Cool stuff you can do with a downhole vertical DAS fiber*

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With a lot of help from

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Nate Lindsey | Zack Spica

Biondo Biondi | William L. Ellsworth

FORGE and SAFOD related to quake detection/location a
using that energy for velocity analysis)

Overview

- Previous studies – passive DAS
- Why is downhole fiber different? (and can be very easy to work with)
- Applications (SAFOD + FORGE)
  - Velocity model building
  - Earthquake/microseismic detection
  - Event location
  - Magnitude estimation
- Conclusions

Where was it used before?

Earthquake detection by template matching (Brady Hot Springs)

- Li & Zhan (2018), *GJI*

Picks-based microseismic event detection/location with DAS

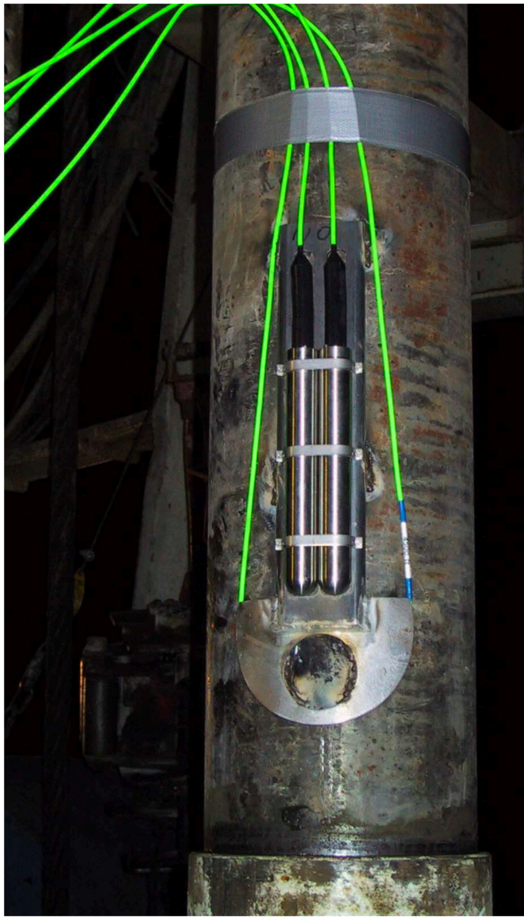
- Karrenbach et al. (2019), *Geophysics*

3-parameter pick version for usage in a deviated well

- Verdon et al. (2020), *Geophysics*

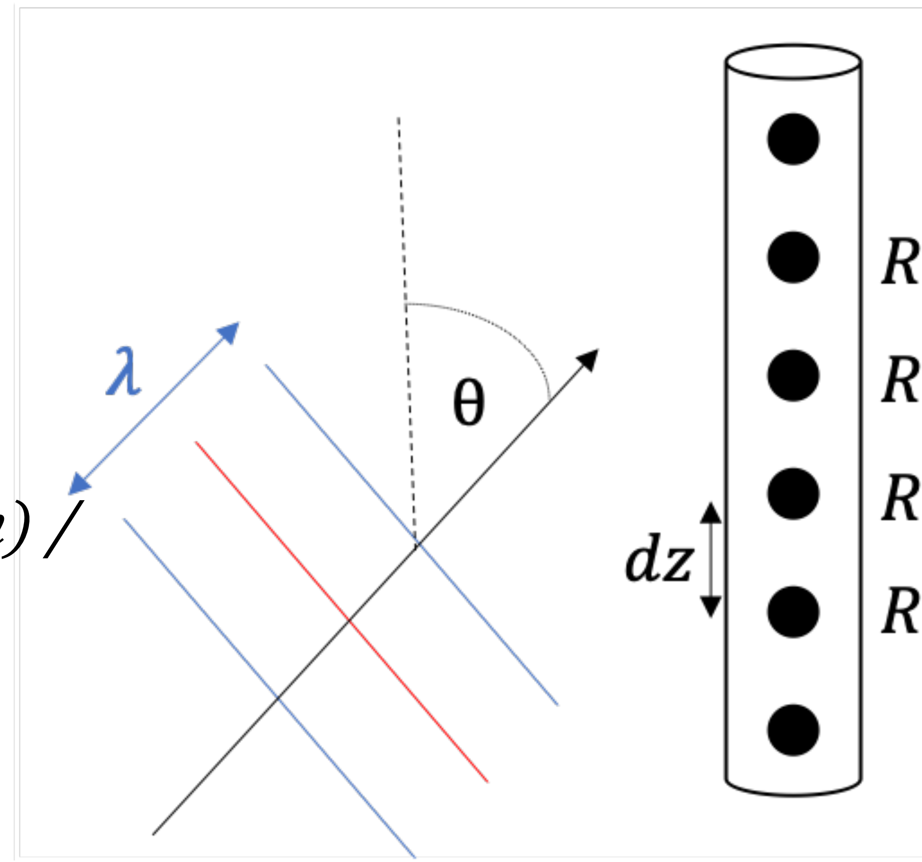
DAS as a downhole sensor

- Can be used in active wells – outside casing
- Resistant to temperature/pressure
  - One-time installation cost
  - Close to target reservoir
  - Great for long-term monitoring
- Wide frequency range – 8 orders of magnitude
  - 10000 s (strain changes) to 10000 Hz (fluid flow)
- High-resolution seismic wavefield
  - Array processing mindset



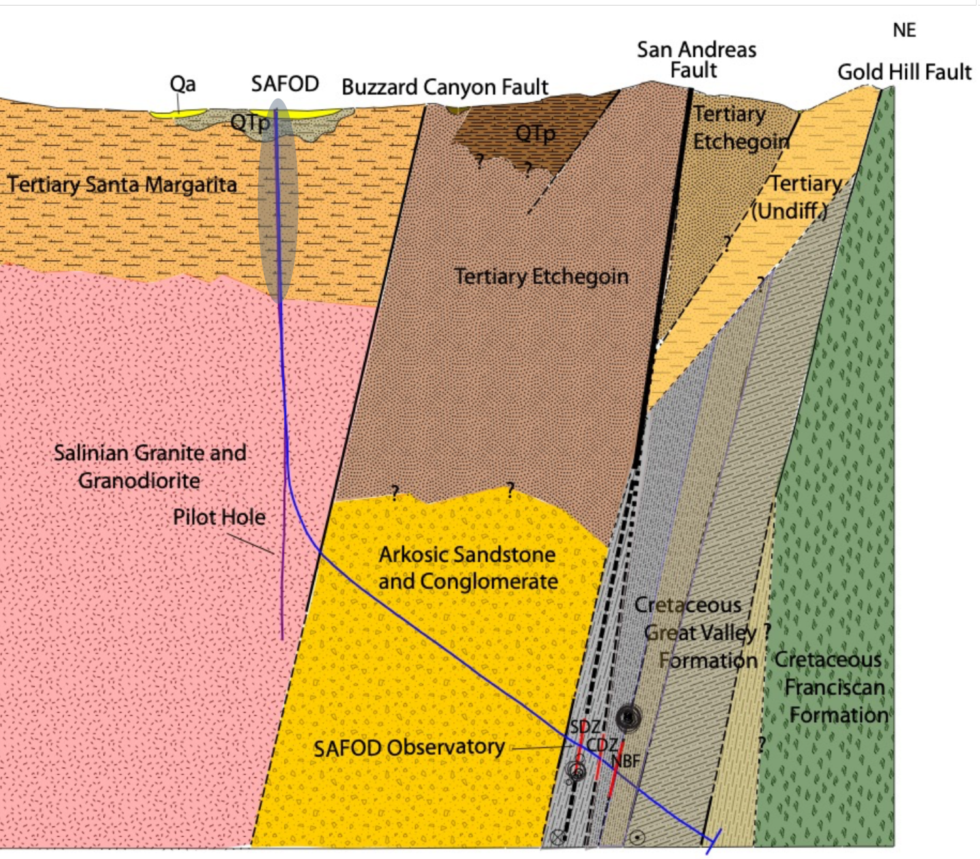
Some simplifying assumptions - vertical fiber

- Key assumptions:
  - Azimuthal symmetry
  - Plane waves
  - Reach bottom of the array first
- Ideal case - source far below the array
  - 1D propagation
  - $t_{R_{n+1}} - t_{R_n} = \frac{Z_{R(n+1)} - Z_{R(n)}}{V_{R(n+1/2)}}$
- Otherwise – scaled by $\cos(\theta)$
  - Incidence angle ≠ geometrical angle!



t al. (2019), Seismic velocity estimation using passive downhole distributed acoustic sensing records – exampl
ndreas Fault Observatory at Depth, *Journal of Geophysical Research: Solid Earth.*

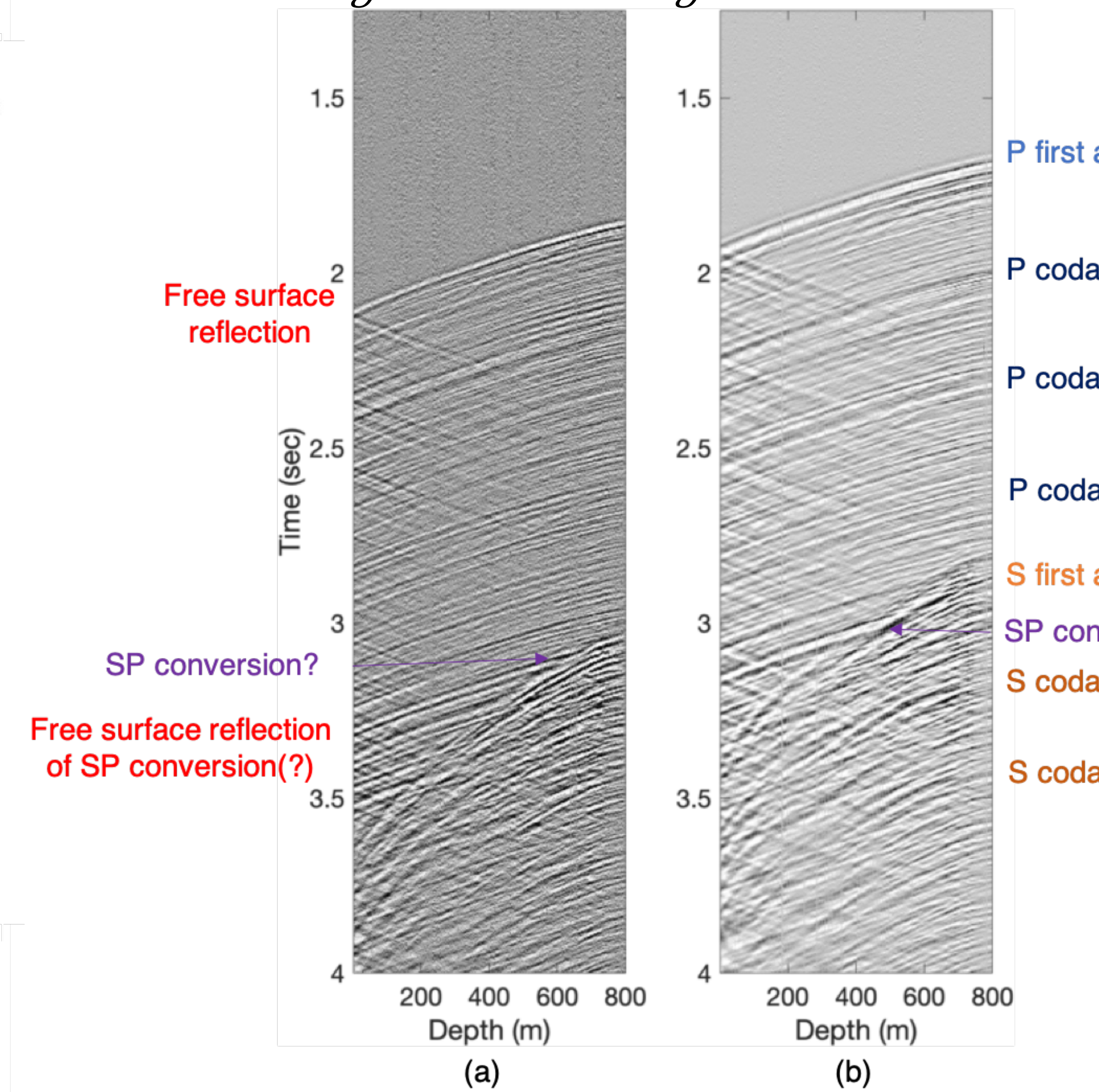
SAFOD setup + data



$M=1.33$ $M=2.46$

$R=11.3\ km$ $R=11.7\ km$

$\theta\downarrow geom=9.54\uparrow o$ $\theta\downarrow geom=12.31\uparrow o$



Summary – estimated velocities

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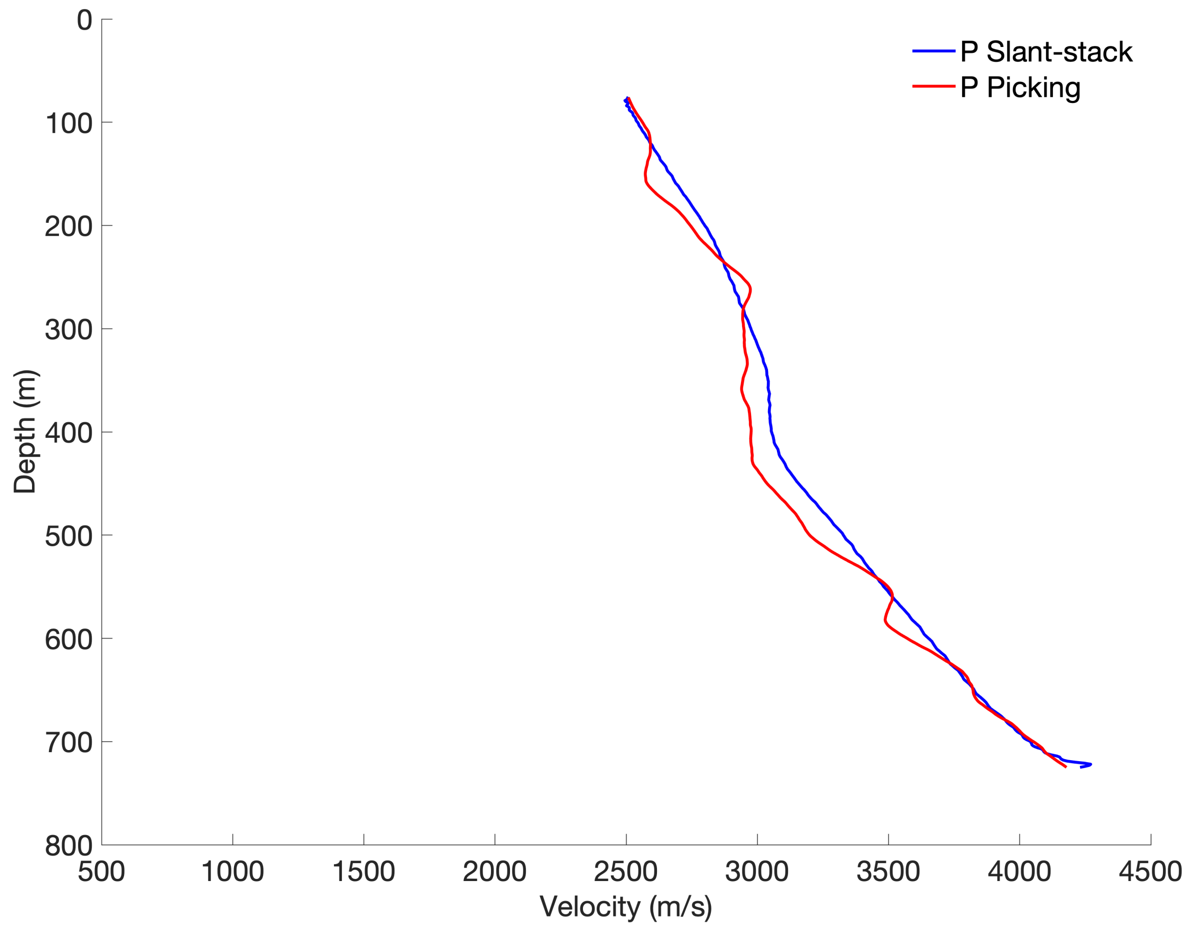

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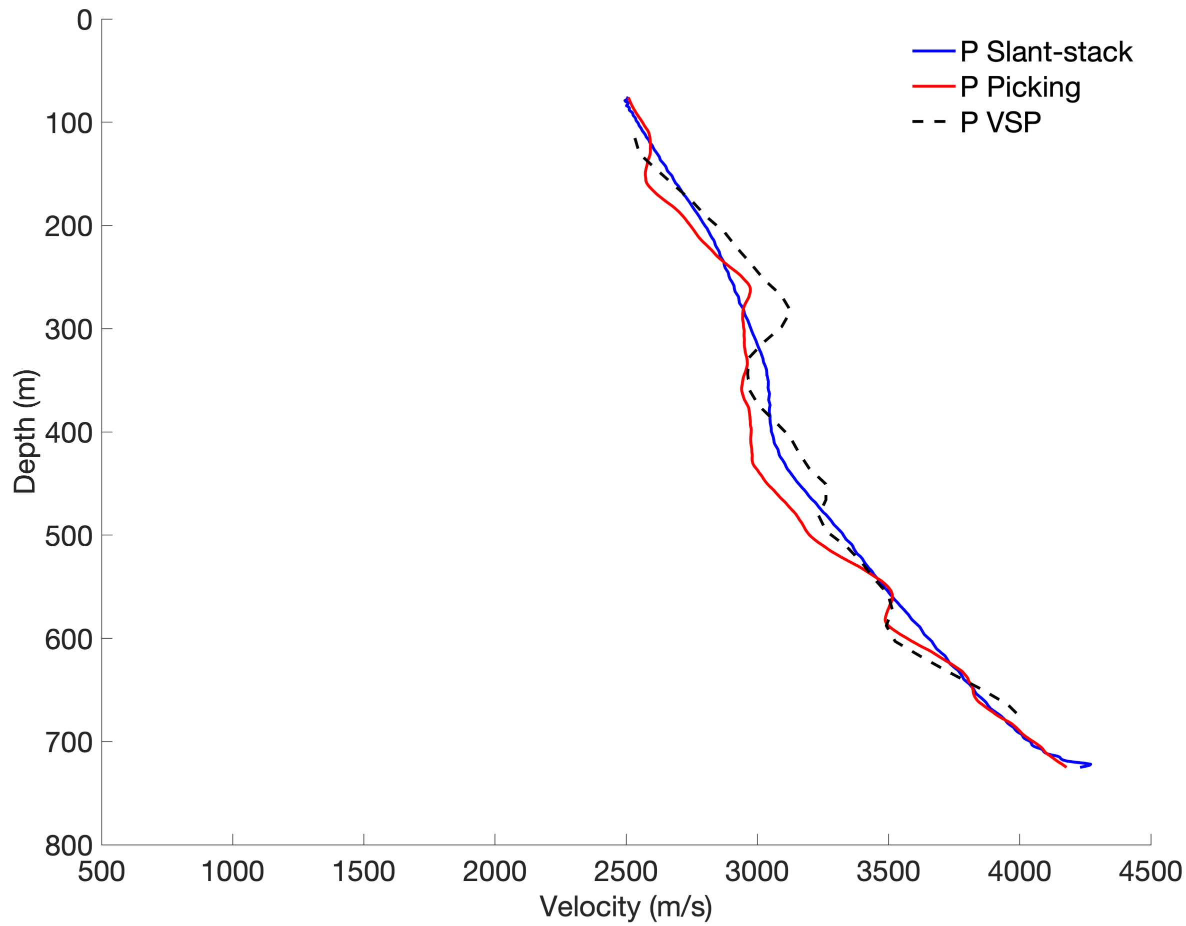

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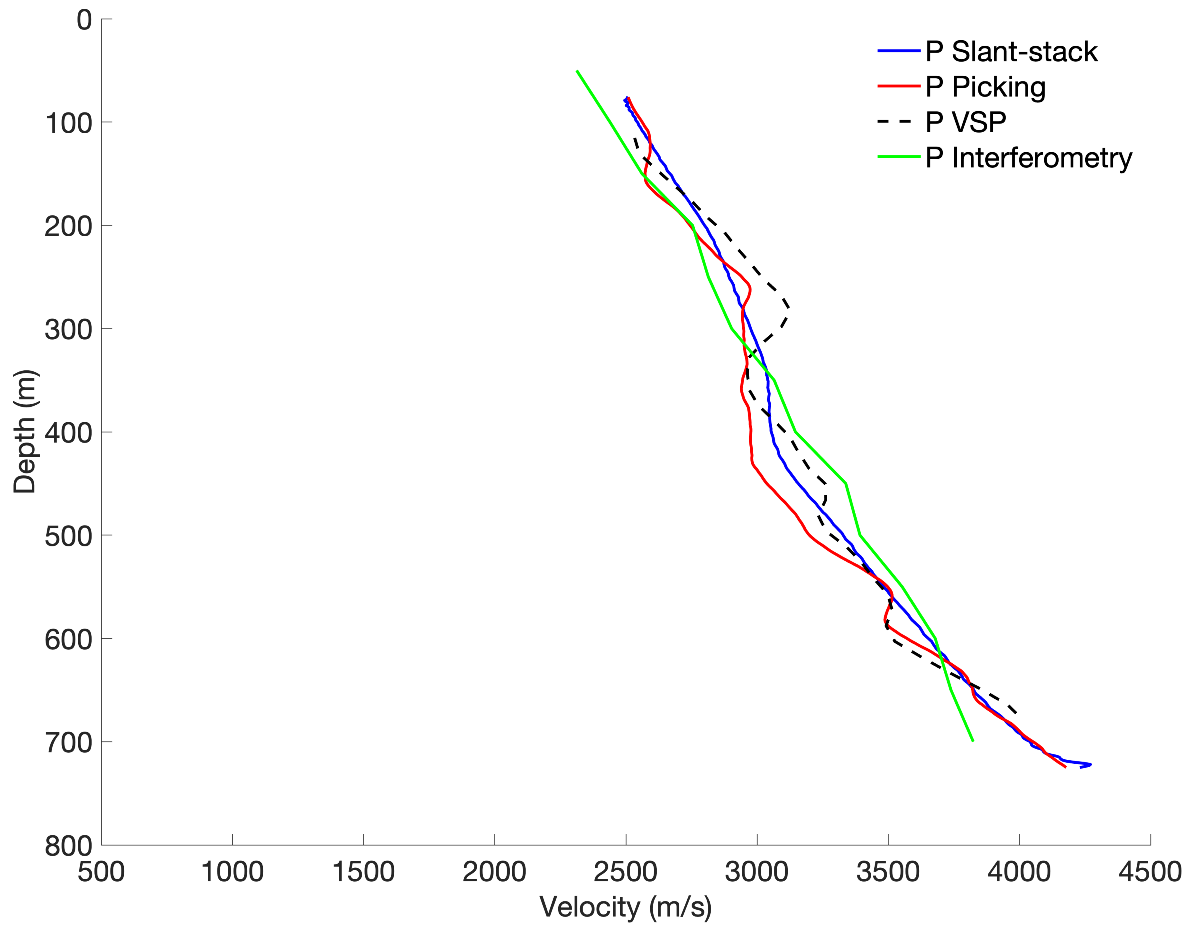

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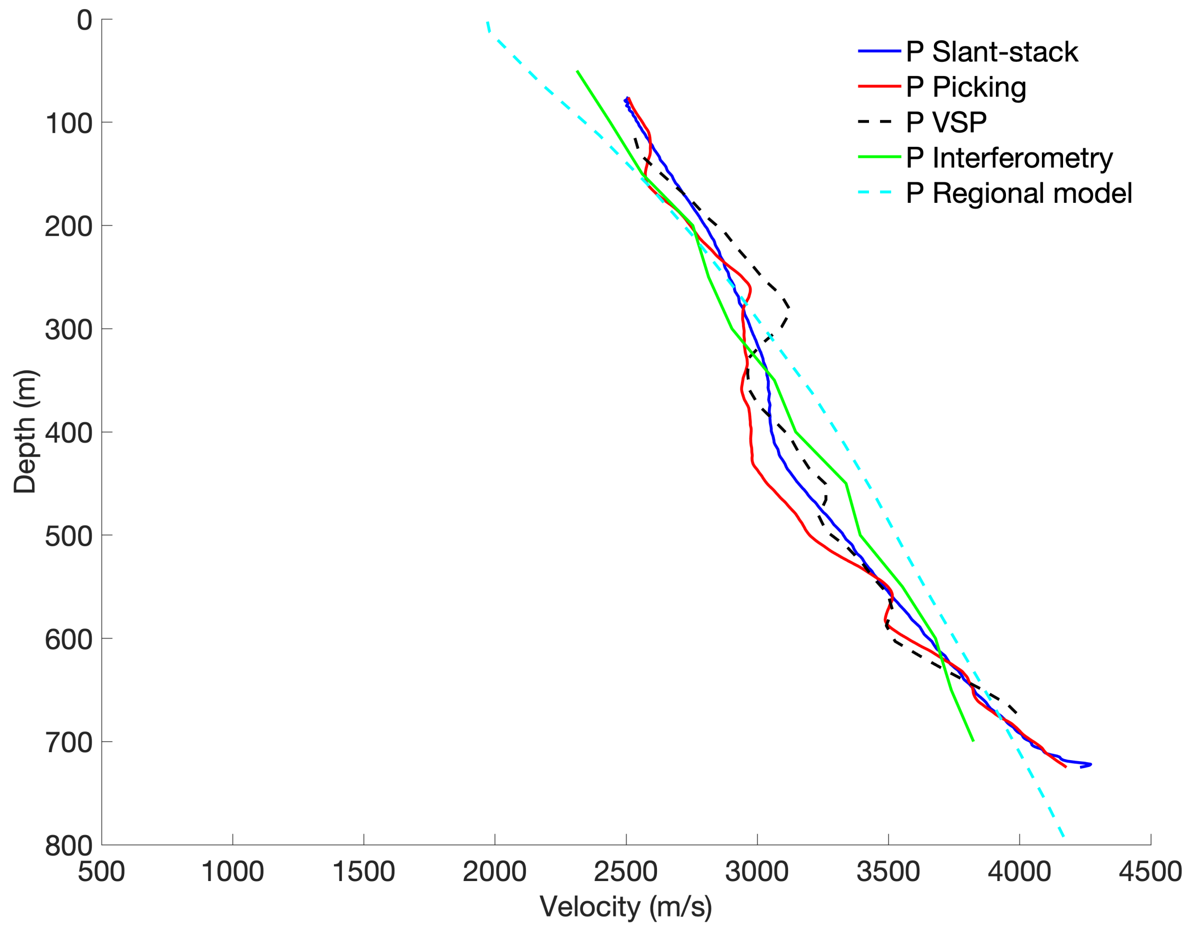

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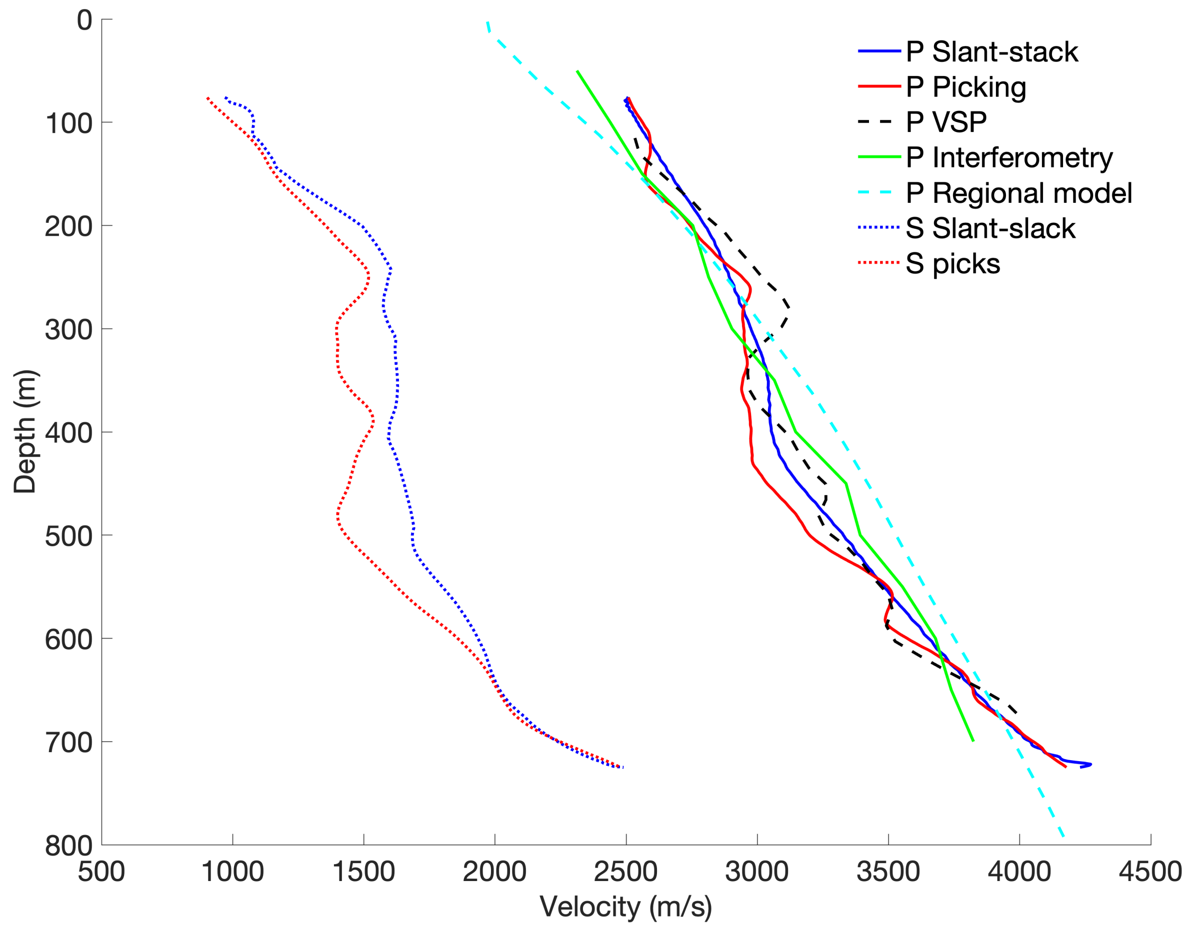

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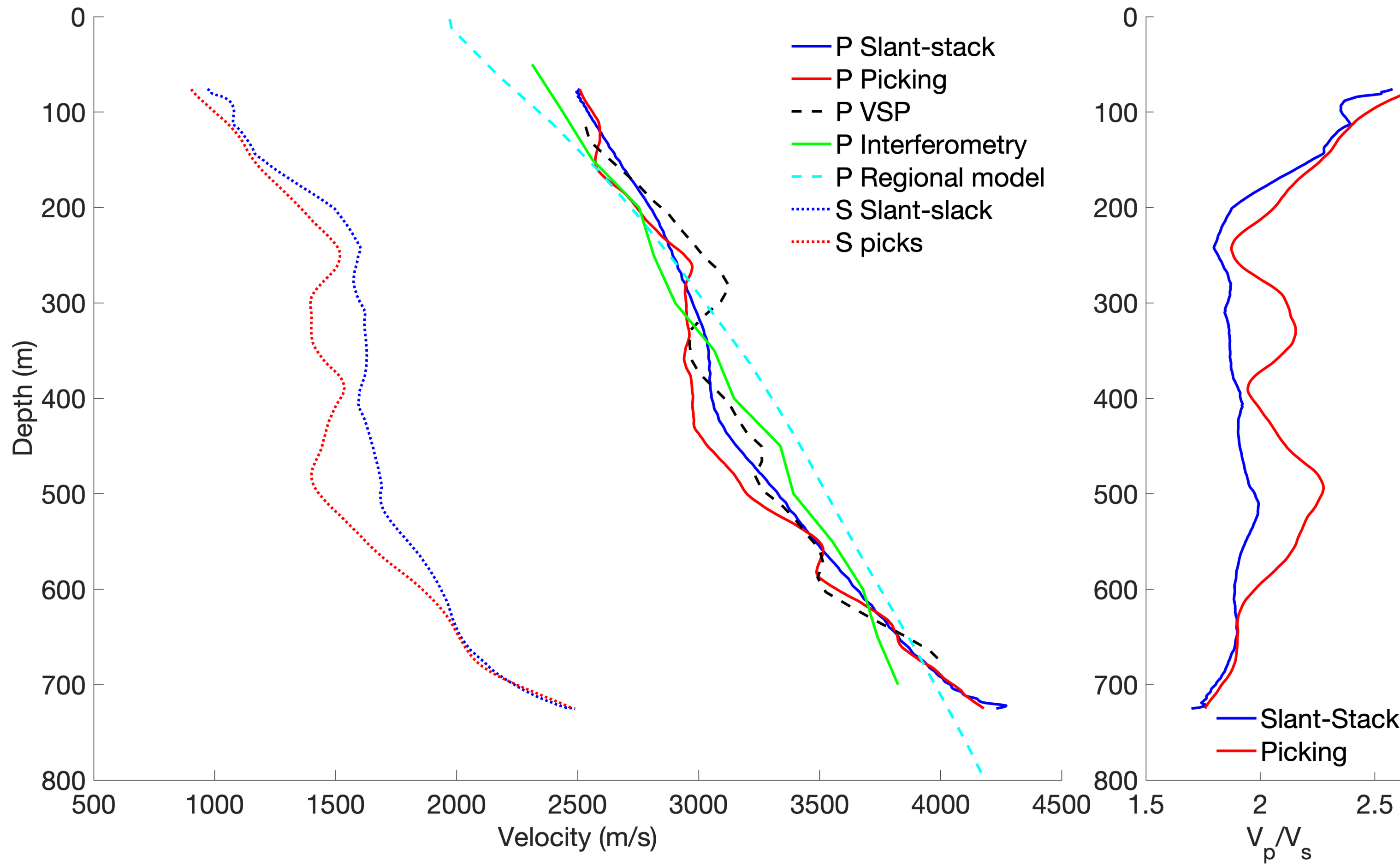
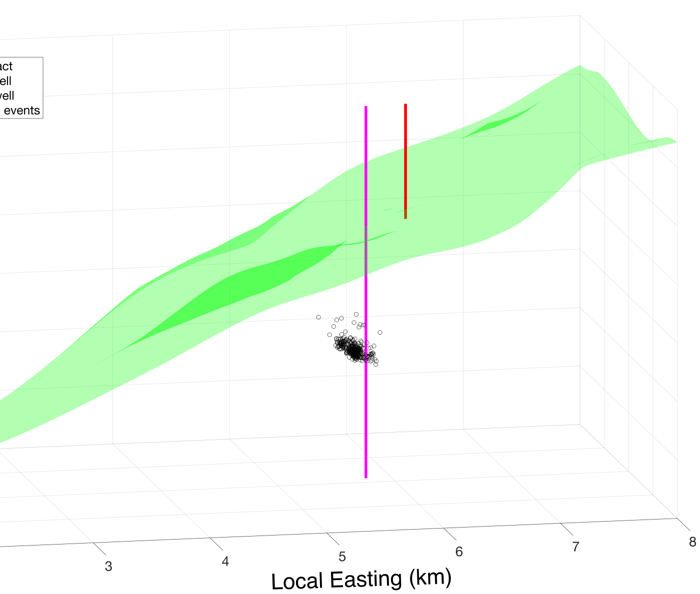
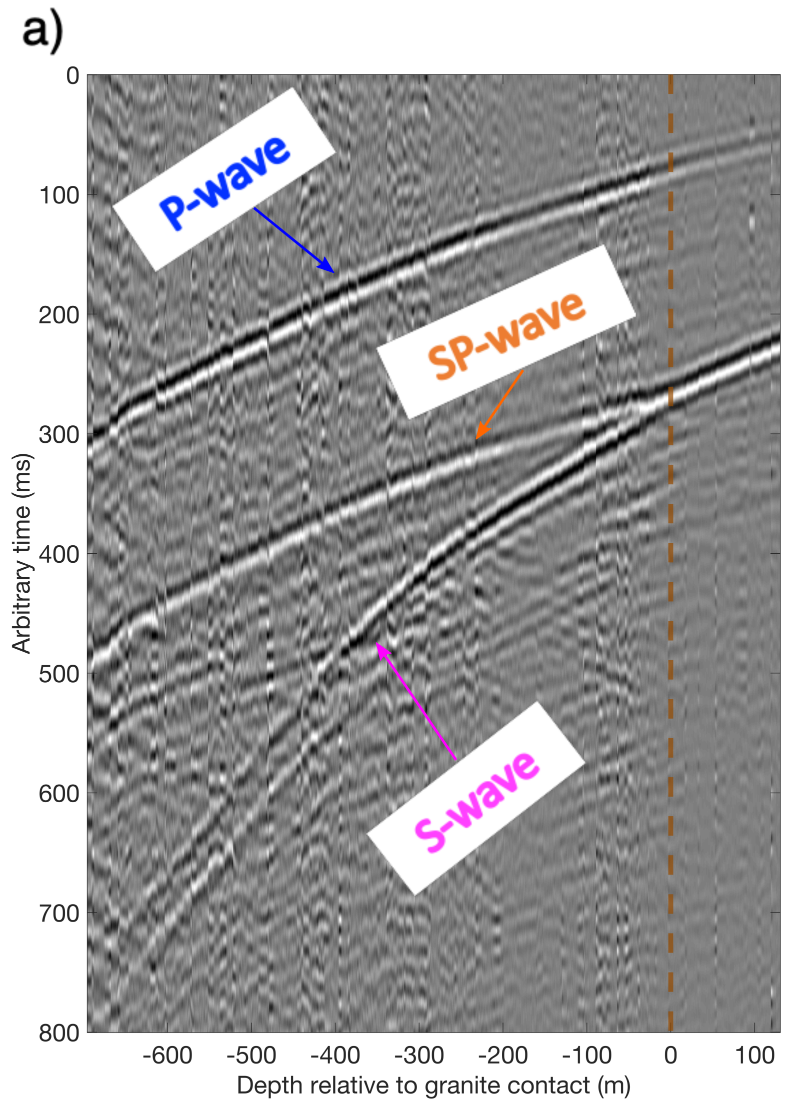
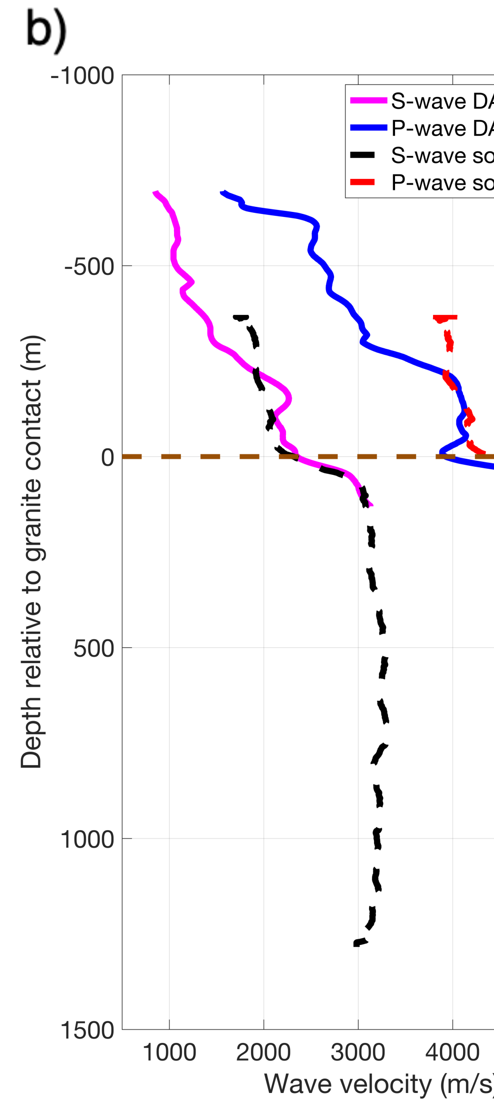
- ormal” V_P / V_S



FORGE site structure





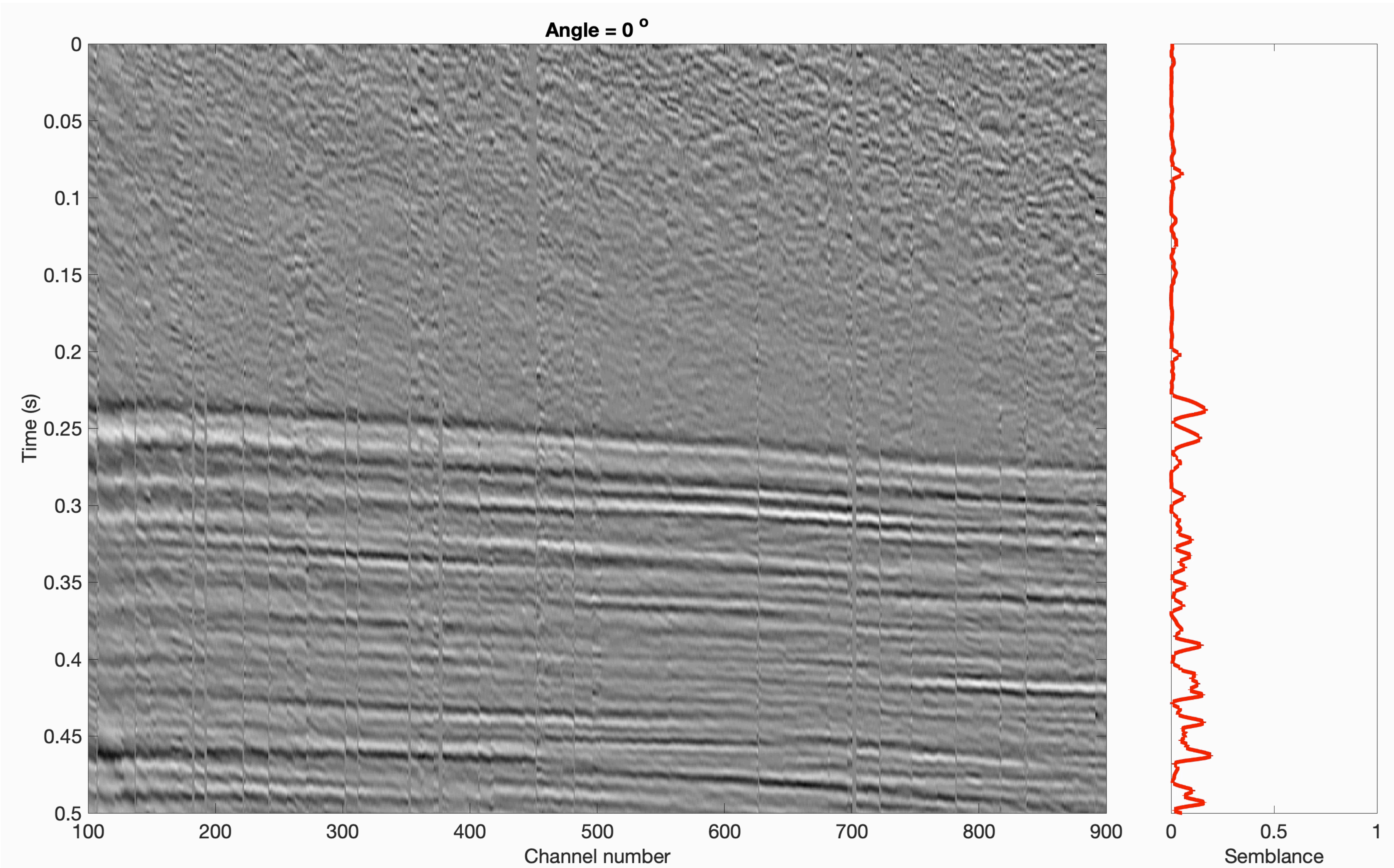


Detection

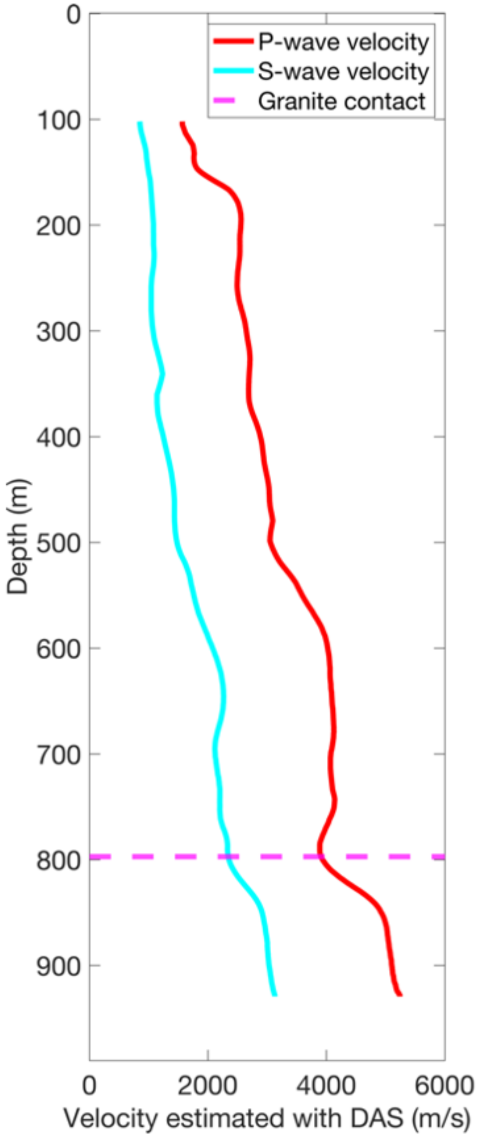
- Velocity model building - from arrival times to subsurface velocity
- For detection – <u>predict</u> arrival times from velocity
  - Depends on unknown angle of incidence
  - Single parameter scan - angle of incidence at bottom of the array
  - (*) Angle of incidence changes along the array – needs to be iteratively corrected for
- Measure data coherency along predicted travel-time curves
  - Semblance is a useful option, others work too
  - Picking free!
  - Have angle of incidence at the bottom of the array as by-product

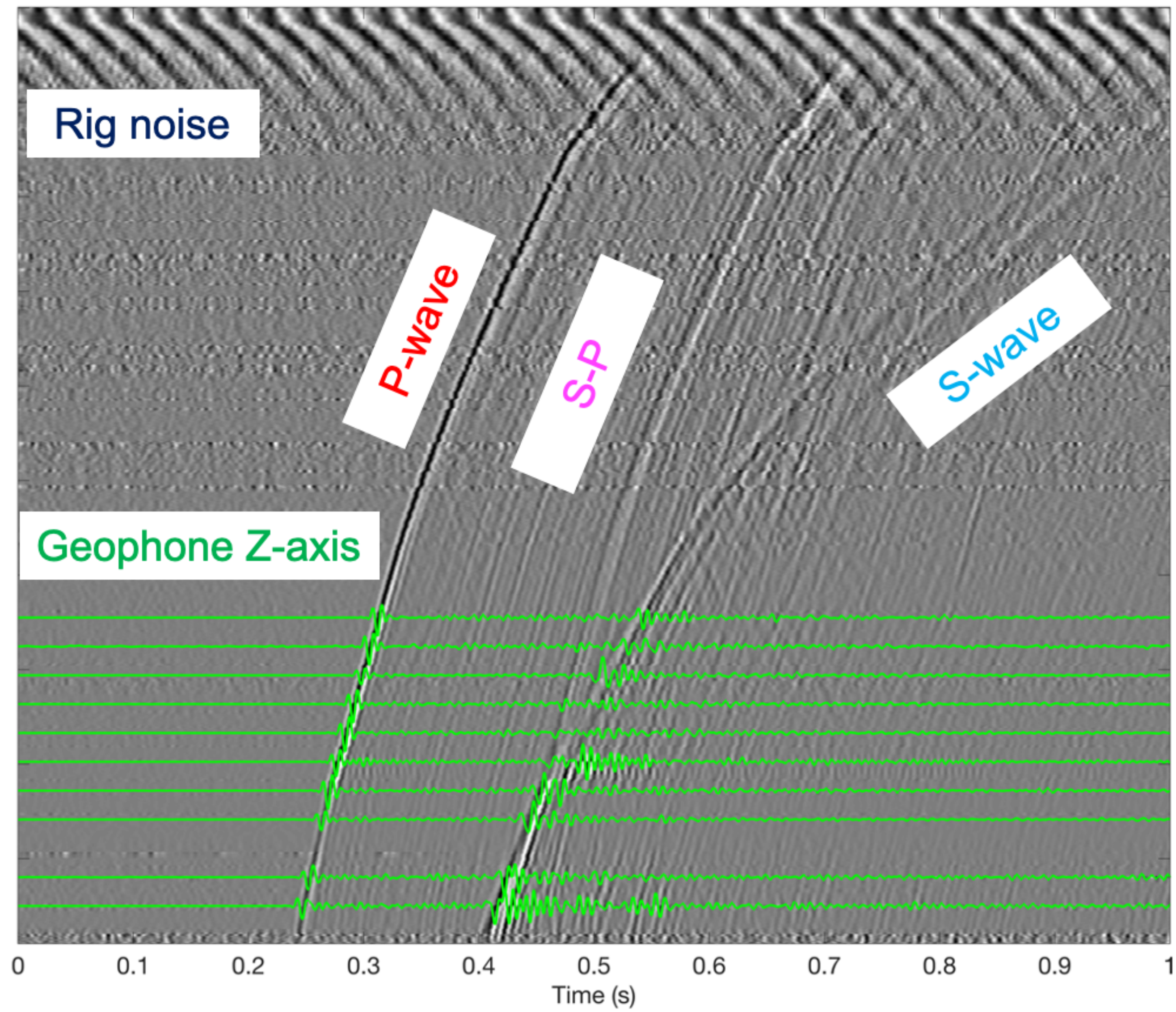
t al. (2019), Velocity-based earthquake detection using downhole distributed acoustic sensing – examples
an Andreas Fault Observatory at Depth, *Bulletin of the Seismological Society of America*.

Angle scan in practice – FORGE example



Microseismic event example





Microseismic detection

Velocity-based DAS detection

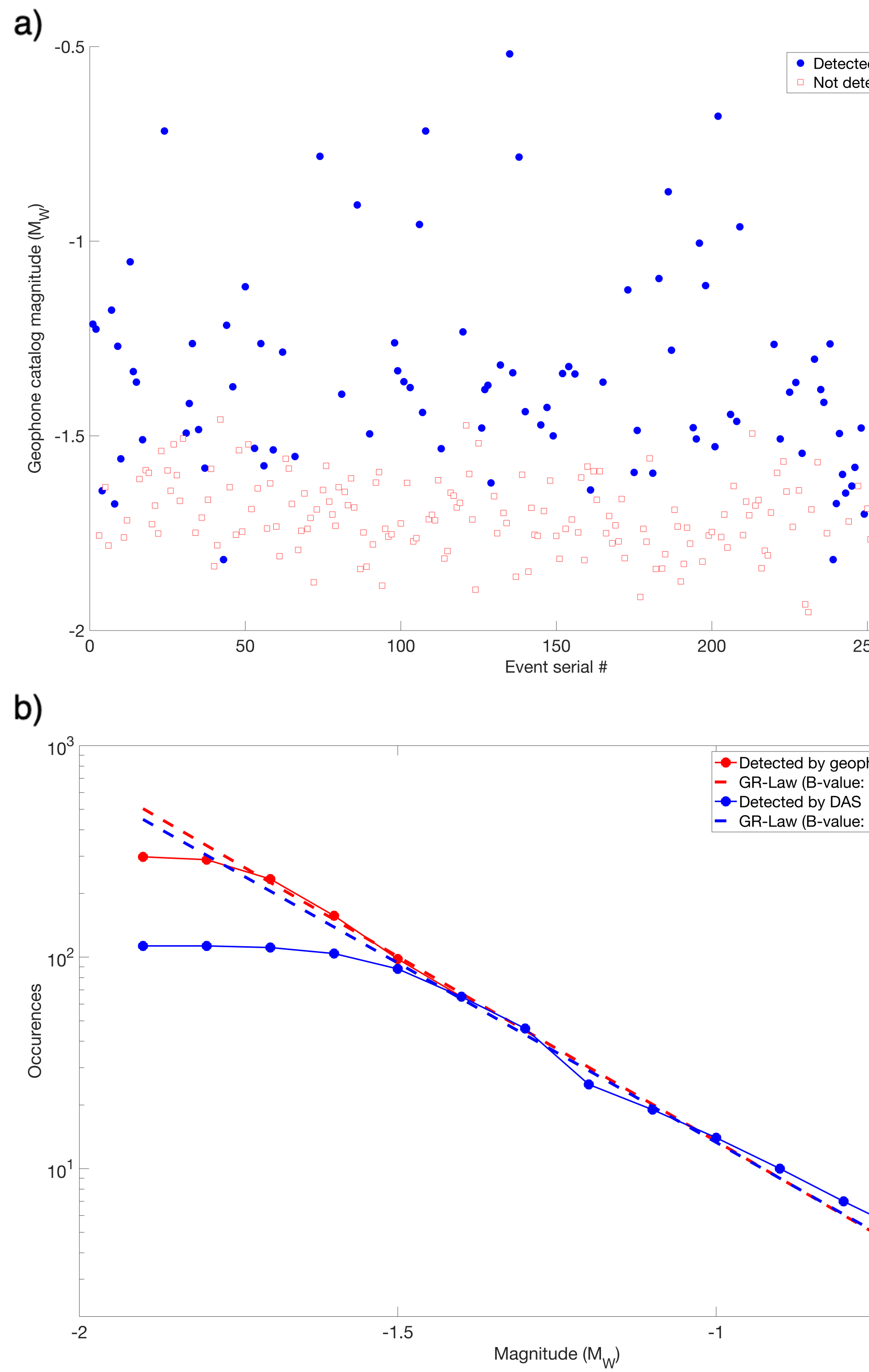
- All events above M=-1.4

SLB geophone catalog

- Complete down to M=-1.7

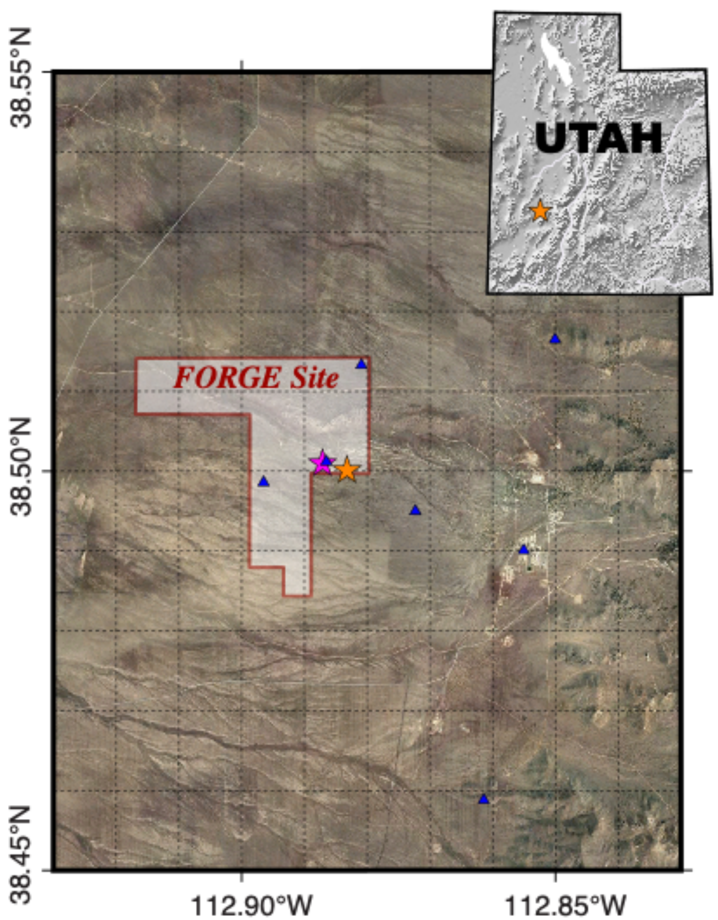
By using DAS for detection, we lose ~0.3 of the magnitude completeness

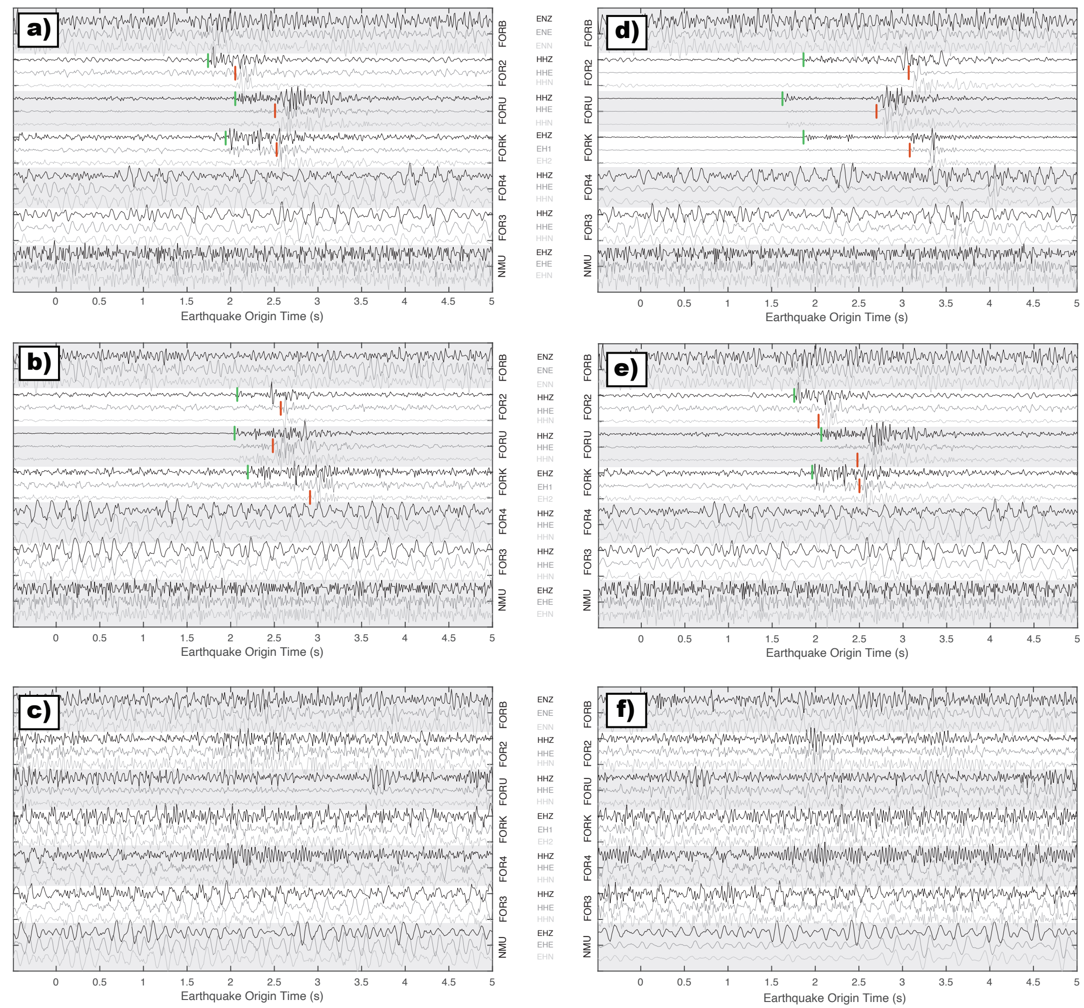
B-value around 1.7 (dominated by small-scale events)



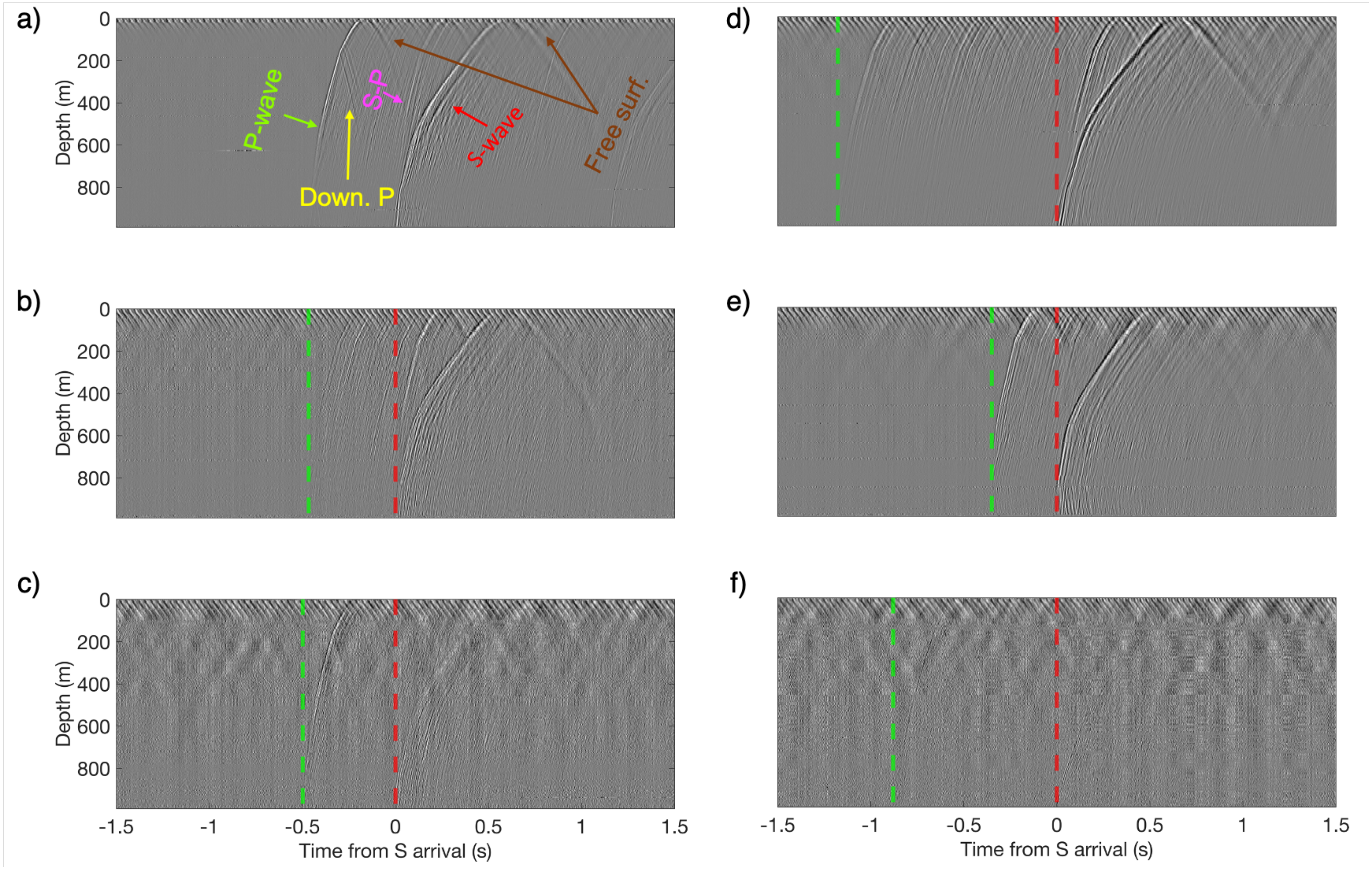
al. (2020), Comparison between Distributed Acoustic Sensing and – Downhole Microseismic Monitoring of the FORGE Geothermal . *Seismological Research Letters [In press]*

Earthquake detection - what we usually have



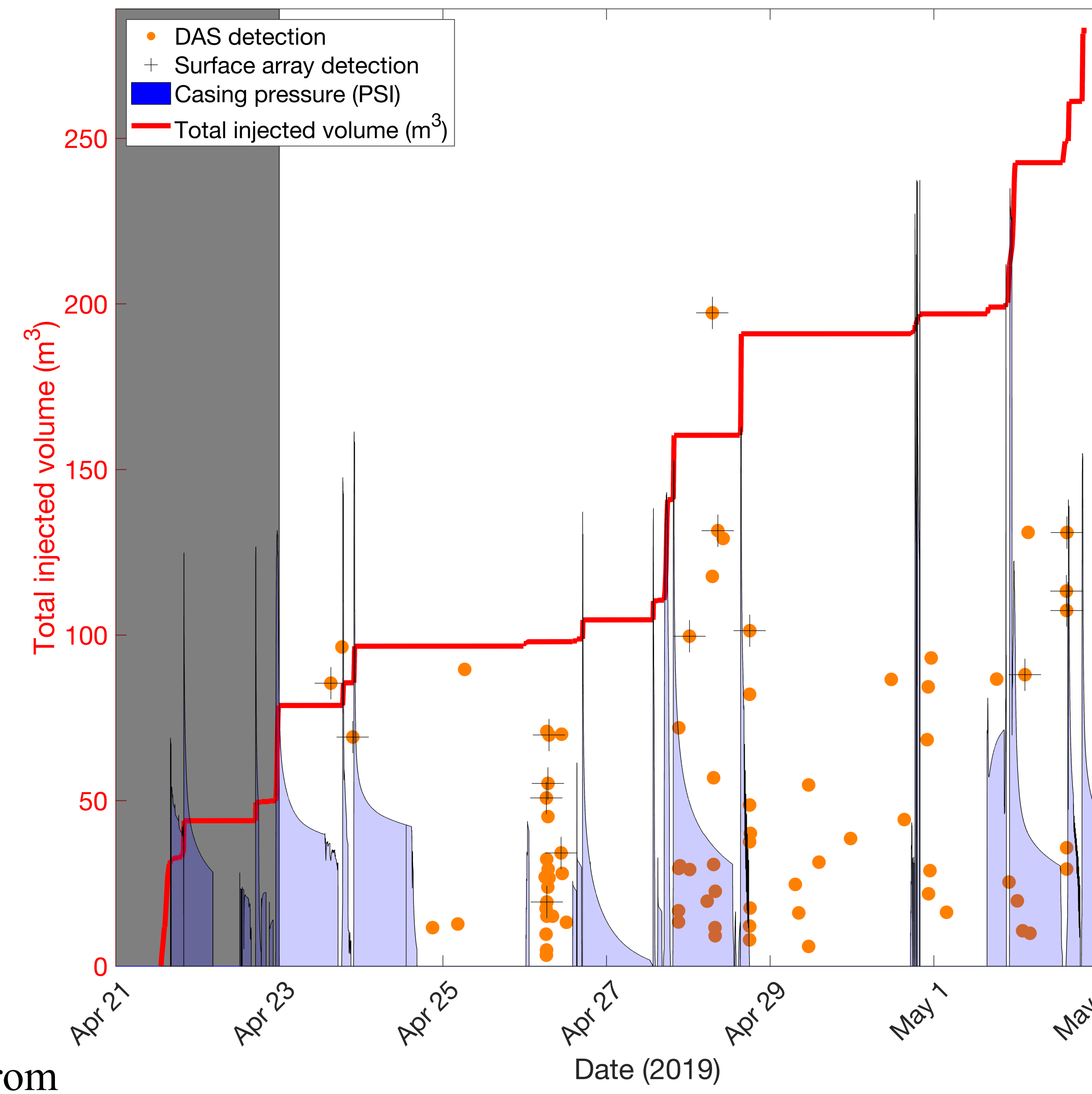


And what they look like with downhole DAS



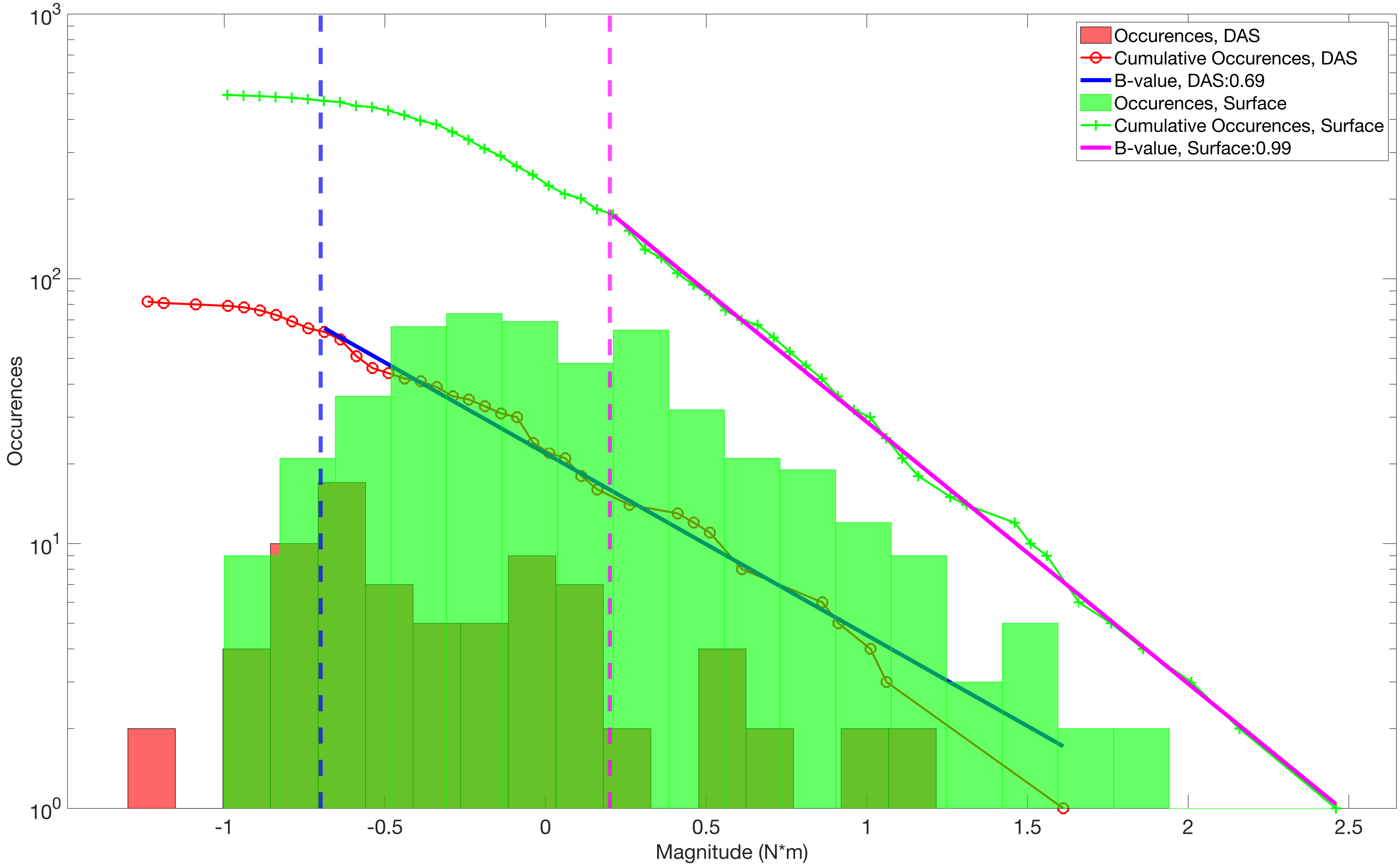
thquake detections

- 10.5 days analysis period
- Regional catalog – 4 events
- DAS – 82 events
- Surface array (+DAS time) – 16



t al. (2020), Low-magnitude seismicity with a distributed acoustic sensing array – examples from E Geothermal Experiment, *arXiv*

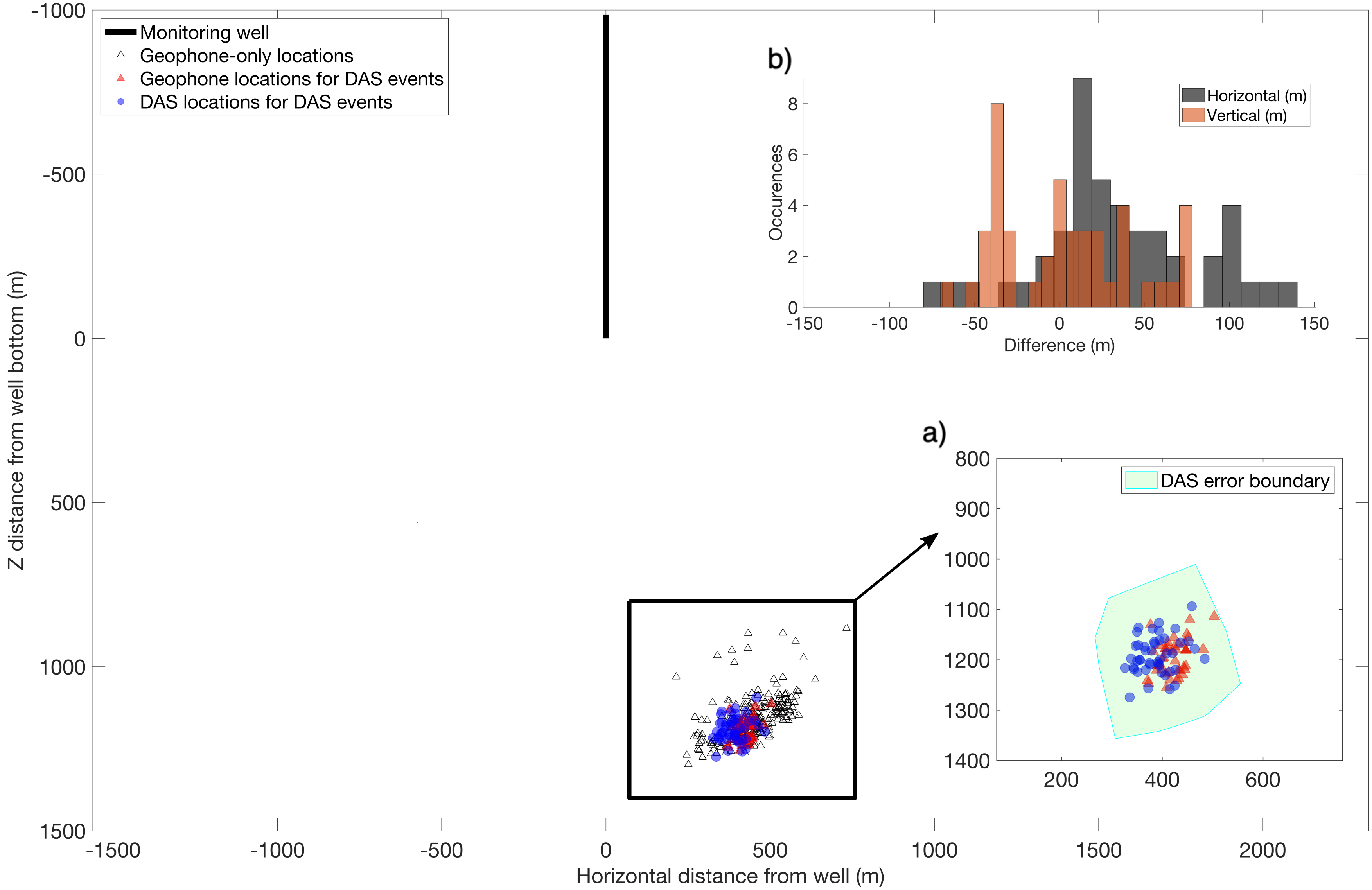
Downhole DAS outperforms surface array



Event location

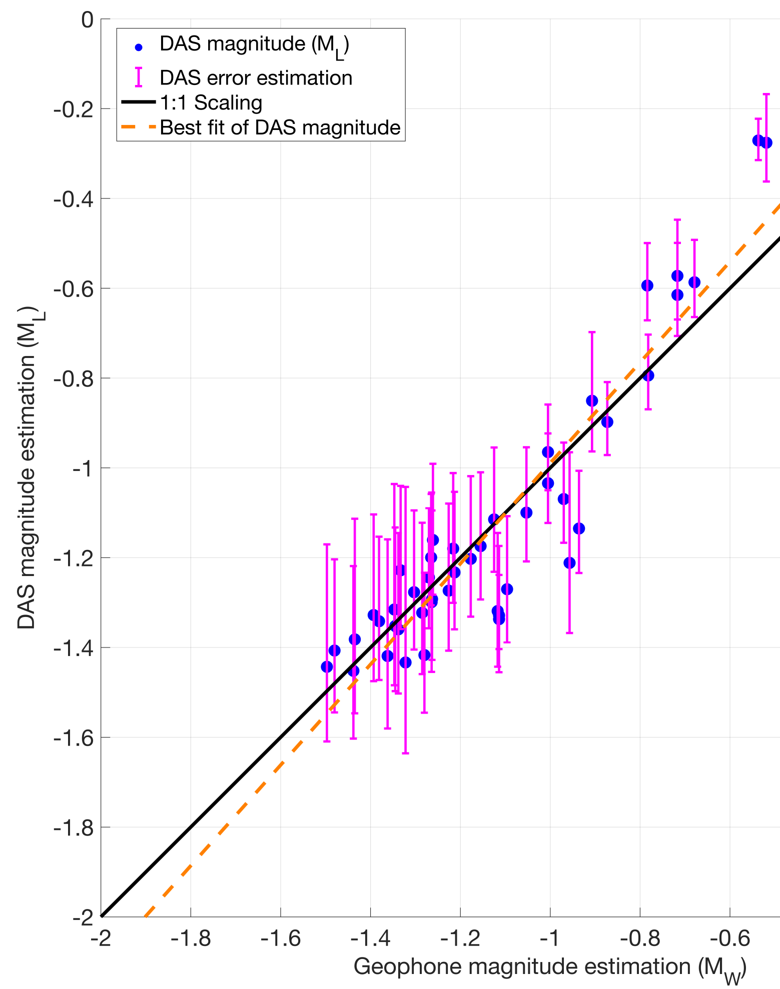
- Single vertical DAS well cannot yield azimuth!
- We have the “angle of incidence” at the bottom of the array
- Can shoot a virtual ray with that angle
  - (Or a straight line if the subsurface velocity is constant)
- S-P arrival time difference indicates where the event is along that ray

Comparison to downhole geophones location



Magnitude estimation

- mi-empirical formulation
  - Depends on distance
- egrate from strain rate to strain
- ke peak strain
  - Avoid noisy channels
  - Choose strongest channels
- $L = \log_{10}(S \times 10^6 \times GL) + 2.56 \times$ $\log_{10}(R) - 1.67$
- 94 correlation coefficient with “fancy” 3-C ophone estimation



Conclusions – downhole vertical DAS

Useful for velocity model building

Detection: downhole geophones > DAS > surface array

Relative magnitude completeness: X-0.3 < X < X+1

Decent location (2-D only) and magnitude estimation

- More complex geometries can resolve azimuthal symmetry

DAS is a strong candidate for long-term monitoring

- Geothermal / EGS
- CO_2 sequestration

Can be beneficially complemented by conventional receivers

Questions for me?
For you – what is this event?