Sparse seismic monitoring at CMC's Newell County CO_2 storage facility

Brendan Kolkman-Quinn, CMC
Don Lawton, CMC, U of C
Malcolm Bertram, CMC, U of C

CREWES Sponsors Meeting 2023
December 7th, 10:30 am

ACT & SPARSE

- Facilitate gigatonne storage with reliable long-term, low-cost geophysical MMV
- Sparse but highly repeatable geophysical data from strategically distributed nodes
- Background monitoring to establish containment and conformance
- Trigger target-oriented active seismic surveys if/when needed

ACT Accelerating CCUS Technologies

SPARSE long-term, low-cost monitoring

Sparse Passive-Active Reservoir monitoring using Seismic, Electromagnetics, gravity, and surface deformation

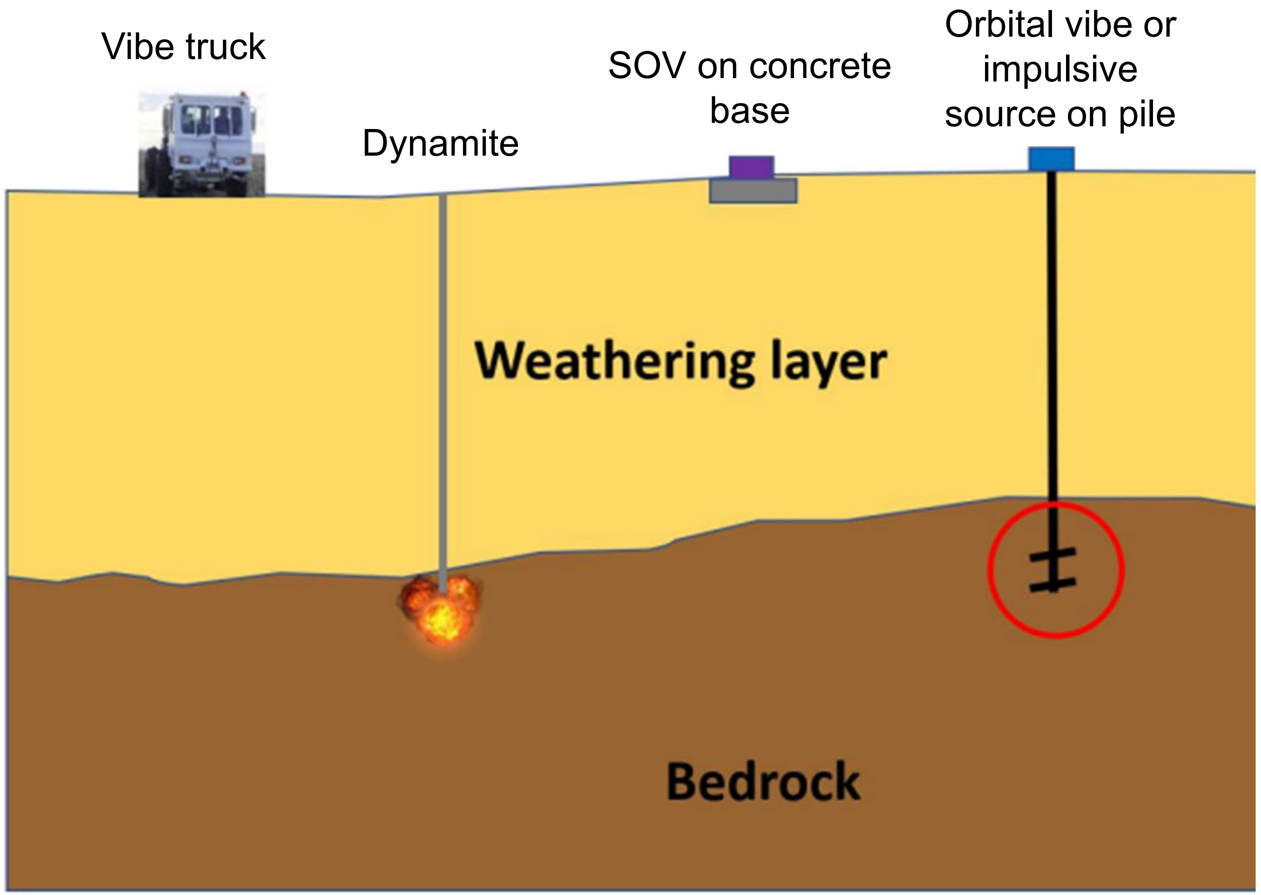
ACT4 – Full proposal

Project consortium

Organisation	Country	Type of organisation
SINTEF (coordinator)	Norway	R&D
Horisont Energi (HE)	Norway	Industry, O&G operator
Neptune Energy (NE)	Norway	Industry, O&G operator
Quad Geometrics (Quad)	Norway	Industry, service/vendor
LBNL (LBNL)	United States	R&D
Carbon Management Canada (CMC)	Canada	R&D
Hyfold Technology	Canada	Industry, service/vendor
University of Calgary (UofC)	Canada	R&D
Q-Eye Labs (QEL)	Canada	Industry, service/vendor
GeoSoftware (GS)	Canada	Industry, service/vendor
Spotlight (Spot)	France	Industry, service/vendor
Precision Impulse (Prec)	UK	Industry, service/vendor

Steel helical pile as source location

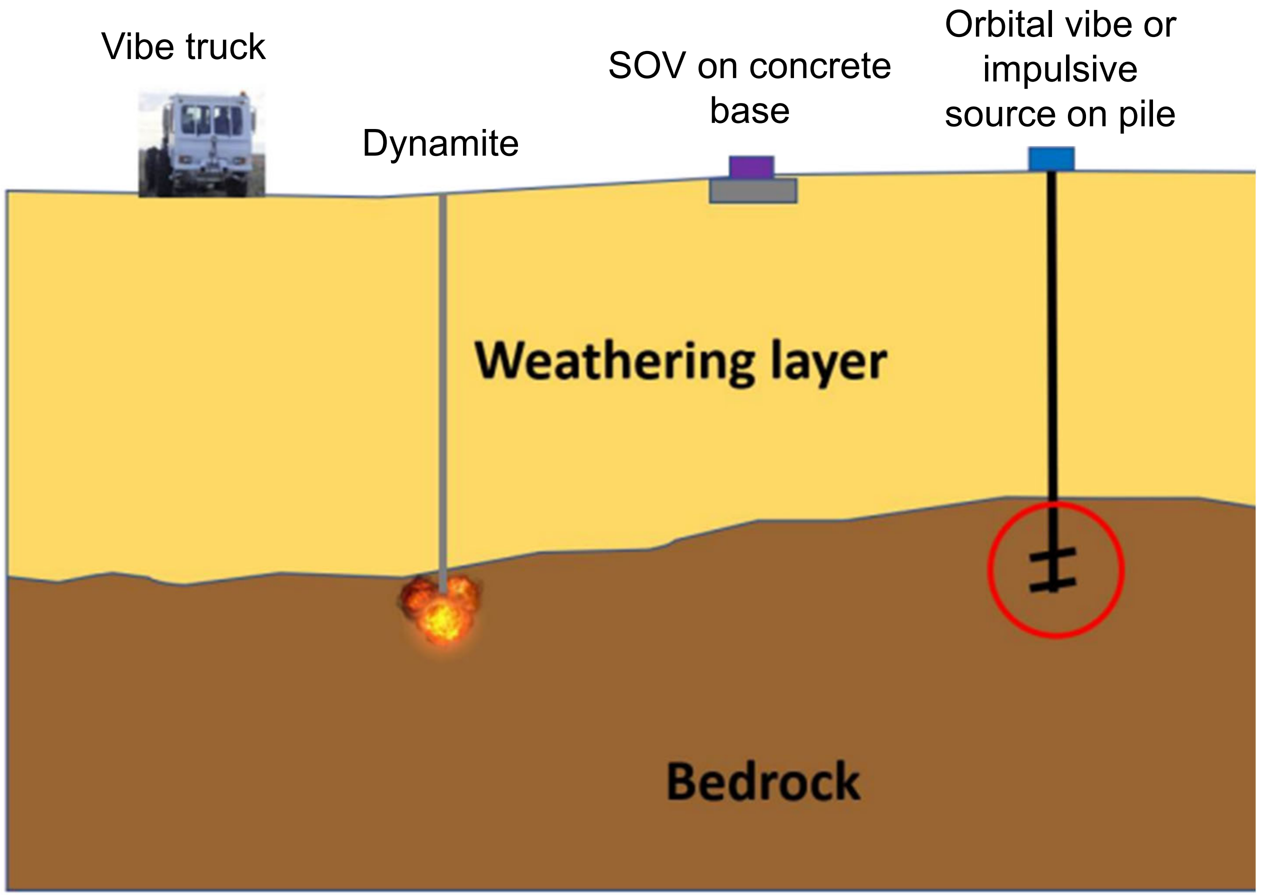
- Impulse or sweep transmitted to steel toe couple to bedrock
- Avoid reverberations & attenuation in weathering layer
- Avoid surface & near-surface repeatability problems from rain, drought, freeze, thaw



Adapted from Lawton et al. (2020)

Steel helical pile as source location

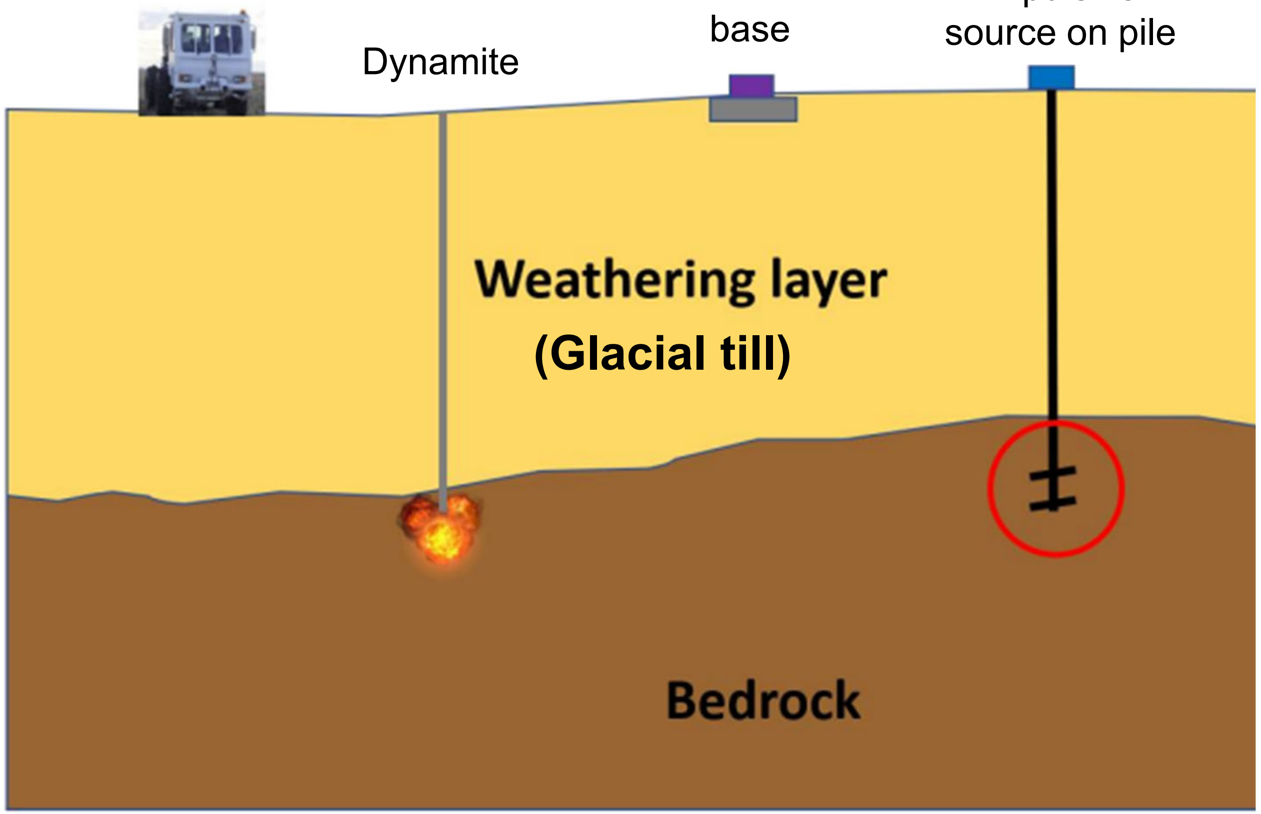
- Impulse or sweep transmitted to steel toe couple to bedrock
- Avoid reverberations & attenuation in weathering layer
- Avoid surface & near-surface repeatability problems from rain, drought, freeze, thaw



Adapted from Lawton et al. (2020)

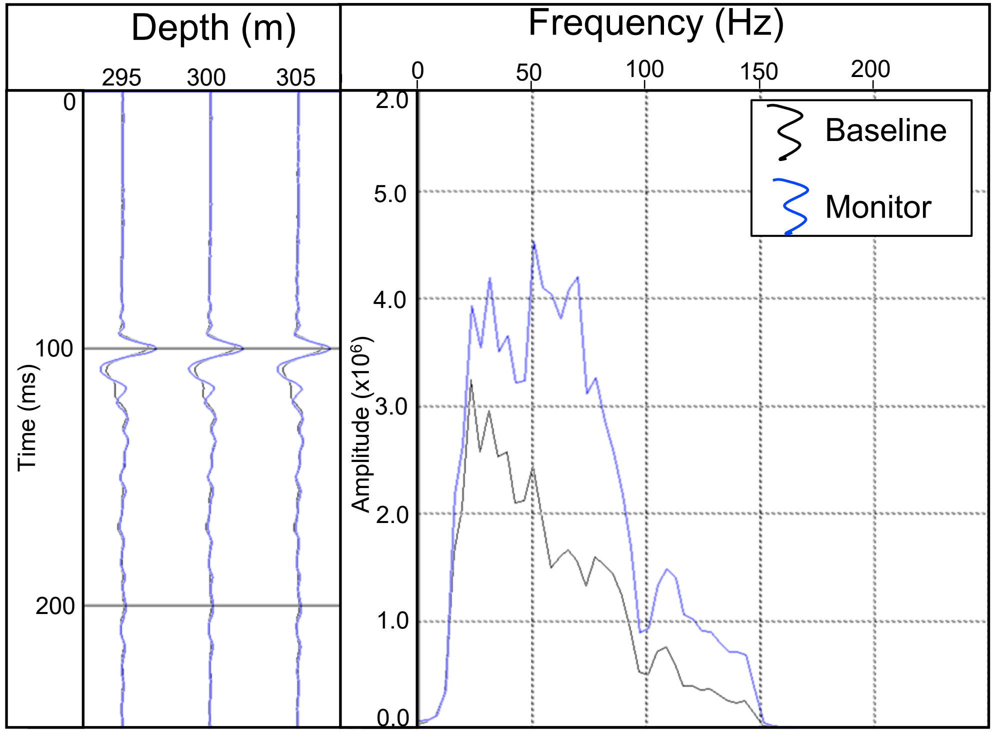
Steel helical pile as source location

- Impulse or sweep transmitted to steel toe couple to bedrock
- Avoid reverberations & attenuation in weathering layer
- Avoid surface & near-surface repeatability problems from rain, drought, freeze, thaw



Adapted from Lawton et al. (2020)

Example of vibroseis surface shots

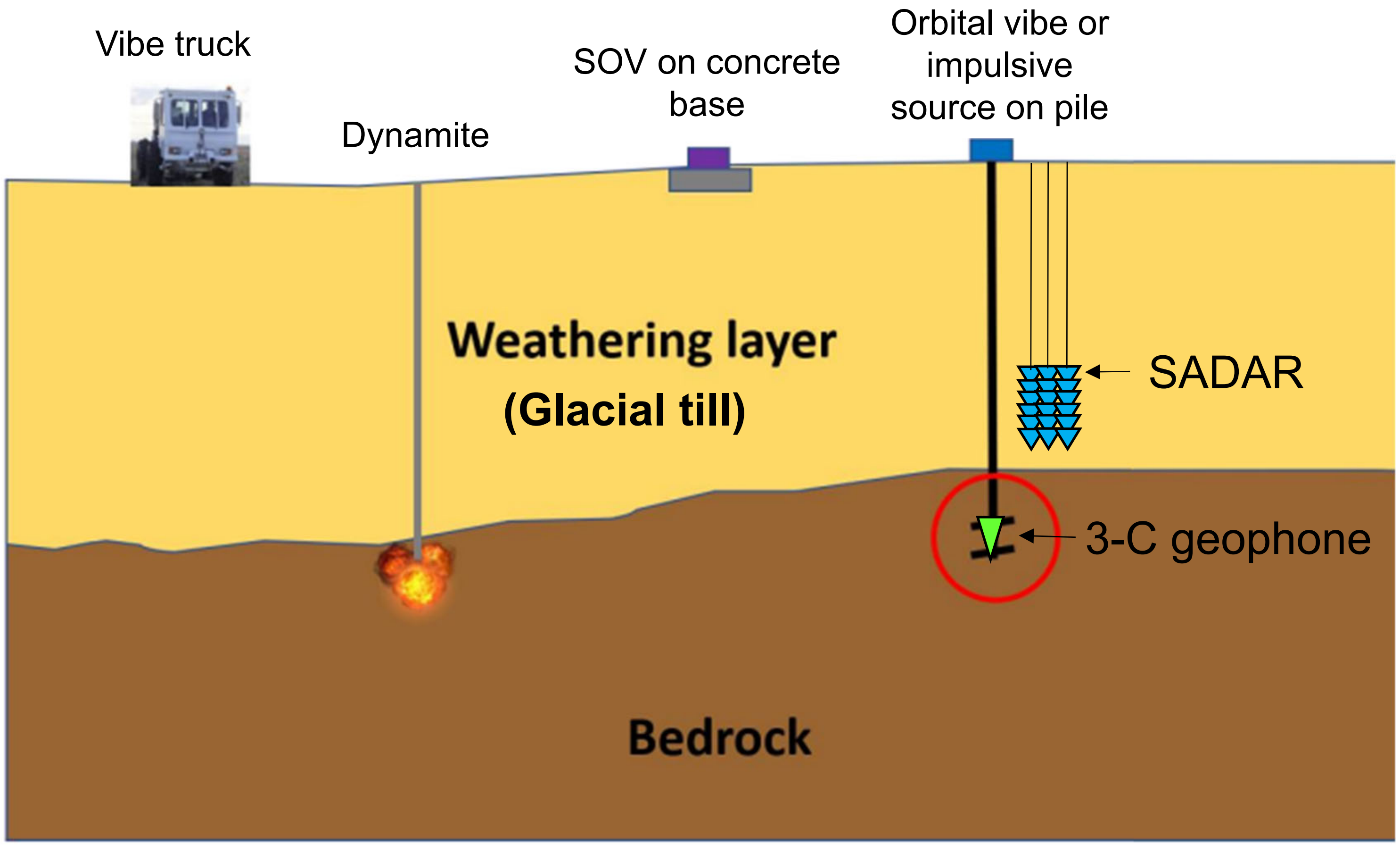


Direct arrivals (borehole geophones)

Amplitude spectra

Steel helical pile as source location

- Impulse or sweep transmitted to steel toe couple to bedrock
- Avoid reverberations & attenuation in weathering layer
- Avoid surface & near-surface repeatability problems from rain, drought, freeze, thaw



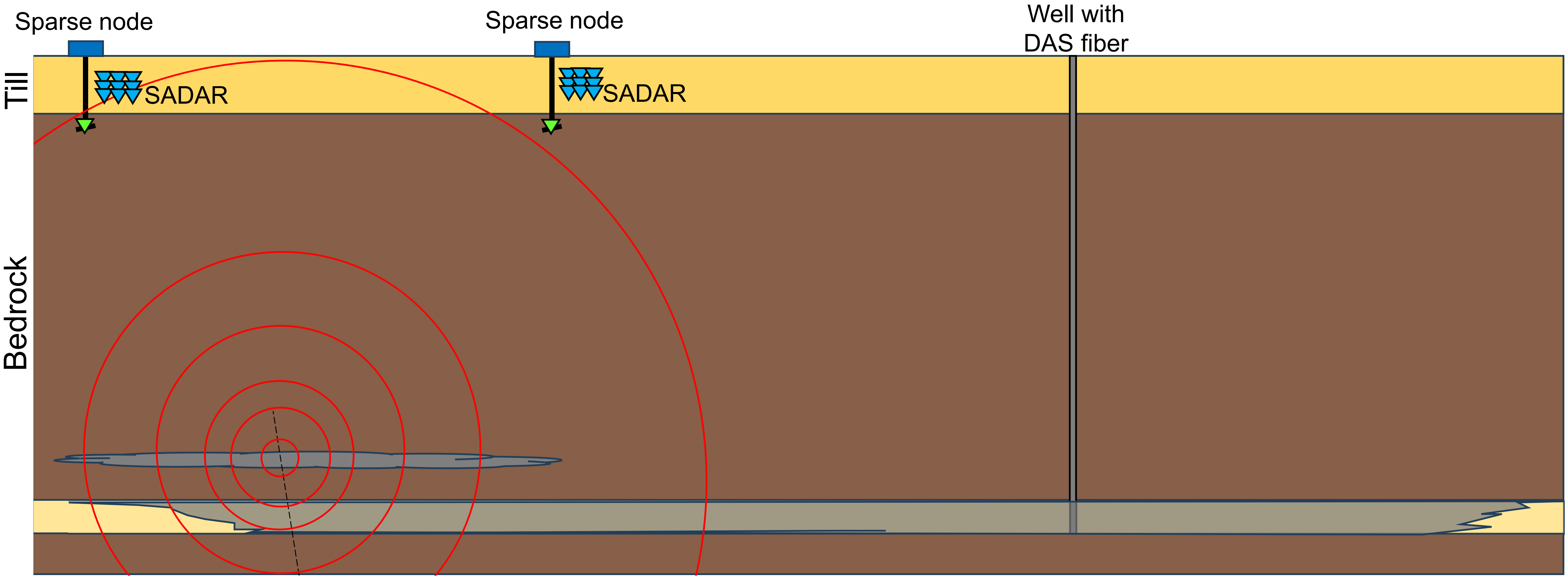
Adapted from Lawton et al. (2020)

Geospace SADAR arrays (Zhang et al., 2023):
- Volumetric phased array
- Multiple 1-C receivers
- Beam-forming

Future screwpiles: 3-C geophone at base
- Record source signature
- Evaluate screw pile transfer function
- Passive & active seismic receiver

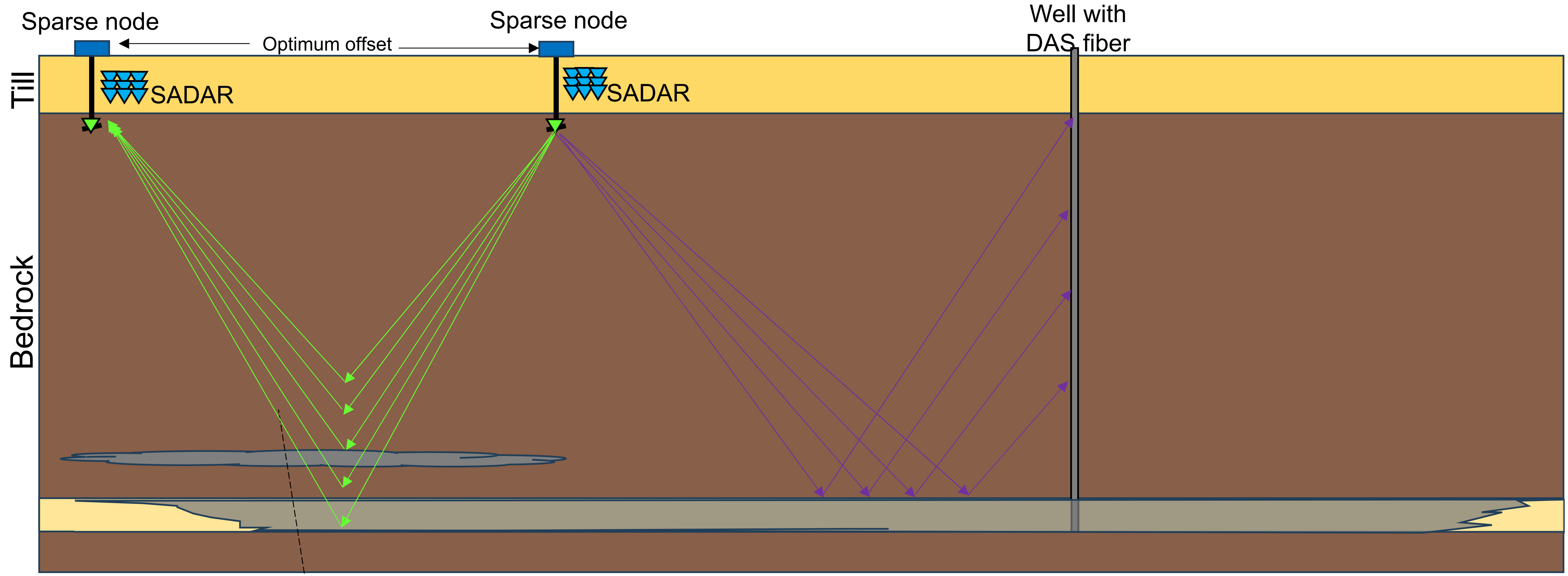
Sparse node concept

- VSP lateral coverage limited to 0.5-1x well depth
- Sparse sources provide both VSP shot gathers & reflection CMPs between nodes
- Passive seismic sensors (Geospace SADAR, geophones, broadband seismometers)



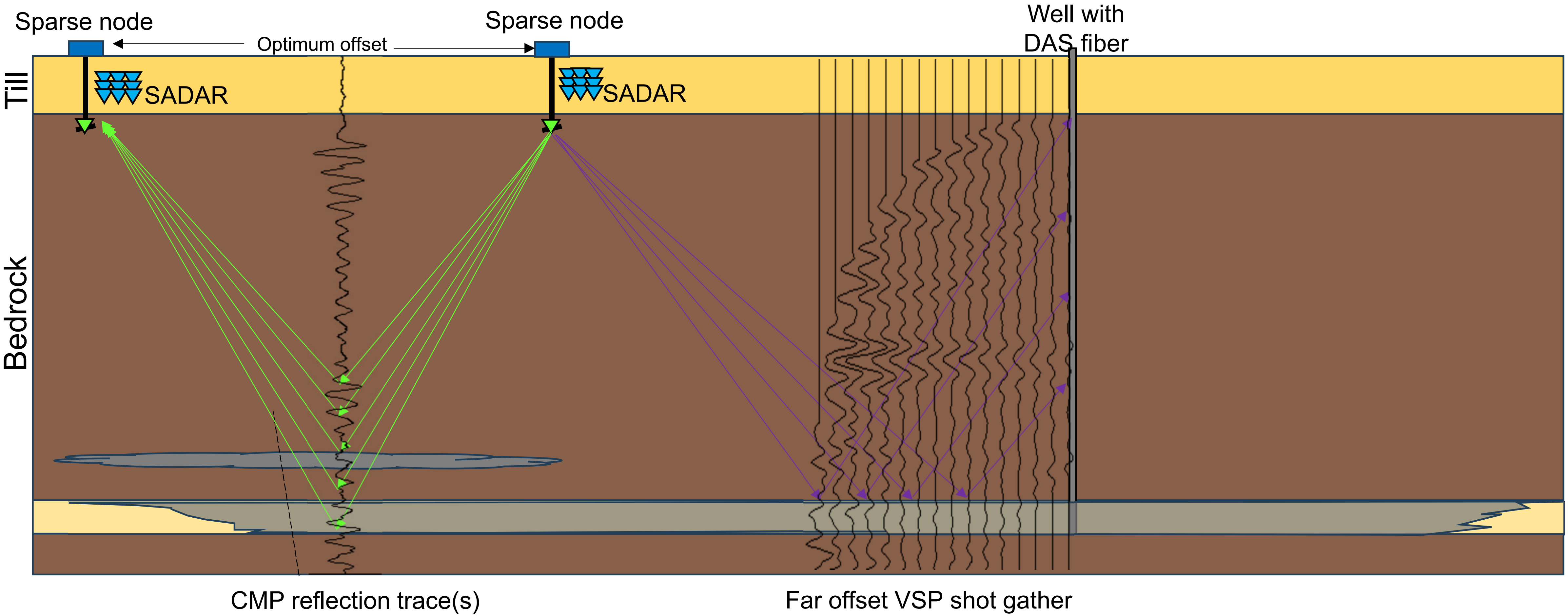
Sparse node concept

- Receivers deep in unconsolidated layer or planted in bedrock
- Dual use: Passive & active-source monitoring avoiding near-surface effects
- Frequent (daily, weekly), highly repeatable source on permanent source point



Sparse node concept

- Receivers deep in unconsolidated layer or planted in bedrock
- Dual use: Passive & active-source monitoring avoiding near-surface effects
- Frequent (daily, weekly), highly repeatable source on permanent source point

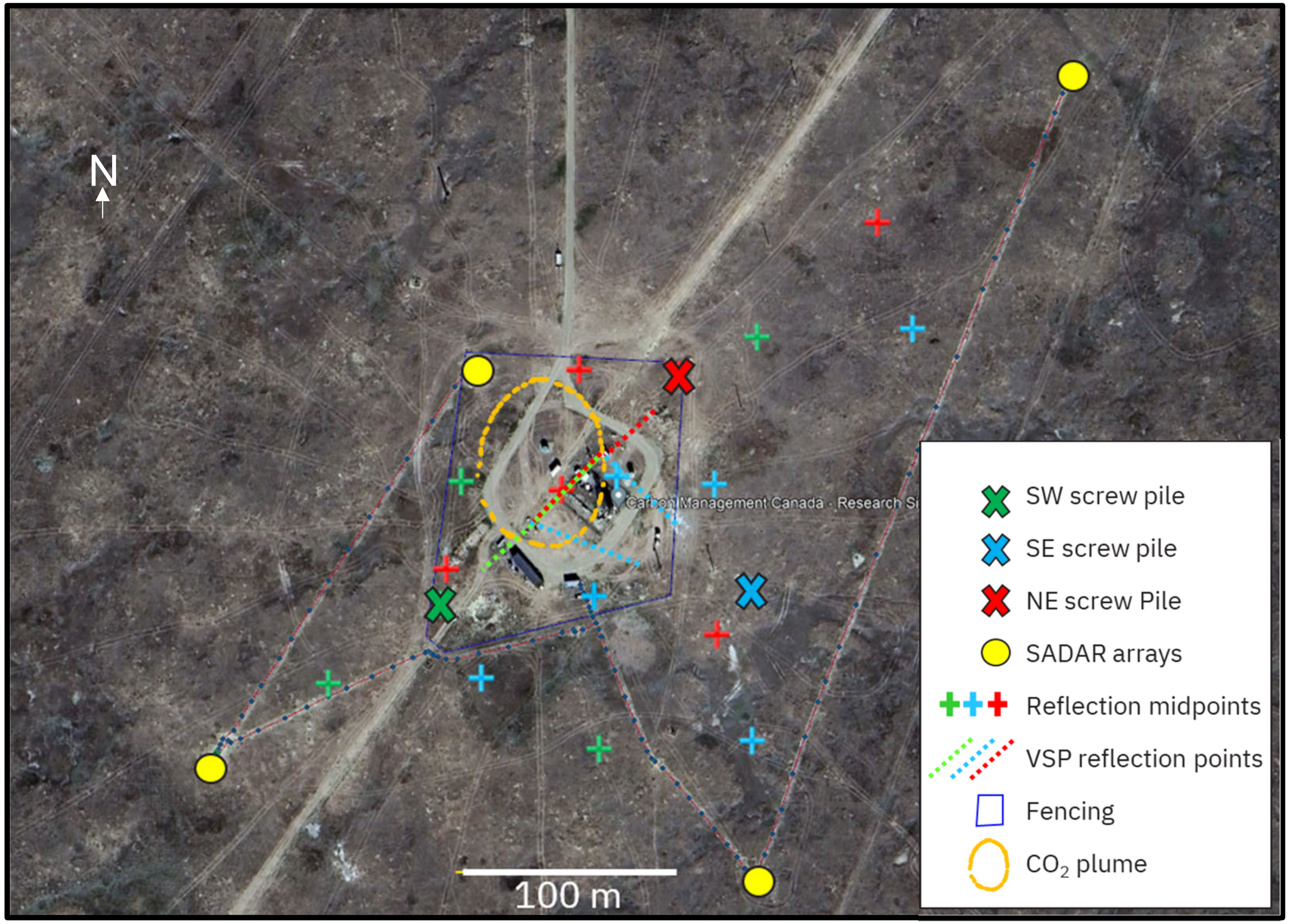


Sparse nodes at CMC's Newell County Facility

- Excellent source & receiver repeatability
- Energetic sources, sensitive receivers for 0.5 to 5 km offsets
- Automated & remotely controlled
- Precise GPS timing
- Trigger target-oriented active seismic surveys if/when needed
- Cost-effective relative to conventional 2D/3D acquisition
- Low-maintenance

Semi-permanent (portable) sources mounted on steel screw-piles (Hyfold, GPUSA)

Permanent receivers (Geospace SADAR arrays, INOVA 3-C geophones)

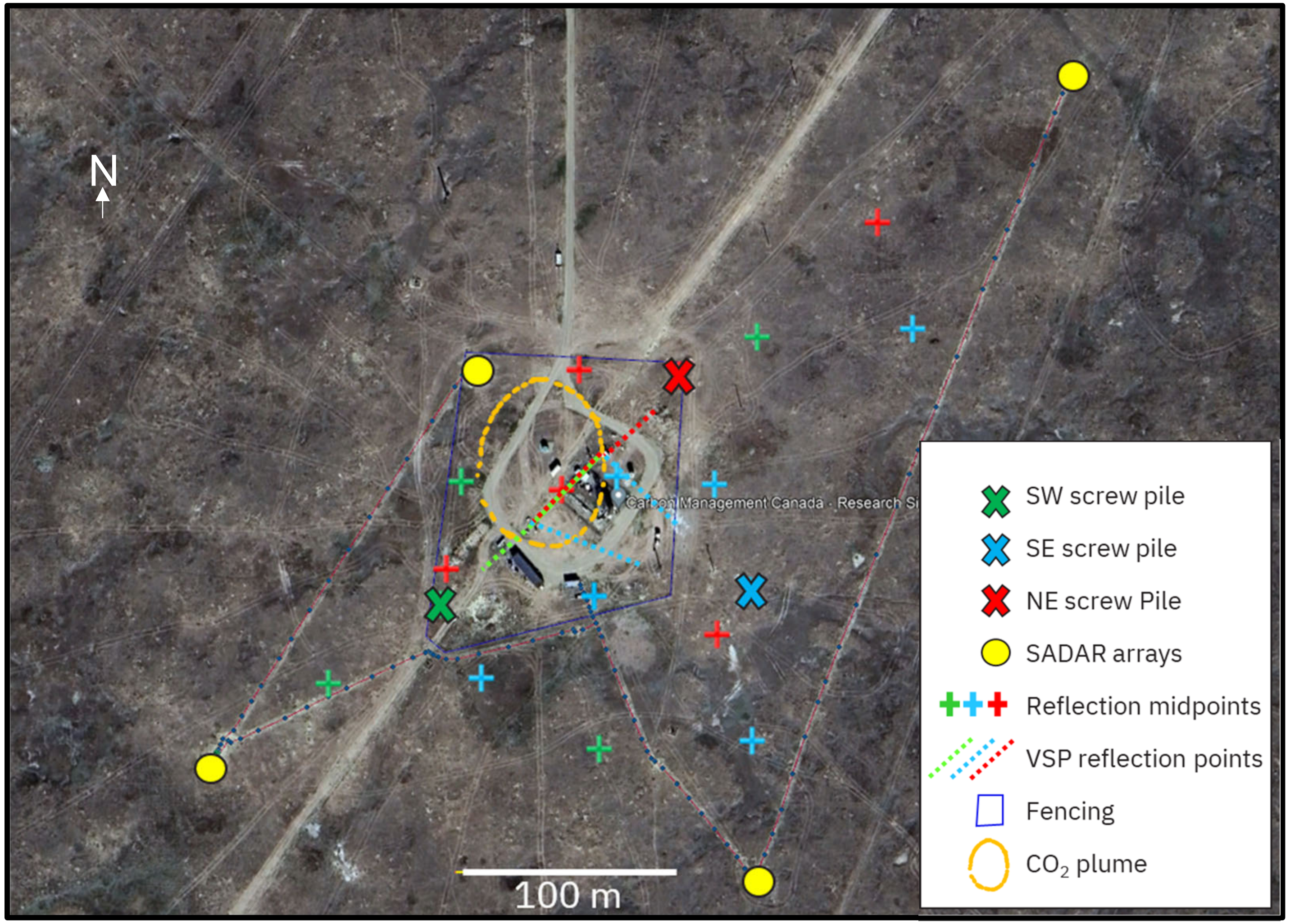


Sparse nodes at CMC's Newell County Facility

- Excellent source & receiver repeatability
- Energetic sources, sensitive receivers for 0.5 to 5 km offsets
- Automated & remotely controlled
- Precise GPS timing
- Trigger target-oriented active seismic surveys if/when needed
- Cost-effective relative to conventional 2D/3D acquisition
- Low-maintenance

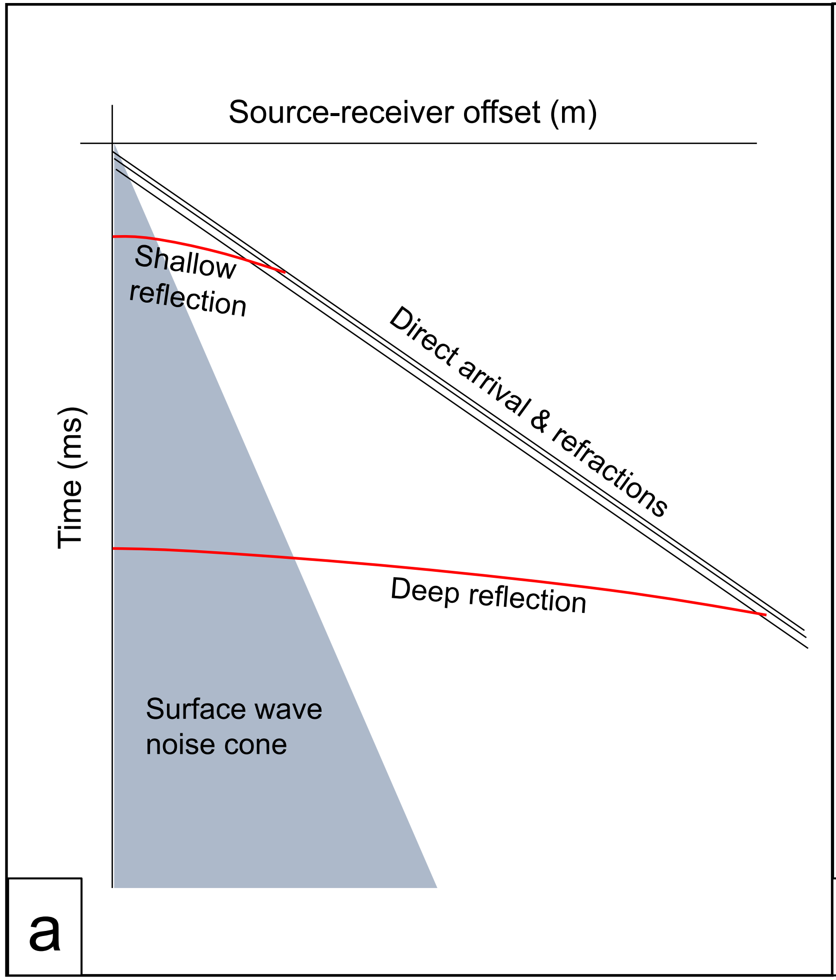
Semi-permanent (portable) sources mounted on steel screw-piles (Hyfold, GPUSA)

Permanent receivers (Geospace SADAR arrays, INOVA 3-C geophones)

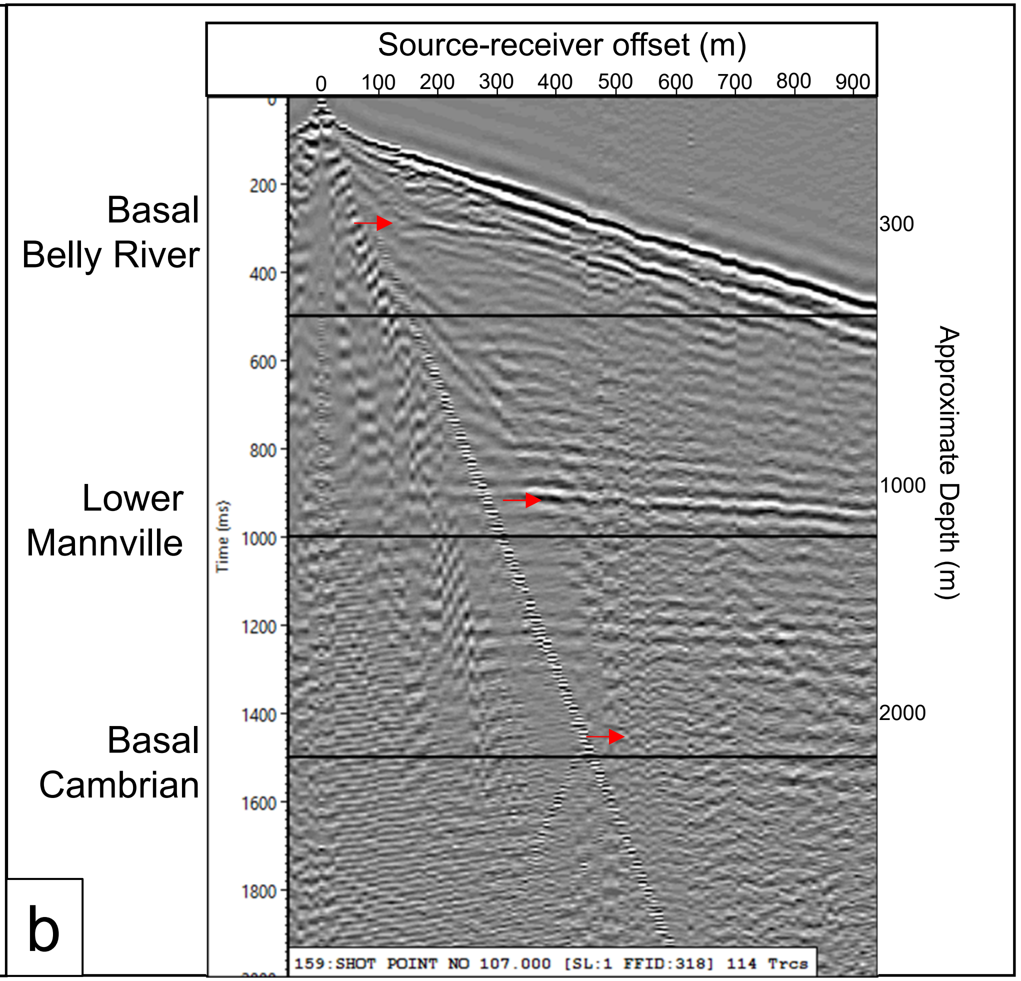


Optimum offset

- Nodes spaced at optimum offset to avoid ground roll, refraction head waves (Hunter & Pullan, 1989)
- Node spacing approximately ~0.5x to 1.5x reservoir depth



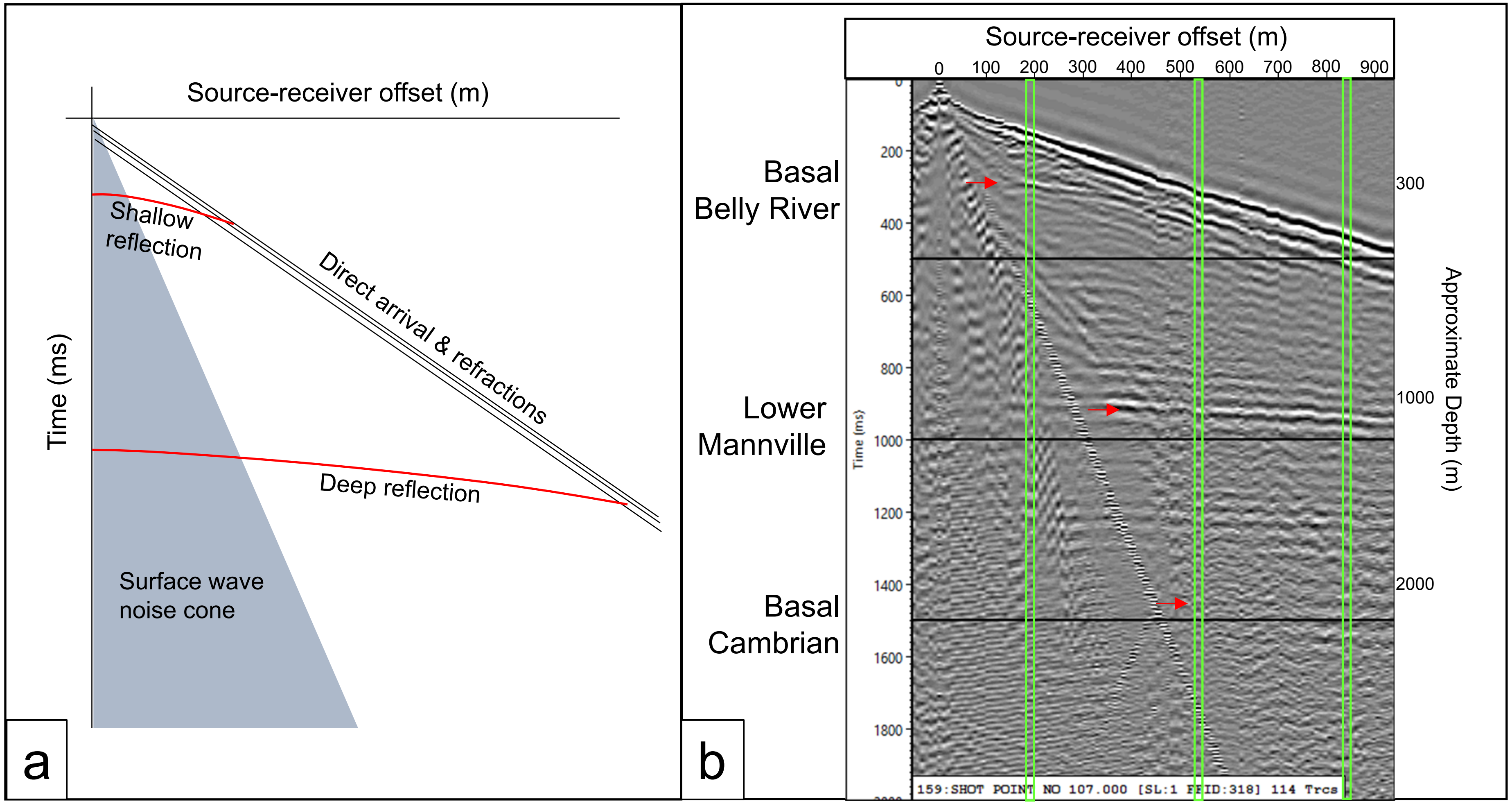
Adapted from Hunter & Pullan (1989)



Surface 2D common shot gather

Optimum offset

- Nodes spaced at optimum offset to avoid ground roll, refraction head waves (Hunter & Pullan, 1989)
- Node spacing approximately ~0.5x to 1.5x reservoir depth



Adapted from Hunter & Pullan (1989)

Surface 2D common shot gather

GPUSA linear orbital vibrator

- Surface Orbital Vibrators (SOV) not currently functional – to be serviced and installed Q2 2024
- Counter-rotation generates net vertical force (Spackman, 2019)
- 100 Hz – 200 Hz maximum frequency (depending on model)

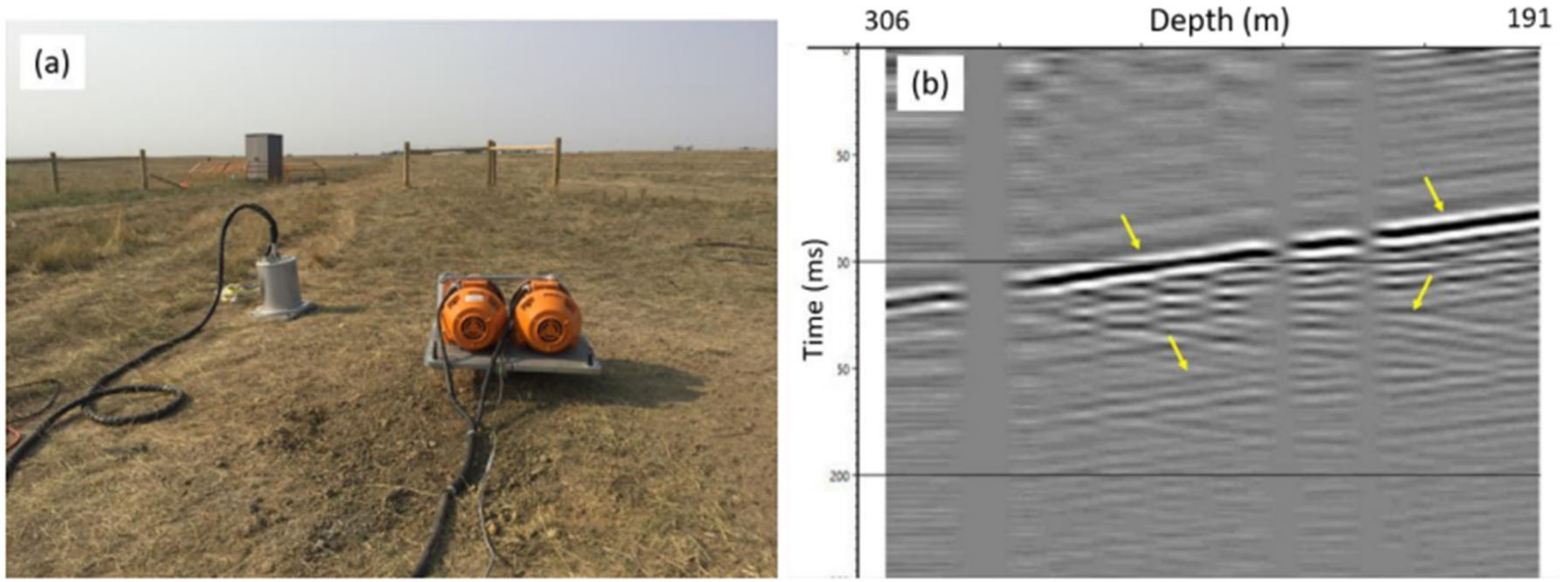


FIG. 5. (a) GPUSA linear vibes at site and (b) correlated VSP shot gather from the smaller of the GPUSA sources.

Lawton et al., 2020

U of C vibe truck on pedestal

- Ad hoc test to determine *maximum* possible frequency from helical pile (20 Hz – 300 Hz sweep)
- Vibe plate was centered and stable on the pedestal
- 10%-15% power with minimum hold down pressure to avoid damaging the pile

Thumper source (CREWES, U of C)

- 100 kg hammer accelerated by compressed nitrogen (Lawton et al., 2013)
- Designed for surface acquisition, but tested ad hoc on the helical pile pedestal
- 400 – 1000 psi tested

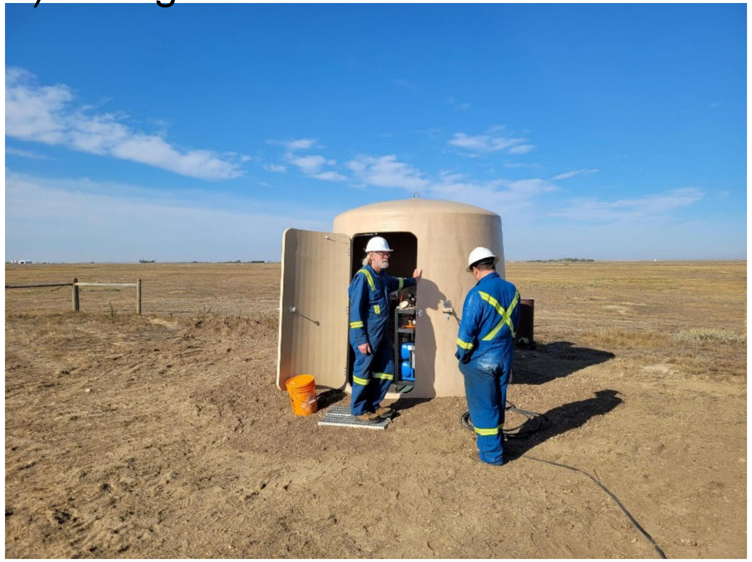
FIG. 2. The USAInc compressed nitrogen accelerated weight-drop source as delivered.
Lawton et al., 2013

Kevin Bertram (CREWES) operating the thumper at CMC's Newell County Facility

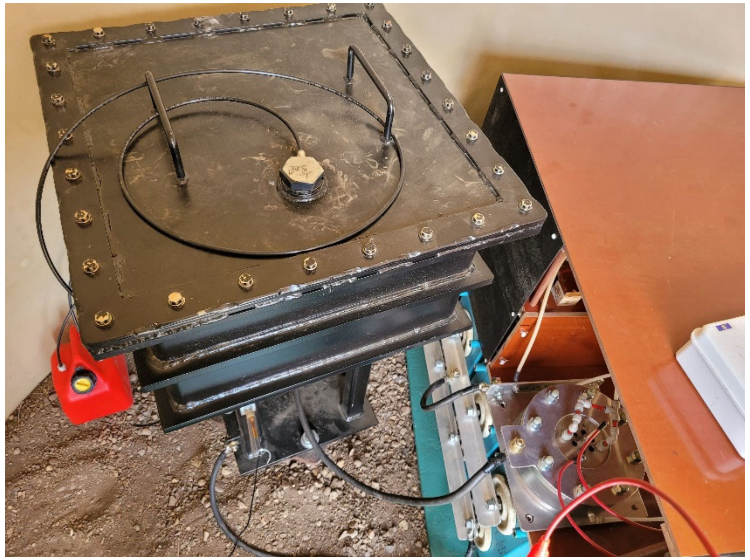
Hyfold plasma source

- Electrically powered, high voltage plasma-discharge impulsive source
- Bolted to pedestal & sheltered with fiberglass shelter
- Programmable shot intervals (2 s minimum)
- Operational in winter temperatures (e.g. -35^{0}C)

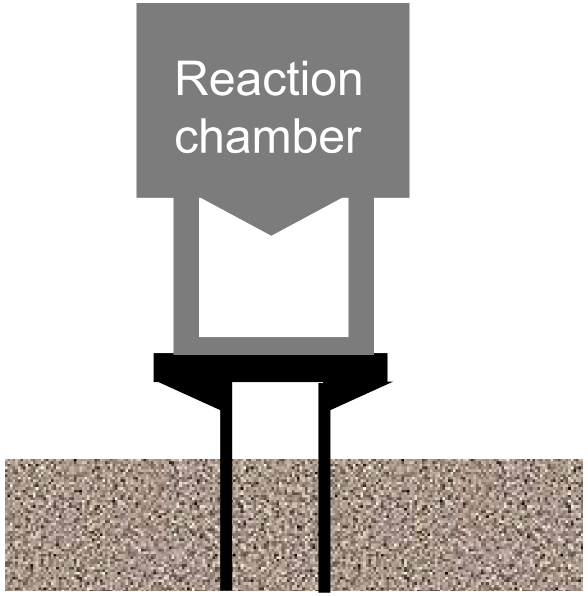
A) Fiberglass shelter for instrumentation



B) Hyfold bolted to pedestal (seen from above)



C) Schematic of source bolted to pedestal



Representative (not exact) example of plasma source (Lawton et al., 2020)

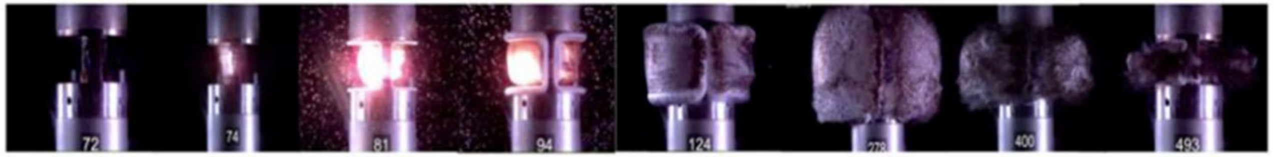
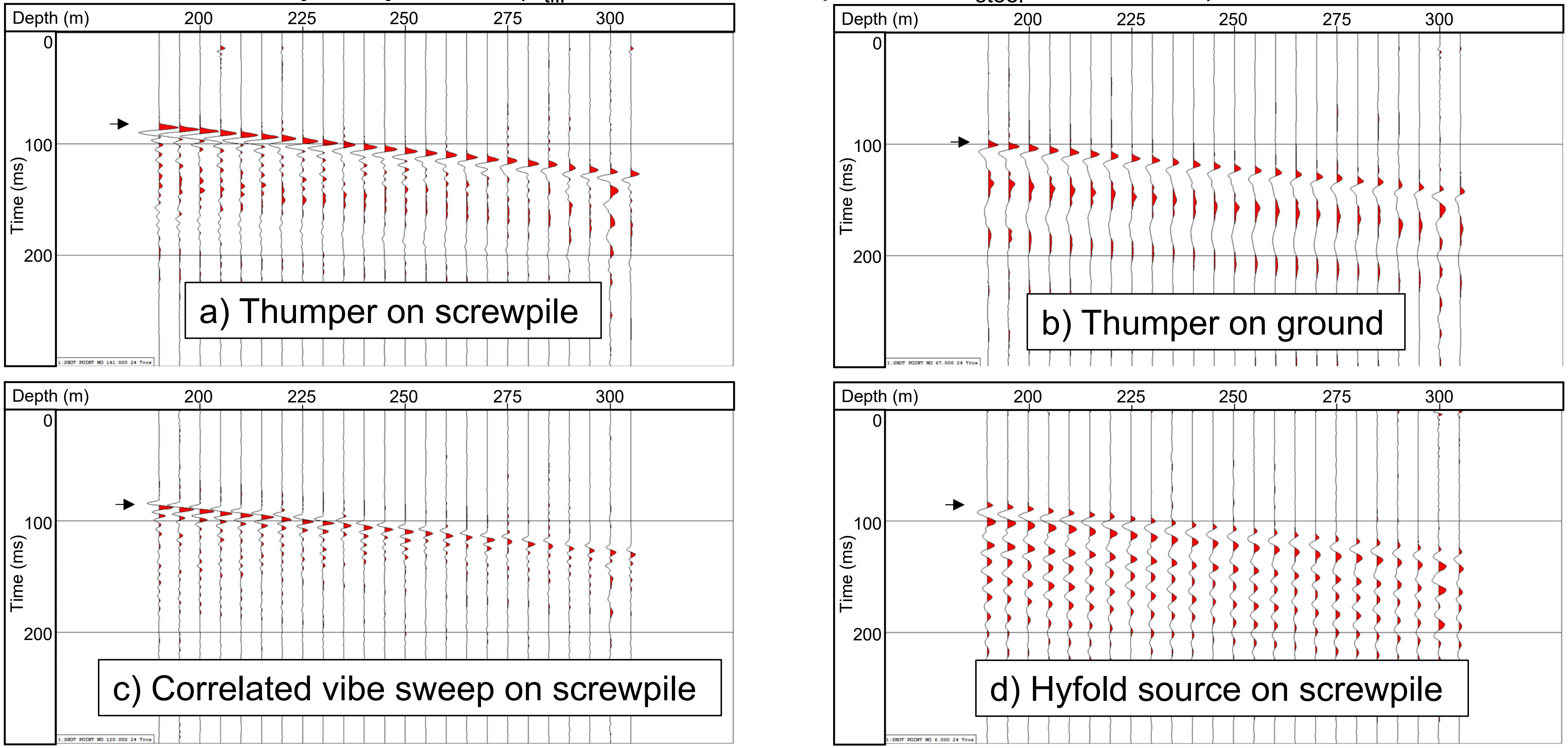


FIG. 7. High speed camera pictures of a duty cycle of the Squid source in the reactor chamber. The energy is generated by a fluid phase change in the reactor. Total duration is 250 ms.

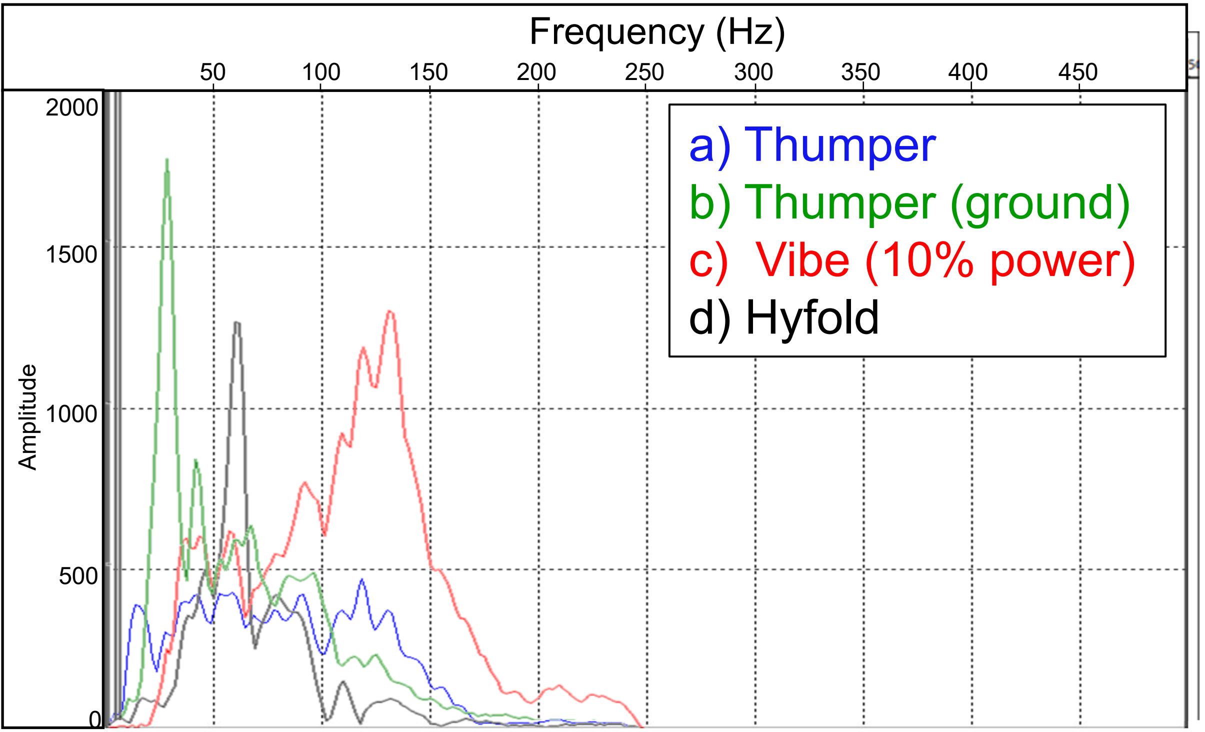
Raw borehole geophone gathers

- Thumper provided expected “front-loaded” impulse response
- Ground shot delayed by 15 ms (v_{till} = 1300 m/s compared to v_{steel} = 5800 m/s)

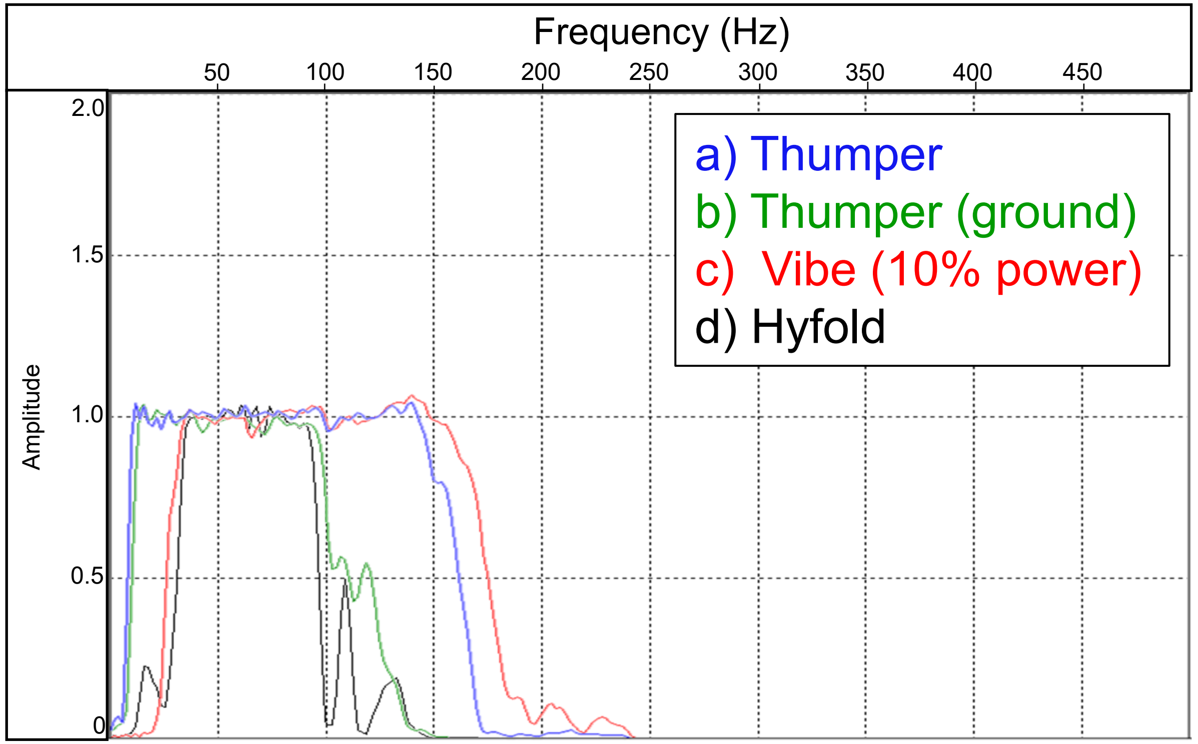


Deconvolved shot gather spectra

- Borehole data: Deterministic deconvolution mitigates unbalanced spectra
- Steel pile solves repeatability problems – bandwidth is a bonus
- Geophone at toe: - determine if transfer function exists
  -sparse node deterministic decon (instead of surface-consistent)



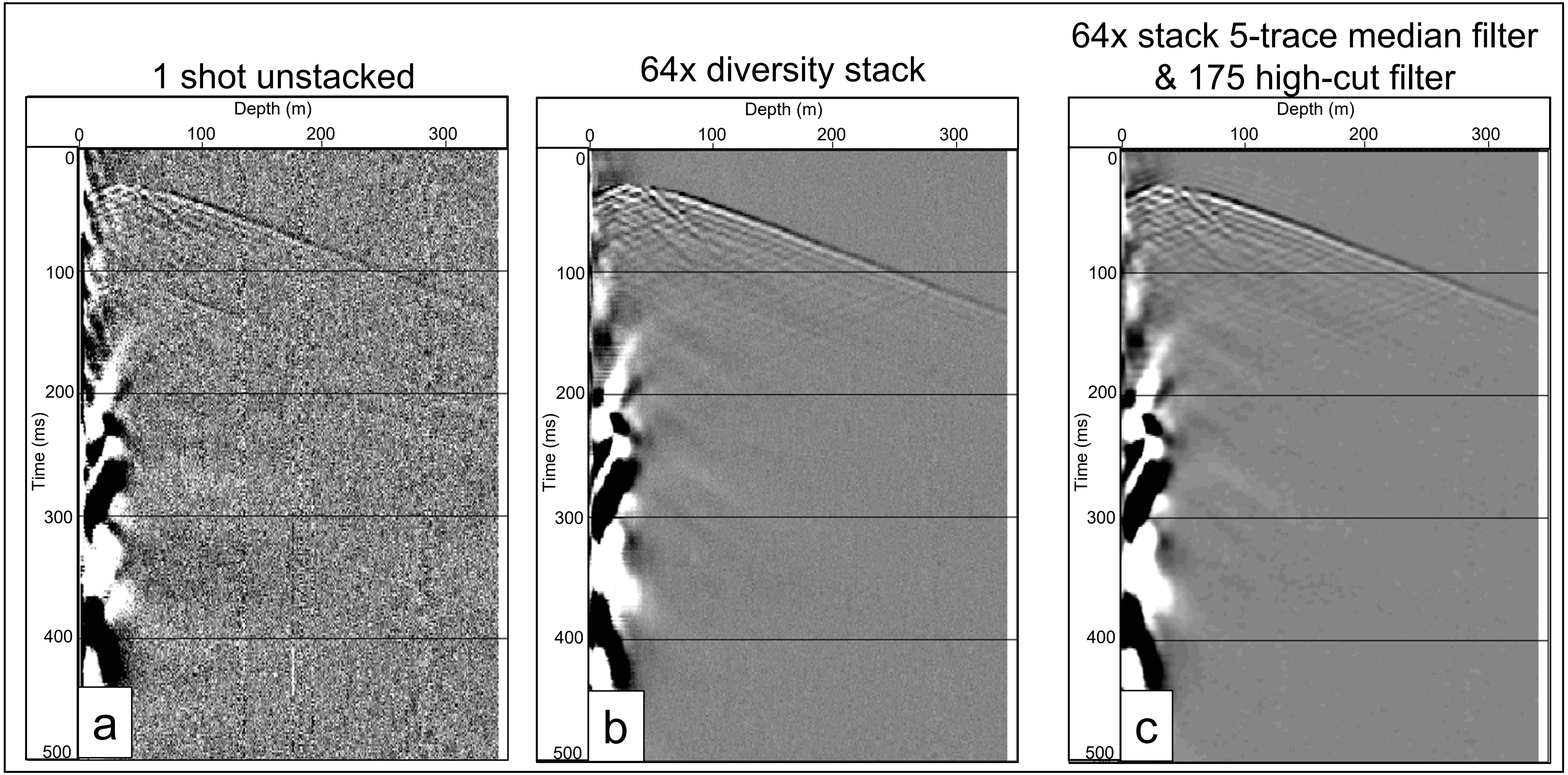
Raw borehole geophone amplitude spectra



Deconvolved amplitude spectra showing recoverable bandwidth

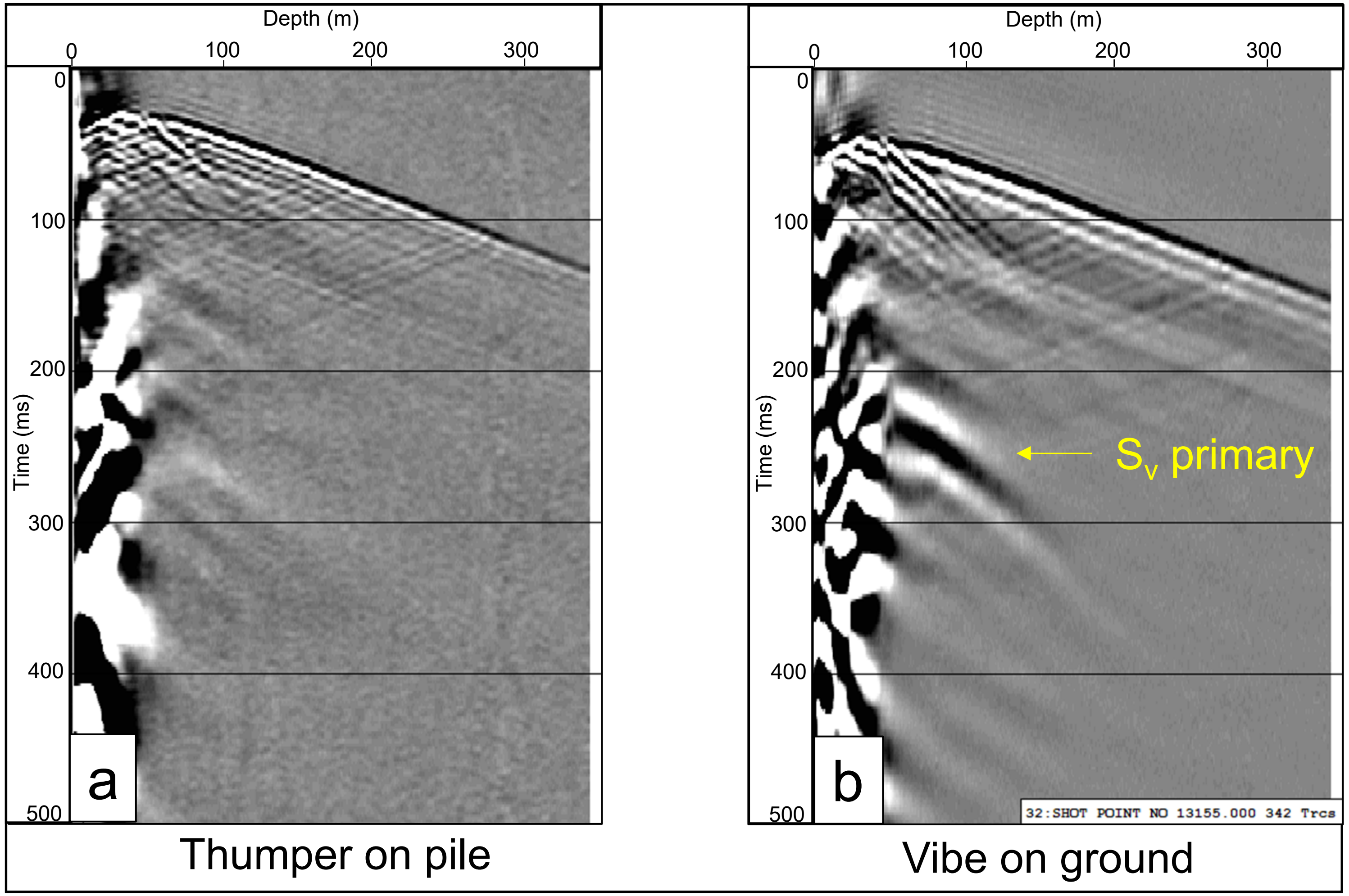
DAS shot gather (thumper on pile)

- SNR improved by stacking - practical limit on # shots before maintenance (unknown ~10^5?)
- Example: 100 shots per day = 36 500 shots per year



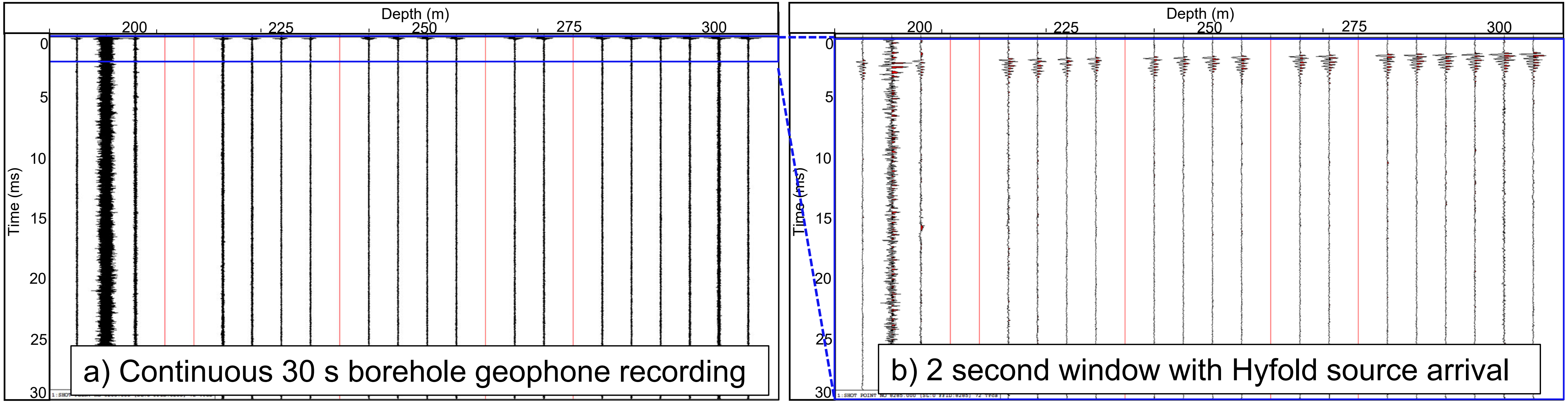
No primary shear waves from pile

- Vibroseis shots cause low-frequency primary shear waves on surface
- Broadband thumper shot on pile caused no clear primary shear waves



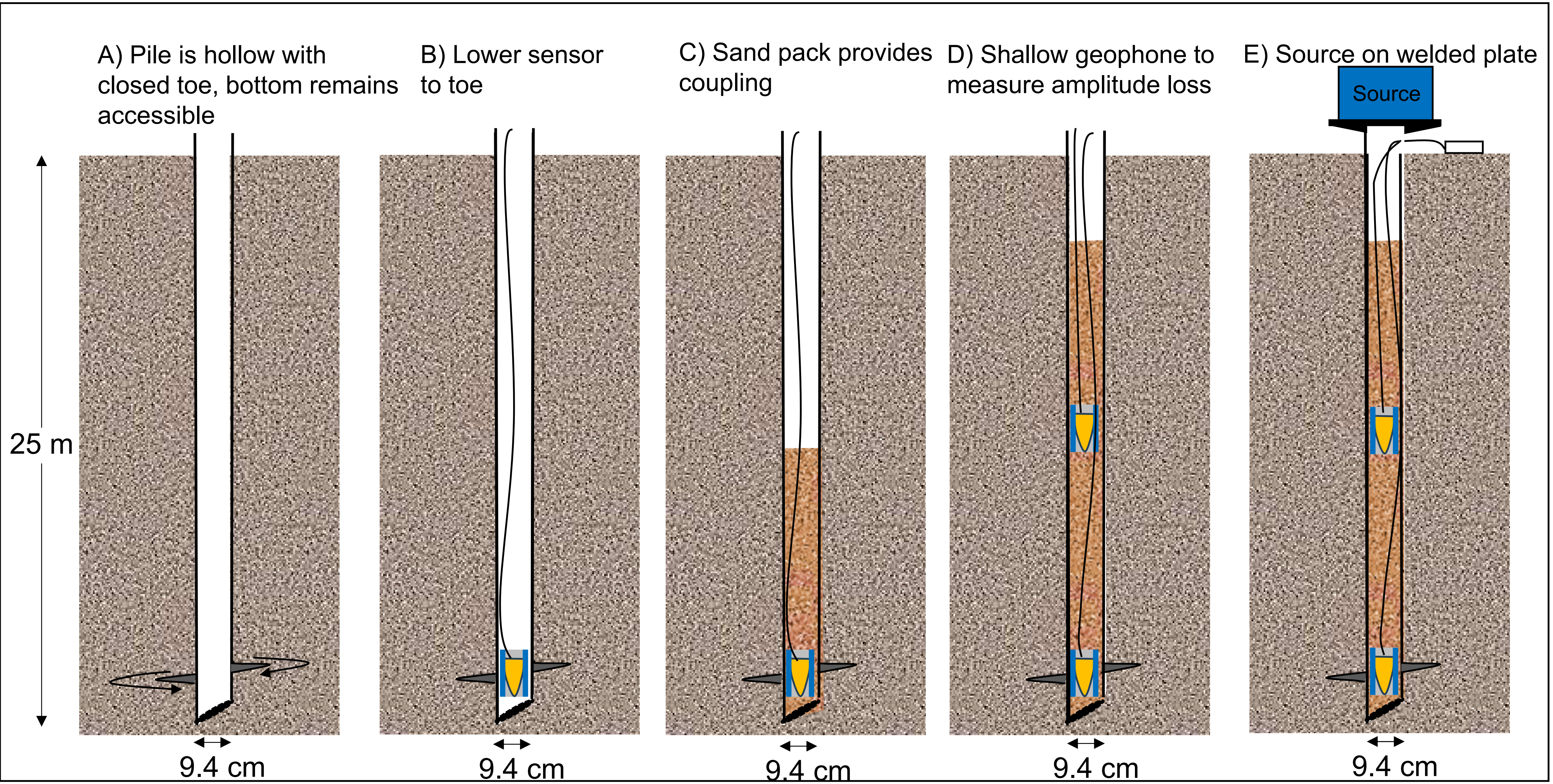
Hyfold source automation

- GPS controlled timing: PPS signal triggers source every 30 s (any interval > 2 s)
- Hyfold trigger signal-to-shot delay: 100 μs +/- 25 μs
- Continuous recording on borehole geophones (30 s), SADAR, and permanent surface geophones
- 2nd iteration of Hyfold source to be installed December 2023 or January 2024 (more impulsive)



Screwpile source & receiver design

- Dual purpose geophone: Record source impulse at toe & act as 3-C high SNR permanent receiver



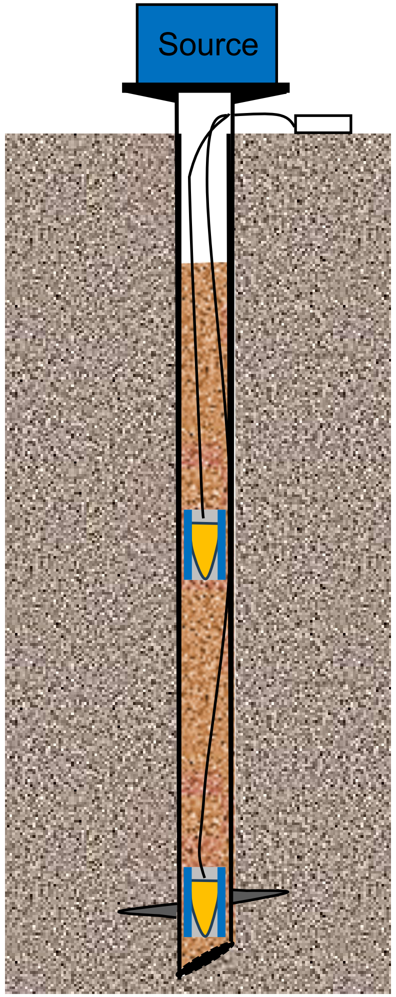
Screwpile behaviour

Observations
- Broadband signal transmission
- P-wave point source at sedimentary bedrock
- Excellent signal repeatability
- No evident resonance effects

Expectations
- Negligible seasonal change on source signature

Unknowns
- Resonance
- Transmission loss, attenuation in screw pile
- Other transfer function effects
- Ghosting/surface multiple effects

Future work
- New instrumented screw piles
- Longitudinal, daily acquisition
- Source & receiver automation



CMC Newell County Facility JIP Subscribers

Supporters

References

Lawton, D. C., Gallant, E. V., Bertram, M. B., Hall, K. W., and Bertram, K. L., 2013, A new S-wave seismic source: *CREWES Research Report*, **25**, 51, 6.

Lawton, D. C., Bertram, M. B., Hunter, T., Maidment, G., and Kolkman-Quinn, B., 2020, Squid: An innovative new ground-coupled electric seismic source for seismic monitoring: *CaMI.FRS Research Report*, **5.**

Spackman, T., 2019, Novel orbital seismic sources at a CO_2 storage monitoring site, Newell County, Alberta: M.Sc. Thesis, University of Calgary.

Zhang, J., Hutchenson, K., Nyffenegger, P., Grant, E., Jennings, J., Tinker, M., Macquet, M., Lawton, D. ; Performance comparison of compact phased arrays and traditional seismic networks for microseismic monitoring at a CO_2 sequestration test site. *The Leading Edge* 2023;; 42 (5): 332–342. doi: https://doi.org/10.1190/tle42050332.1.