# Shear wave arrivals in surface microseismic data

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# Why are S-waves not often documented from surface microseismic data?

Spectraseis

1. Are shear waves produced by hydraulic fracturing?
2. Can the S-wave energy released be enough to overcome attenuation?
3. Can the shear wave be recorded at the surface?

The answer to all these questions is **YES.**

**Recording shear waves at the surface requires the right equipment**

# Instrumentation necessary to observe S-waves

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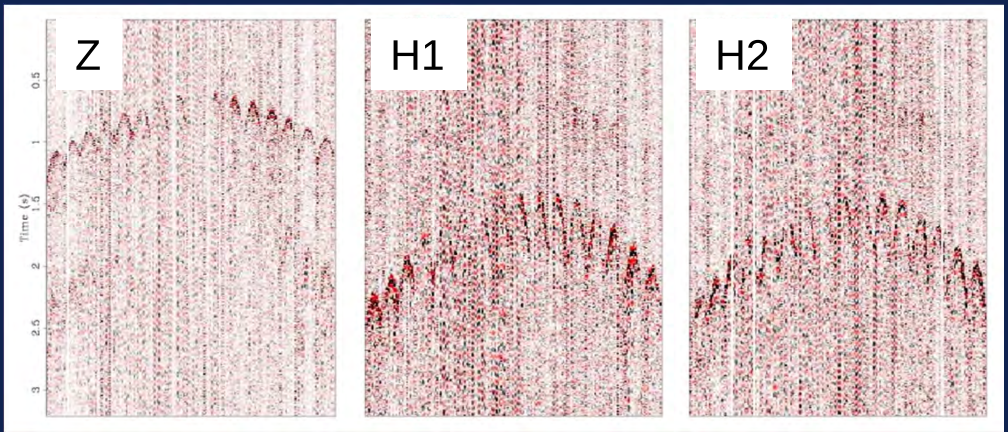
Three-component instruments

Most S-wave energy exists on the horizontal components

Broadband instruments

S-wave energy central frequency is < ½ of the P




**Recording S-waves decreases risks by capturing weaker microseisms and eliminating false positive**

# Overview

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Theory

Modeling

Data examples

- Mannville
- Montney
- Wolfcamp
- Mississippian Carbonate
- Eagle Ford

Using the S-waves

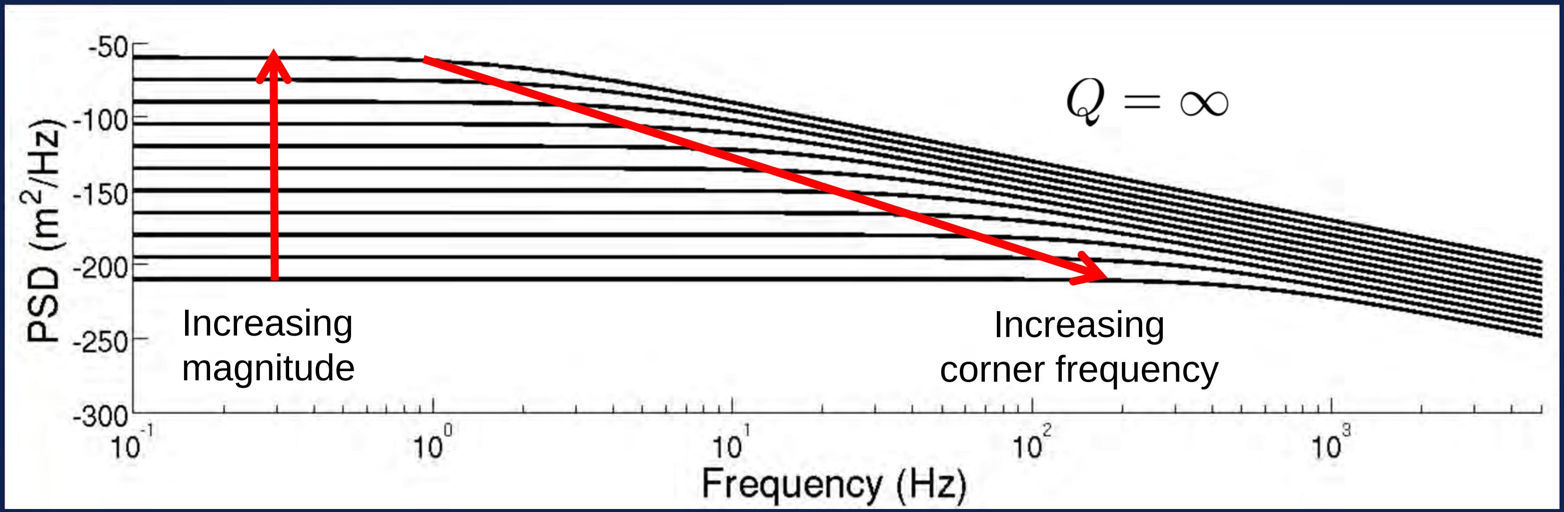
Summary

**Analytics, numerical, and data agree**

# Introduction

(micro)Seismology

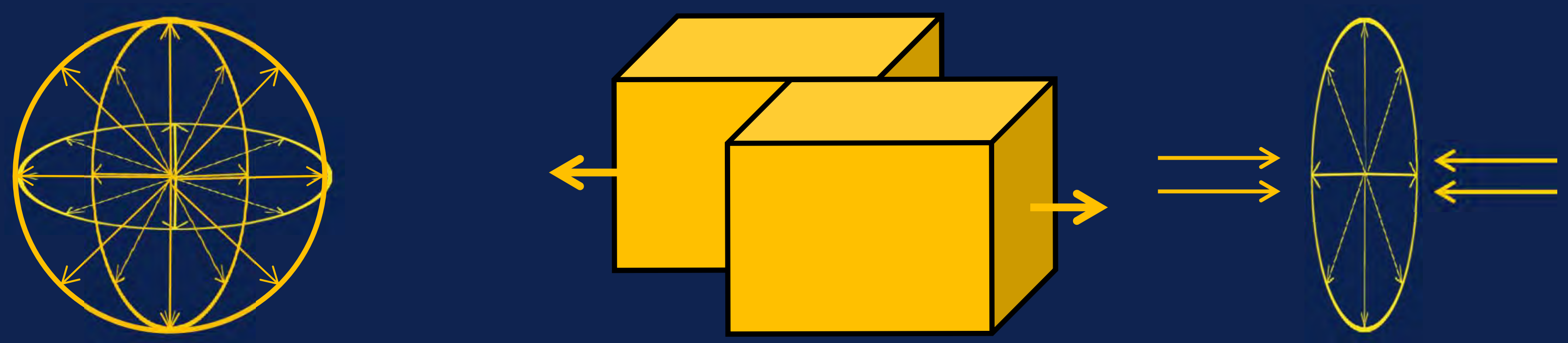
- All fractures produce compressional and shear waves
- Energy released in the from of shear waves is greater, often an order of magnitude, than compressional waves, for common fracture mechanisms
- All fractures release significant energy in the low frequency bands




**Corner frequency does not mean bandwidth**

# Fracture mechanisms

| Isotropic (explosion) | Double Couple (DC) | Compensated Linear Vector Dipole (CLVD) |
|---|---|---|



| P-waves only | P- and S-waves | P- and S-waves |
|---|---|---|

**All fractures can be decomposed into these three mechanisms**

# Are strong shear waves produced by hydraulic fracturing?

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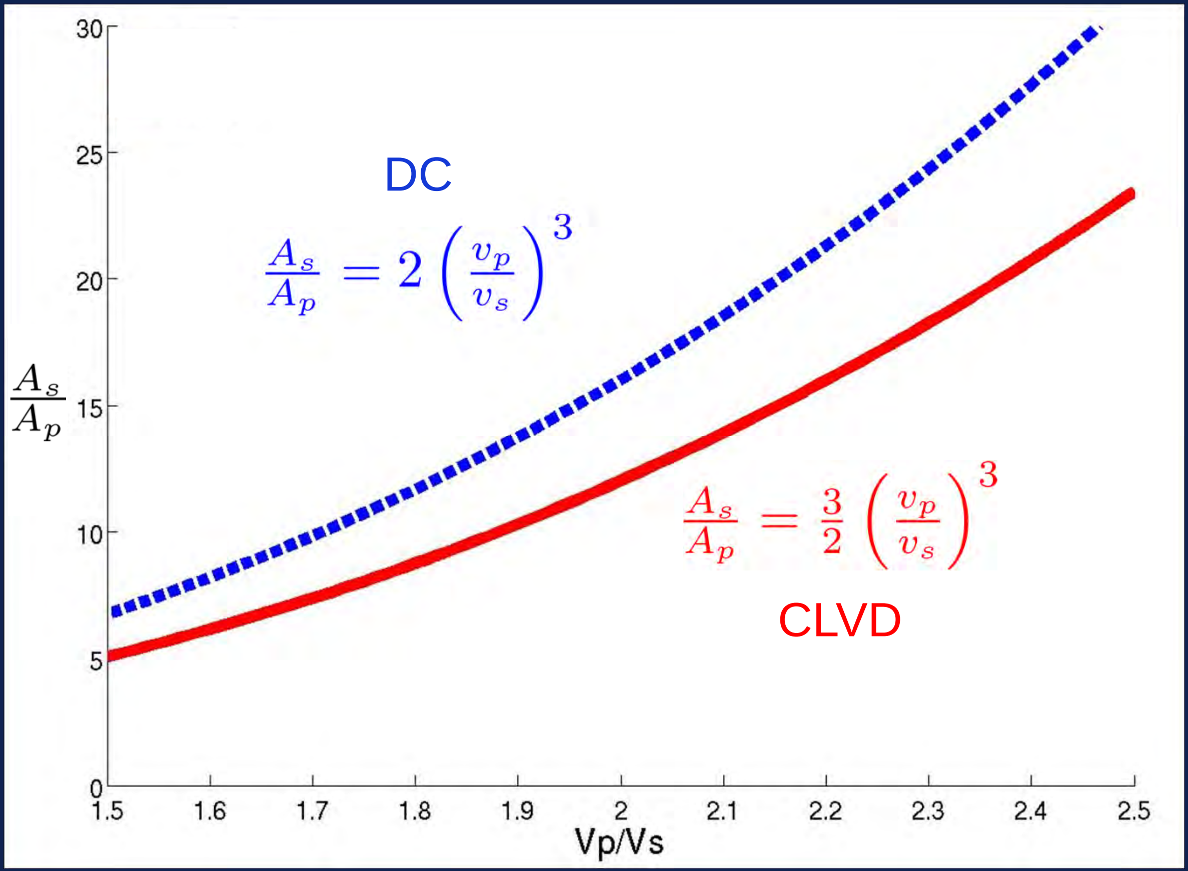
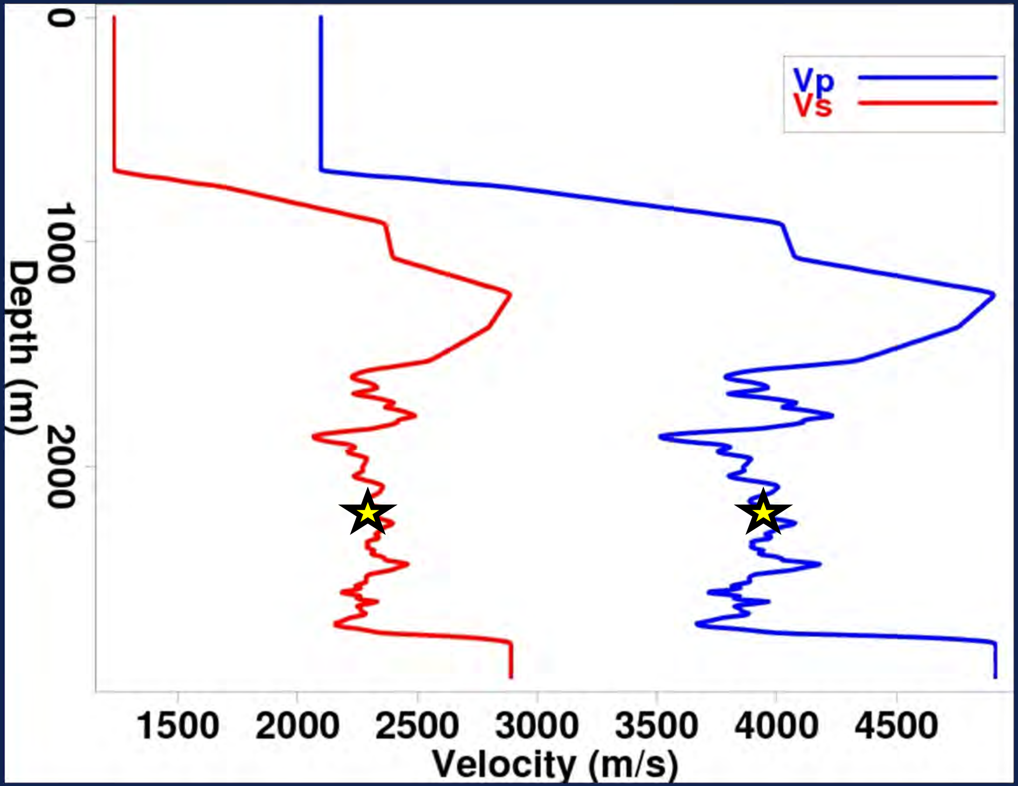



Average amplitude over the unit sphere is a function of Vp/Vs ratio

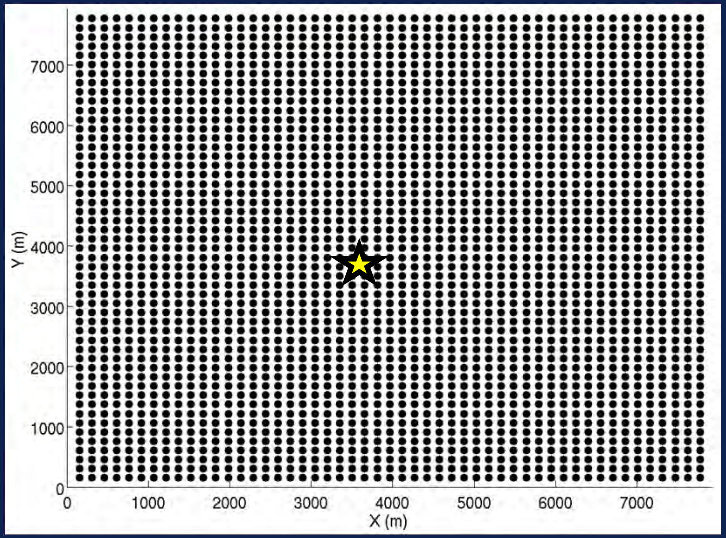
**Theory predicts that S-wave energy dominates**

# Numerical modeling

Velocity model




Surface array




$$Q_p = Q_s = 100$$

**Elastic propagation of a DC and CLVD source from the starred location**

# Are strong shear waves produced by hydraulic fracturing?

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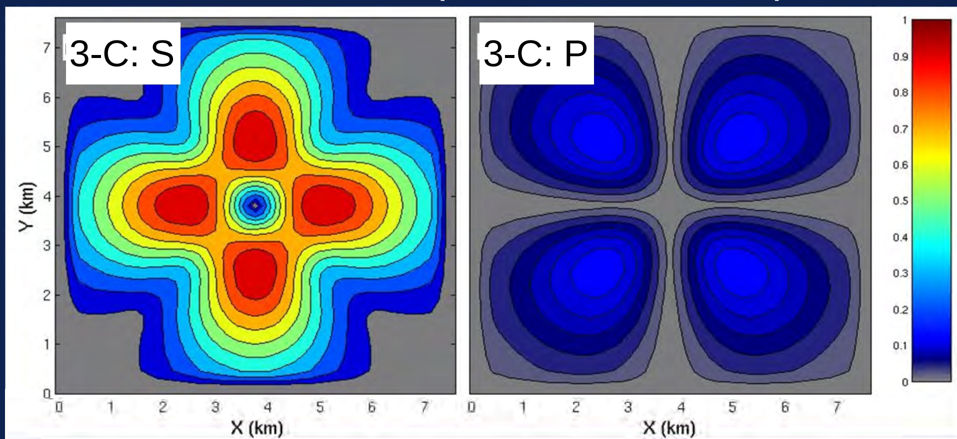
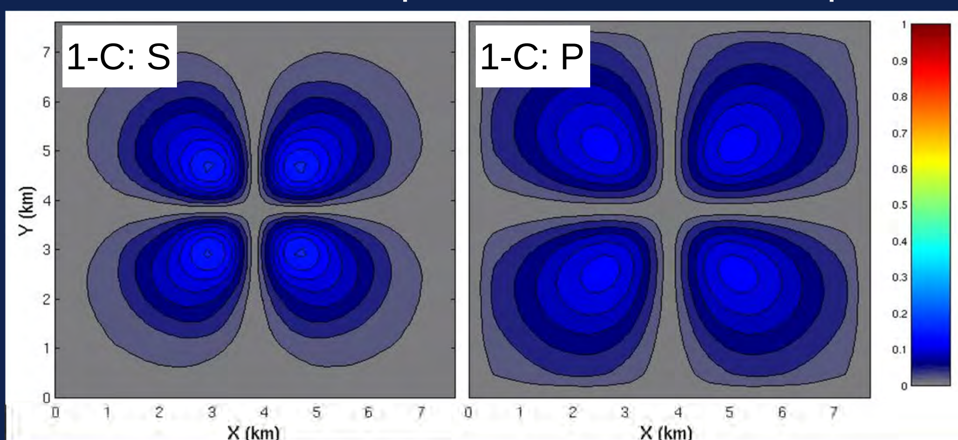
Normalized RMS amplitude for all components




Normalized RMS amplitude for vertical component




DC source

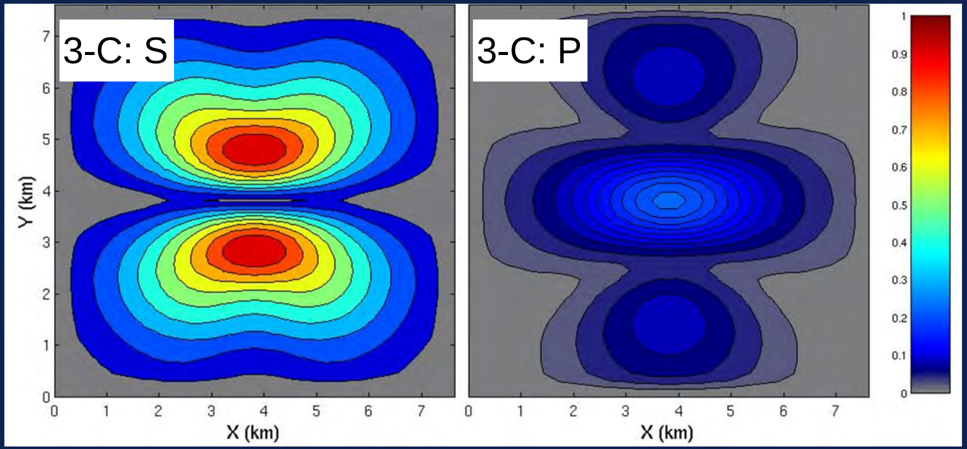
$$\begin{bmatrix} S_{xx} & S_{xy} & S_{xz} \\ S_{yx} & S_{yy} & S_{yz} \\ S_{zx} & S_{zy} & S_{zz} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

**Modeling predicts that S-wave energy dominates**

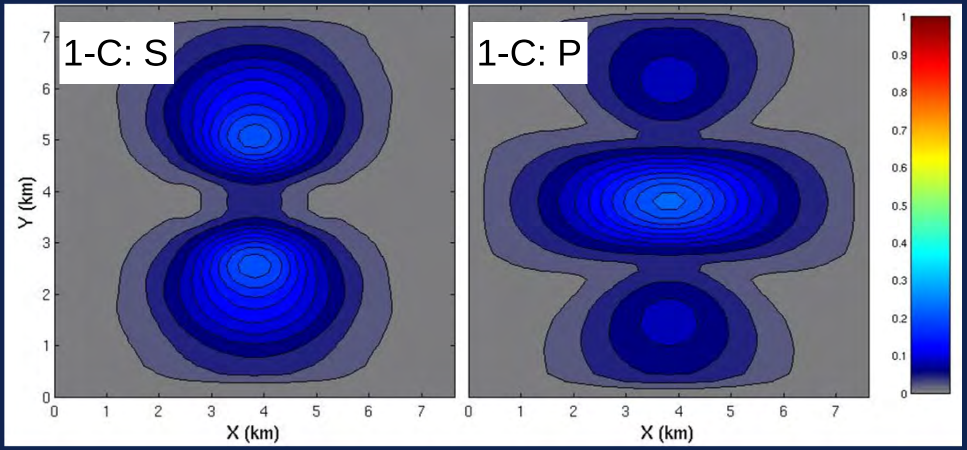
# Are strong shear waves produced by hydraulic fracturing?

Spectraseis

Normalized RMS amplitude for all components




Normalized RMS amplitude for vertical component




CLVD source

$$\begin{bmatrix} S_{xx} & S_{xy} & S_{xz} \\ S_{yx} & S_{yy} & S_{yz} \\ S_{zx} & S_{zy} & S_{zz} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -2 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

**When all 3 components are considered, S-wave has considerably more energy**

# Is the S-wave energy released enough to overcome attenuation?

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## DC

| $Q_s$ | Normalized S Amplitude |
|---|---|
| 100 | 9.26 |
| 50 | 7.28 |
| 25 | 4.69 |
| ⋮ | ⋮ |
| 12 | 2.08 |
| ⋮ | ⋮ |
| 9 | 1.33 |
| 8 | 1.08 |
| 7 | 0.84 |

| $Q_p$ | Normalized P Amplitude |
|---|---|
| 100 | 1.00 |

## CLVD

| $Q_s$ | Normalized S Amplitude |
|---|---|
| 100 | 4.39 |
| 50 | 3.46 |
| 25 | 2.25 |
| ⋮ | ⋮ |
| 13 | 1.13 |
| 12 | 1.01 |
| 11 | 0.77 |
| ⋮ | ⋮ |
| 7 | 0.41 |

| $Q_p$ | Normalized P Amplitude |
|---|---|
| 100 | 1.00 |

**It is geologically unreasonable for the entire column to have such low Qs**

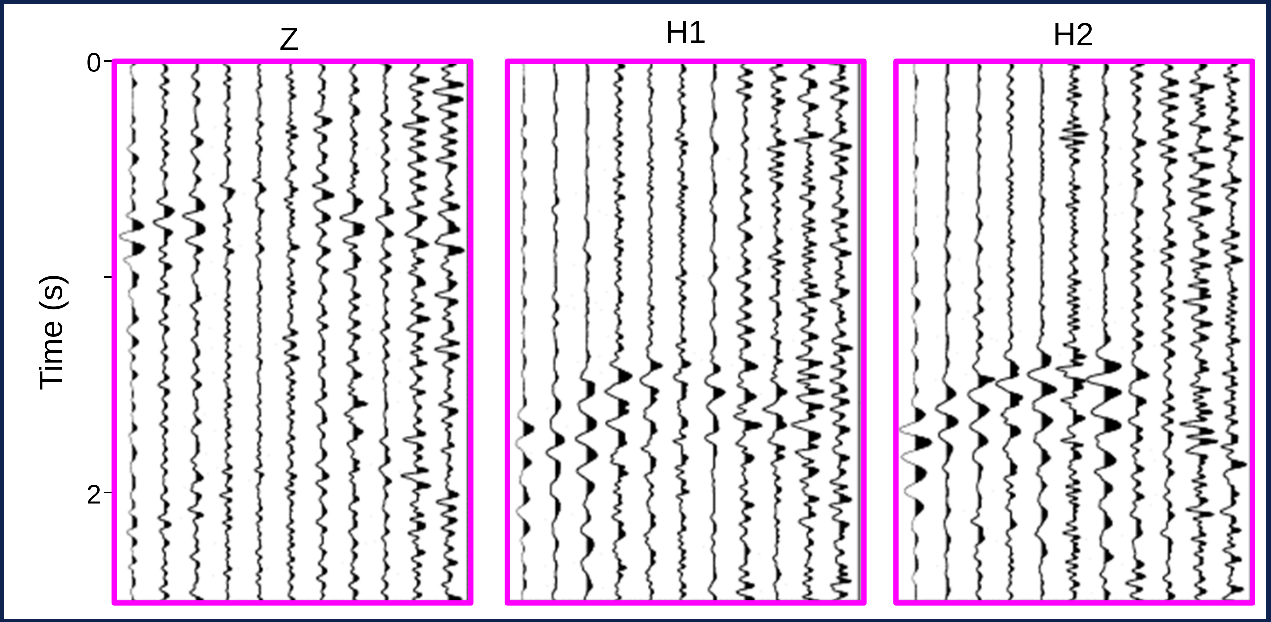
# Data examples

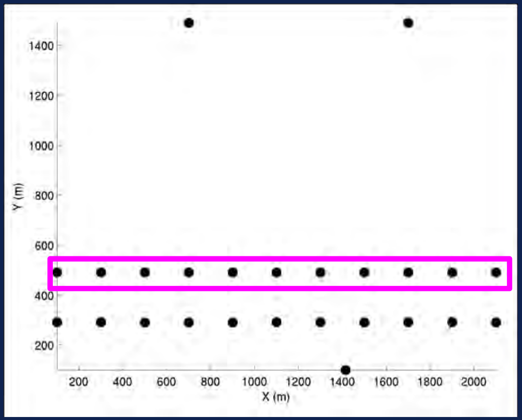
## From various geologies and geographies

- Mannville
- Montney
- Wolfcamp
- Mississippian Carbonate
- Eagle Ford

# Mannville – Alberta, Canada

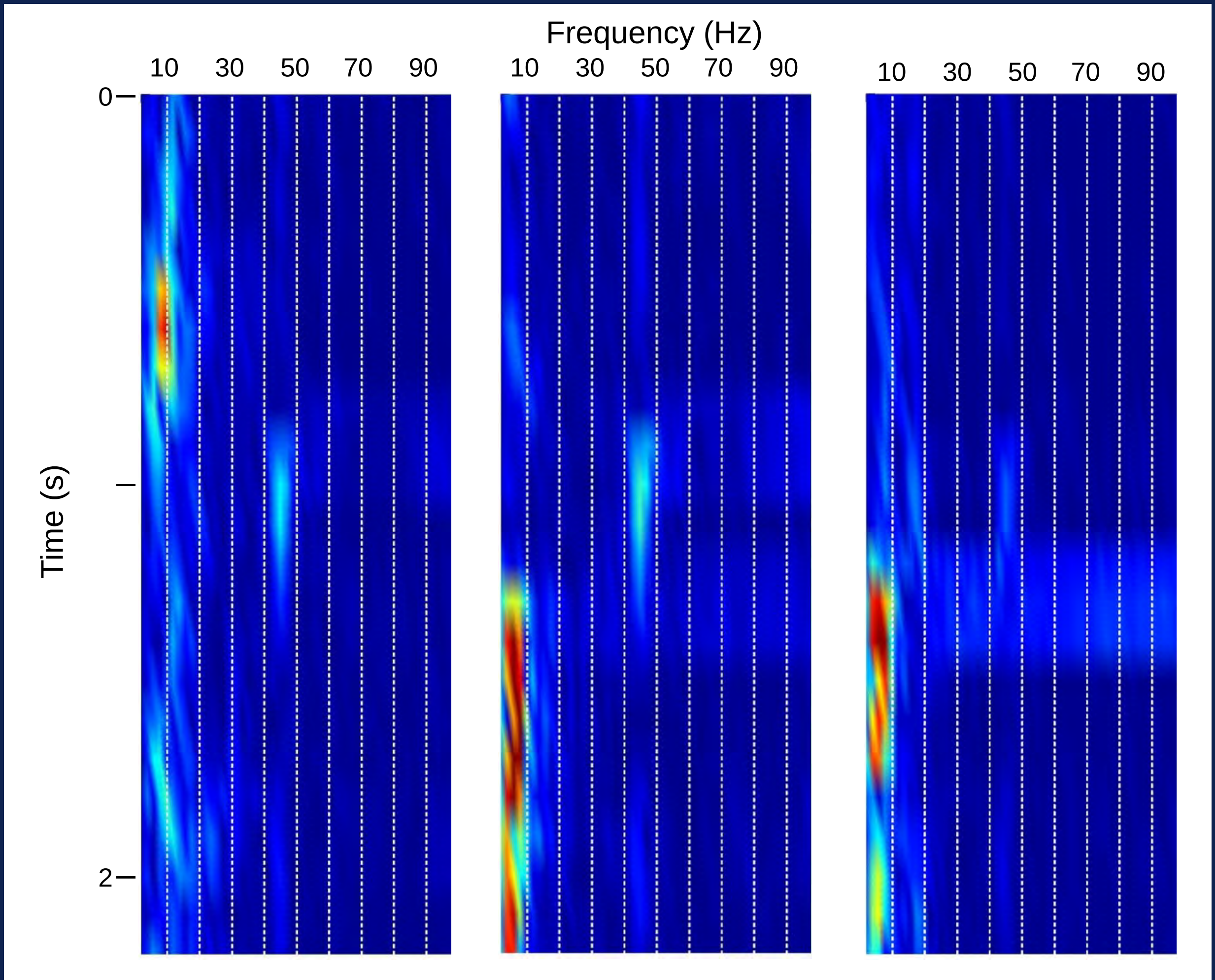
Well depth : 850 m
Bandpass : 5 – 30 Hz



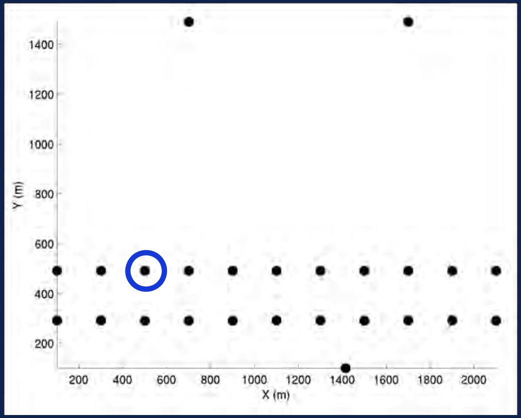




**Are S waves observable? Answer: Yes**

# Mannville – Alberta, Canada

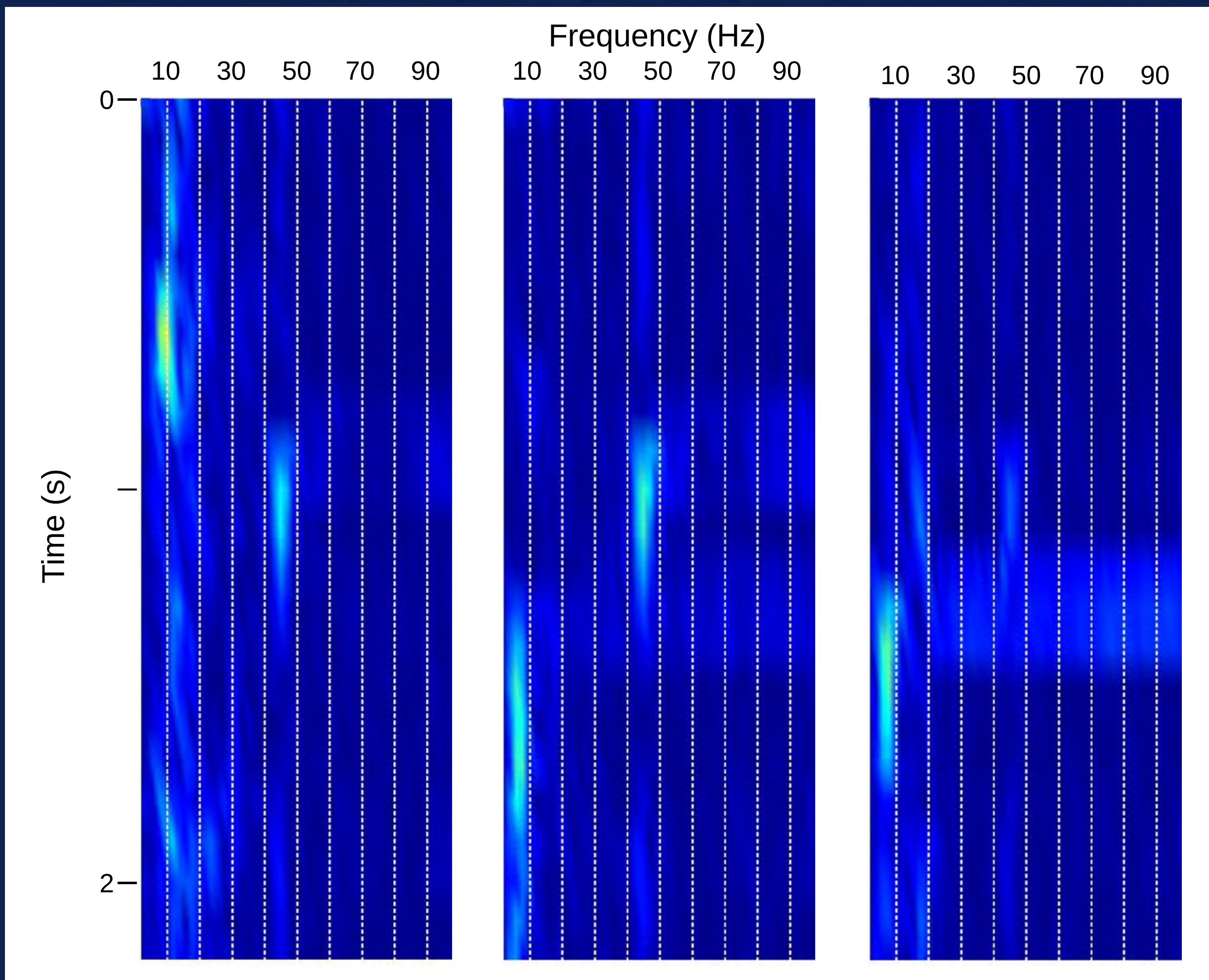



Well depth : 850 m

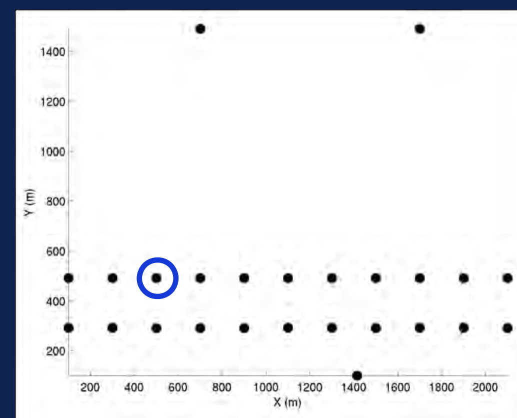



**All energy below 15 Hz, requires broadband 3C instruments**

# Mannville – Alberta, Canada

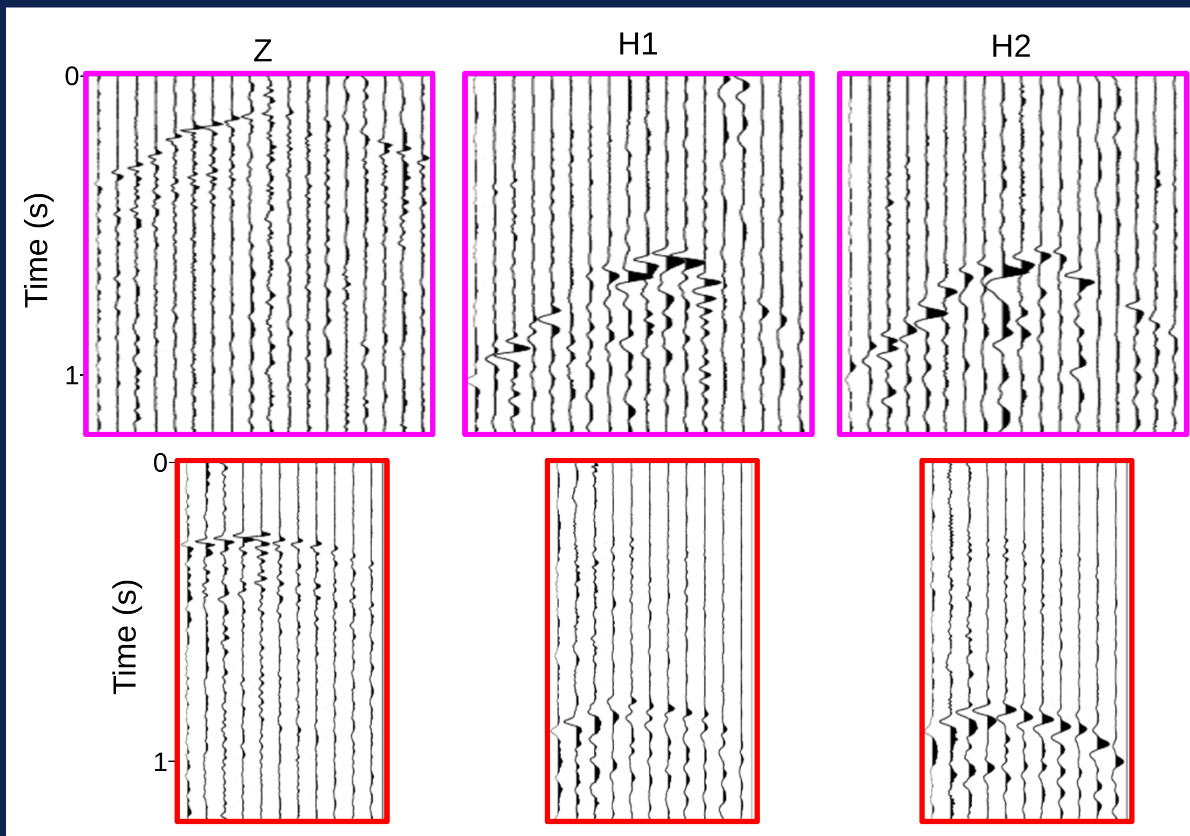



Well depth : 850 m
Instrument response for a 15 Hz phone applied

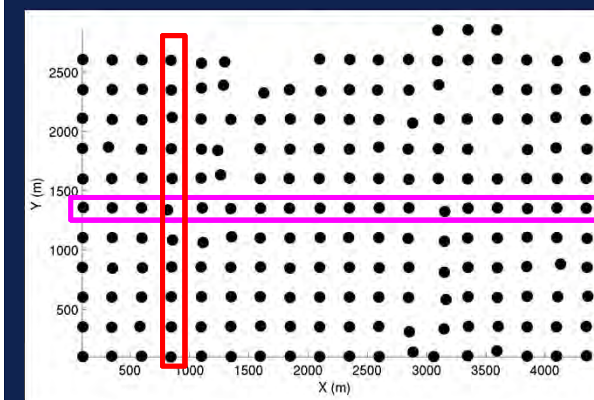



**Low-frequency content requires broad-band 3C instruments**

# Montney – British Columbia, Canada

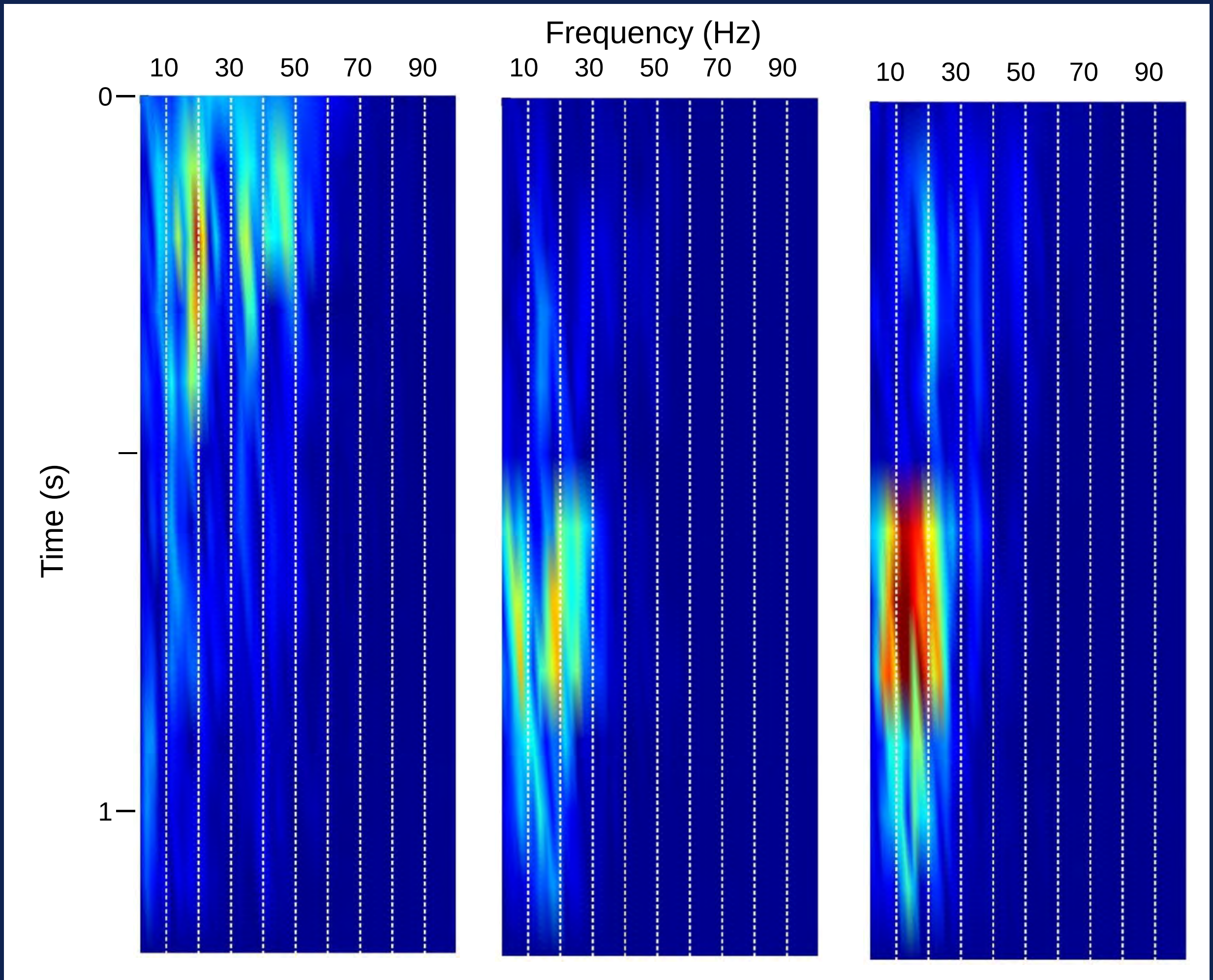



Well depth : 2200 m
Bandpass : 5 - 100 Hz

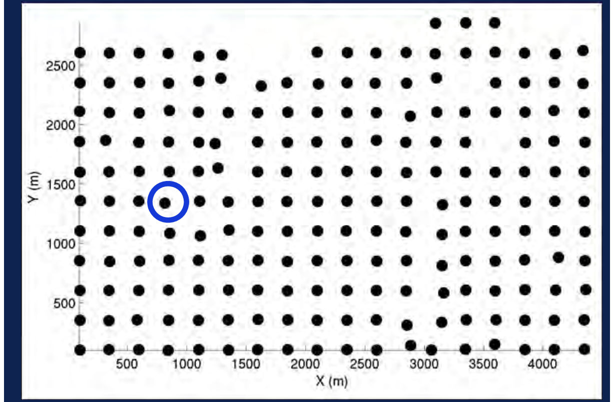



**198 station imaging project where S waves are dominant**

# Montney – British Columbia, Canada




Well depth : 2200 m




**S wave bandwidth from 6 – 20 Hz requires broadband 3C instruments**

# Wolfcamp – West Texas, USA

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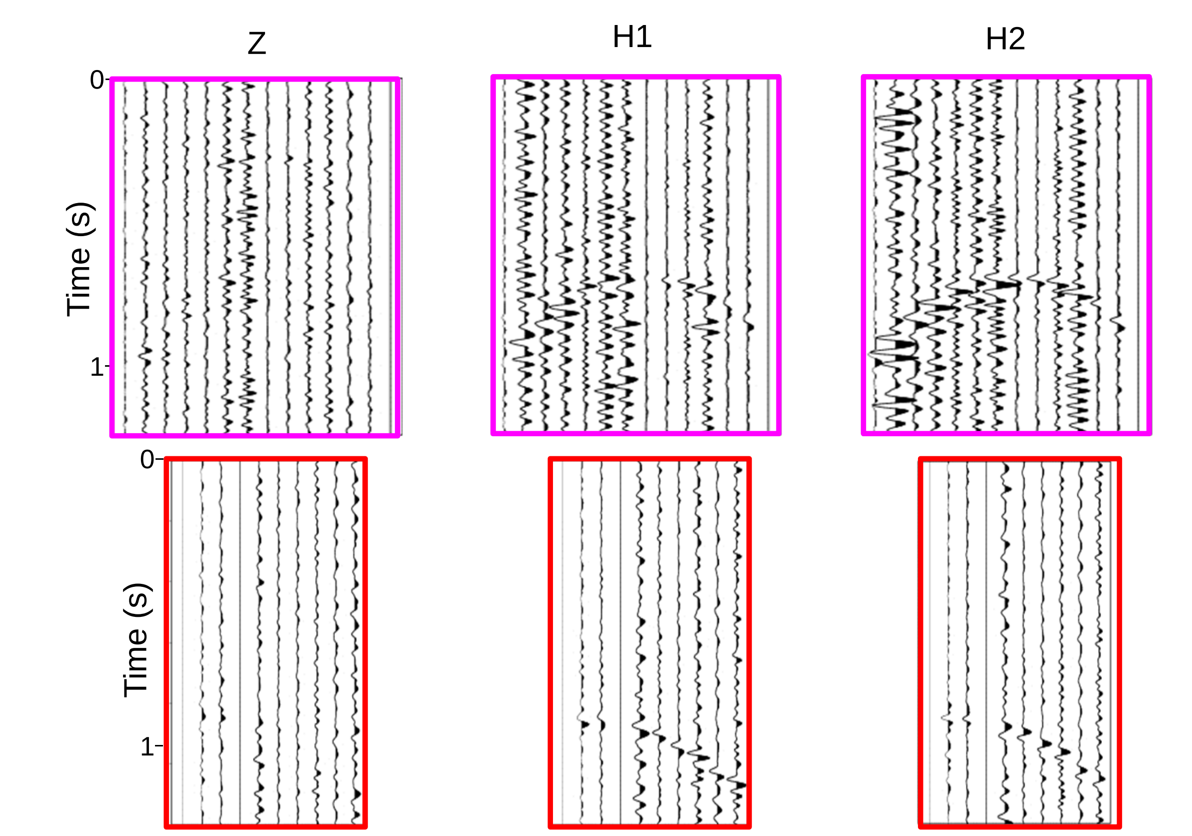
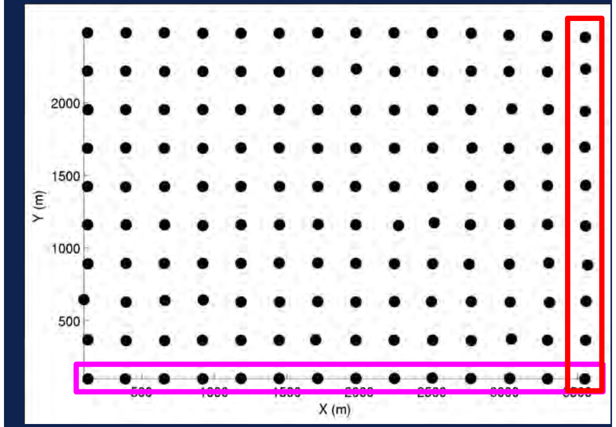


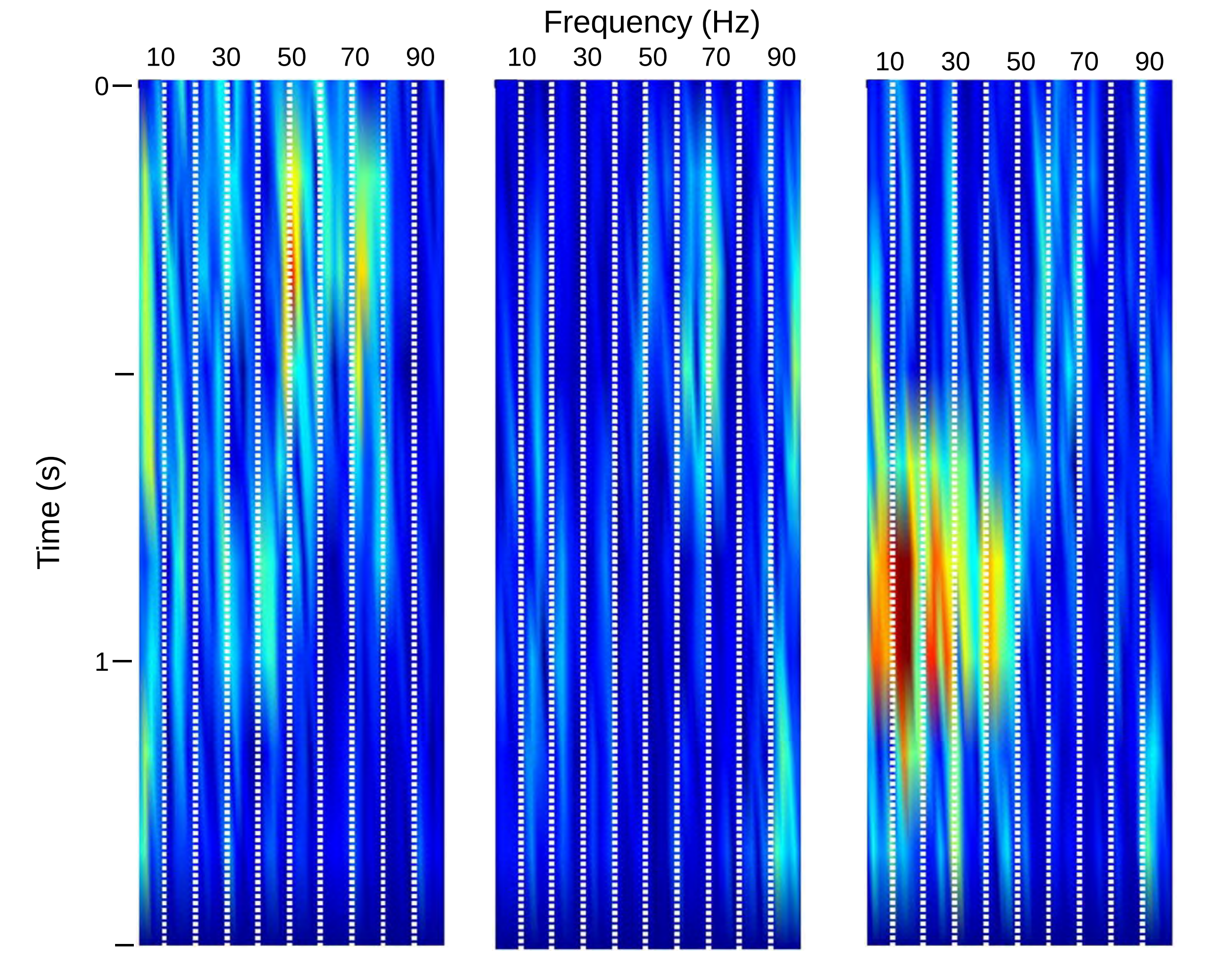

Well depth : 1900 m
Bandpass : 5 – 60 Hz



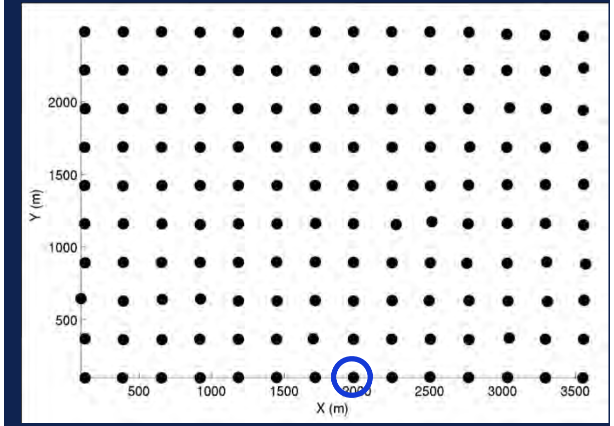

**140 station imaging project where S waves dominate the wave field**

# Wolfcamp – West Texas, USA

Spectraseis



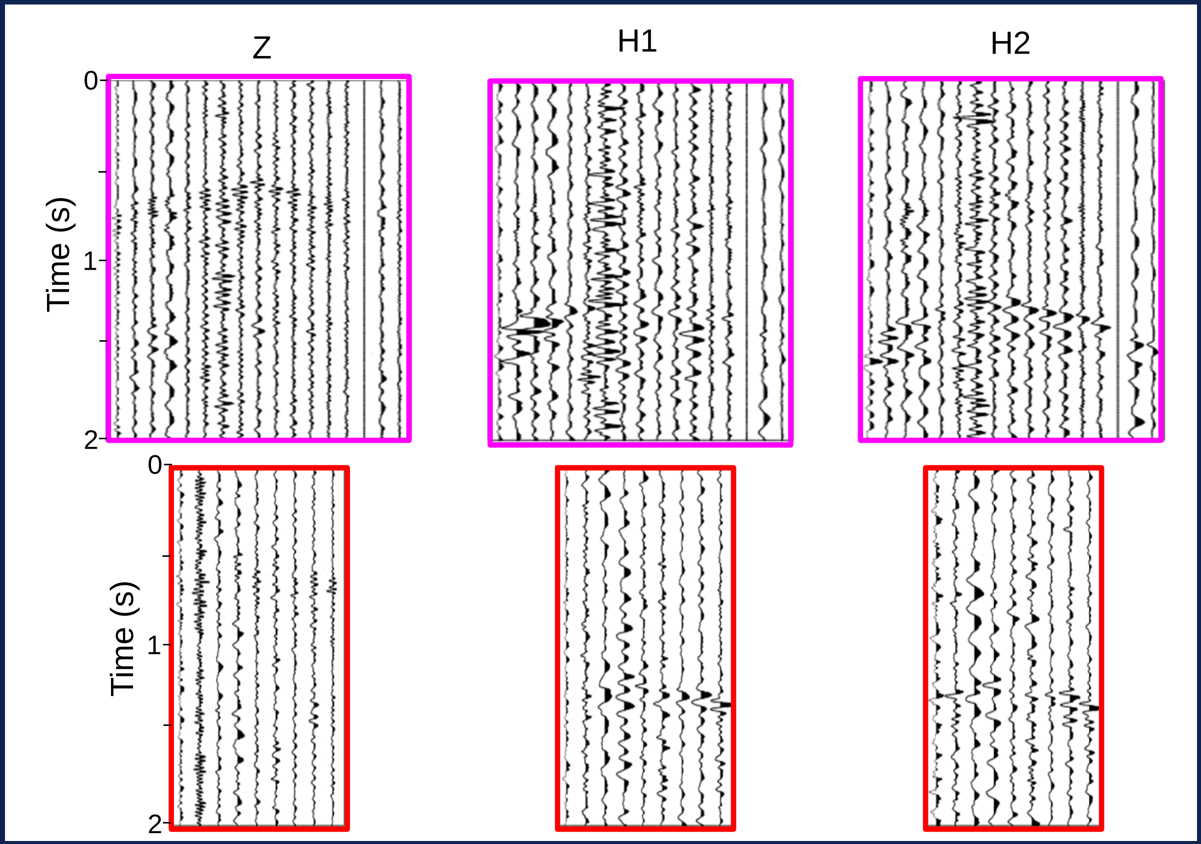

Well depth : 1900 m



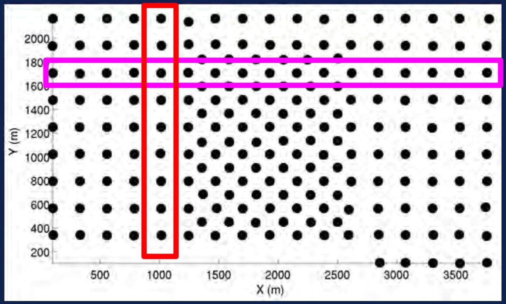

**S wave bandwidth from 5 – 20 Hz requires broadband 3C instruments**

# Mississippian Carbonate – Oklahoma, USA

Spectraseis

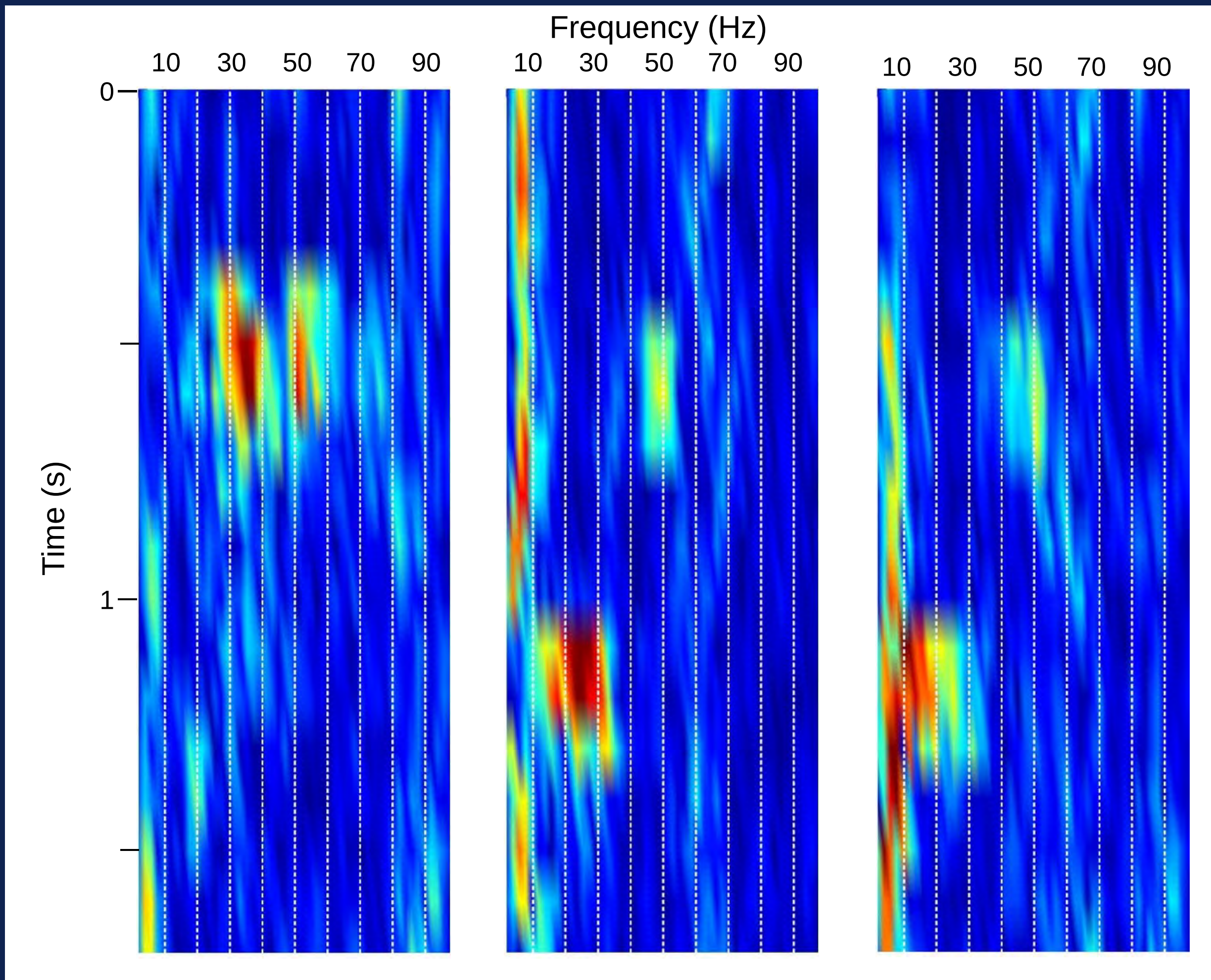



Well depth : 1700 m
Bandpass : 5 – 60 Hz

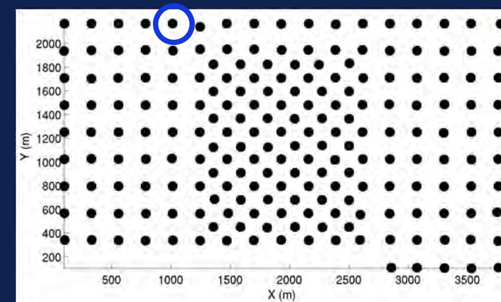



**201 station imaging project where S waves are clear**

# Mississippian Carbonate – Oklahoma, USA



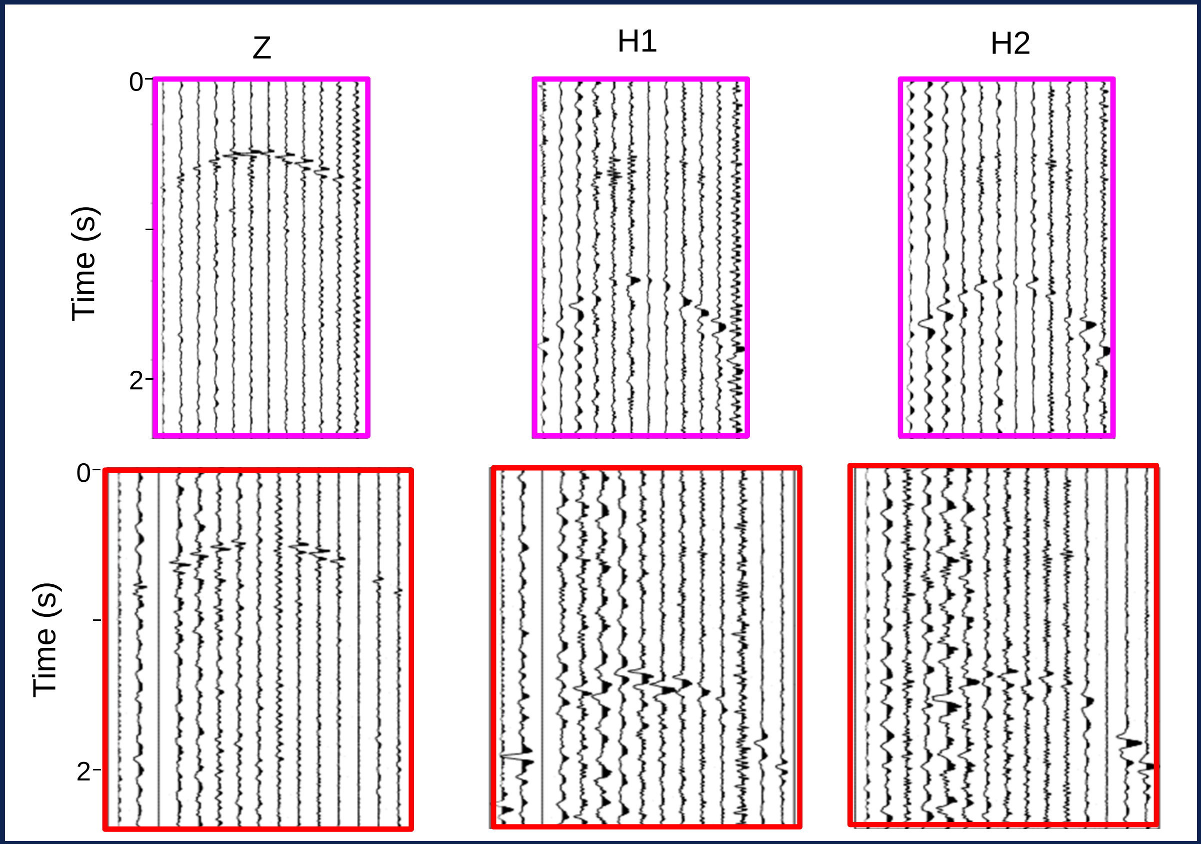

Well depth : 1700 m



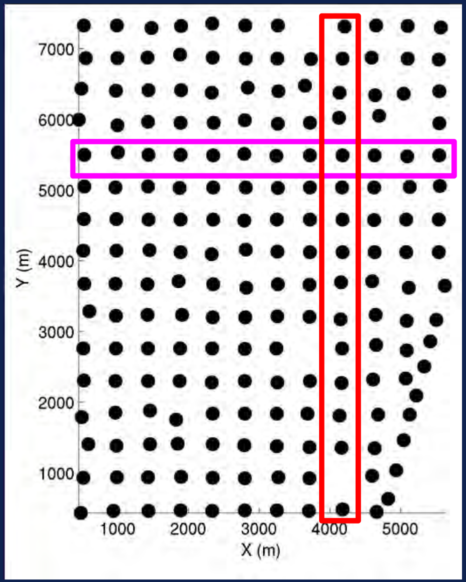

**S wave bandwidth from 13 – 30 Hz requires broadband 3C instruments**

# Eagle Ford – South Texas, USA

Spectraseis

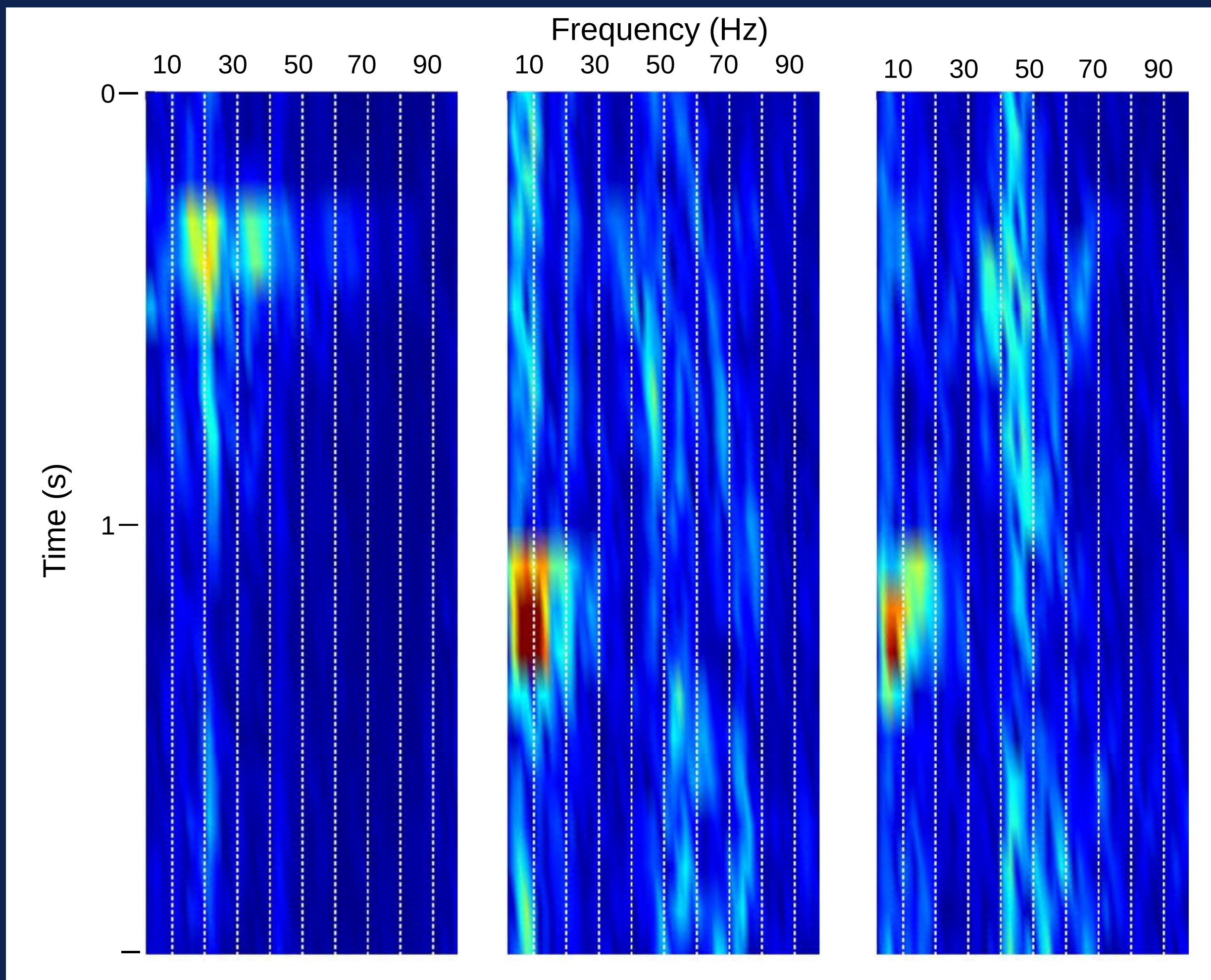



Well depth : 2550 m
Bandpass : 5 – 40 Hz

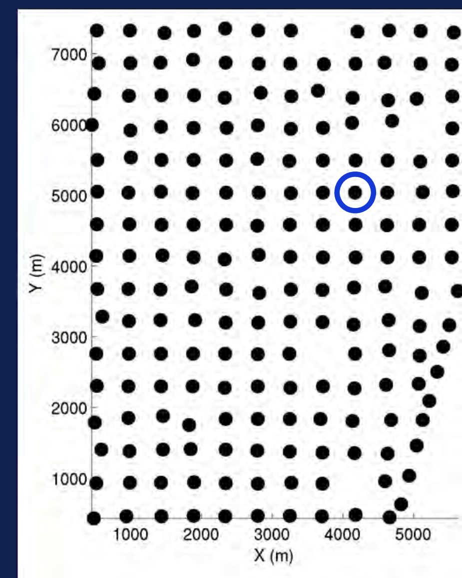



**187 station imaging project where S waves are strong**

# Eagle Ford – South Texas, USA




Well depth : 2550 m



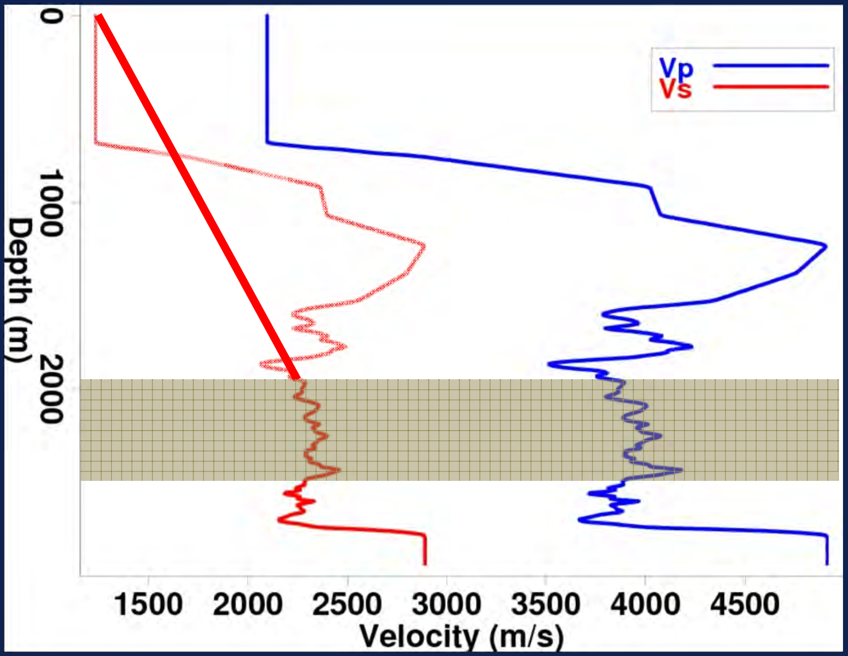

**S wave bandwidth from 3 – 17 Hz requires broadband 3C instruments**

# Using the Shear waves

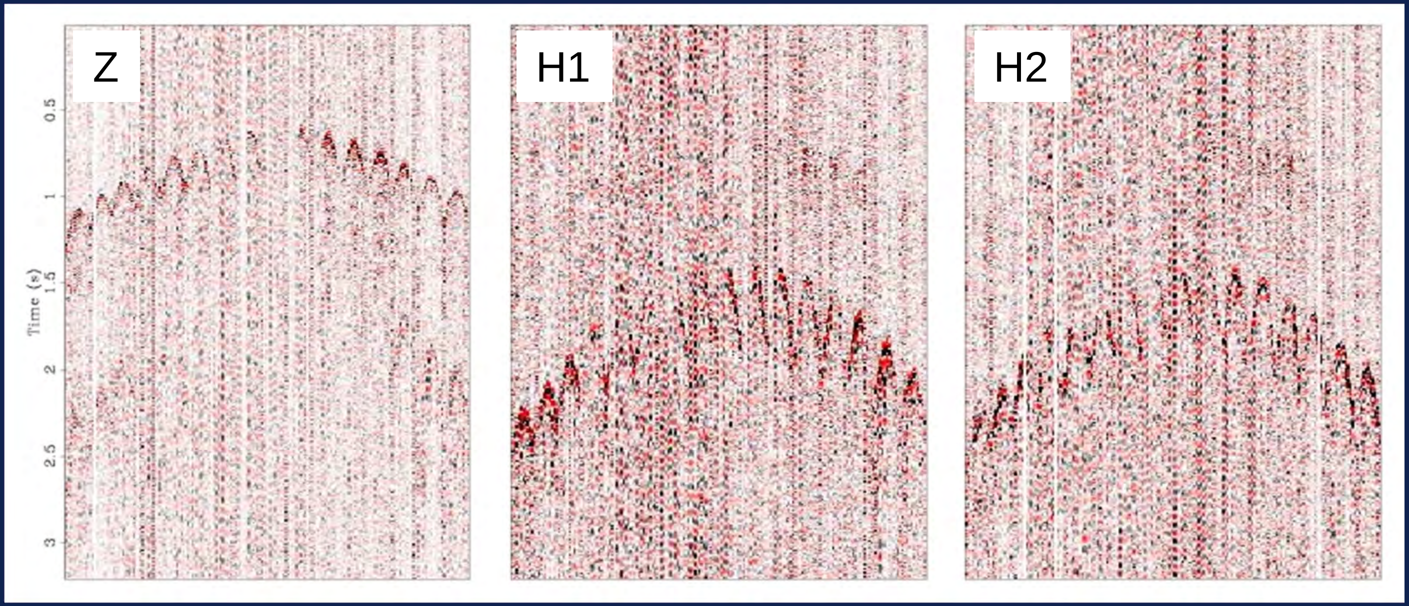
# Collect appropriate data

- Collect the data you need to exploit S-waves

- Velocity information along travel path



# Avoid false positives




Appropriate P-S separation

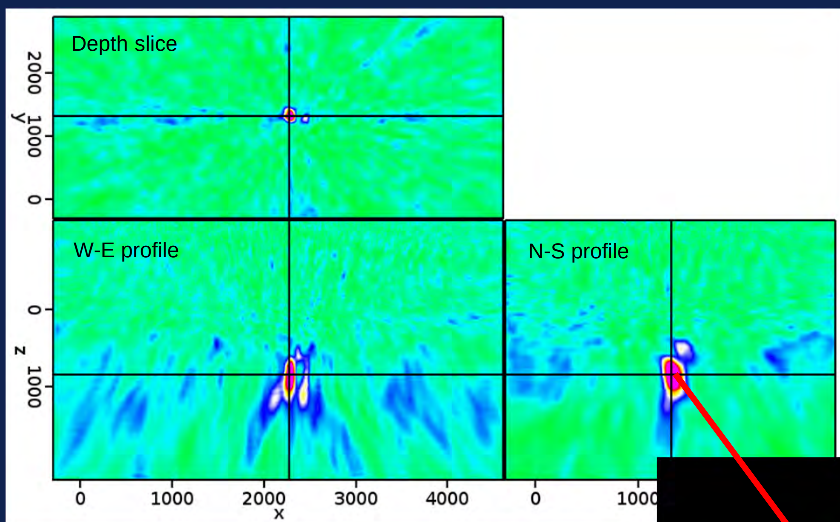
Appropriate P and S move outs

**Extra quality control step of analyzing P-S separation gives high confidence in any detected events**

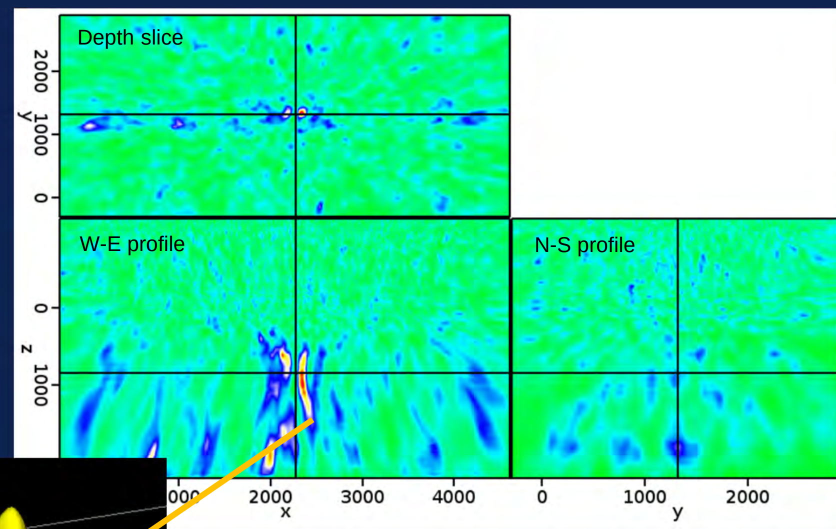
# Fracture characterization

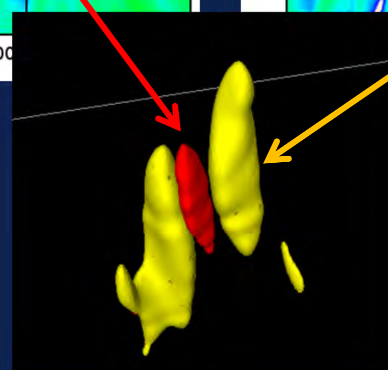


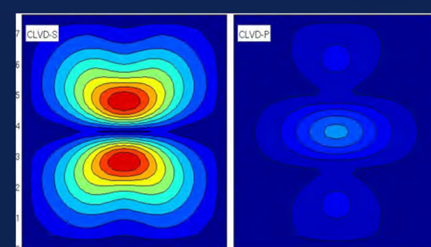
P-wave image




S-wave image






**Moment tensor is better constrained when using both P and S-waves**

# Summary

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- Fracture events release most of their energy as shear waves
- S-waves are produced by hydraulic fracturing and are usually the strongest arrival recorded at the surface
- Broad band and 3C phones are essential to capturing the shear arrivals at the surface
- Shear data can be used in many phases of the microseismic workflow
- Collect the data you need to fully realize the potential of the S-waves

# Acknowledgements

We would like to thank

Company A

Devon Energy

Fasken Oil and Ranch

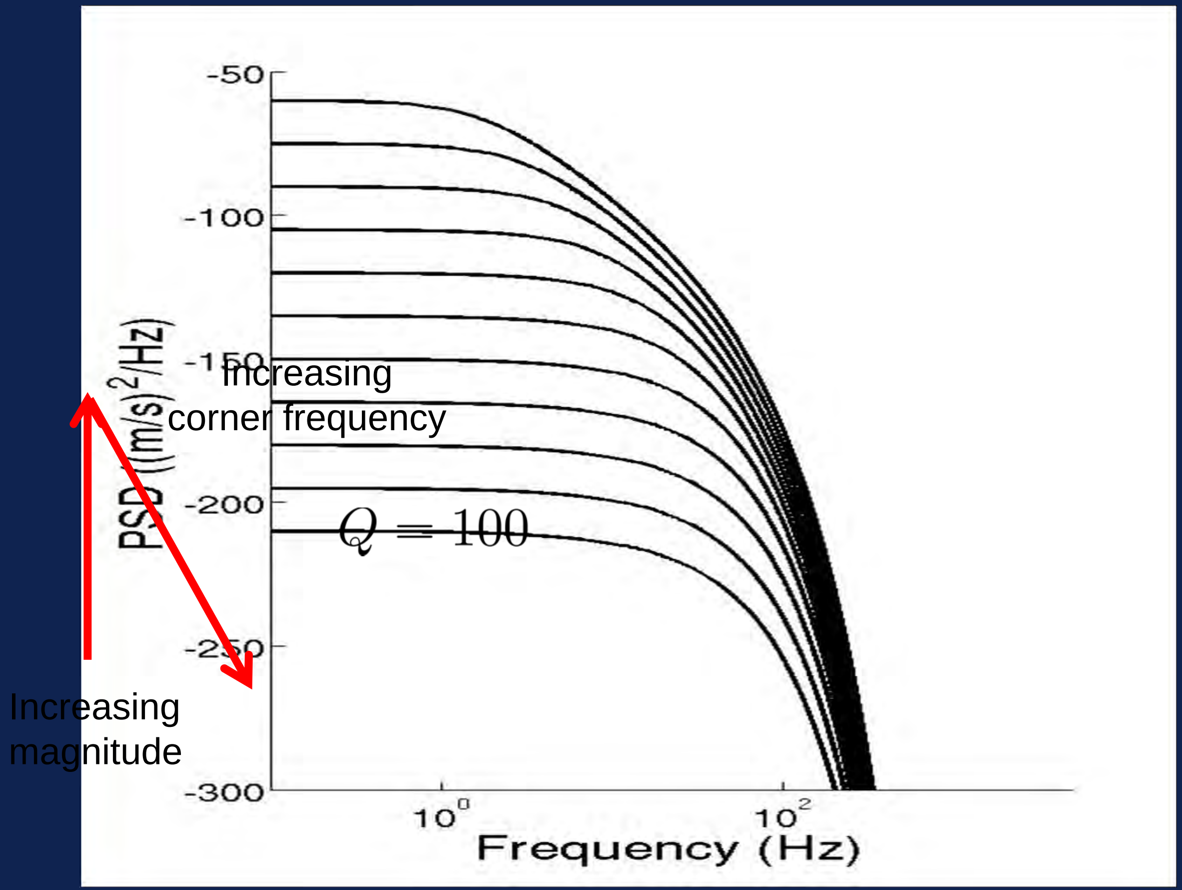
Forest Oil

Progress Energy

and our colleagues at Spectraseis

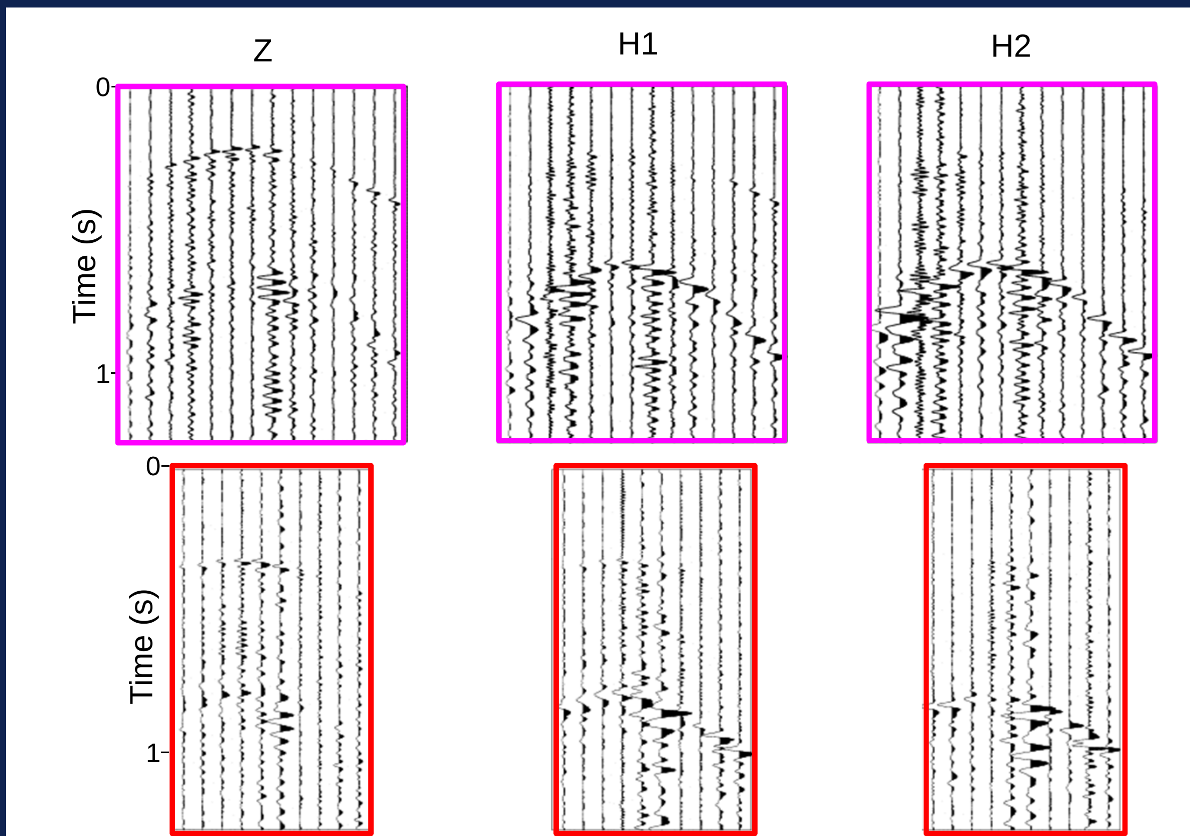
Spectraseis

Spectraseis

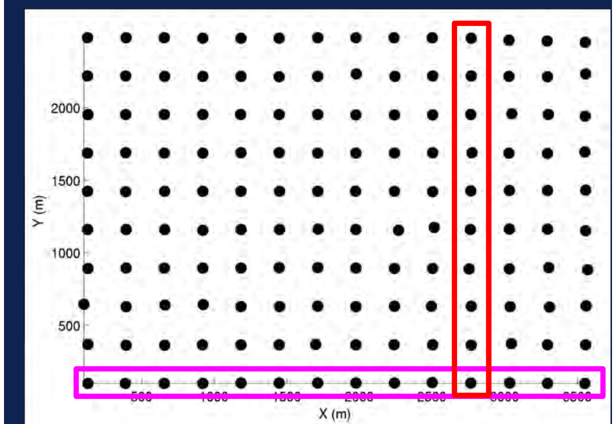


# Wolfcamp – West Texas, USA

Spectraseis




Well depth : 1900 m
Bandpass : 5 – 100 Hz




**140 station imaging project where S waves dominate the wave field**

# Collect appropriate data

- Collect the data you need to exploit S-waves

- Velocity information along travel path