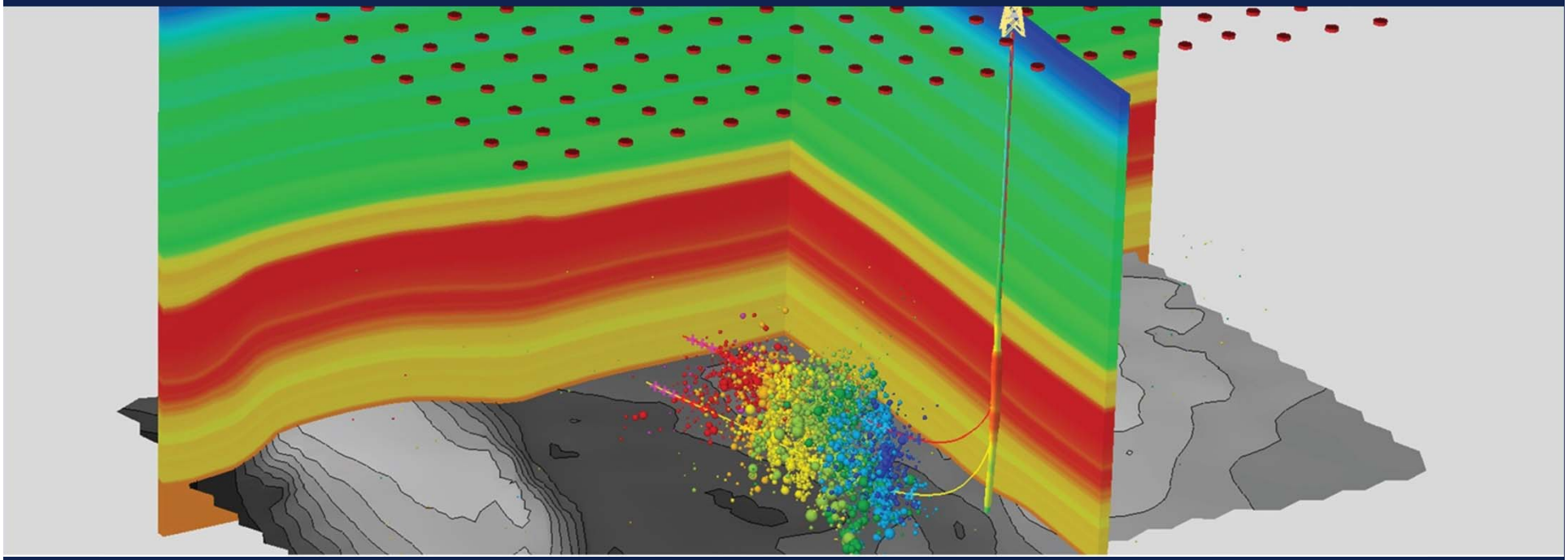
Spectraseis



The Signal and the Noise:

Why shallow boreholes may not always provide the expected benefits

Ben Witten

Why would an operator invest in a sub-surface microseismic array?

Spectraseis

(A) Data quality issues

- Poor near-surface conditions, e.g. swamp, muskeg, severe statics
- High surface noise
- Access and array design constraints, e.g. forests

Value is derived from improved data quality. A subsurface array may be the best technical solution

(B) Economic drivers

- Cost comparison with deep borehole or surface arrays
- Imaging cost per stage falls as more stages are monitored using the same array

Value is derived from reduced price per stage imaged. A sub-surface array may be the most cost-effective option

Two main drivers for considering a sub-surface array
This presentation focuses on data quality benefits from improved S/N

Surface vs. sub-surface
Two time traces - which is which?

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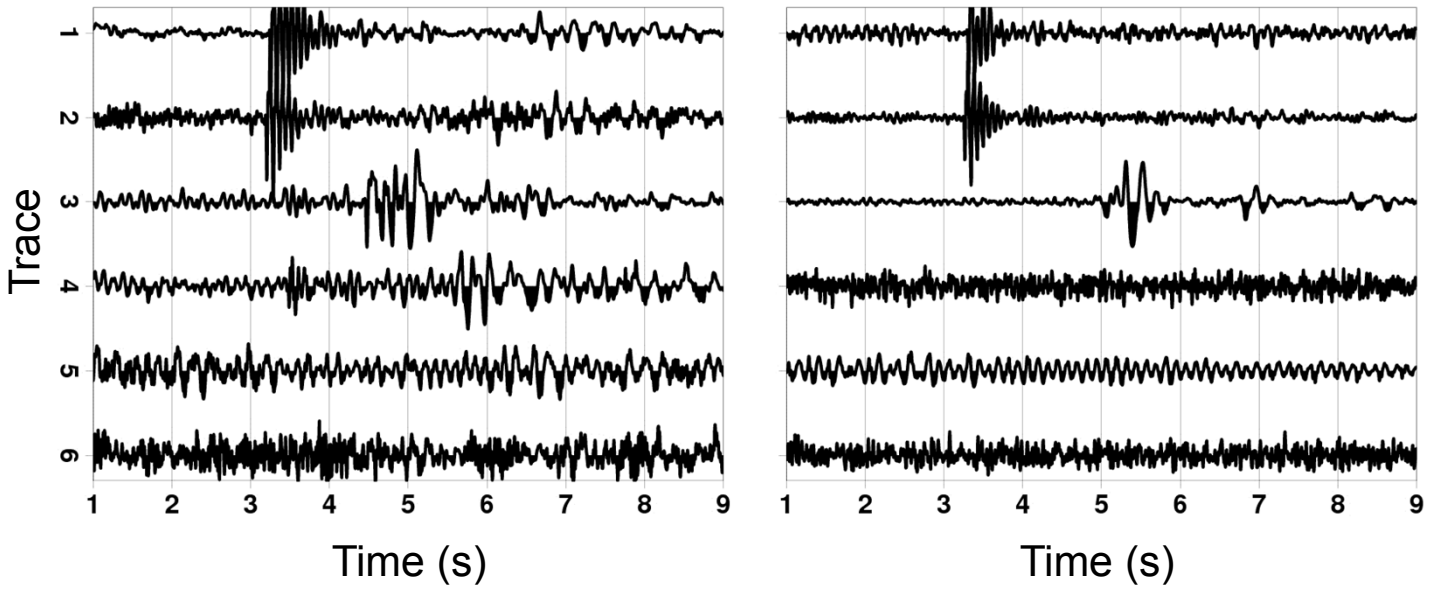

Surface shallow borehole pairs for vertical component

Very little difference in S/N between the two

Conventional wisdom on surface vs. shallow borehole

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- Noise amplitude decreases with depth
- Signal amplitude decreases away from the source

But is that the whole story?

Conventional wisdom on surface vs. shallow borehole

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✓ Noise amplitude decreases with depth

– Signal amplitude decreases away from the source ??

Both the numerator and denominator are important in S/N

Conventional wisdom on surface vs. shallow borehole

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✓ Noise amplitude decreases with depth

– Signal amplitude decreases away from the source ??

- The very near surface has a low Q (can be the case, i.e. swamp, but in other cases may not play a significant role)
- Closer to source – this distance is usually insignificant
- Geophysics may dictate a decrease in signal closer to the source !
  - » Free surface effect
  - » Velocity effects

We'll look at the signal side more carefully

Agenda

- Noise modeling
- Signal modeling
- Observations
- Conclusions

Noise modeling

What is the near surface geology?

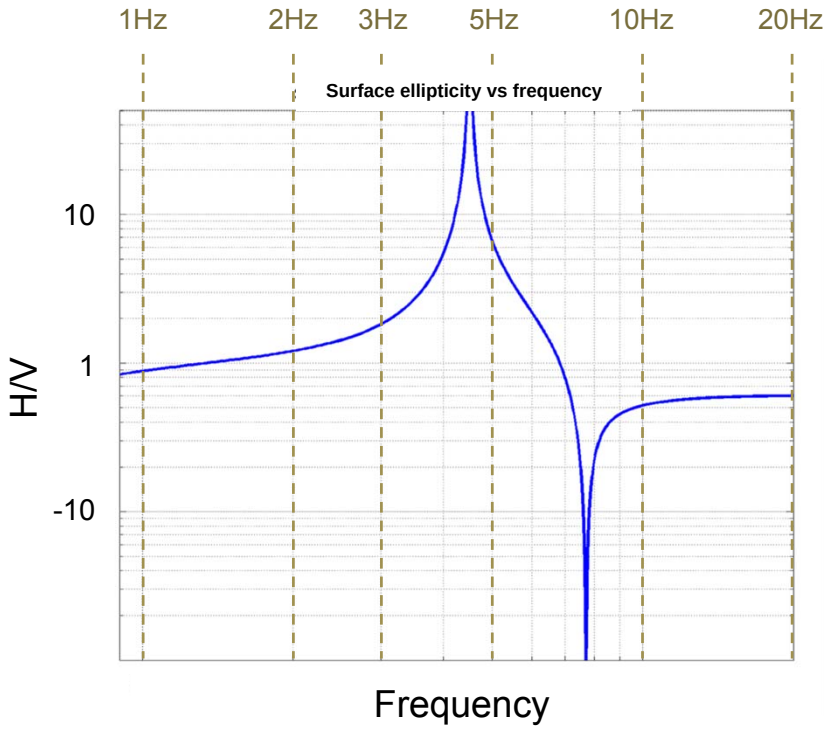
What are the main sources of surface noise?

What is the frequency content of the noise?

What is the frequency content of the signal at the receiver?

Surface-wave modeling can be used to estimate noise decay
Will not address body wave noise

Surface-wave modeling



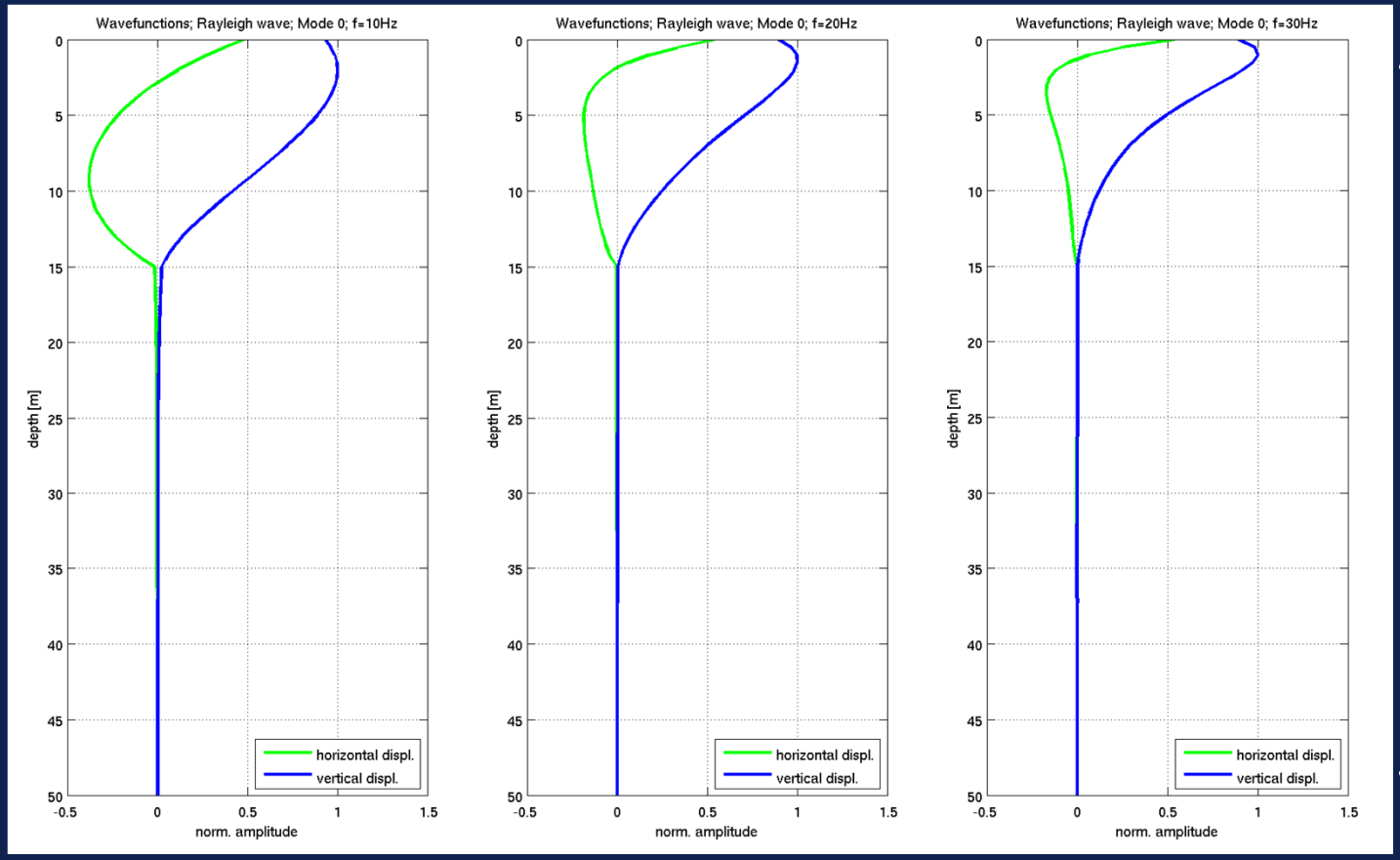
Model

Thickness	Vp	Vs	Rho
15	600	250	1500
80	1800	900	2200
690	2600	1150	2200
135	3100	1600	2350
Infinite	4900	2350	2500

Using an earth model we can see how the surface waves will decay with depth

Amplitude decay with depth

10 Hz 20 Hz 30 Hz



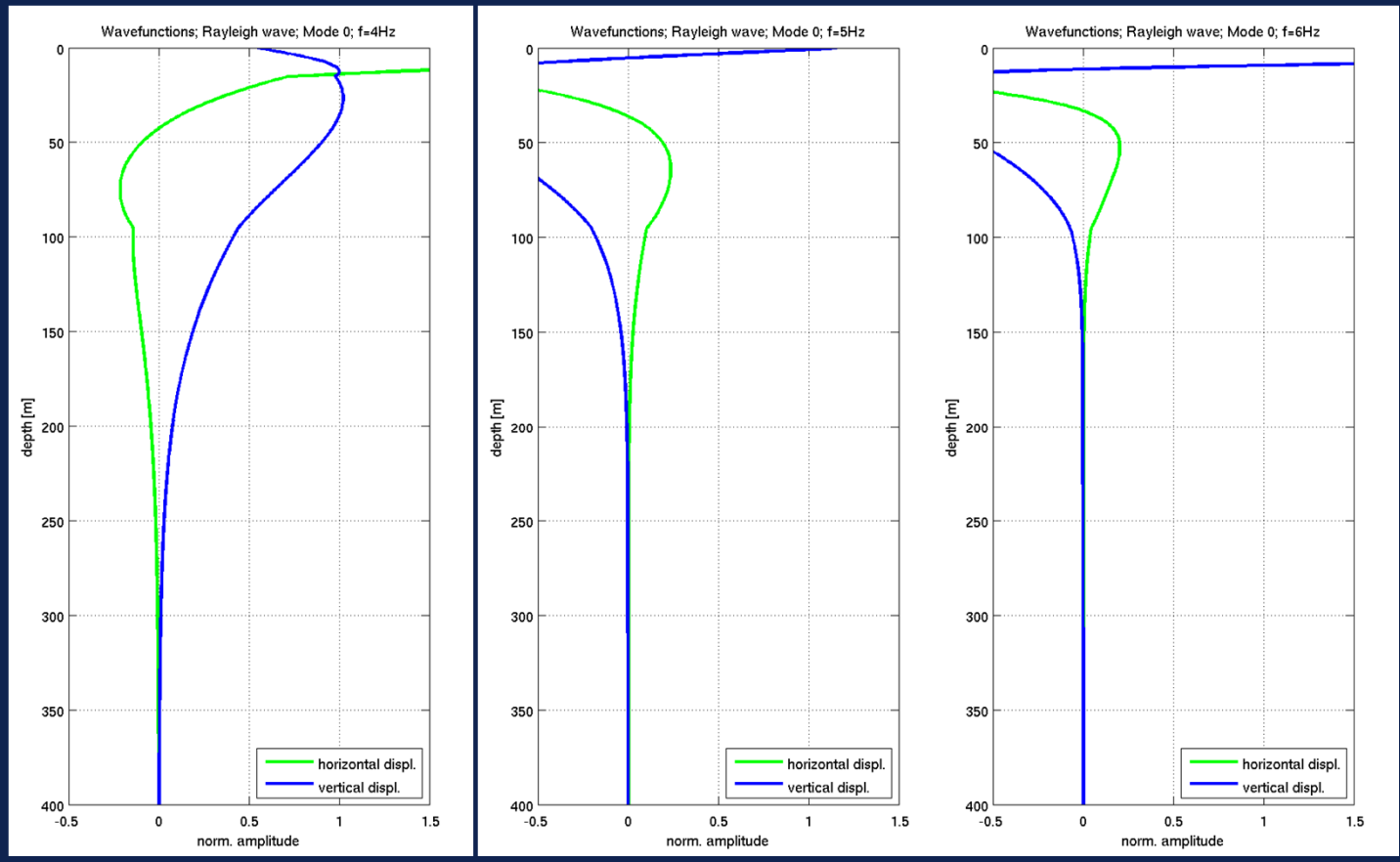
Energy above 10 Hz is attenuated by 15 m

50m

Vertical component of surface wave is not a maximum at the surface

Amplitude decay with depth

4 Hz 5 Hz 6 Hz



Energy below 6 Hz persists below 150 m

400m

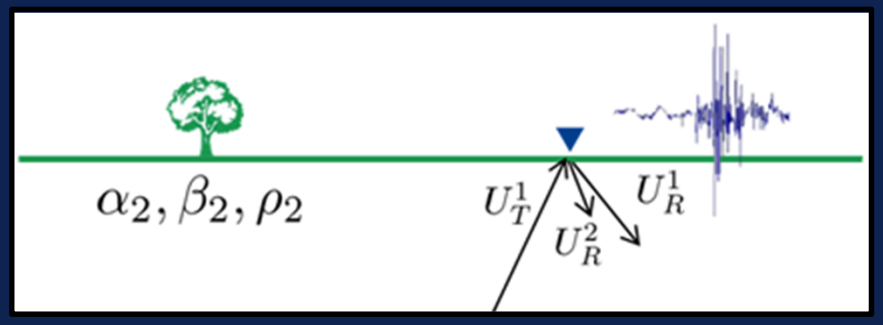
Surface waves significantly decrease with depth
Smaller denominator in S/N

Signal modeling

- Common in earthquake seismology is to remove site effects
- Local conditions affect signal amplitude
- Local conditions include:
  - physical parameters at the sensor
  - sensor location (surface vs buried)

Seismologists remove site effects to get at nature of the signal
However, they could be advantageous for detecting weak signals

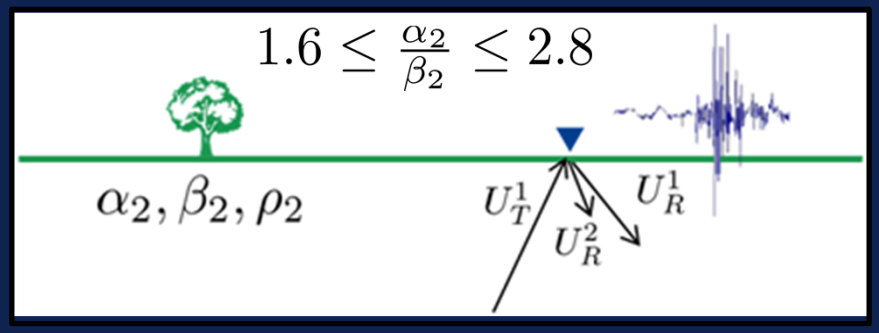
Free surface amplification



Remove the effects of the free surface reflection

Free surface amplifies the recorded signal

Free surface amplification



$$S_h(t) = \frac{1}{2} \cdot H(t)$$

$$S_v(t) = \frac{1-2\beta^2 p^2}{2\sqrt{1-\beta^2 p^2}} \cdot H(t) - \beta p \cdot Z(t)$$

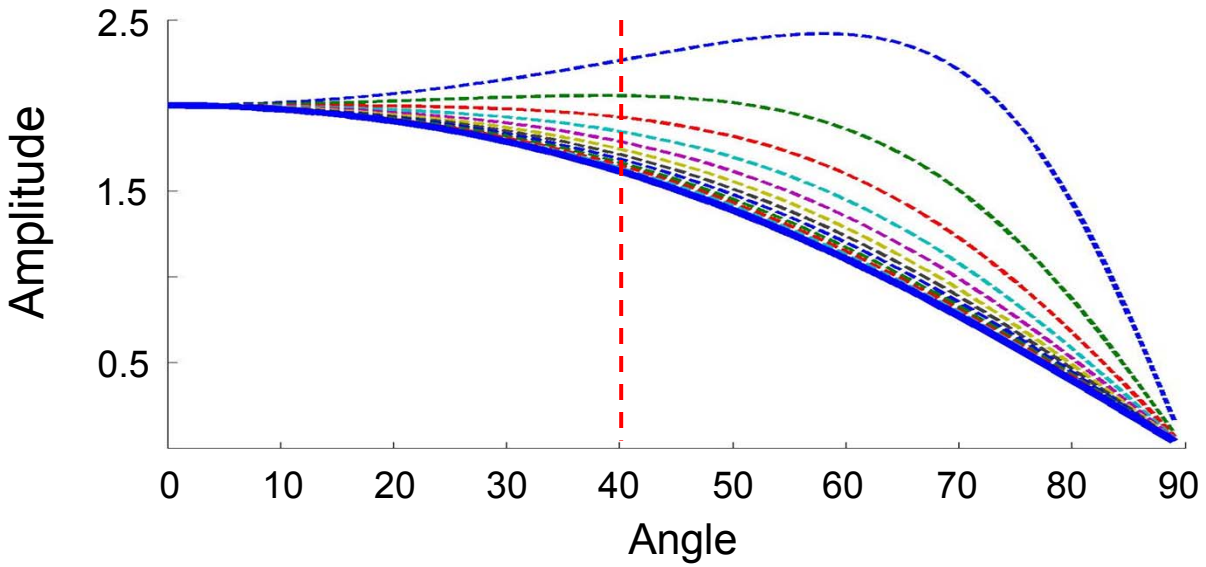
$$P(t) = \frac{1-2\beta^2 p^2}{2\sqrt{1-\alpha^2 p^2}} \cdot Z(t) + \frac{\beta^2 p}{\alpha} \cdot H(t)$$

(The removal of free surface interactions from three component seismograms, Kennett **JGI**, 1991)

Also Aki and Richards (Chapter 5, problems)

The free surface provides a unique amplification

Vertical P-wave amplification



Thickness	Vp	Vs	Rho
15	600	250	1500

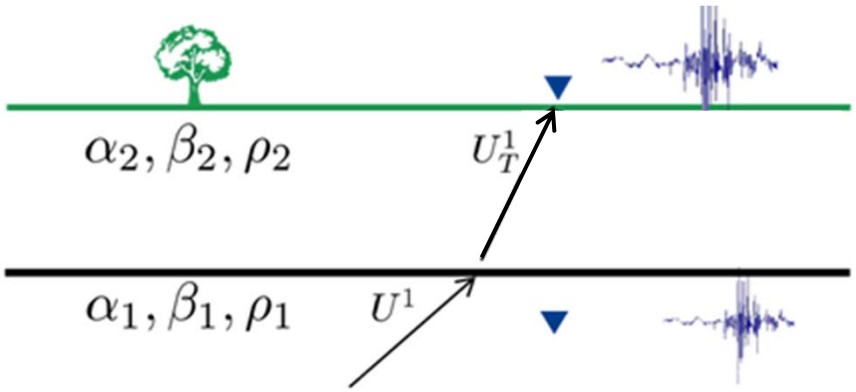
} thick blue line

Lines are Vp/Vs ratios from 1.6 to 3.6)

Below the red line should capture most of the arrival angles

For usual angles of incidence, the amplification is ~2

Low velocity amplification



$$1 \leq \frac{\alpha_1}{\alpha_2} \leq 5 \quad 1 \leq \frac{\beta_1}{\beta_2} \leq 5$$

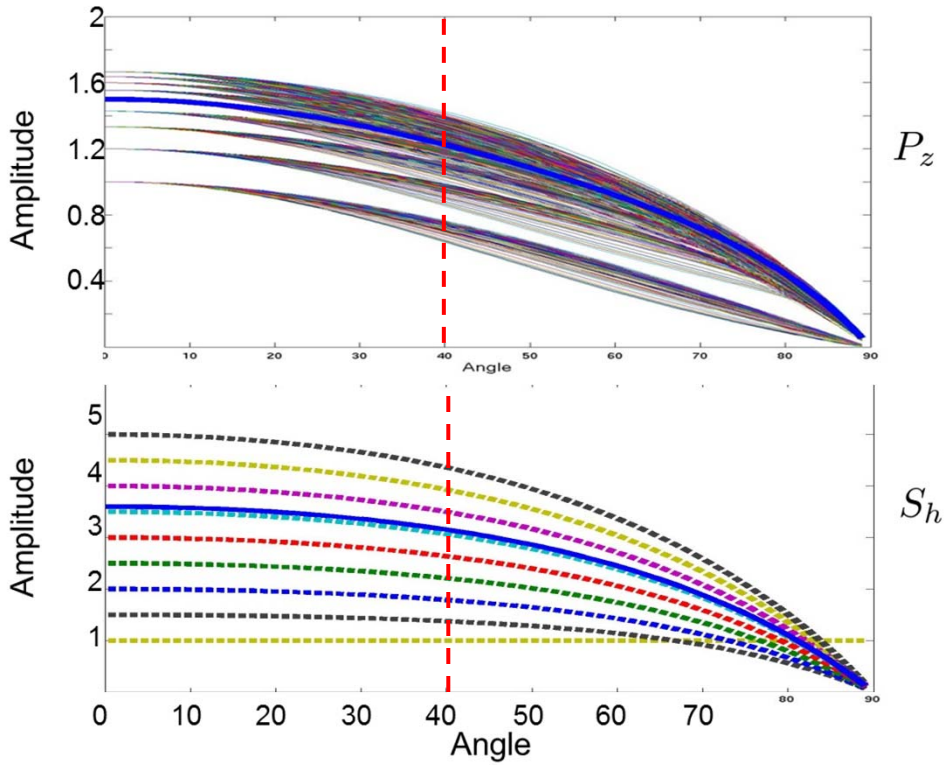
$$1.6 \leq \frac{\alpha_1}{\beta_1} \leq 2.8$$

See: Aki and Richards

(P and Sv are in Table 5.3 and equations 5.40 Sh is in Table 5.2 and equations 5.33)

Amplitude is a function of physical parameters and angle of incidence

Low velocity amplification



Amplitude of transmitted waves for vertical component of P and Sh modes.

Vary $\alpha_1, \alpha_2, \beta_1, \beta_2$ where $\alpha_1 \leq \alpha_2$ and $\beta_1 \leq \beta_2$

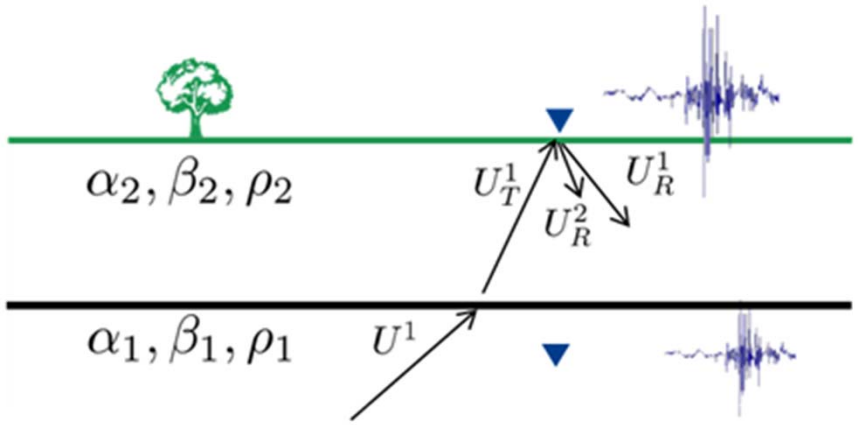
Pz amplification is 1.5

Sh amplification is 3.5

Thickness	Vp	Vs
15	600	250
80	1800	900

P-wave amplification between 1 and 1.7
Sh-wave amplification between 1 and 5

Both free surface and velocity amplification

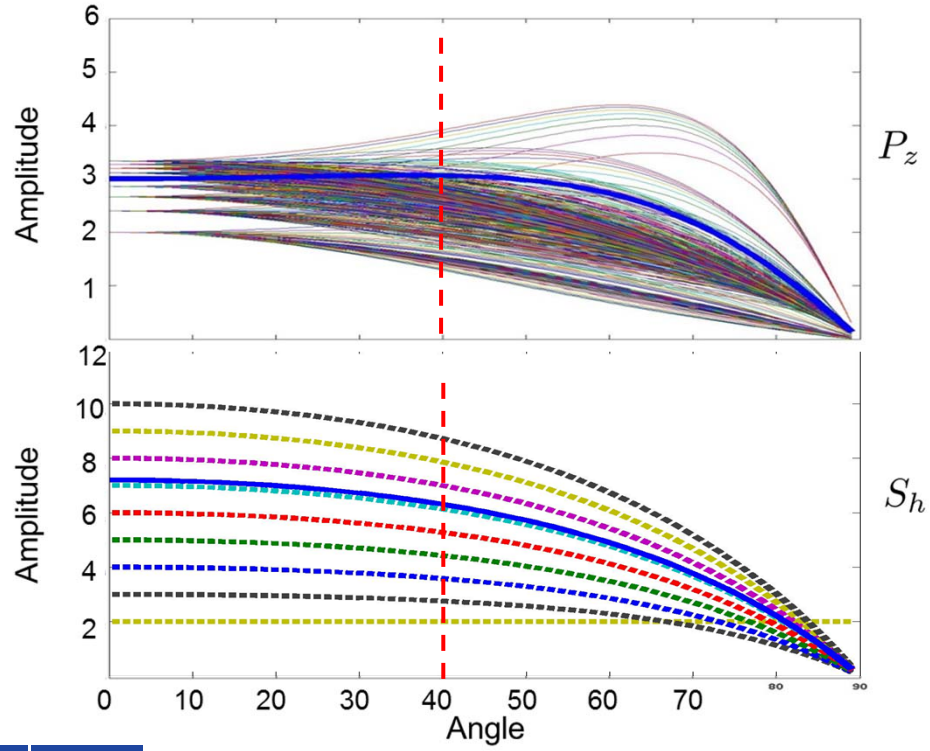


$$1 \leq \frac{\alpha_1}{\alpha_2} \leq 5 \quad 1 \leq \frac{\beta_1}{\beta_2} \leq 5$$

$$1.6 \leq \frac{\alpha_1}{\beta_1} \leq 2.8$$

Now consider both of the effects from a low velocity and free surface amplification

Amplification from free surface and velocity



Dark blue line is from the previous model

Pz amplification is 3

Sh amplification is 7

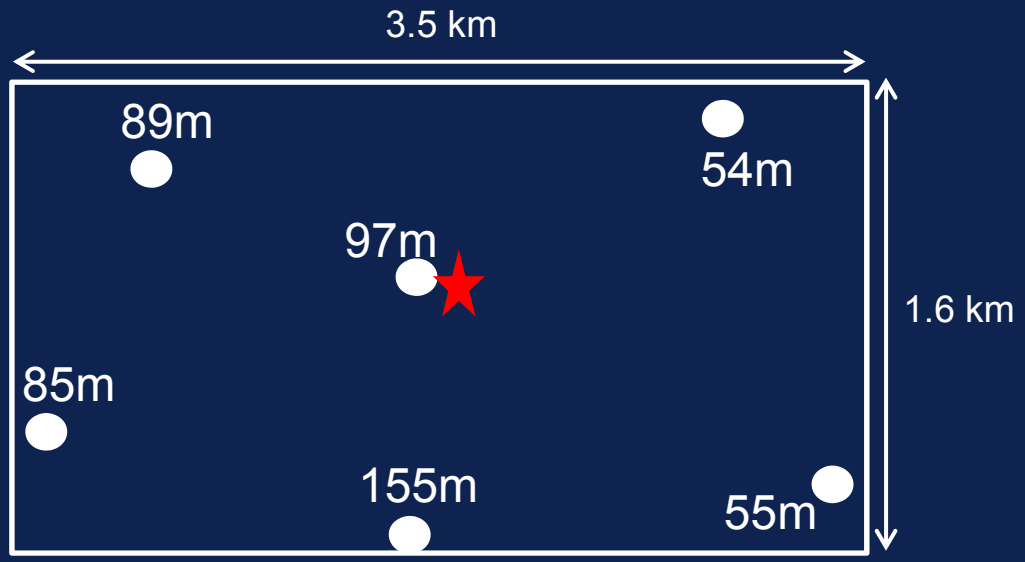
Thickness	Vp	Vs
15	600	250
80	1800	900

Overall P-wave amplification between 2 and 3.4
Overall Sh-wave amplification between 2 and 10

Observations

Treatment well depth: ~800 m

★ : Well head

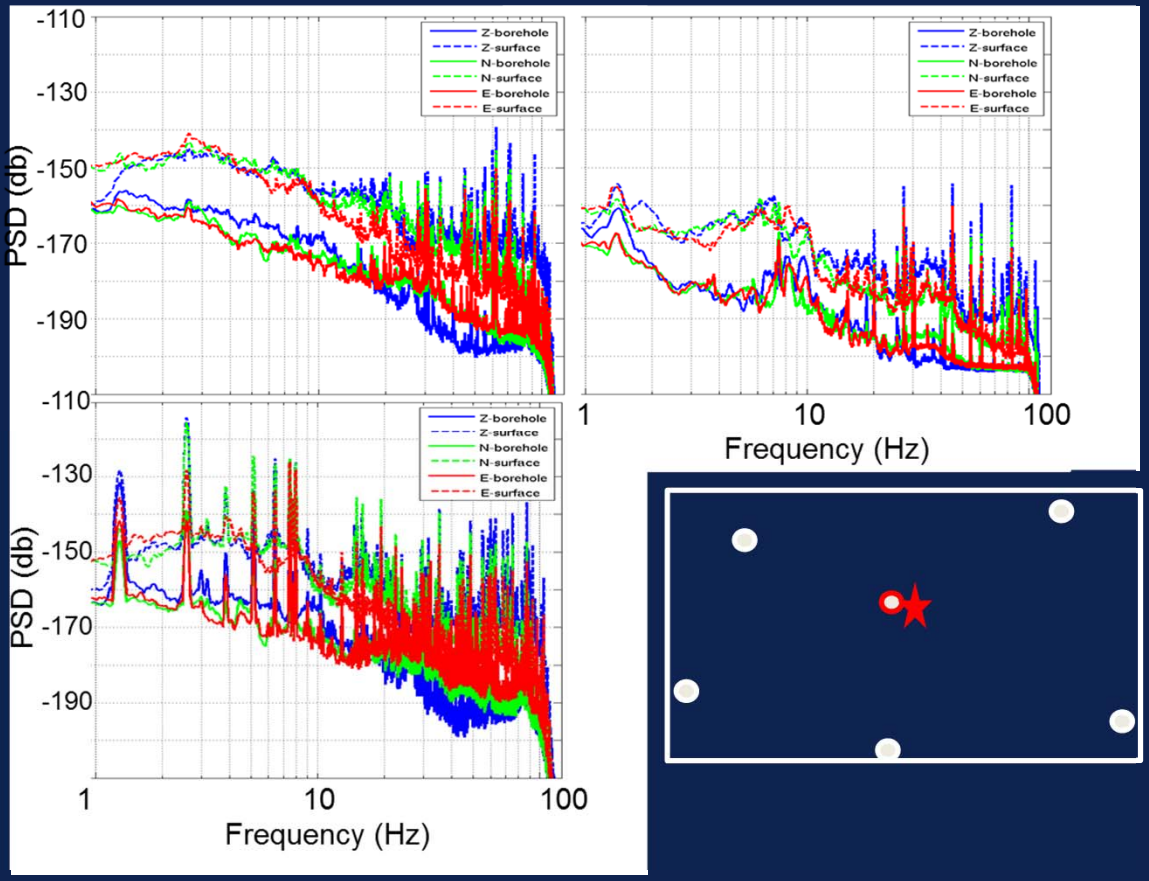


172 surface stations

6 co-located shallow boreholes with depths between 54 and 155 m

Surface and downhole sensors are identical

Example spectra

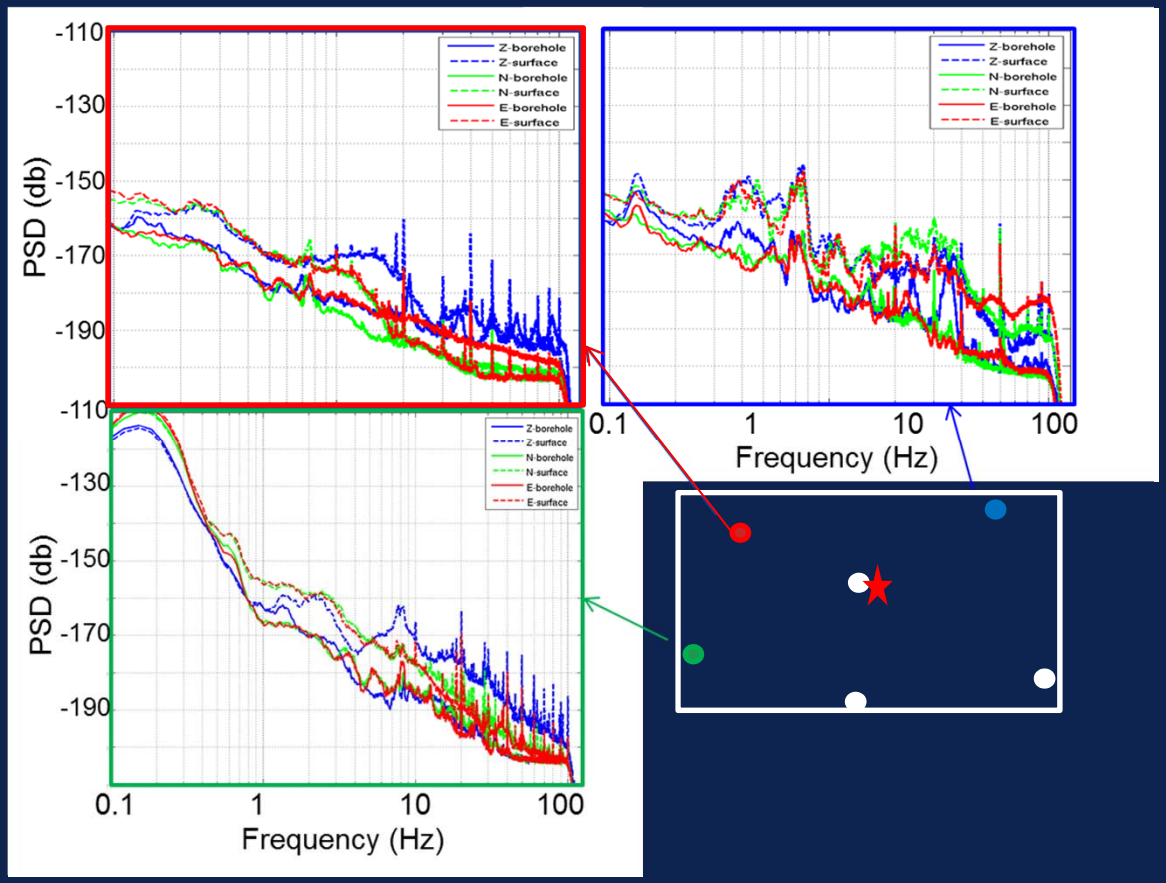


Spectral analyses for different time windows

Noise levels vary with time, but surface and downhole track each other

10-20 dB of difference in the noise between surface and shallow sondes

Other locations



Downhole and surface noise tracks

10-20 dB of difference

Need a 3 to 10 times amplification to keep S/N

Surface vs. shallow borehole
Two time traces - which is which?

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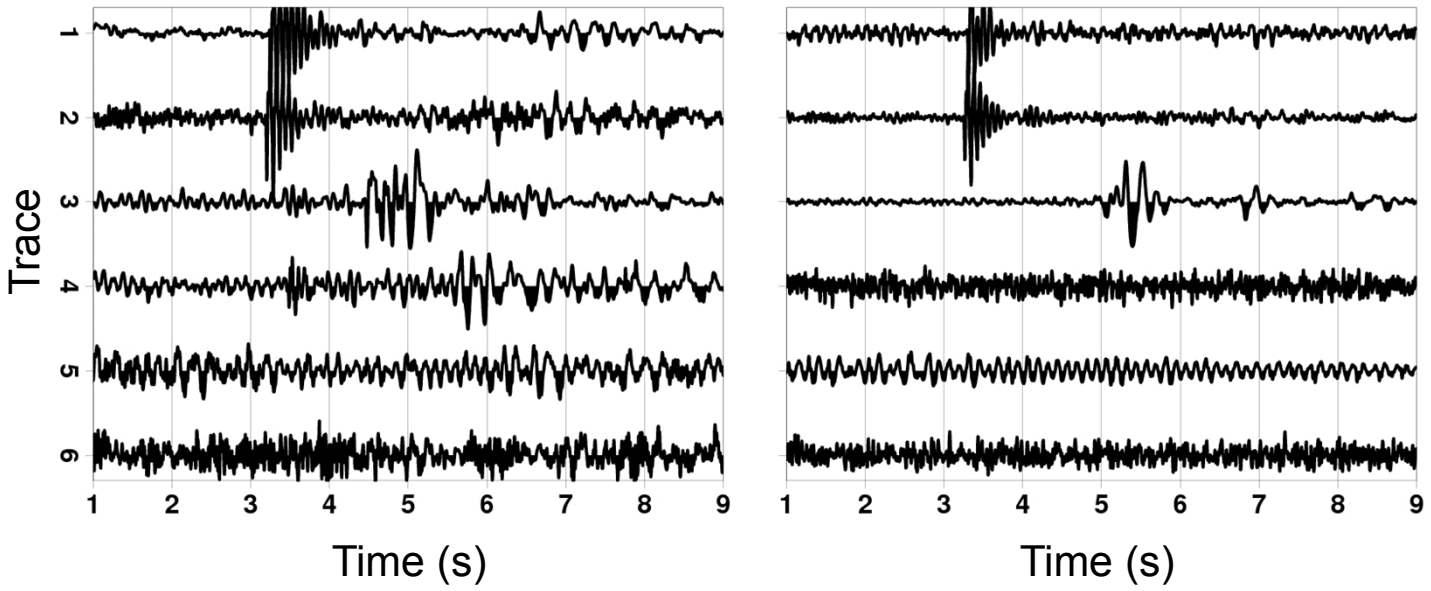
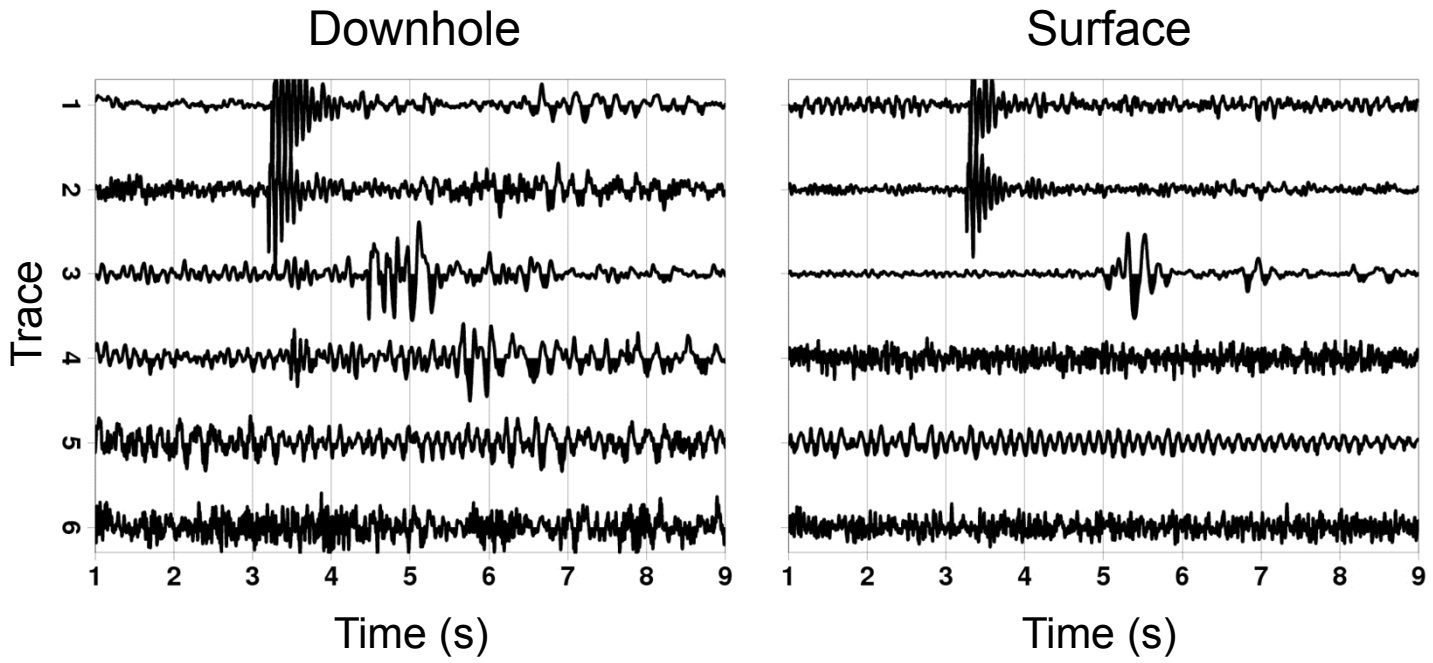


Surface shallow borehole pairs for vertical component

Very little difference in S/N between the two

Surface vs. shallow borehole
Two time traces - which is which?

Spectraseis



Trace balanced data

Surface/ shallow borehole pairs for vertical component

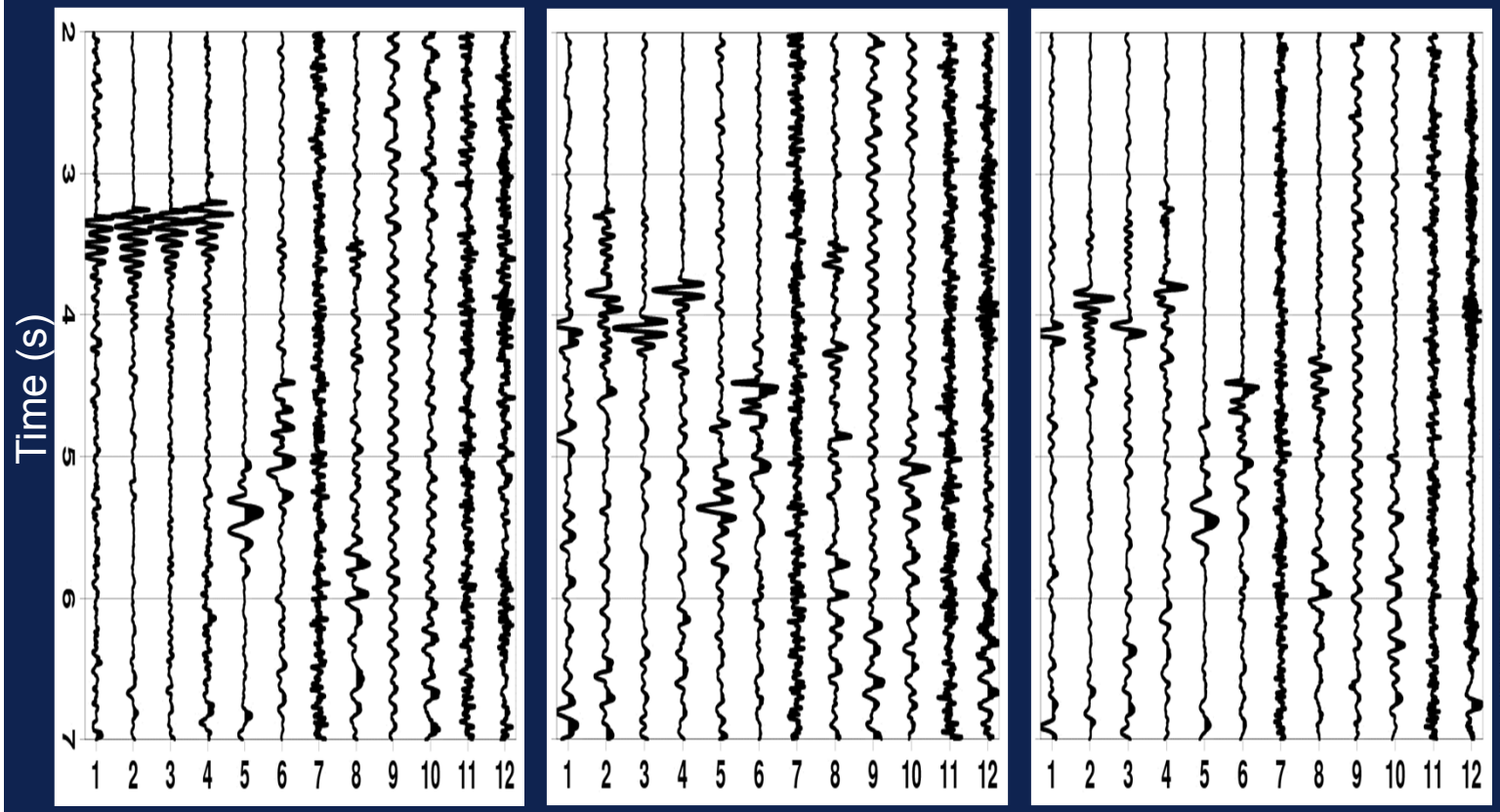
Very little difference in S/N between the two

Trace data

Vertical

Easting

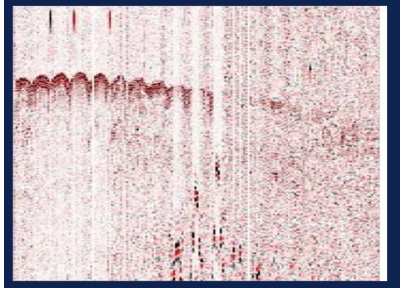
Northing



Traces balanced

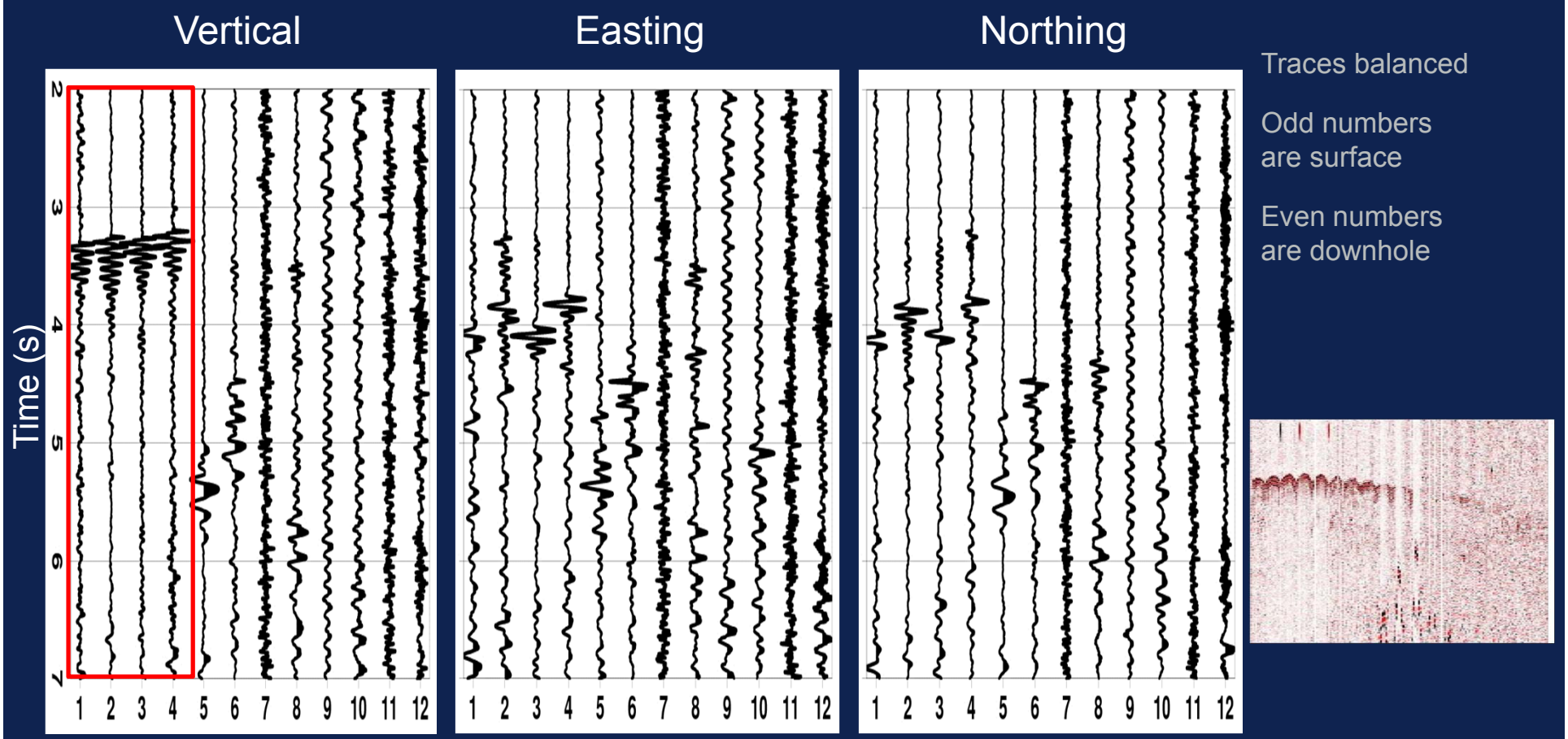
Odd numbers are surface

Even numbers are downhole



Signal to noise is not significantly different between surface and downhole

Trace data



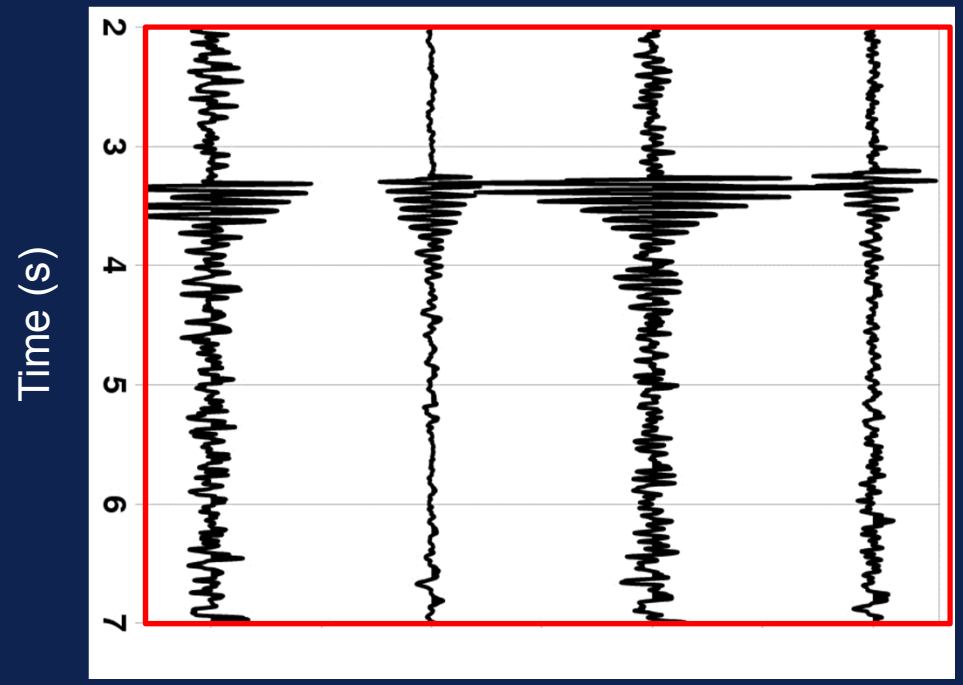
Traces balanced

Odd numbers are surface

Even numbers are downhole

Signal to noise is not significantly different between surface and downhole

Trace data



Not trace balanced

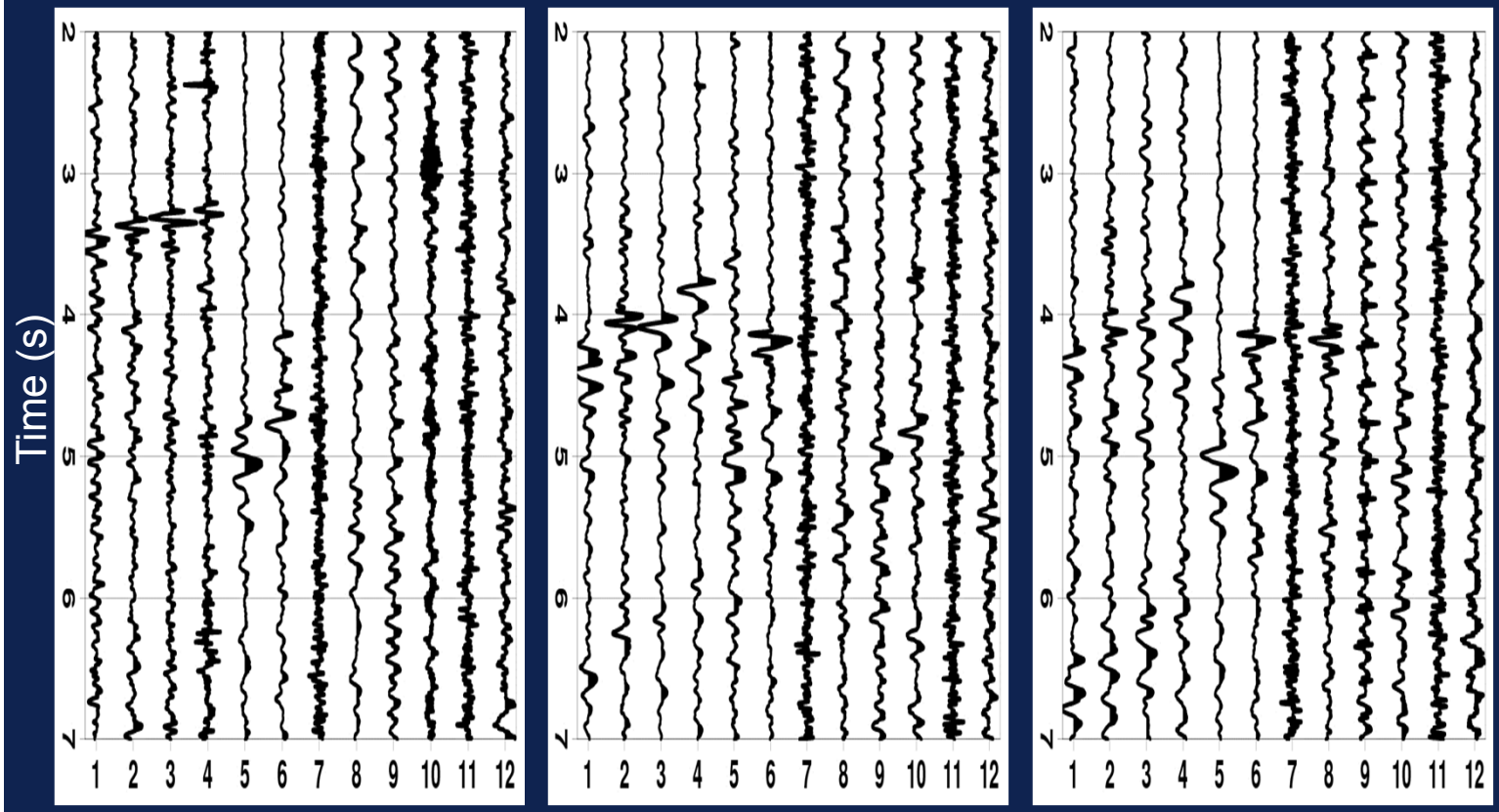
Noise levels are lower in the shallow boreholes
Signal levels are higher at the surface

Trace data

Vertical

Easting

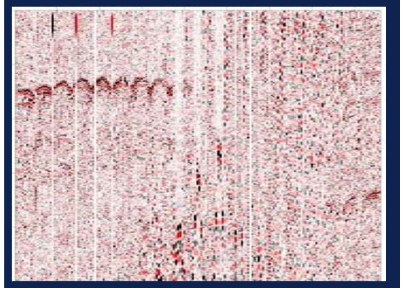
Northing



Traces balanced

Odd numbers are surface

Even numbers are downhole



Signal to noise is not significantly different between surface and downhole

Conclusions

- Getting better data is a function of signal and noise
- Noise tends to decrease with depth
- Signal may increase at surface
- Understanding your area can help predict the S/N benefit of installing a sub-surface array

Near-surface signal amplification may offset noise reduction and eliminate the desired S/N benefits of a sub-surface microseismic array

Acknowledgements

We would like to thank Apache Energy Corporation for allowing us to show the data examples

Spectraseis