Examining the phase property of nonstationary Vibroseis wavelet

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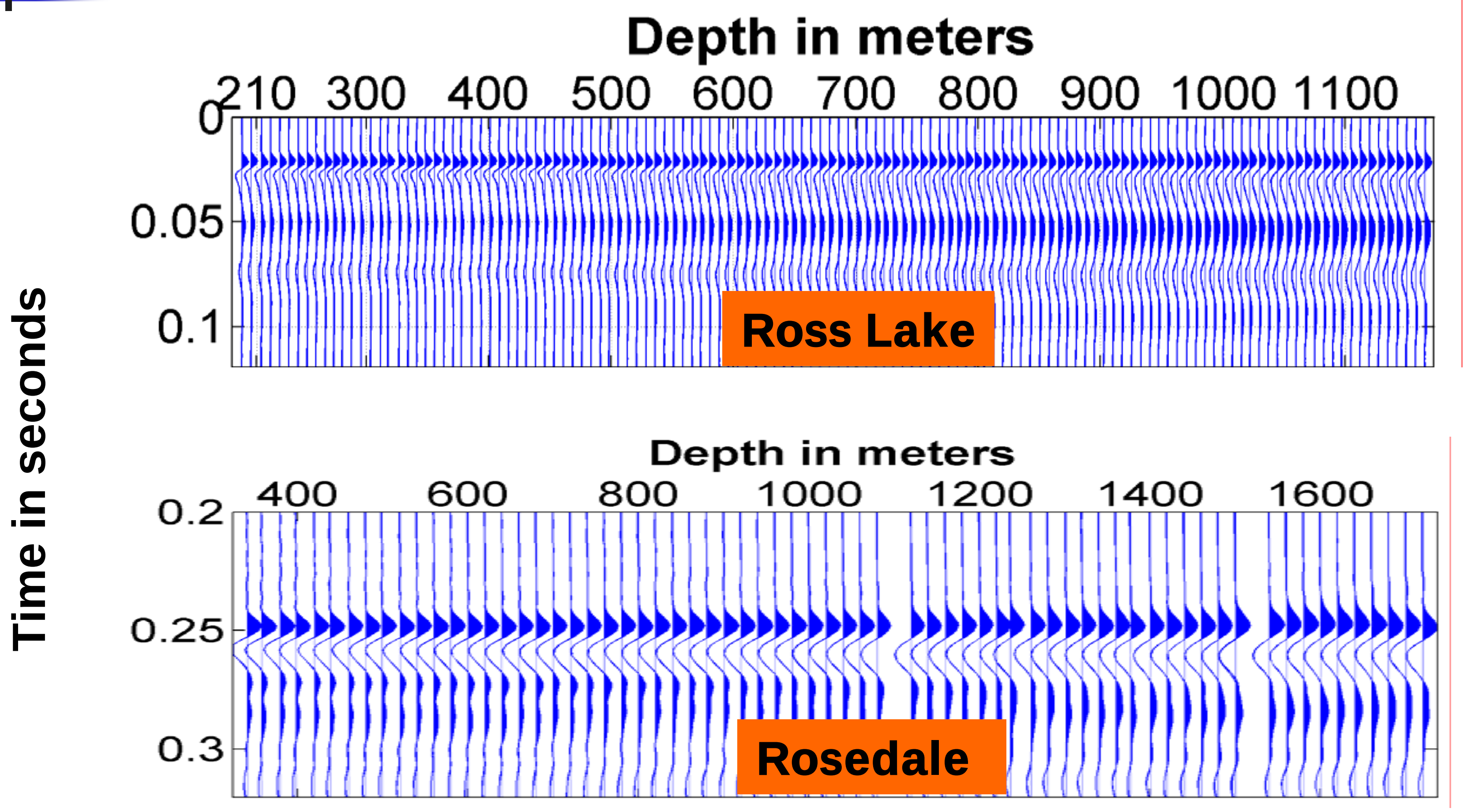
Outline

- Objective
- Observed wavelets from VSPs
- Examine the phase property of the observed wavelet
- A theoretical perspective
- Conclusions
- Acknowledgements

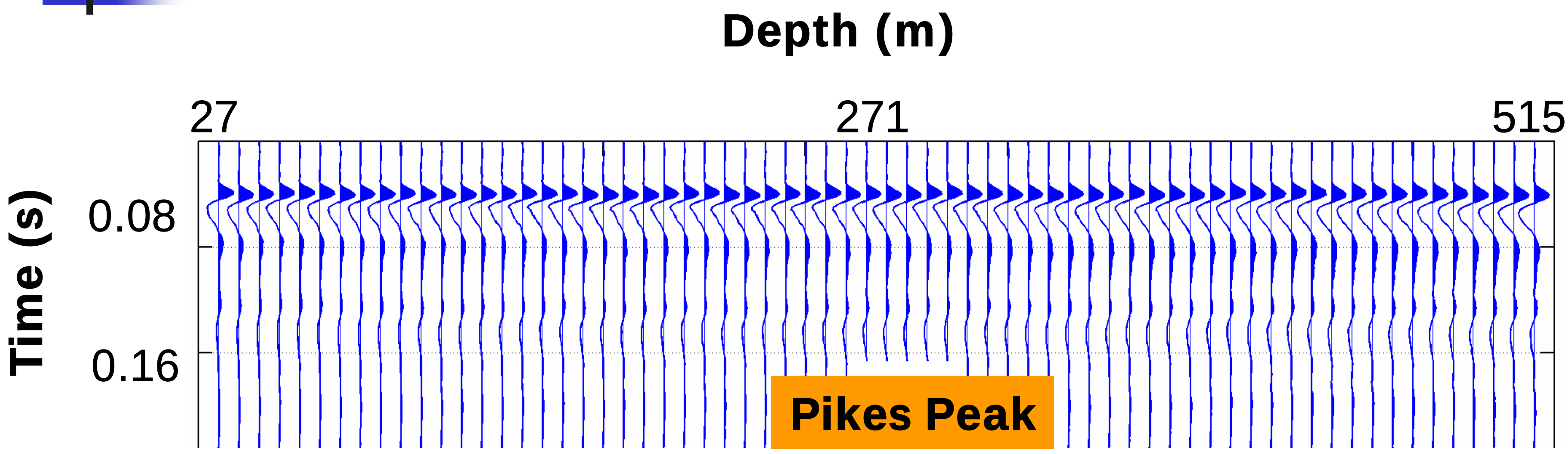
Objective

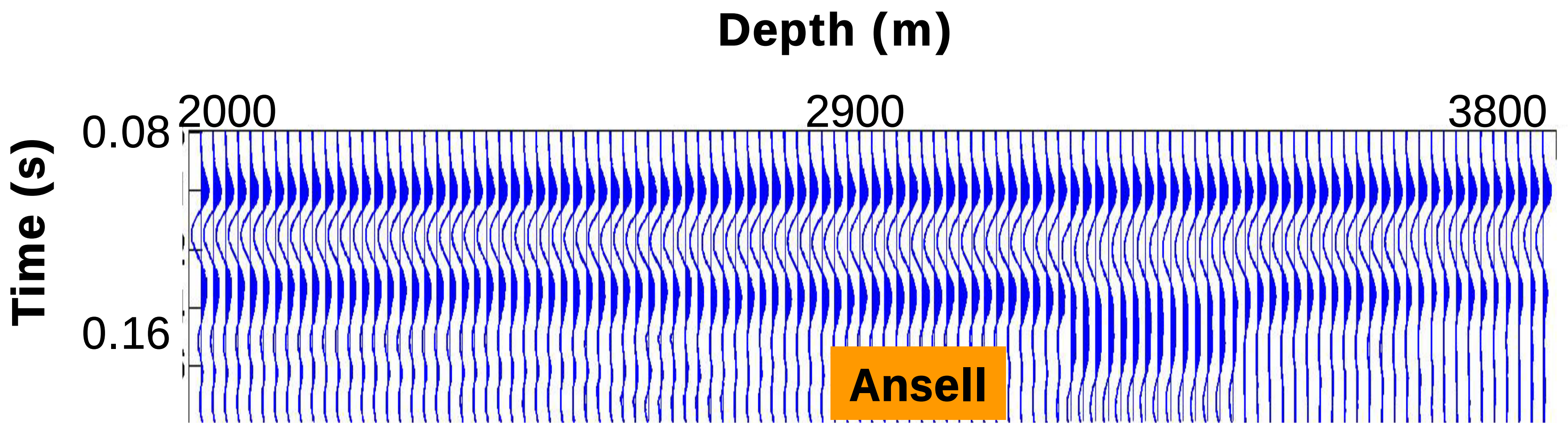
From VSPs, we found that the observed Vibroseis wavelet is close to minimum phase, which is contradictory to the traditional assumption.
Here we give an explanation for the effective minimum phase property.

Observed wavelets from VSP wavefield separation

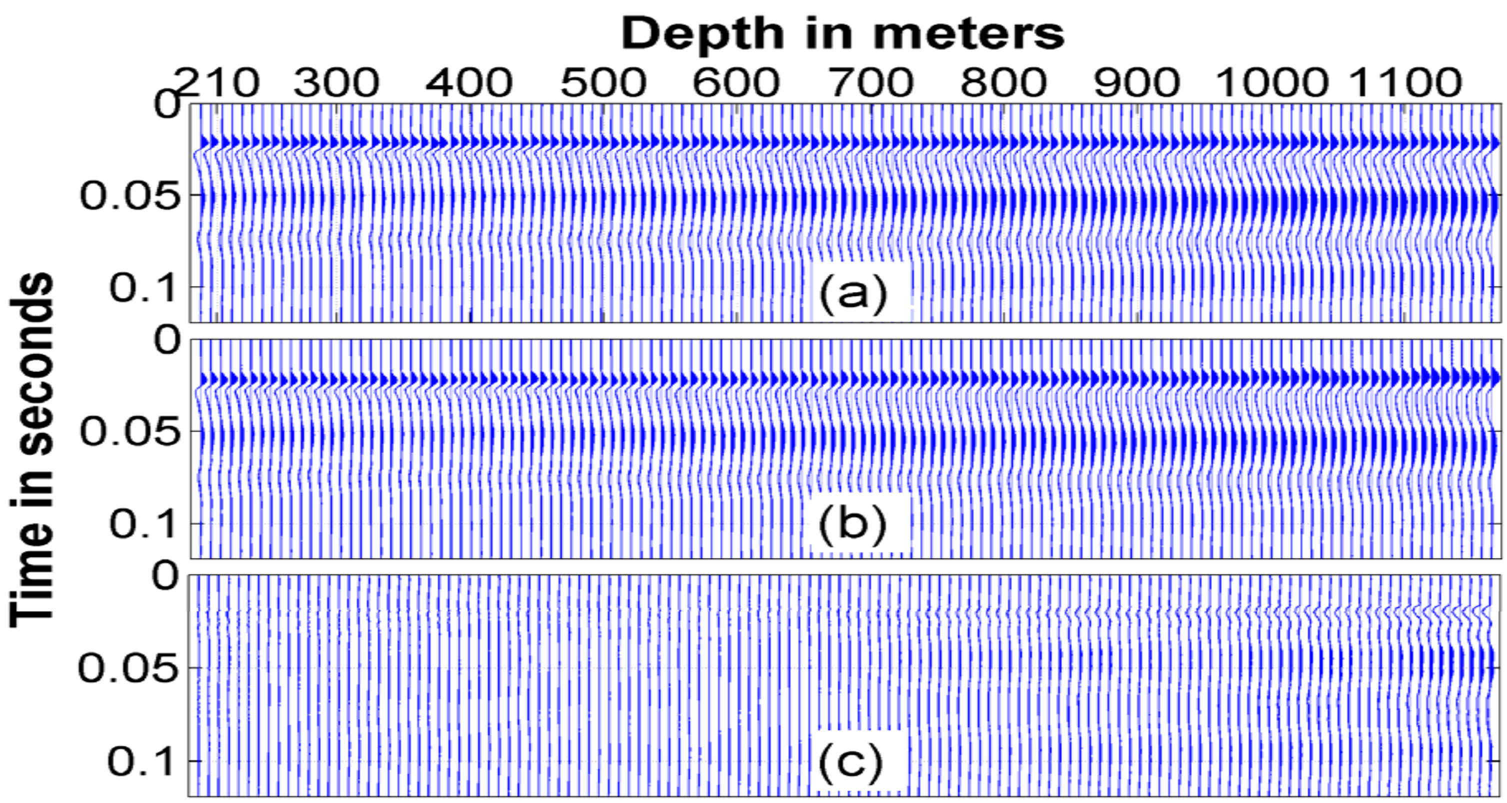


Observed wavelets from VSP wavefield separation



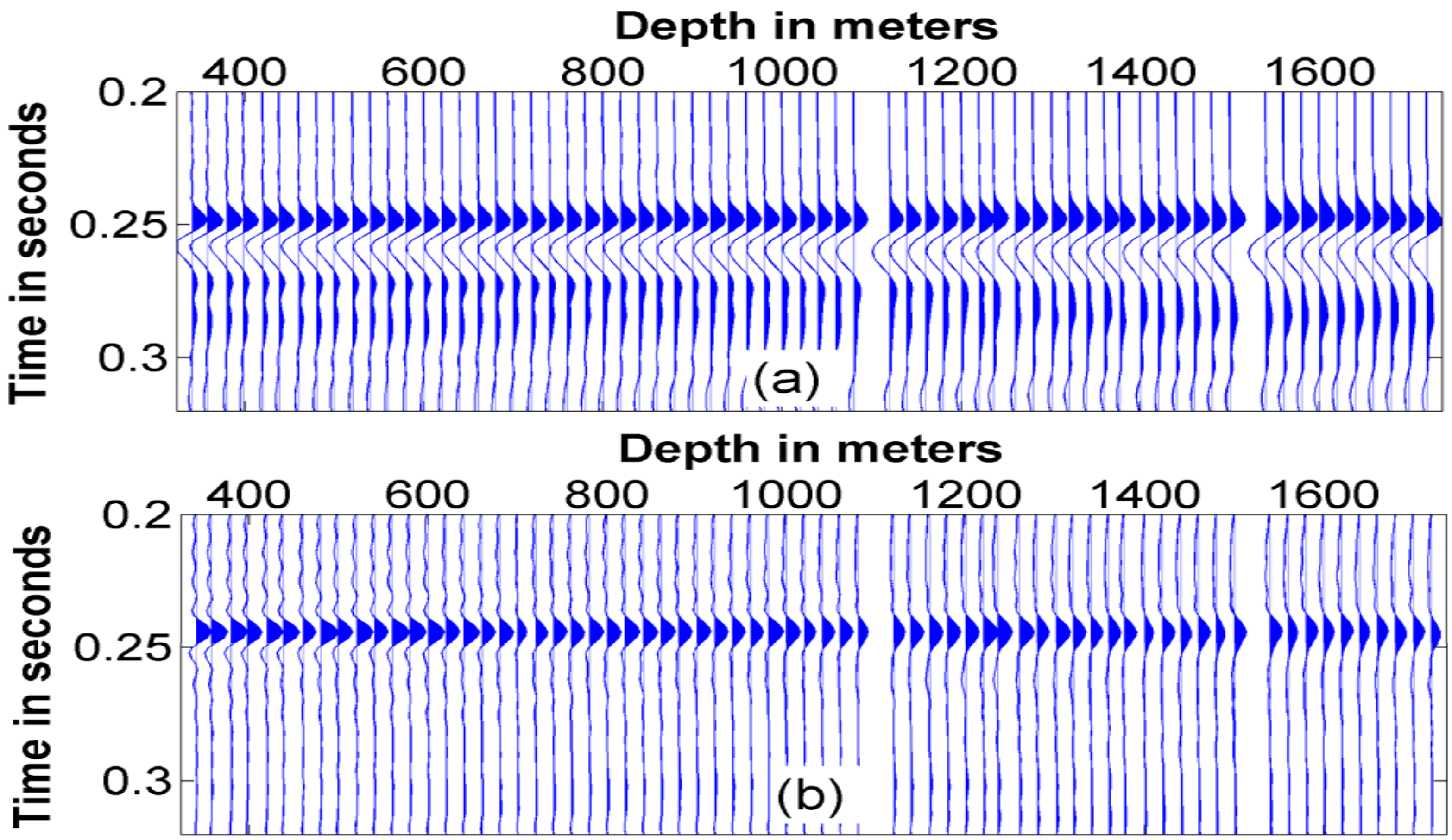


Observed wavelets and their minimum phase equivalents. (Ross Lake 10-140Hz)



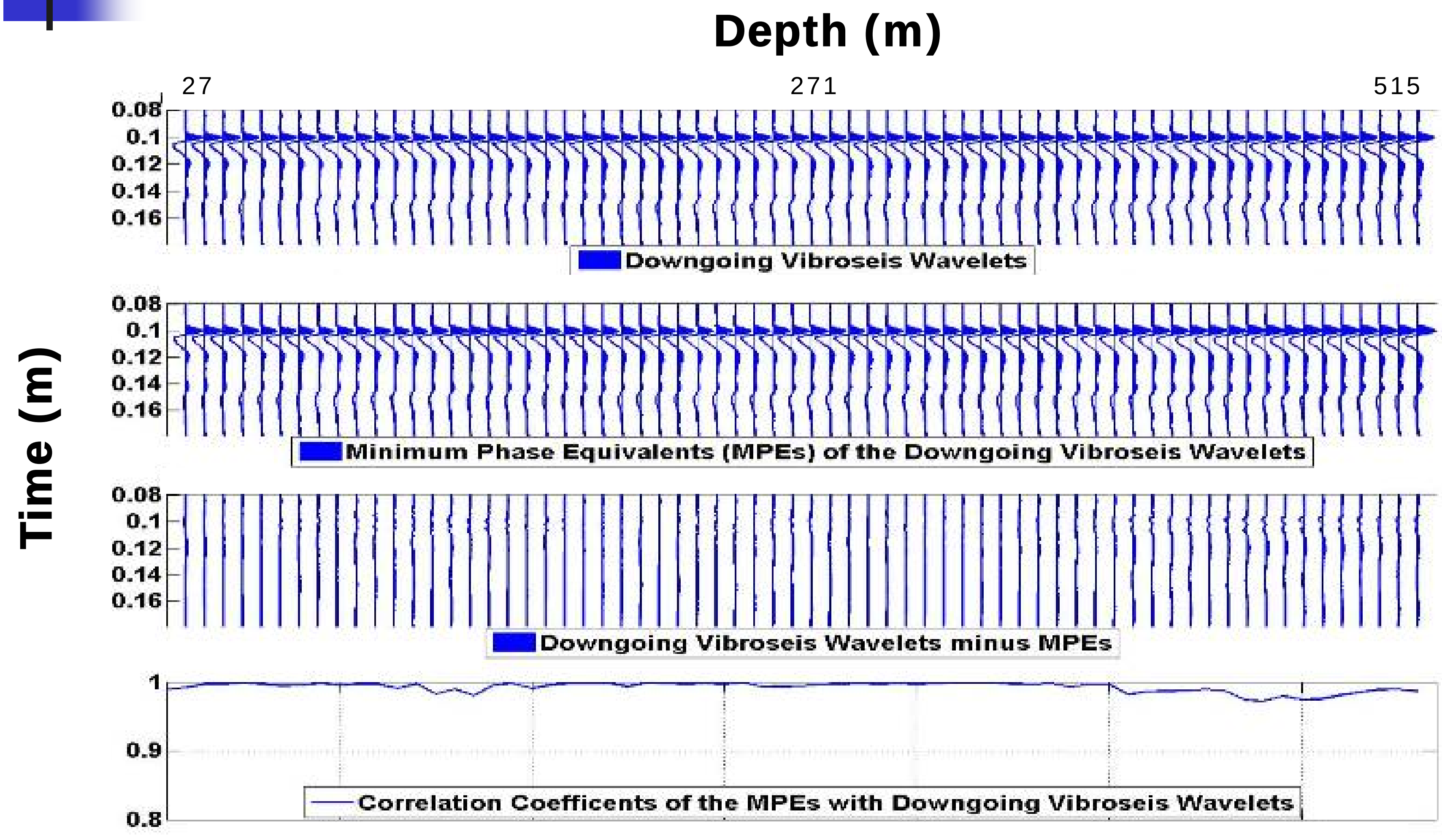
(a) Directly observed wavelets (normalized to peak amplitude).
(b) Minimum phase equivalents.
(c) The difference.

Observed wavelets and Wiener spiking deconvolution (Rosedale 10-96Hz)

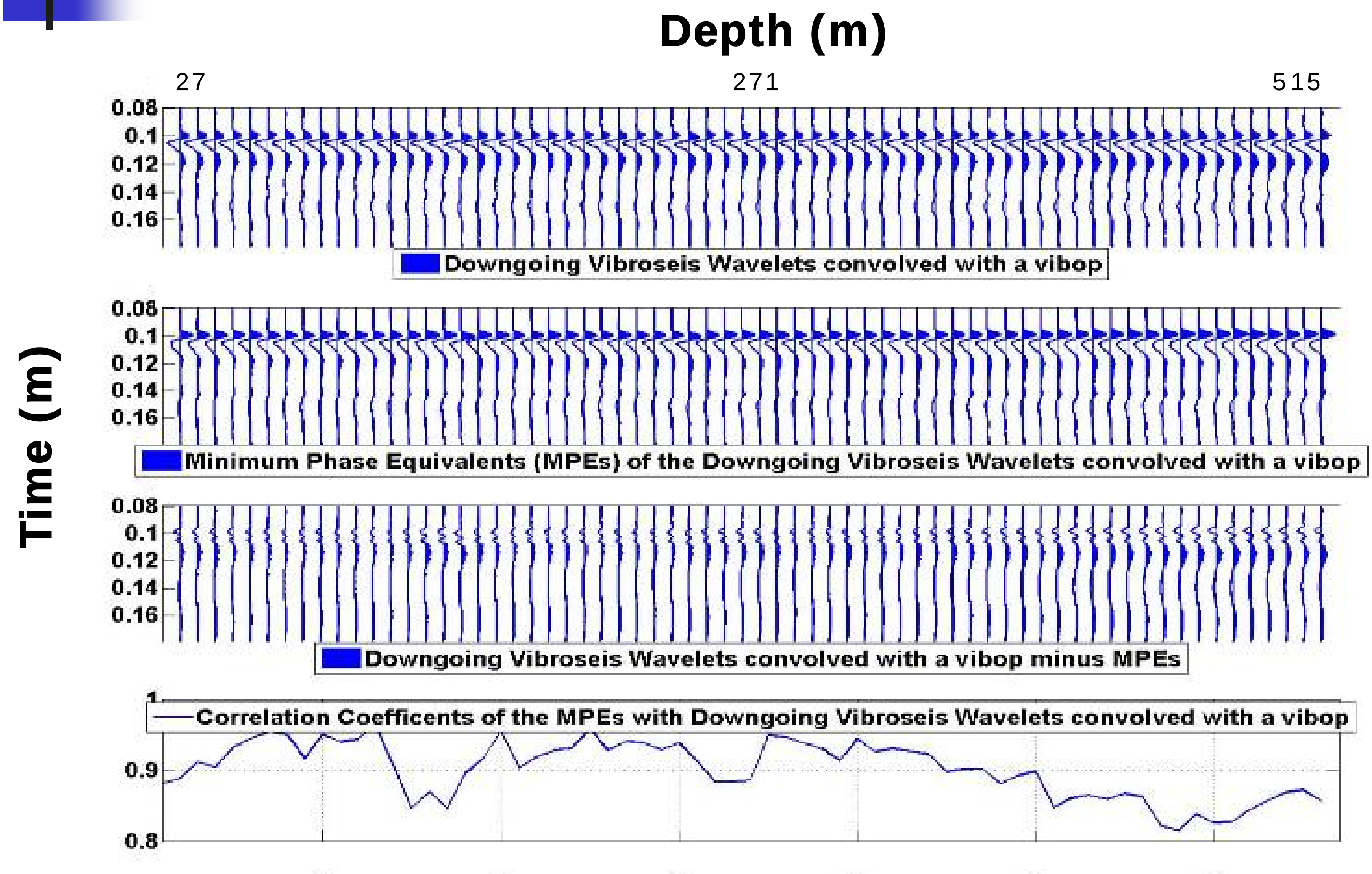


(a) Directly observed wavelets (normalized to peak amplitude).
(b) Results of Wiener deconvolution.

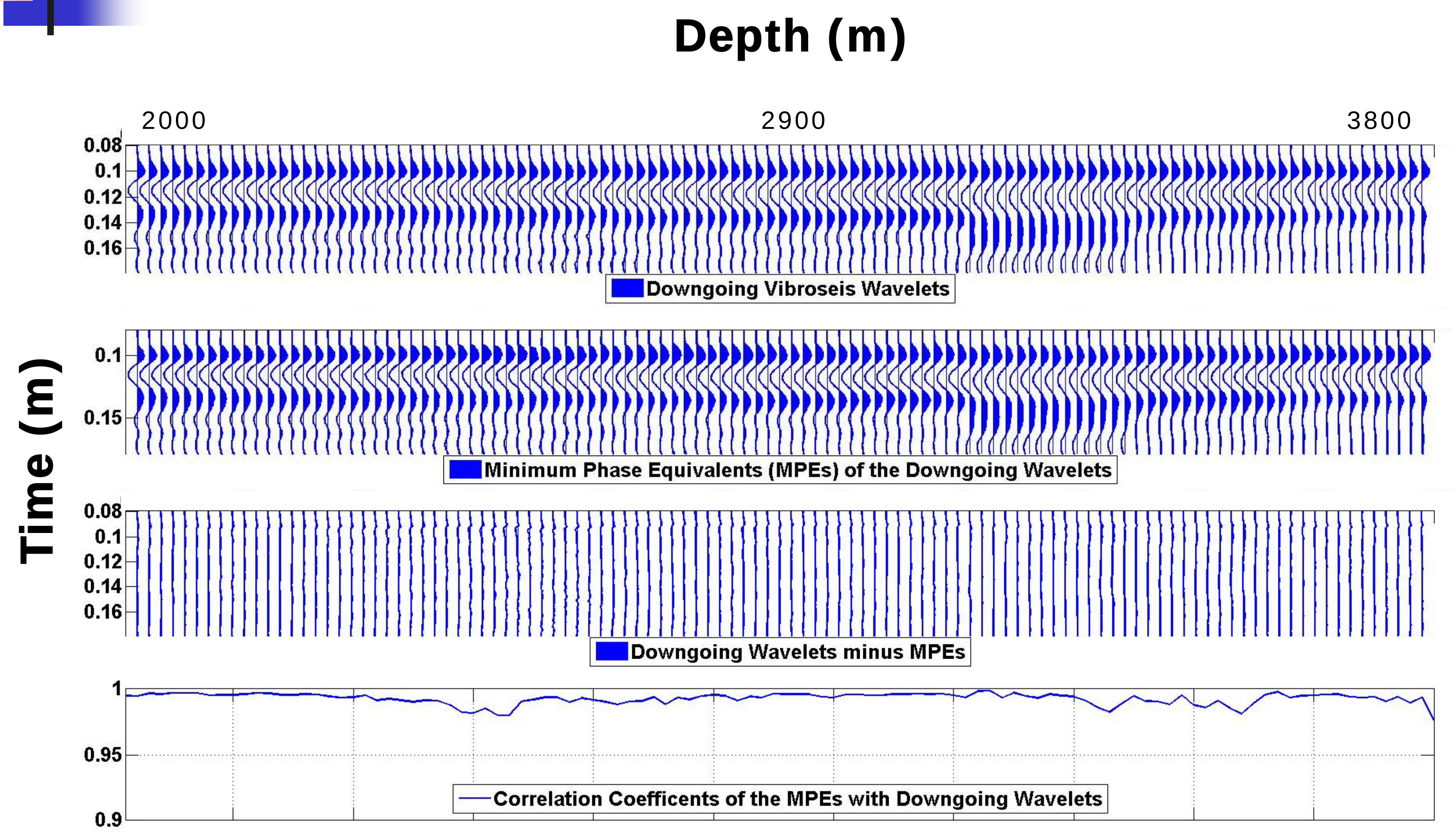
Observed wavelets (without vibop) and their minimum phase equivalents. (Pikes Peak 8-200Hz)



Observed wavelets (with vibop) and their minimum phase equivalents. (Pikes Peak 8-200Hz)



Observed wavelets and their minimum phase equivalents (Ansell).



Uncorrelated trace model

$$X_{ob} = \underbrace{W_v * \underbrace{I_{ns} * R_{ec} * \ldots * D_{iff} * Q_{filt}}_{\text{Minimum phase}}}_{\text{Effective minimum phase}} \bullet r$$

Zero phase

Minimum phase

Effective minimum phase

$W_v = Sweep \otimes Sweep$ or $W_v = Sweep^{-1} * Sweep$

Sweep crosscorrelation **Sweep deconvolution**

$*$ **Stationary convolution** $\otimes$ **Crosscorrelation**

$\bullet$ **Nonstationary convolution**

Amplitude (or Power) Spectra

$$\left|\hat{X}_{ob}\right| = \left|\hat{W}_{v}\right|\left|\hat{I}_{ns}\right|\left|\hat{\mathrm{R}}\mathrm{e}\,c\right|\cdots\left|\hat{D}_{iff}\right|\left|\hat{Q}_{filt}\right|$$

Here a hat (^) indicates Fourier transform, reflectivity has been dropped assuming either VSP wavefield separation or deconvolution spectral separation.

Minimum phase computation

$$\phi_{\min} = H\left(\ln\left|\hat{W}_v\right|\right) + H\left(\ln\left|\hat{I}_{ns}\right|\right) + \cdots + H\left(\ln\left|\hat{Q}_{filt}\right|\right)$$

Since, by assumption, all filters are minimum phase except the first which is zero phase, this differs from the true phase only by the first term.

Minimum phase computation

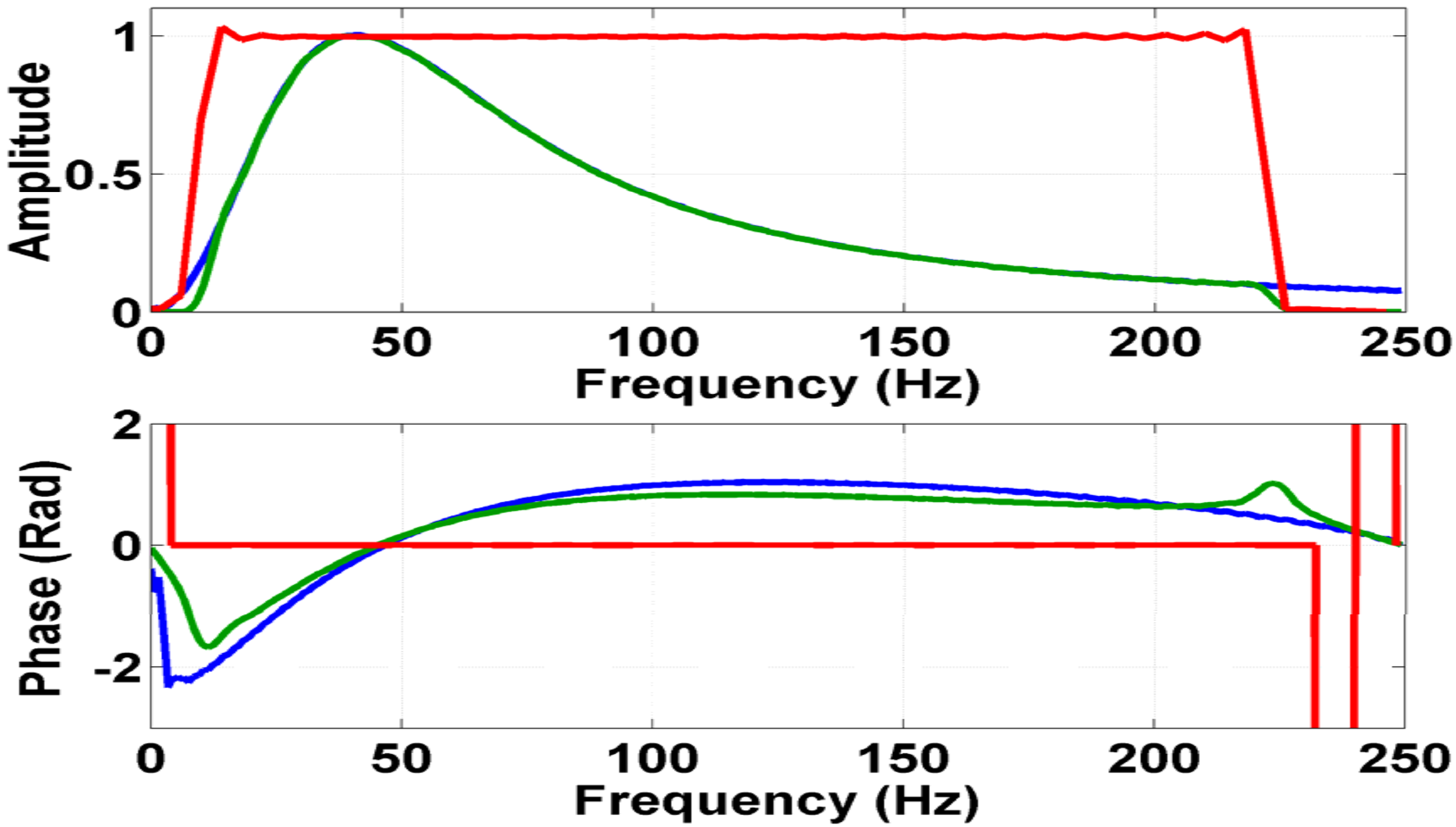
It follows that we can explain our observations if

$$H\left(\ln\left|\hat{W}_v\right|\right) << H\left(\ln\left|\hat{I}_{ns}\right|\right) + \cdots + H\left(\ln\left|\hat{Q}_{filt}\right|\right)$$

This is in fact usually true because $\left|\hat{W}_v\right| = 1$

for all frequencies except those near the end of the sweep. The effect of the end of the sweep is not large because the Hilbert transform is effectively a local operator.

Minimum phase computation



Klauder

Minimum phase

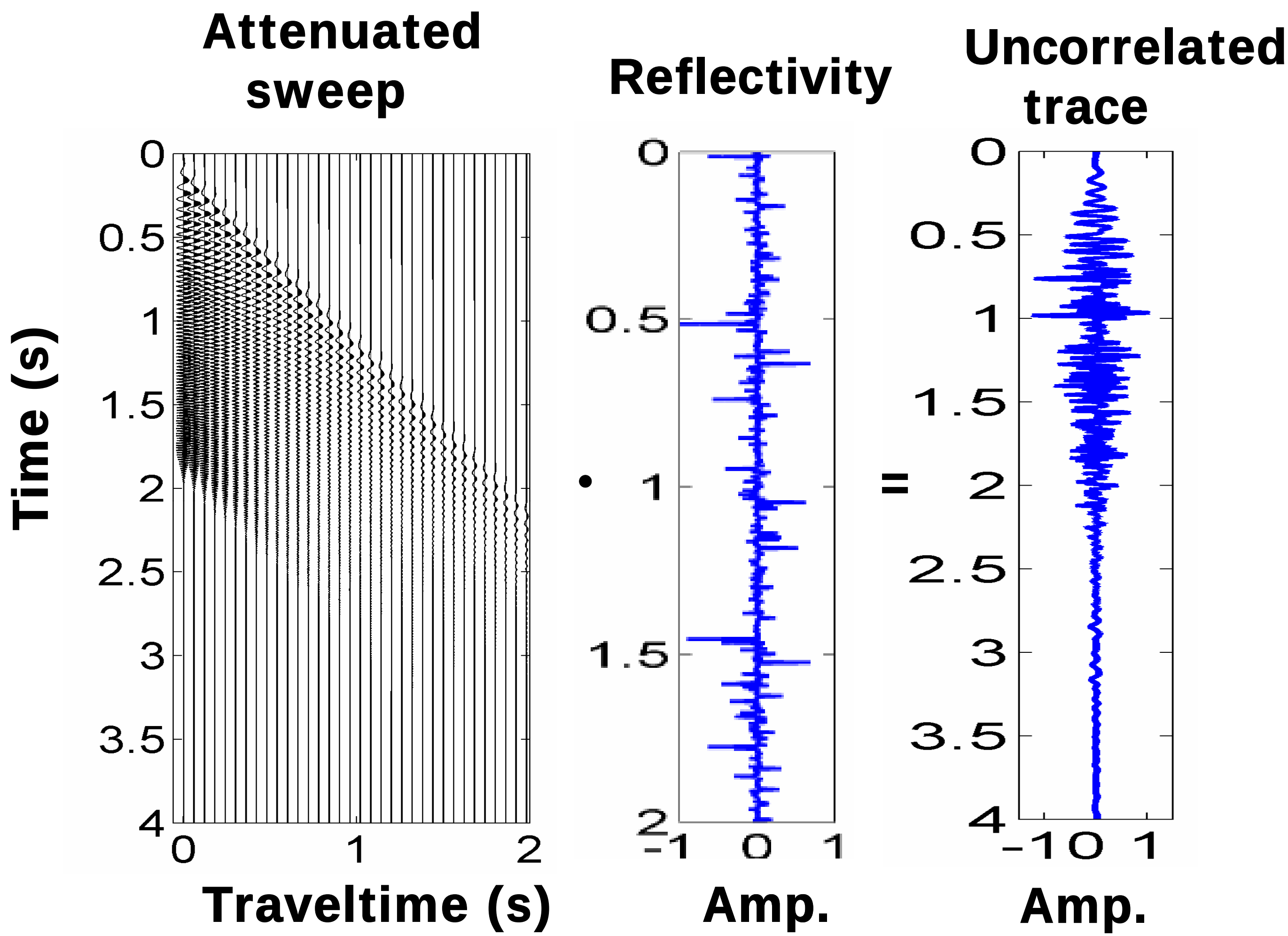
Minimum phase equivalent

Minimum phase computation

So, we expect, from theoretical grounds, that the phase of the minimum-phase equivalent should be nearly equal to the phase of the vibroseis wavelet because:

- The vibroseis effect is contained in a filter that is broad-band unit amplitude spectrum and zero phase
- The Hilbert transform will calculate a very small phase from such a result
- All other filters involved are minimum phase or nearly so.

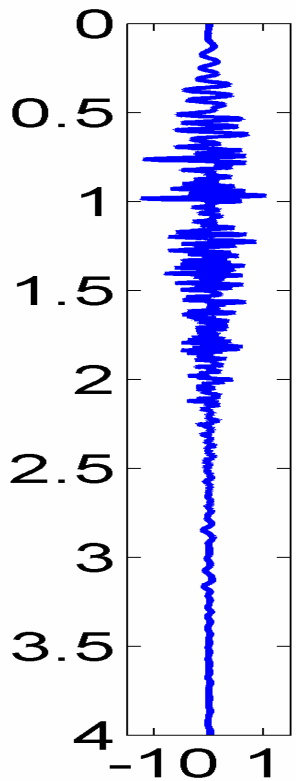
Attenuated synthetic traces using cross-correlation and FDSD (Brittle and Lines,2001)



- Nonstationary convolution

Attenuated synthetic traces using cross-correlation and FDSD (Brittle and Lines,2001)

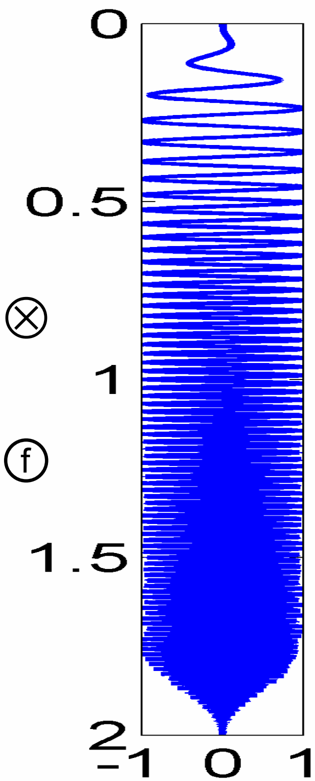
Uncorrelated trace



⊗

ⓕ

Sweep



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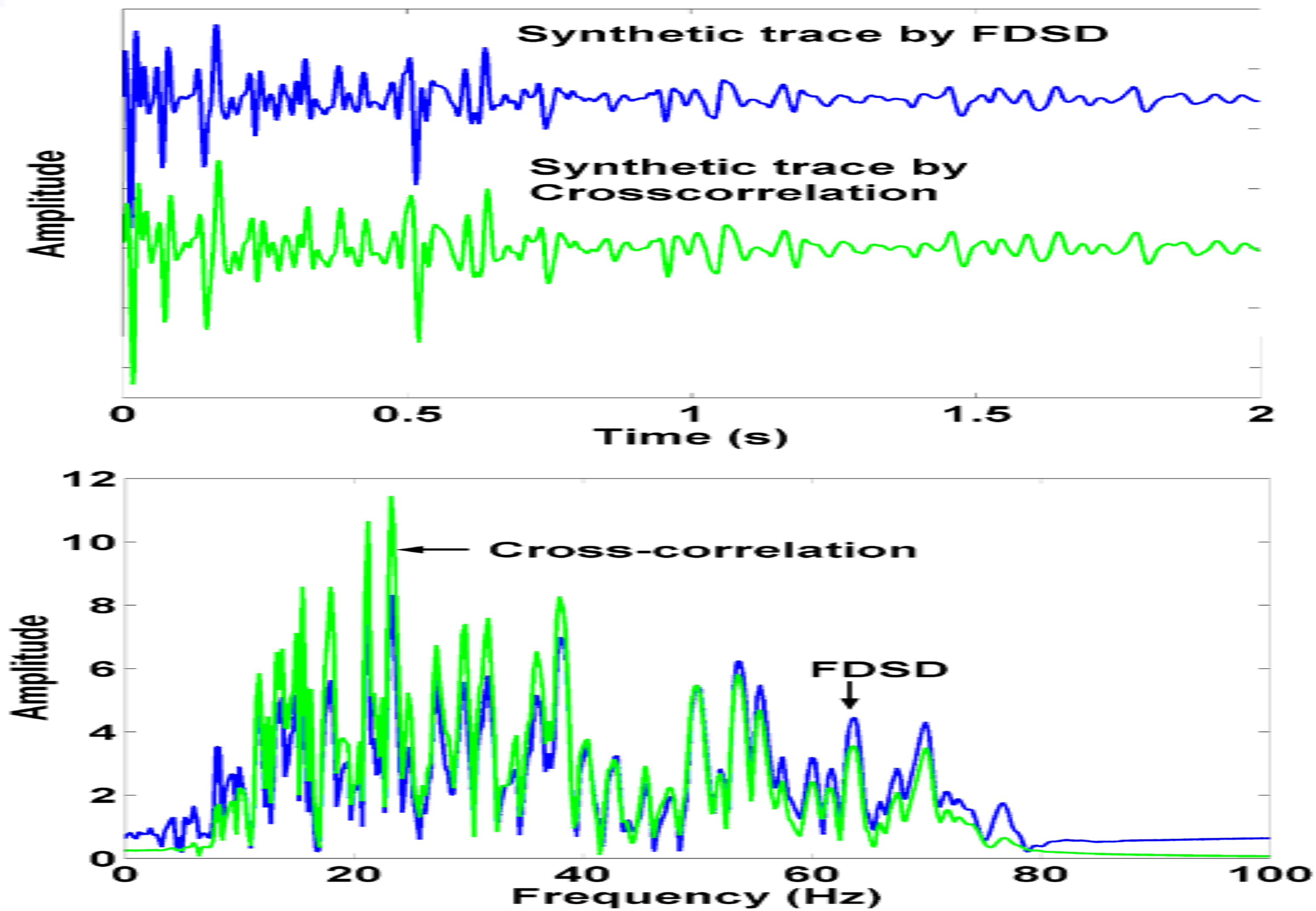
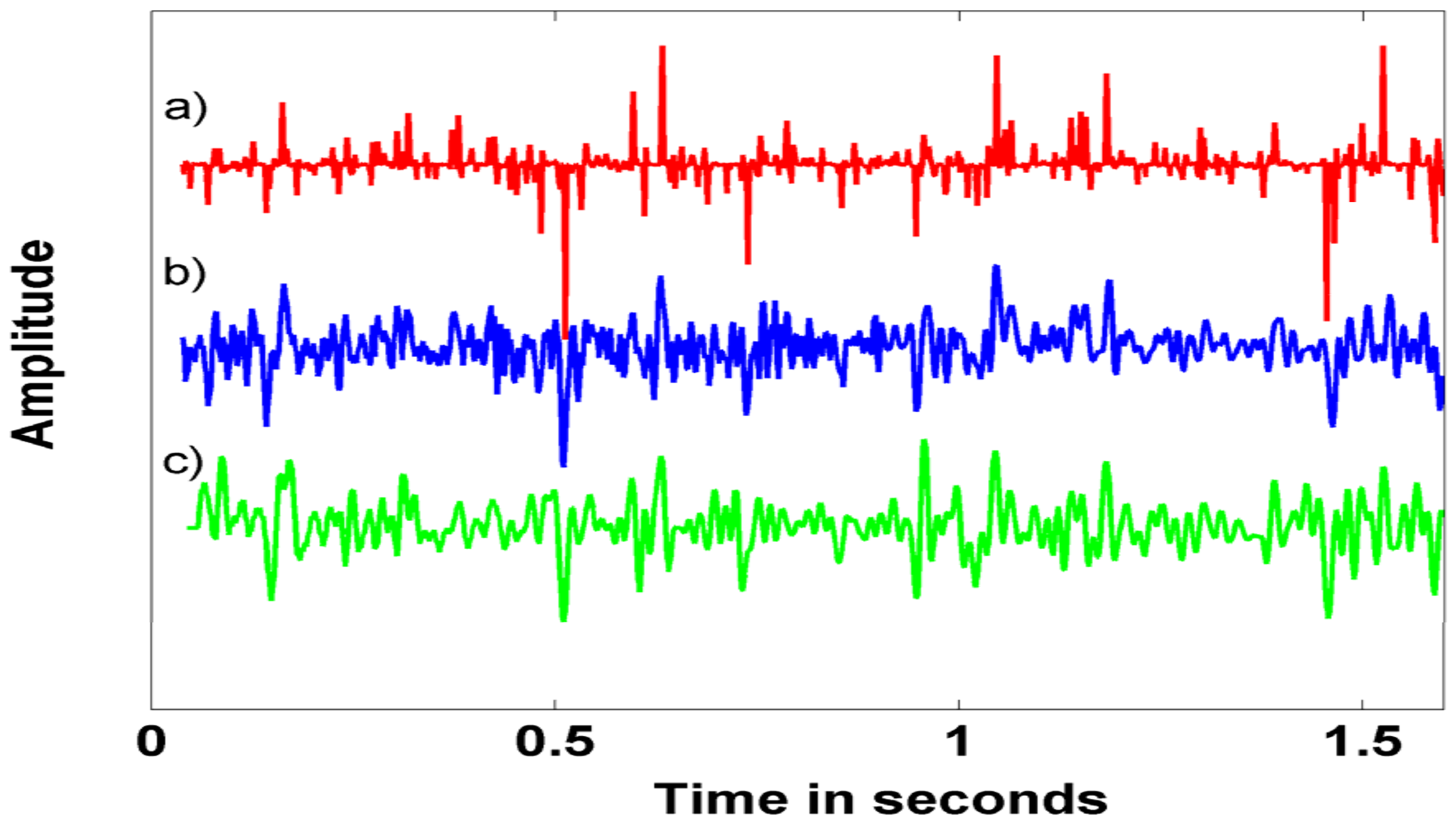
Correlated or sweep-deconvolved Vibroseis trace.

⊗ **Cross-correlation** ⓕ **FDSD**

Comparison of synthetic trace from FDSD and cross-correlation

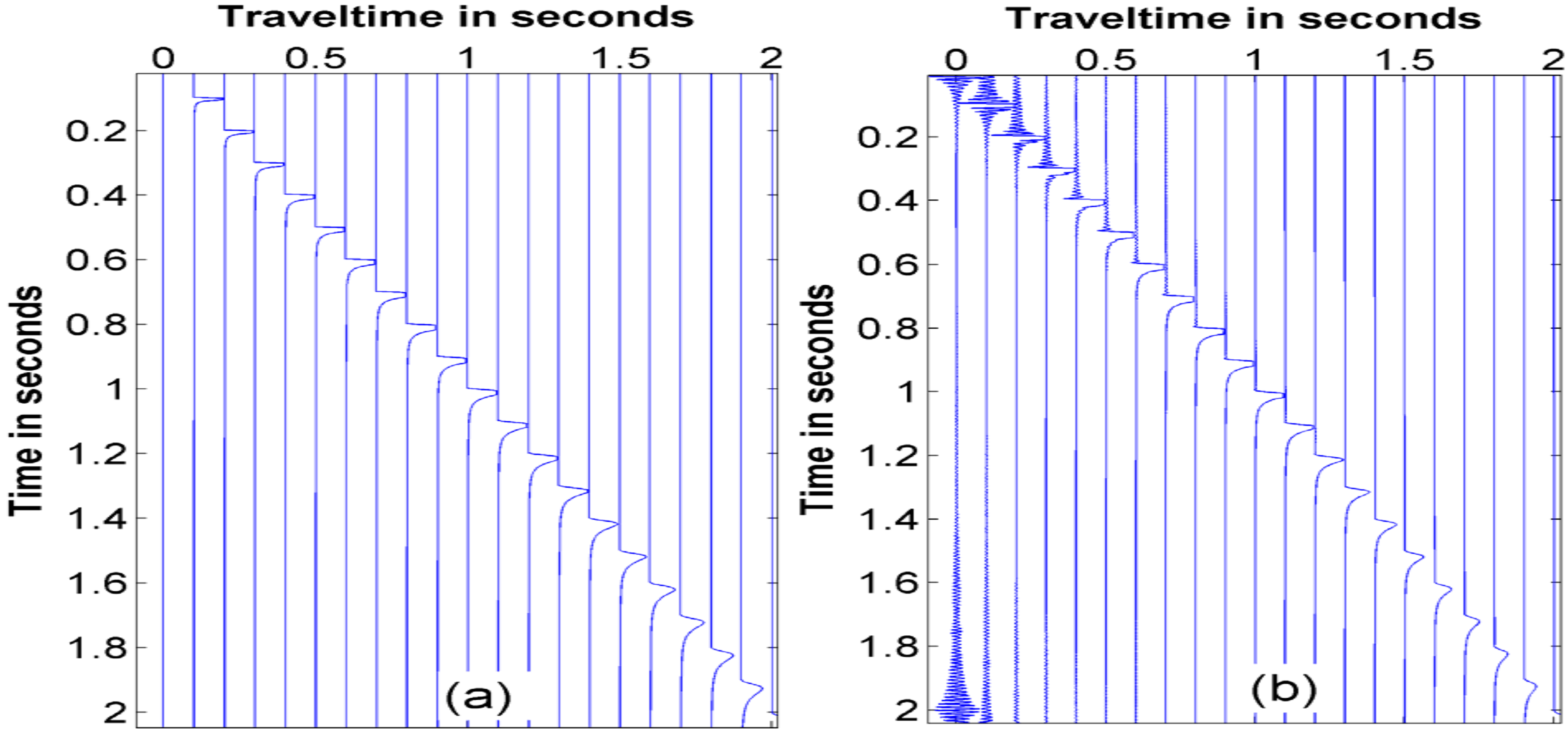


Comparison of deconvolved traces with the input reflectivity



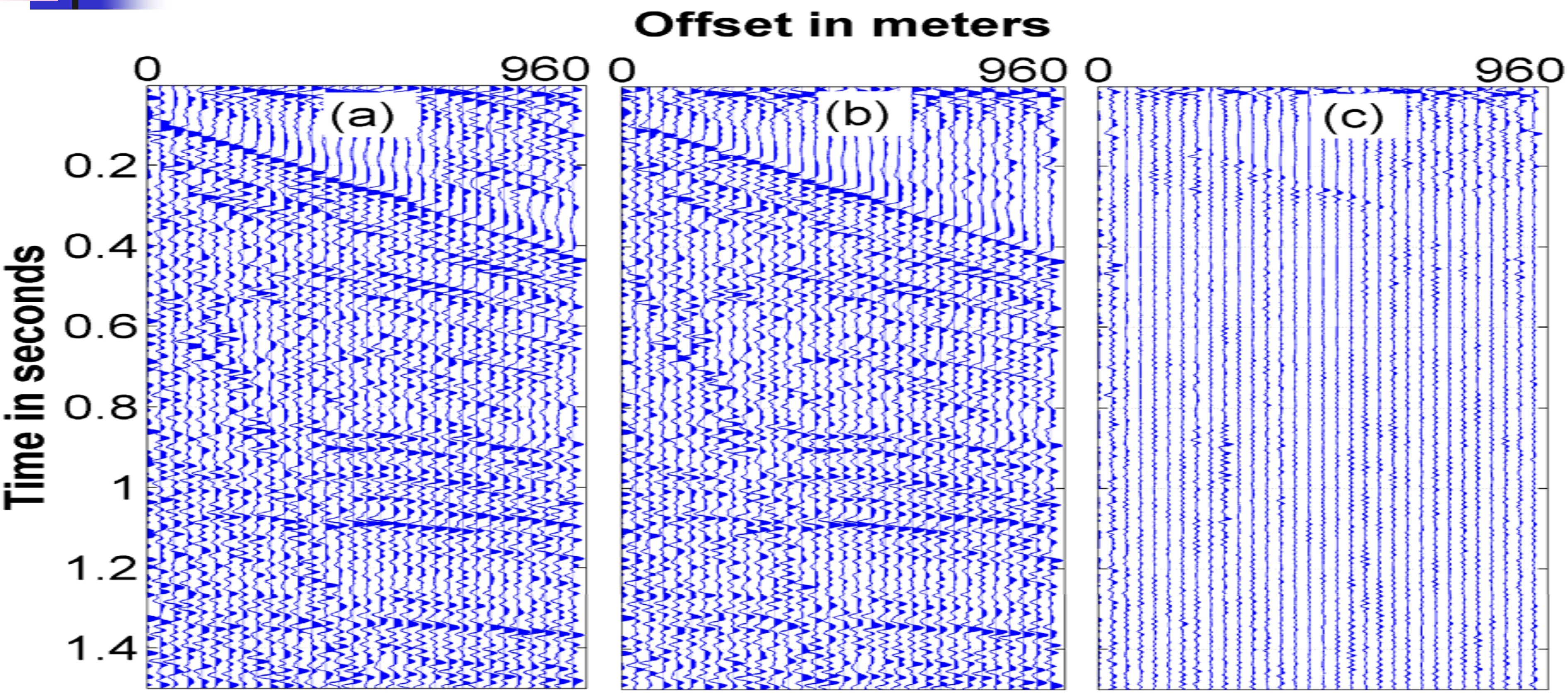
a) Synthetic reflectivity.
b) FDSD+Gabor deconvolution.
c) Cross-correlation +Gabor deconvolution.

Impulse response of Q filter and wavelet estimates from sweep-removed data



(a) Impulse response of the forward Q filter.
(b) Wavelet estimates from sweep-removed data.

FDSD + Gabor deconvolution and Correlation + Gabor deconvolution



(a) The FDSD+ minimum-phase Gabor deconvolution.
(b) The crosscorrelation+ minimum-phase Gabor deconvolution.
(c) The difference.

Discussion

The reason for the effective minimum phase property of Vibroseis wavelet:

- Klauder wavelet is broad band and zero phase
- Minimum-phase attenuation
- Minimum-phase instrument response
- Other minimum phase filters are also involved

Conclusions

- The embedded wavelet found in correlated Vibroseis data is, for practical purposes, effectively minimum phase.
- The broad band Klauder wavelet plays a lesser role in the phase of the wavelet than the other factors with minimum phase property.
- This implies that Vibroseis data does not require a phase correction to agree with the minimum phase assumption in a typical deconvolution algorithm.

Acknowledgements

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Thank you !