Lecture 3: Spectral Content

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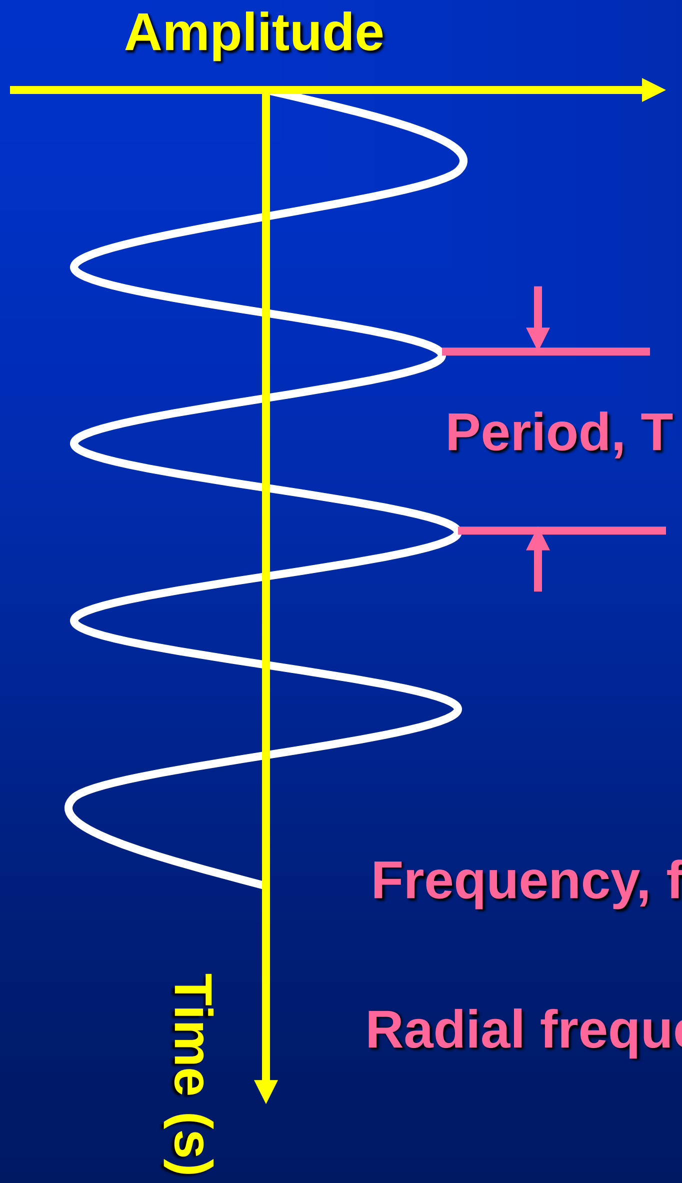
Learner Objectives

After this section, you will be able to:

- Visualize time- and space-variant signals in terms of their spectral components
- Be able to describe the impact of low-pass, high-pass, and band-pass filtering
- Evaluate strong, constructive interference from thin beds in terms of tuning thickness

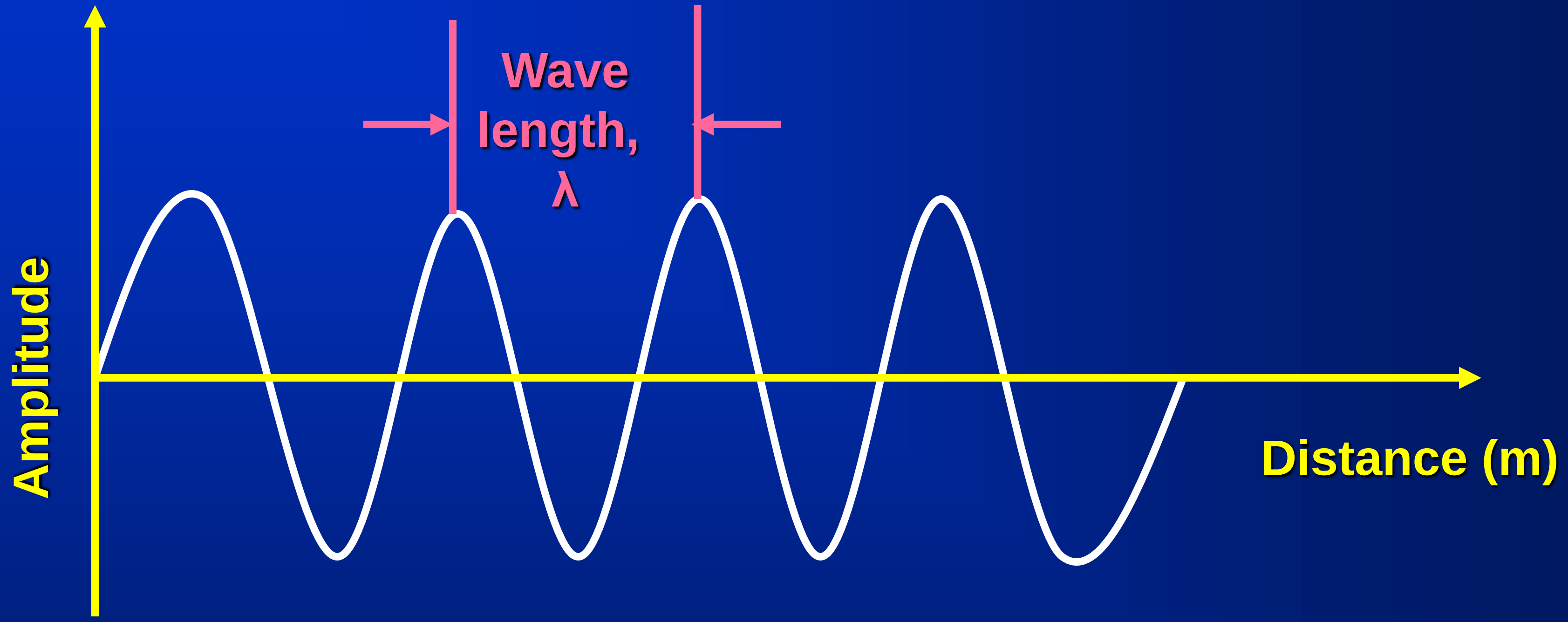
Periodic vibrations (in time)



Frequency, $f=1/T$ (measured in Hz)

Radial frequency, $\omega=2\pi f=2\pi/T$ (measured in radians/s)

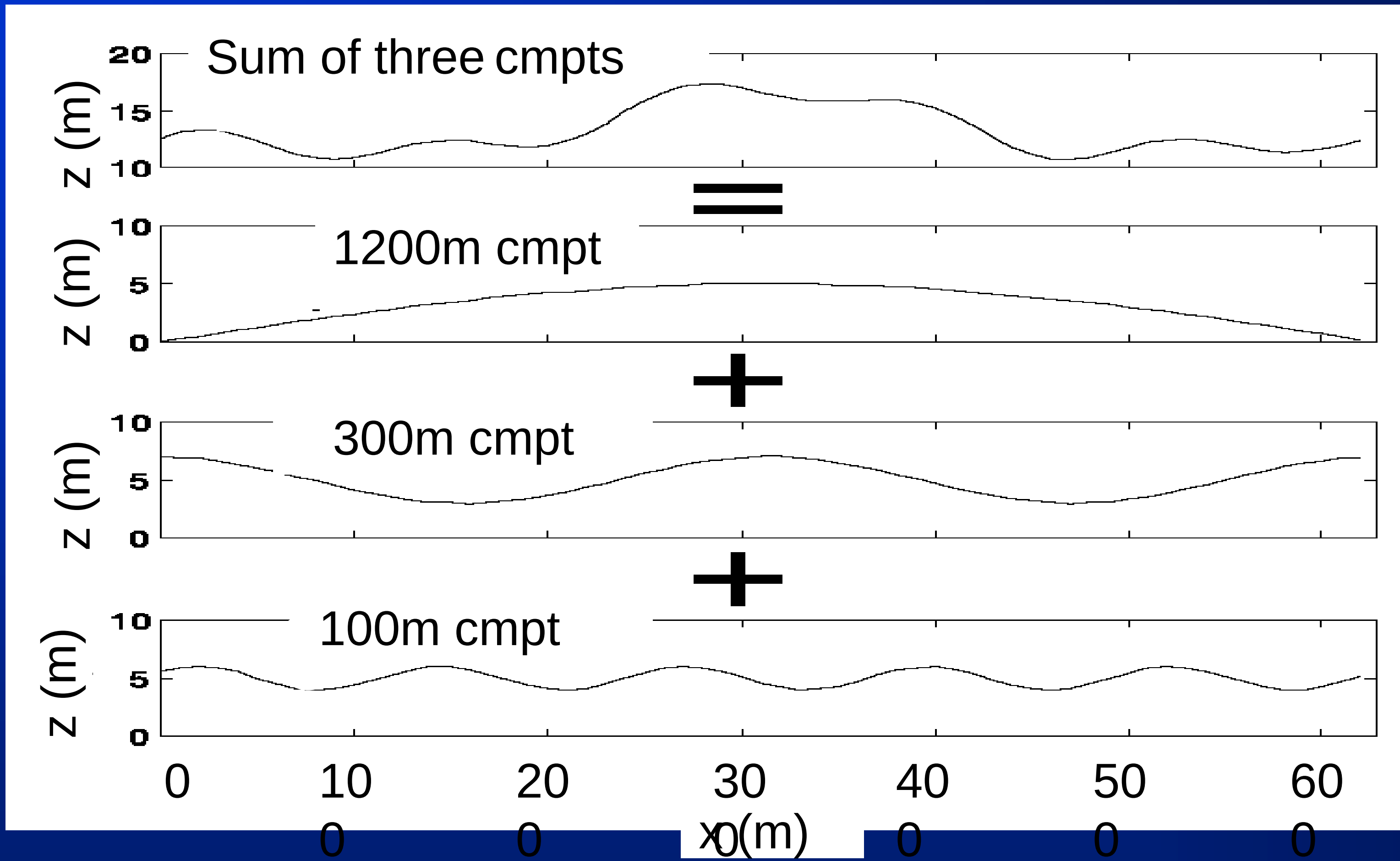
Periodic vibrations (in space)



Radial frequency, $\omega=2\pi /T$ (measured in Hz)

Wavenumber, $k=2\pi /\lambda$ (measured in radians/m)

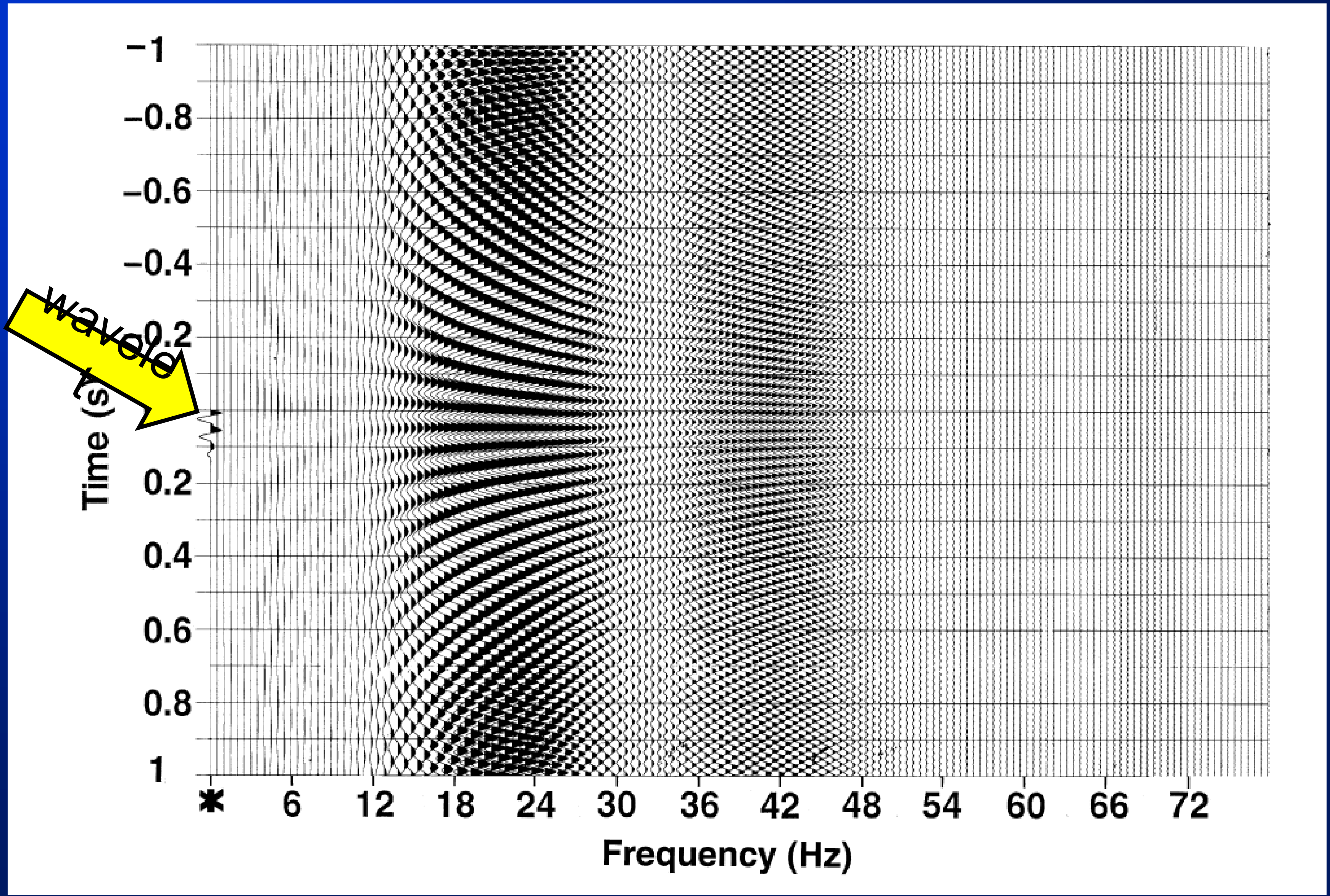
Spectral analysis of topography



Any function can be decomposed into sinusoids of different amplitude, phase, and frequency.

(Bergbauer et al, 2003)

Spectral analysis of a seismic wavelet



(Yilmaz, 2001)

Forward Fourier Transforms

$$D_c(\omega) = \sum_{t=-T}^{T} d_{even}(t)\cos(\omega t) =$$

Fourier cosine transform

$$D_s(\omega) = \sum_{t=0}^{T} d_{odd}(t)\sin(\omega t)$$

Fourier sine transform

$$D(\omega) = \sum_{t=0}^{T} d(t)\exp(+i\omega t)$$

Complex Fourier transform

$$D(\omega) = D_c(\omega) + iD_s(\omega)$$

Inverse Fourier Transforms

$$d_{even}(t) = \sum_{\omega=0}^{\omega_{\max}} D_c(\omega)\cos(\omega t)$$

Fourier cosine transform

$$d_{odd}(t) = -\sum_{\omega=0}^{\omega_{\max}} D_s(\omega)\sin(\omega t)$$

Fourier sine transform

$$d(t) = \sum_{\omega=0}^{\omega_{\max}} D(\omega)\exp(-i\omega t)$$

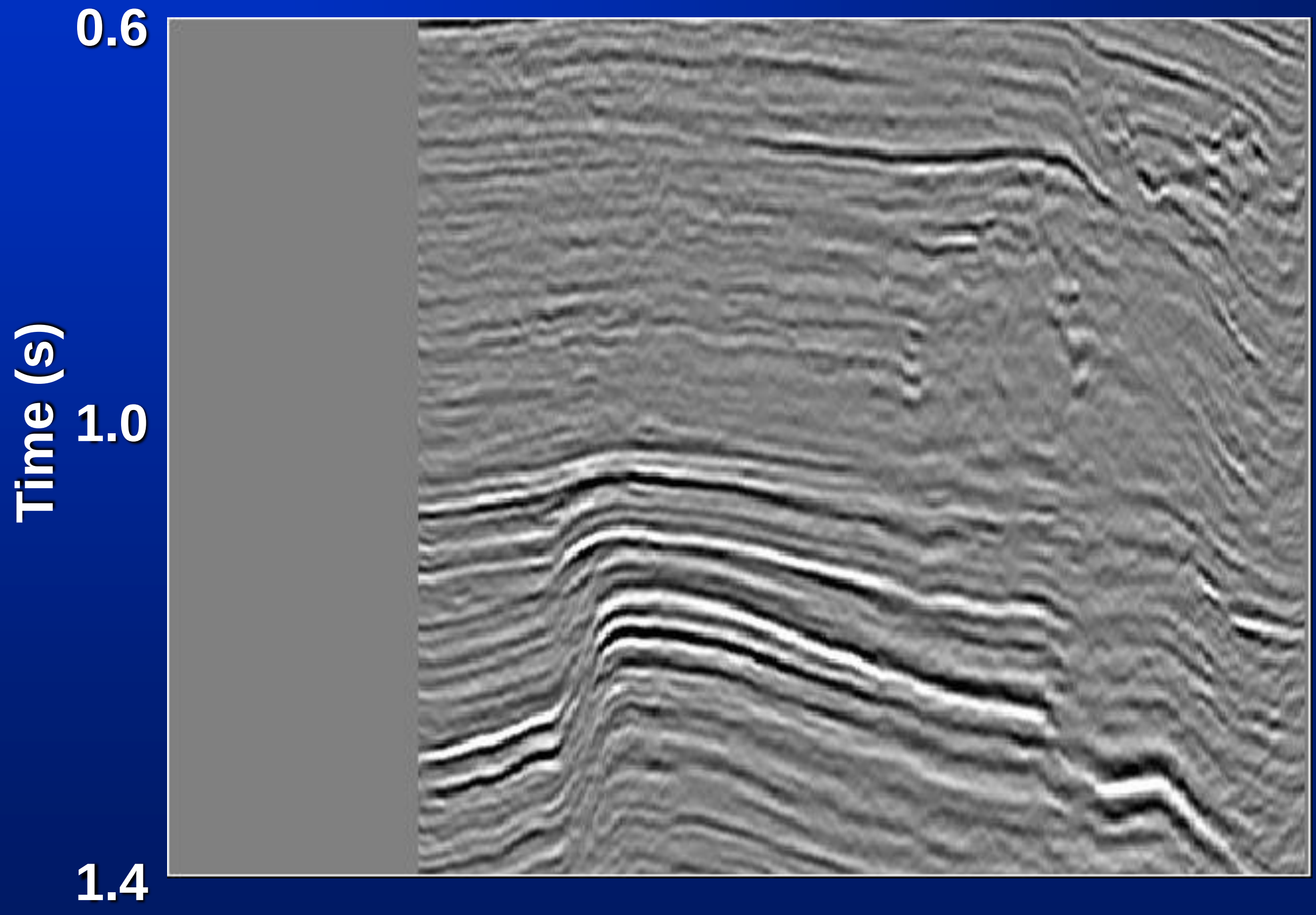
Complex Fourier transform

$$d(t) = d_{even}(t) + d_{odd}(t)$$

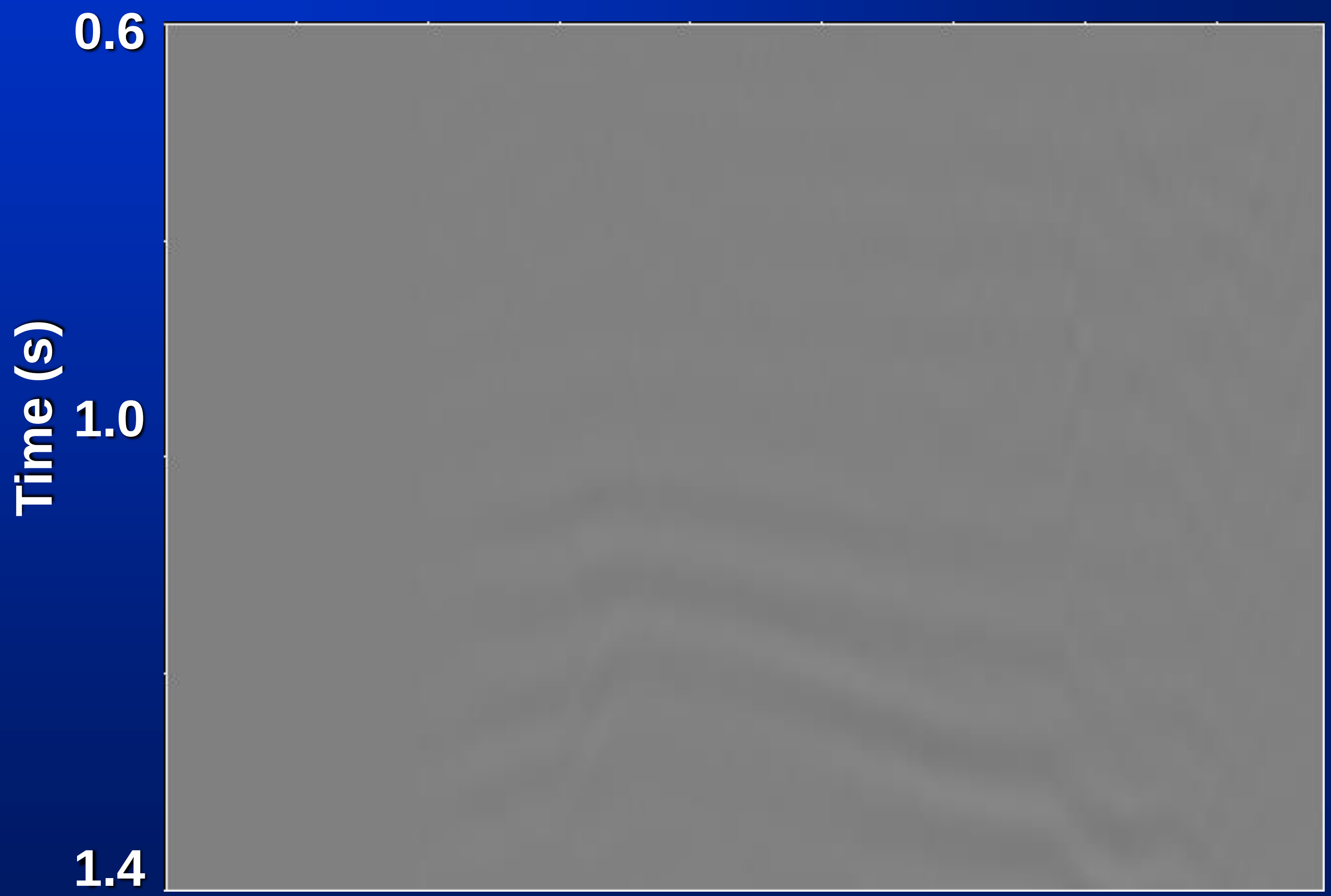
Wavelength

$$\lambda = \frac{v}{f} = \frac{10000\text{ft/s}}{50\text{/s}} = 200\text{f}t$$

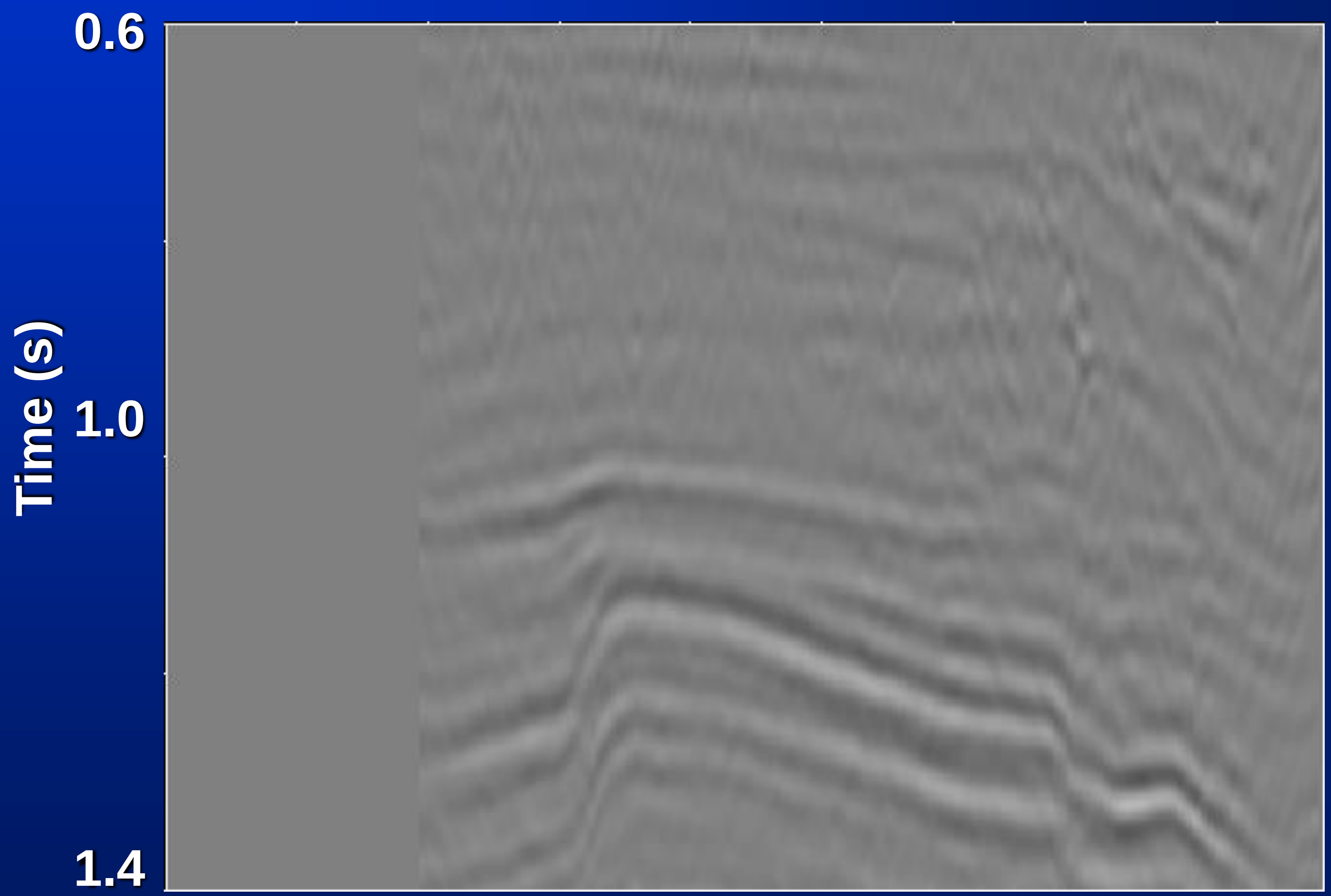
Original data (west Texas)



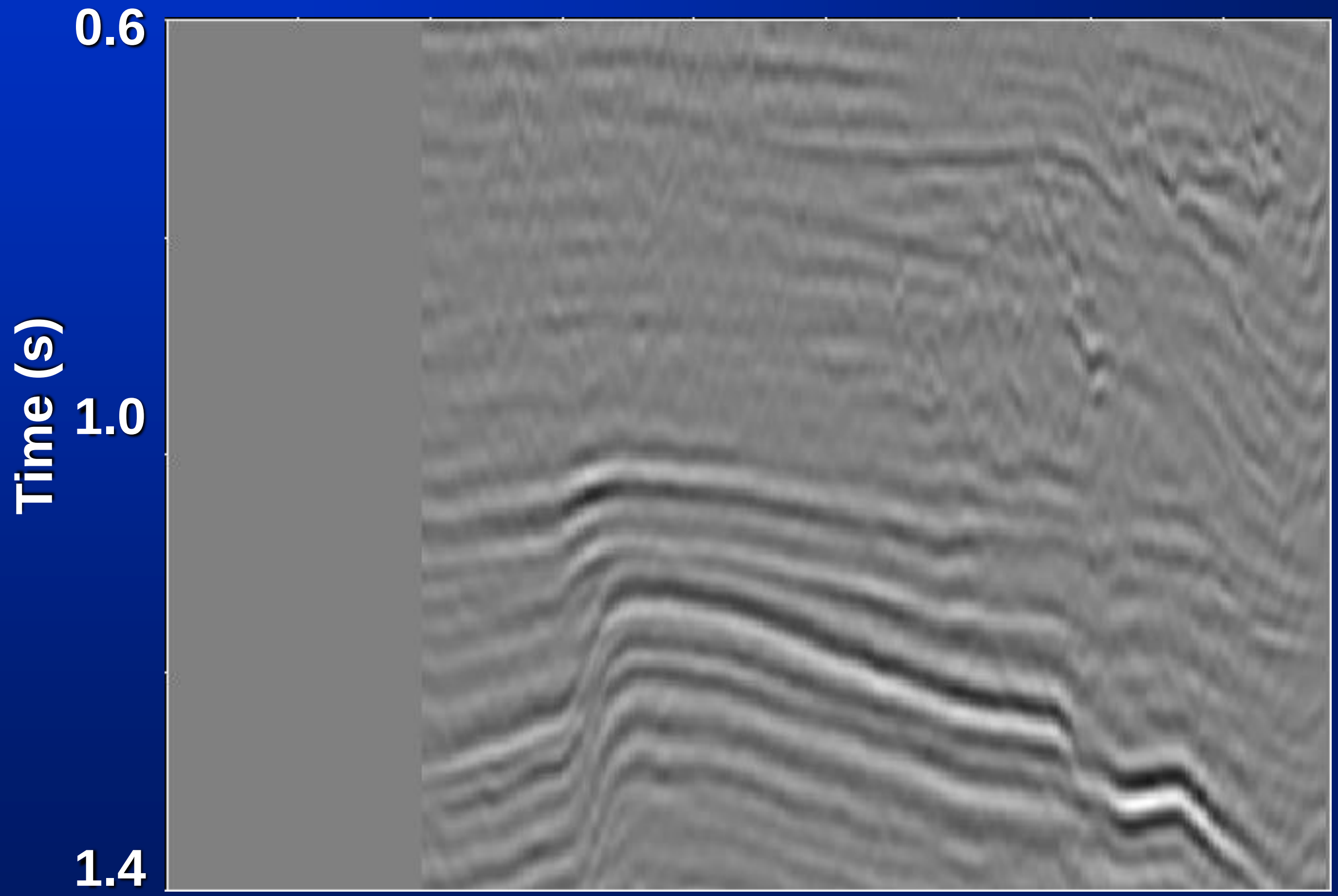
Low-pass filter (f_{high}=10 Hz)



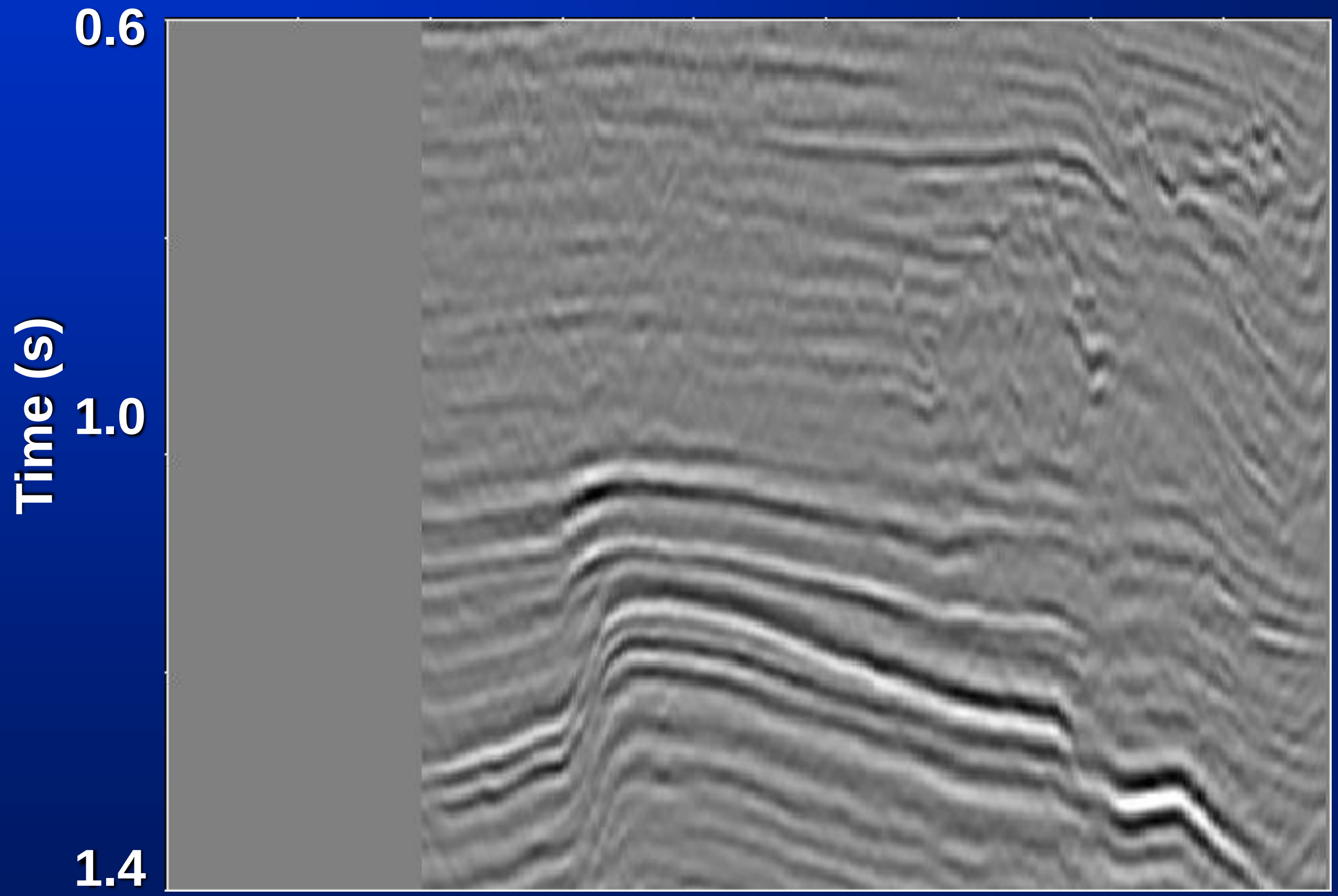
Low-pass filter (f_{high}=20 Hz)



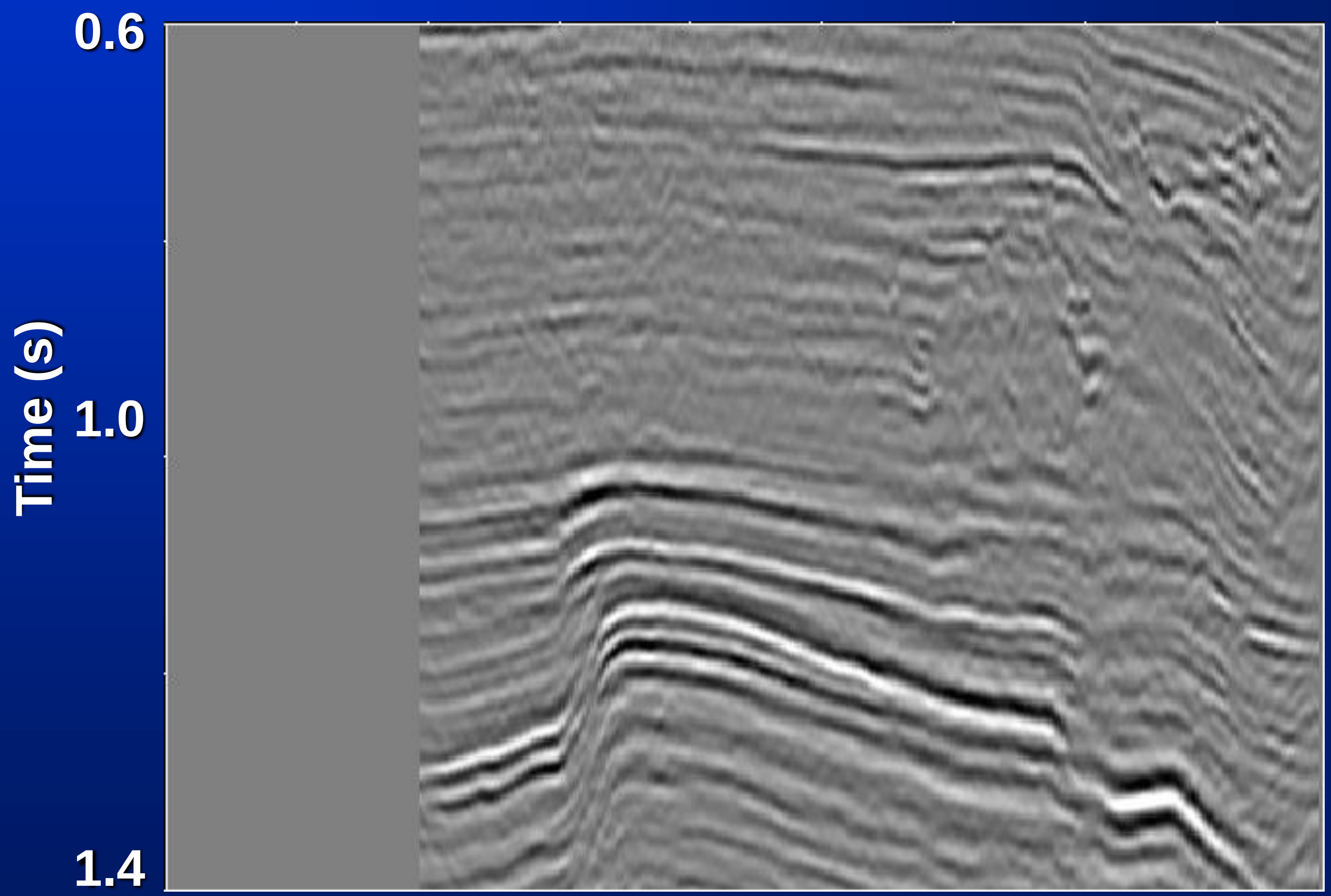
Low-pass filter (f_{high}=30 Hz)



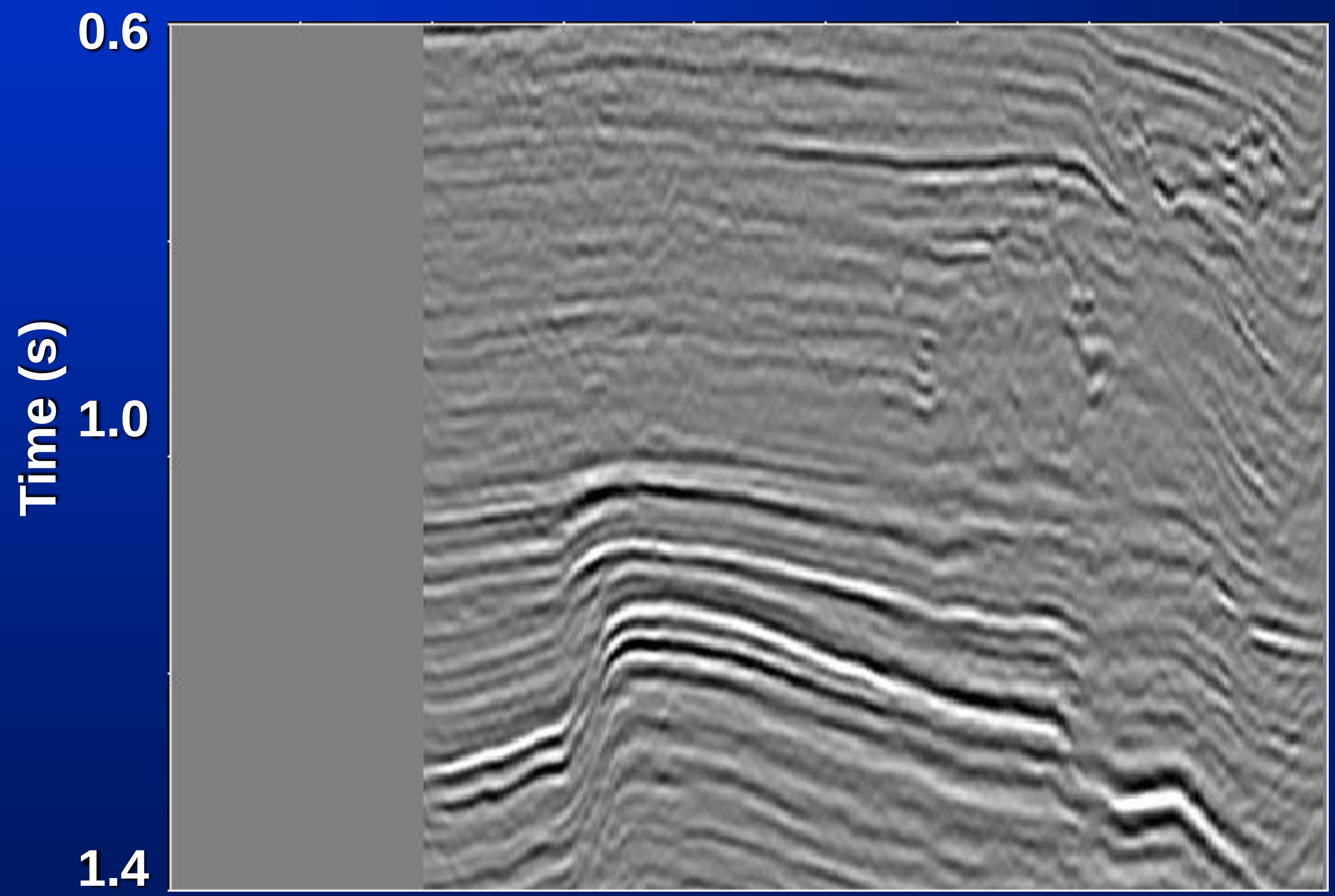
Low-pass filter (f_{high}=40 Hz)



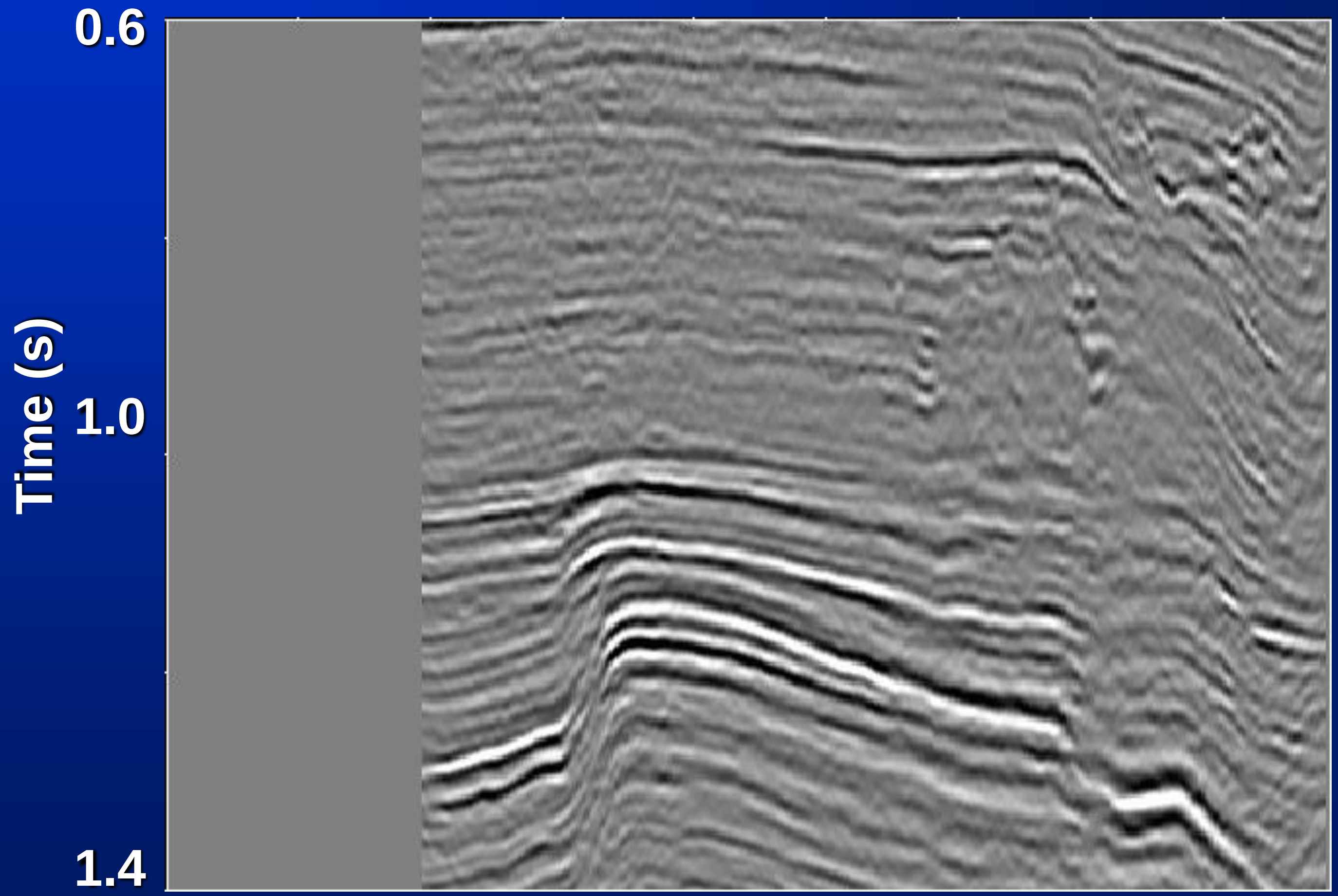
Low-pass filter (f_{high}=50 Hz)



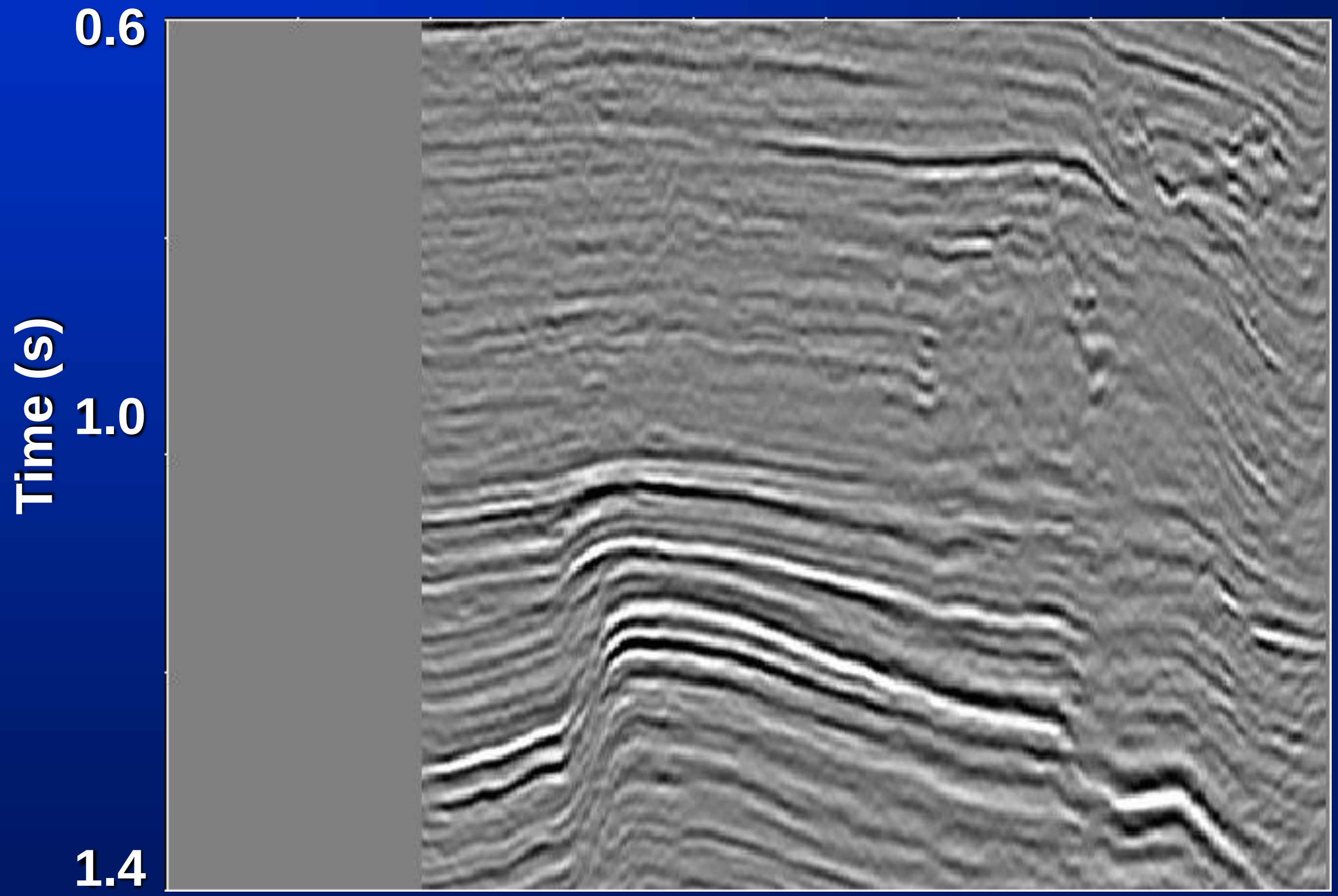
Low-pass filter (f_{high}=60 Hz)



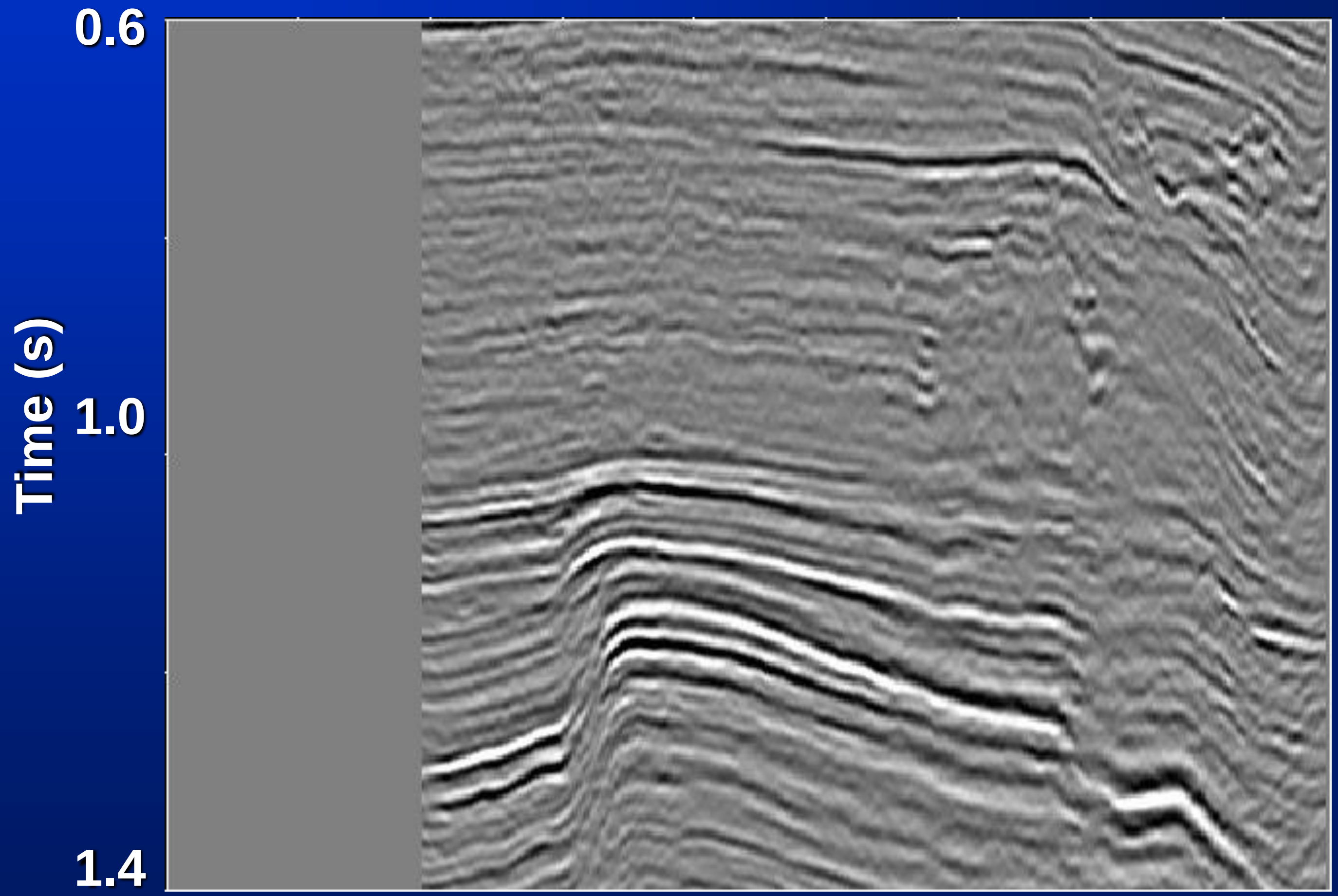
Low-pass filter (f_{high}=70 Hz)



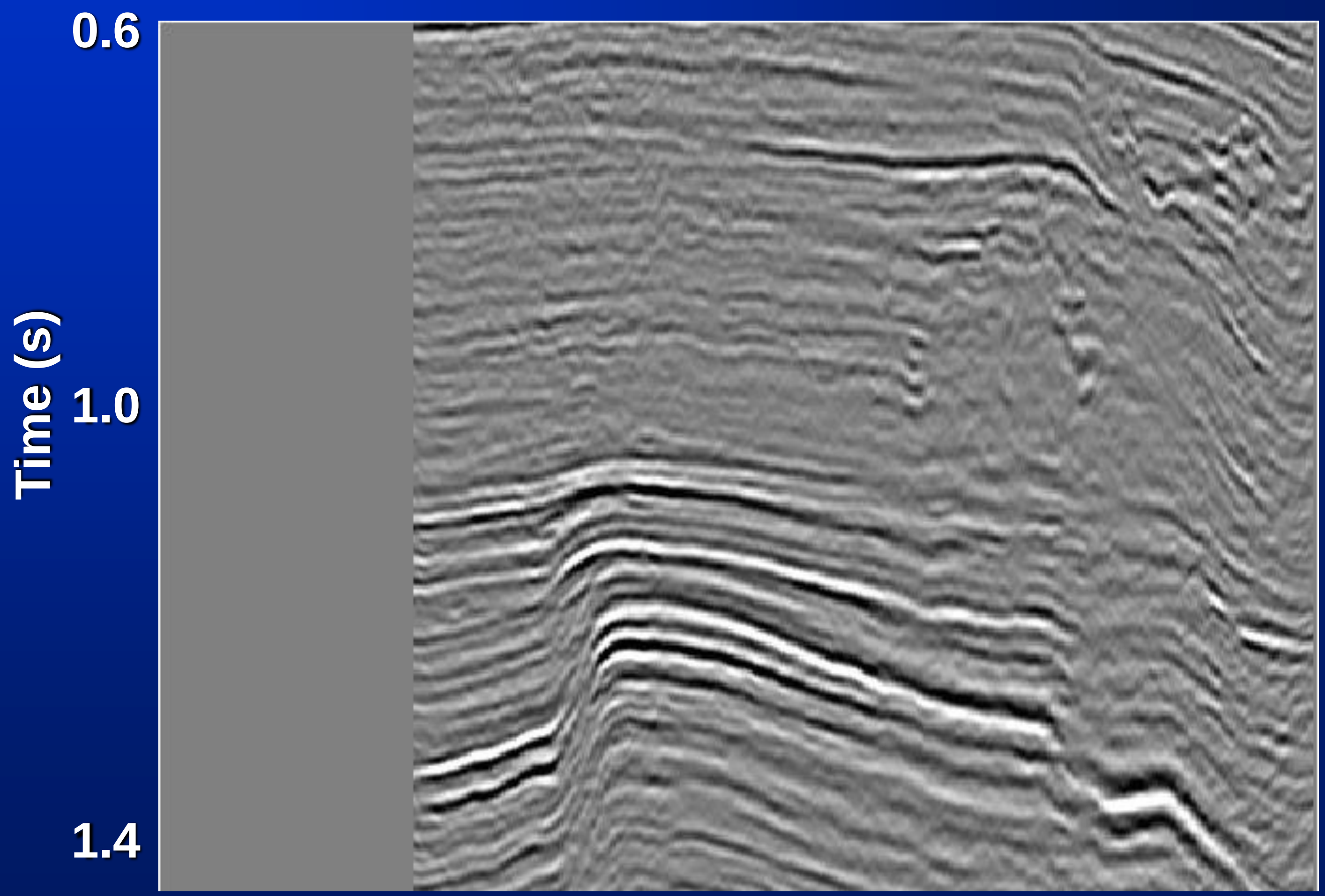
Low-pass filter (f_{high}=80 Hz)



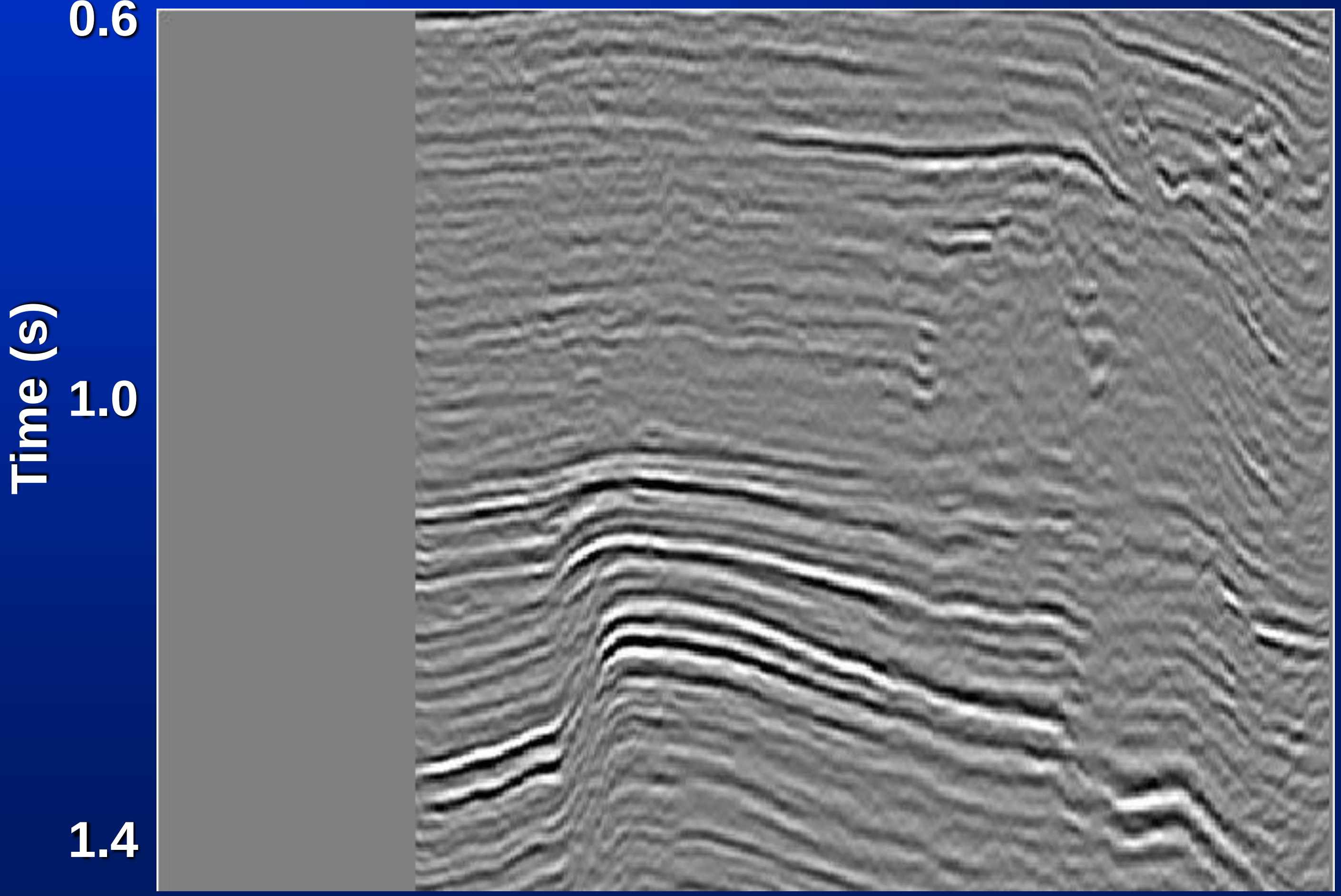
Low-pass filter (f_{high}=90 Hz)



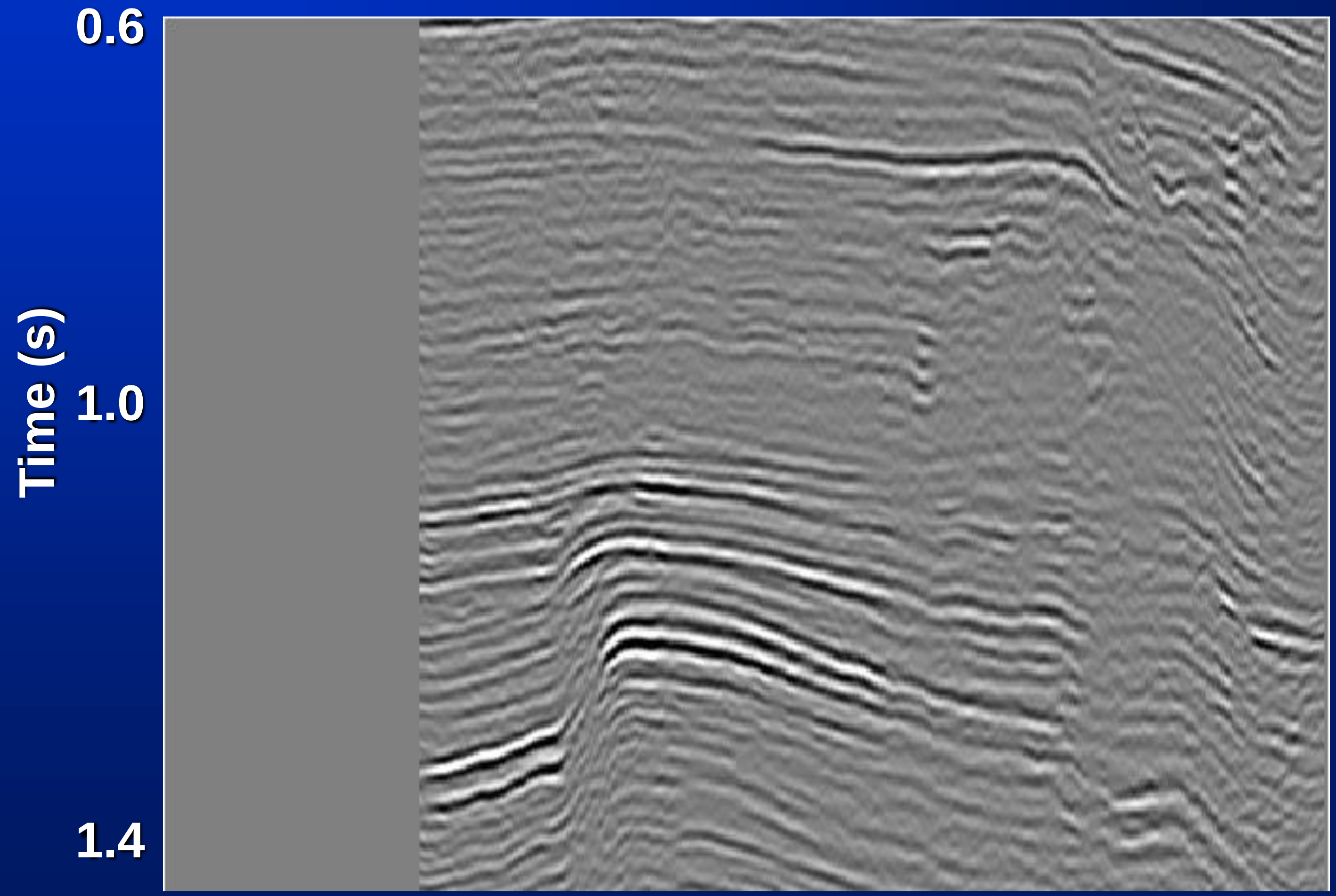
High-pass filter (f_{low}=10 Hz)



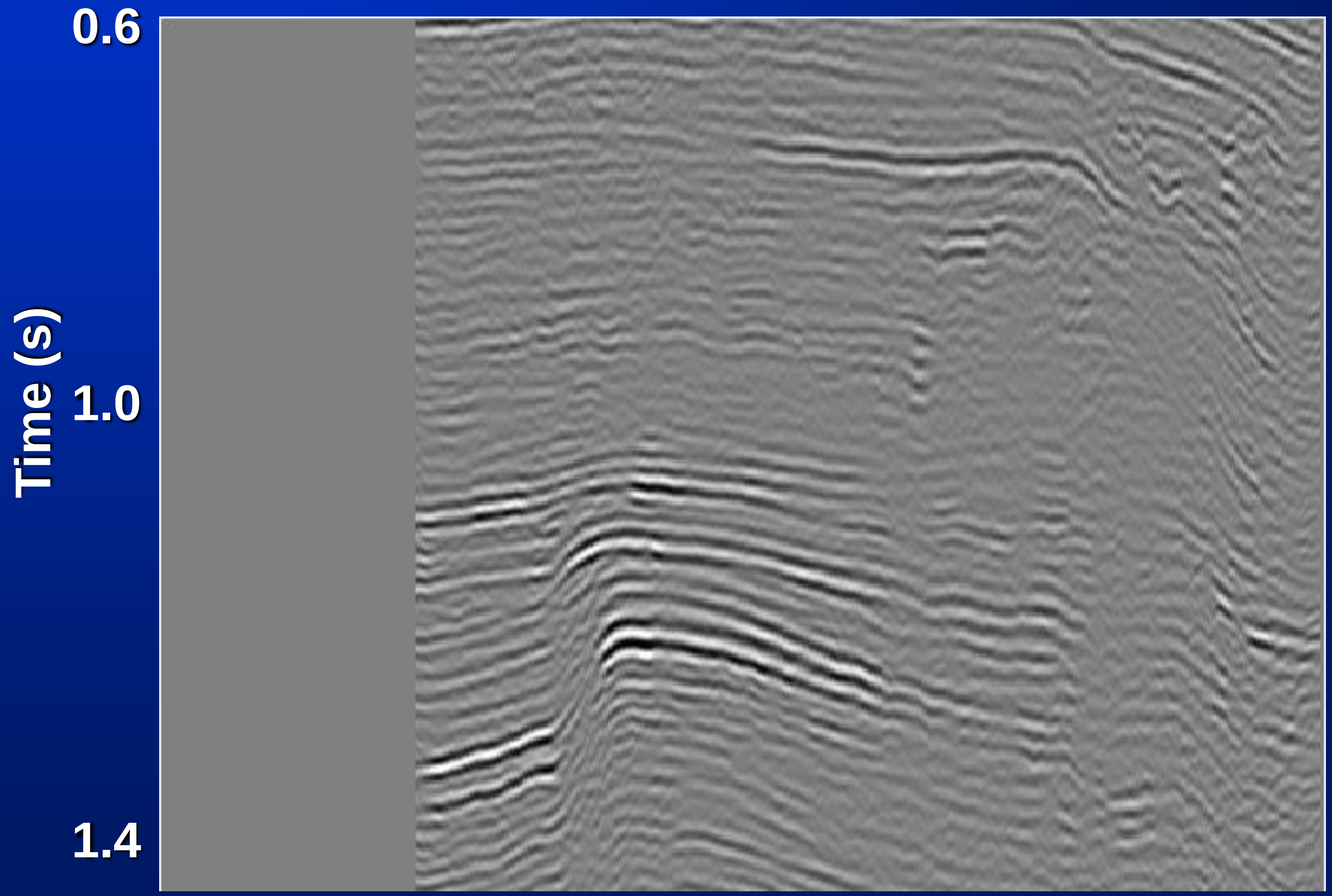
High-pass filter (f_{low}=20 Hz)



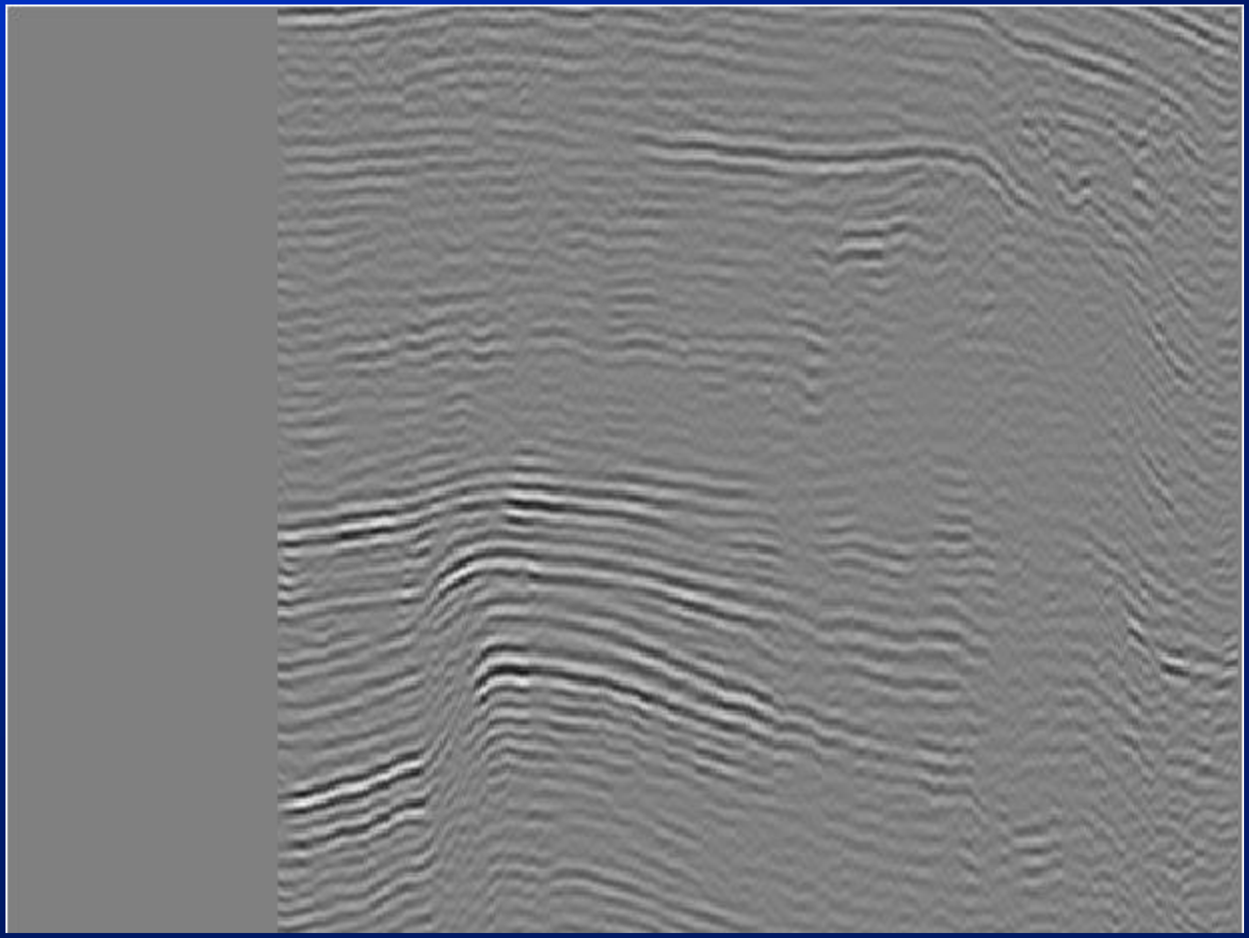
High-pass filter (f_{low}=30 Hz)



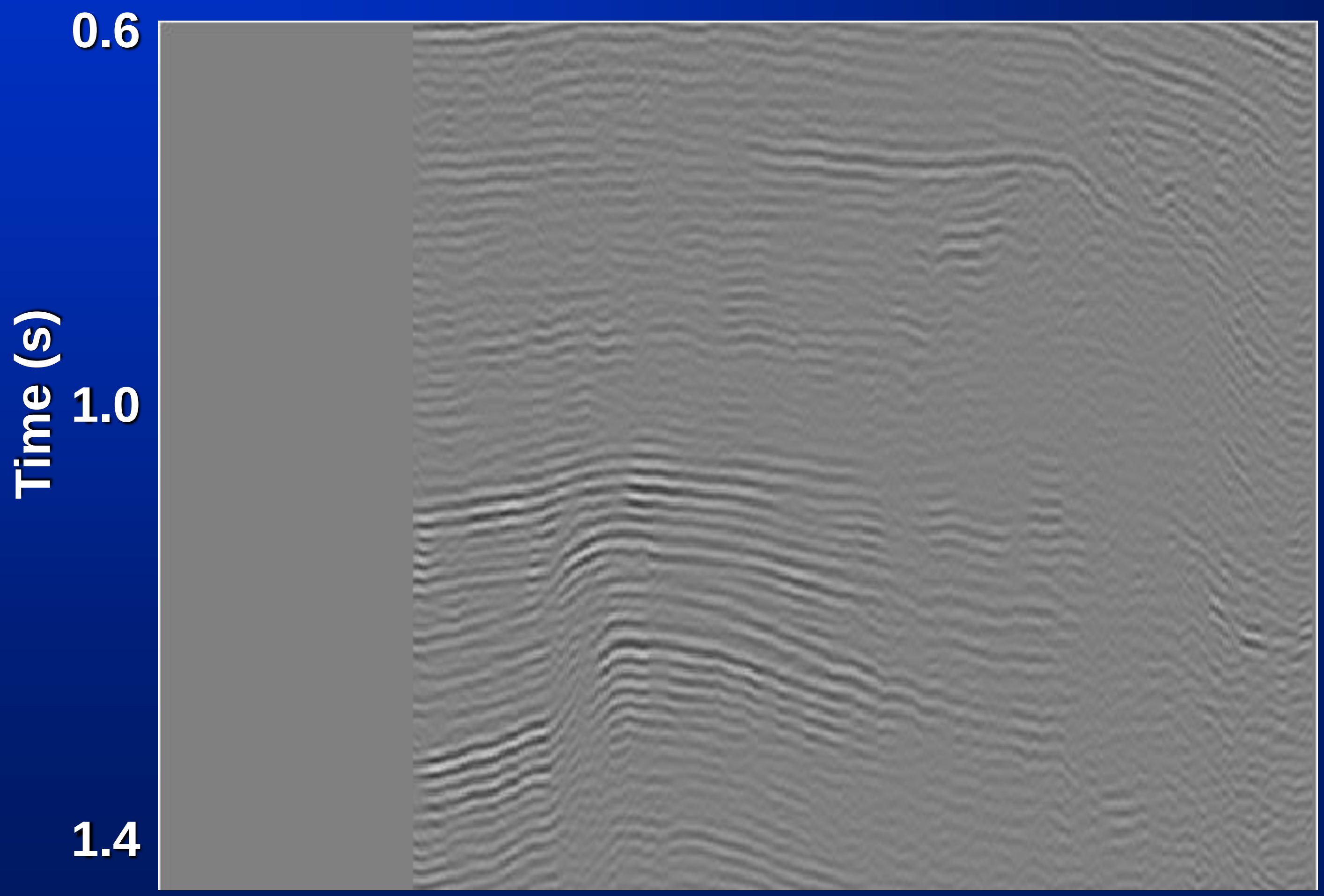
High-pass filter (f_{low}=40 Hz)



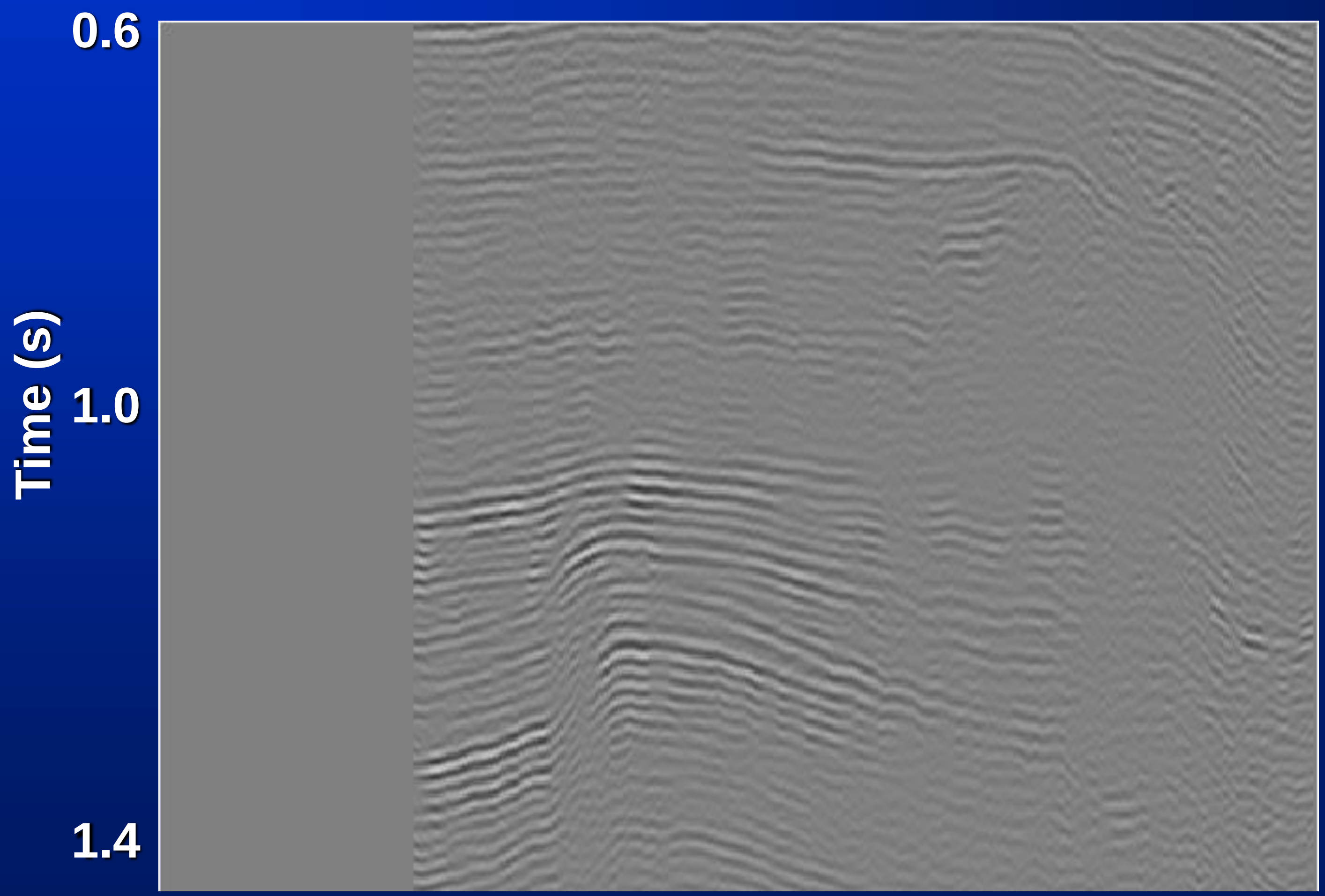
High-pass filter (f_{low}=50 Hz)



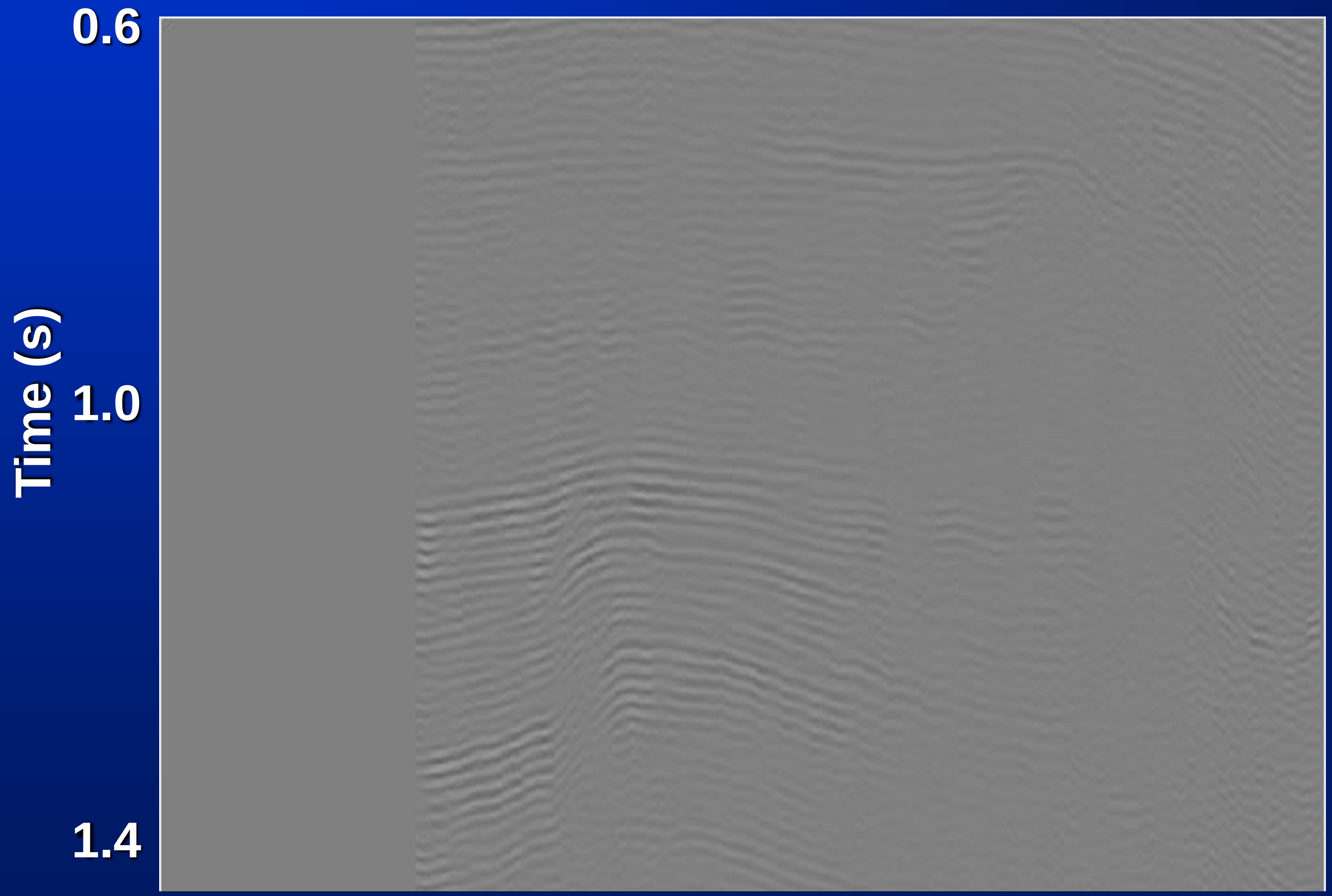
High-pass filter (f_{low}=60 Hz)



High-pass filter (f_{low}=70 Hz)

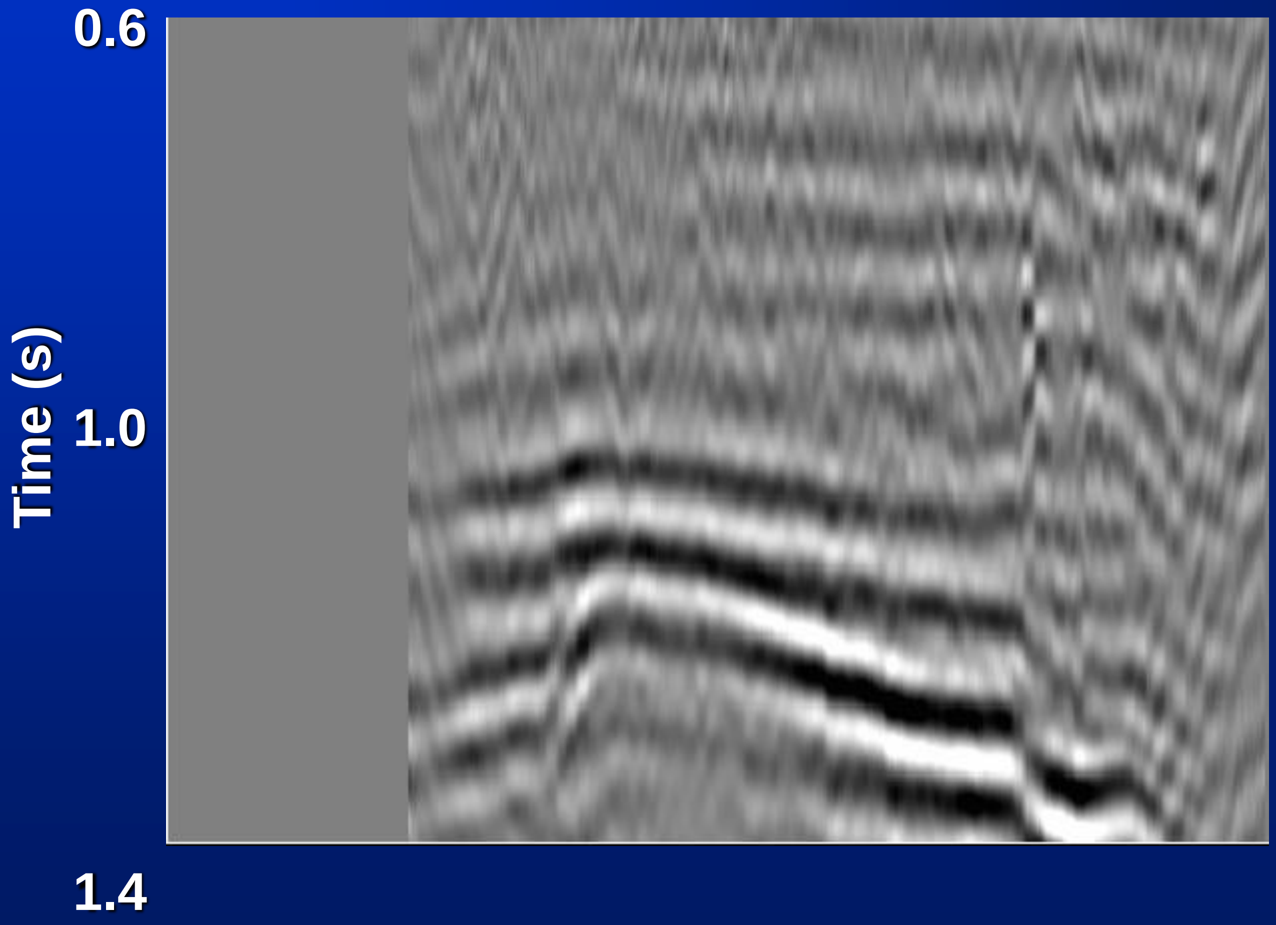


High-pass filter (f_{low}=80 Hz)

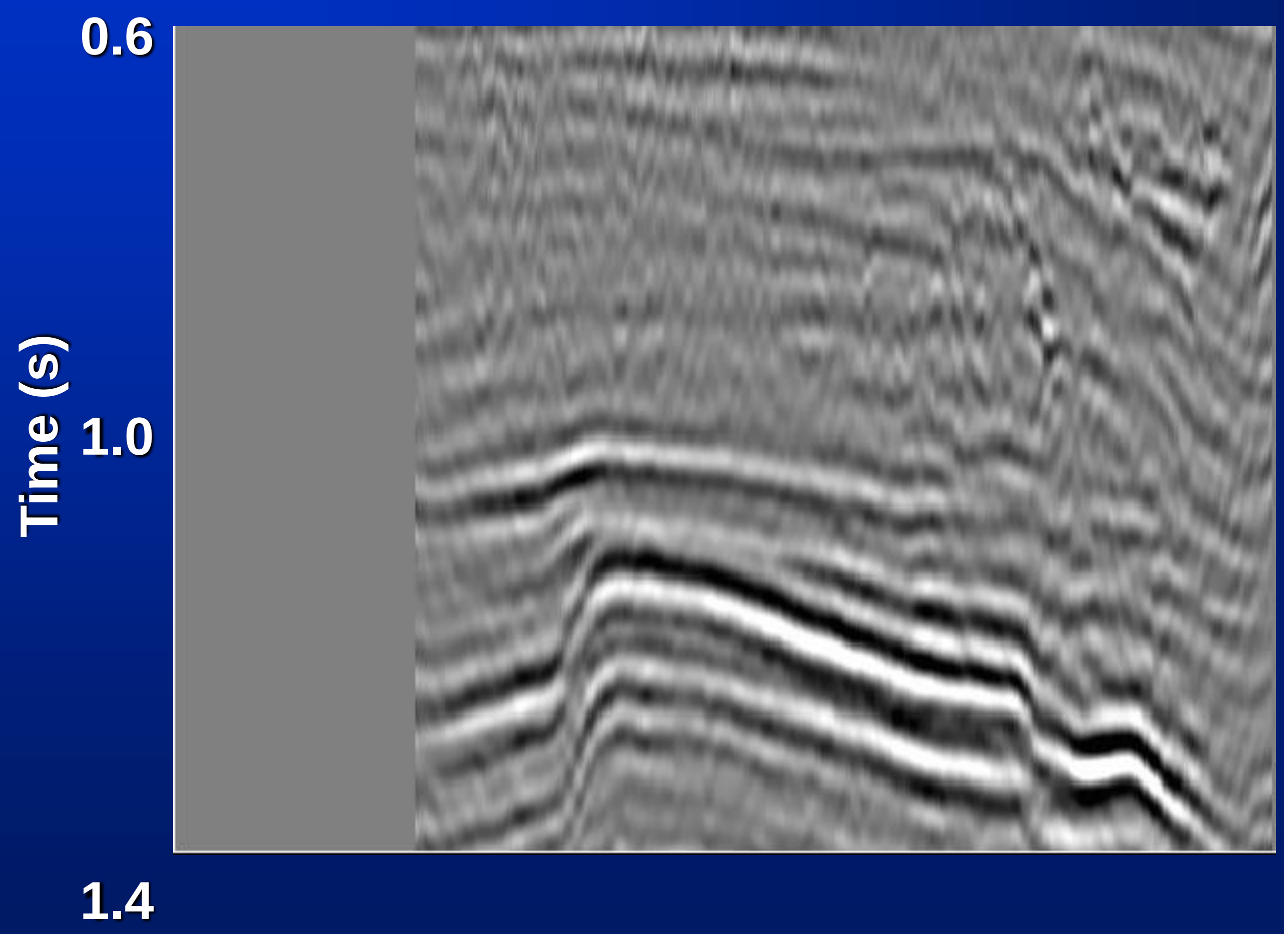


High-pass filter (f_{low}=90 Hz)

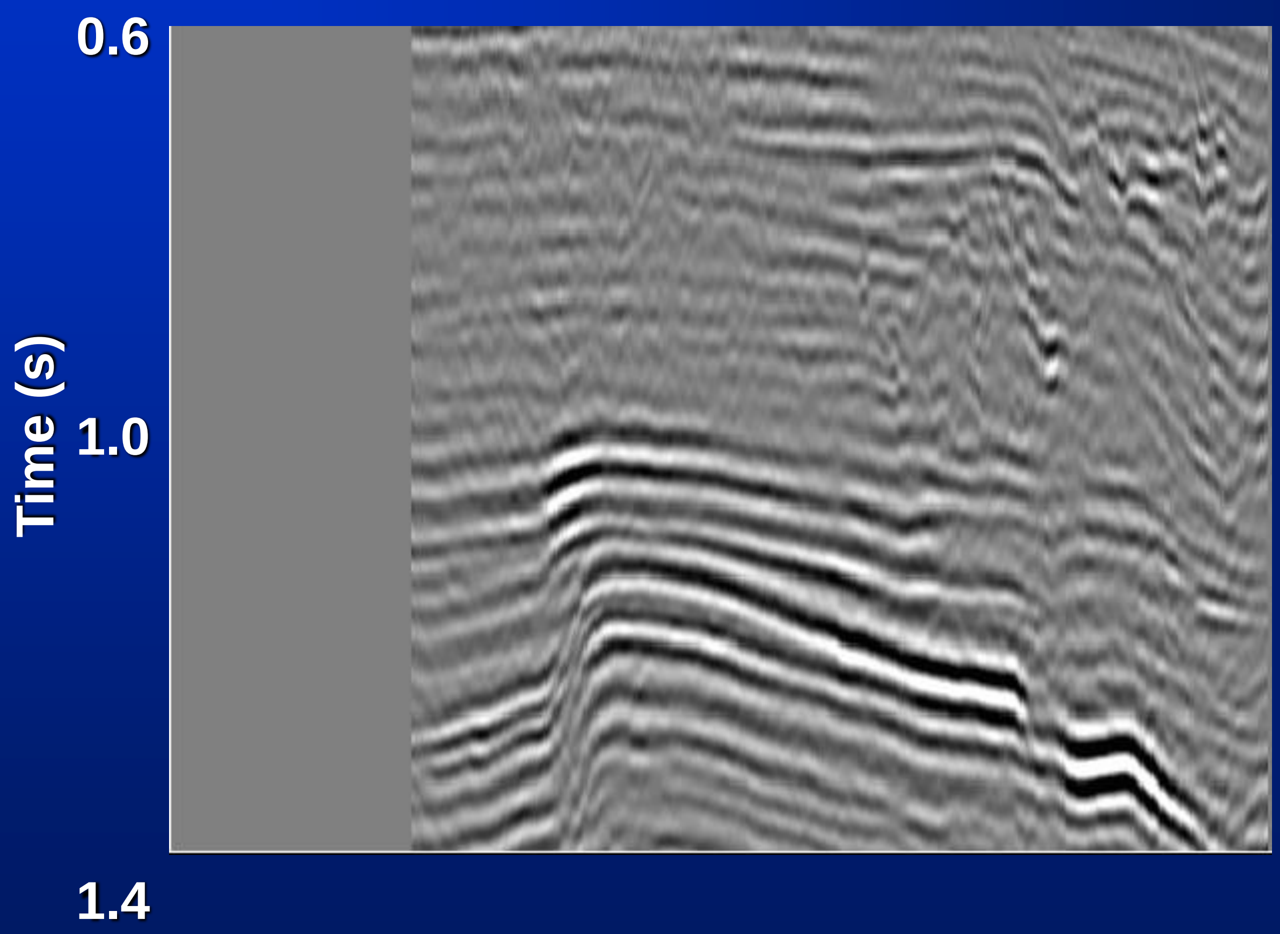
Band-pass filter (0-10 Hz)



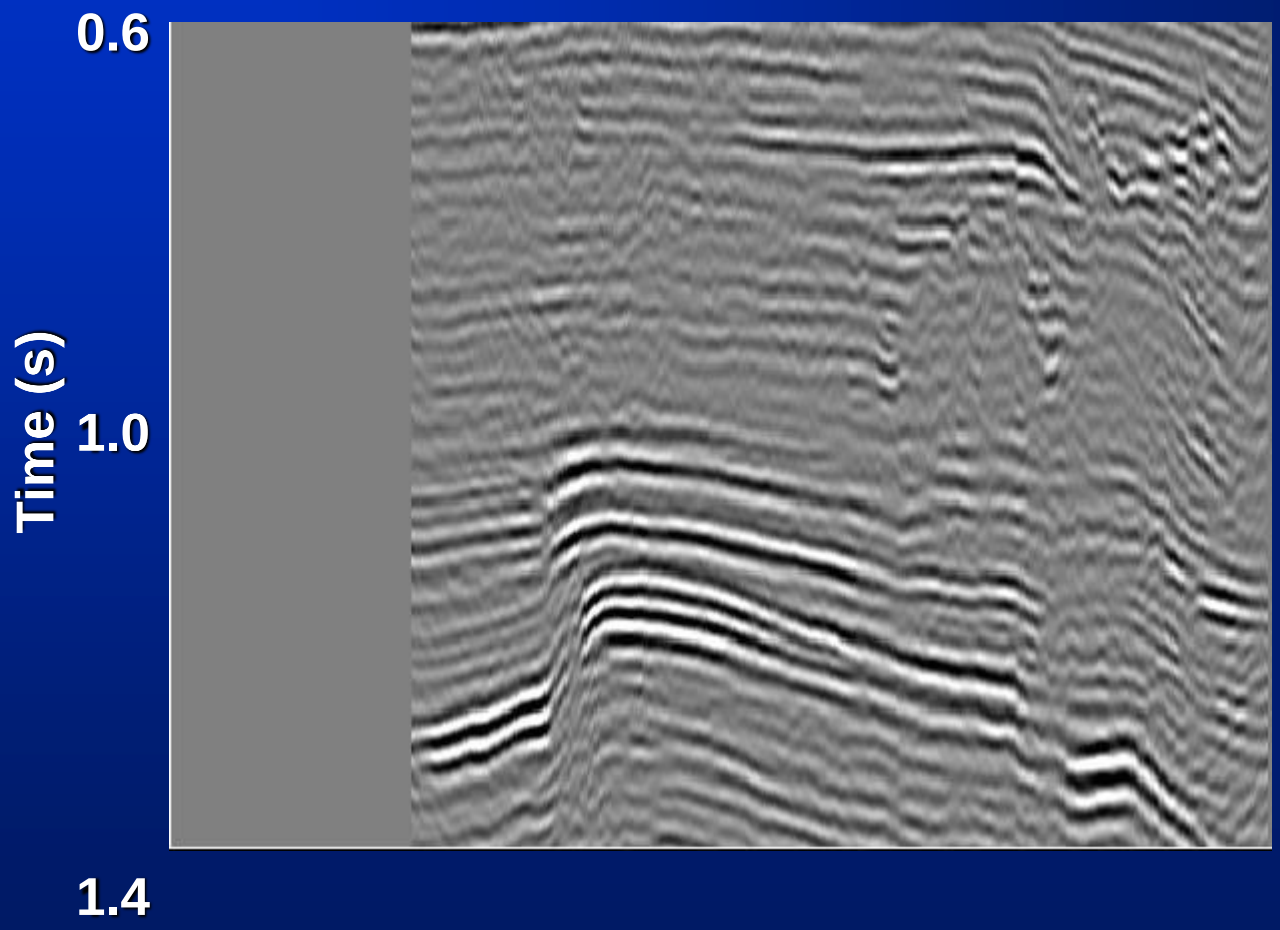
Band-pass filter (10-20 Hz)



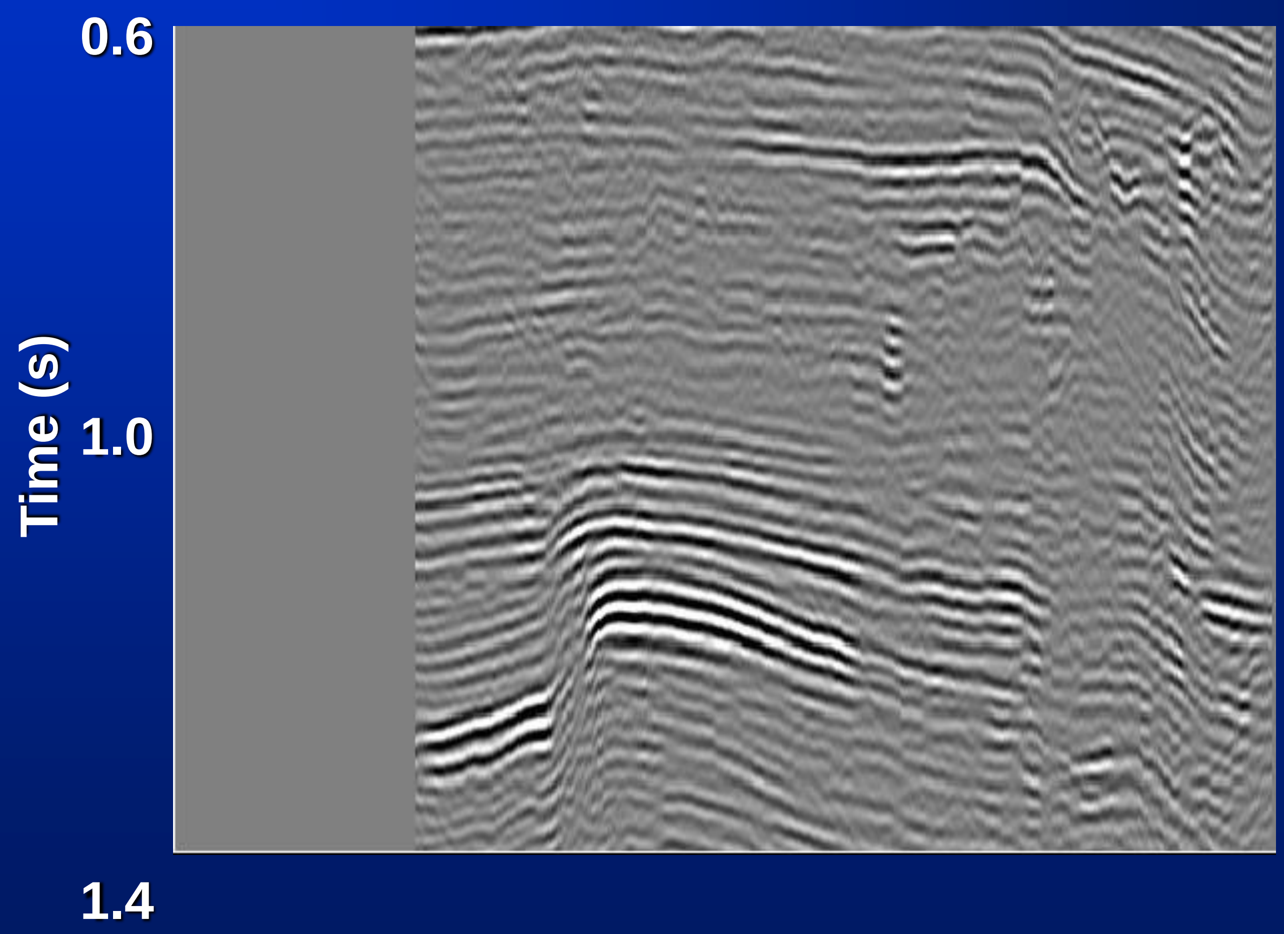
Band-pass filter (30-40 Hz)



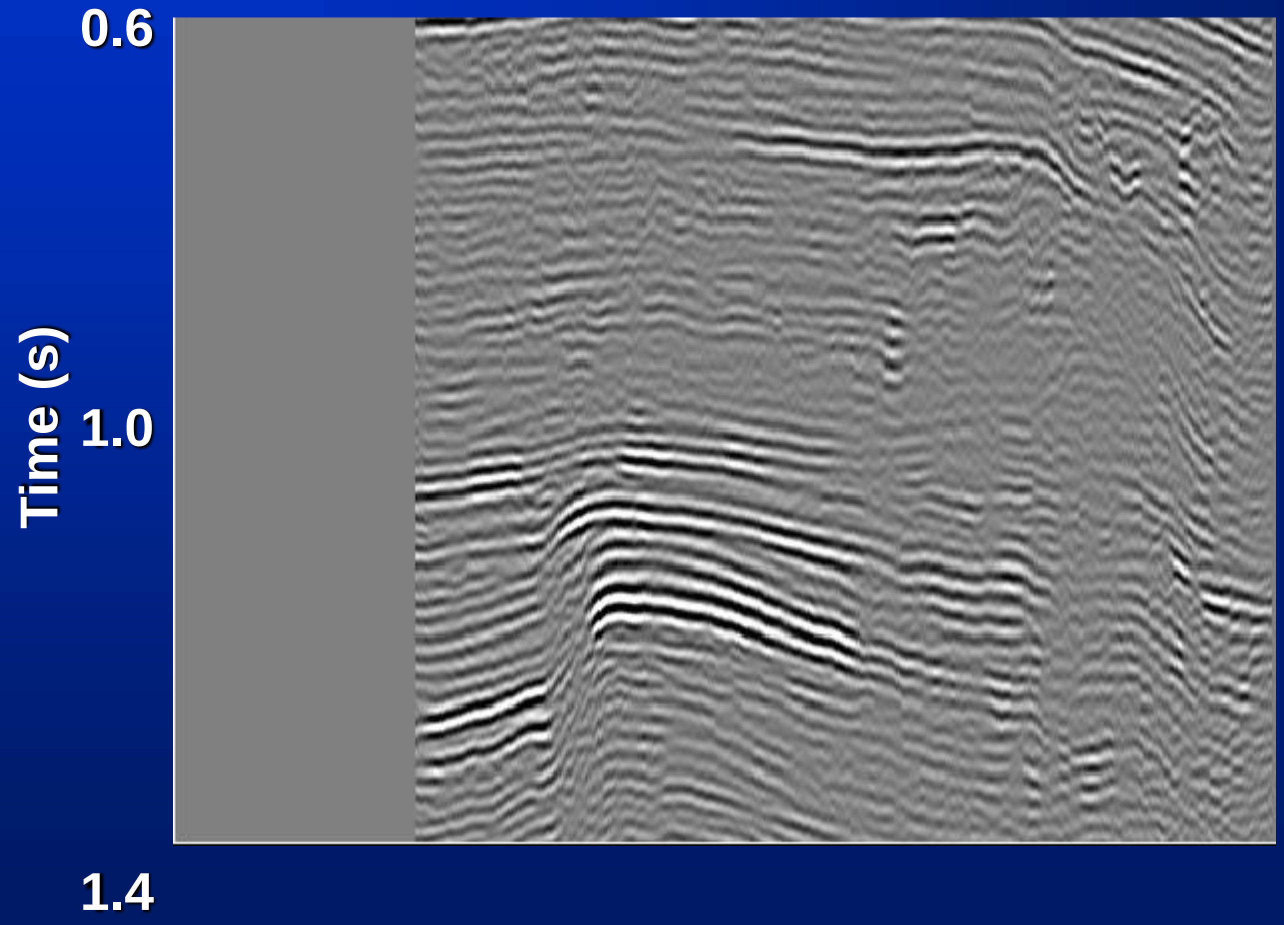
Band-pass filter (40-50 Hz)



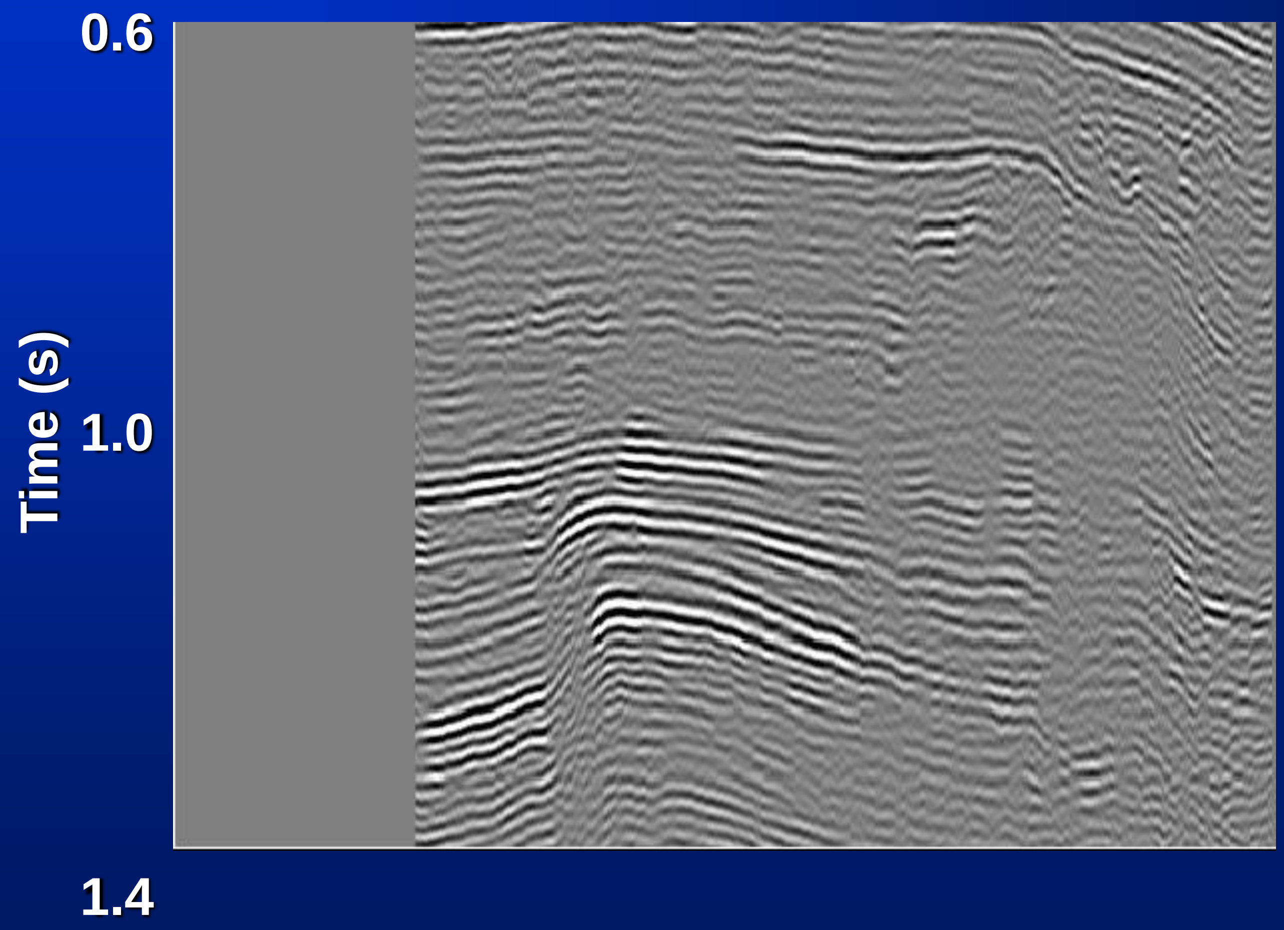
Band-pass filter (50-60 Hz)



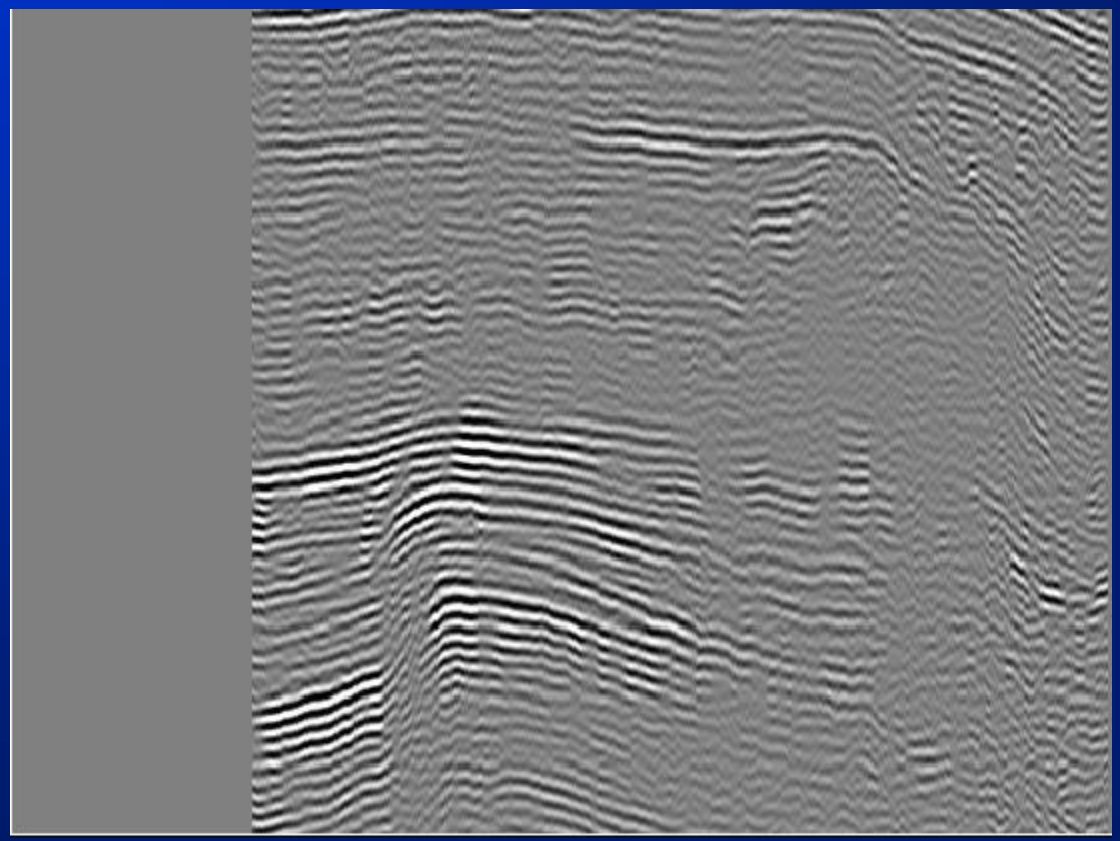
Band-pass filter (60-70 Hz)



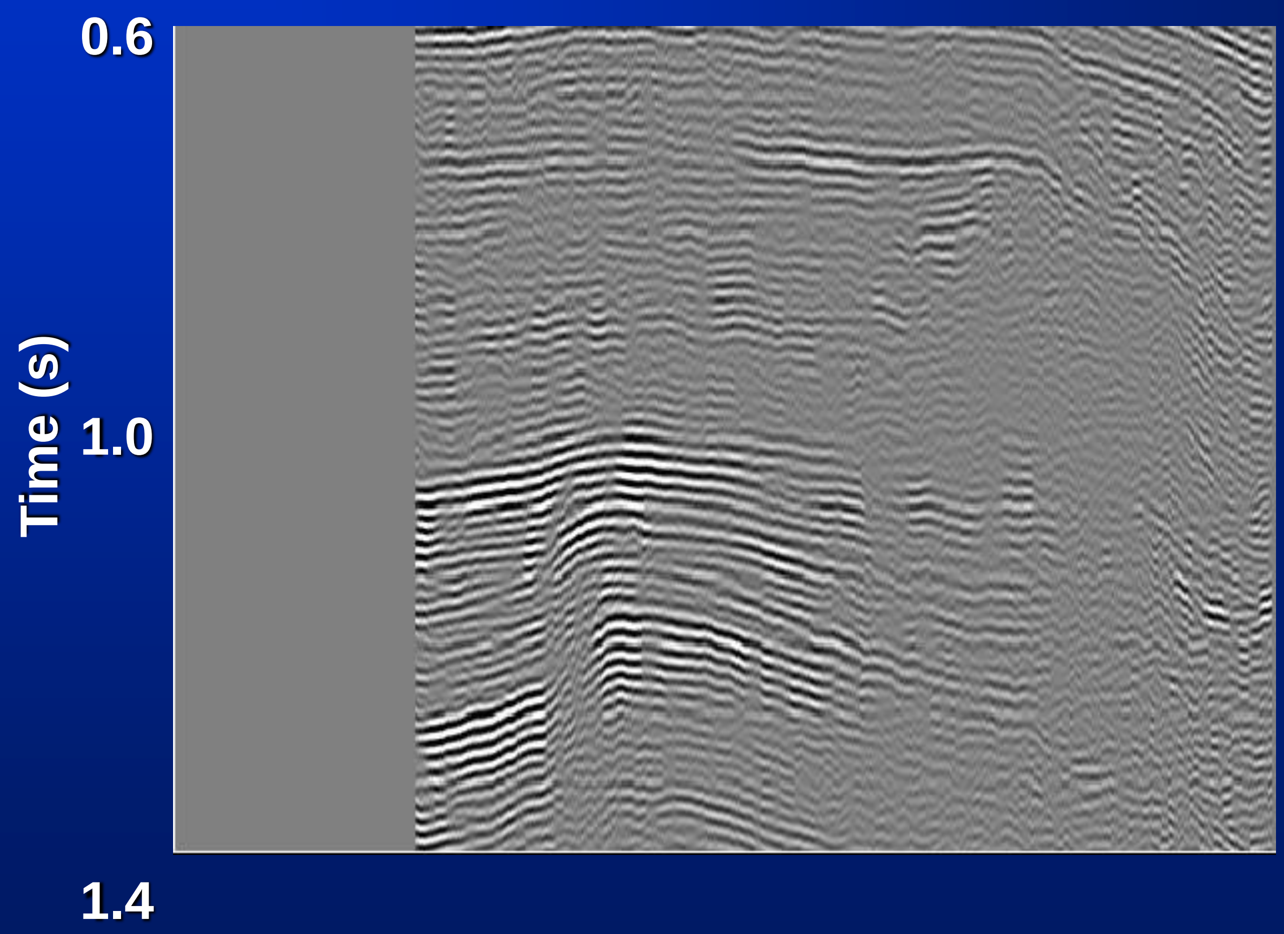
Band-pass filter (70-80 Hz)

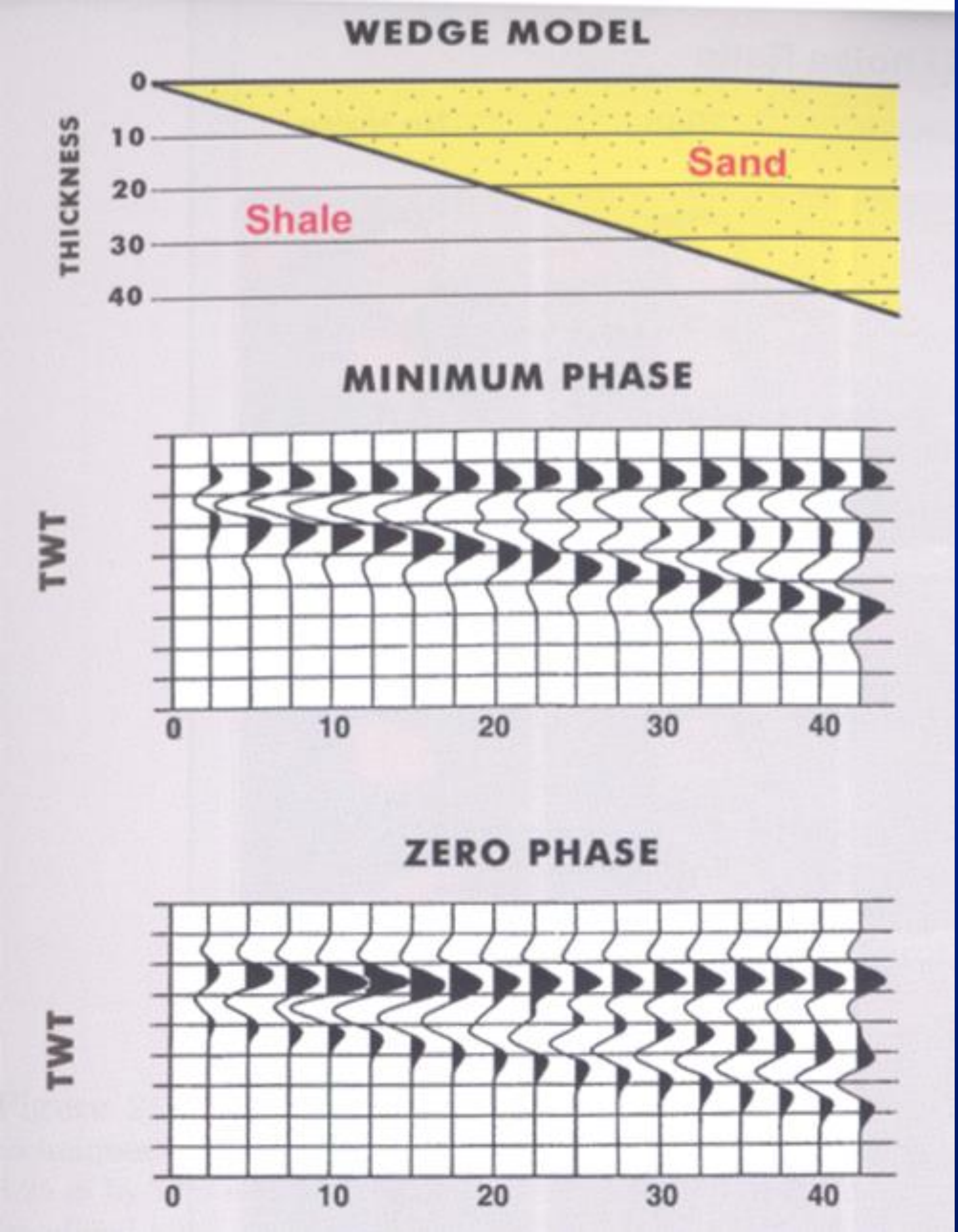


Band-pass filter (80-90 Hz)



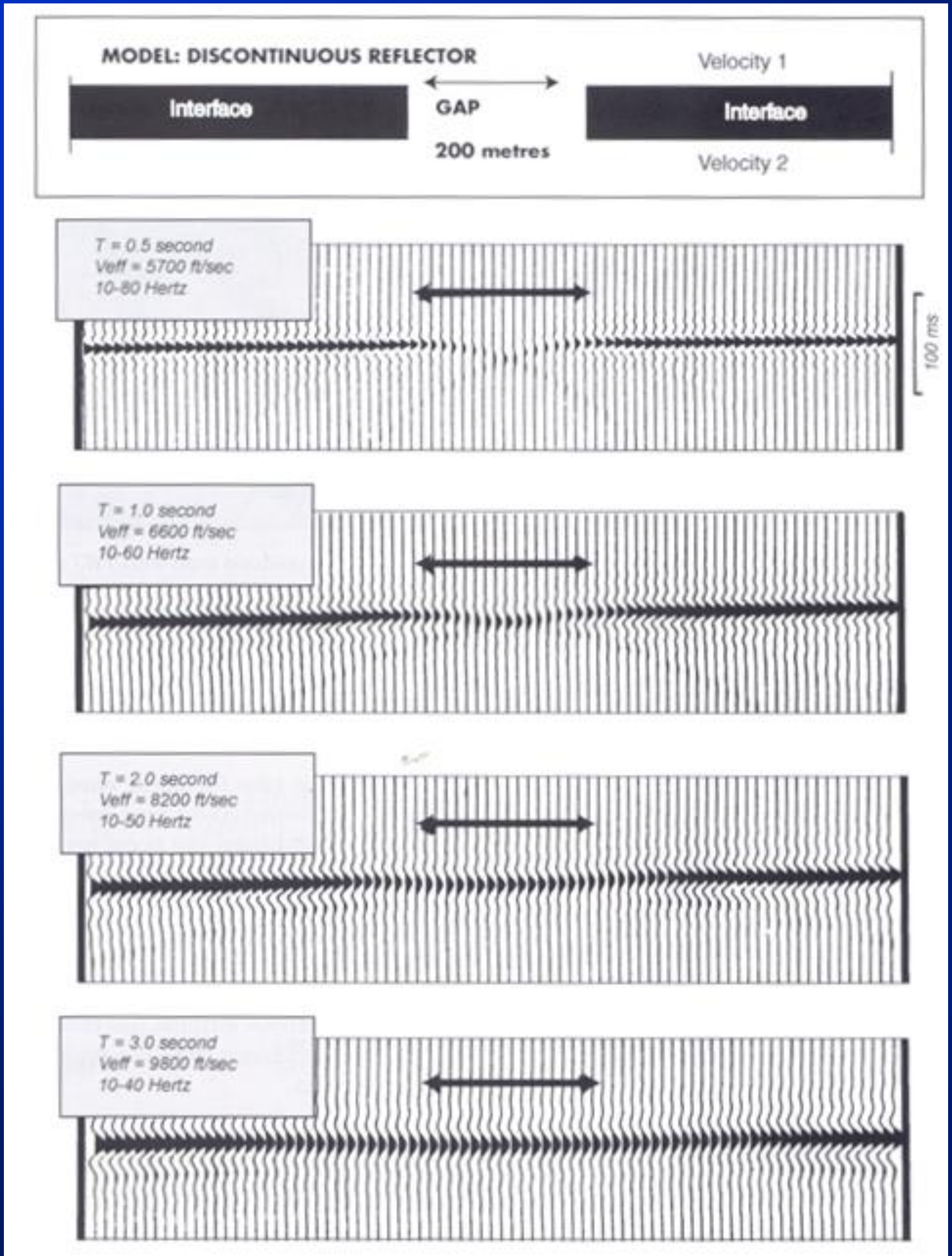
Band-pass filter (90-100 Hz)



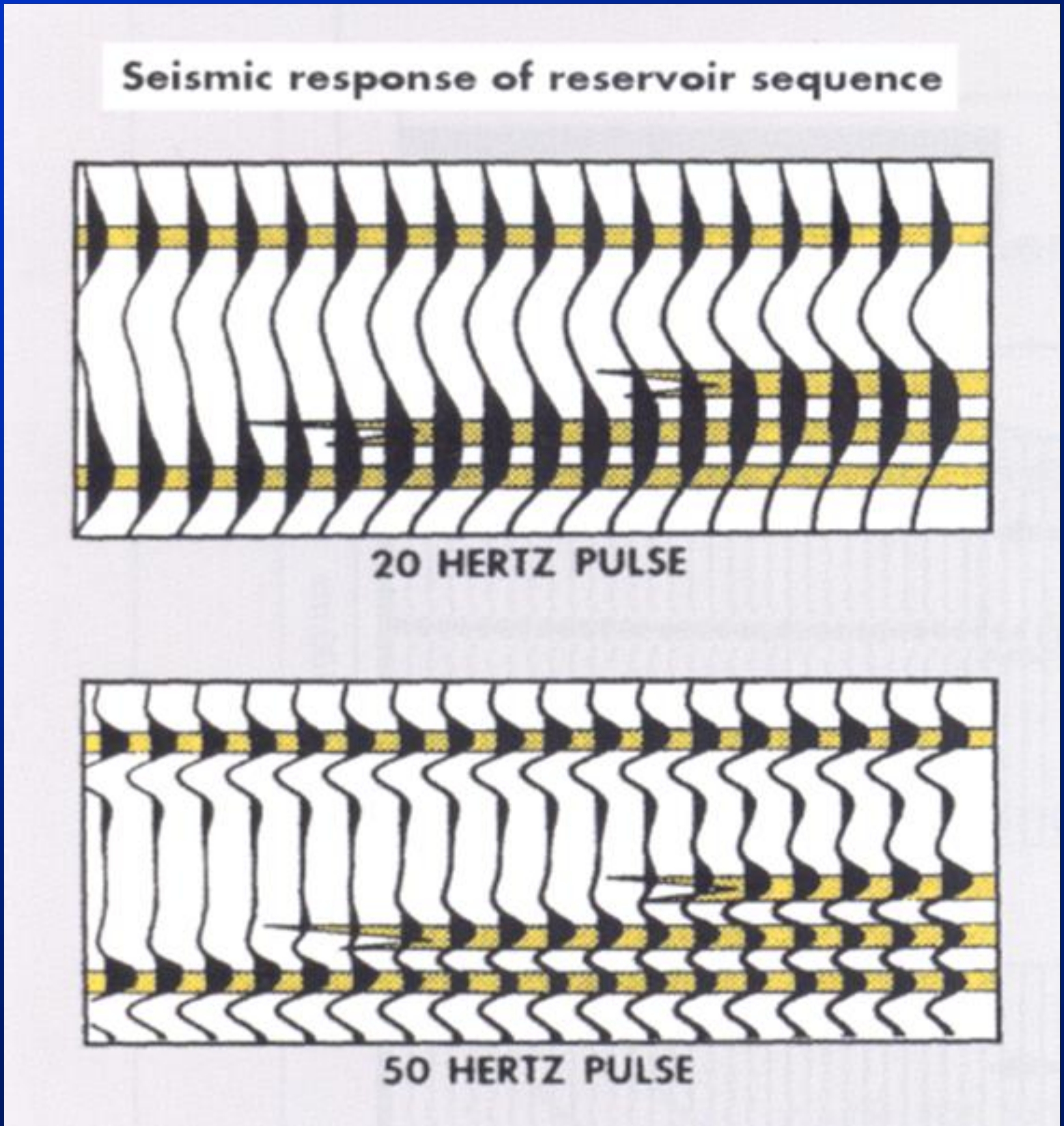


50 Hz wavelet
Period=1/50=0.020 s

(Veeken, 2007)

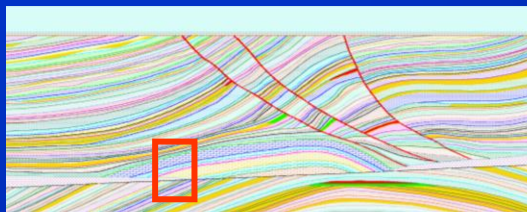

MODEL: DISCONTINUOUS REFLECTOR
Velocity 1
Interface
GAP
Interface
200 metres
Velocity 2
T = 0.5 second
Veff = 5700 ft/sec
10-80 Hertz
100 ms
T = 1.0 second
Veff = 6600 ft/sec
10-60 Hertz
T = 2.0 second
Veff = 8200 ft/sec
10-50 Hertz
T = 3.0 second
Veff = 9800 ft/sec
10-40 Hertz

(Veeken, 2007)


Seismic response of reservoir sequence
20 HERTZ PULSE
50 HERTZ PULSE

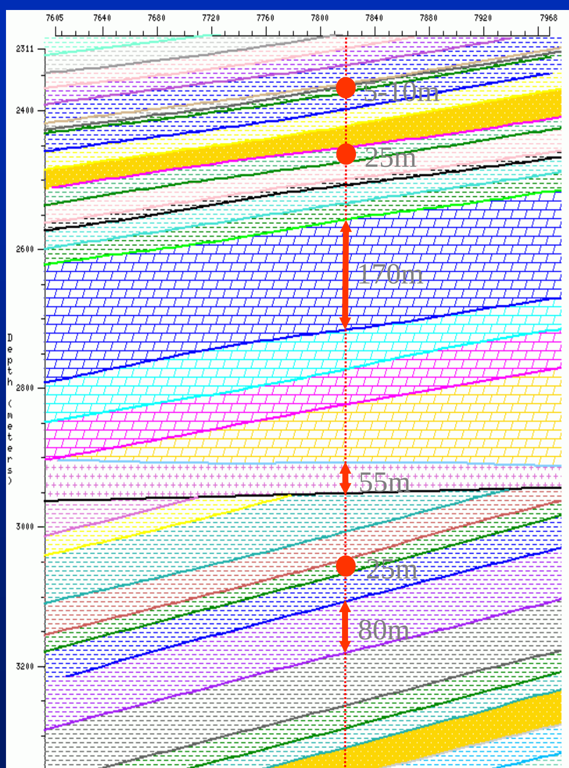
(Veeken, 2007)

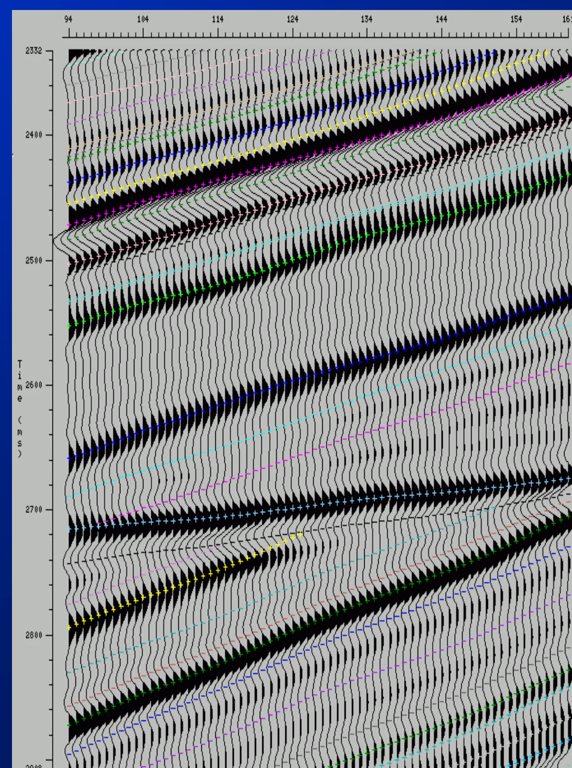
Layer Thickness and resolution

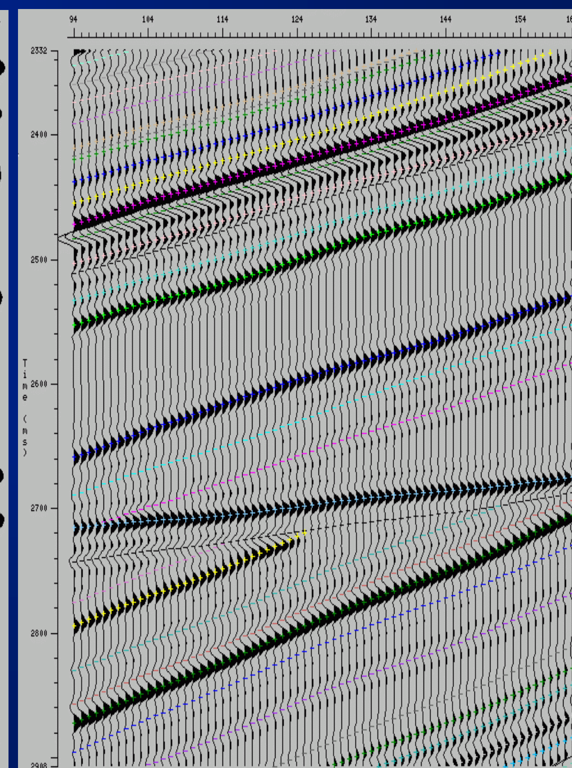


5-10-30-40 Hz

5-10-60-80 Hz

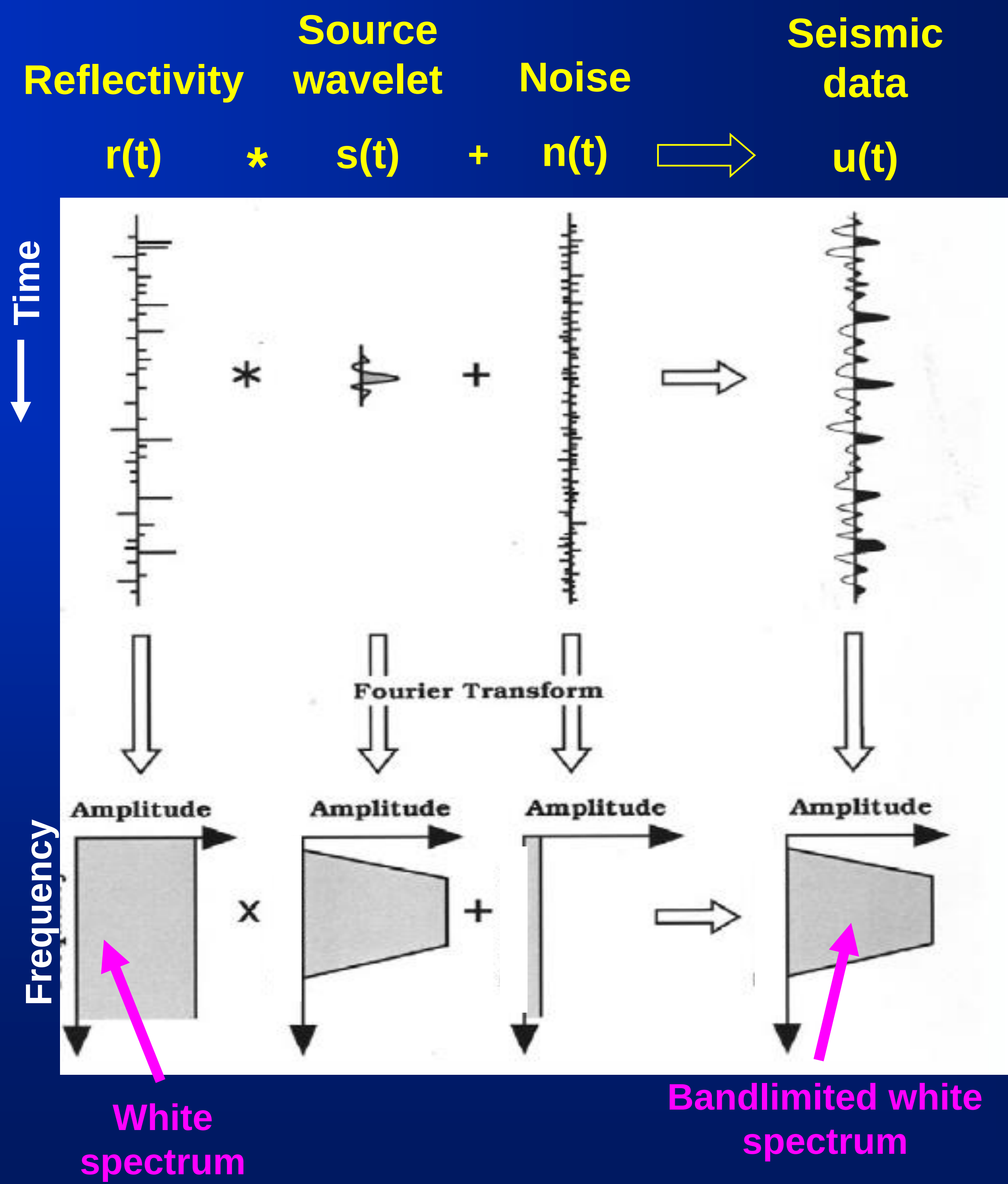






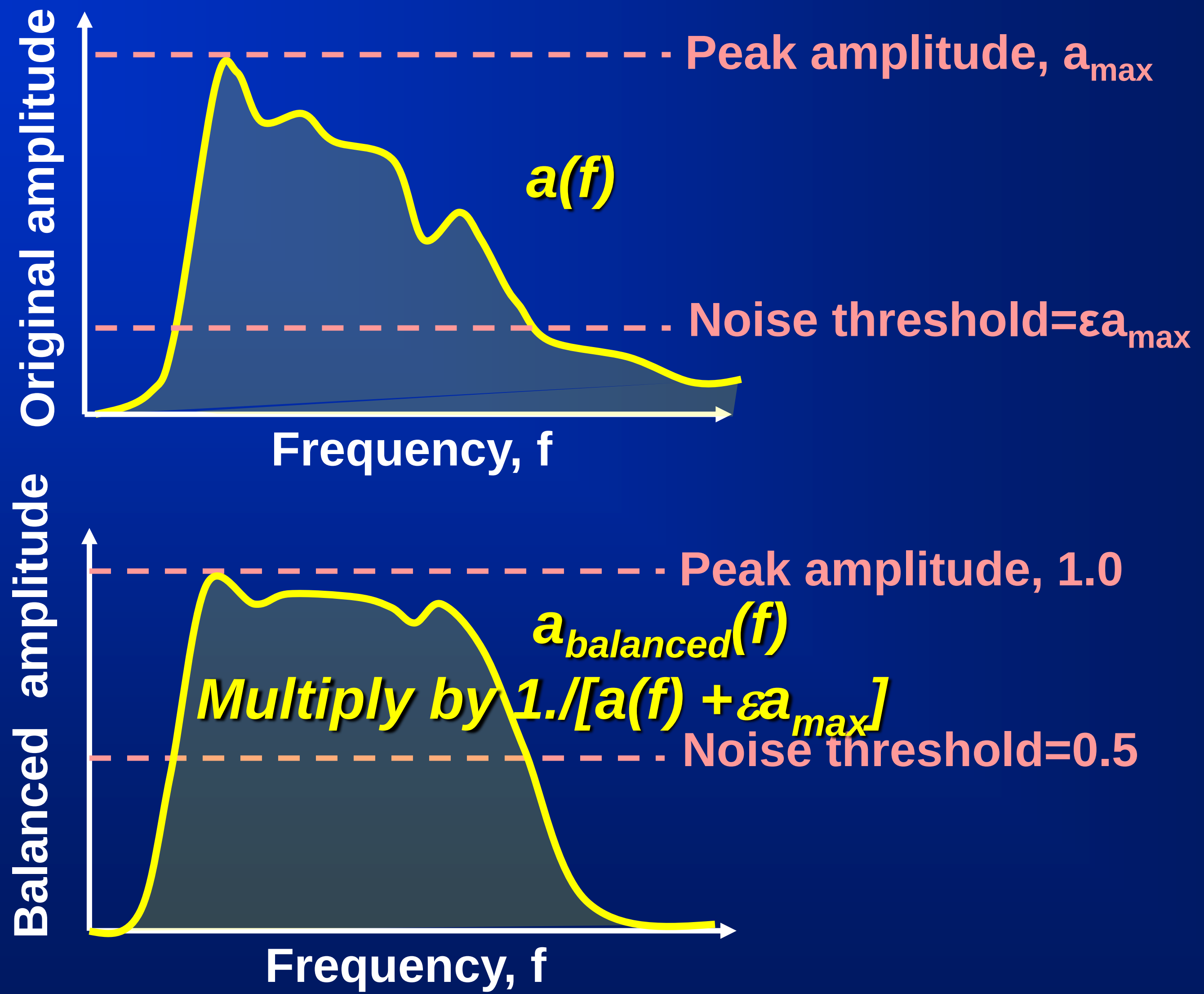
(Martin, 2004)

Long window spectral decomposition and the convolutional model

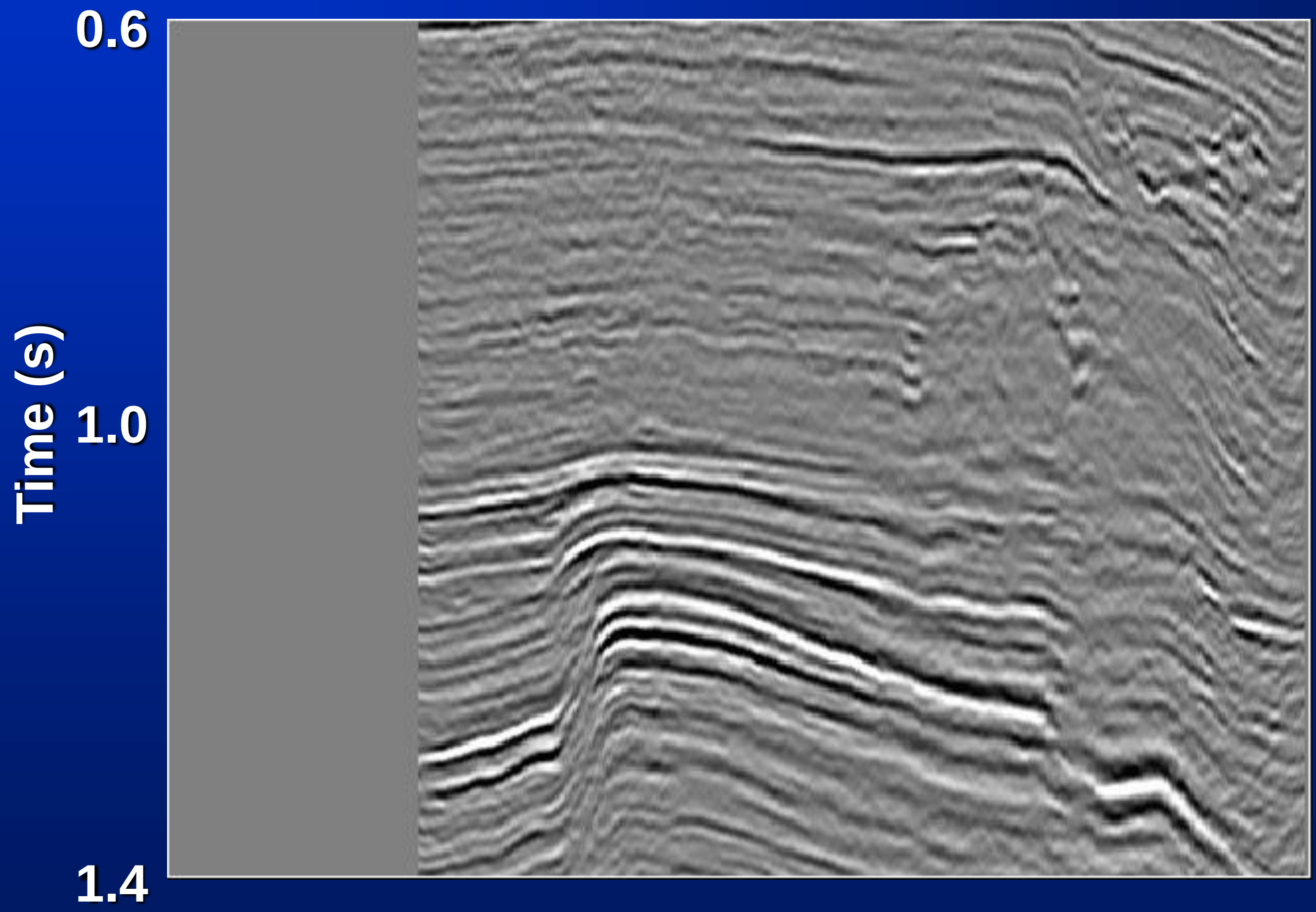


(Partyka et al, 1999)

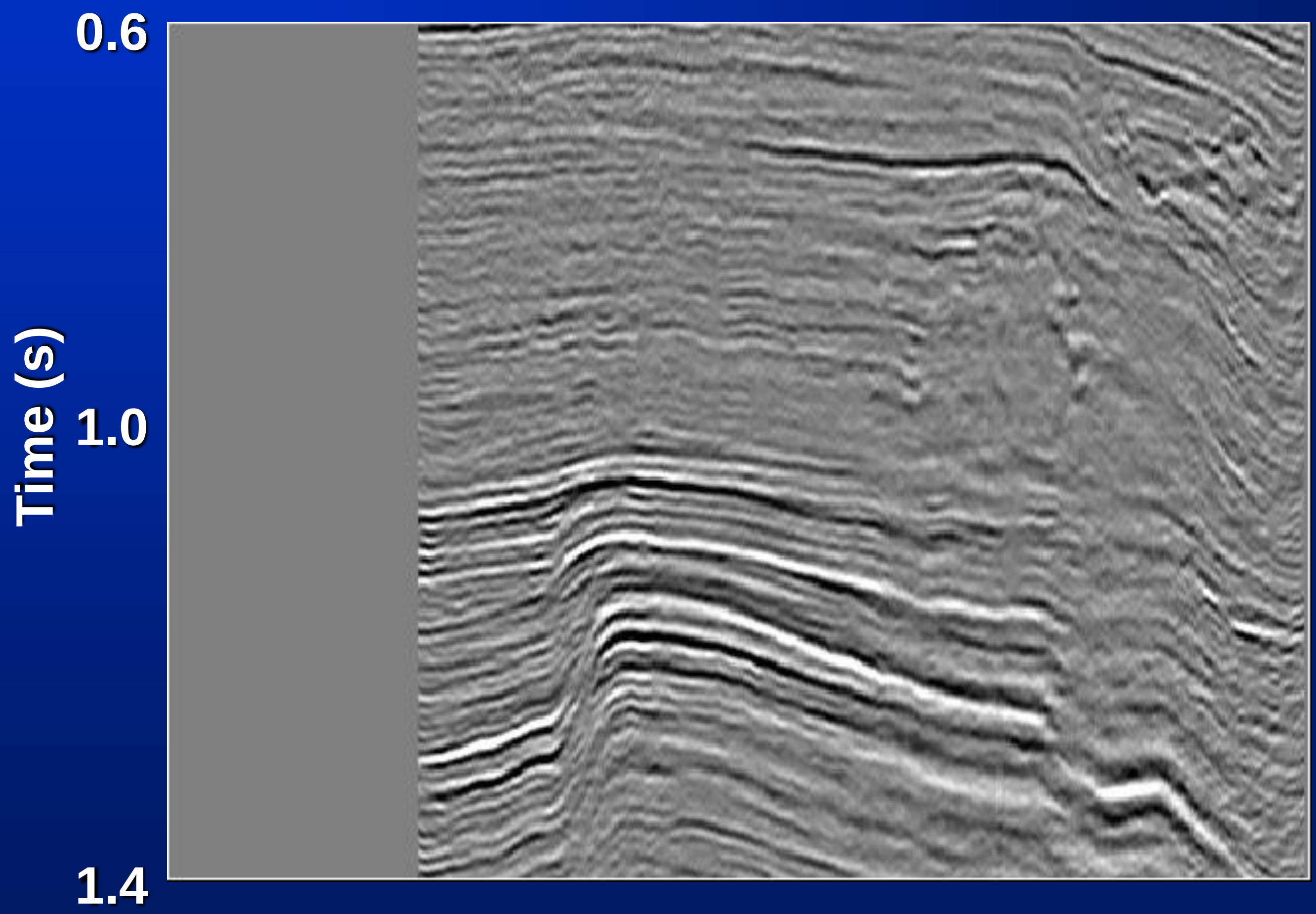
Spectral balancing



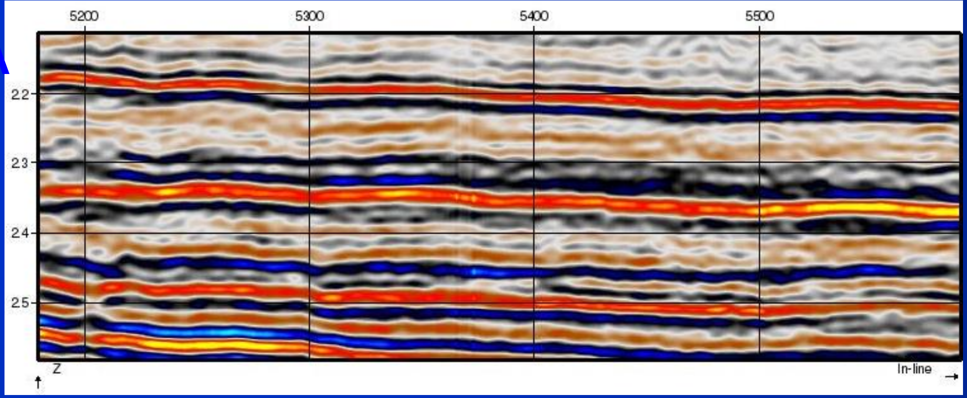
Original data (west Texas)



Spectrally balanced data

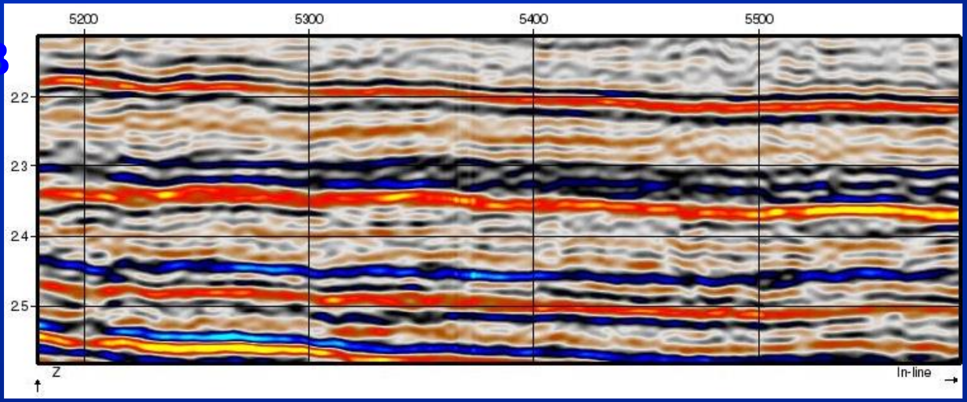


A



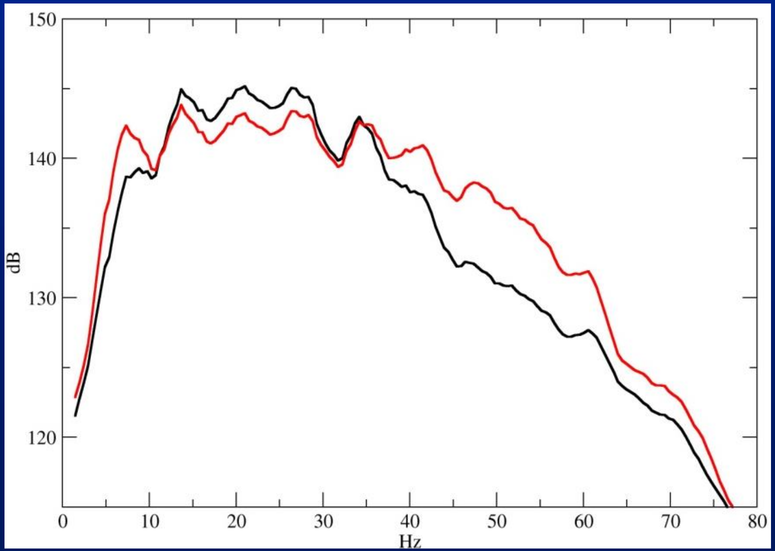
Original data

B



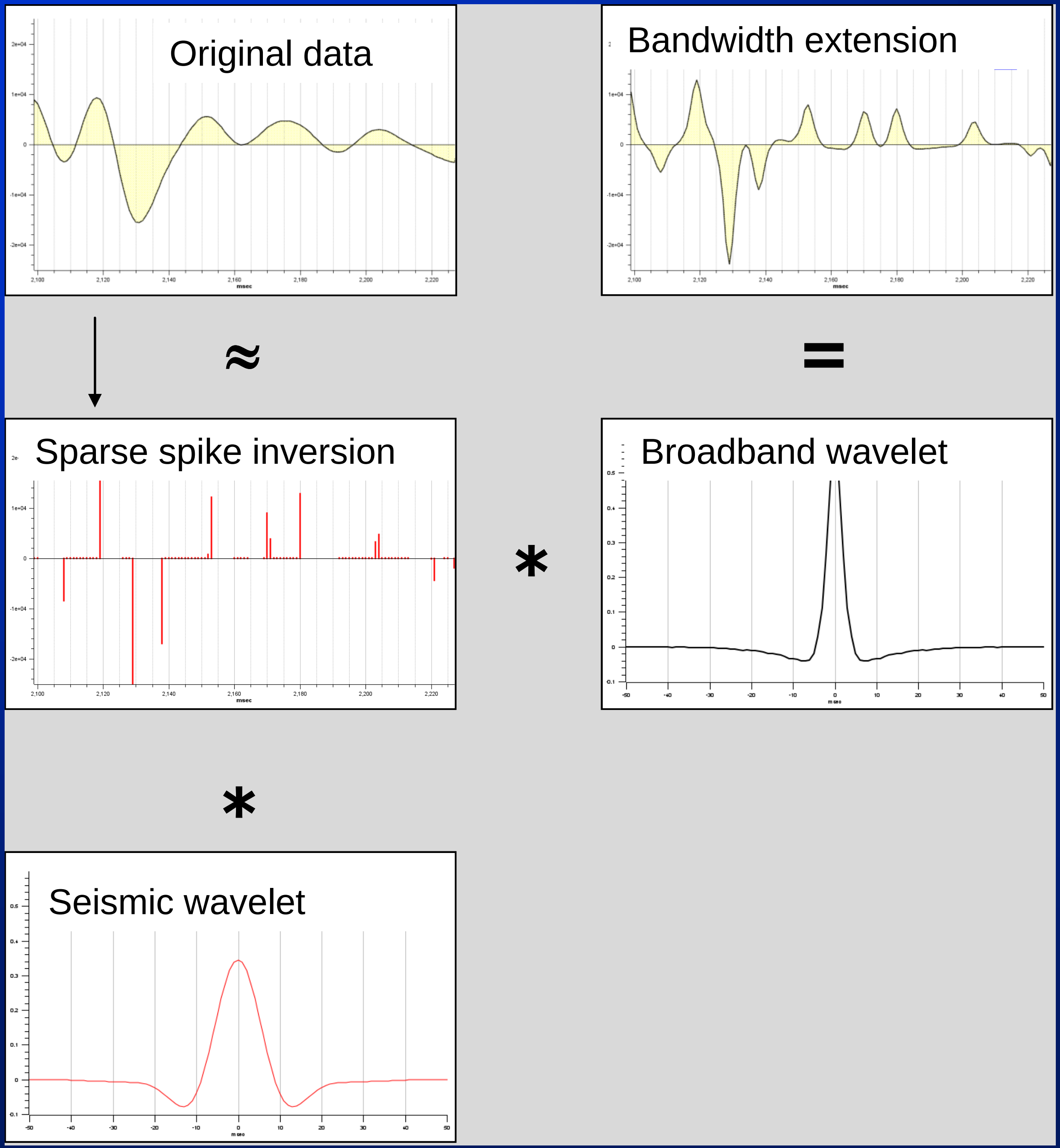
Data after spectral balancing

C



(Carrao et al., 2011)

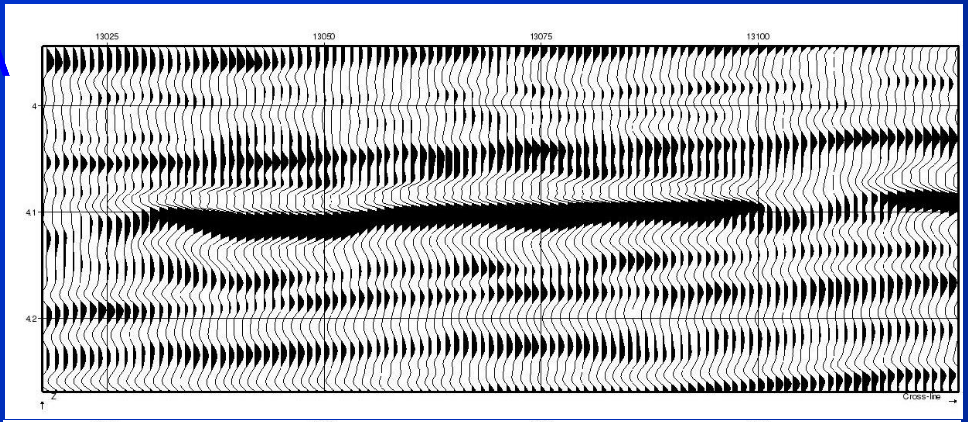
Bandwidth Extension



(Carrao et al., 2011)

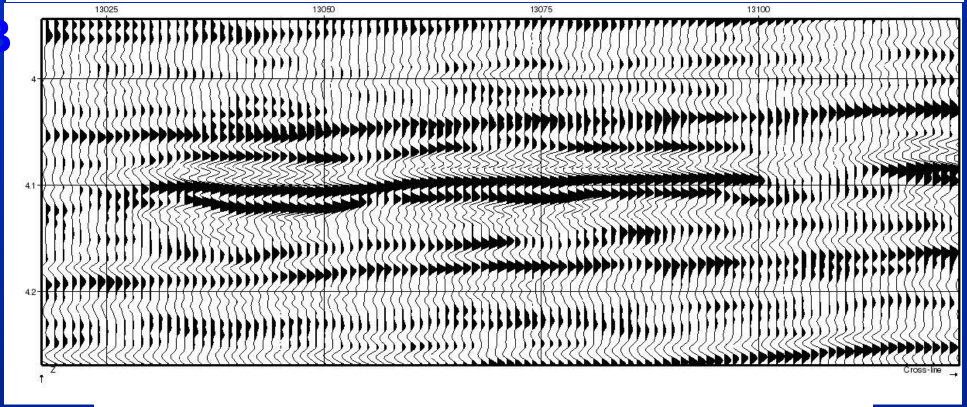
Bandwidth Extension

A



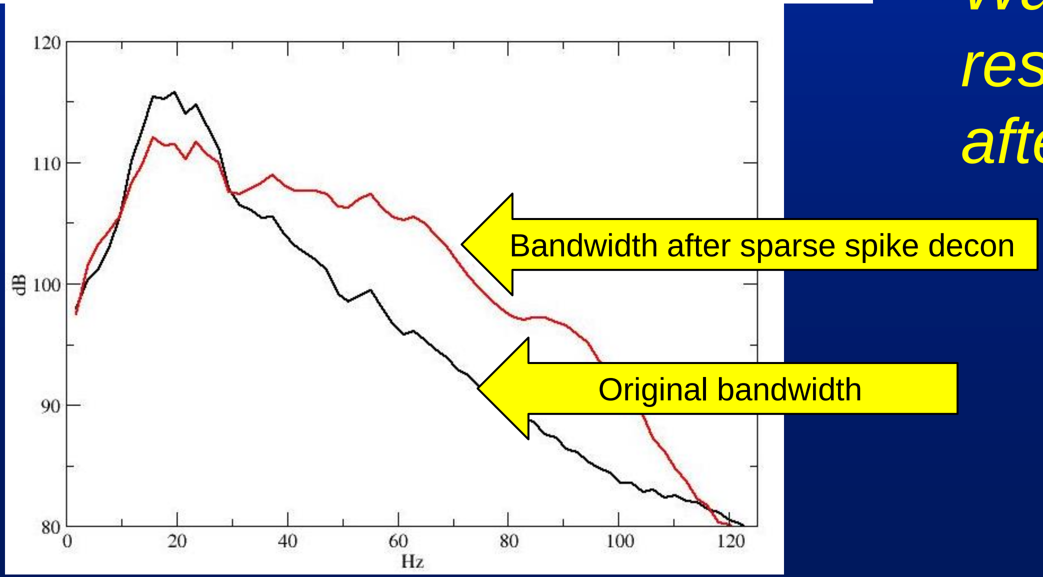
Original data

B



Data after sparse spike deconvolution

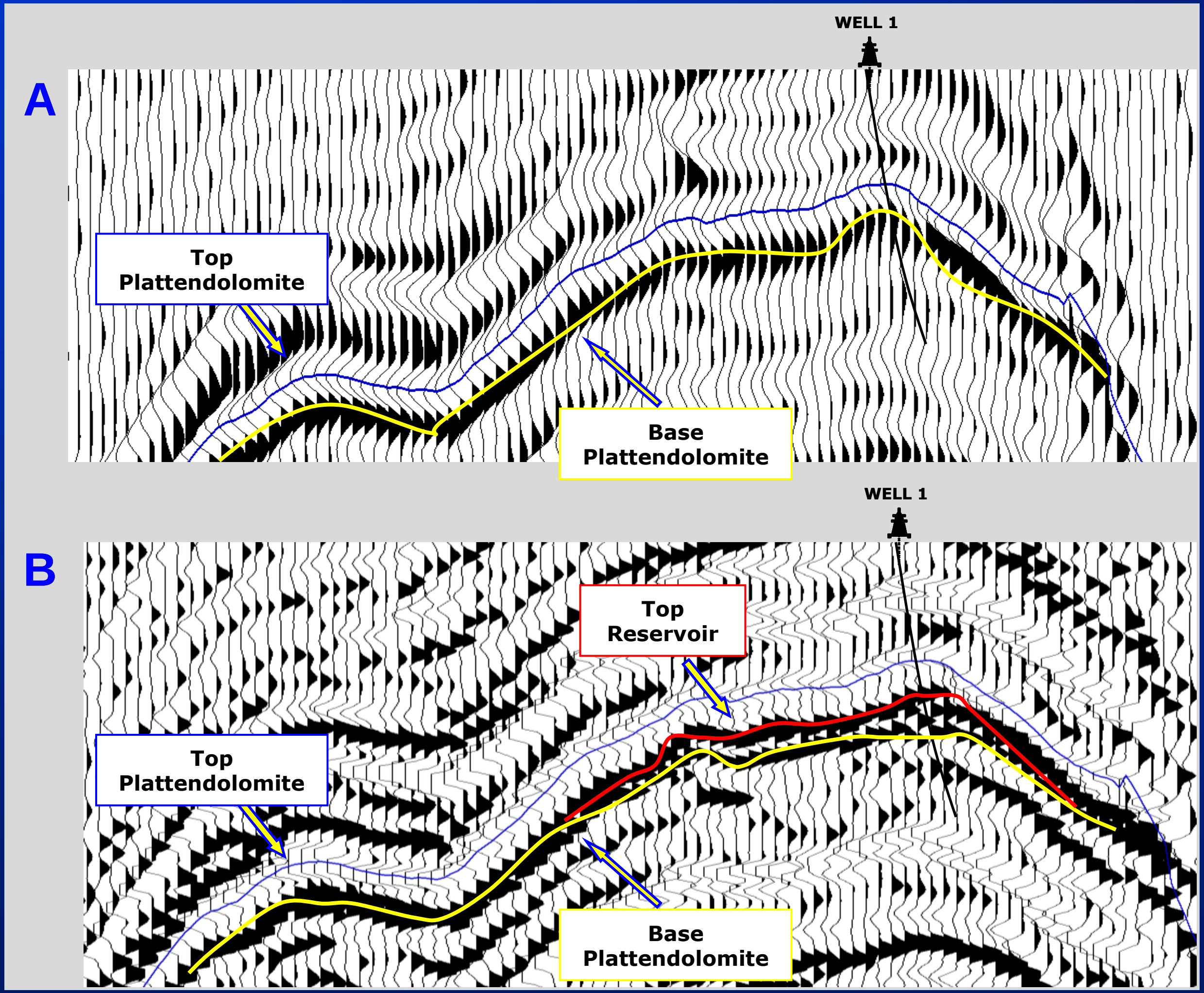
C



Warning! Always compare resulting data to well logs after bandwidth extension!

(Carrao et al., 2011)

Bandwidth Extension

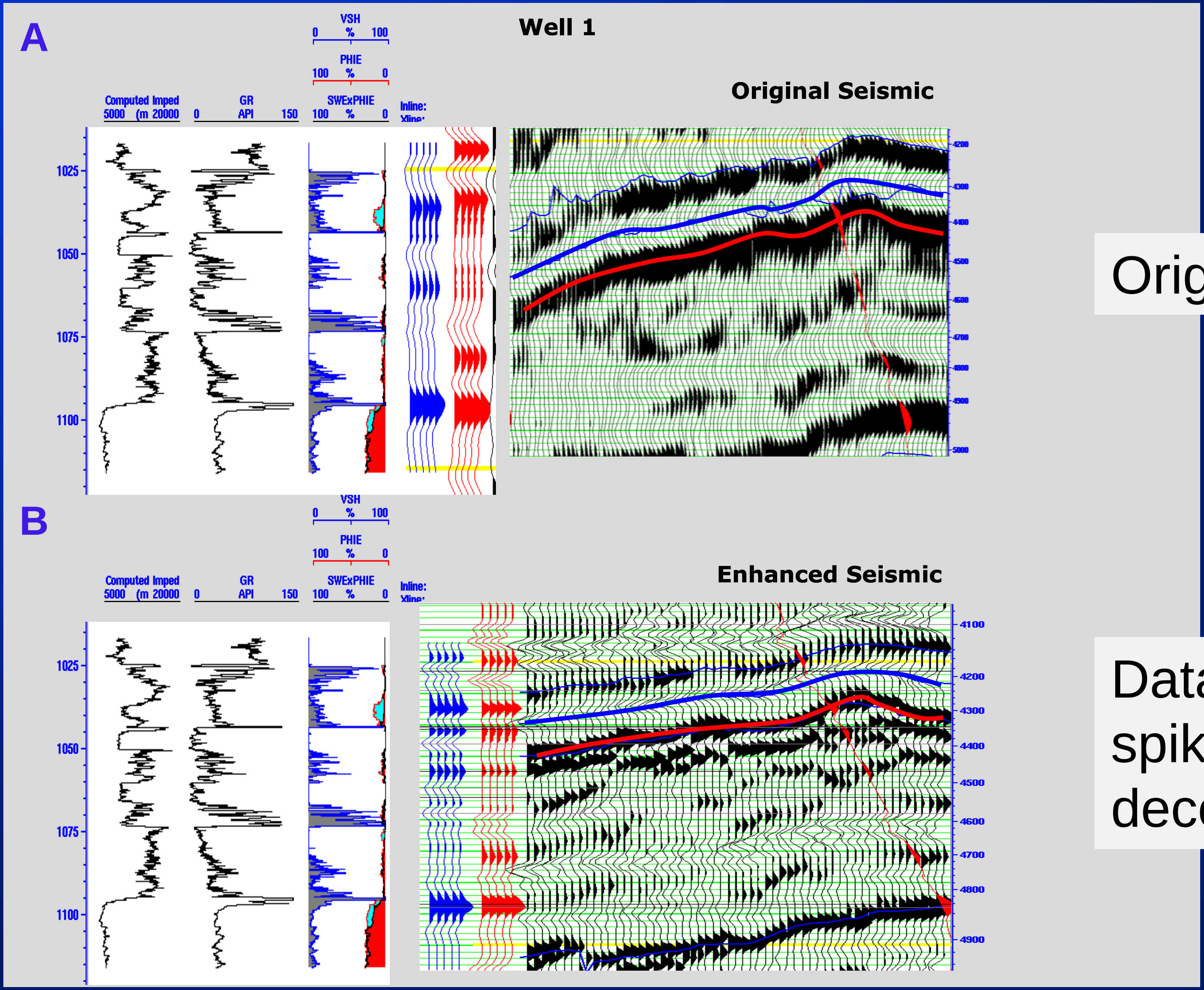


Original data

Data after sparse spike deconvolution

(Carrao et al., 2011)

Bandwidth Extension: Check well ties!

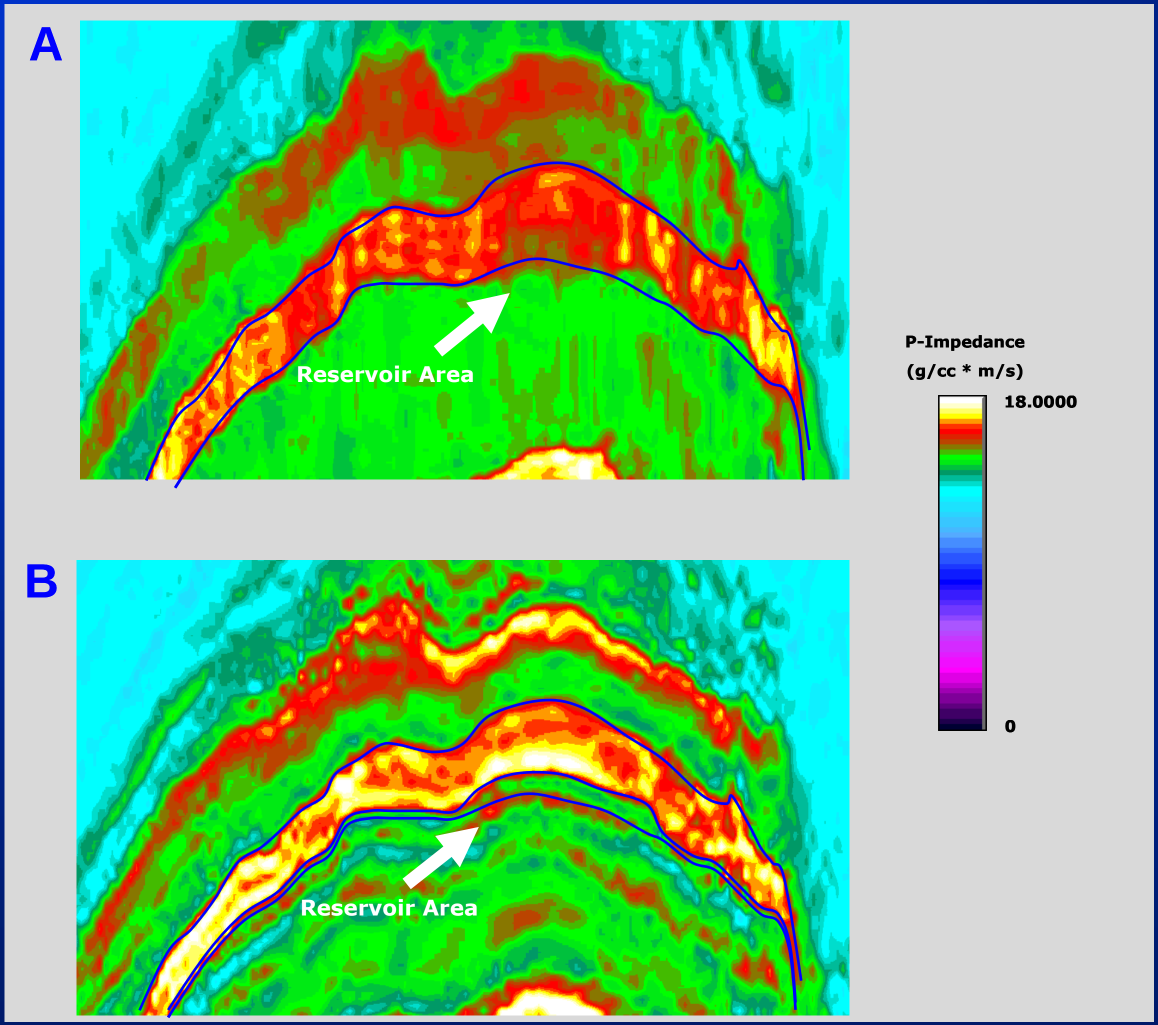


Original data

Data after sparse spike deconvolution

(Carrao et al., 2011)

Bandwidth Extension: Influence on impedance inversion

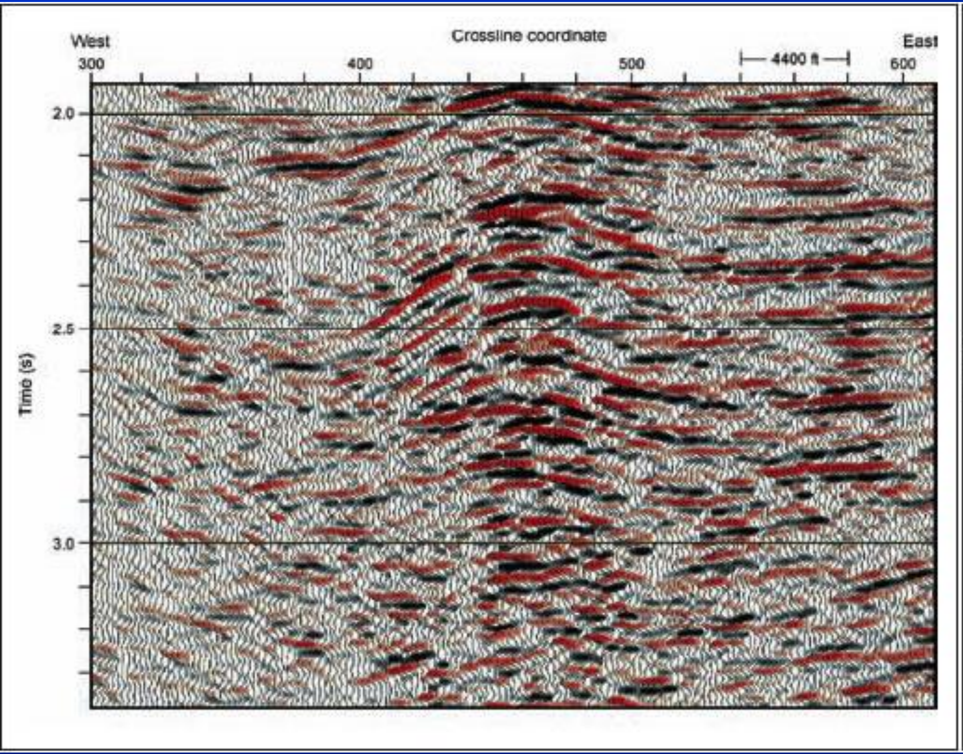


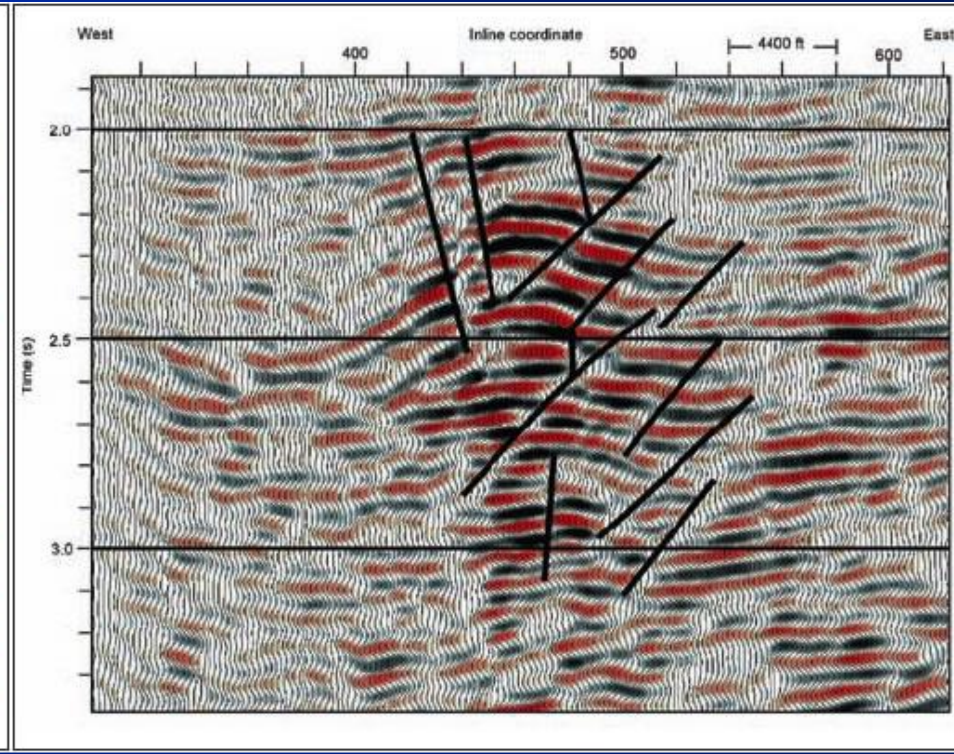
Original data

Data after sparse spike deconvolution

(Carrao et al., 2011)

Improving interpretability by throwing away data



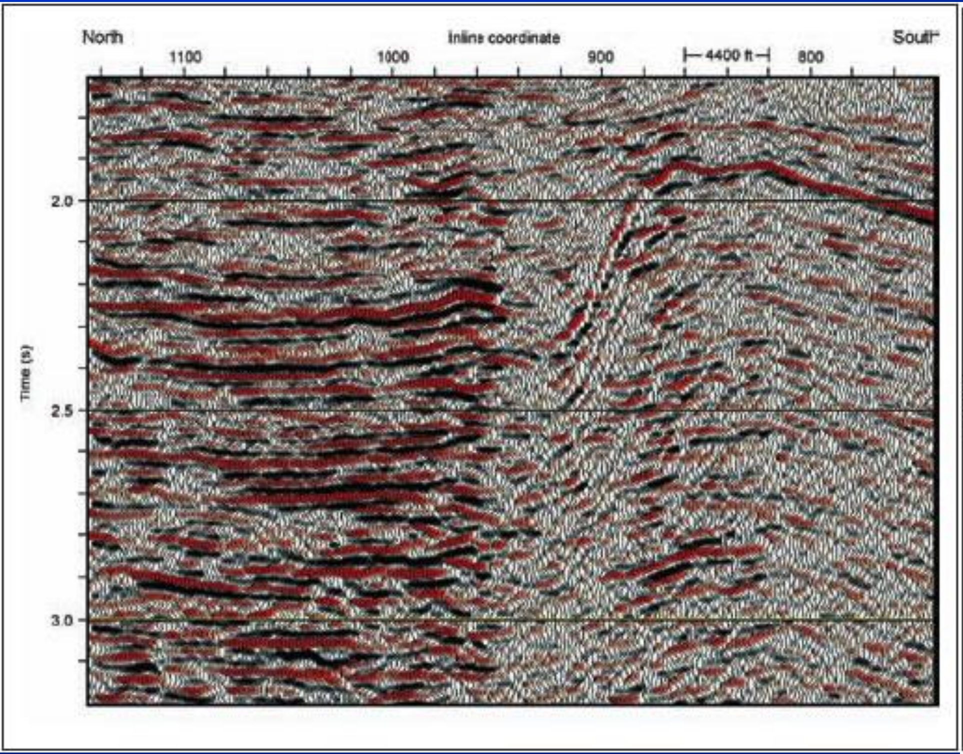


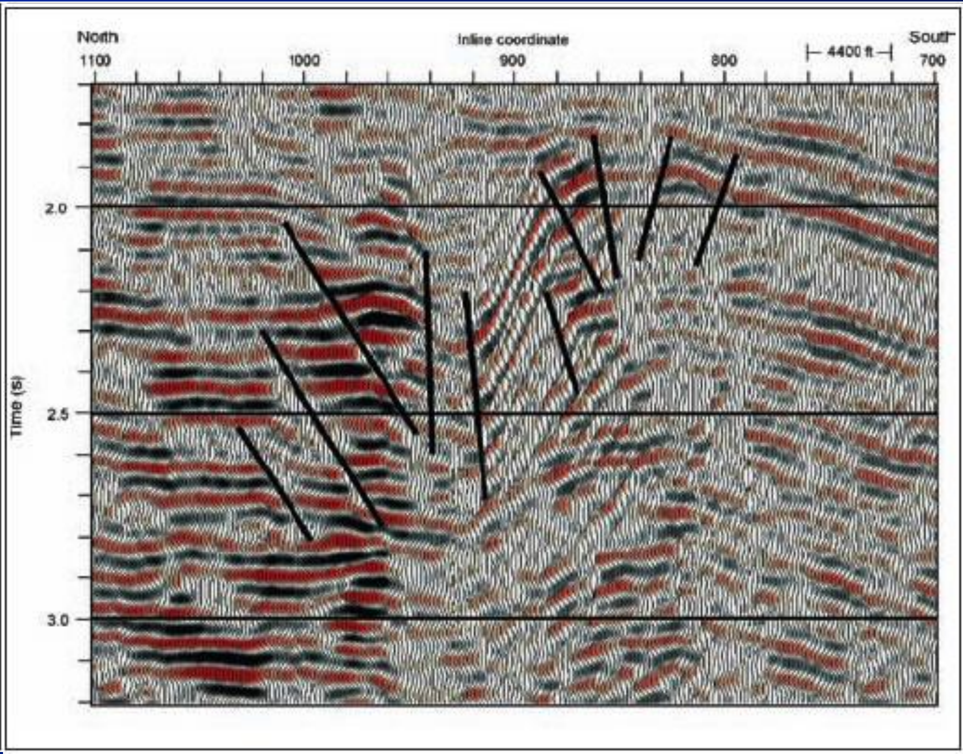
Poor statics negatively impact the high frequencies in this broad band 8-80 Hz data

Data filtered back to 8-16 Hz (low frequencies less impacted by poor statics)

(Hardage, 2009)

Improving interpretability by throwing away data





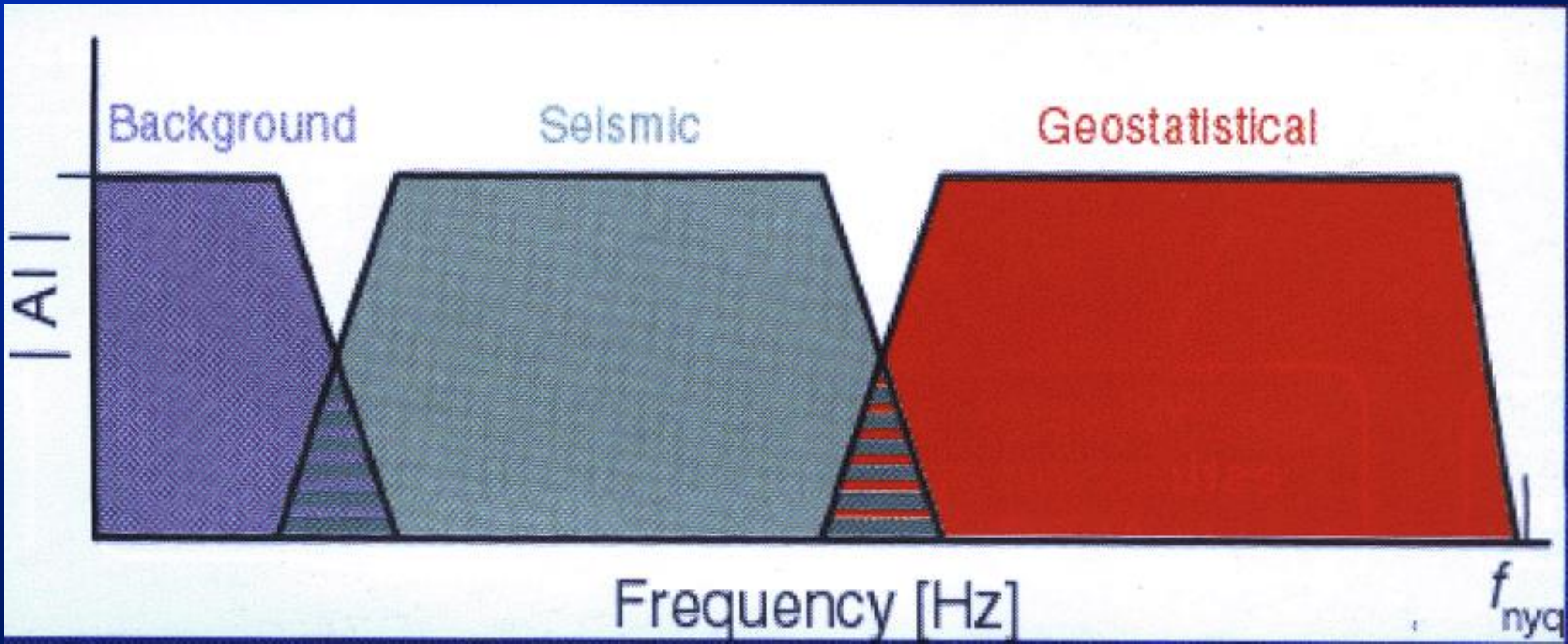
Poor statics negatively impact the high frequencies in this broad band 8-80 Hz data

Data filtered back to 8-16 Hz (low frequencies less impacted by poor statics)

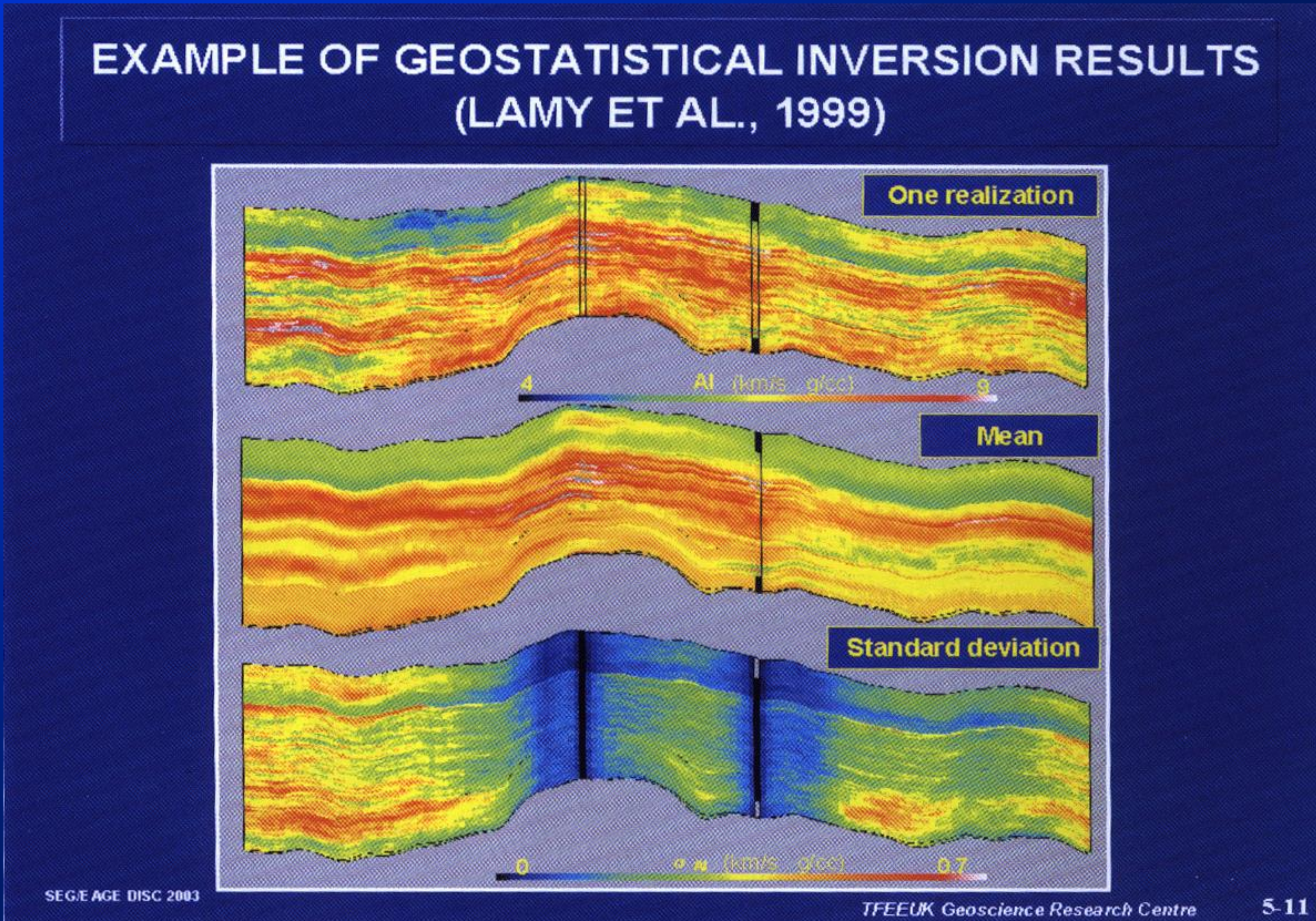
(Hardage, 2009)

Seismic bandwidth and resolution

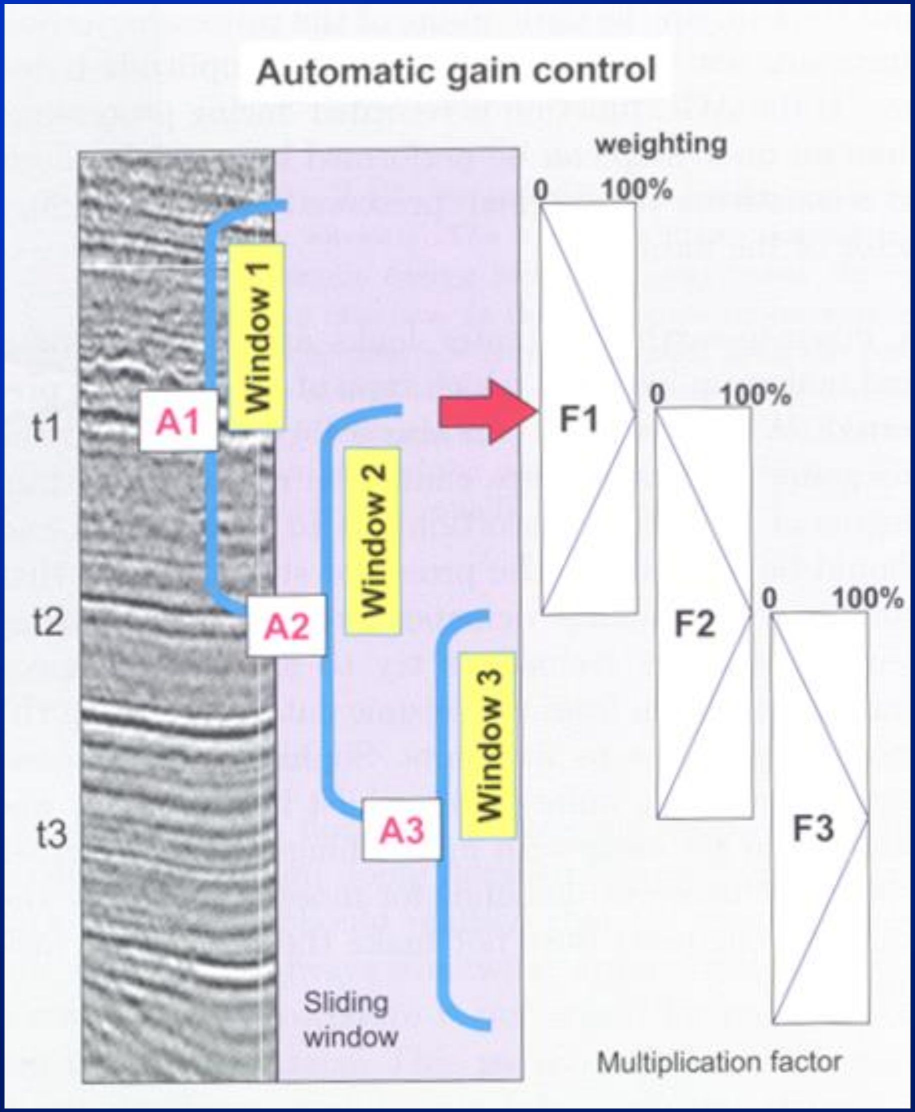
- We obtain low frequencies(< 5 Hz) from horizon interpretation, velocity analysis, and well logs
- We obtain medium frequencies (5-100 Hz) from seismic waveforms (amplitude data)
- We obtain high frequencies (> 150 Hz) from integrating well control using geostatistics or neural networks



(Dubrule, 2003)

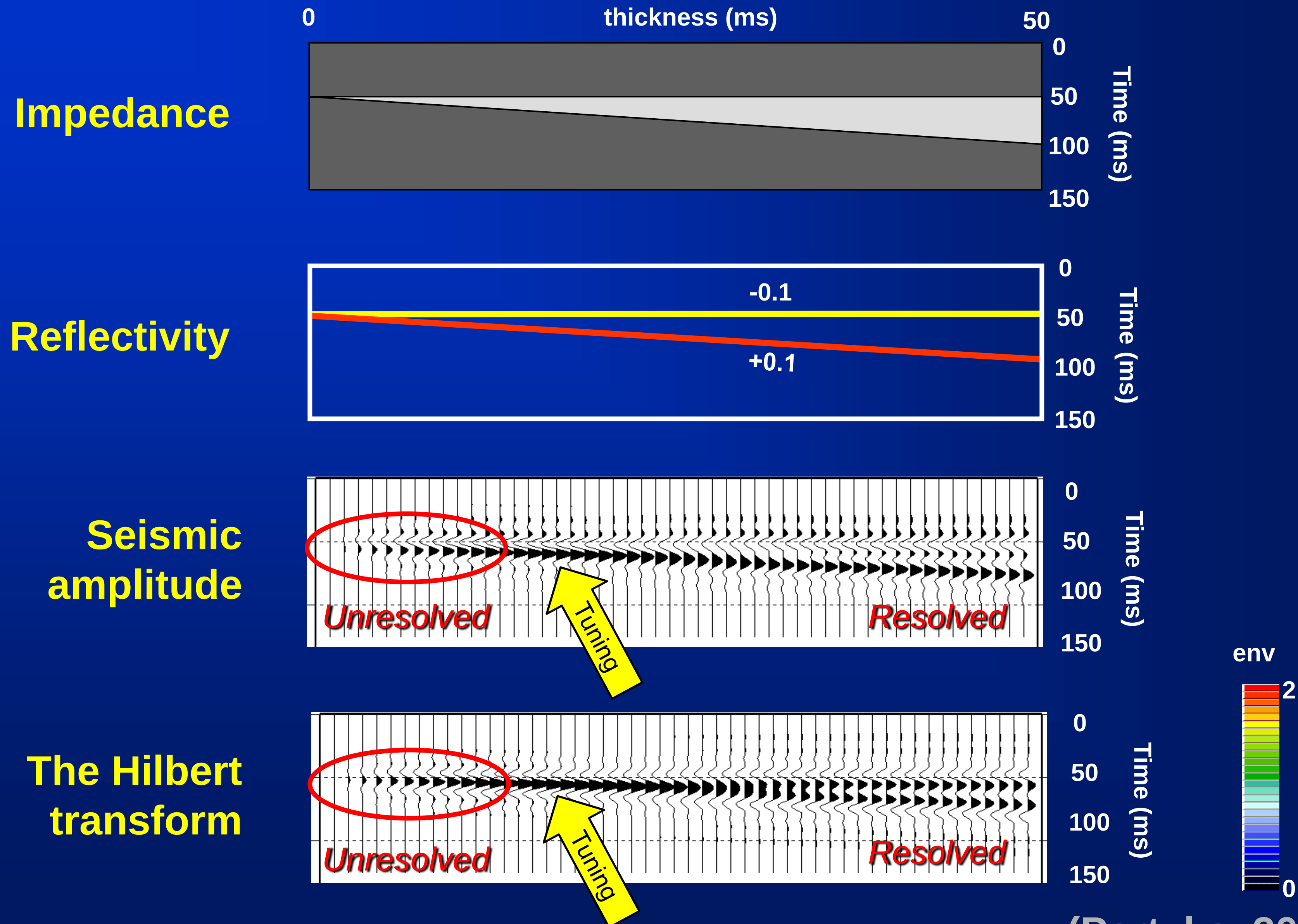


(Dubrule, 2003)


Automatic gain control
weighting
0
100%
Window 1
A1
t1
F1
0
100%
Window 2
A2
t2
F2
0
100%
Window 3
A3
t3
F3
Sliding
window
Multiplication factor

(Veeken, 2007)

Thin bed tuning and the wedge model



(Partyka, 2001)

Summary

- Seismic data are band-limited, limiting vertical and lateral resolution
- The loss of high frequencies limits our ability to resolve thin beds
- The loss of low frequencies limits our ability to estimate the actual value of impedance, and hence lithology and porosity
- Constructive and destructive interference gives rise to the tuning frequency phenomenon, which allows us to estimate layer thicknesses below ¼ wavelength limits