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Shallow Q_P and Q_S estimation from multicomponent VSP data

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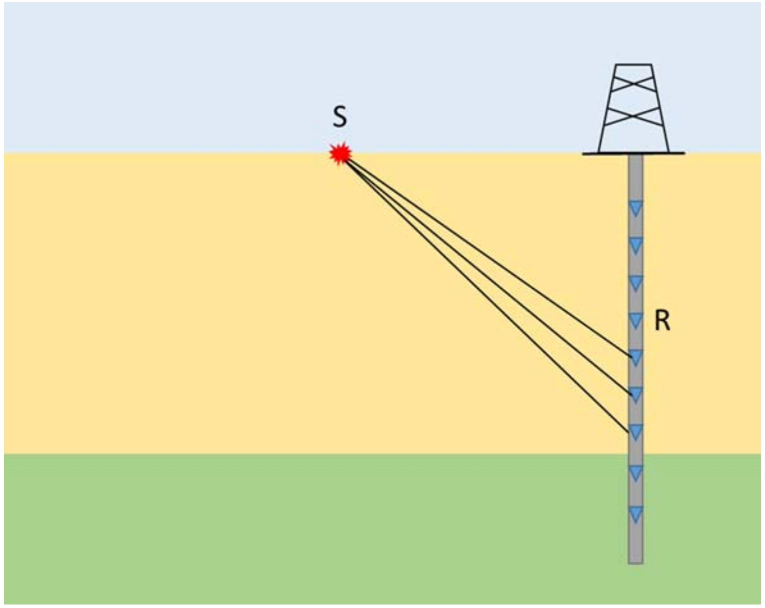
Outline

- Introduction
- Theory
  - Spectral-ratio method
  - Dominant frequency matching
- Study area
- Synthetic VSP data analysis
- Field VSP data analysis
- Conclusions
- Acknowledgements

Introduction

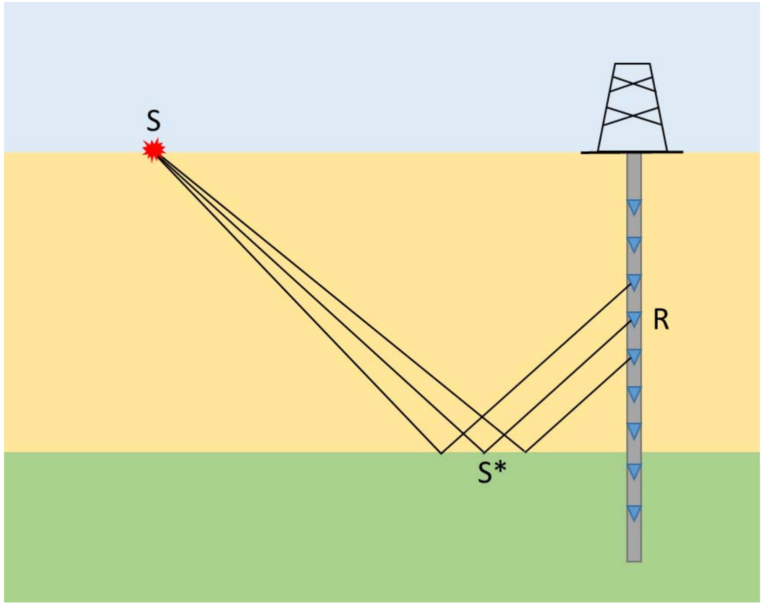
Down-going waves propagating to the borehole receivers.



- The downgoing wavefield give us access to the wavelet at different receiver depths.
- Oversaturation in the amplitudes in the shallow receivers results in a overestimation of Q.
- Shallow layers are expected to show low Q values because poorly consolidated rocks are usually present.

Introduction

Up-going waves propagating to the borehole receivers.



- Using the upgoing wavefield may help to estimate Q in the shallow layers.
- Reflectors can be used as secondary sources.
- In this case the source would be farther from the shallow receivers.

Theory

- **Spectral-ratio method**

$$lsr(Q, \Delta t, f) = ln\frac{|\hat{w}(t_2,f)|}{|\hat{w}(t_1,f)|} = -\frac{\pi f \Delta t}{Q}, \quad (1)$$

where $\Delta t = t_2 - t_1$. The interval Q between t_1 and t_2 can be computed by a least square fit of a first order polynomial.

- **Dominant Frequency Matching**

$$fc_1 = \frac{\sum_{k=1}^{n} f(A_1)^2}{\sum_{k=1}^{n}(A_1)^2} \quad (2)$$

$$fc_2 = \frac{\sum_{k=1}^{n} f(A_2)^2}{\sum_{k=1}^{n}(A_2)^2} \quad (3)$$

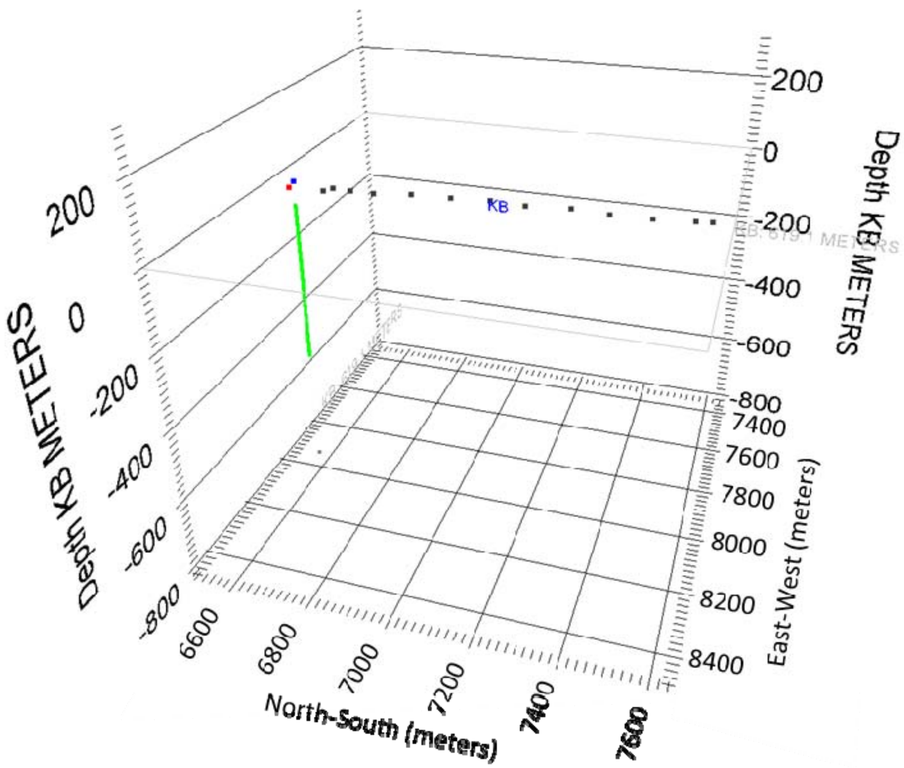
where, $A_2 = A_1 T e^{-\frac{\pi f \Delta t}{Q}}$, T correspond to the frequency independent loss and Q represent the frequency-dependent attenuation.

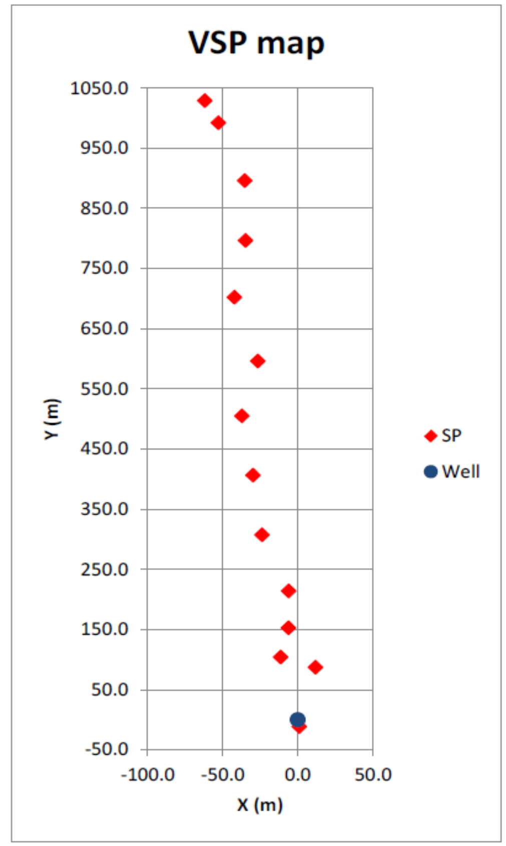
$$Obj = (fc_1 - fc_2)^2 Qtest. \quad (4)$$

Study Area

VSP Geometry

- Fourteen source points with **dynamite** and an **EnviroVibe** source.
- 222 receivers at 2m spacing (60-500m depth).

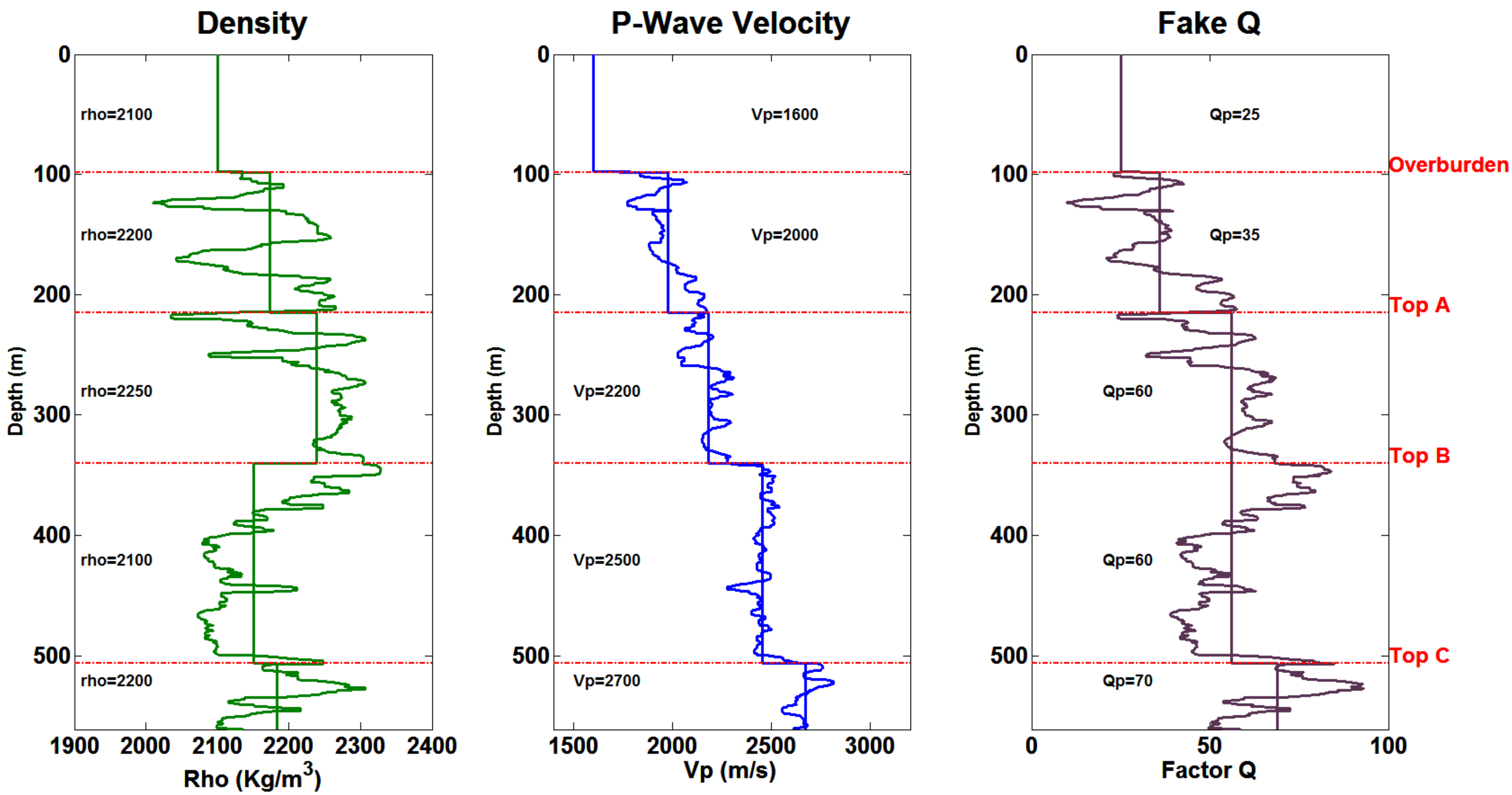




Taken from, Hall et al. (2012)

Well log data

Density and p-wave velocity logs, blocked into five horizontal layers.



Synthetic VSP data analysis

Forward Modelling using well log data from Well B.

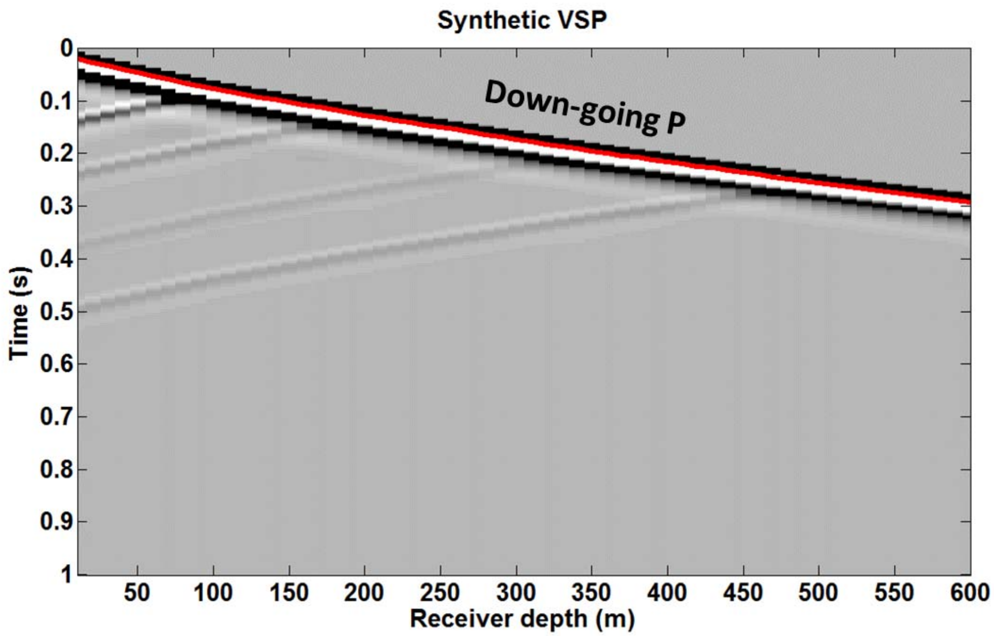
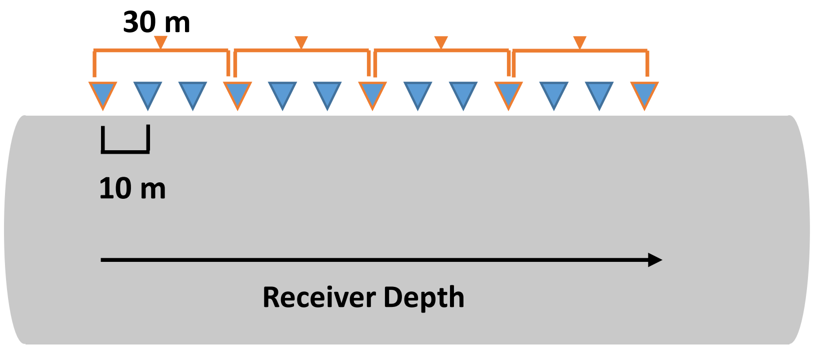
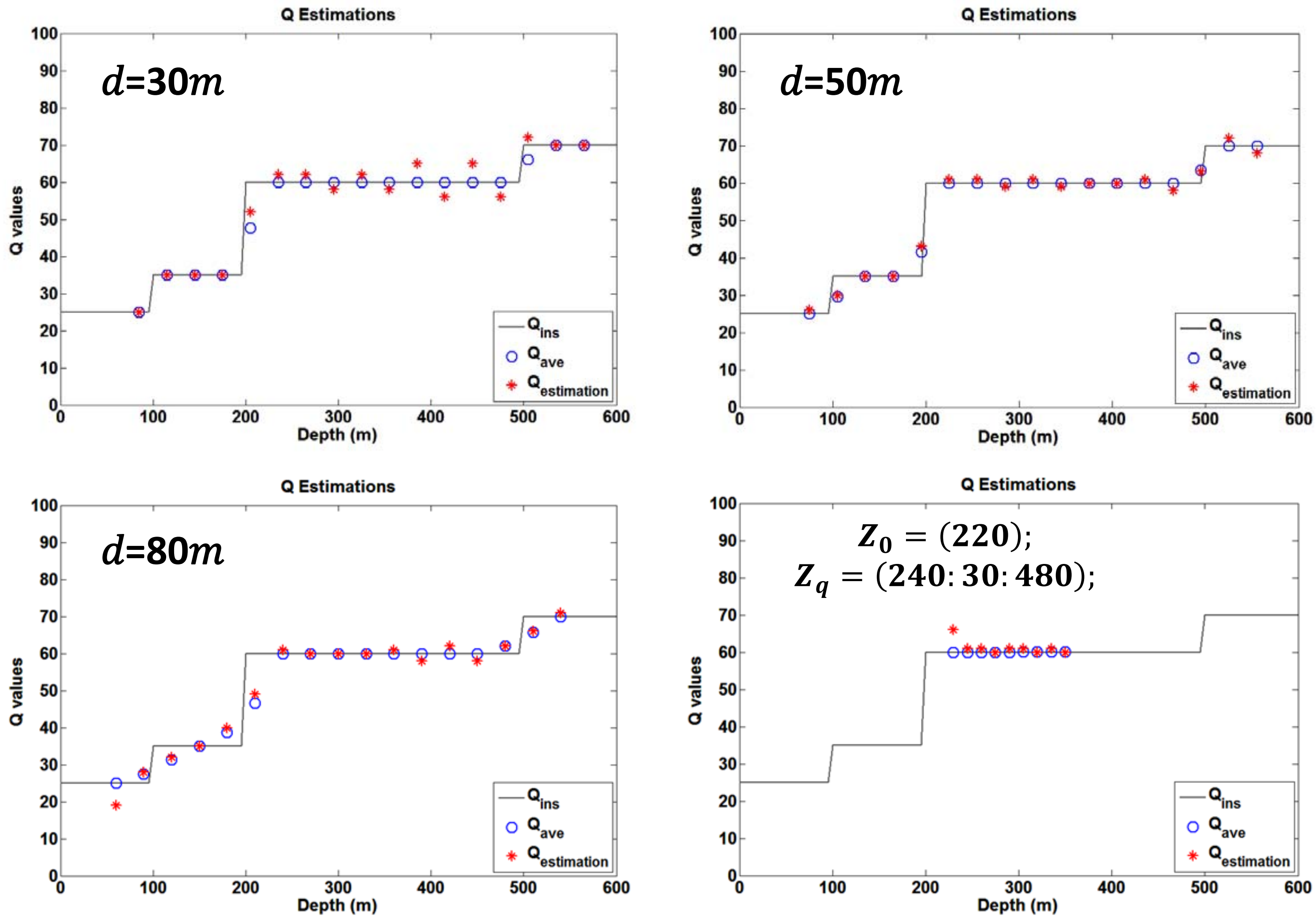


Diagram for Q_P estimation from synthetic down-going wavefield using the dominant frequency method from CREWES toolbox



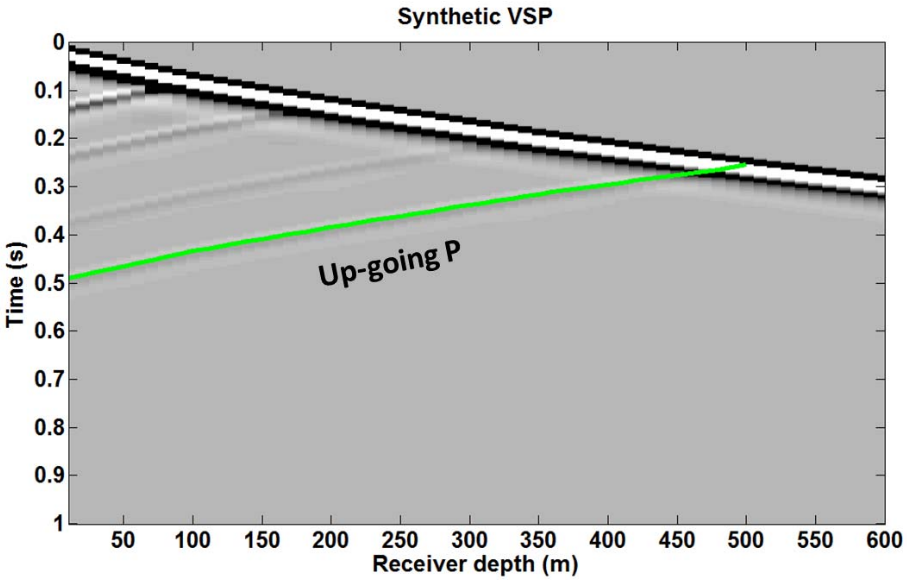
Q_P estimation from synthetic VSP data



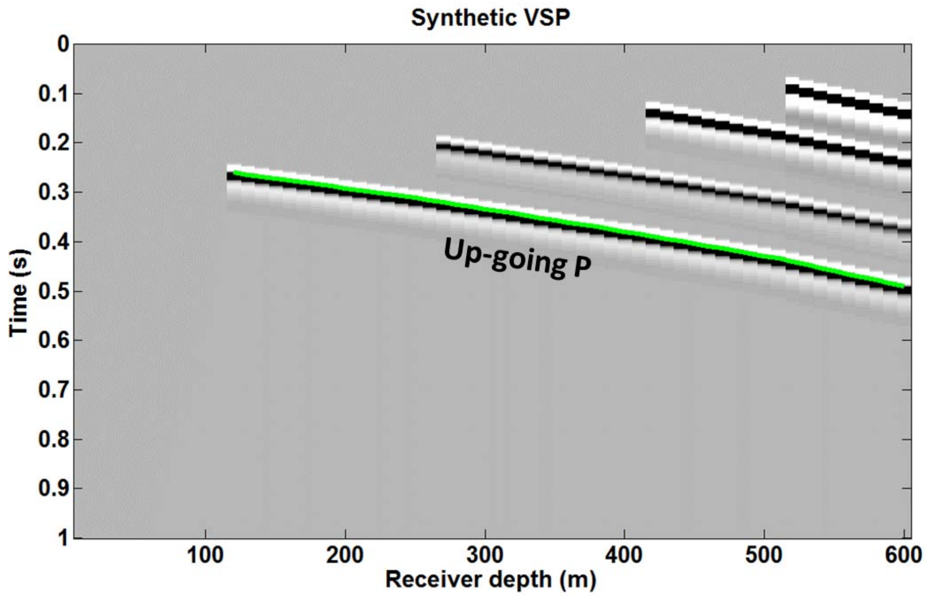
Down-going wavefield

Synthetic VSP data analysis

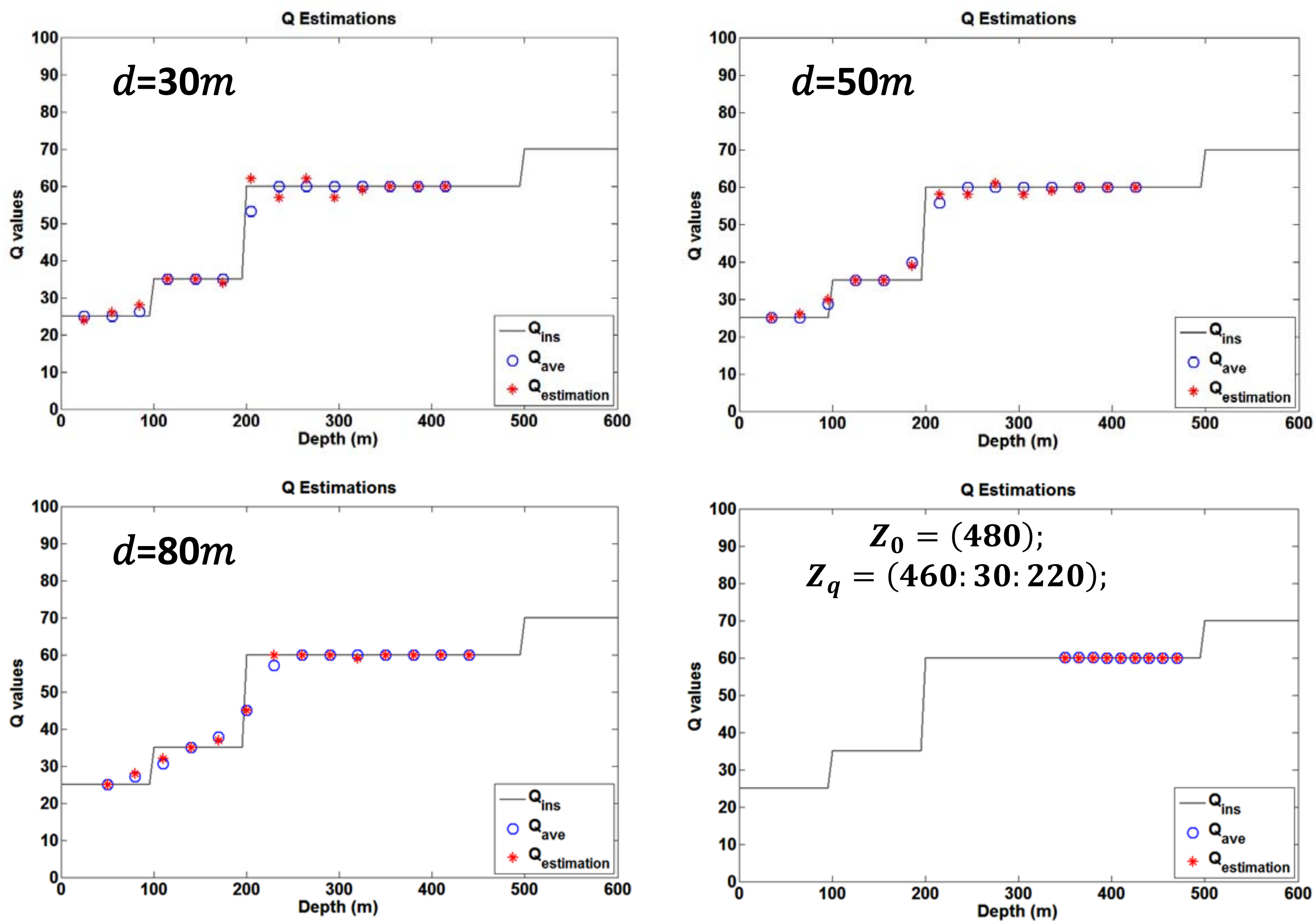
Forward Modelling based on Well B, showing up-going events.



Flipped in depth



Q_P estimation from synthetic VSP data

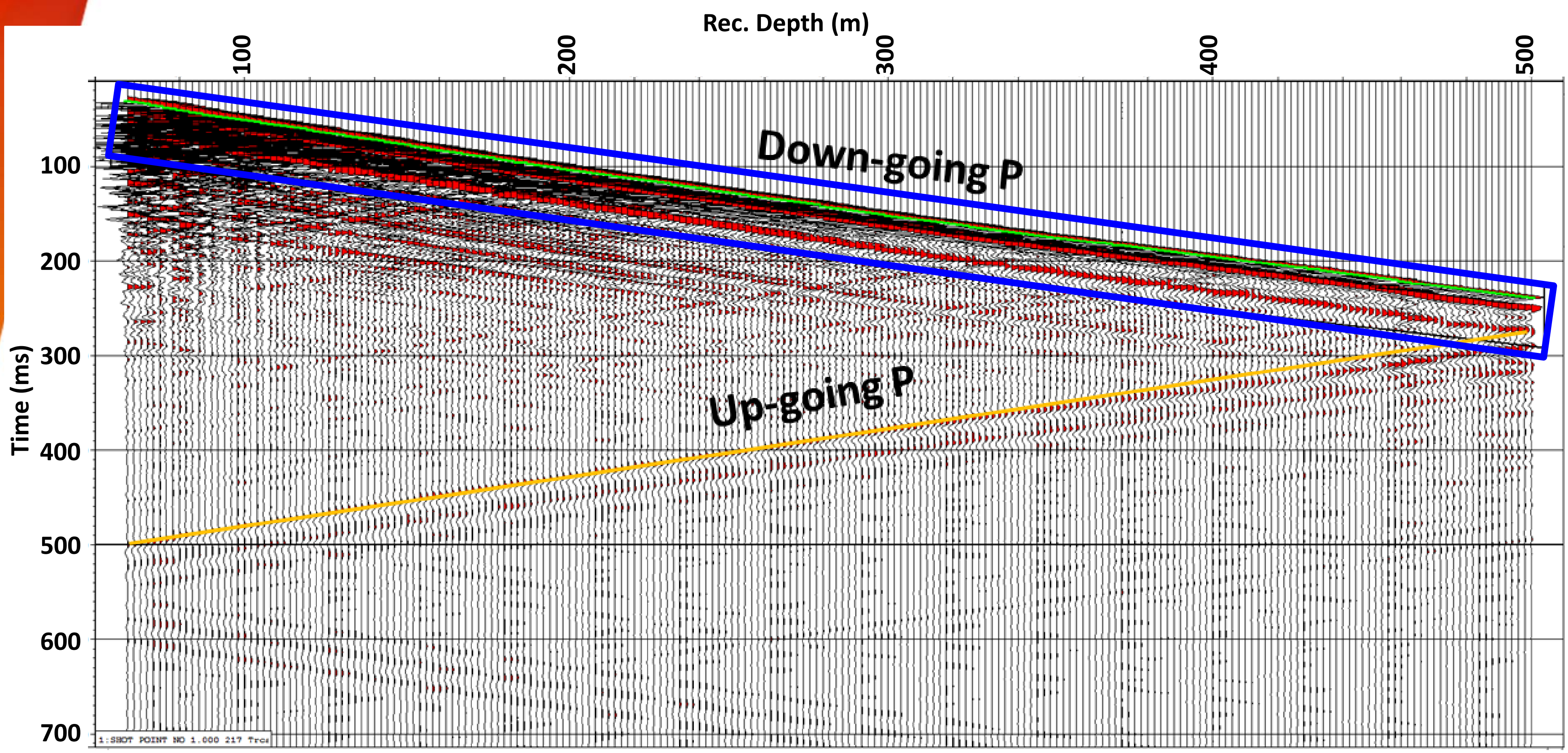


Up-going wavefield

Field VSP Data Analysis

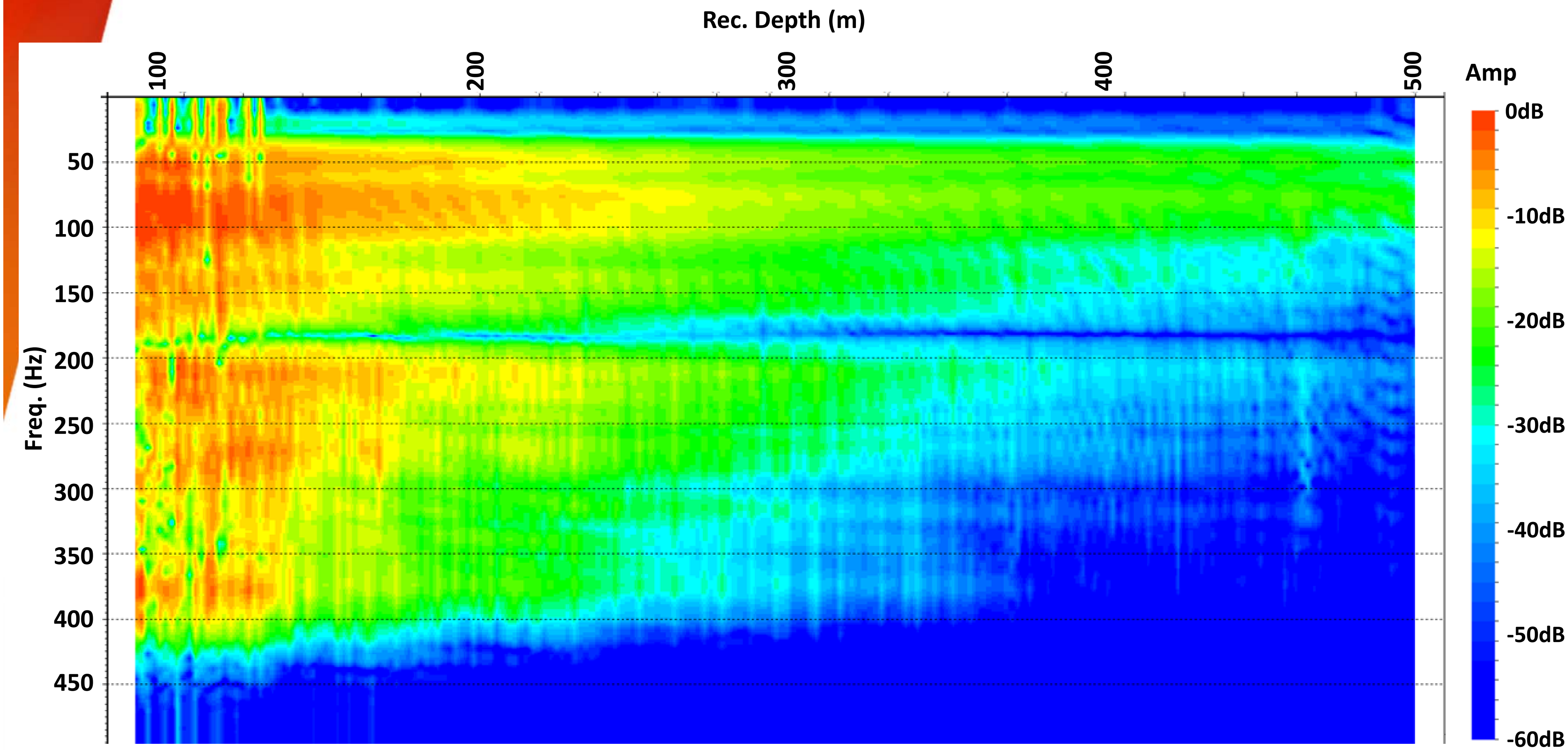
Dynamite Source

Field VSP Data Analysis



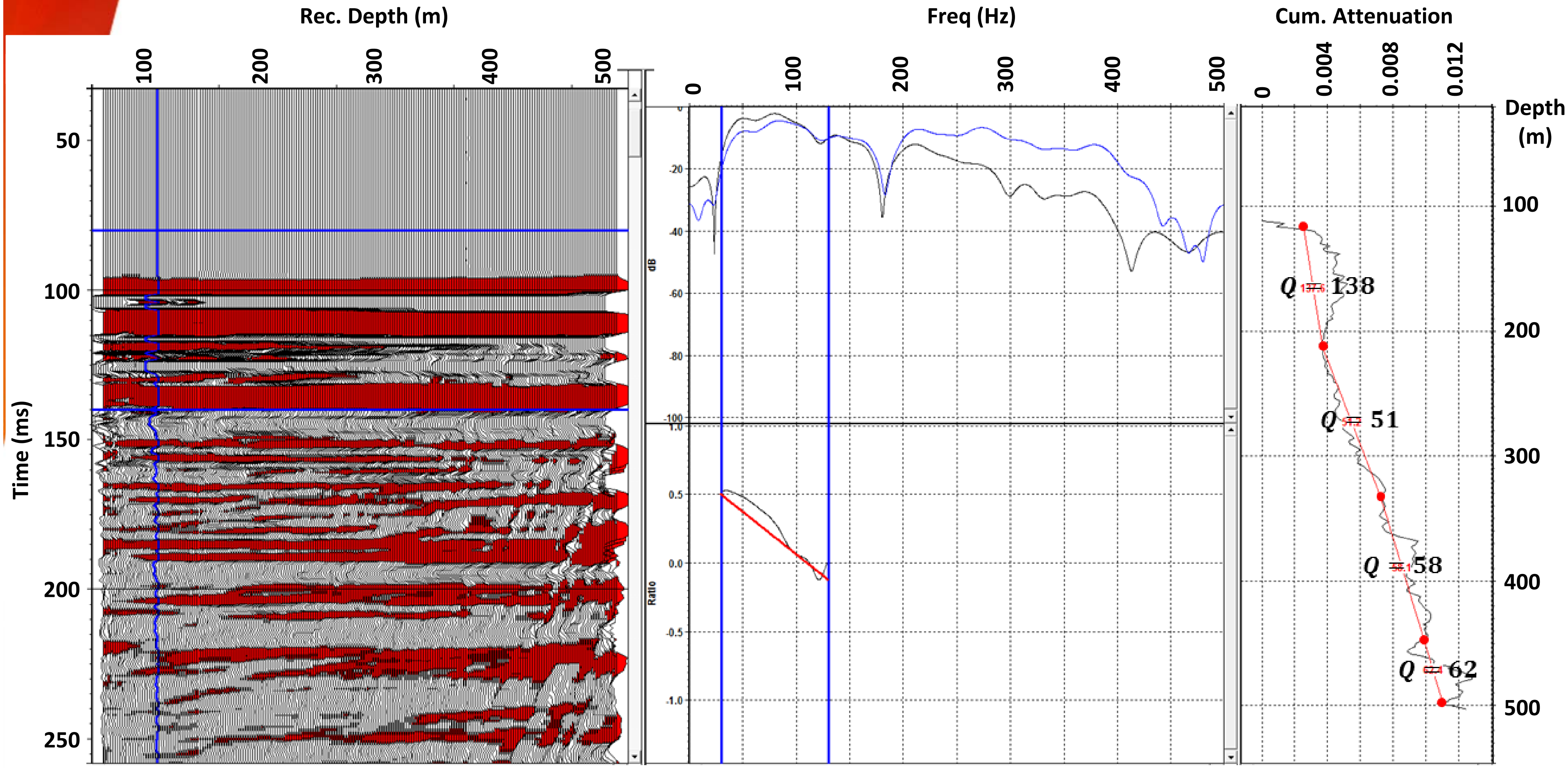
Seismic gather: Shot point 1 using a dynamite source (Z component)

Amplitude Spectra – Downgoing wavefield



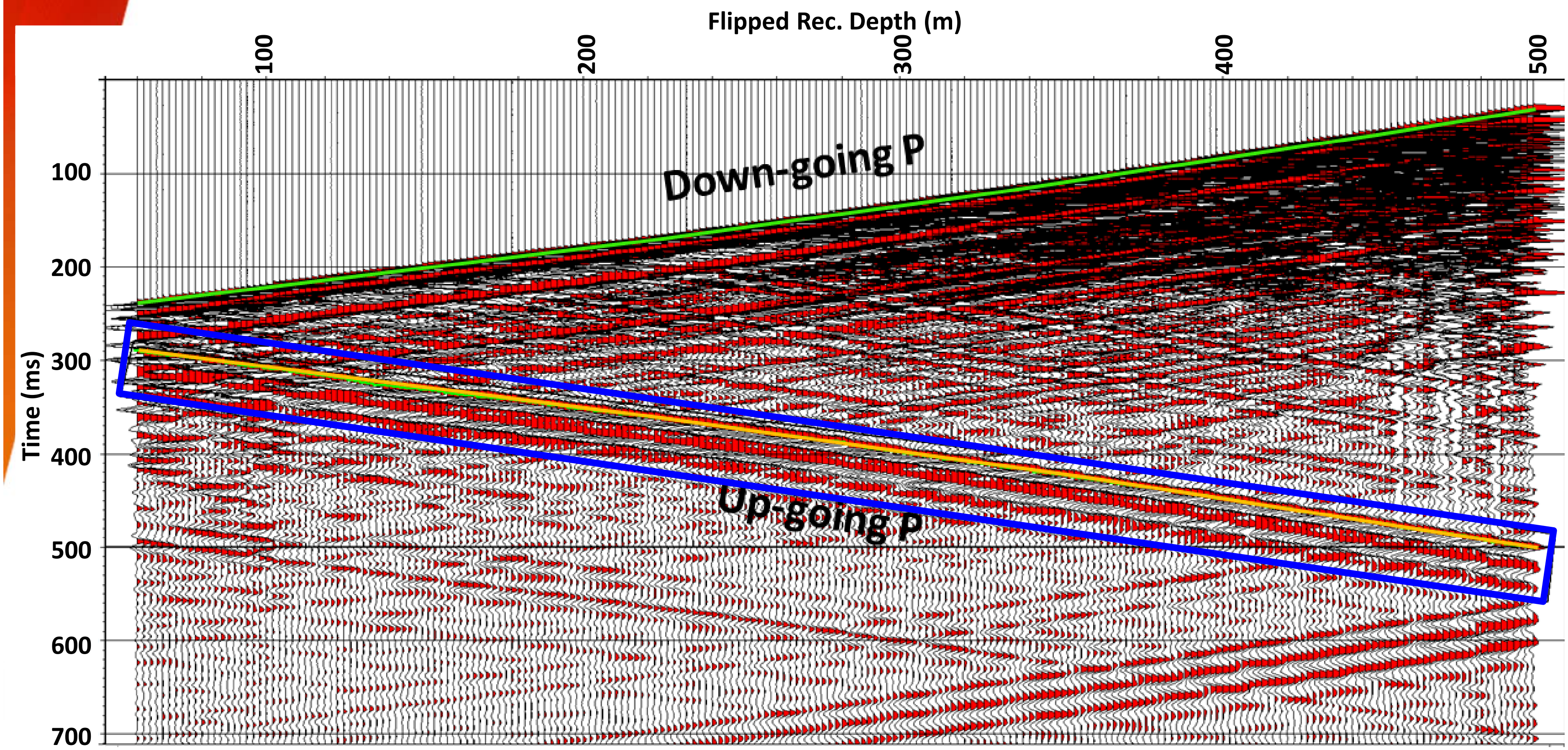
Shot point 1 using a dynamite source (Z component)

Q_P Analysis - Downgoing wavefield



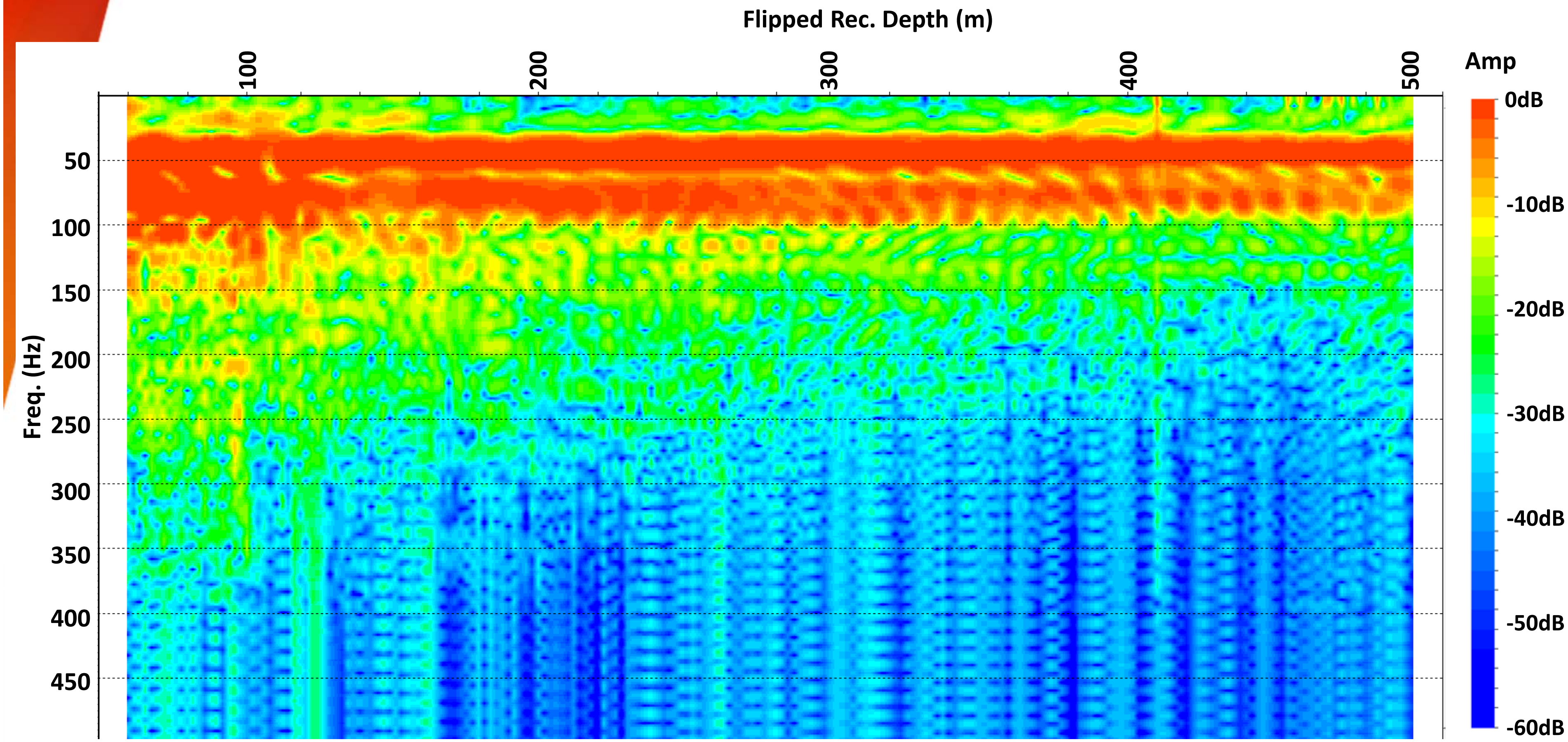
Spectral-ratio method from VISTA software
Frequency band: 30-130 Hz

Field VSP Data Analysis



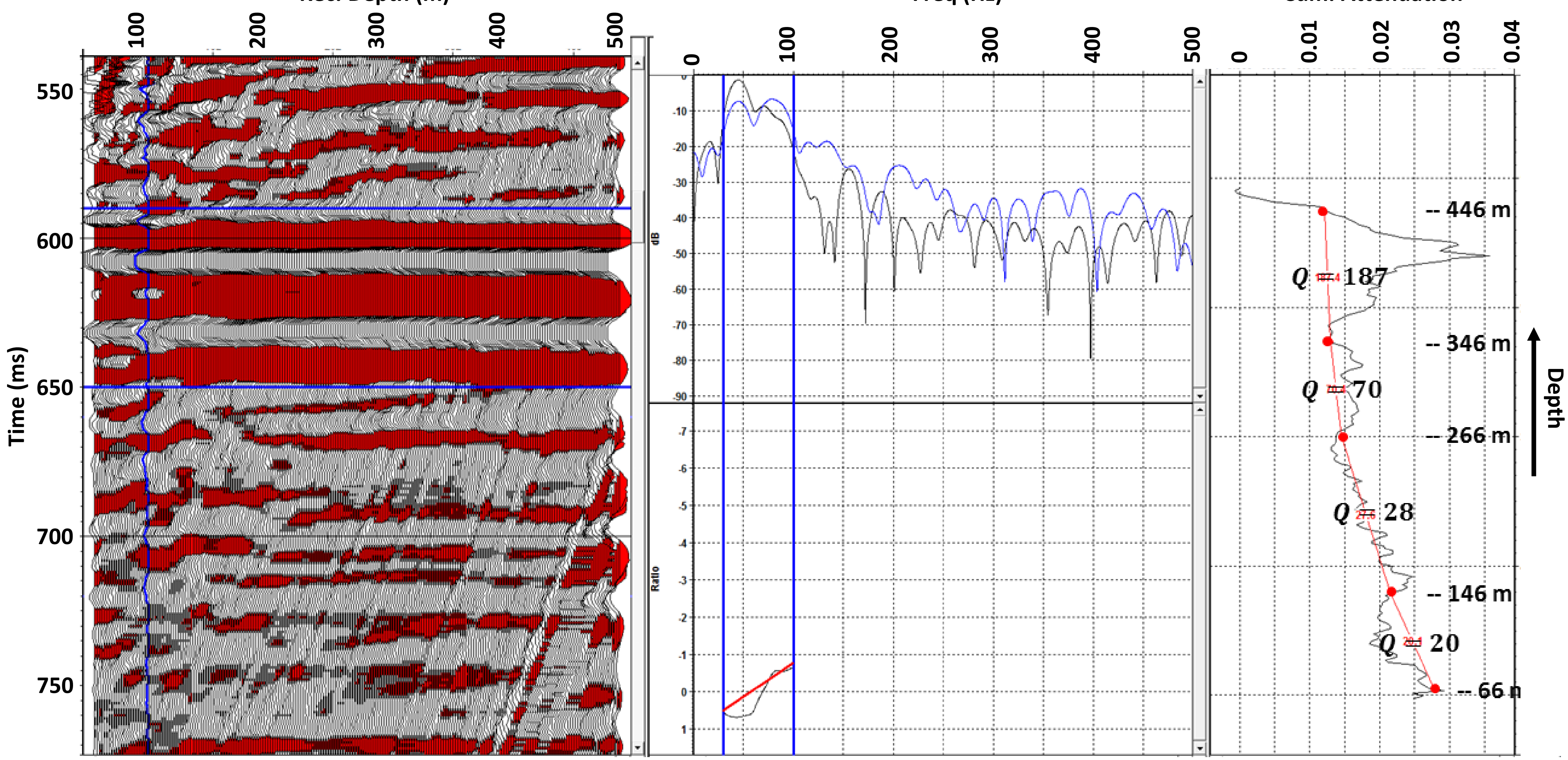
Seismic Gather: Shot point 1 using a dynamite source (Z component) - Flipped

Amplitude Spectra - Upgoing wavefield



Shot point 1 using a dynamite source (Z component)

Q_P Analysis – Upgoing Wavefield



Spectral-ratio method from VISTA software

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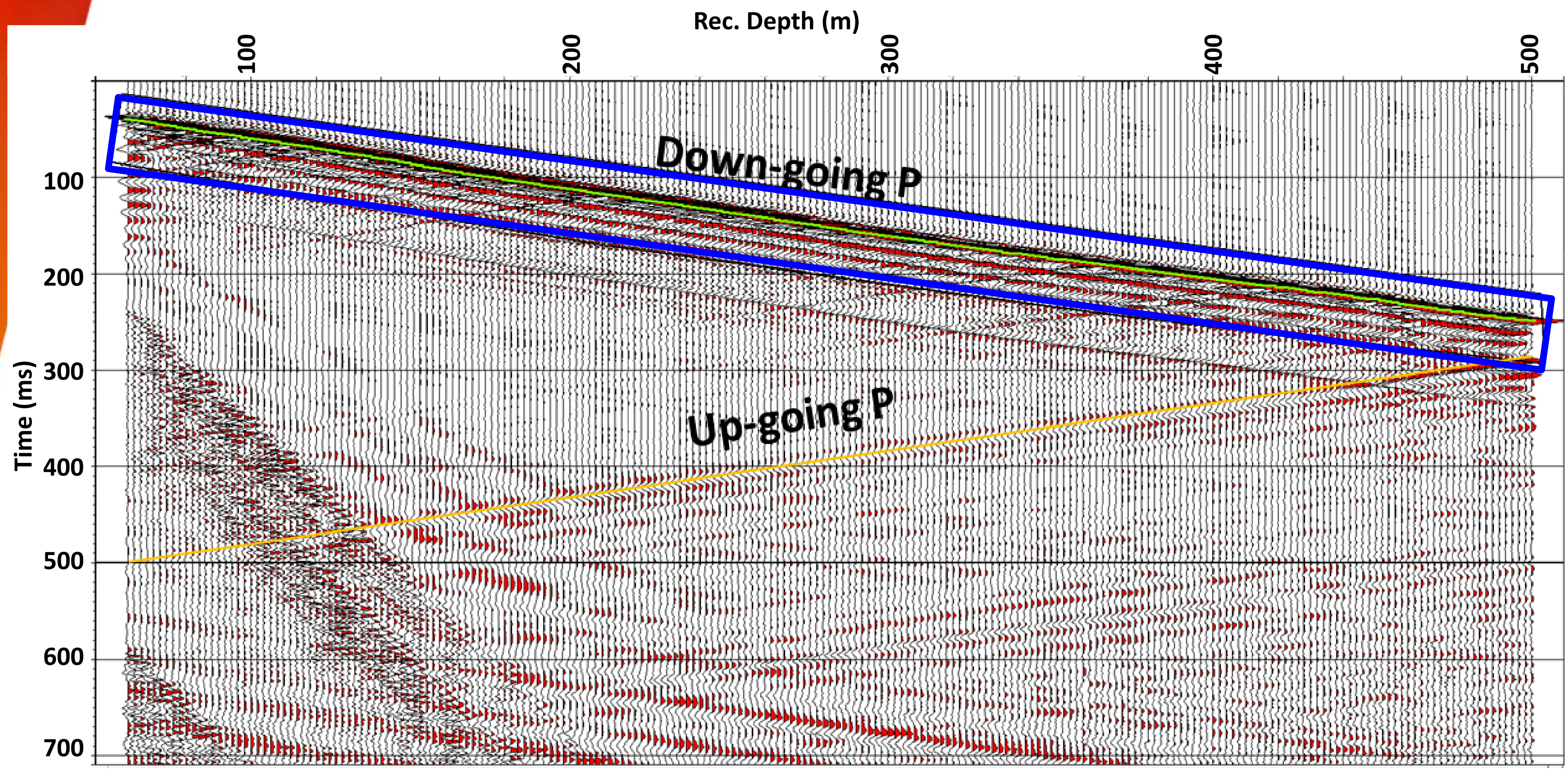
Field VSP Data Analysis

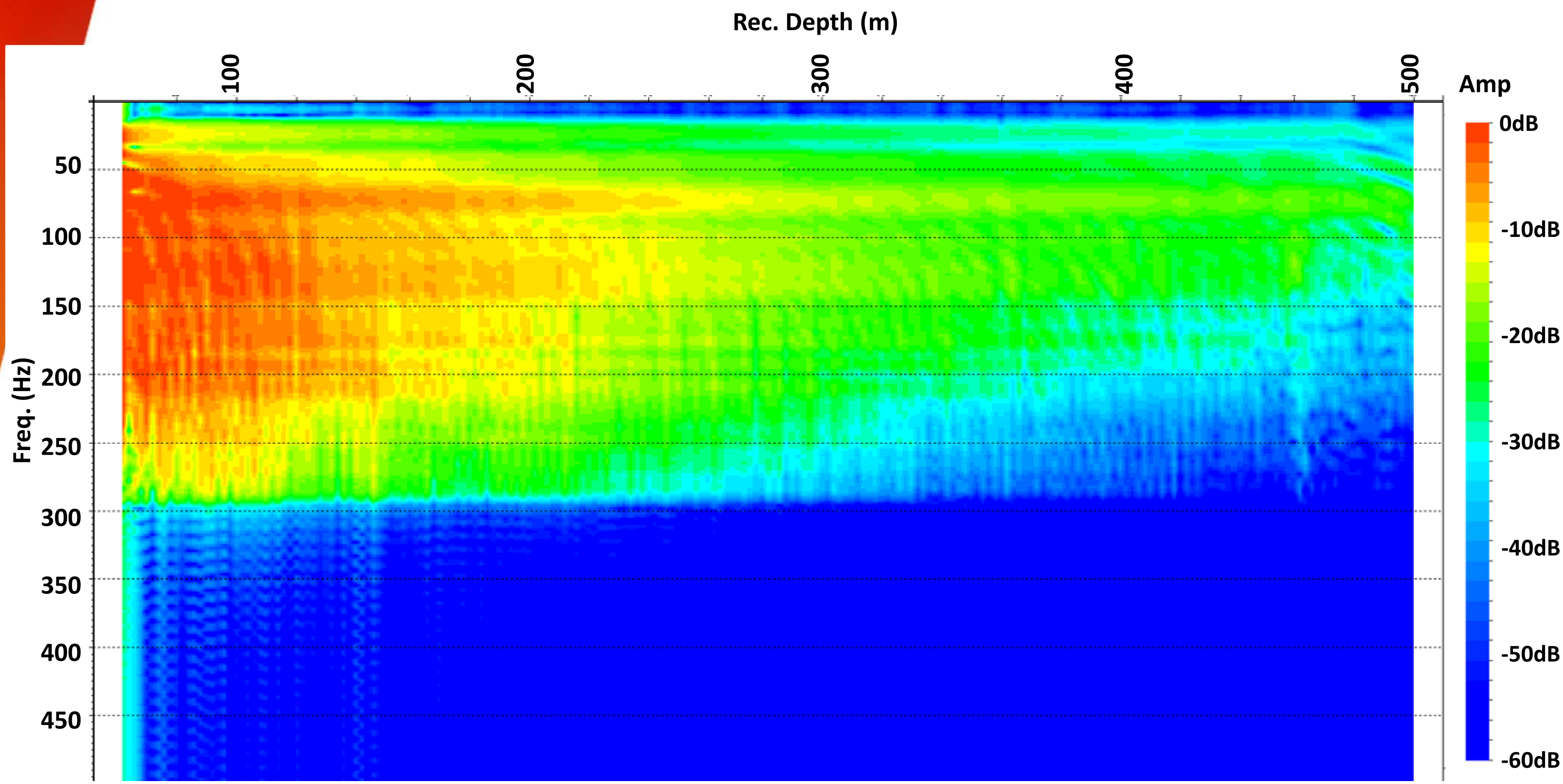
EnviroVibe Source

Field VSP Data Analysis



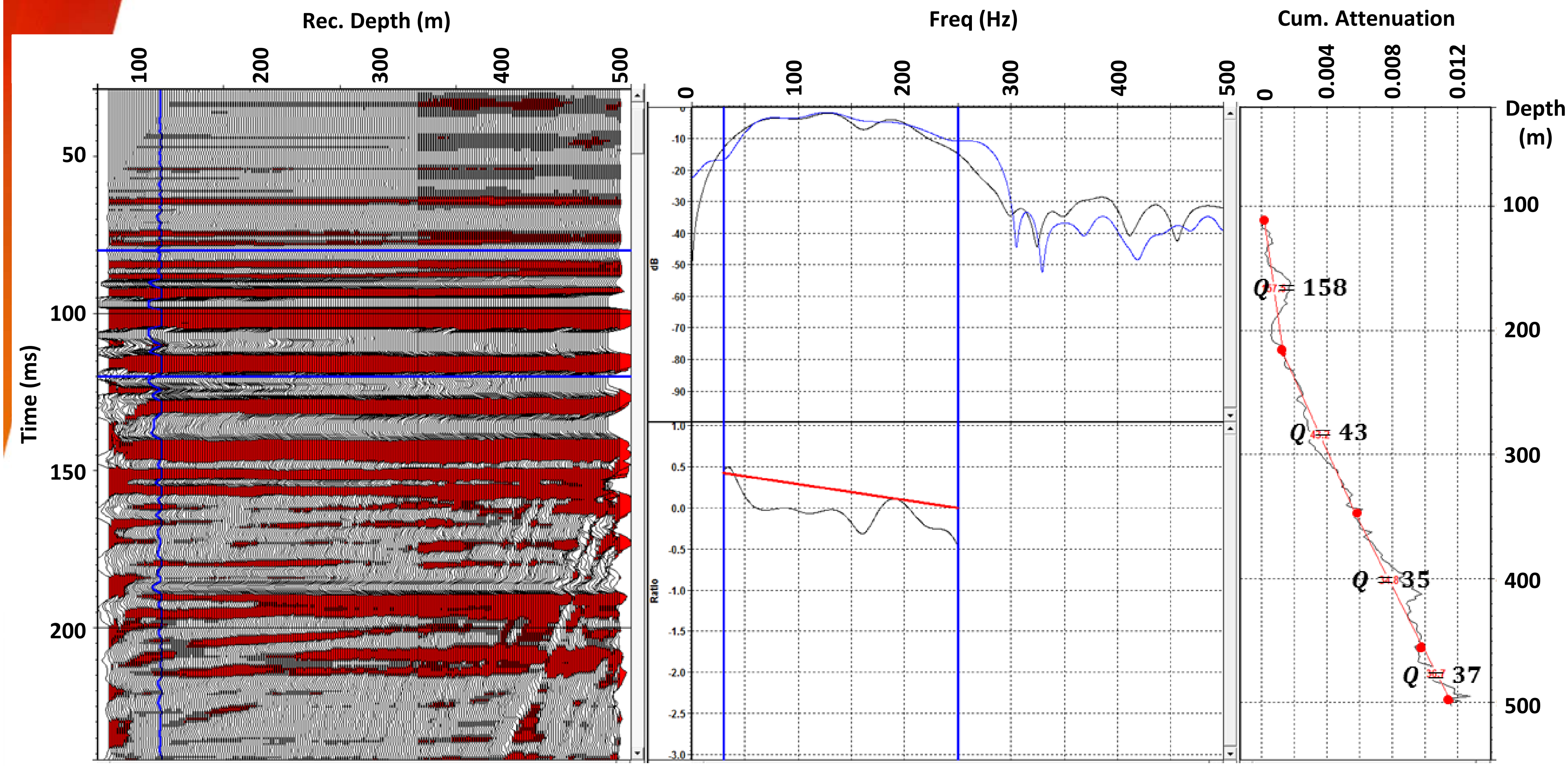
Seismic Gather: Shot point 1 using an EnviroVibe source (Z component)

Amplitude Spectra - Downgoing wavefield



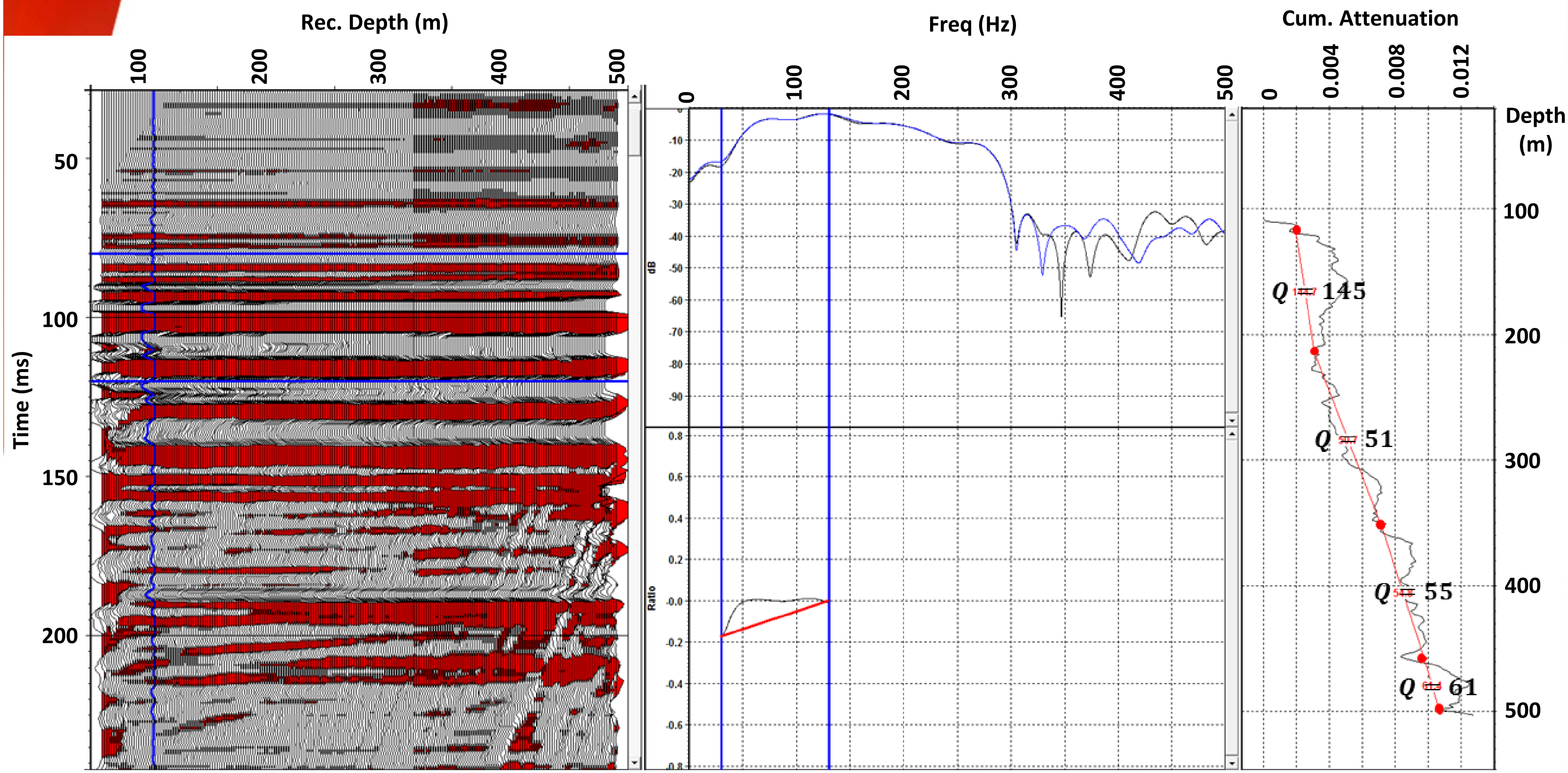
Shot point 1 using an EnviroVibe source (Z component)

Q_P Analysis – Downgoing Wavefield



Spectral-ratio method from VISTA software.
Frequency band: 30-250 Hz

Q_P Analysis – Downgoing Wavefield

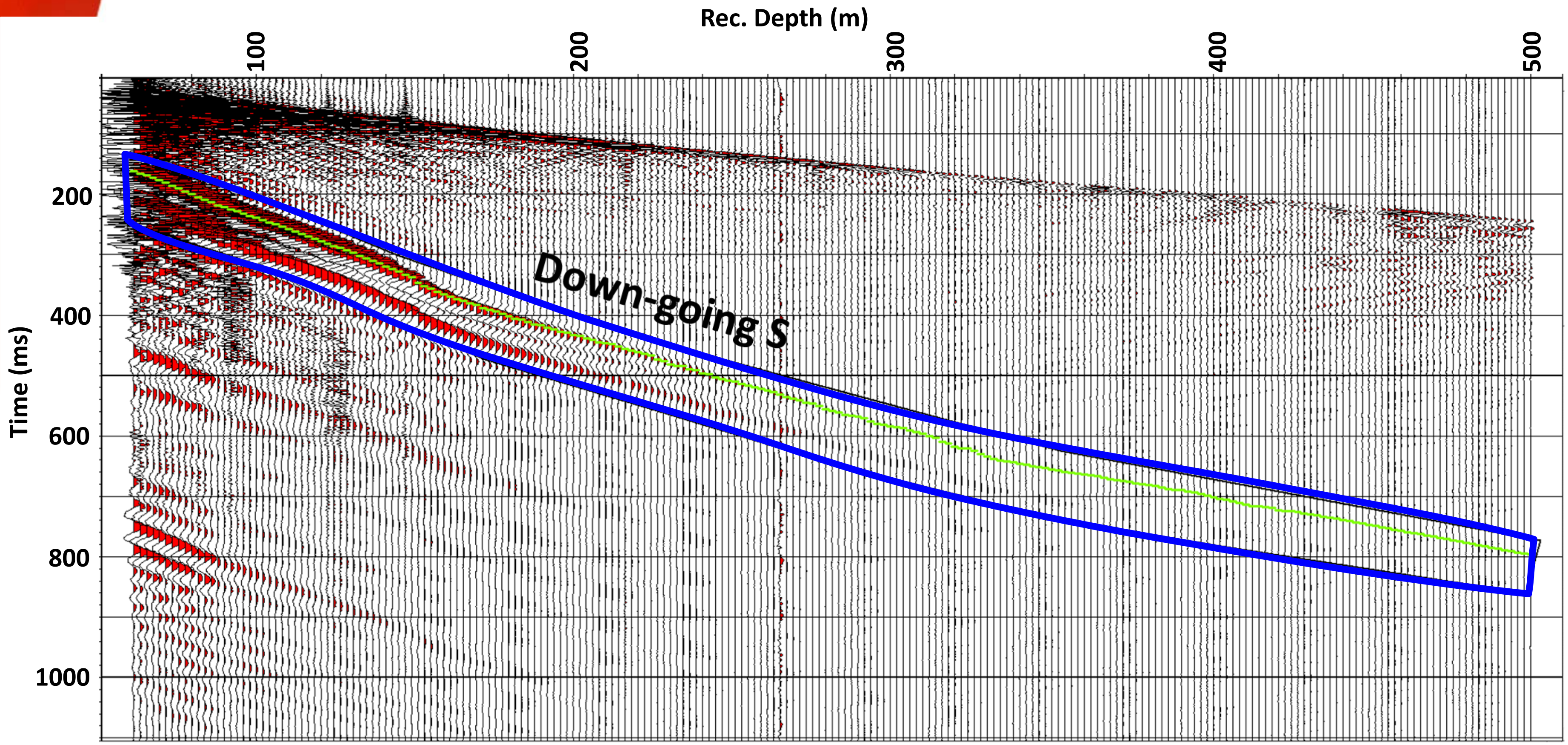


Spectral-ratio method from VISTA software.
Frequency band: 30-130 Hz

Q_S Estimation from downgoing wavefield

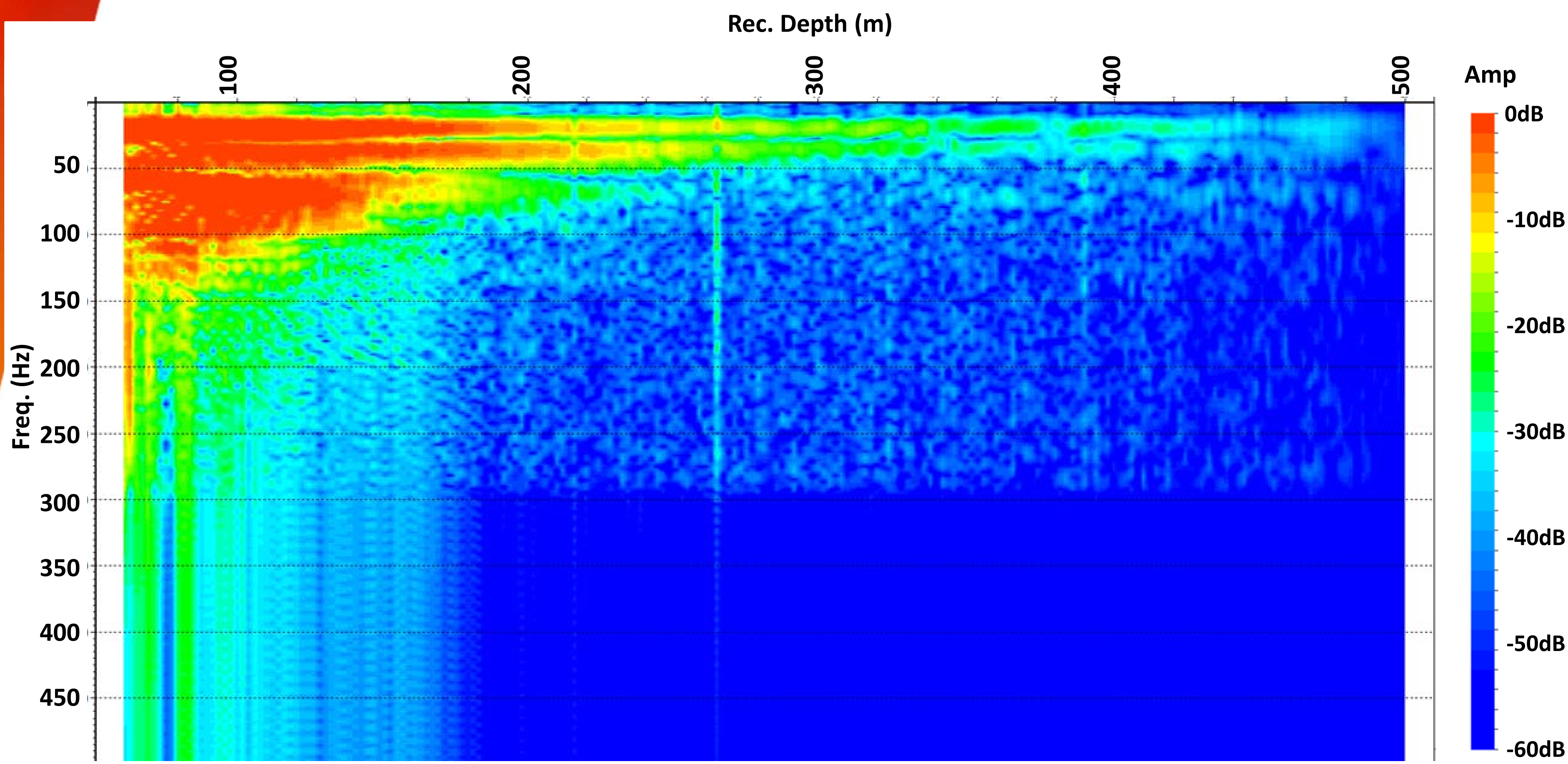
EnviroVibe Source

Field VSP Data Analysis



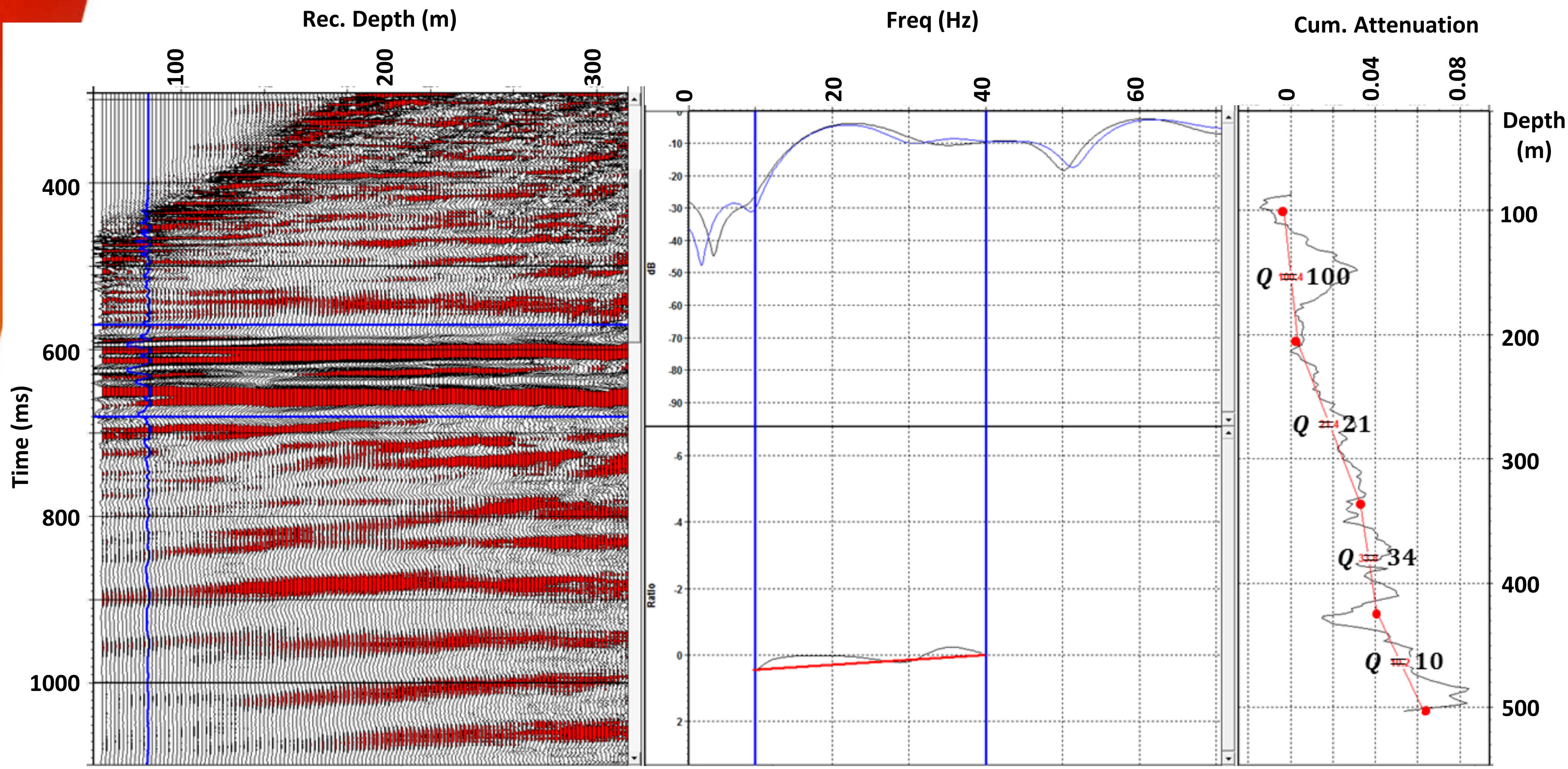
Seismic Gather: Shot point 1 using an EnviroVibe source (Hmax component)

Amplitude Spectra - Downgoing shear wave



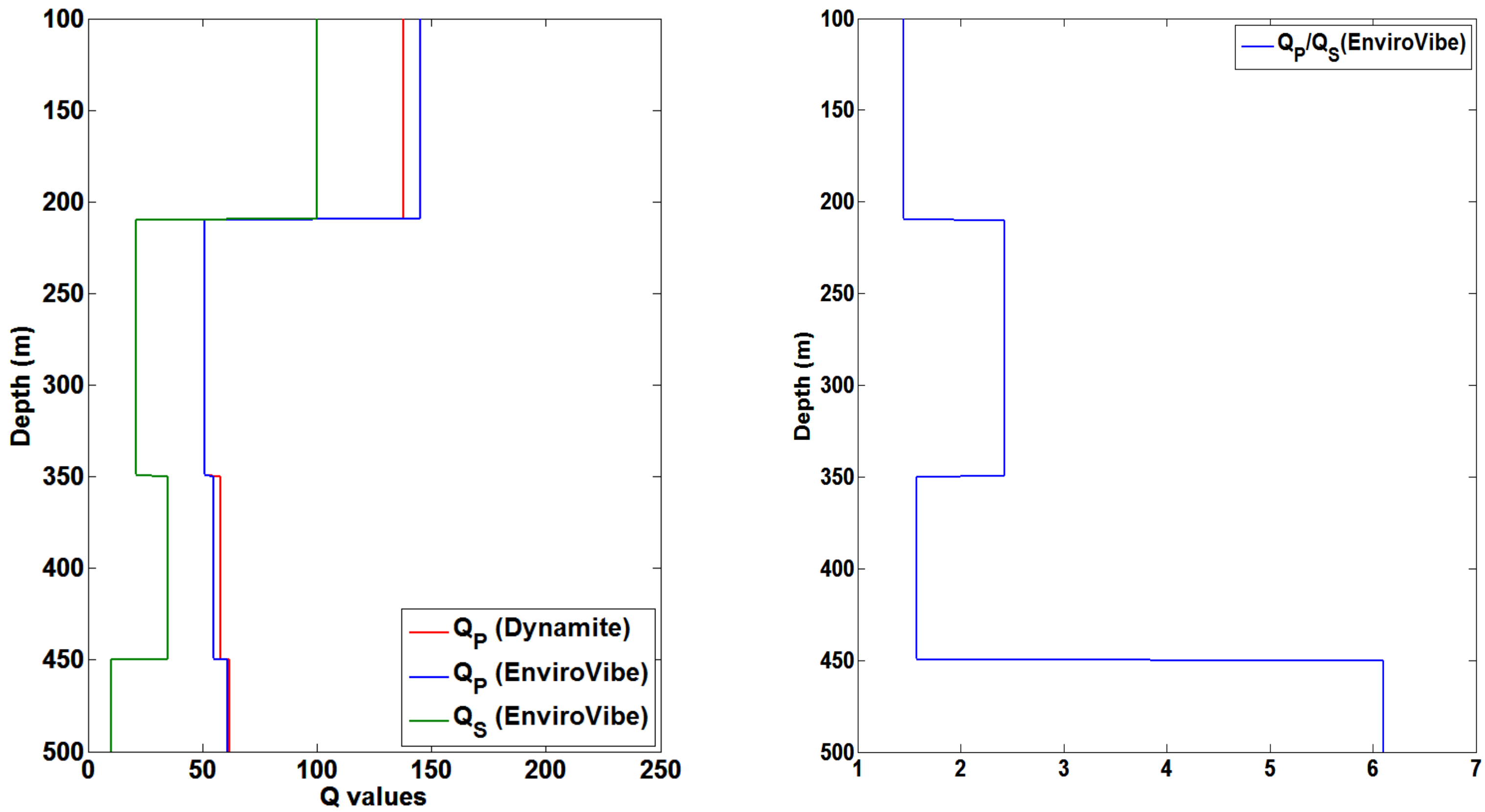
Shot point 1 using an EnviroVibe source (Hmax component)

Q_S Analysis – Downgoing Wavefield



Spectral-ratio method from VISTA software.
Frequency band: 10-40 Hz

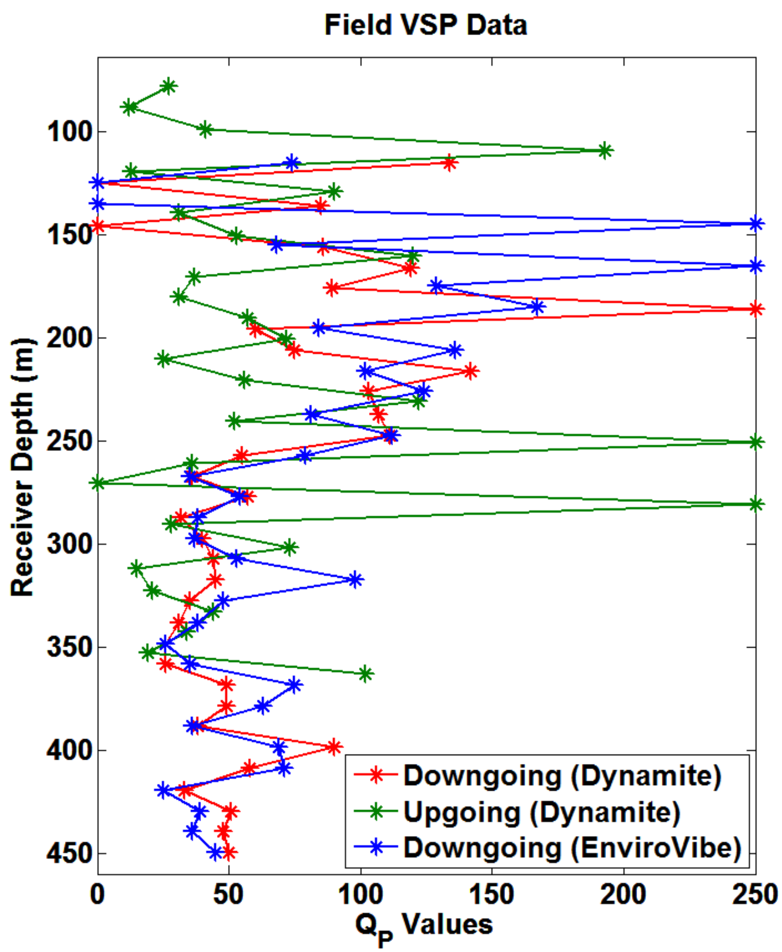
Q estimation from down-going wavefield



Spectral-ratio method from VISTA software

Q_P estimations using dominant frequency

CREWES Toolbox



Conclusions

- Using up-going waves we were able to compute reliable Q values for the shallow layer. Q_P values range from 20-28 from 66-266m depth.
- The spectral-ratio method is very sensitive to the frequency band chosen for the analysis.
- Q_P values range from 43-37 from 210-500m depth using a frequency band from 30-250Hz. Whereas using a frequency band from 30-130Hz Q_P values range from 51-61.
- Estimations done with the dominant frequency matching were more stable regardless of the type of source. Q_P values are around 40 from 100-250m depth and approximately 50 from 250-450m depth.
- Q_S values were estimated from the down-going wavefield with the EnviroVibe source. Results showed that shear waves attenuate faster than p-waves leading to lower Q_S values.
- Q_S values range from 21-34 from 200-420 depth.

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Conclusions

- Q_P/Q_S values range from 1.45-2.4 from 100-400m depth.
- The walkaway VSP data also show a very good converted-wave energy.
- Q_S will be computed from the up-going converted wavefield.

Acknowledgements

- Unidentified company for access to the field VSP data
- CREWES sponsors
- NSERC through grant CRDPJ 379744-08.
- GEDCO/Schlumberger for VISTA software
- CREWES students and staff

- **Thanks**

- **Questions?**

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References

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Processing flow using VISTA software

Step 1
- Geometry

Step 2
- First Breaks Picking

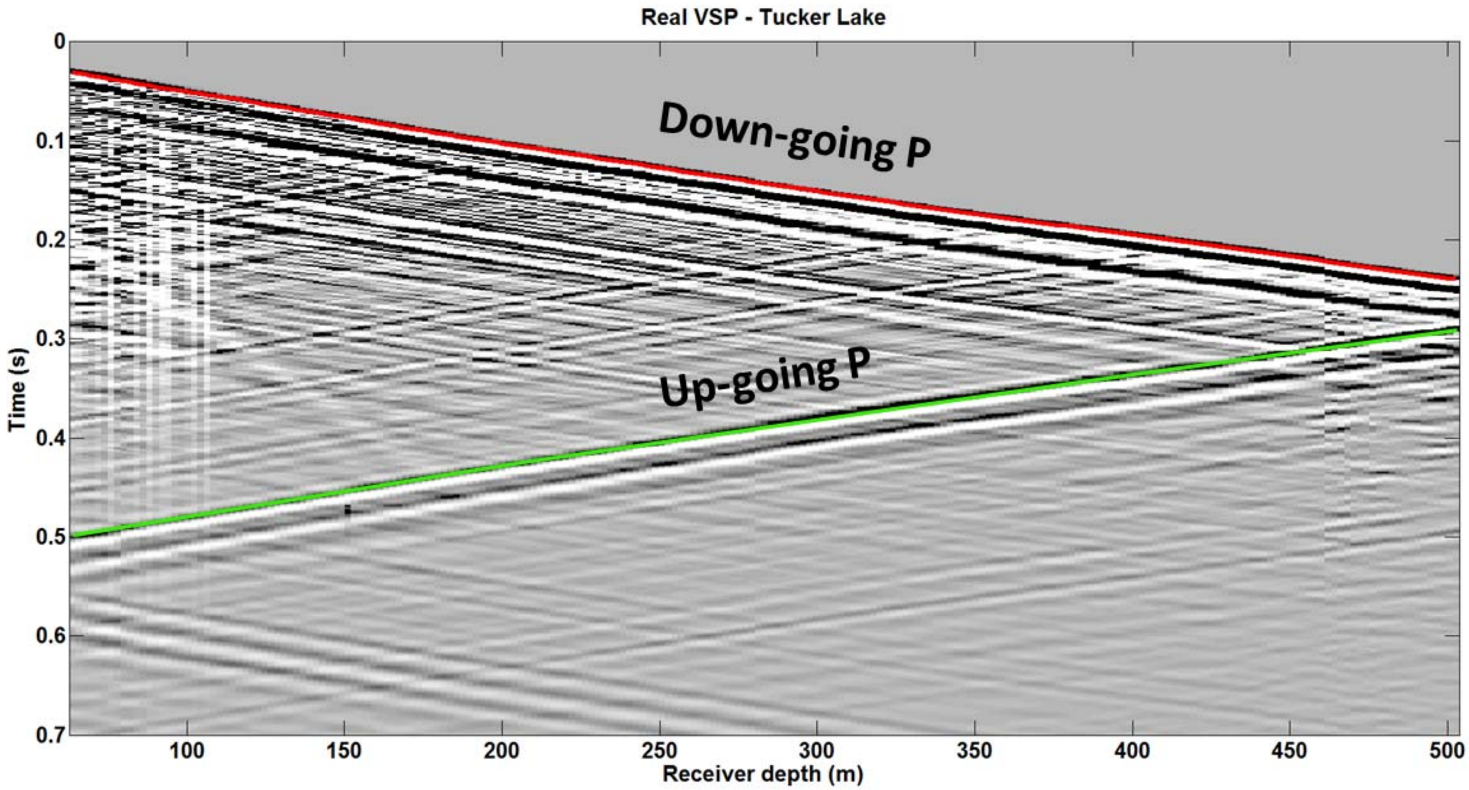
Step 3
- Flatten

Step 4
- Mean scaling

Step 5
- Median filter

Step 6
- Q analysis

Dynamite



Real VSP - Tucker Lake
Down-going P
Up-going P
Time (s)
Receiver depth (m)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
100
150
200
250
300
350
400
450
500

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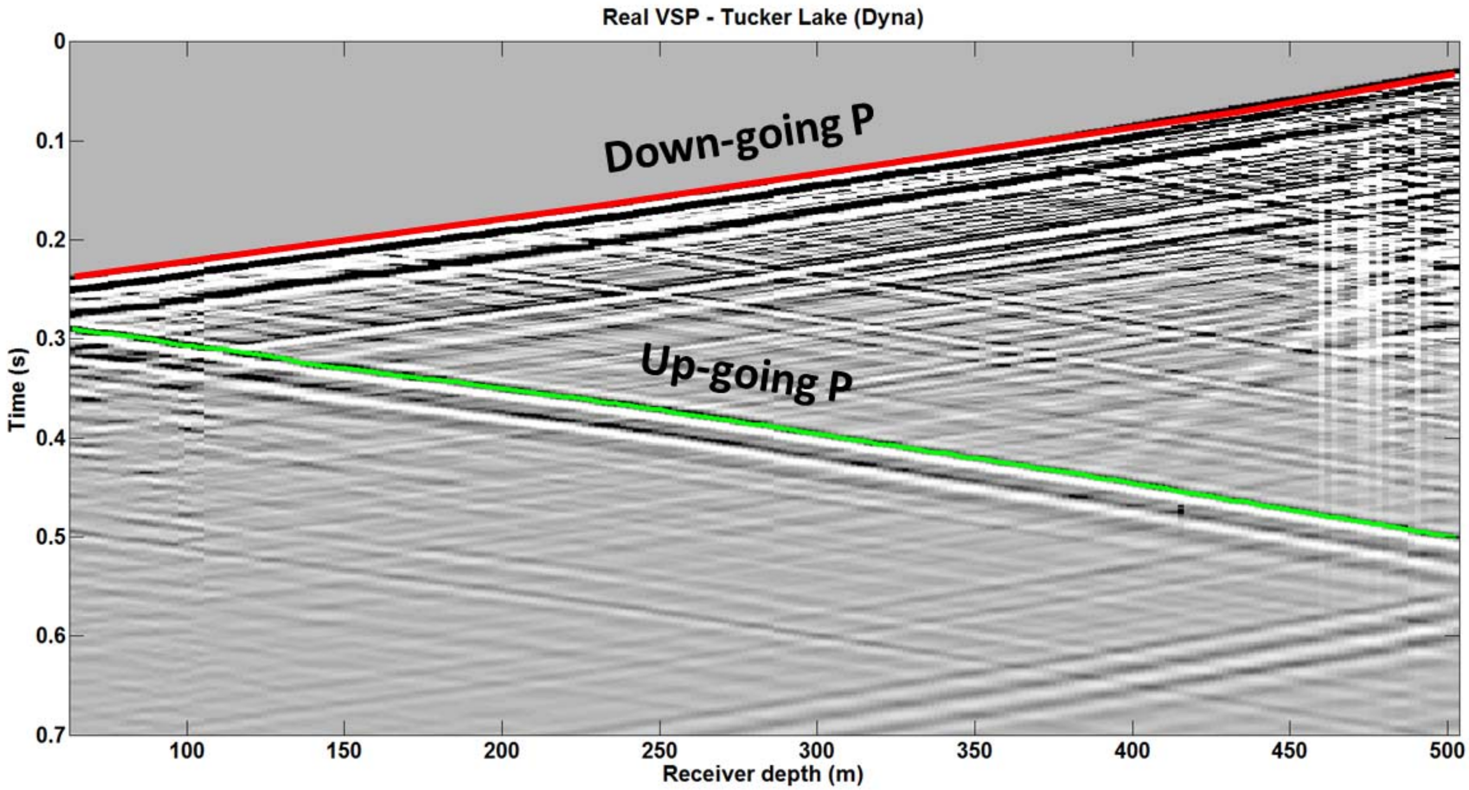
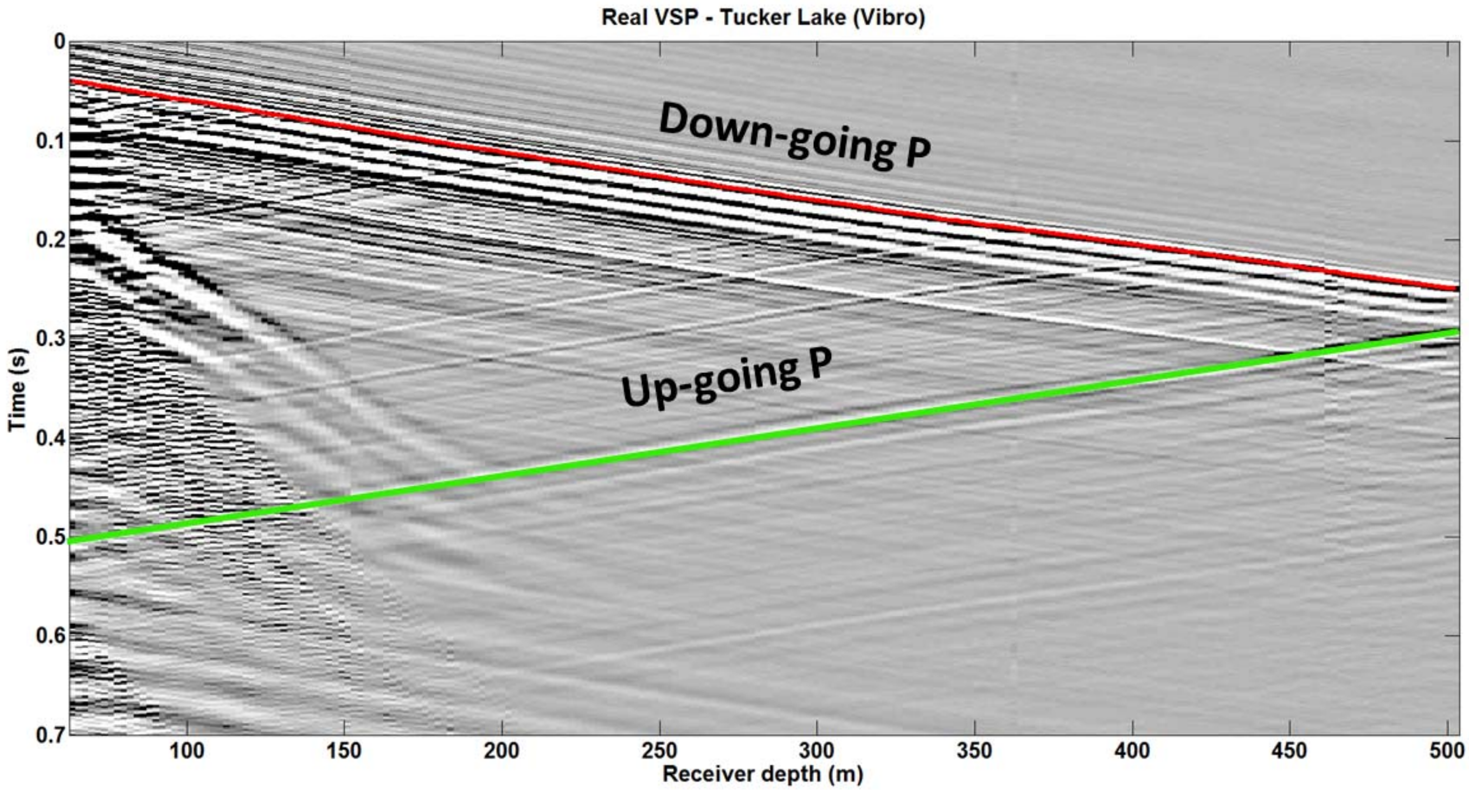
Dynamite

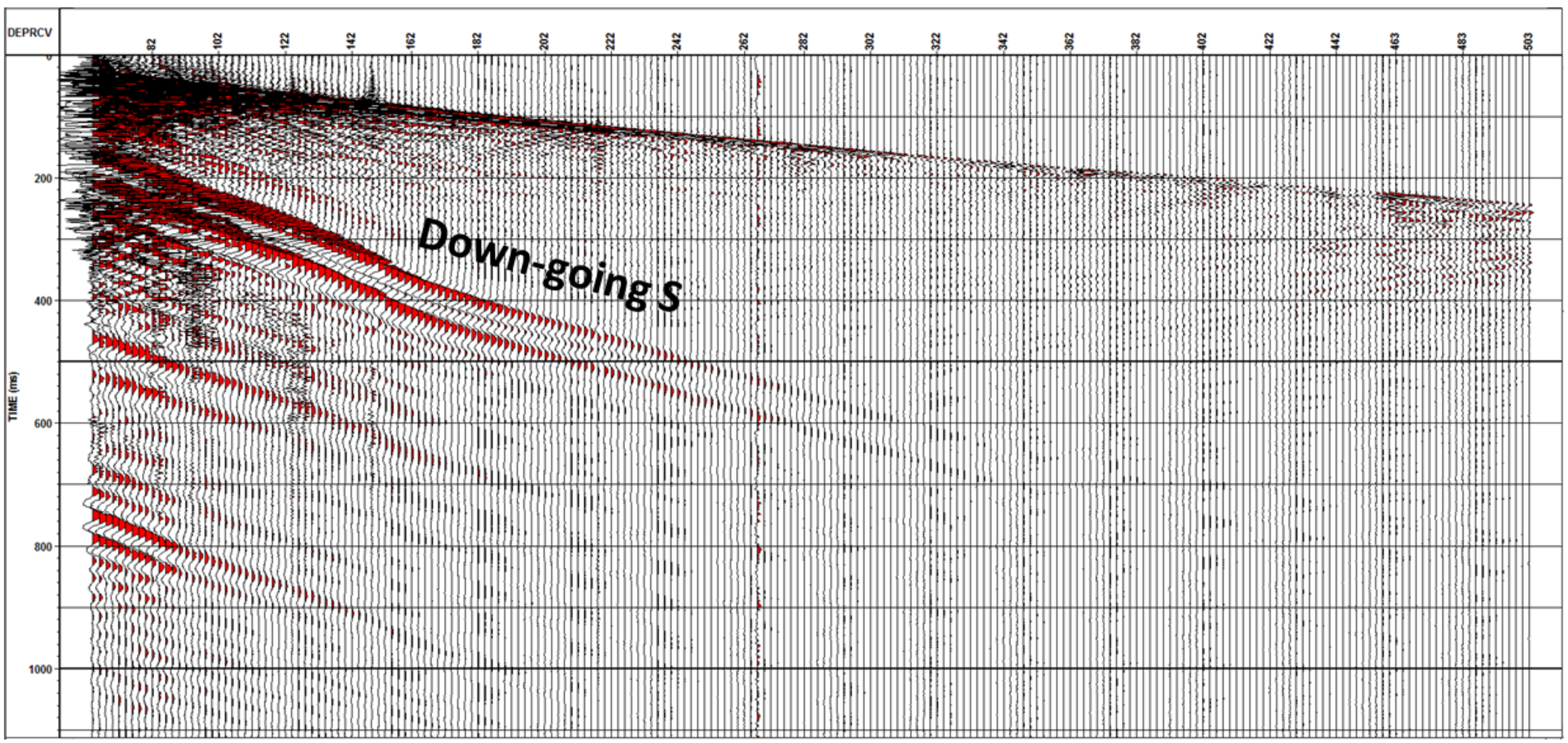


Vibroseis

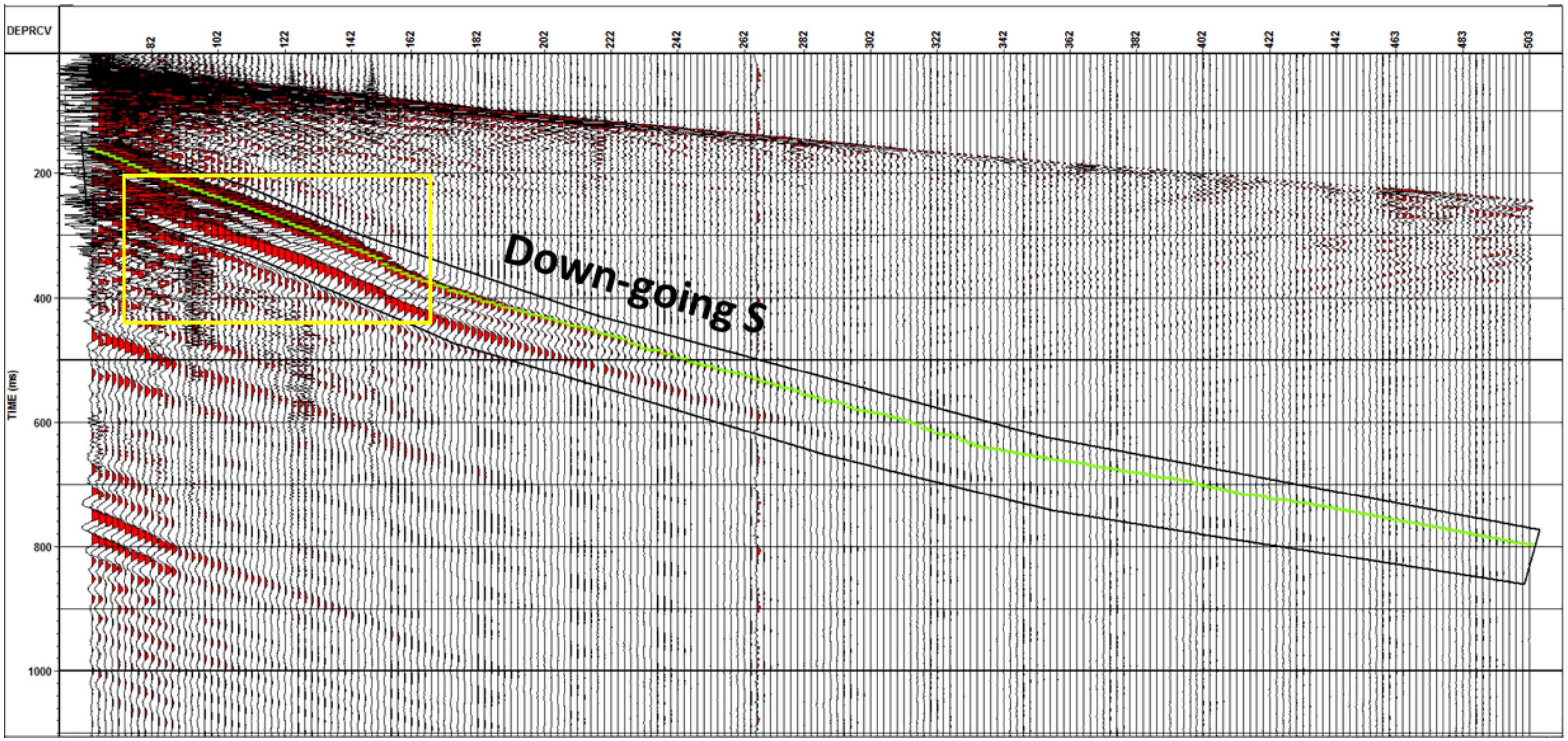


Real VSP - Tucker Lake (Vibro)
Down-going P
Up-going P
Time (s)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
100
150
200
250
300
350
400
450
500
Receiver depth (m)

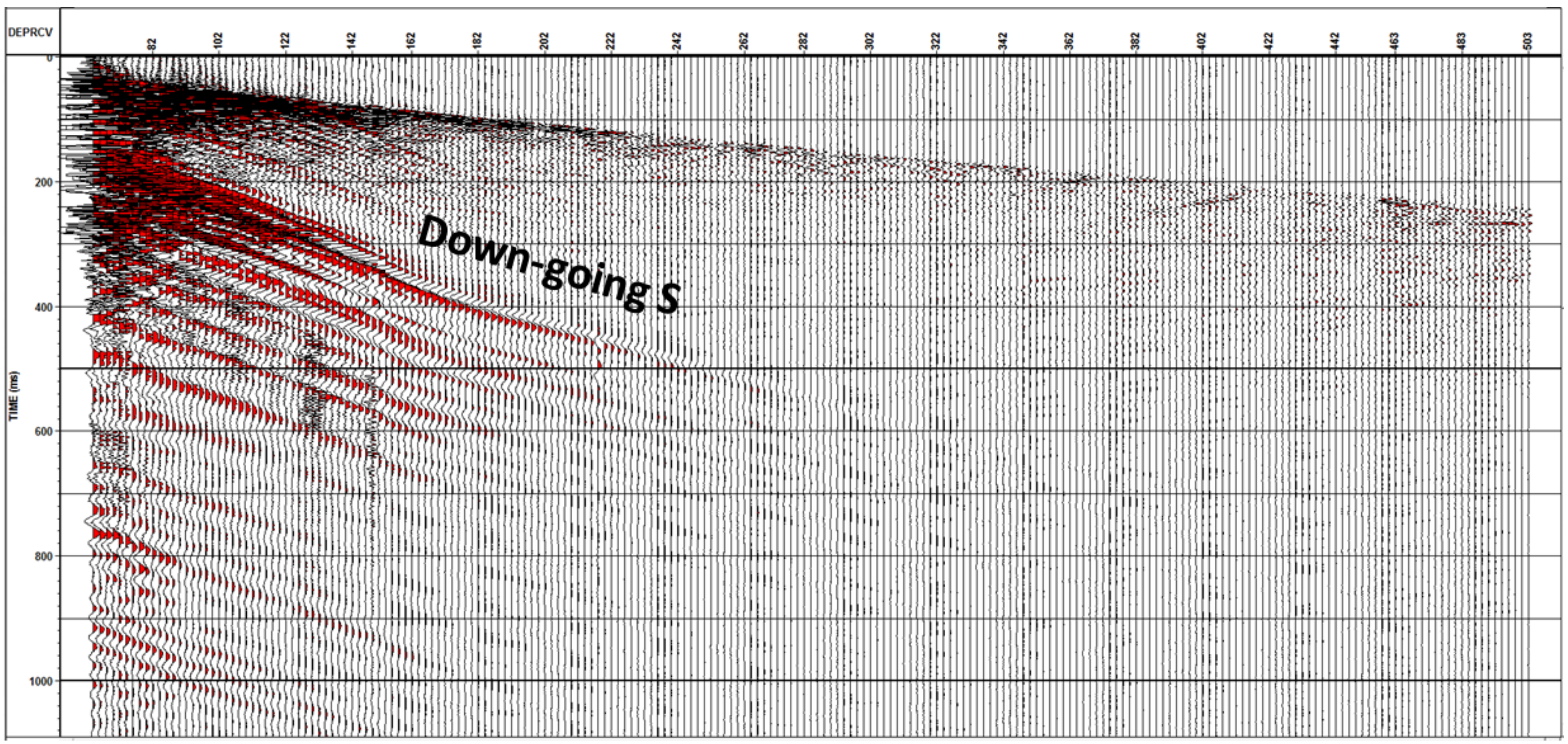
Shot 1: X Component (EnviroVibe)



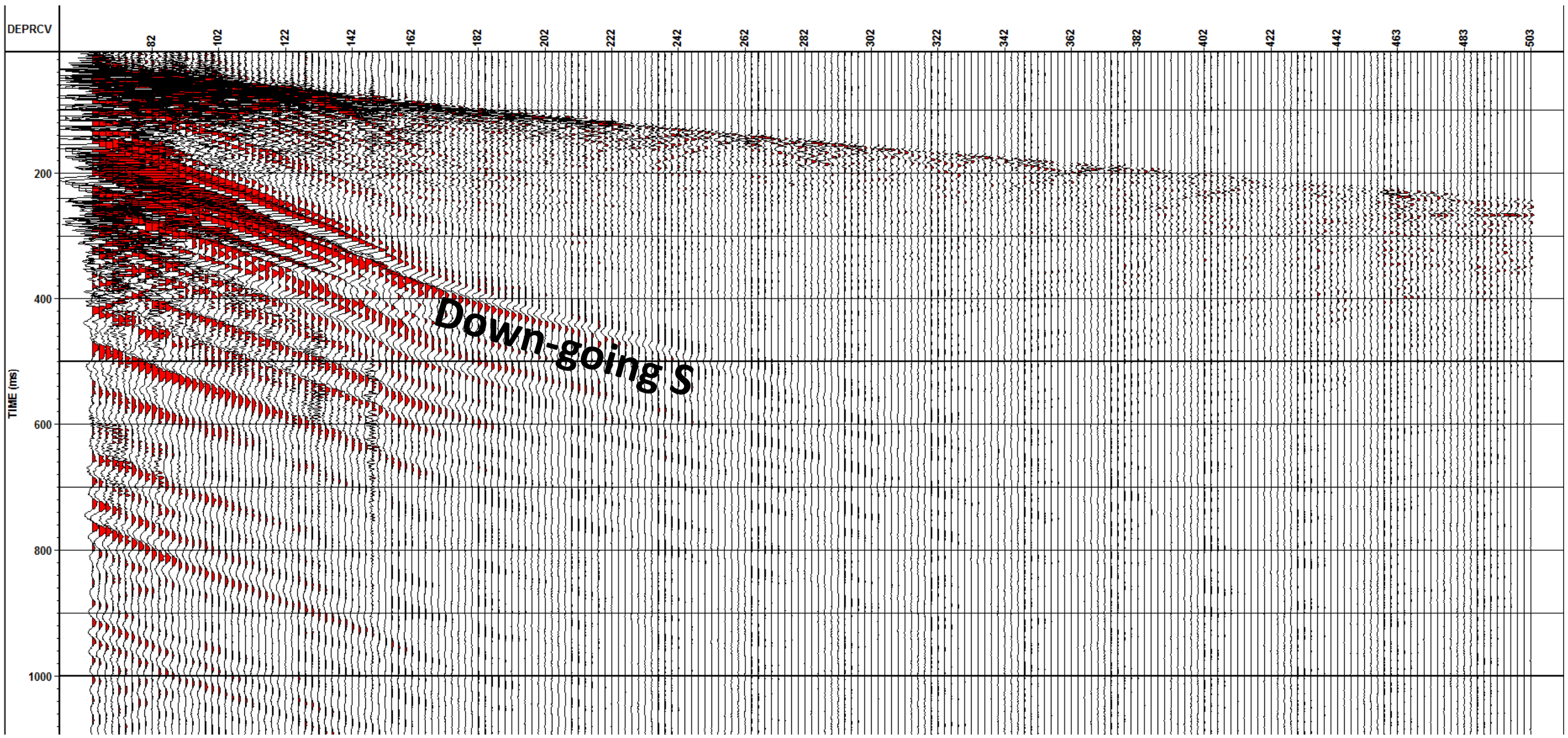
Shot 1: Hmax (EnviroVibe)



Shot 1: Y Component (EnviroVibe)



Shot 1: Hmin (EnviroVibe)



Q_{ins} corresponds to the instantaneous Q obtained from well log data, $Q_{estimation}$ corresponds to the values estimated from the synthetic down-going wavefield and Q_{ave} corresponds to the average Q given by equation 12, where $Q_k = Q_{ins}$,

$$Q_{ave}^{-1} = \frac{1}{t} \sum_{k=1}^{n} \frac{\Delta t_k}{Q_k}. \qquad (12)$$

$$RD_{flipped} = shift - RD,$$

where RD is the receiver depth, $RD_{flipped}$ is the flipped receiver depth, and $shift$ is the maximum plus minimum receiver depth (566 m).

Ideas for future work include:

- Adding noise to the synthetic VSP to study how the noise affect our Q estimation.
- Performing an elastic forward modelling using shear wave velocity from well logs close to borehole. Then, compute a synthetic VSP to estimate Q_S values.
- Q_P and Q_S estimation from offset VSP data. The X component of the offset VSP shots shows an up-going shear wavefield with a strong energy that can be used to estimate Q_S.