Shear wave arrivals in surface microseismic data

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

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

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

Theory
Modeling
Data examples
• Mannville
• Montney
• Wolfcamp
• Mississippian Carbonate
• Eagle Ford

Using the S-waves

Summary

Analytics, numerical, and data agree
(micro)Seismology

- All fractures produce compressional and shear waves
- Energy released in the form 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

All fractures can be decomposed into these three mechanisms:

- **Isotropic (explosion)**: P-waves only
- **Double Couple (DC)**: P- and S-waves
- **Compensated Linear Vector Dipole (CLVD)**: P- and S-waves
Are strong shear waves produced by hydraulic fracturing?

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?

Modeling predicts that S-wave energy dominates.

Normalized RMS amplitude for all components

Normalized RMS amplitude for vertical component

DC source

\[
\begin{bmatrix}
S_{xx} & S_{xy} & S_{xz} \\
S_{yx} & S_{yy} & S_{yz} \\
S_{zx} & S_{zy} & S_{zz}
\end{bmatrix} = \begin{bmatrix}
0 & 1 & 0 \\
1 & 0 & 0 \\
0 & 0 & 0
\end{bmatrix}
\]
Are strong shear waves produced by hydraulic fracturing?

Normalized RMS amplitude for all components

Normalized RMS amplitude for vertical component

When all 3 components are considered, S-wave has considerably more energy
Is the S-wave energy released enough to overcome attenuation?

<table>
<thead>
<tr>
<th>$Q_s$</th>
<th>Normalized S Amplitude</th>
<th>$Q_p$</th>
<th>Normalized P Amplitude</th>
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It is geologically unreasonable for the entire column to have such low $Q_s$.
Data examples
From various geologies and geographies

- Mannville
- Montney
- Wolfcamp
- Mississippian Carbonate
- Eagle Ford
Mannville – Alberta, Canada

Are S waves observable? Answer: Yes

Well depth: 850 m
Bandpass: 5 – 30 Hz
Mannville – Alberta, Canada

All energy below 15 Hz, requires broadband 3C instruments

Well depth: 850 m
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

140 station imaging project where S waves dominate the wave field

Well depth: 1900 m
Bandpass: 5 – 60 Hz
Wolfcamp – West Texas, USA

Well depth: 1900 m

S wave bandwidth from 5 – 20 Hz requires broadband 3C instruments
Mississippian Carbonate – Oklahoma, USA

Well depth: 1700 m
Bandpass: 5 – 60 Hz

201 station imaging project where S waves are clear
Mississippian Carbonate – Oklahoma, USA

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

Well depth : 1700 m
Eagle Ford – South Texas, USA

Well depth : 2550 m
Bandpass : 5 – 40 Hz

187 station imaging project where S waves are strong
Eagle Ford – South Texas, USA

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

Well depth : 2550 m
Using the Shear waves
Collect appropriate data

- Collect the data you need to exploit S-waves
- Velocity information along travel path
Avoid false positives

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

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

- 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
We would like to thank

- Company A
- Devon Energy
- Fasken Oil and Ranch
- Forest Oil
- Progress Energy

and our colleagues at Spectraseis
Increasing magnitude

Increasing corner frequency

$Q = 100$
Wolfcamp – West Texas, USA

140 station imaging project where S waves dominate the wave field

Well depth : 1900 m
Bandpass : 5 – 100 Hz
Collect appropriate data

- Collect the data you need to exploit S-waves

- Velocity information along travel path