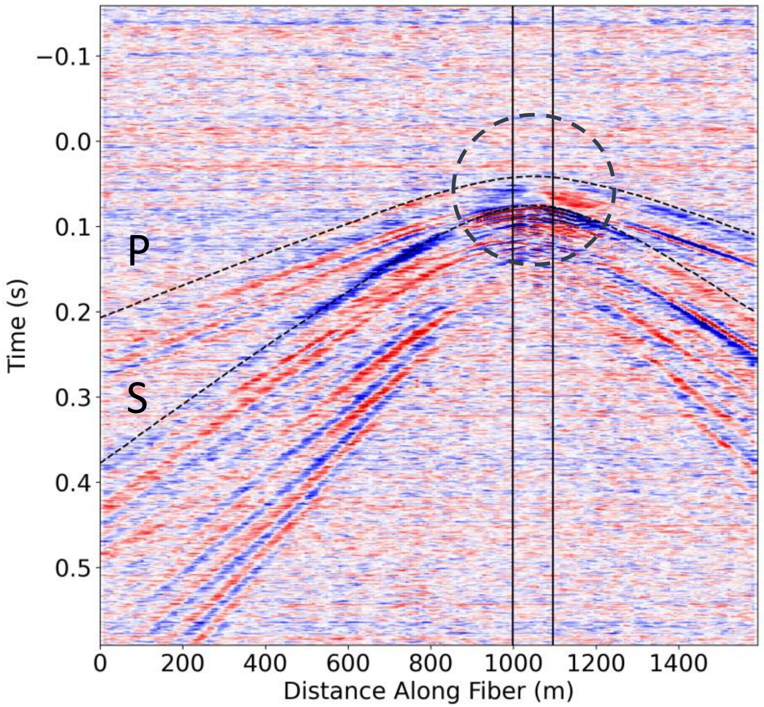


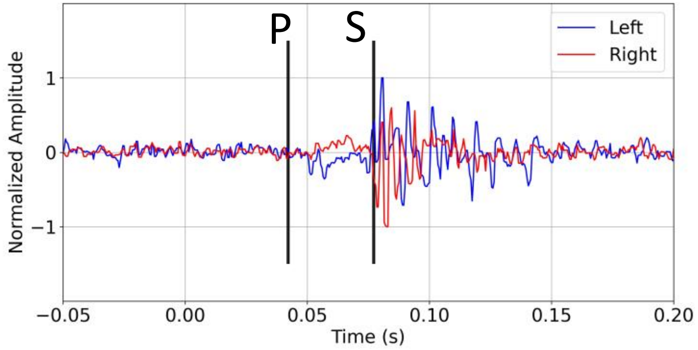
Microseismic Near-Field Strain

Observation

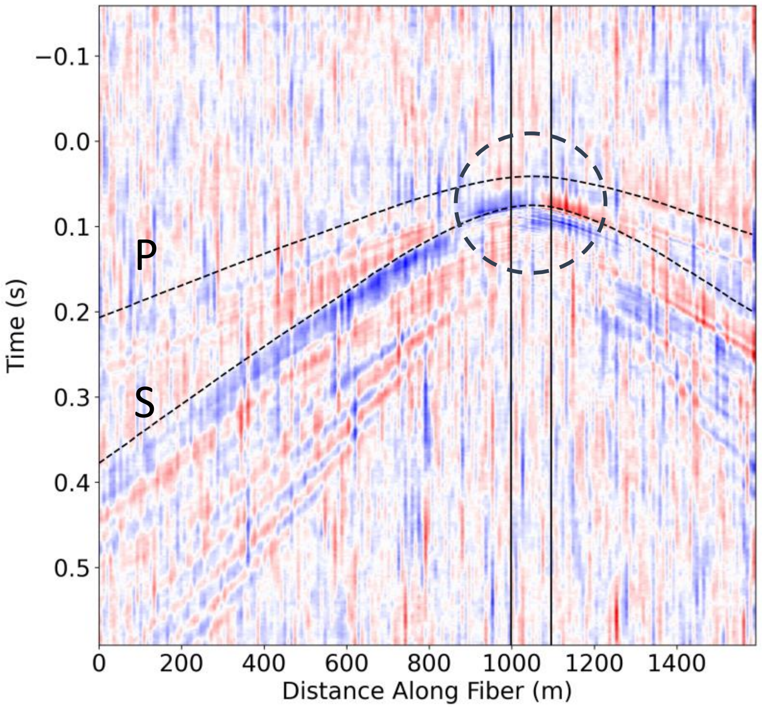


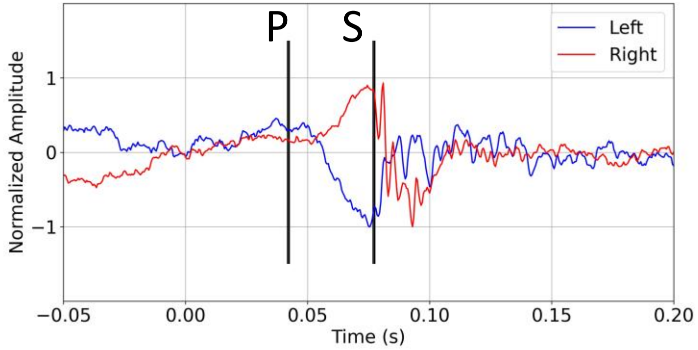
DAS Strain Rate





DAS Strain





Moment Tensor Point Source Solution

Strain Microseismics (Rodriguez and Wuestefeld, 2020)

In homogeneous isotropic media, the displacement **u** of a moment tensor point source M_{jk} is:

$$
\begin{aligned}
u_i(\mathbf{x},t) = {} & \frac{1}{4\pi\rho}\frac{1}{r^4}(15\gamma_i\gamma_j\gamma_k - 3\delta_{jk}\gamma_i - 3\delta_{ik}\gamma_j - 3\delta_{ij}\gamma_k)\int_{r/V_P}^{r/V_S}\tau M_{jk}(t-\tau)d\tau && \text{Near field} \\
& + \frac{1}{4\pi\rho V_P^2}\frac{1}{r^2}(6\gamma_i\gamma_j\gamma_k - \delta_{jk}\gamma_i - \delta_{ik}\gamma_j - \delta_{ij}\gamma_k)M_{jk}\left(t-\frac{r}{V_P}\right) && \text{Intermediate field for P} \\
& - \frac{1}{4\pi\rho V_S^2}\frac{1}{r^2}(6\gamma_i\gamma_j\gamma_k - \delta_{jk}\gamma_i - \delta_{ik}\gamma_j - 2\delta_{ij}\gamma_k)M_{jk}\left(t-\frac{r}{V_S}\right) && \text{Intermediate field for S} \\
& + \frac{1}{4\pi\rho V_P^3}\frac{1}{r}(\gamma_i\gamma_j\gamma_k)\dot{M}_{jk}\left(t-\frac{r}{V_P}\right) && \text{Far field for P} \\
& - \frac{1}{4\pi\rho V_S^3}\frac{1}{r}(\gamma_i\gamma_j\gamma_k - \delta_{ij}\gamma_k)\dot{M}_{jk}\left(t-\frac{r}{V_S}\right) && \text{Far field for S}
\end{aligned}
$$

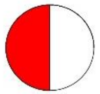
Aki and Richards (2002)

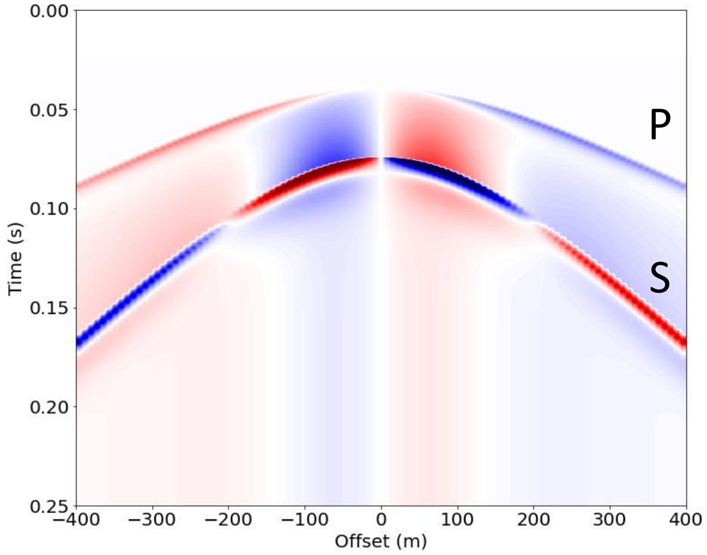
Radiation pattern -> Source orientation

Source time function -> Source process

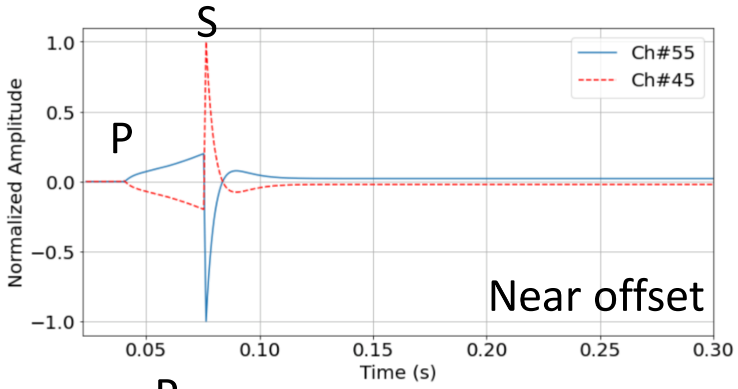
NF, IF, and FF

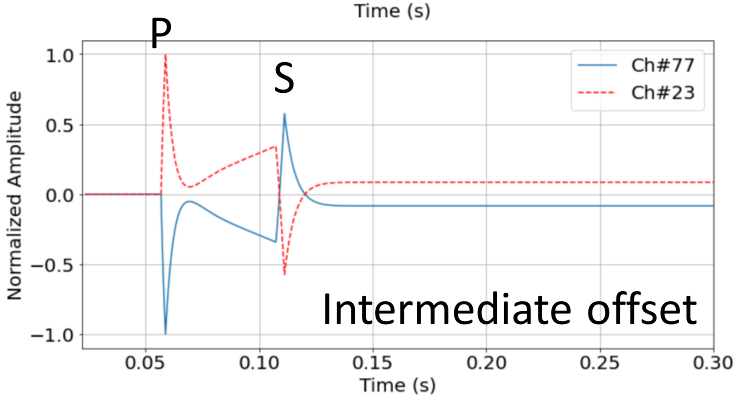
Double Couple
Mxz

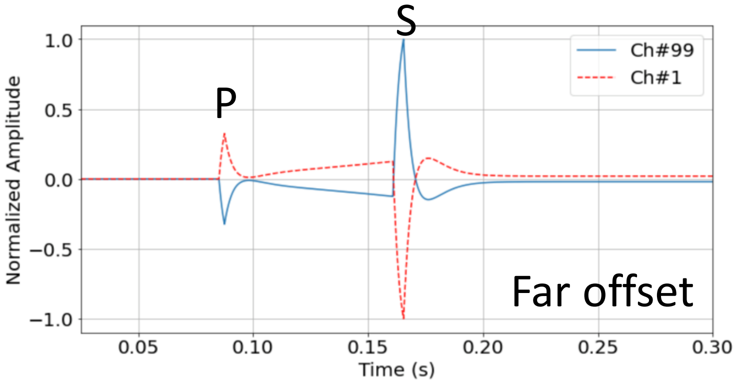




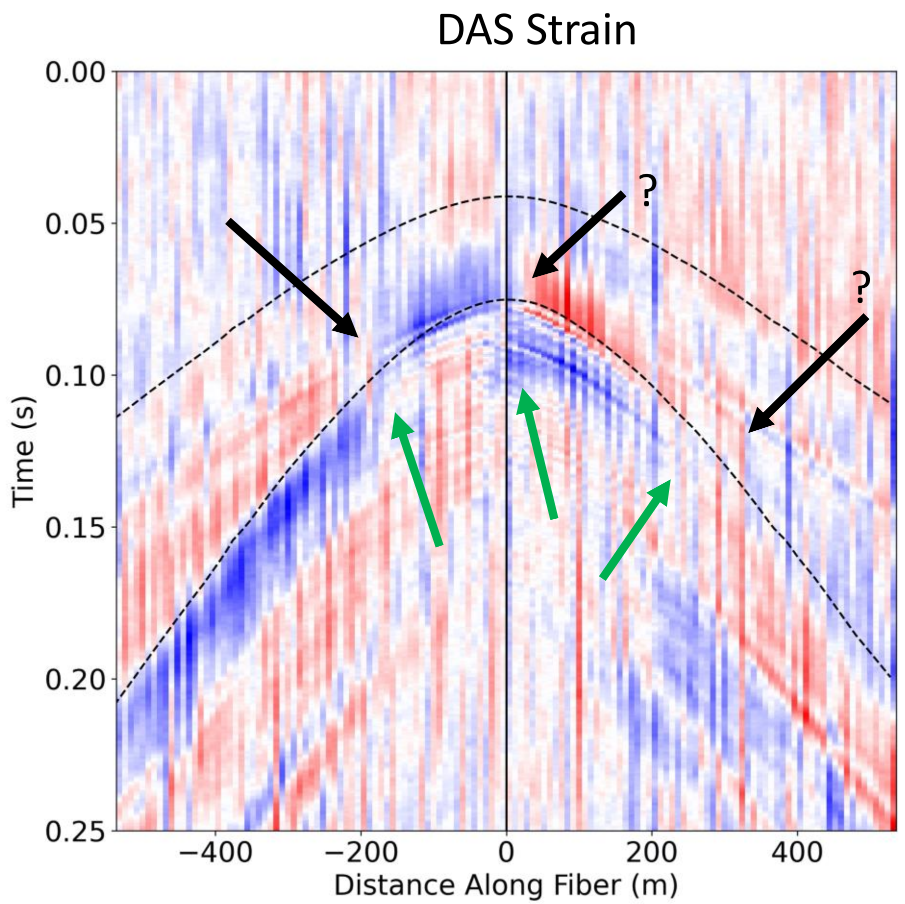
Synthetic DAS Strain with 8 m spacing and 14 m GL

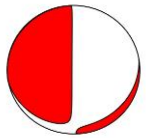




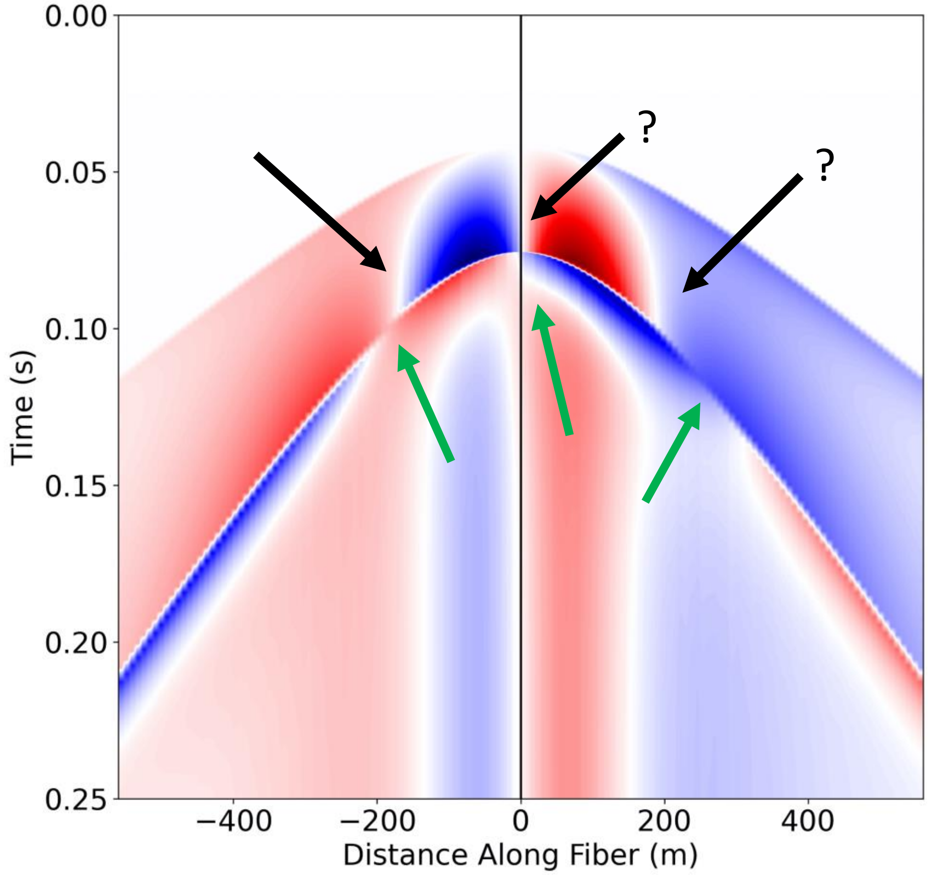


Field Data Example





Moment tensor from surface array:
Dip 88˚, strike 0˚ from
ideal perpendicular fracture



Conclusion

- Downhole fiber-optic cable with DAS technique enables close-up observation of the microseismic phenomena
- Microseismic guided waves
  - Seismic inversion of dispersion curves for thickness, shear wave velocity, and VTI parameters of the shale layer
  - Constraining event depth (inside/outside the shale reservoir) based on the occurrence of guided waves
- Microseismic near-field strain signals
  - Exhibiting a ramping amplitude between P and S direct arrivals
  - Spatial variation (source orientation) and temporal variation (source process): potential values for monitoring of hydraulic fracturing operations

Acknowledgments

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RCP Members

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RCP Associate Members

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RCP Contributors

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