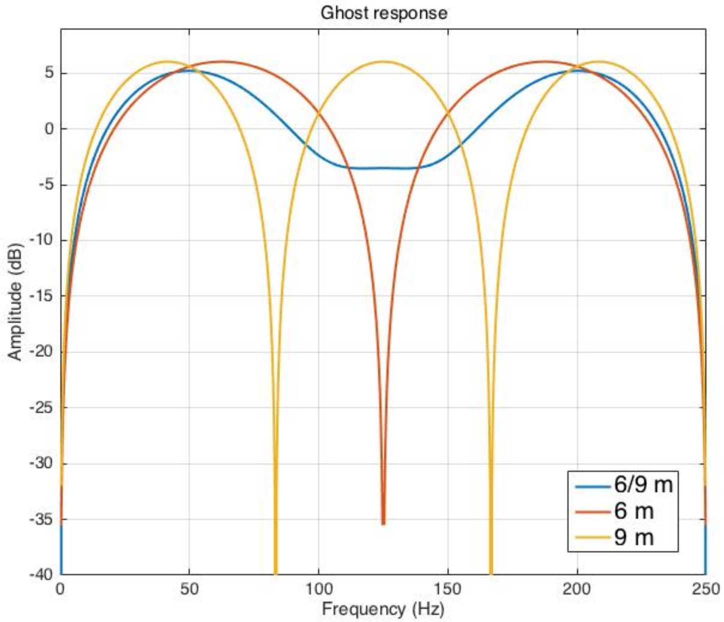
A comparison of marine broadband source strategies

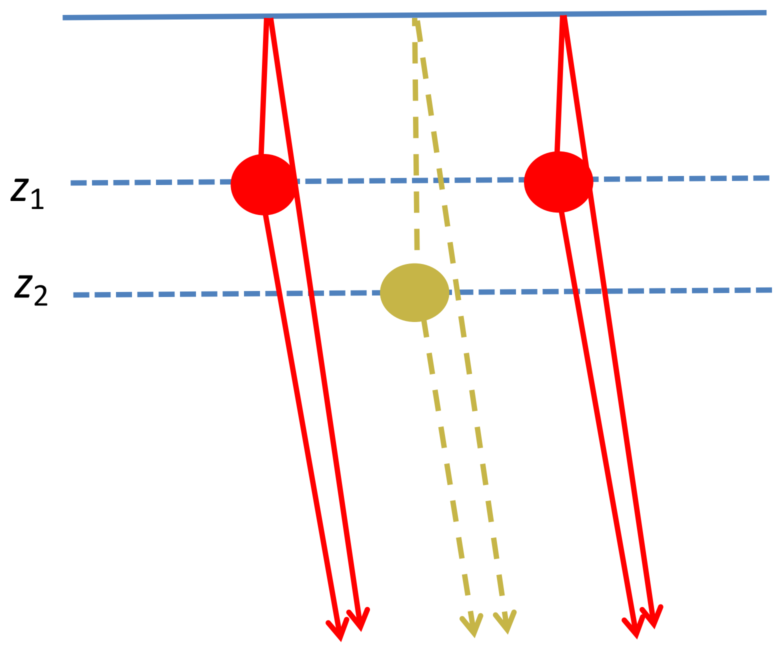
Kjetil E. Haavik

Introduction

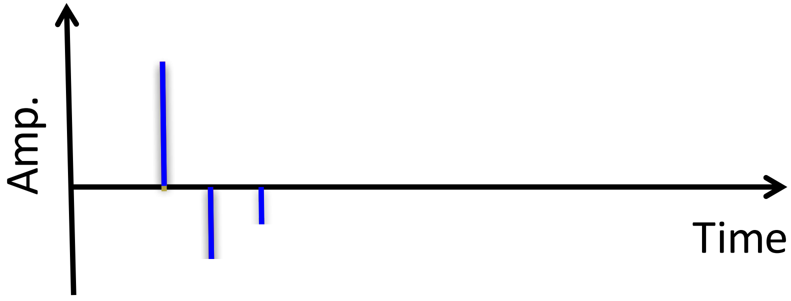
- Broadband seismic data – the new acquisition standard
- Several broadband sources exist
  - Mostly dual-level-sources
- Other strategies have also been proposed
  - Slanted arrays (Shen, 2014)
  - Variable source depth acquisition (Haavik and Landrø 2015)
- This presentation:
  - Motivation for broadband sources
  - Existing BB sources
  - Present VSDA
  - Present simple modeling study of VSDA, dual-level source and conventional source

Motivation for BB sources





Avoid deep notches in the spectrum

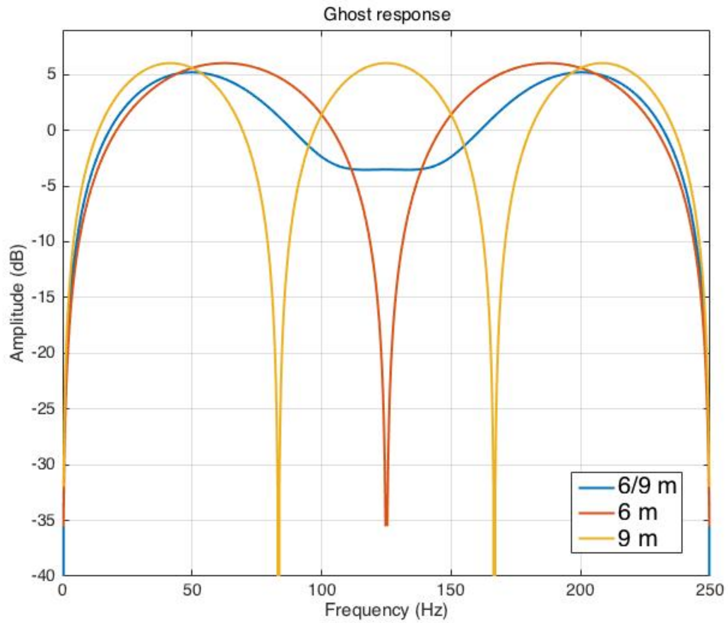


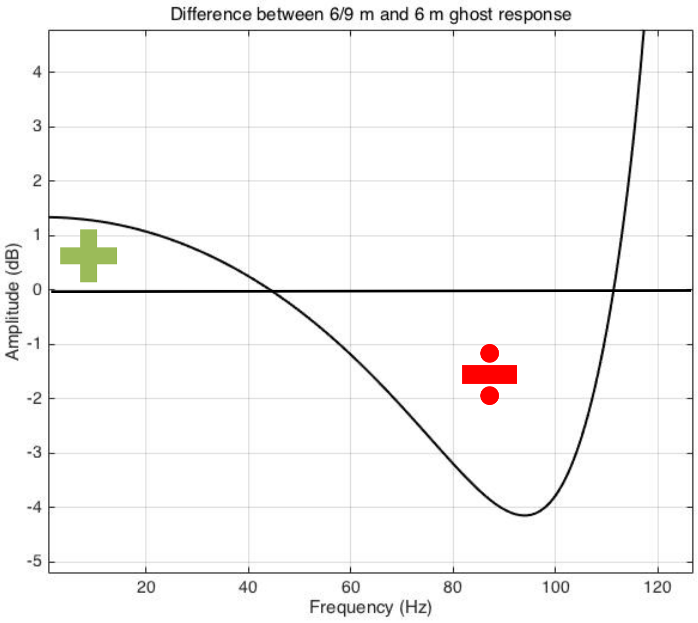
Broadband sources and deghosting - Existing Solutions

- Multi-level sources:
  - GeoSource (PGS)
  - BroadSource (CGG)
  - Delta V (Schlumberger)

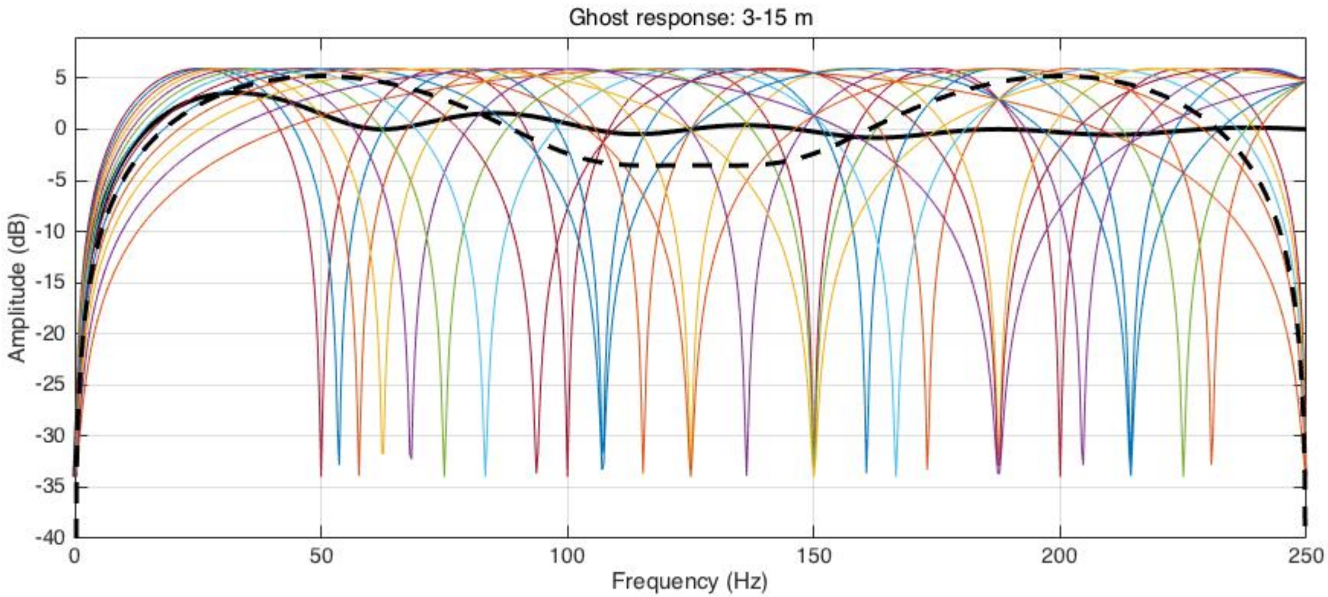
Optimal deghosting (Posthumus, 1993)

1D/Directional designature/deghosting (e.g. Wang et al. 2015, Agudo et al., 2016)





Broadband sources and deghosting: VSDA



- Pros:
  - Increase low frequencies
  - Ghost-notch diversity
  - High S/N at all freq.
- Cons:
  - Ghost notch in all shots
  - Less practical
  - More difficult to process

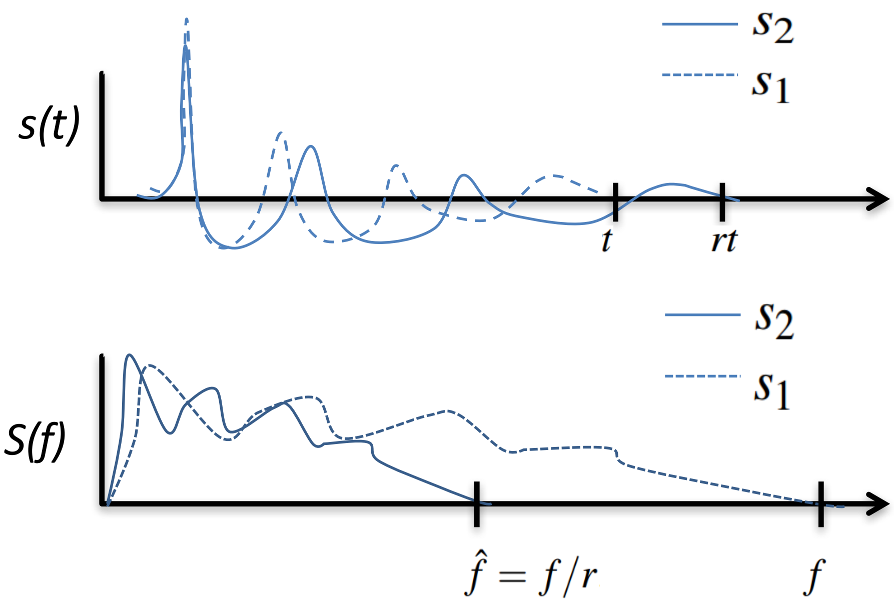
$(S/N)_1 = 4$

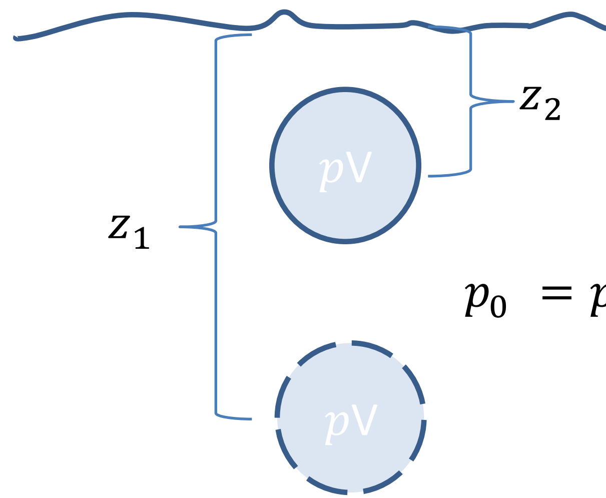
$(S/N)_2 = 2$

$S/N \propto \sqrt{n}$ $\longrightarrow$ Need 4 traces of $(S/N)_2$ to get $(S/N)_1$

Haavik and Landrø (2015), Geophysics

Air-gun signatures vs. Depth (1)



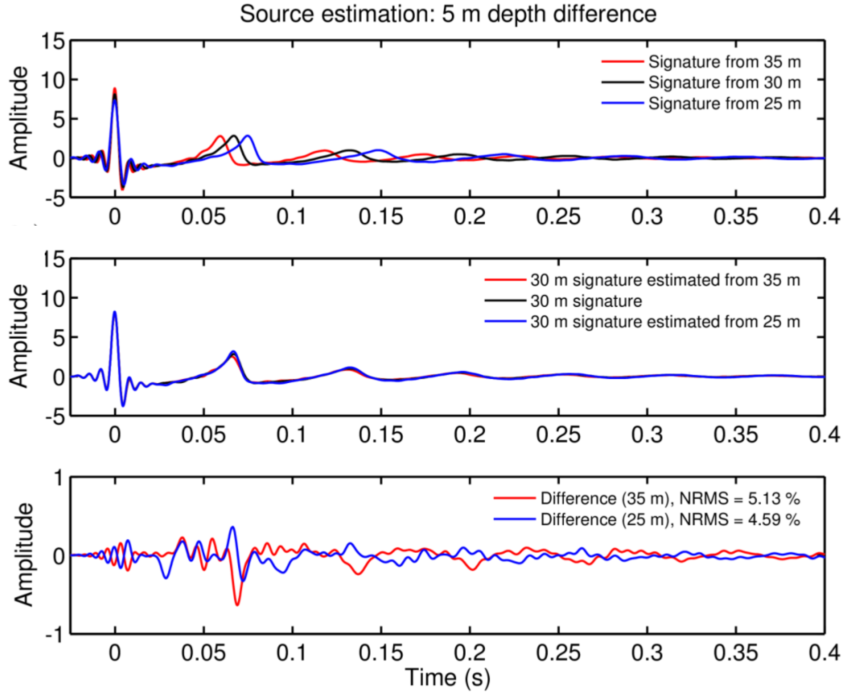


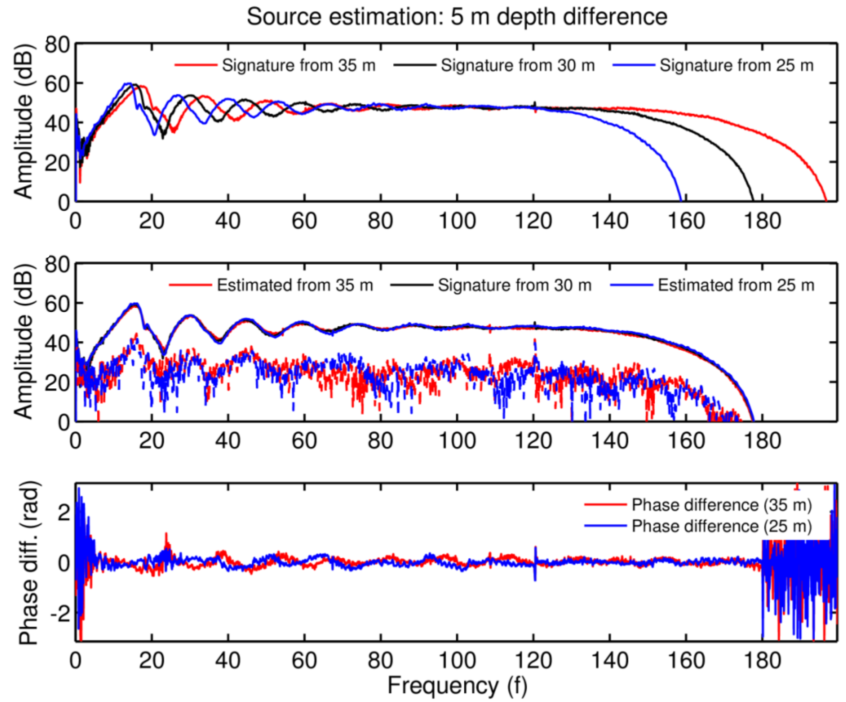
$$p_0 = p_{atm} + \rho g z$$

$$s_2(t) = \frac{1}{r} s_1(rt) \qquad r = \frac{T_2}{T_1} = const. \quad T = C\,\frac{(pV)^{1/3}}{p_0^{5/6}}$$

Haavik and Landrø (2016), Geophysics

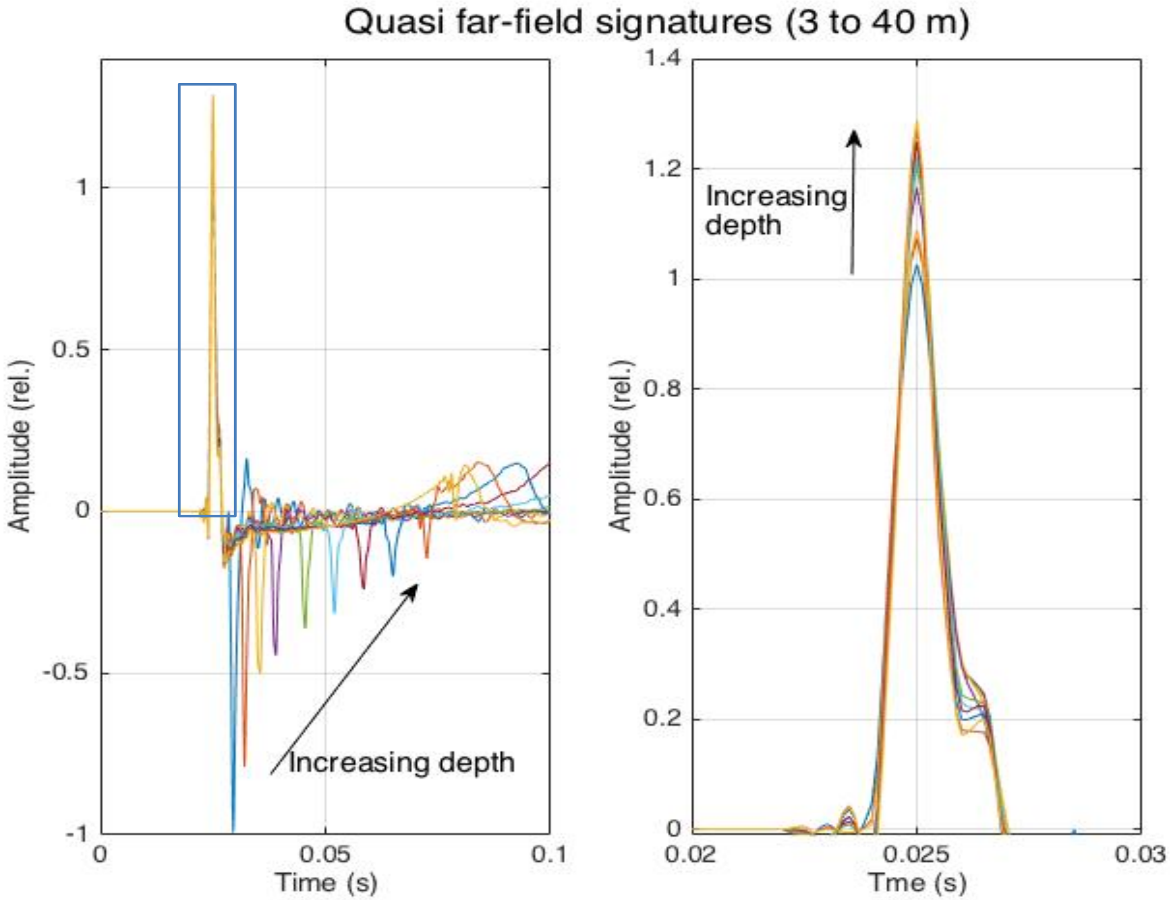
Air-gun signatures vs. Depth (2)





Figures from Haavik and Landrø (2016)

Air-gun signatures vs. Depth (3)



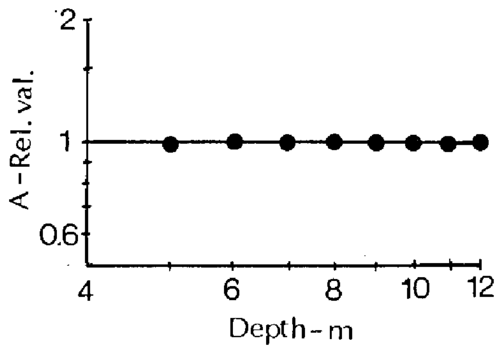
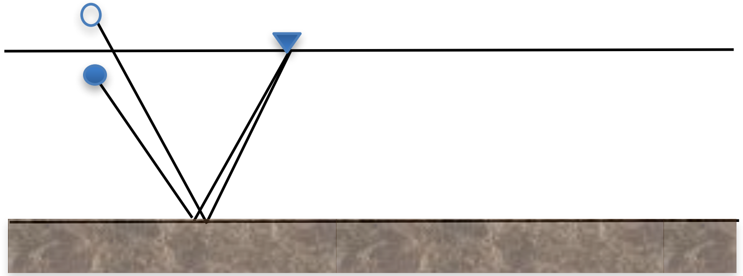


Figure from
Vaage et al. (1983)

Data from 600 cu-inch air gun, receiver 20 m below source

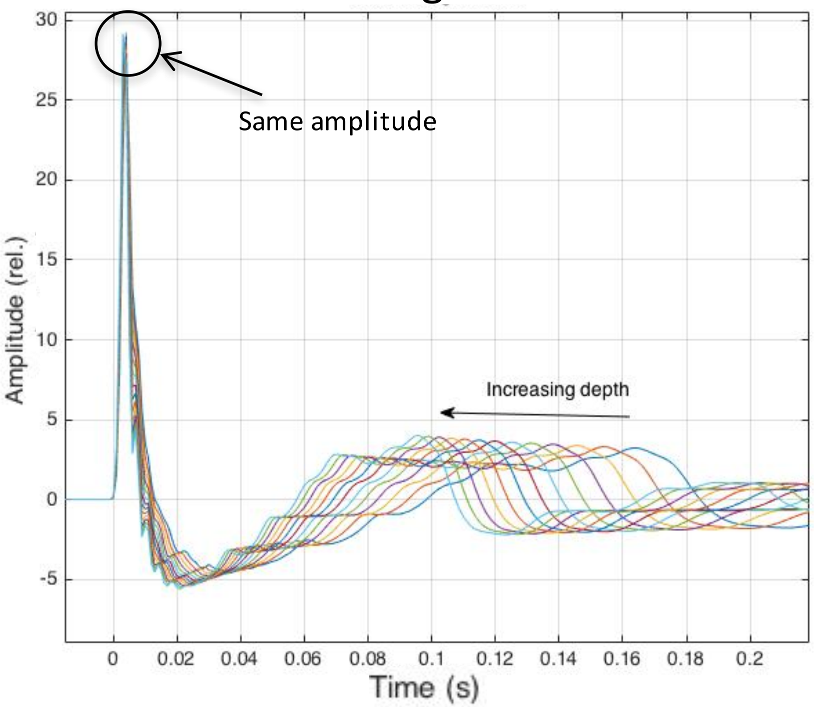
Modeling of data

- 24 air guns in 3 sub-arrays
- Layered medium (upscaled log)
- Ray-tracing modeling (primaries only, no attenuation, no receiver ghost)
- Source scaling for estimating signatures
- Three different cases:
  - VSDA: 3 - 15 m source depths
  - 6/9 m source (2 at 6 m + 1 at 9 m)
  - Single level source at 6 m
- 24 Shots (one VSDA-period 3-4-5-...14-15-14-...-4)
  - Shot spacing: 18 m
  - Receiver spacing: 6 m.
- Pink noise added to data

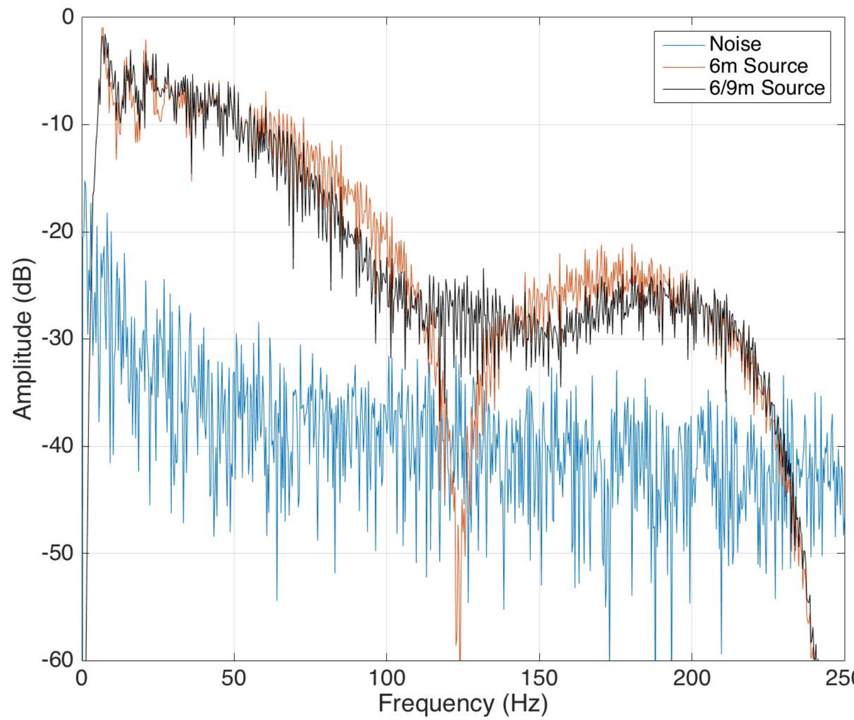


Sources and Noise

Source signatures



Signal and noise



Processing of data

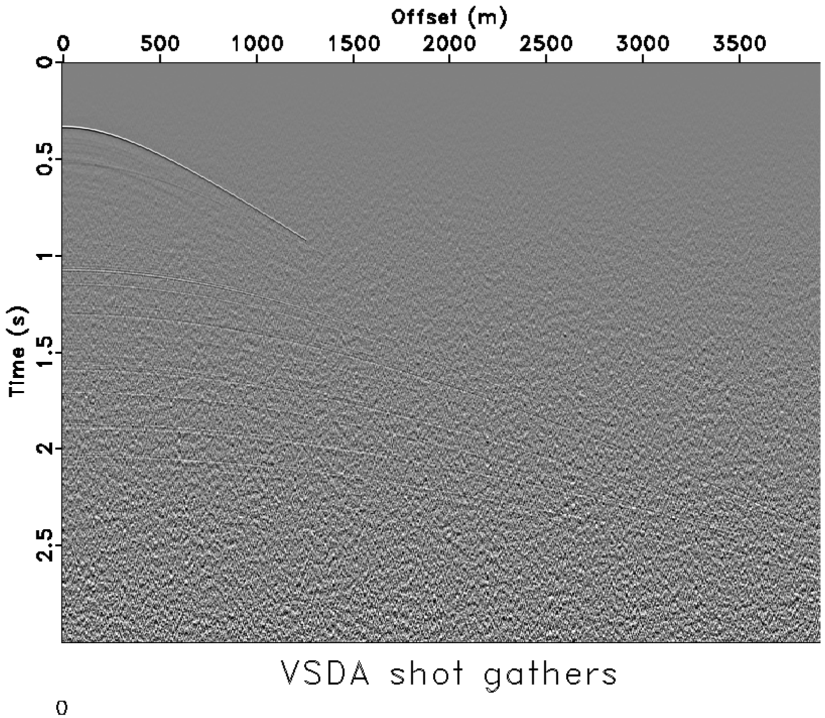
- 1D redatum to sea surface (shot/mirror-shot for VSDA)
- 1D designature
- 1D designature + 1D deghosting
  - Damped deghosting for 6/9 m and 6 m data
  - Least squared deghosting of VSDA
- Sort to CMP
- Time gain
- NMO-correction
- Stack

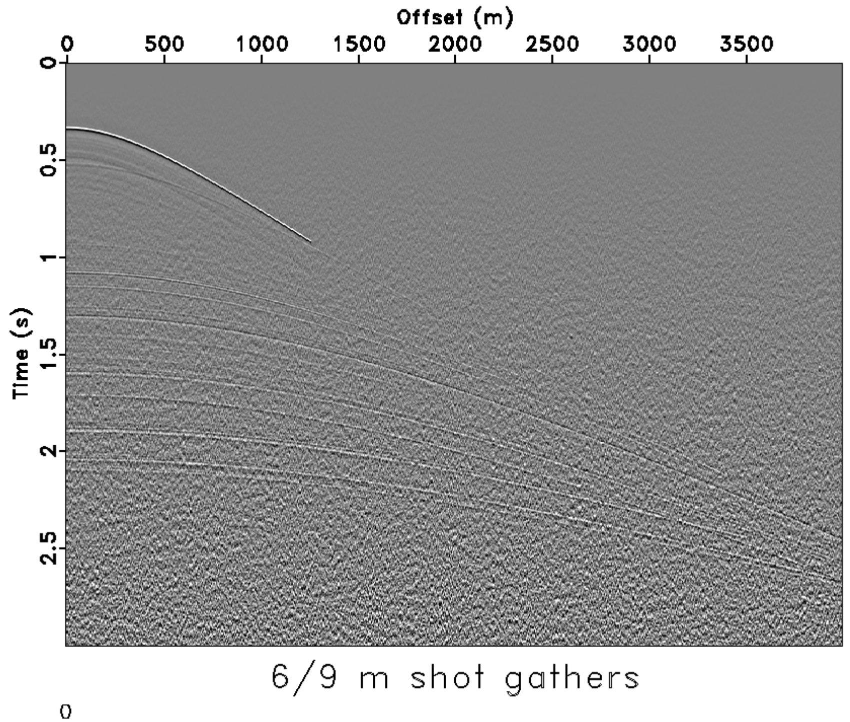
$$R(\omega) = \frac{\sum_{i=1}^{N} \overline{G_i(\omega)}\, D_i(\omega)}{\sum_{i=1}^{N} |G_i(\omega)|^2}$$

$$R(\omega) = \frac{\overline{G(\omega)} D(\omega)}{|G(\omega)|^2 + \varepsilon^2}$$

LS-deghosting alá Soubaras (2010)

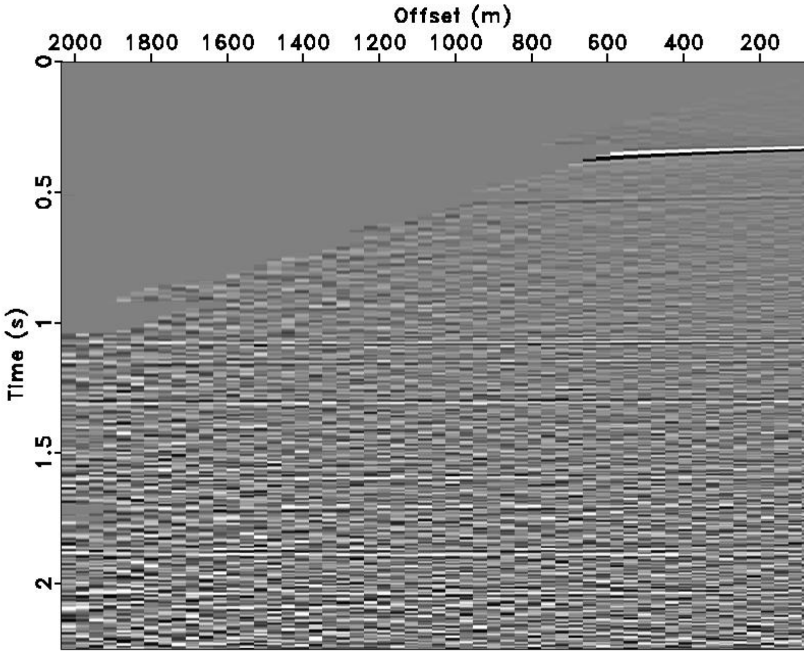
Shot gathers



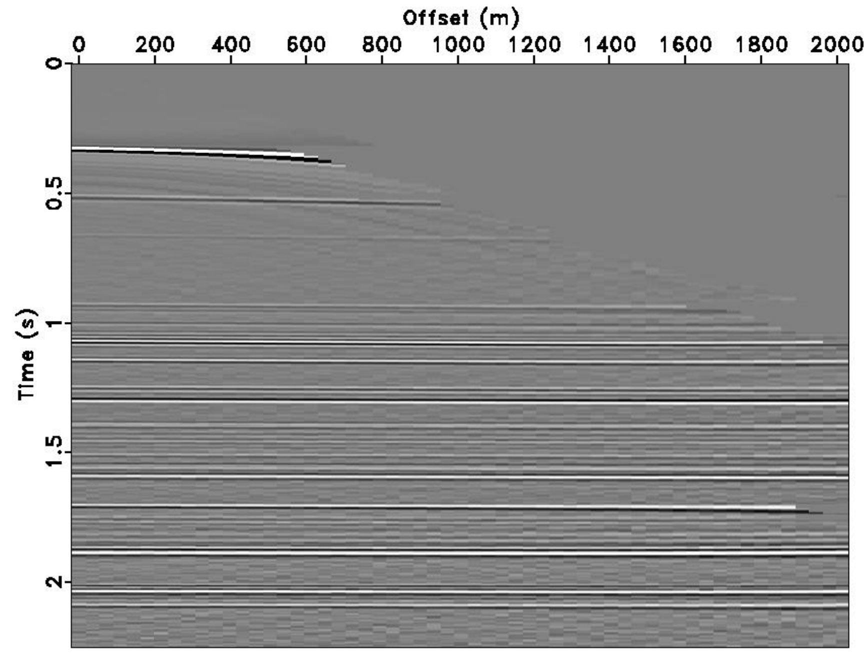


Bandpass filter: 10-80Hz
Time gain: t^(1.5)

Designature + NMO-corrected

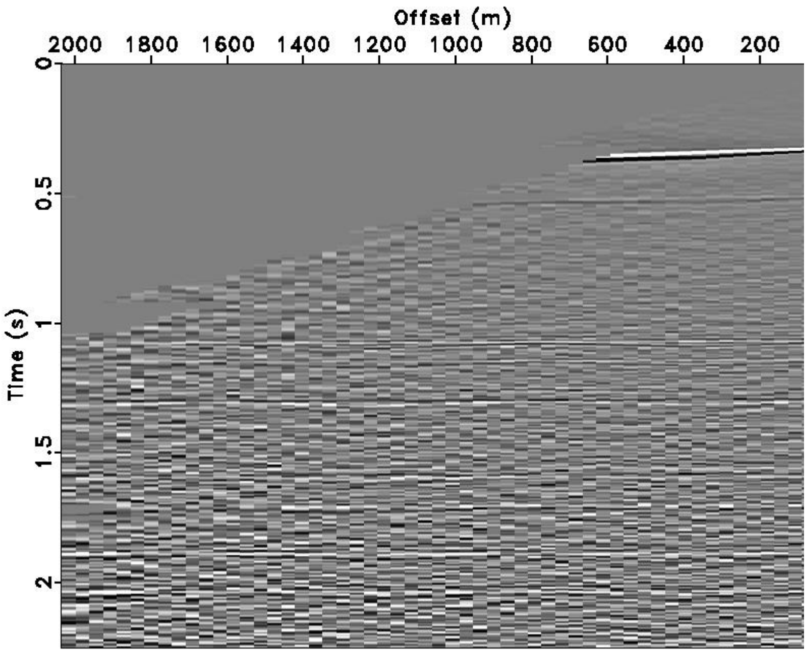


6/9 m source – NMO–corrected

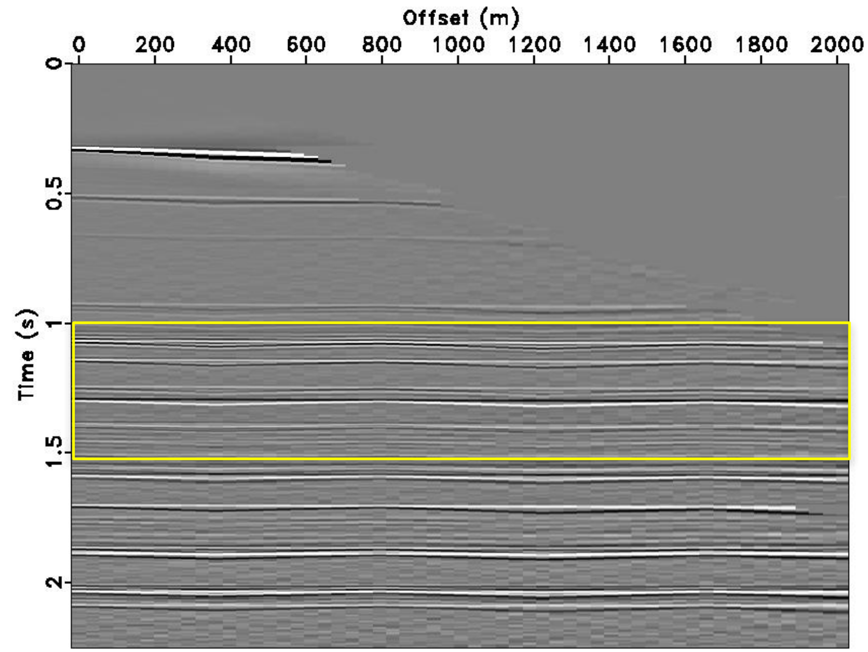


6/9 m source – NMO–corrected

Designature + NMO-corrected

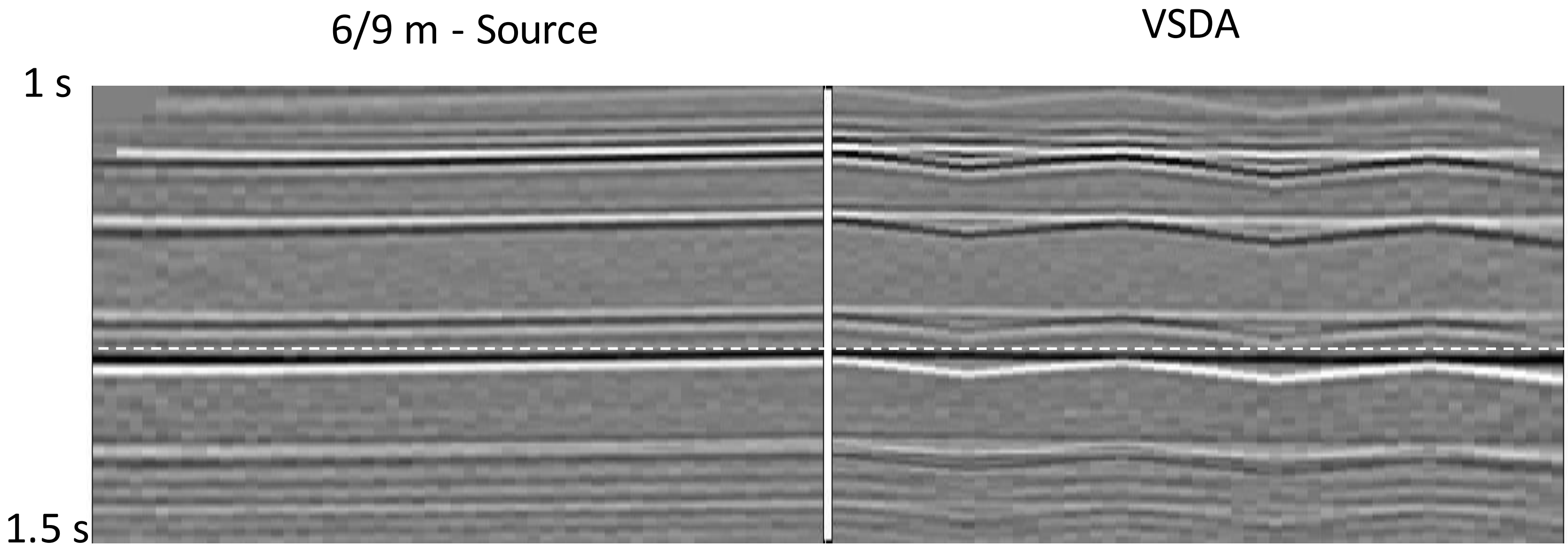


VSDA – NMO–corrected

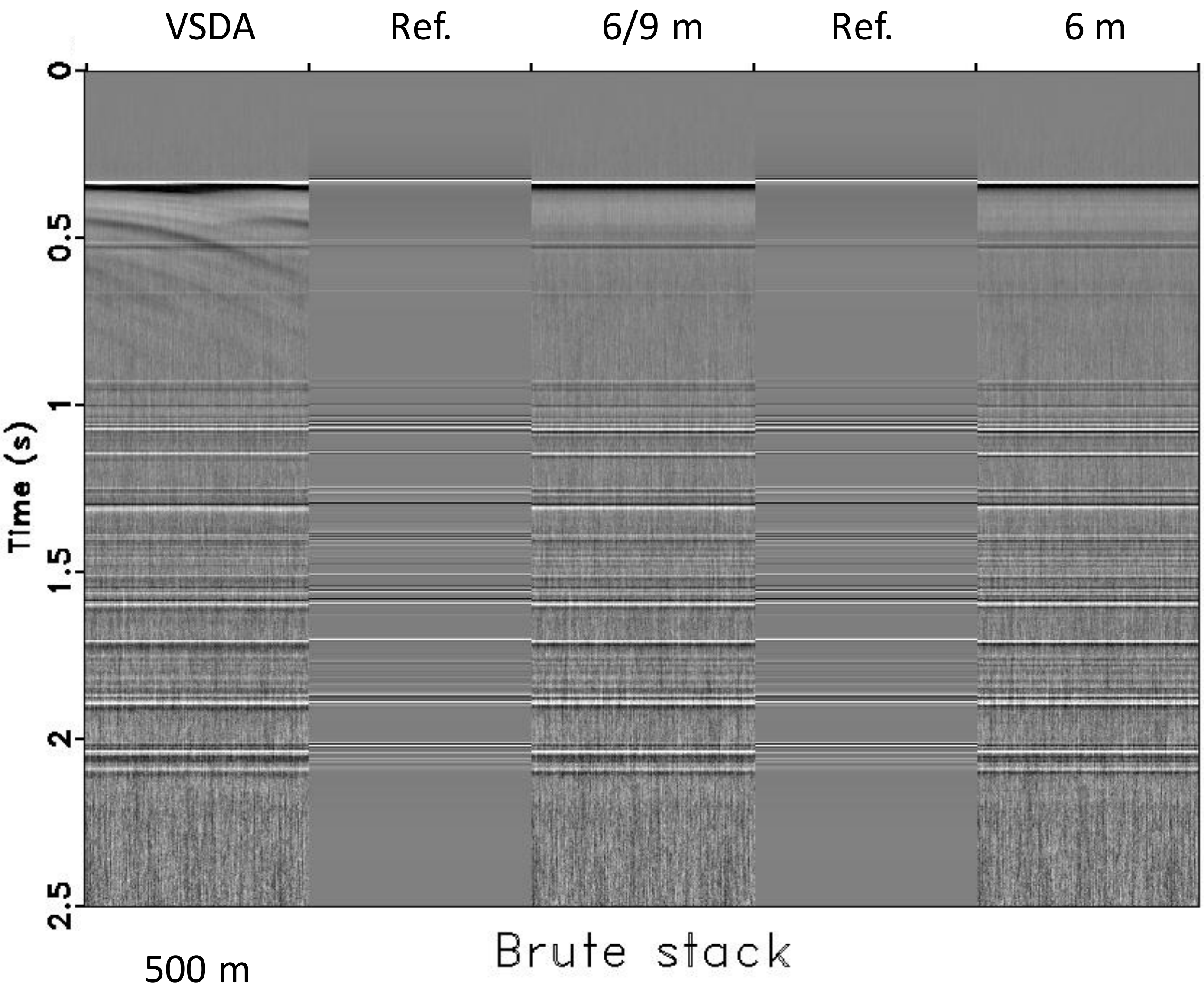


VSDA – NMO–corrected

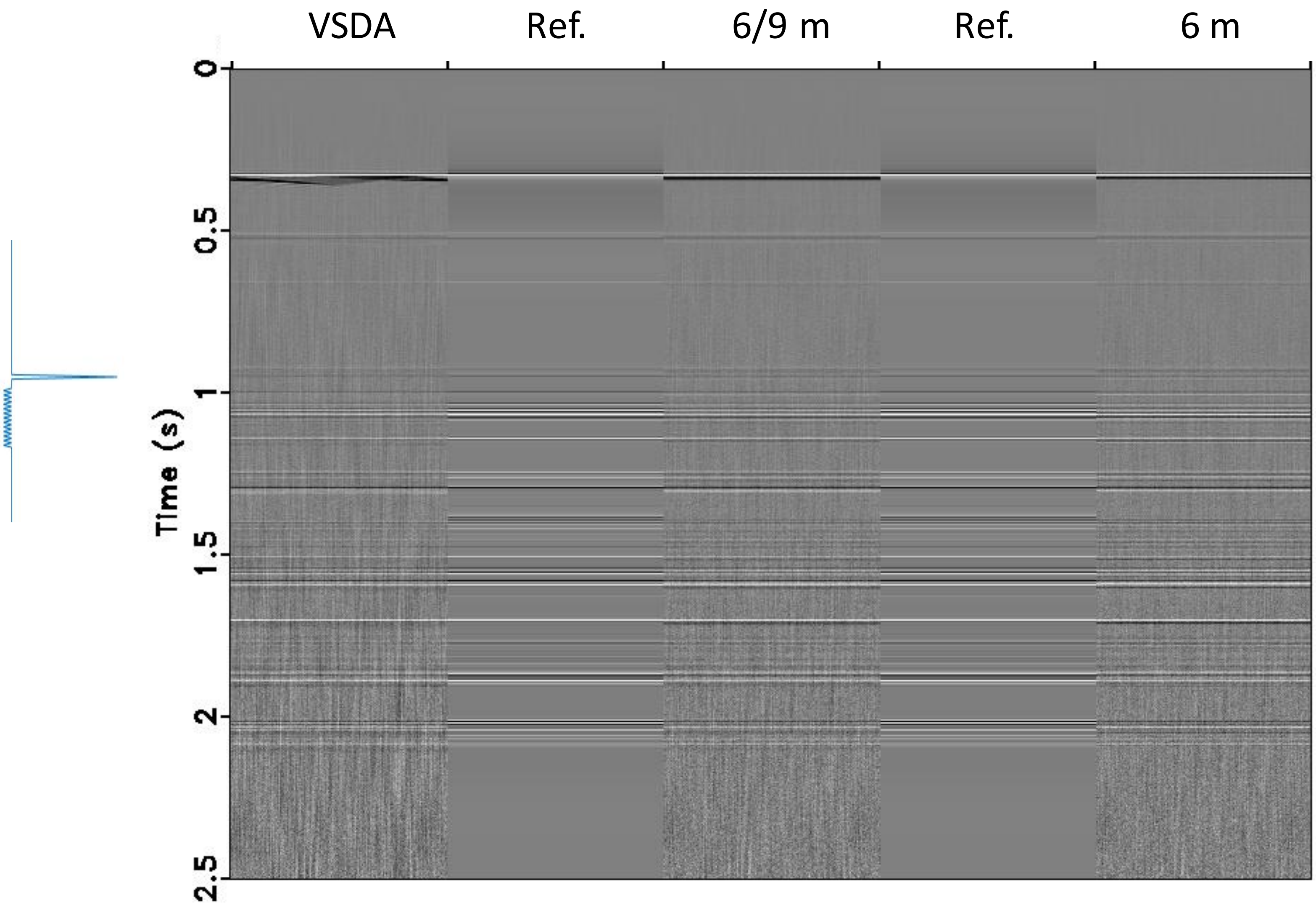
Designature + NMO-corrected



Brute stack



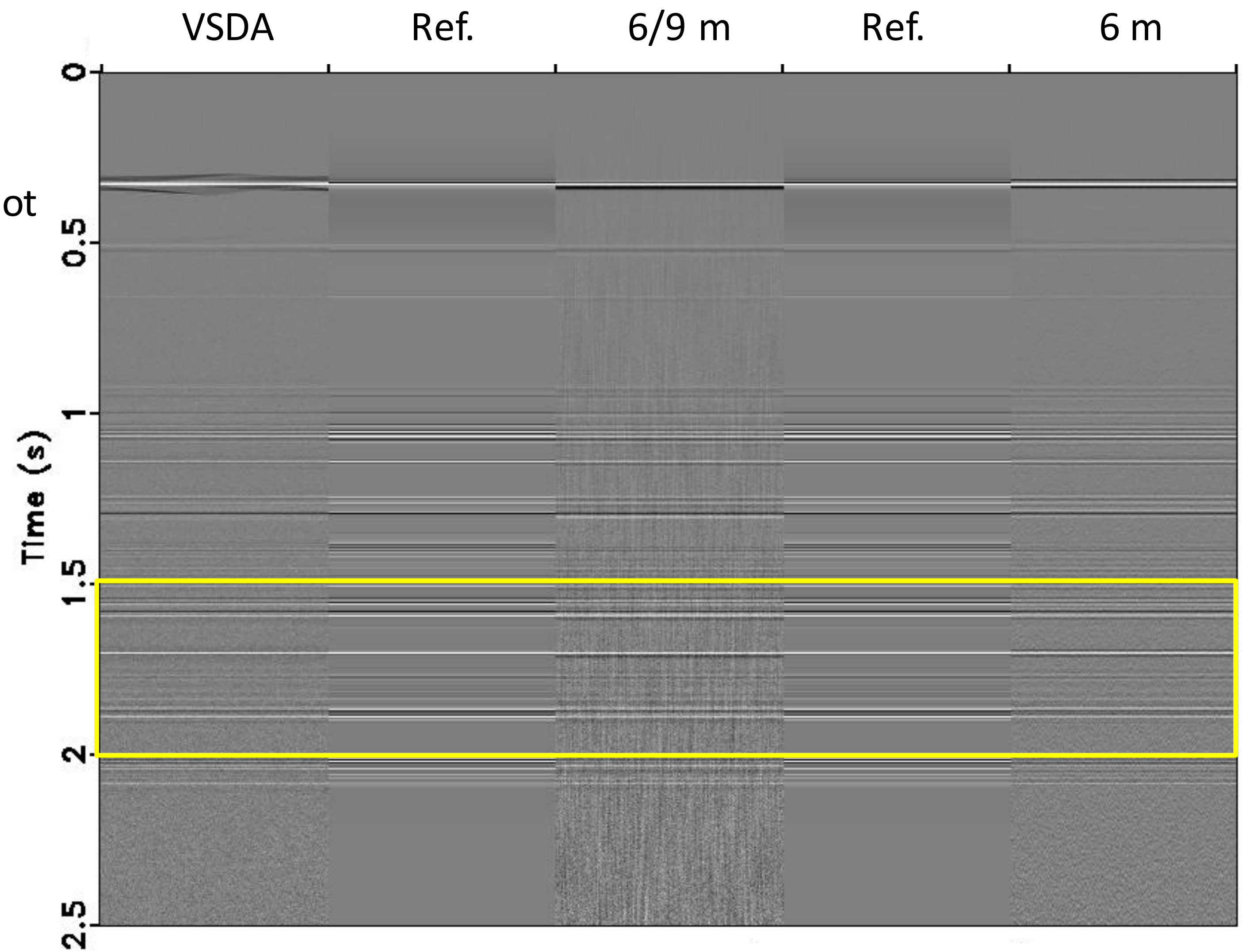
Designature-stack



1D signature applied

Designature-stack

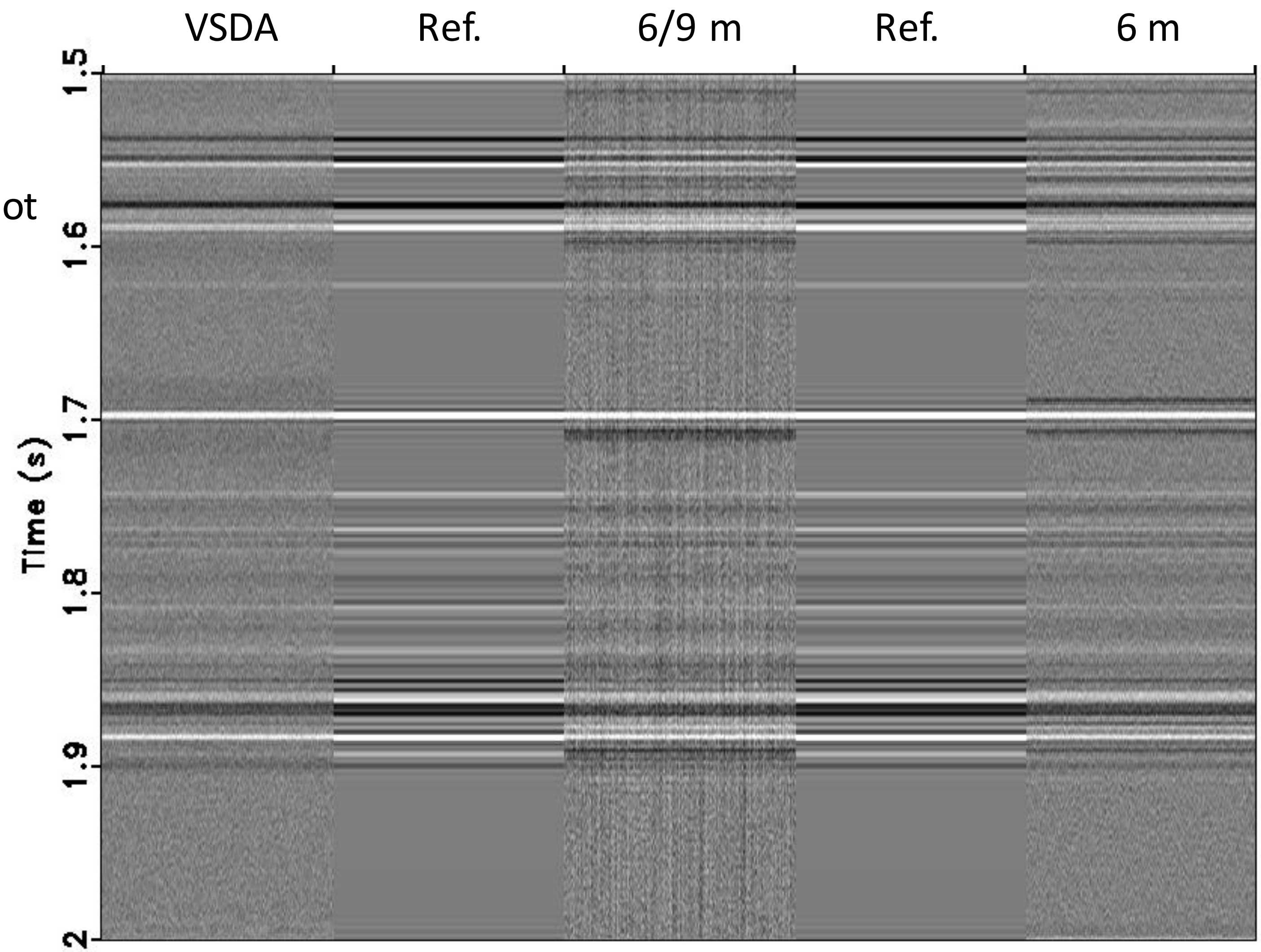
Shot +
mirror shot



1D signature applied

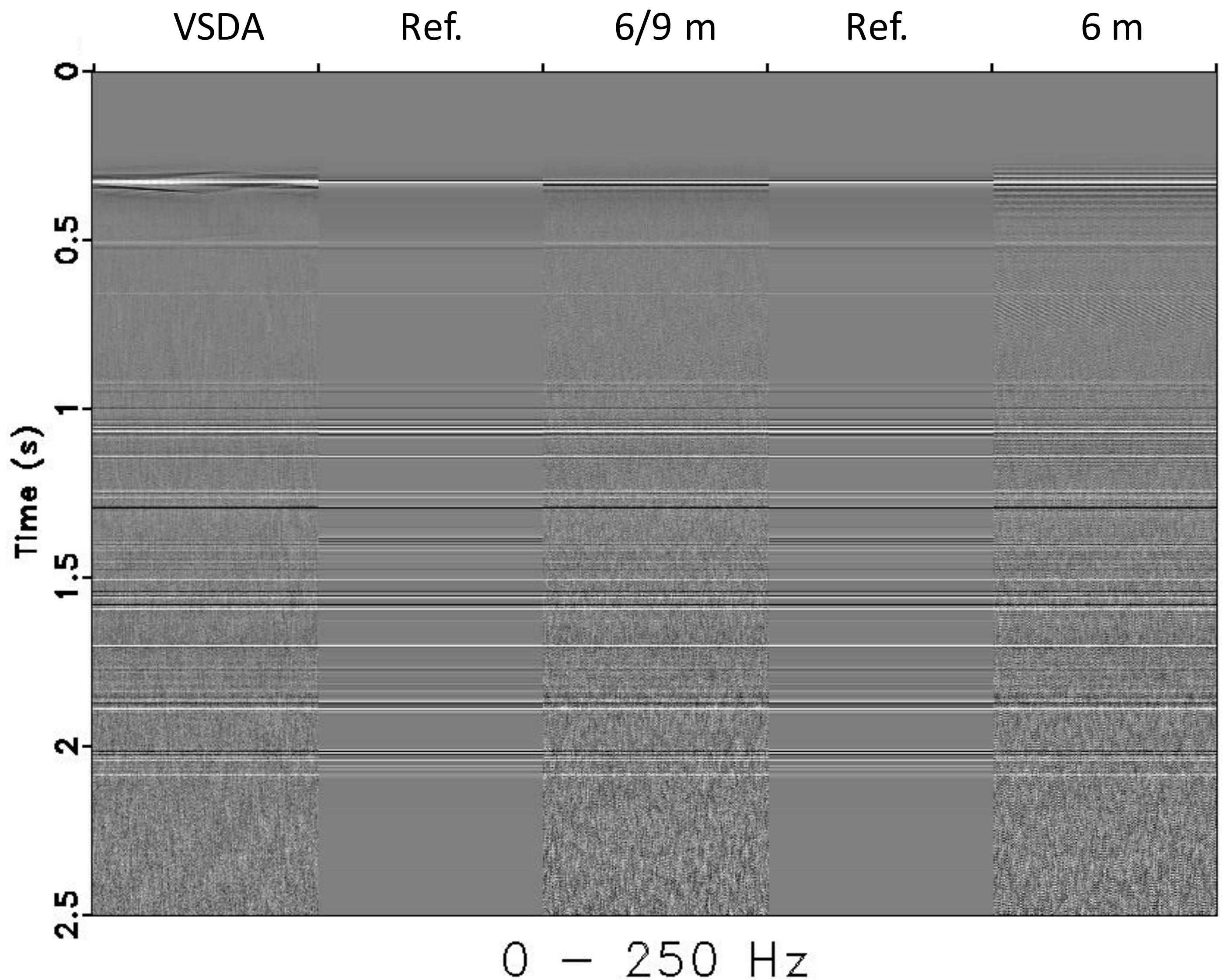
Zoom in: Designature-stack

Shot +
mirror shot

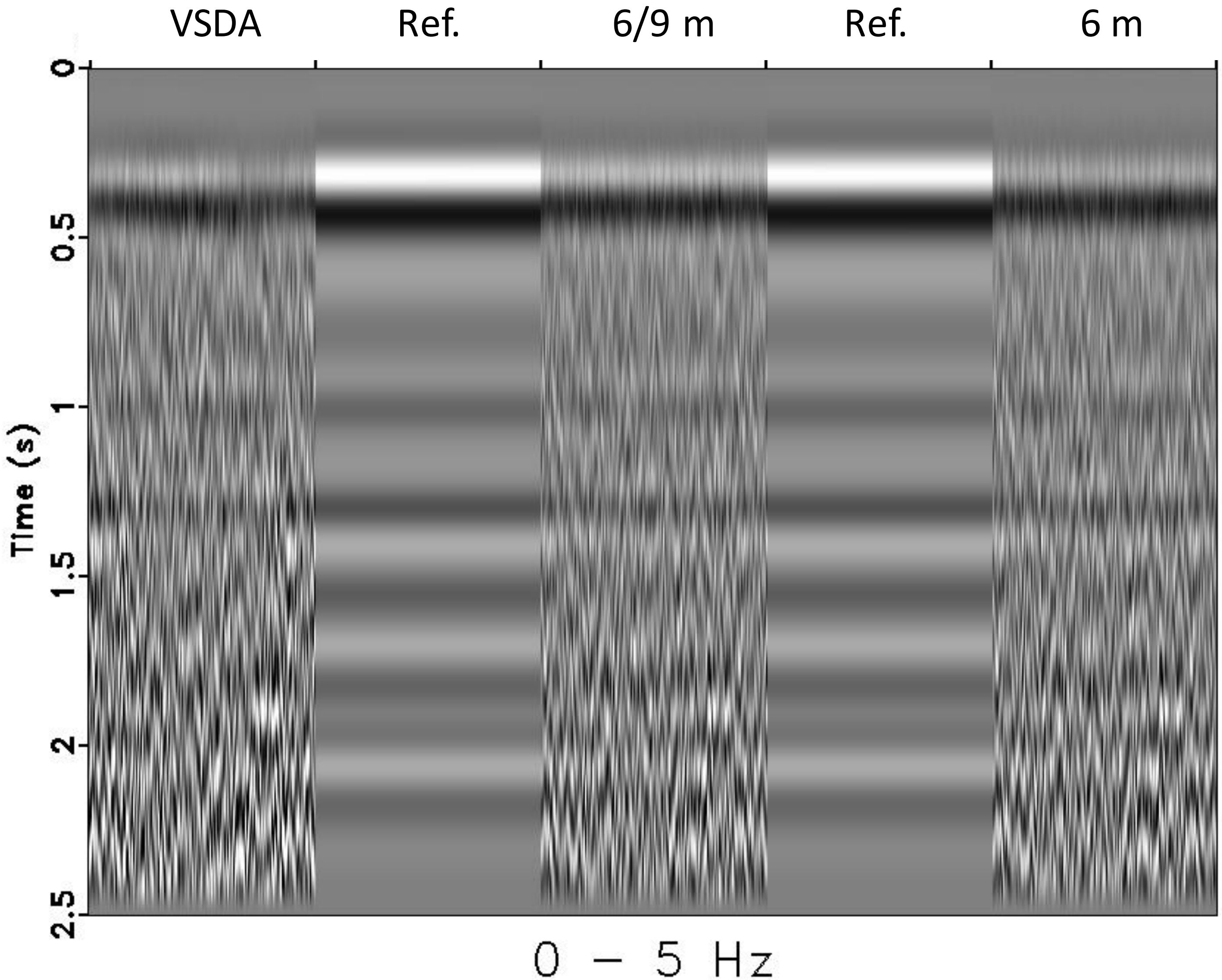


1D signature applied

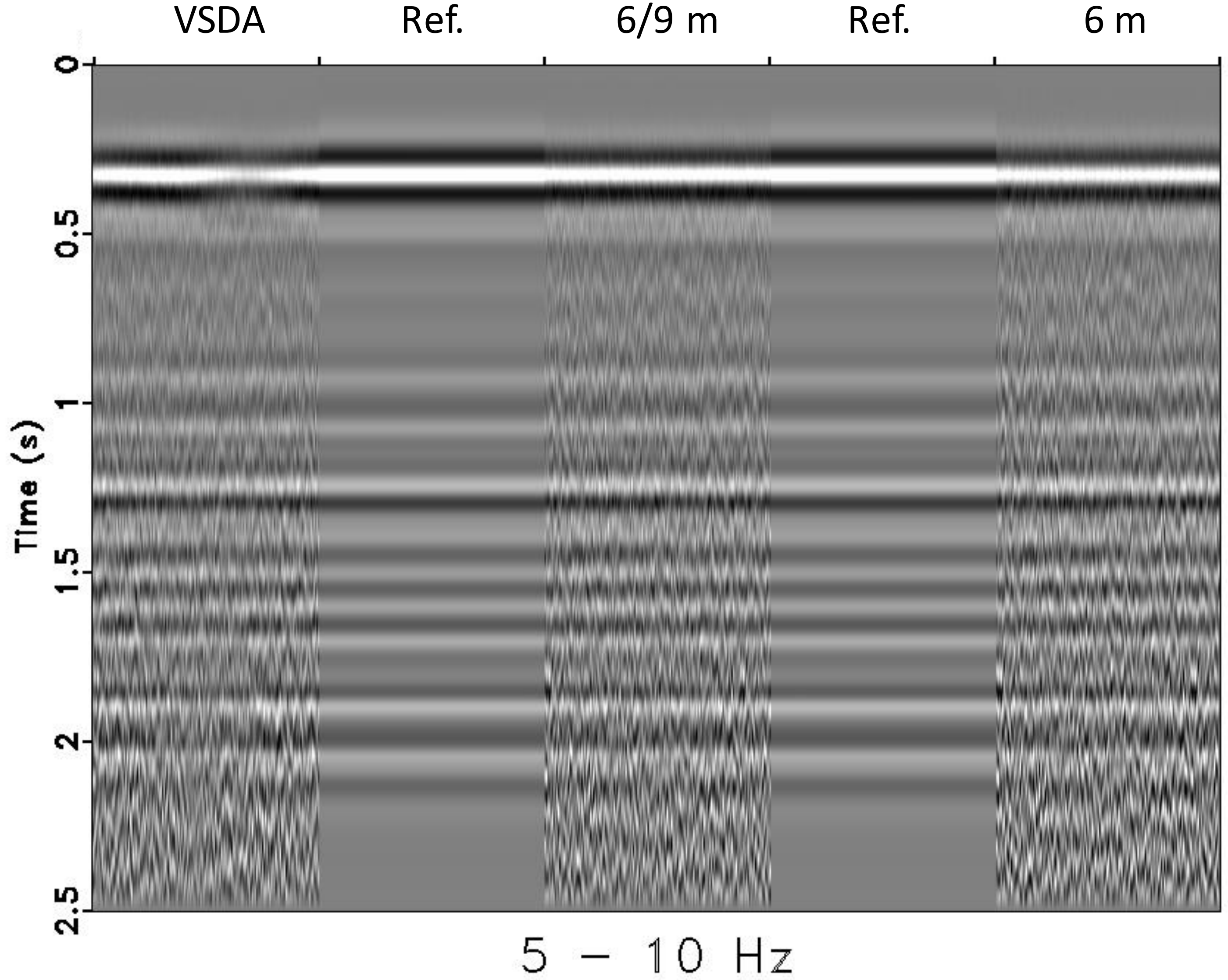
Designature/Deghost - Stack



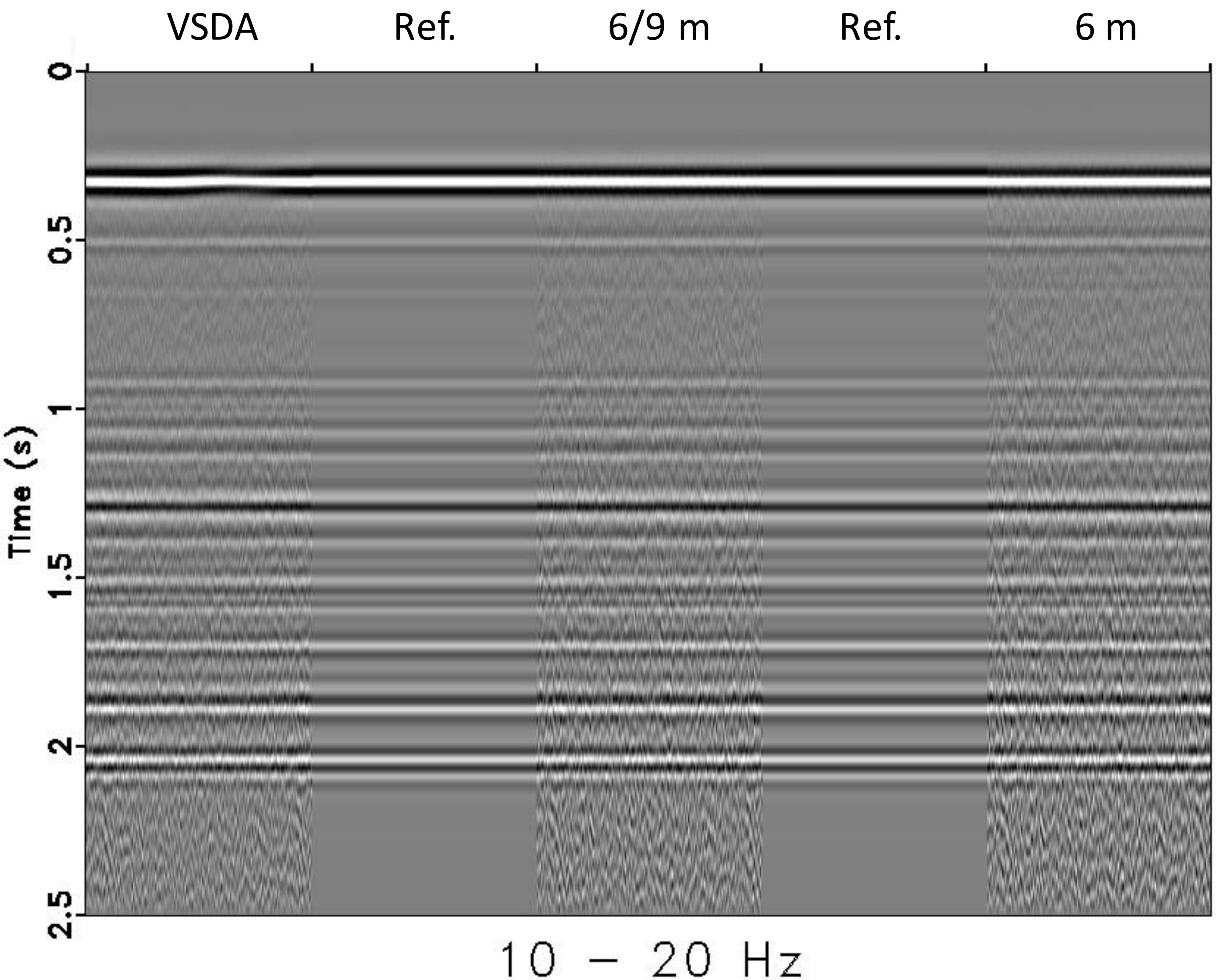
Designature/Deghost - Stack



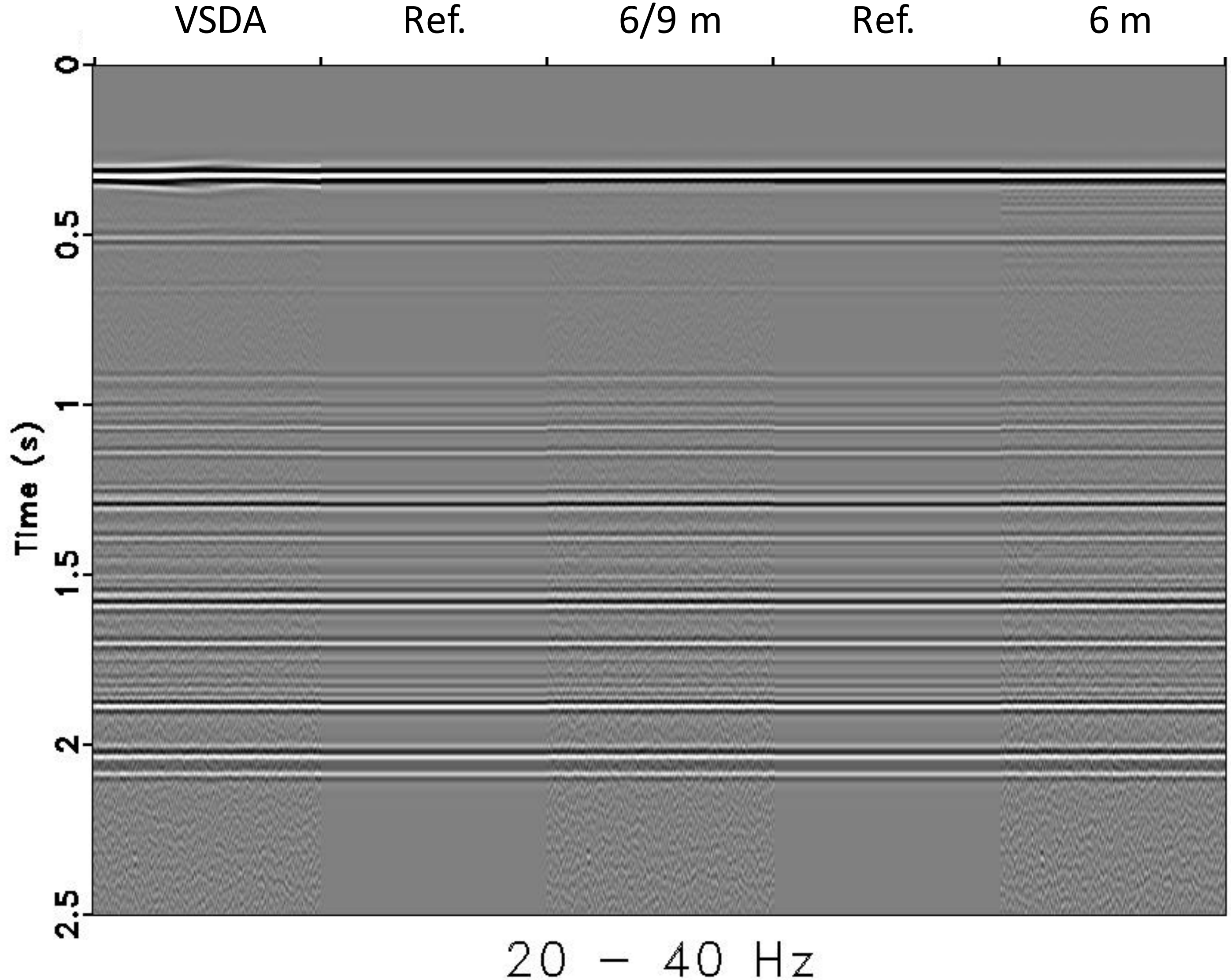
Designature/Deghost - Stack



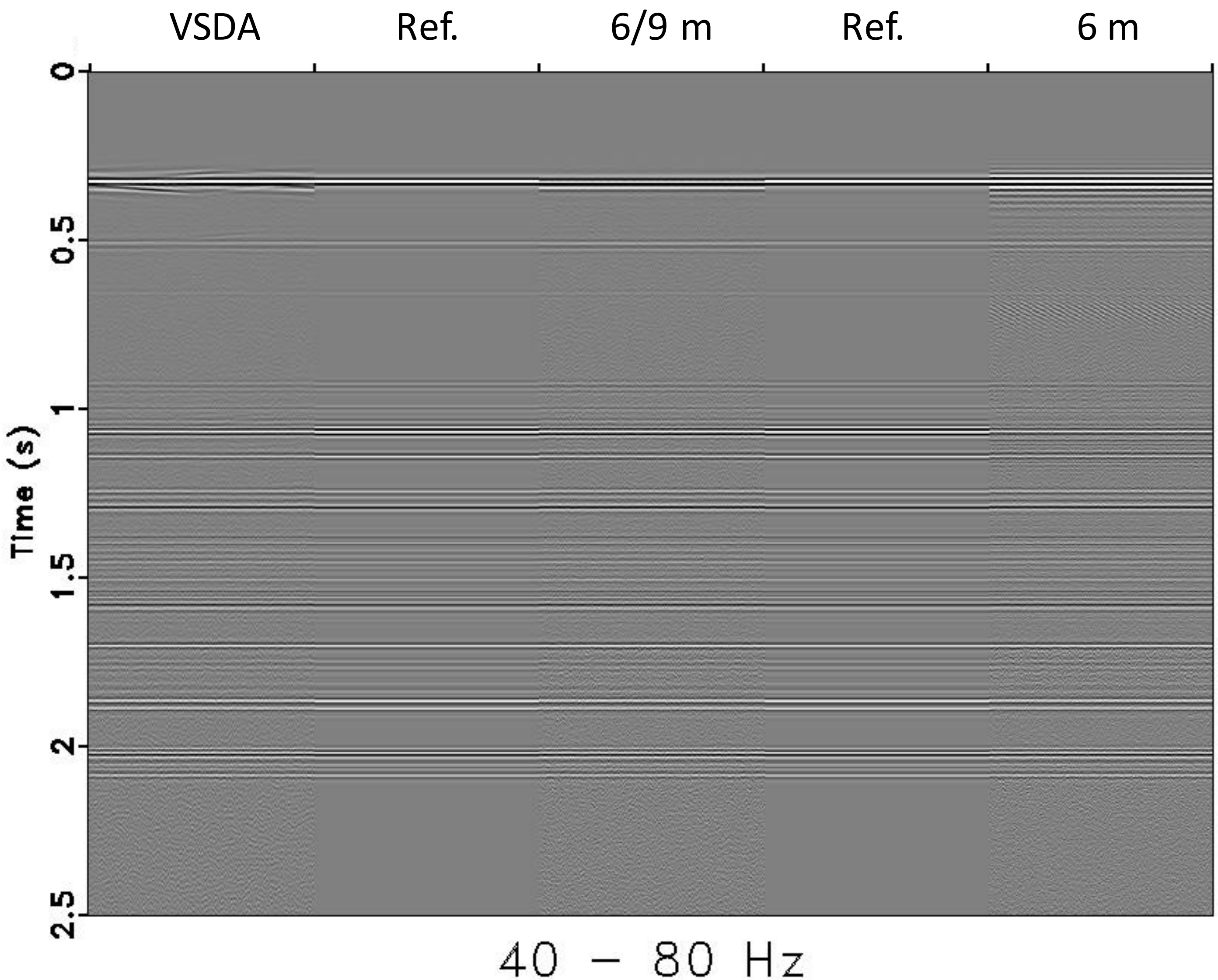
Designature/Deghost - Stack



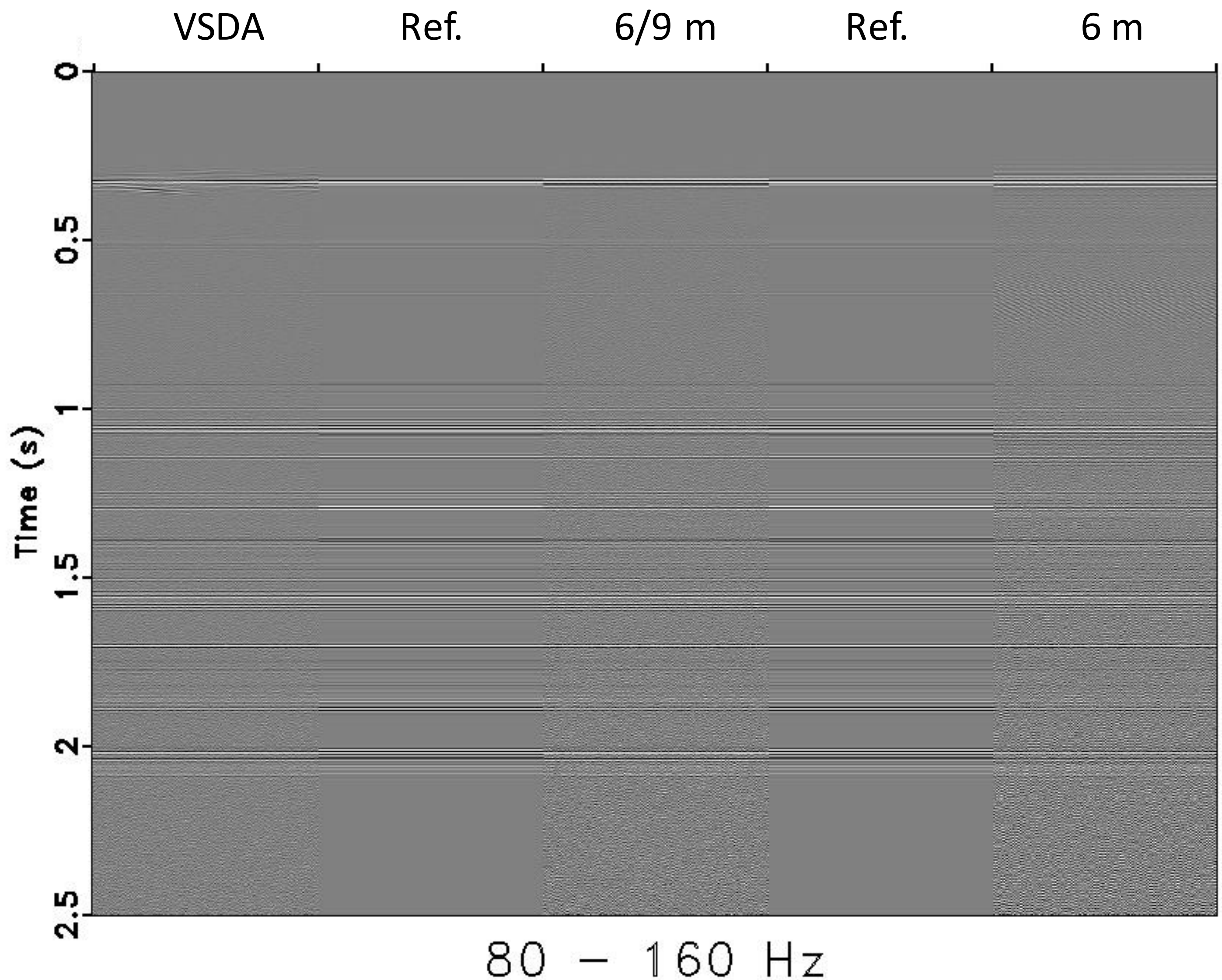
Designature/Deghost - Stack



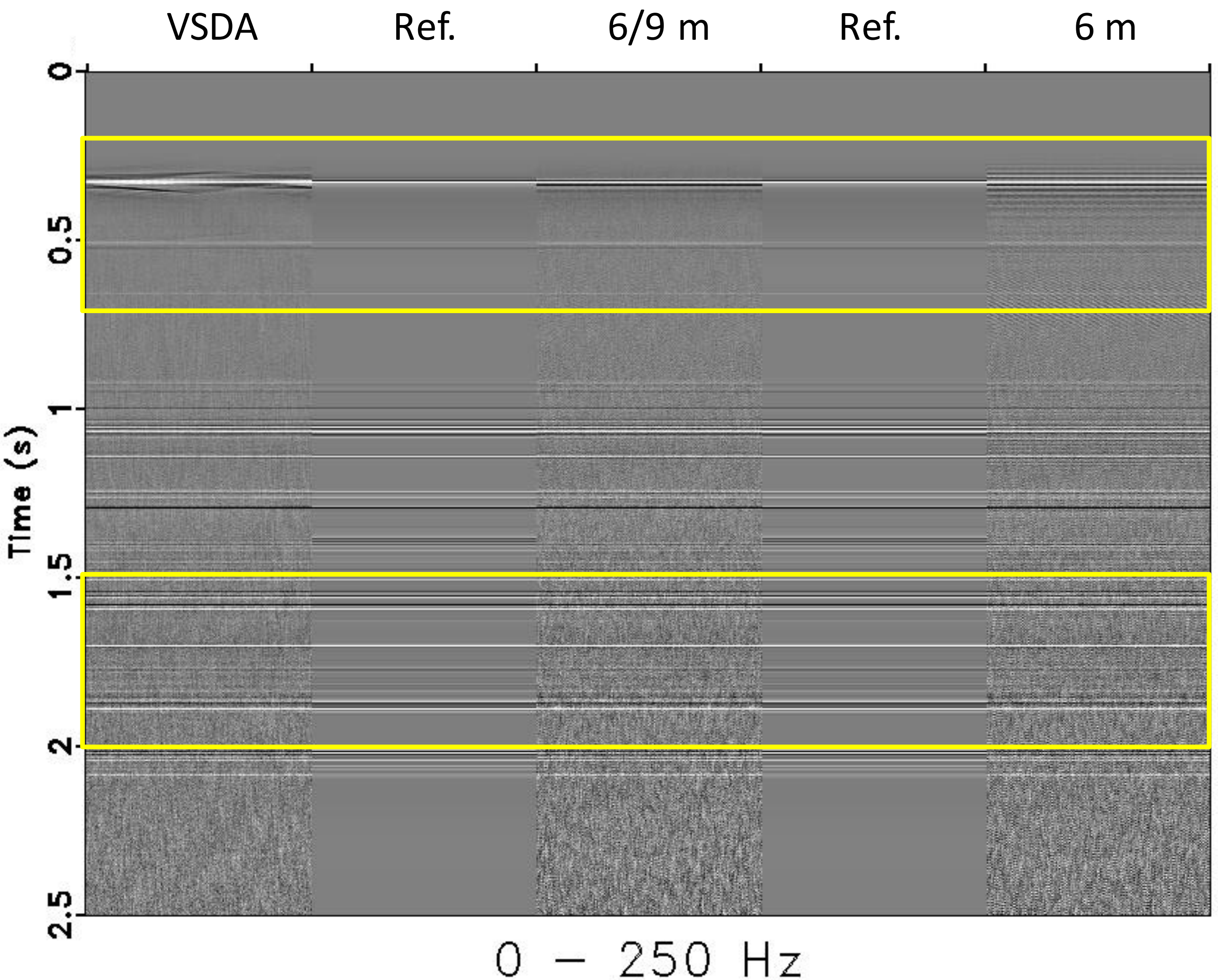
Designature/Deghost - Stack



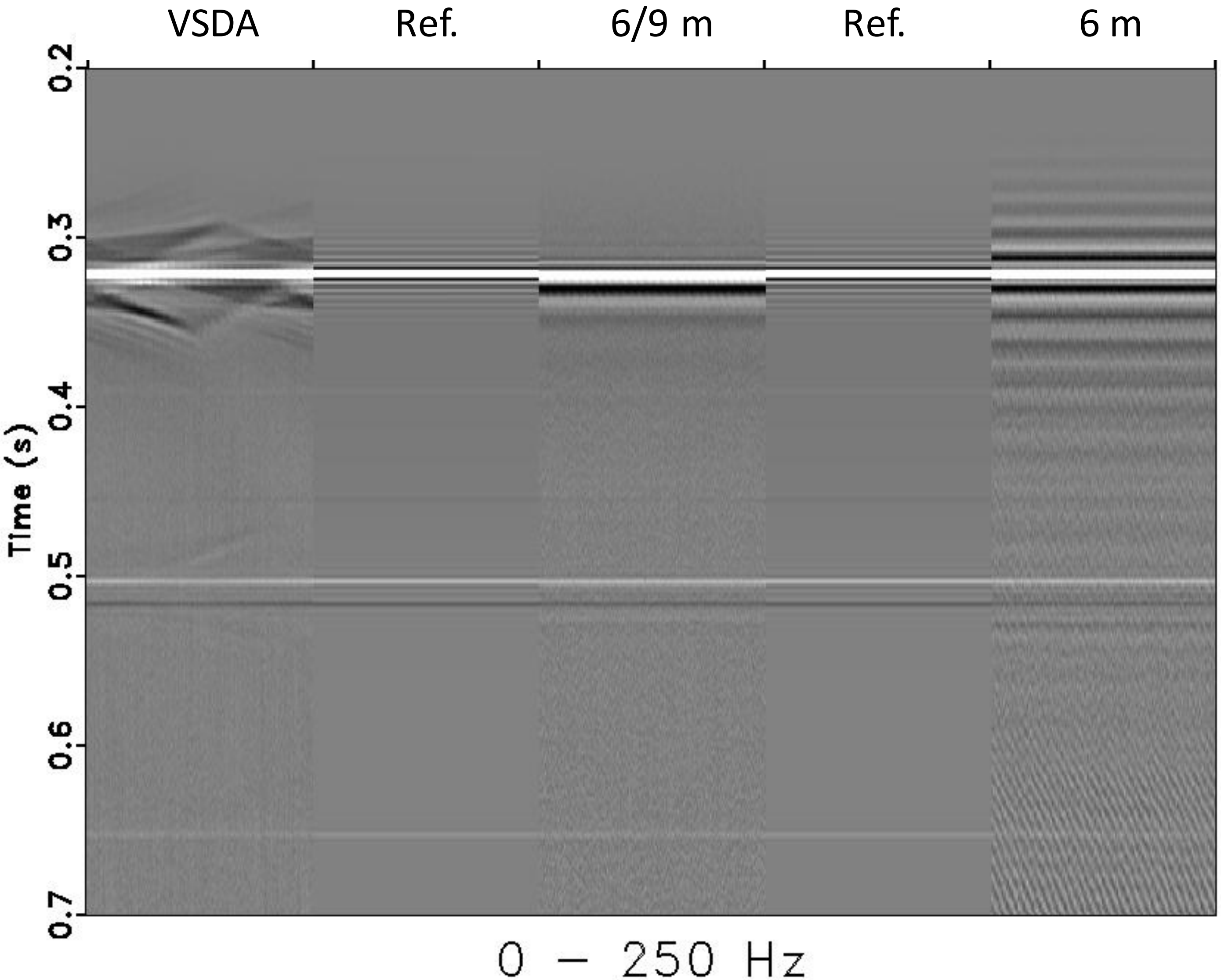
Designature/Deghost - Stack



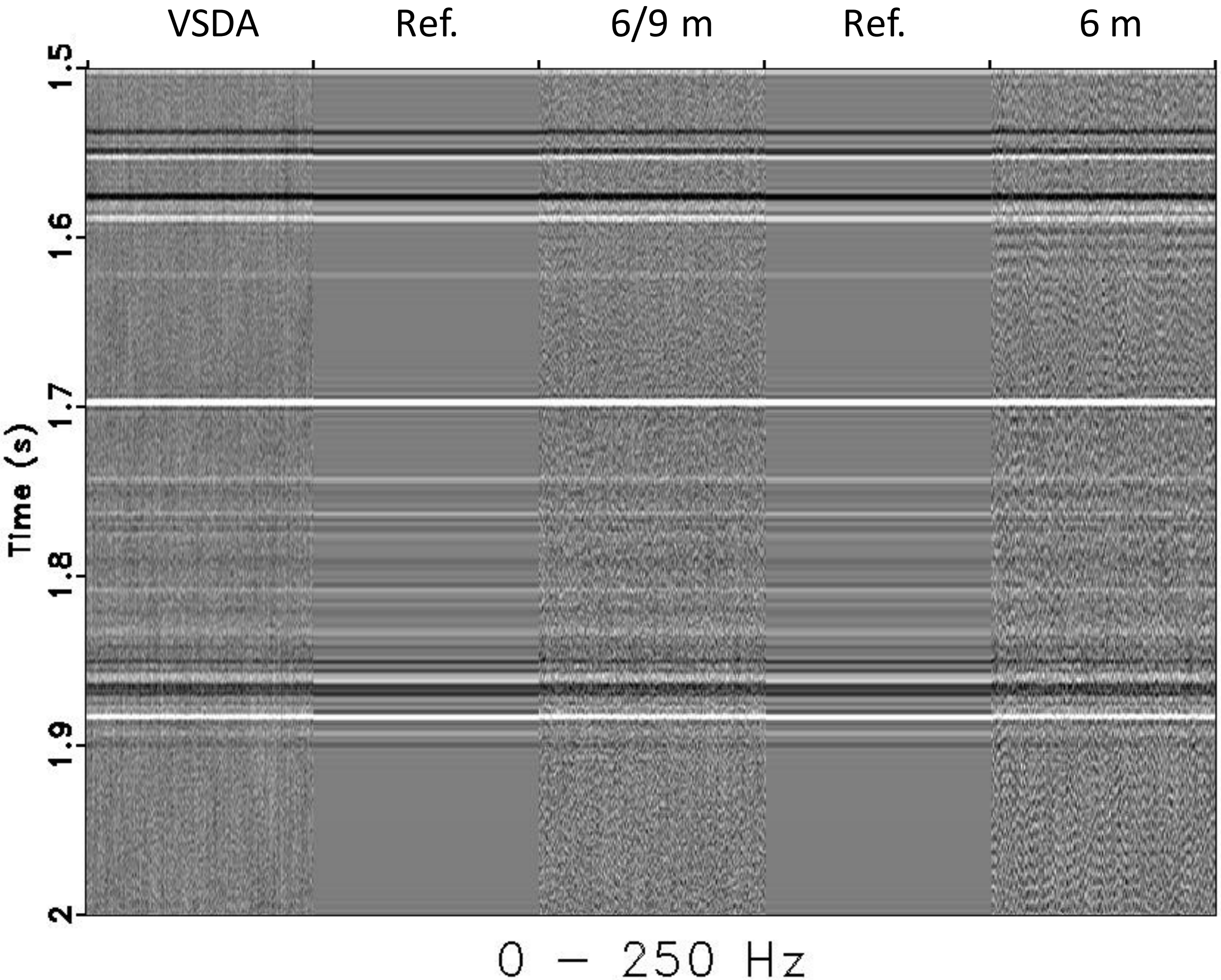
Designature/Deghost - Stack



Zoom in 1:Design./Deghost - Stack

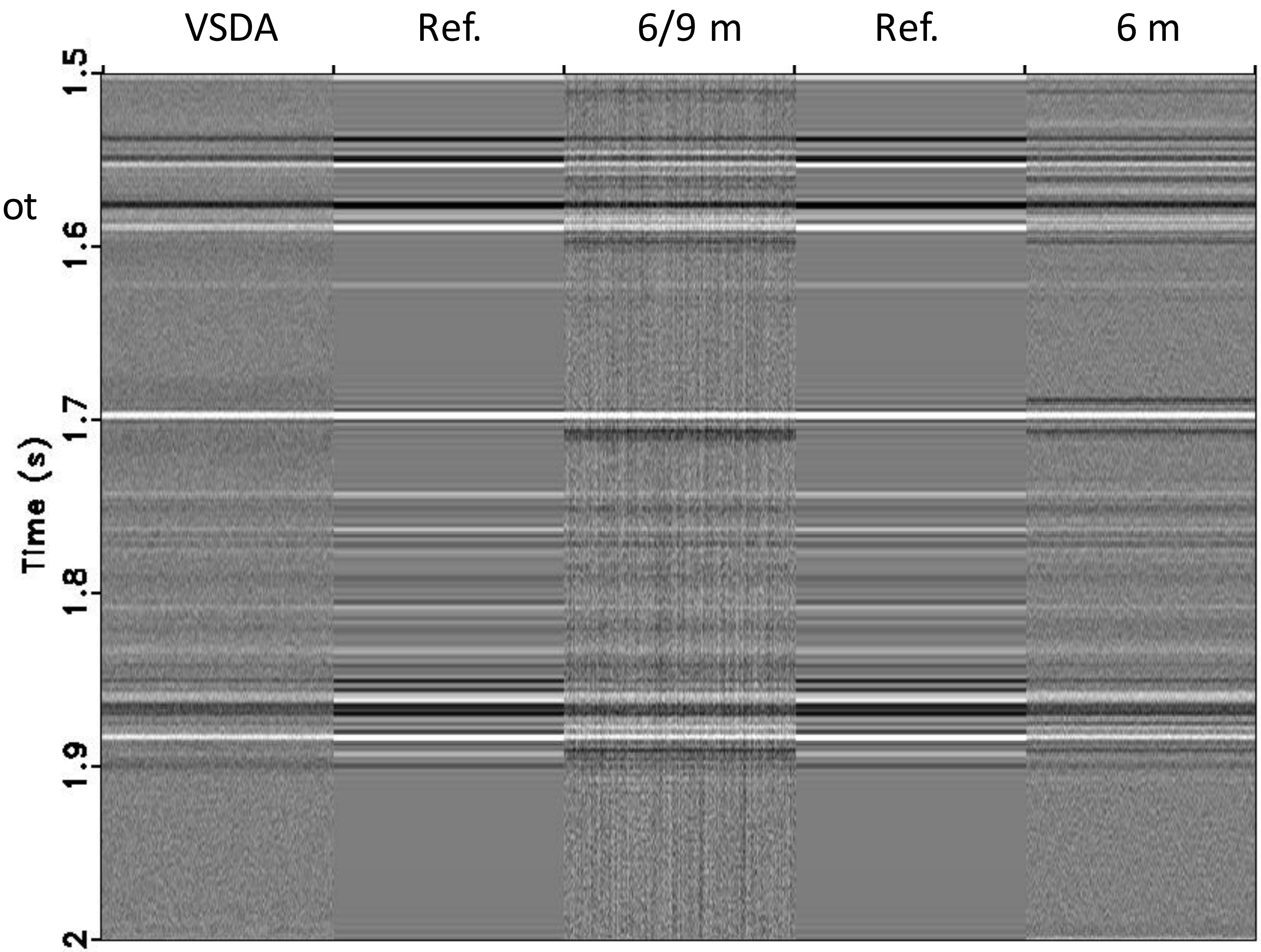


Zoom in 2:Design./Deghost - Stack



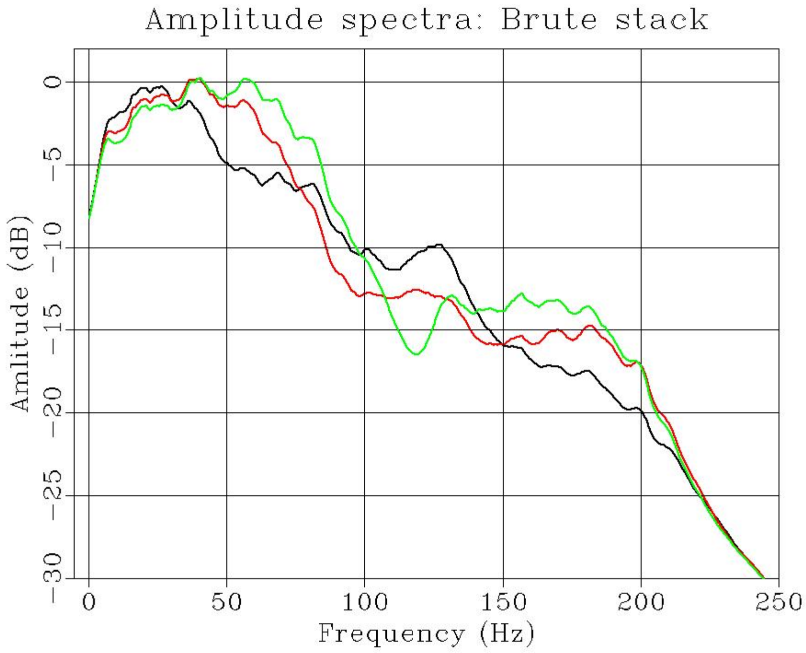
Zoom in: Designature-stack

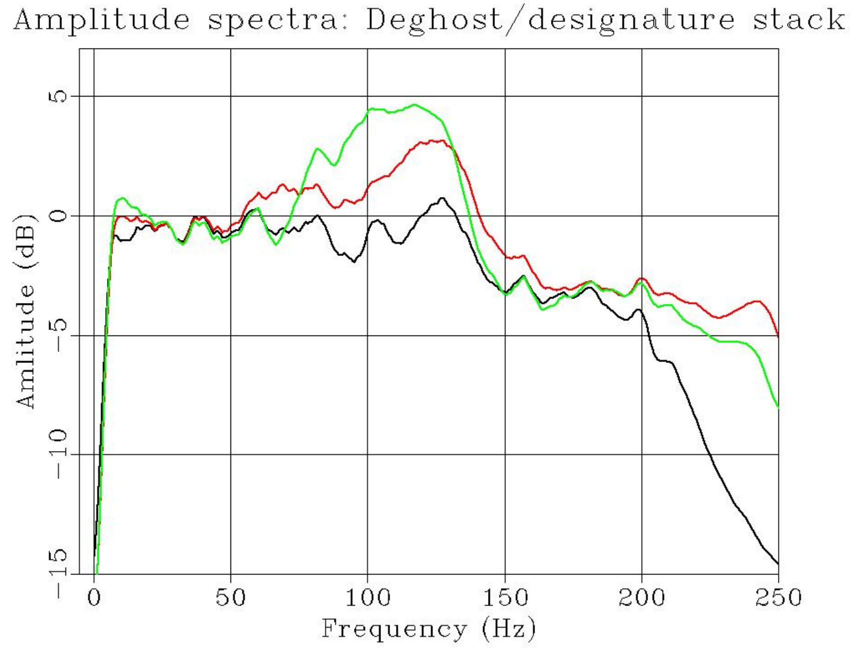
Shot +
mirror shot



1D signature applied

Amplitude Spectra





VSDA, 6/9 m source, 6 m source

Discussion

- Good results are obtained with VSDA:
  - Artifacts only observed in shallow parts of image
  - Shot + ghost shot → Broadband data with zero-phase wavelet
- VSDA and 6/9 m-source results in better images than a single level source at 6 m.
- The multi-level source (6/9 m) results in better images than the single level source
- VSDA results in data with less noise in the frequency band 80-160 Hz. This is due to ”peak”-diversity.
- Notch diversity in VSDA makes LS-deghosting suitable
- Directional deghosting needed to use VSDA for AVO analysis
  - (Pre-stack deghosting, Soubaras, 2012)

- Further work:
  - Model VDSA data over more realistic model
  - More realistic modeling: Attenuation, multiples, etc.
  - Perform AVO feasibility study
  - Study S/N effects for VSDA

Conclusions

- Good results obtained with all source strategies
  - VSDA > 6/9 m > 6 m at frequencies around notch frequency for 6 m source depth.
- VSDA has some issues with shallow geology better designature/deghosting may improve this issue
- VSDA + designature → Broadband data.
  - Deghosting will make further improve the image

References

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- Wang, P. Nimsaila, D. Zhuang, Z. Fu, H. Shen, G. Poole, and N. Chazaloel. (2015) Joint 3d source-side deghosting and designature for modern air-gun arrays: 77th EAGE meeting. Th N103 10.
- Agudo, Ó.C., P. Caprioli and D-J. van Manen (2016) A spatially compact source designature filter. Geophysics Vol.81. No.2

Comparison of receiver and source deghosting approaches

- Multi-component streamer → - Monopole + dipole source

$$p_{\deg}(\omega, k_x, k_y, z) = \frac{1}{2}\left(p(\omega, k_x, k_y, z) - \frac{\omega\rho}{k_z} v_z(\omega, k_x, k_y, z)\right)$$

- Over/under streamers → - Dual depth source

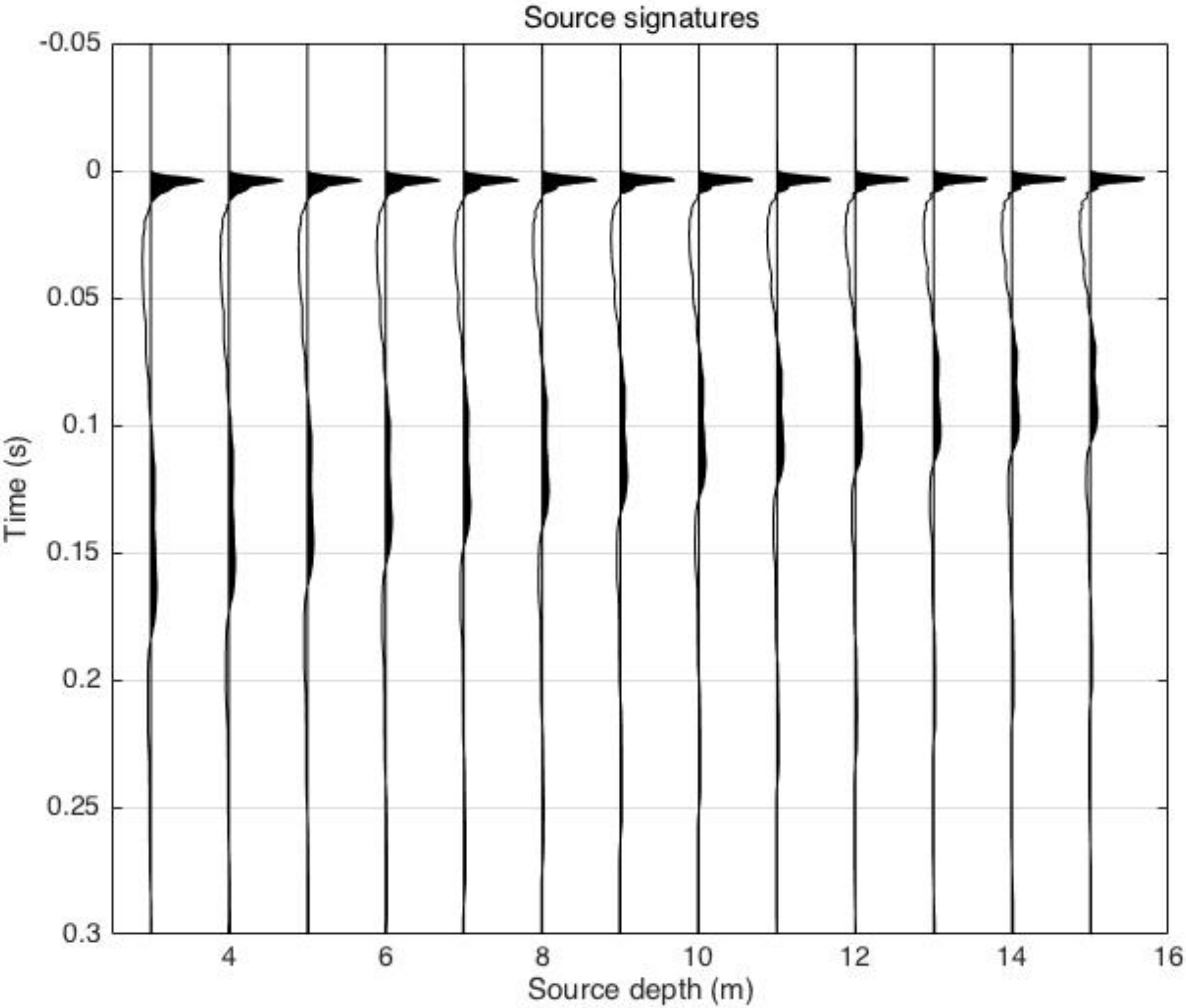
$$R(\omega) = \frac{\overline{G_1(\omega)}D_1(\omega) + \overline{G_2(\omega)}D_2(\omega)}{|G_1(\omega)|^2 + |G_2(\omega)|^2}$$

- Variable-depth streamer → - Variable source-depth acquisition (VSDA)

$$R(\omega) = \frac{\sum_{i=1}^{N} \overline{G_i(\omega)}\, D_i(\omega)}{\sum_{i=1}^{N} |G_i(\omega)|^2}$$

- Conventional streamer+FK-filter → - Conventional acquisition+ designature

Tenghamn (2007), Posthumus (1993), Soubaras (2010), Robertsson (2008), Meier et al. (2015)



Source signatures
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
Time (s)
4
6
8
10
12
14
16
Source depth (m)

Brute stack