# Seismic Attributes - from Interactive Interpretation to Machine Learning

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## Conditioning of Migrated, Stacked Data

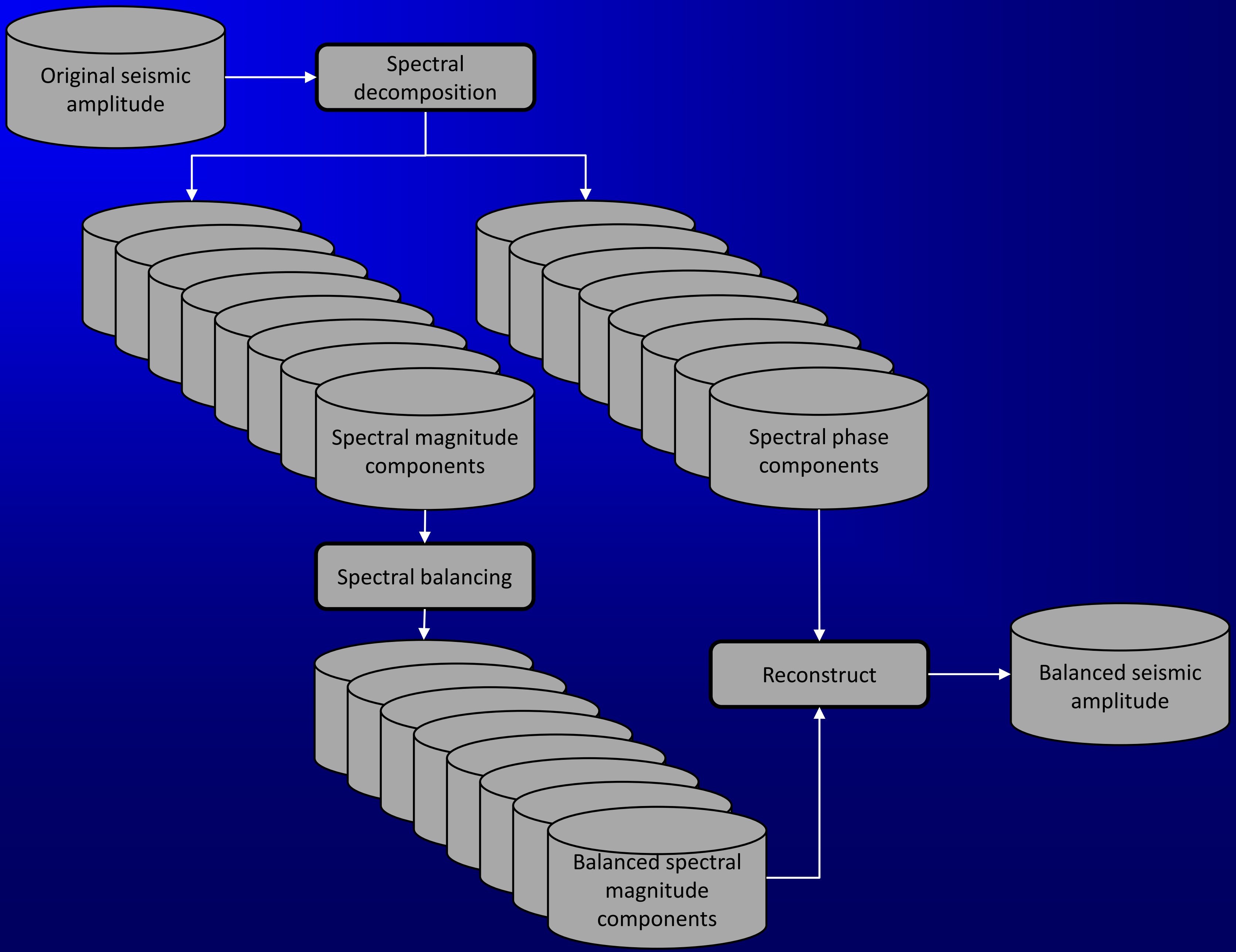
## Spectral Balancing and Bandwidth Extension

# Data Conditioning

## After this section you should be able to:

- Examine the spectrum of your data and determine whether subsequent spectral balancing can help
- Evaluate alternative bandwidth extension techniques using simple wedge models

# Spectral Balancing



# Adaptive whitening

Assume the signal $s(t)$ is the convolution of a wavelet, $w(t)$, with the reflectivity series $r(t)$
Assume the measured data is the signal $s(t)$ plus noise $n(t)$:

$$s(t) = w(t) * r(t)$$
$$y(t) = s(t) + n(t)$$

If we can estimate the spectra of the noise and of the wavelet, in frequency domain the deconvolution is

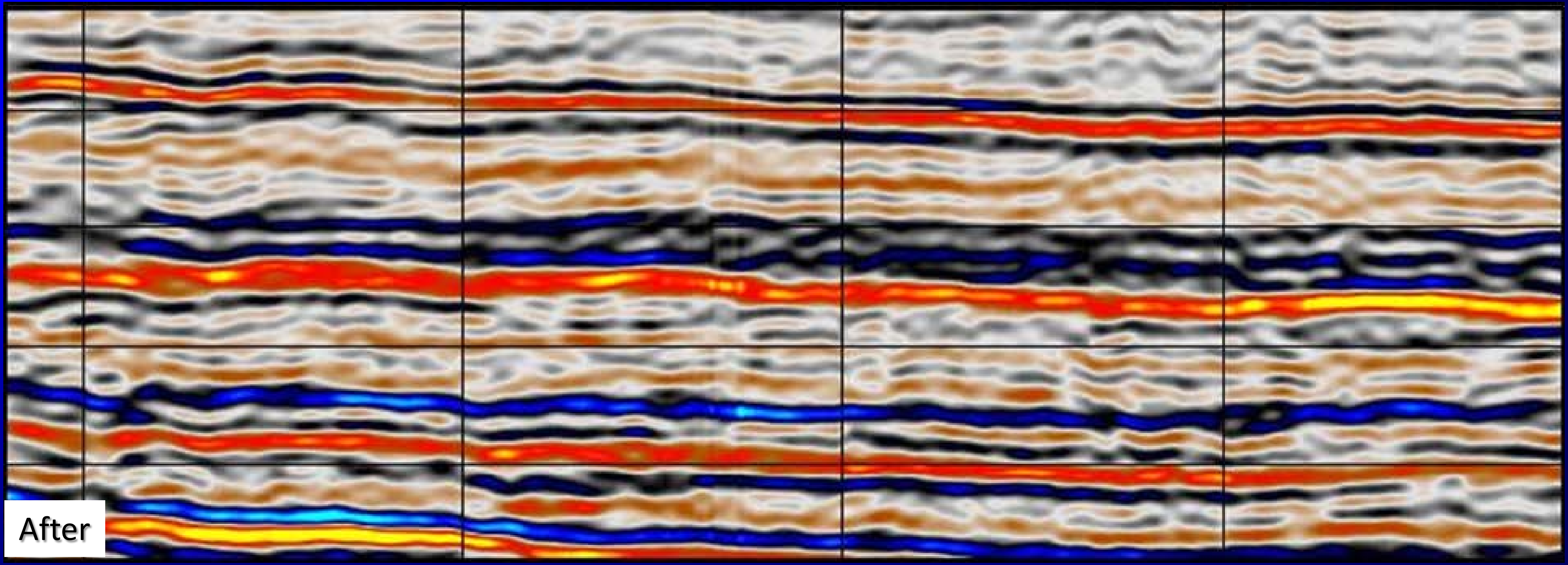
$$\hat{R}(f) = \frac{1}{W(f)} \frac{\|S(f)\|^2}{\|S(f)\|^2 + \|N(f)\|^2} Y(f)$$

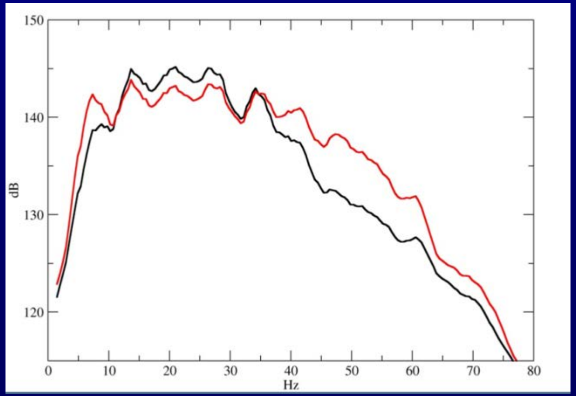
where $S(f)$, $N(f)$, are in general unknown but can be estimated by assuming the signal and noise are uncorrelated. Then $S(f)$ is estimated by cross-correlating adjacent traces and $S(f)+N(f)$ by autocorrelation of adjacent traces. If $R(f)$ is white, we can assume $W(f) \approx S(f)$.



(Corrao et al., 2011)

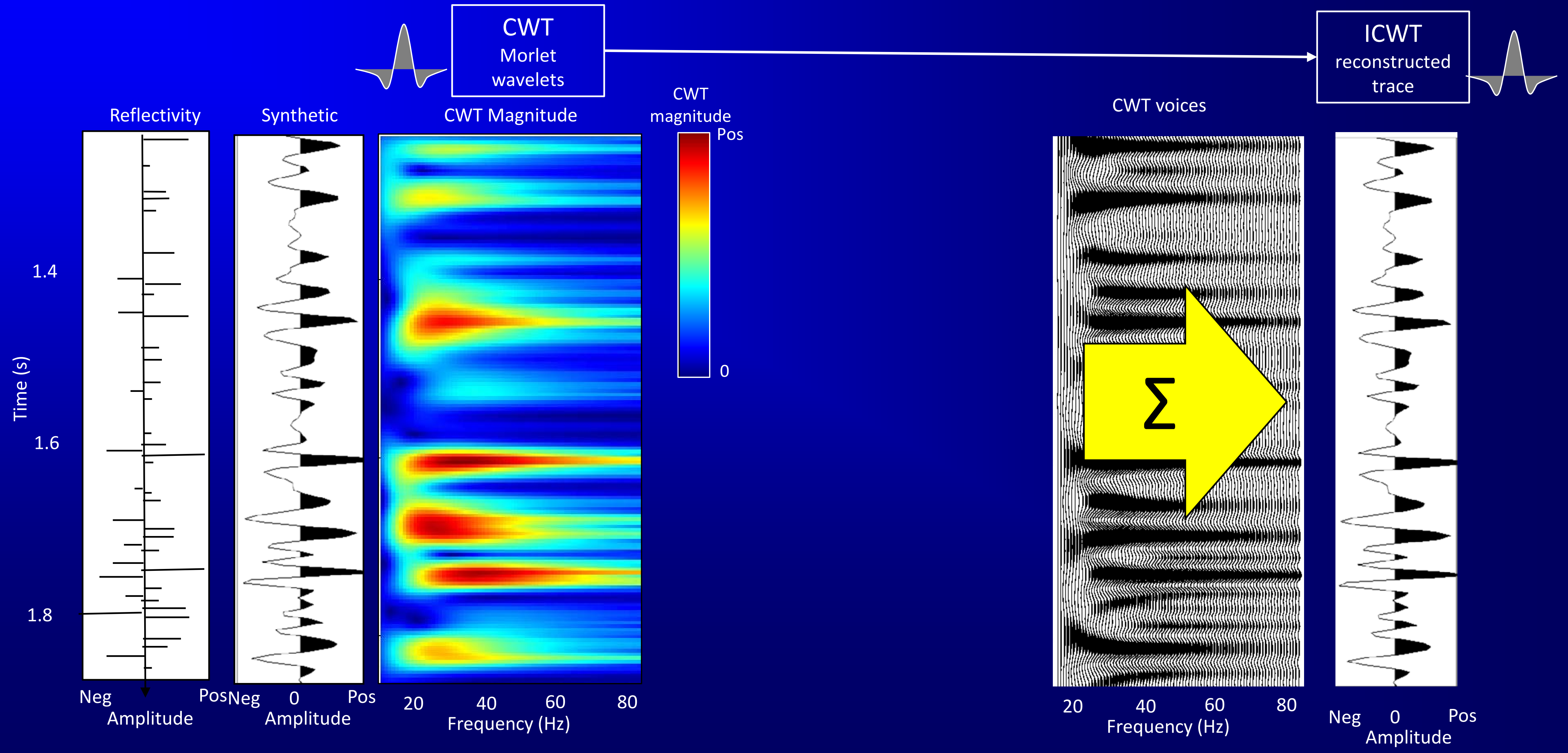
# Adaptive whitening




(Corrao et al., 2011)

# Spectral balancing using spectral components

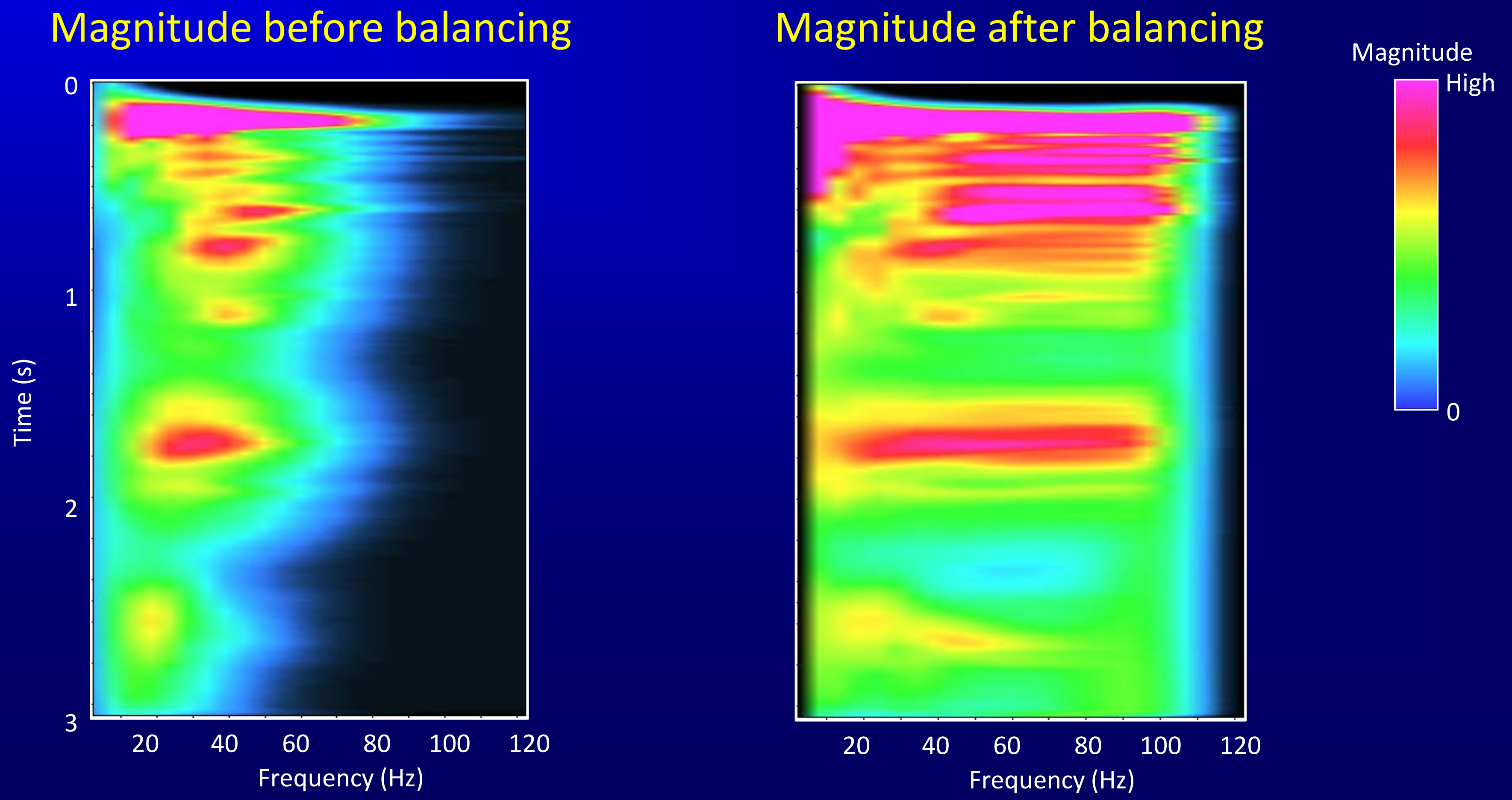



(Matos and Marfurt, 2011)

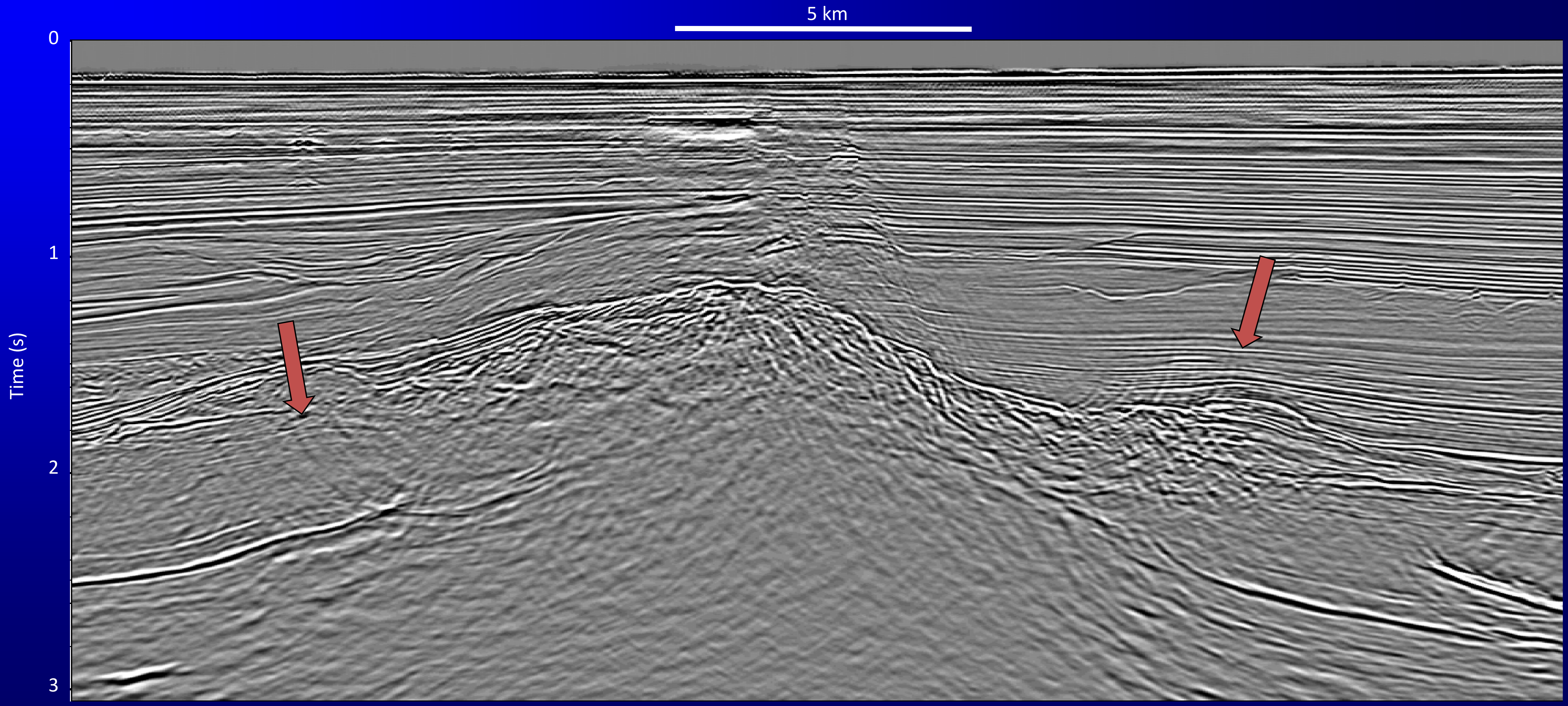
# Spectral balancing using spectral magnitude components

$$P(t, f, x, y) \equiv a^2(t, f, x, y)$$

$$a_{flat}(t, f, x, y) = \left\{ \frac{\underset{f}{MAX}\left[P_{avg}(t, f)\right]}{P_{avg}(t, f) + \varepsilon \underset{f}{MAX}\left[P_{avg}(t, f)\right]} \right\}^{1/2} a(t, f, x, y)$$



# Spectral Balancing

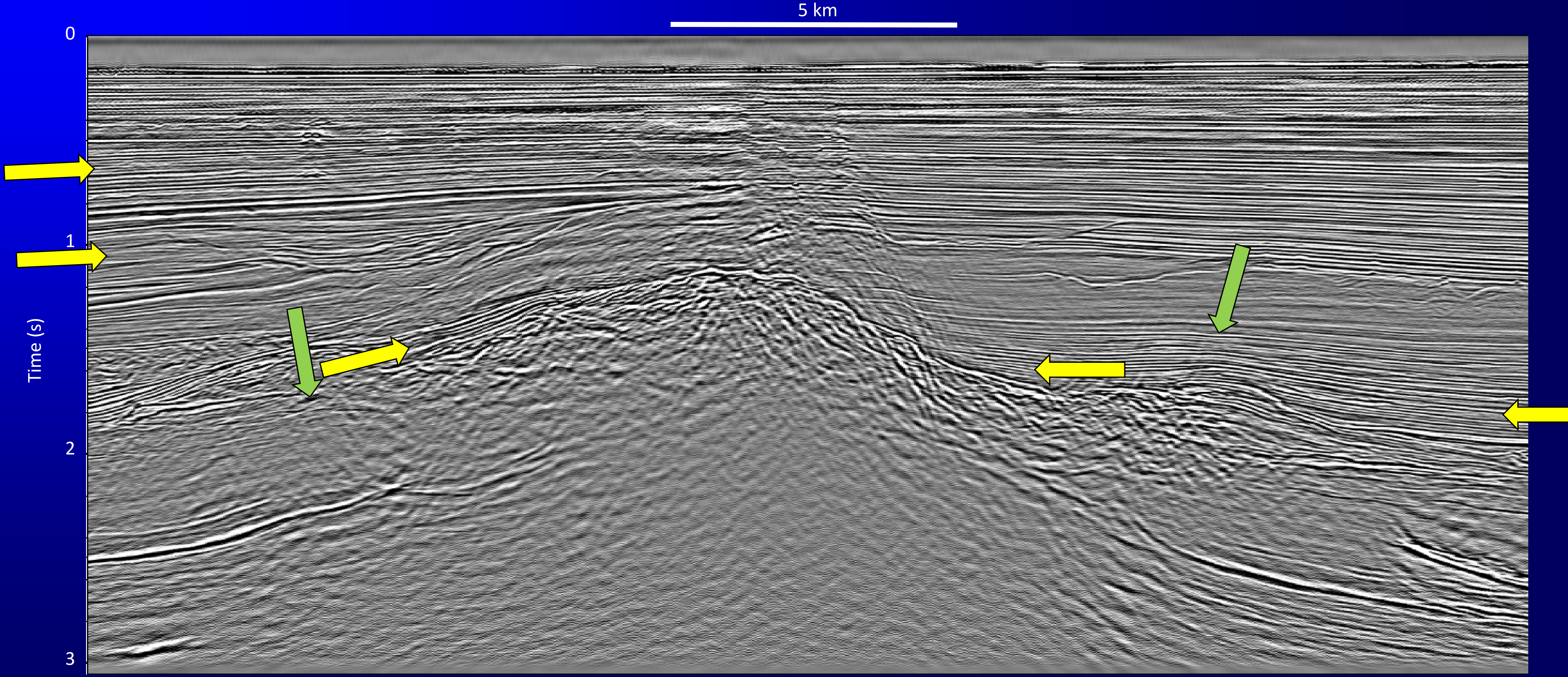



Original data resample to 2 ms



(Marfurt, 2018)

# Spectral Balancing

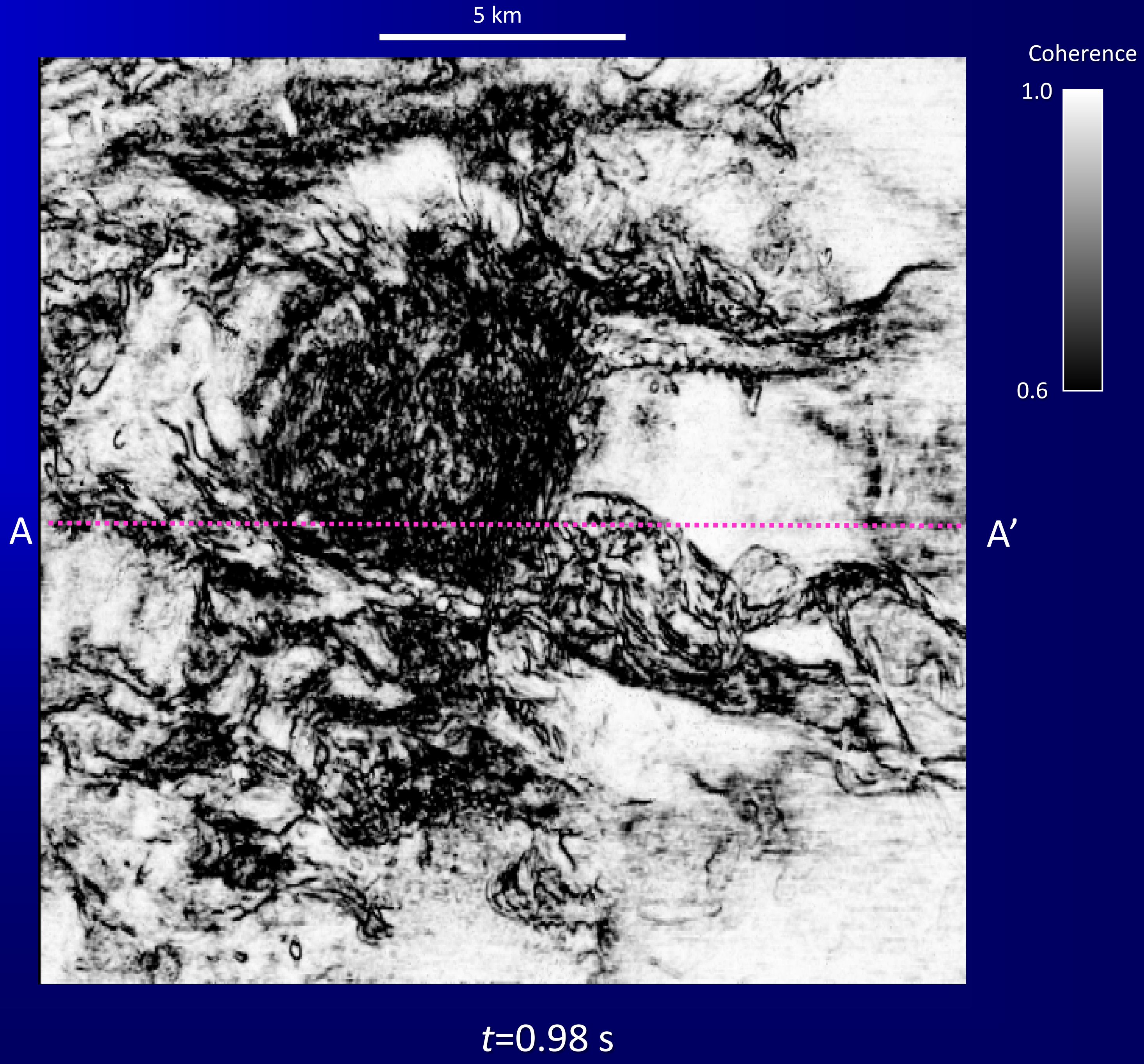



After spectral balancing



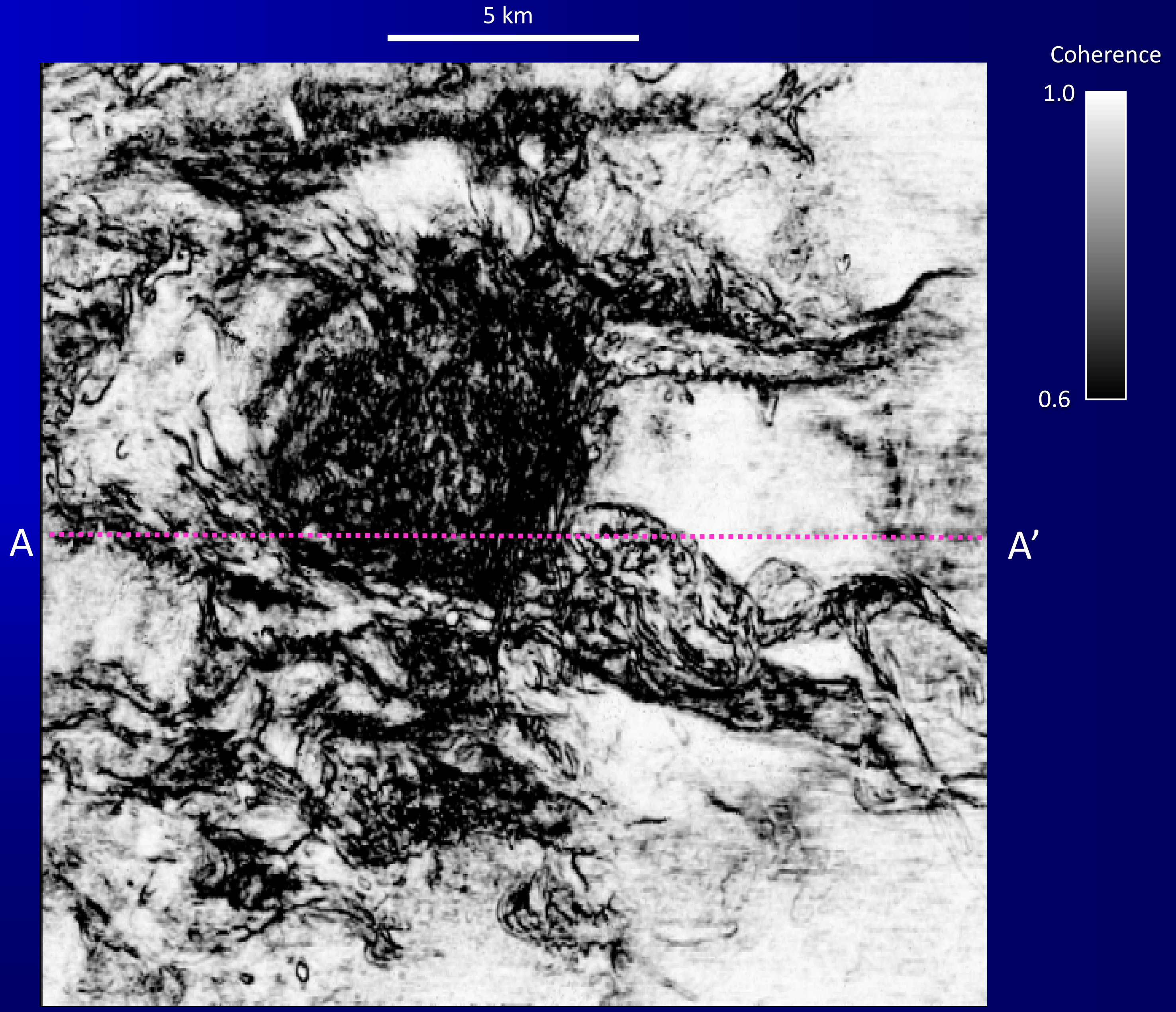
(Marfurt, 2018)

# Coherence computed before spectral balancing




(Marfurt, 2018)

# Coherence computed after spectral balancing



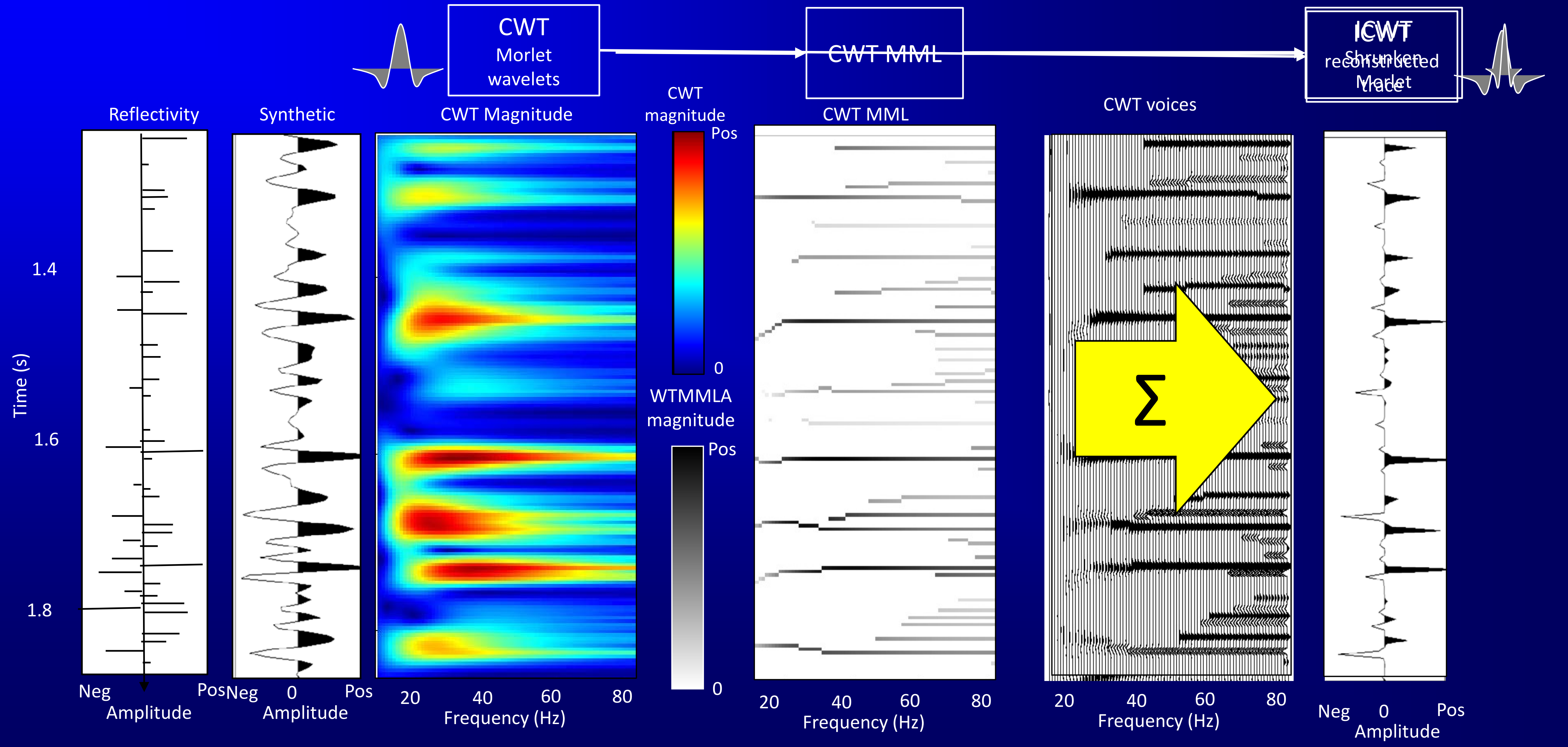

*t*=0.98 s

(Marfurt, 2018)

# Poststack Data Conditioning of Migrated Data

- Spectral balancing
- Bandwidth extension

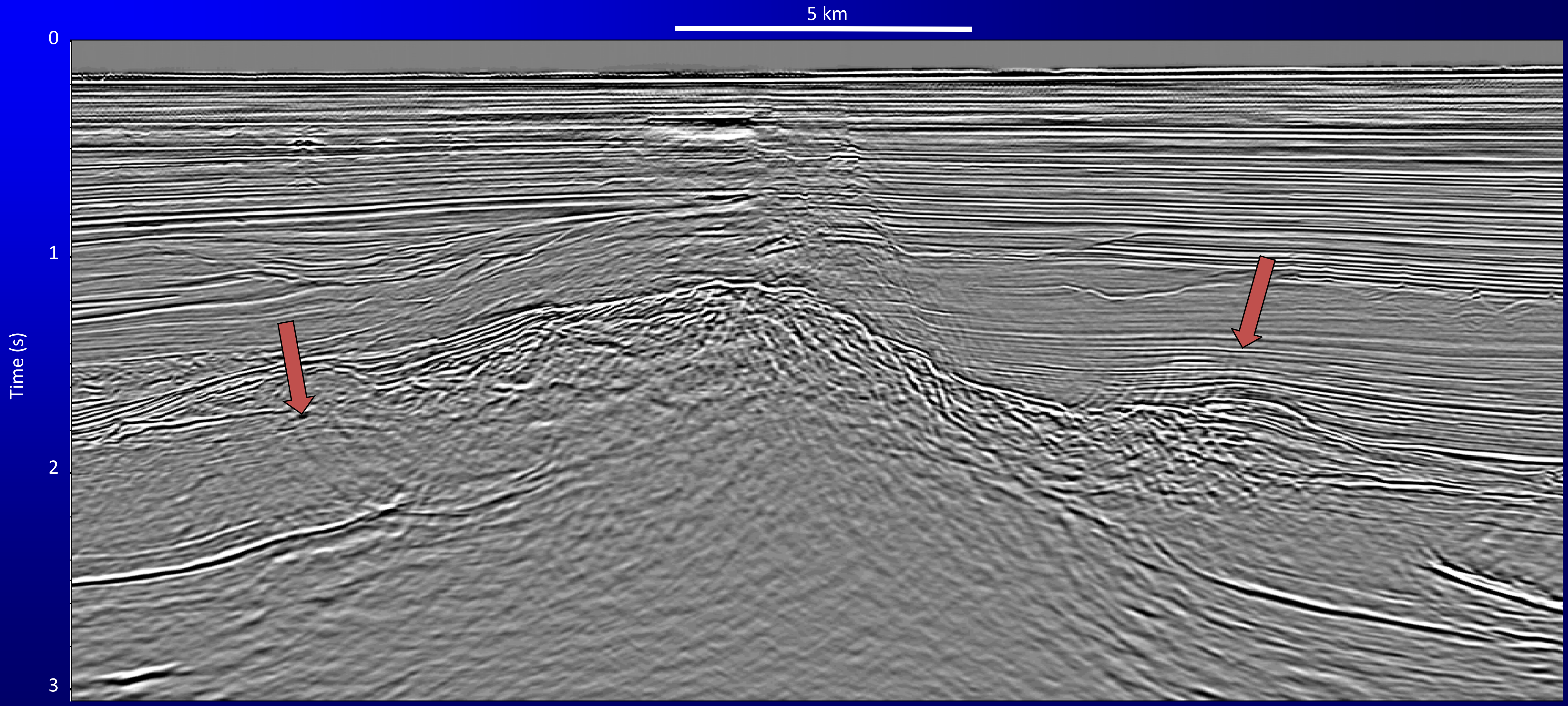
# Bandwidth extension using Mallat's concept of spectral ridges






(Matos and Marfurt, 2011)

# Bandwidth extension using inverse CWT "deconvolution"

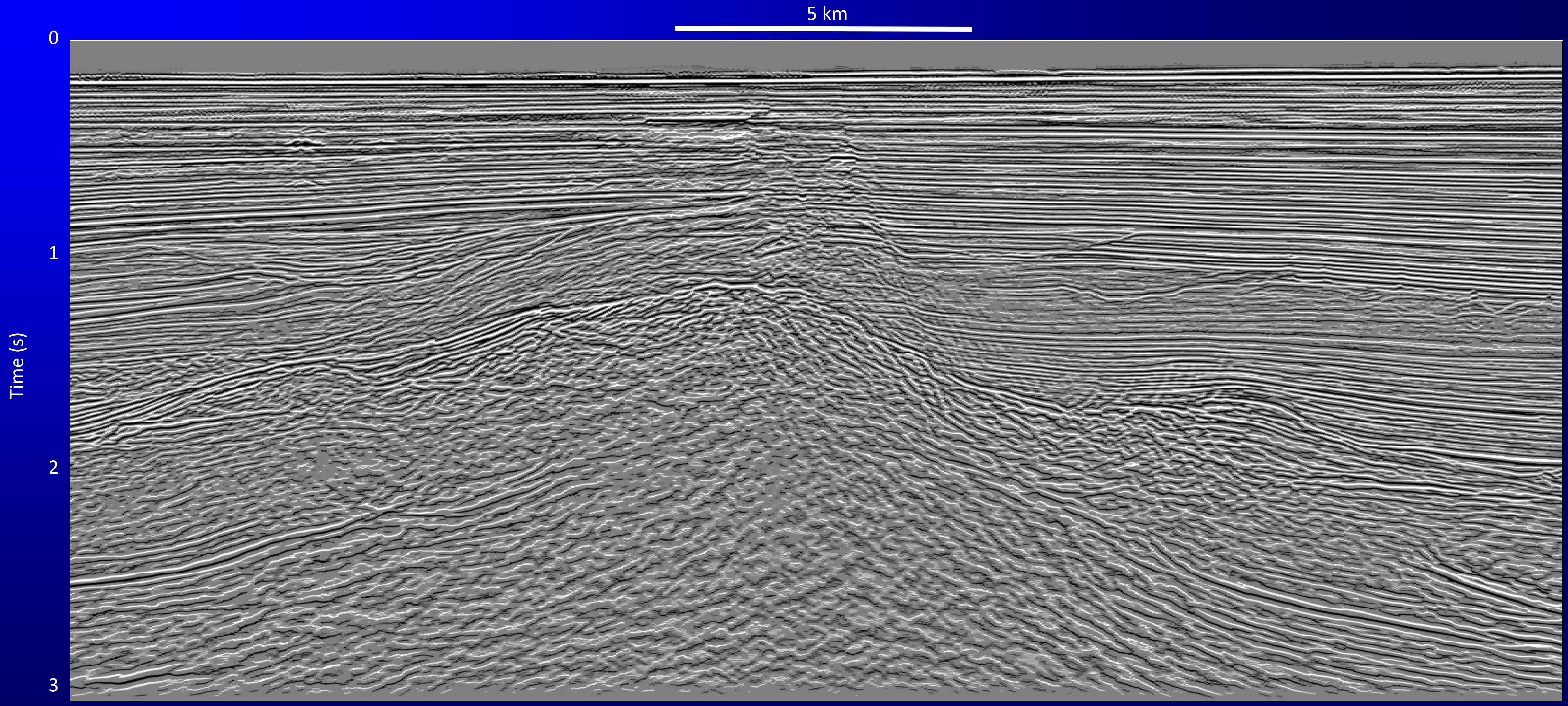



Original data resample to 1 ms



(Marfurt, 2018)

# Bandwidth extension using inverse CWT "deconvolution"

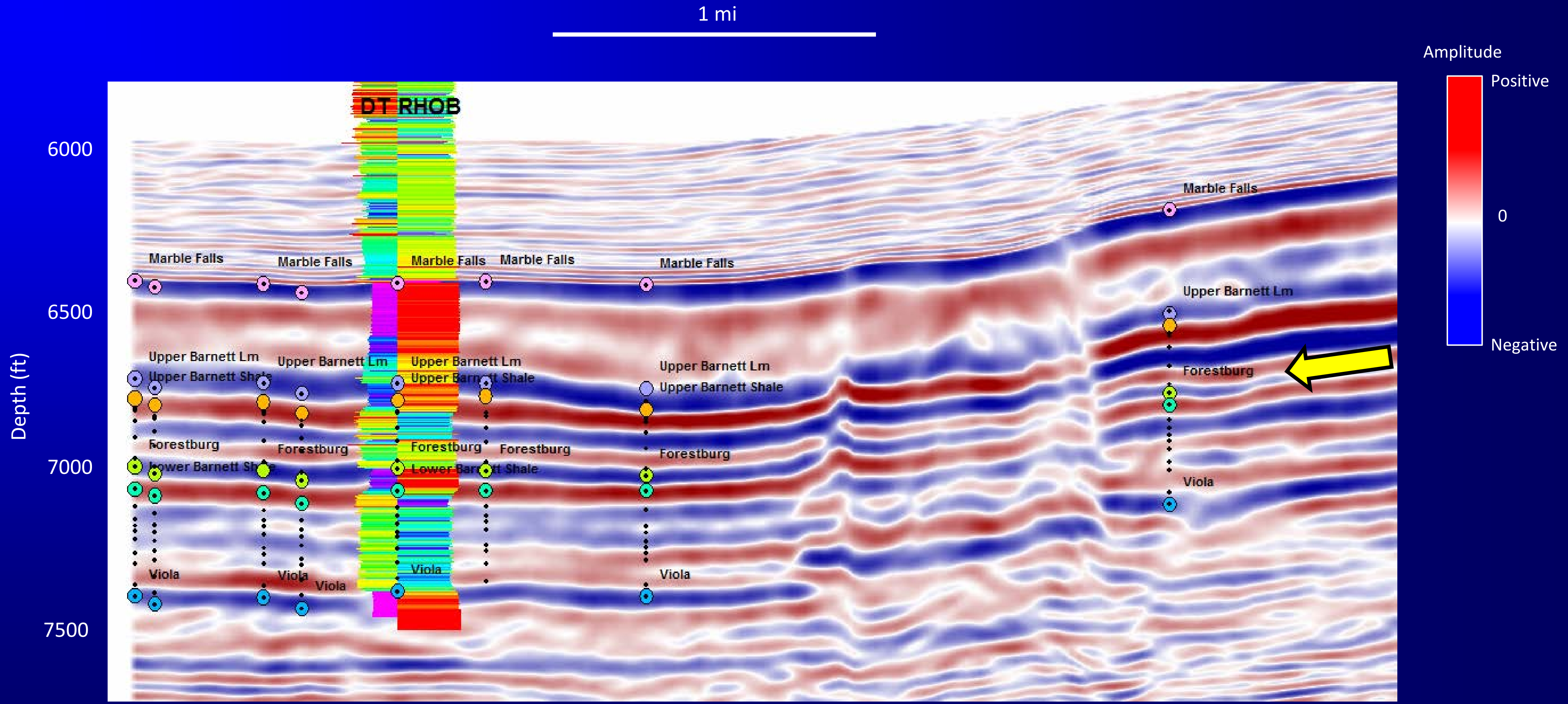



After bandwidth extension



(Marfurt, 2018)

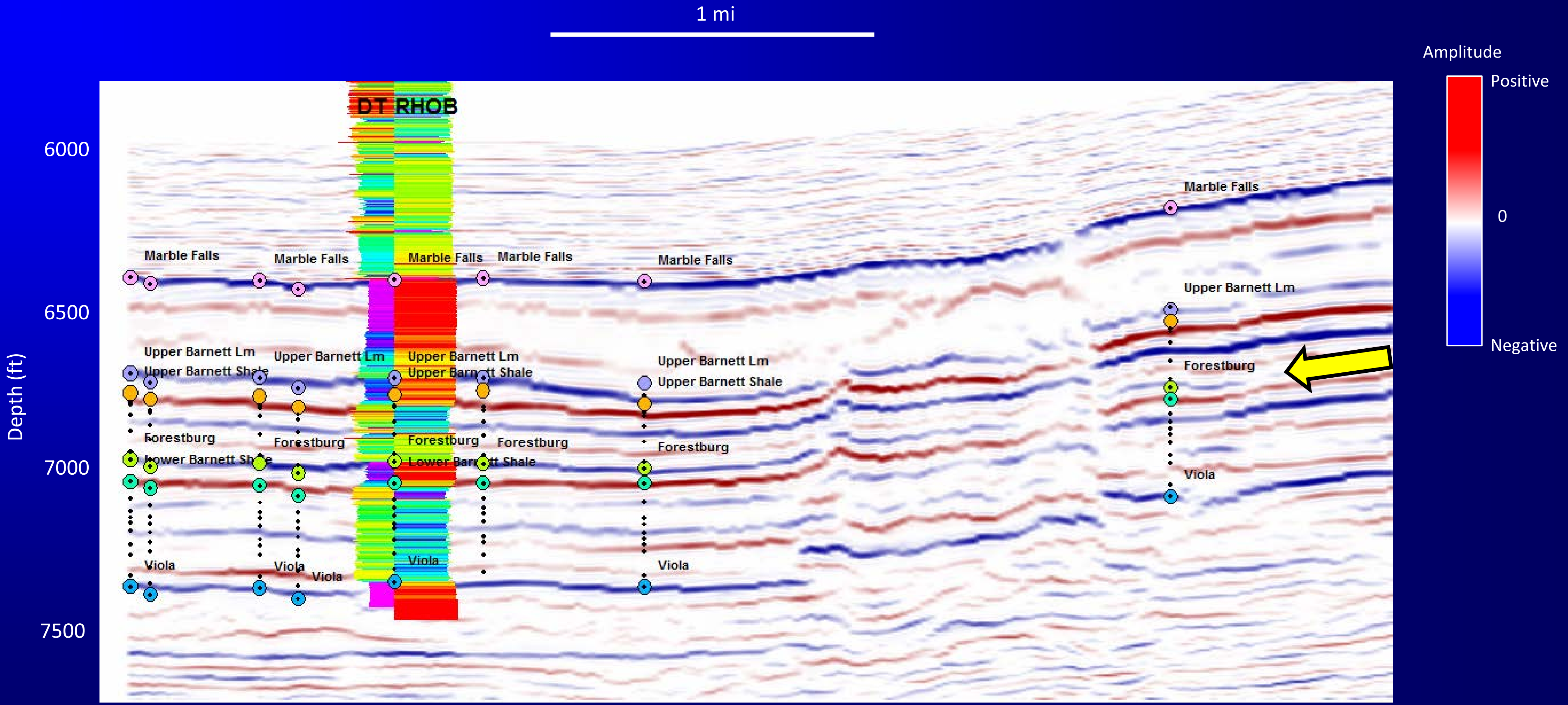
# Original Seismic Amplitude for a Barnett Shale survey






(Matos and Marfurt, 2011)

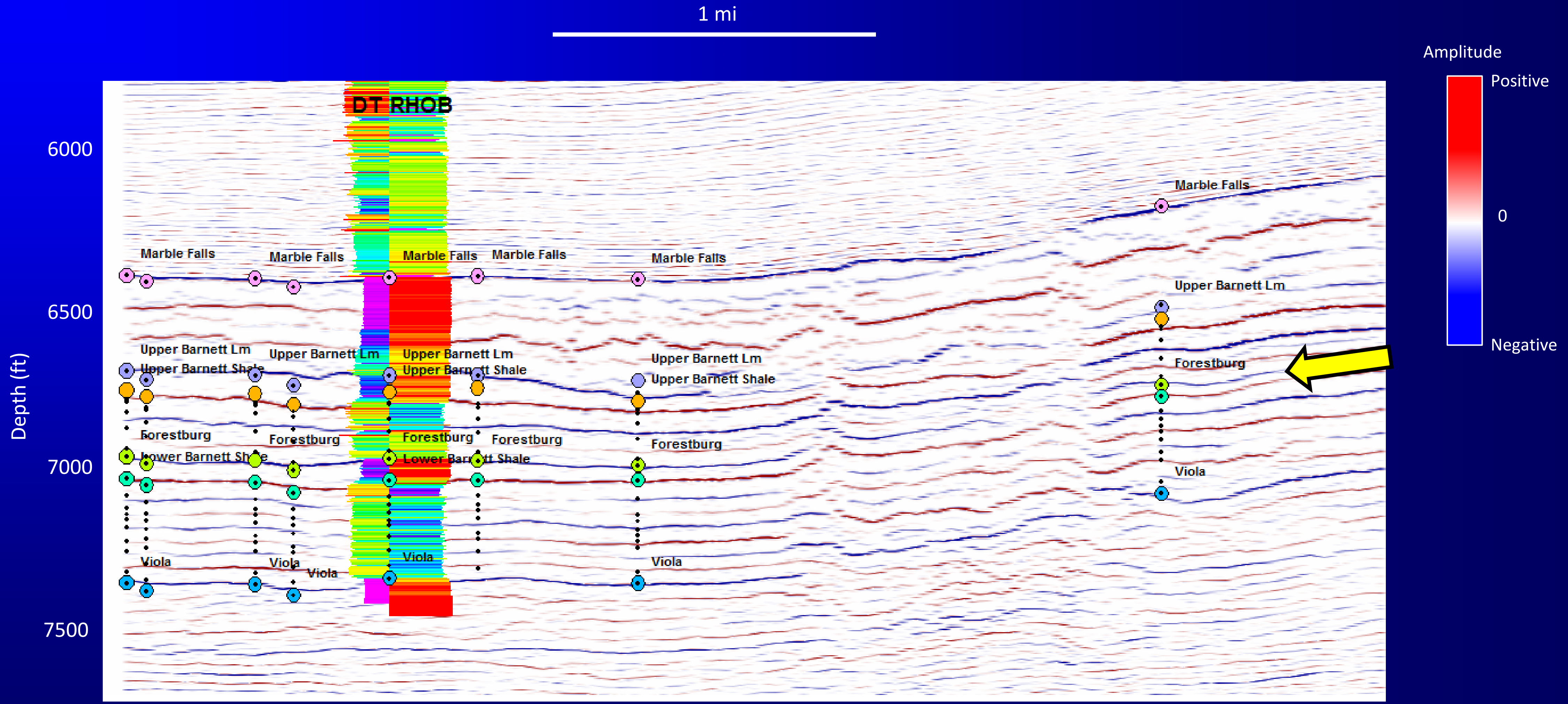
# “Bandwidth extension” using the inverse CWT





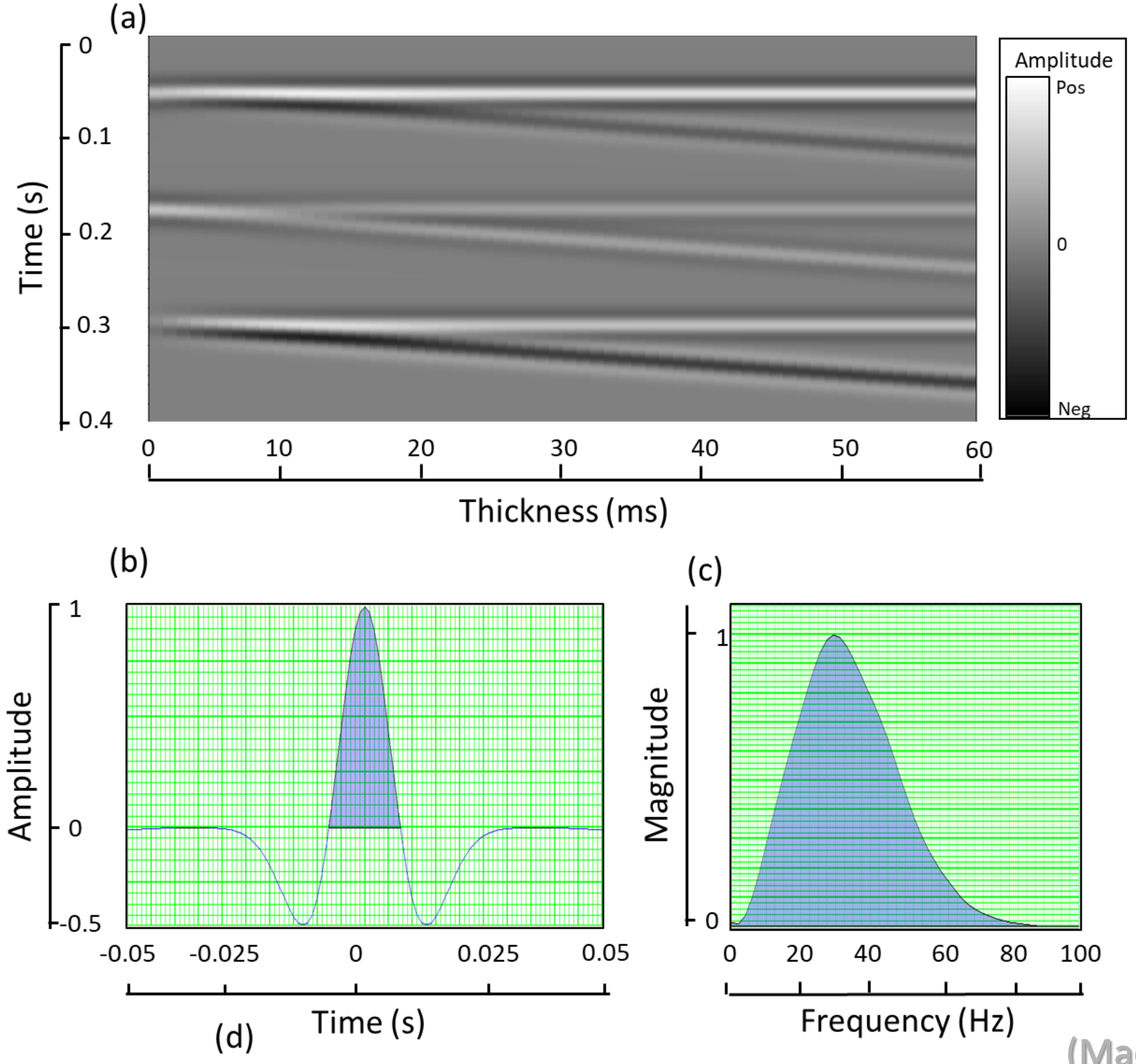

(Matos and Marfurt, 2011)

# Bandwidth extension using a basis-pursuit algorithm



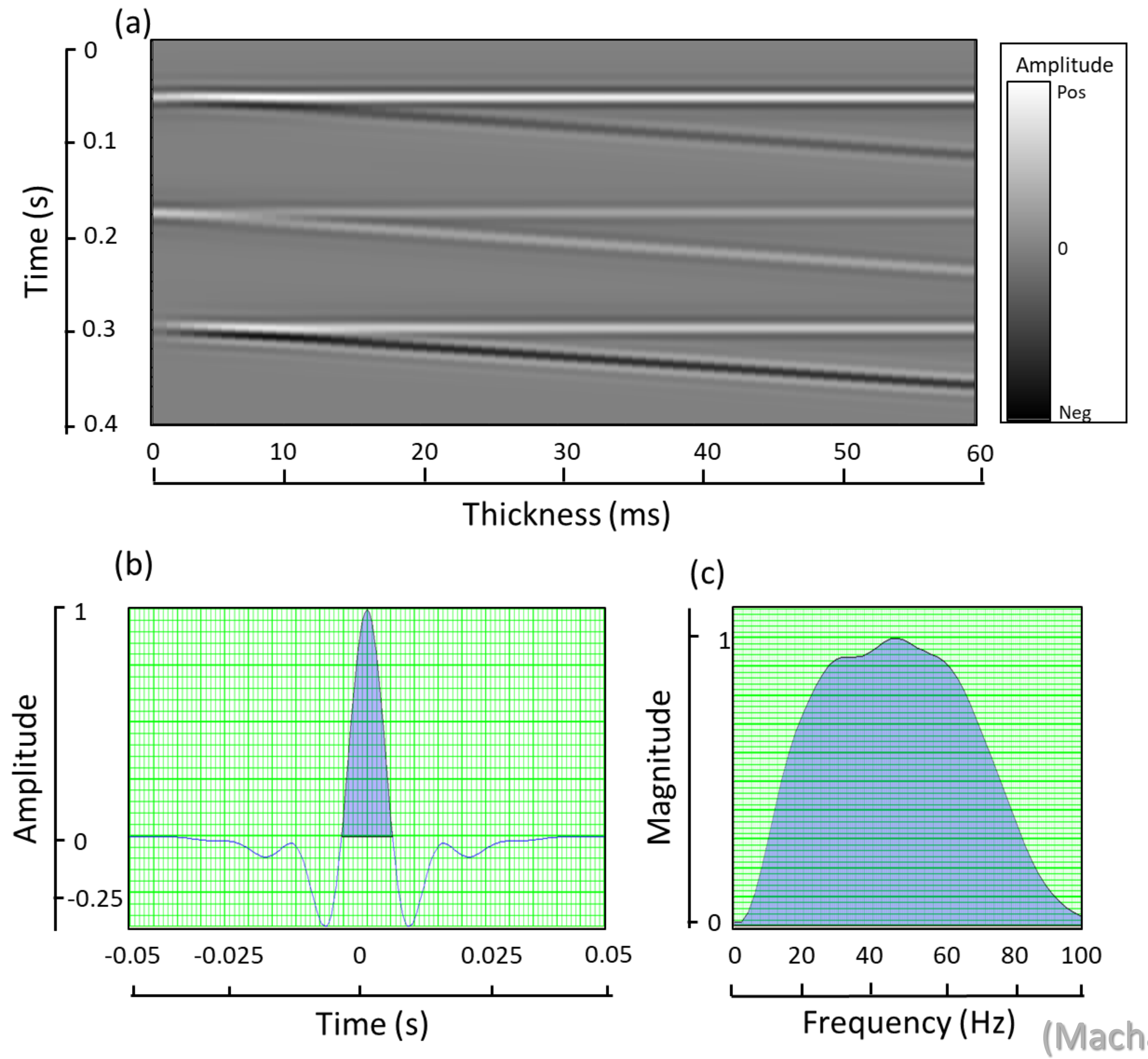

(Matos and Marfurt, 2011)

# Three simple wedge models



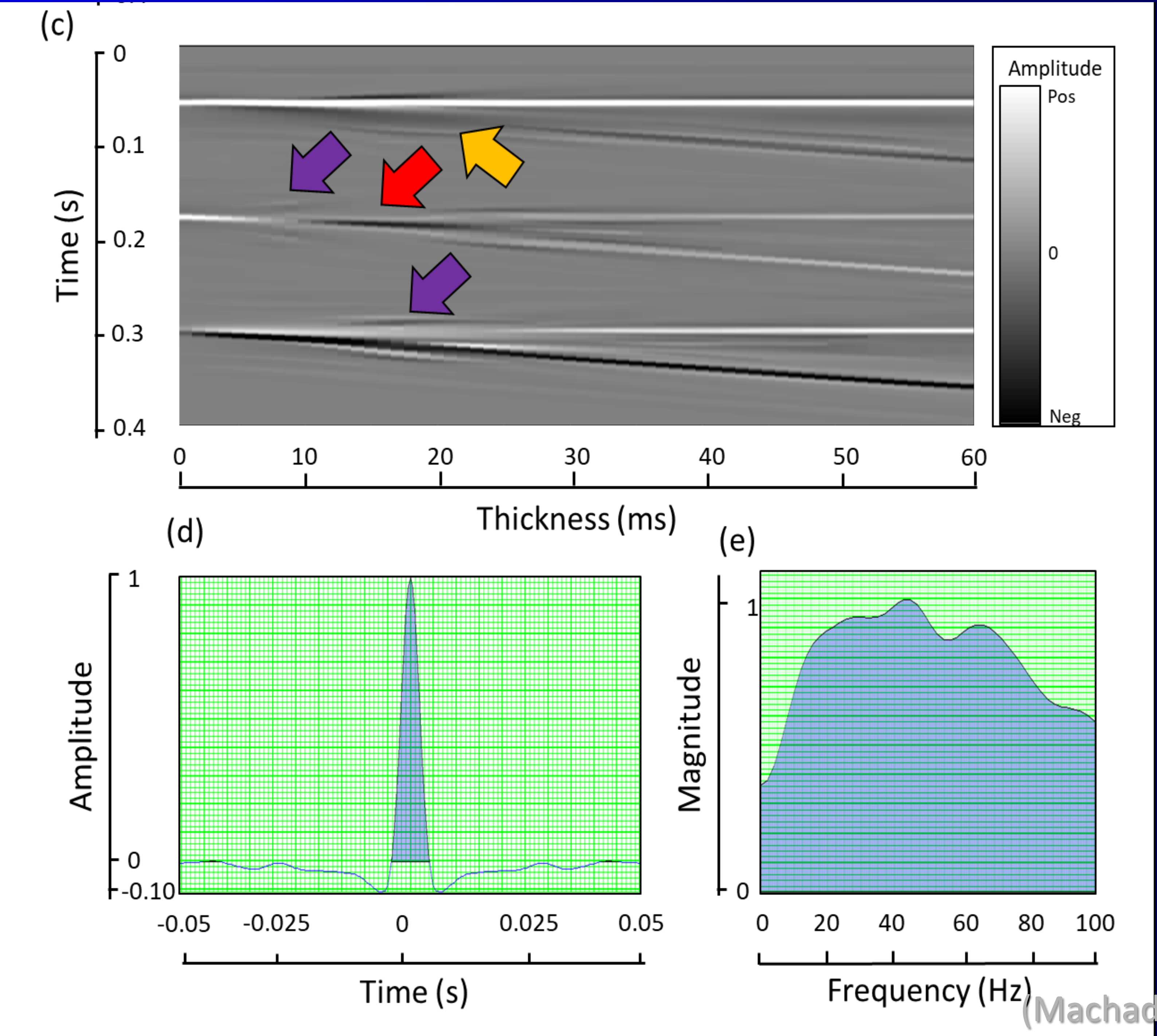

(Machado, 2018)

# After spectral balancing



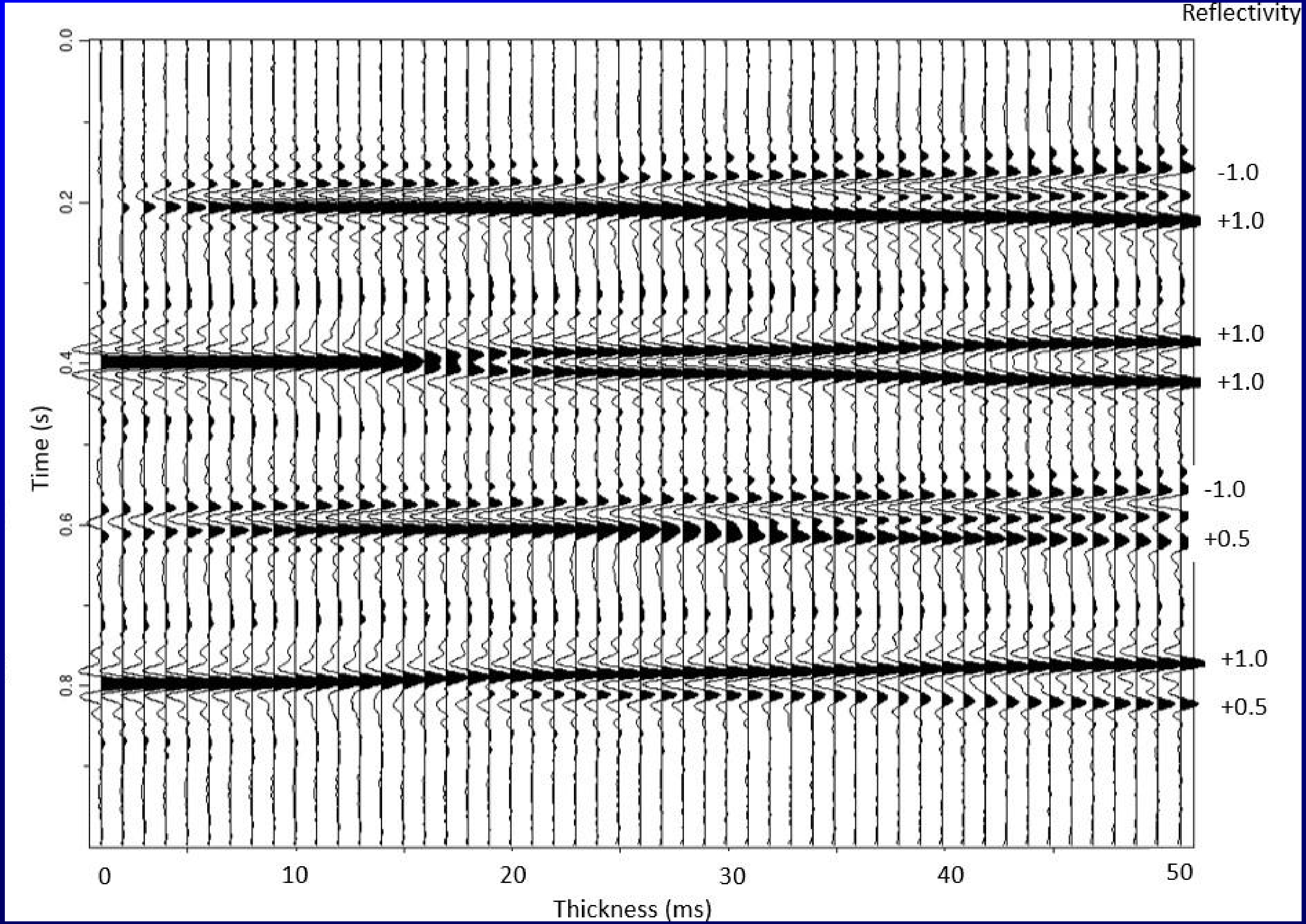

(Machado, 2018)

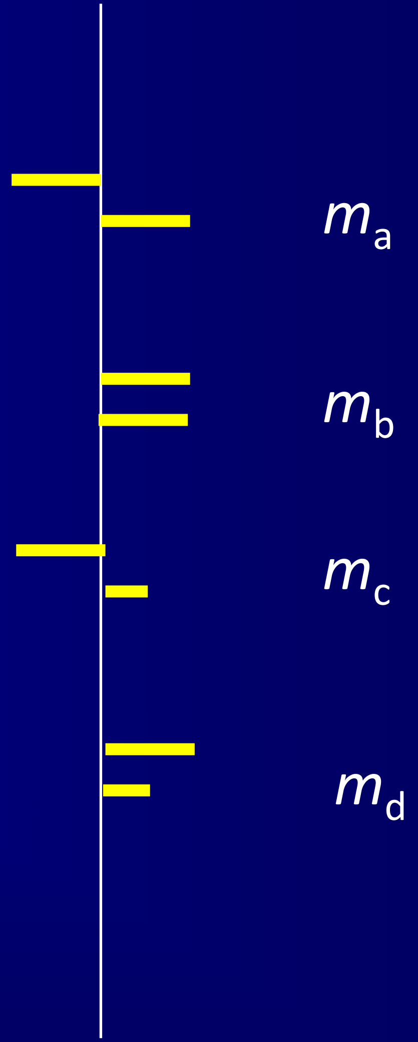
# After CWT-based bandwidth extension




(Machado, 2018)

# Review of Chung and Lawton's (1995) thin-bed (wedge) models




Note that $m_c=½m_a-½m_b$ and $m_d=-¼m_a+¾m_b$



(Chopra et al., 2023)

# Bandwidth extension based on thin-bed reflectivity inversion

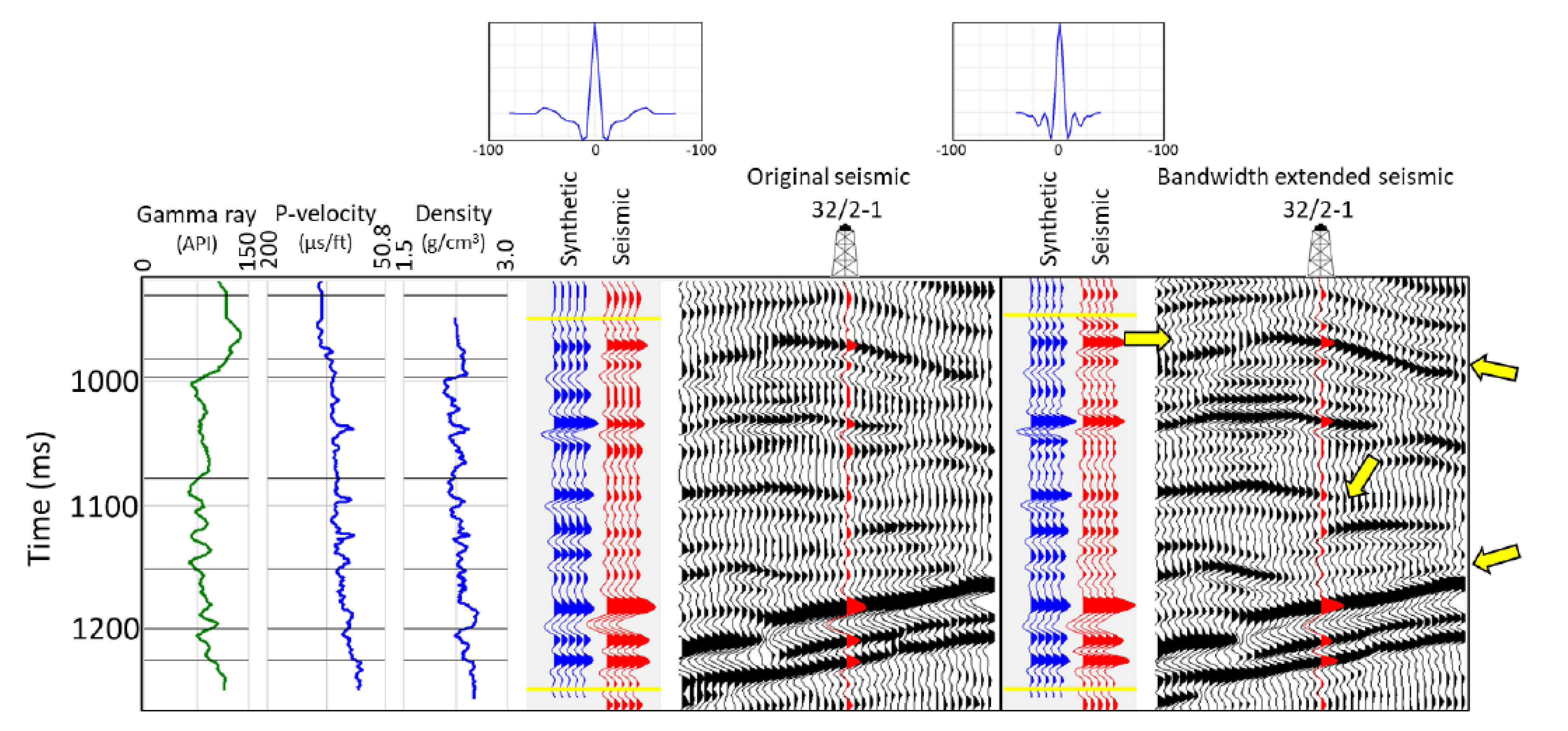
- Traditionally, we represent the response of geologic horizons as a system of spikes with an unknown coefficients
- If we know the seismic wavelet, we can estimate the location, polarity, and amplitude of these spikes
- We can then apply a bandpass filter to the spikes to generate a higher-resolution version of the seismic data

Solve using maximum likelihood least-squares?

- Alternatively, we can represent the response of geologic layers as a system of doublets with unknown coefficients
- If we know the seismic wavelet, we can estimate the location, polarity, and amplitude of these doublets
- We can then apply a bandpass filter to the spikes to generate a higher-resolution version of the seismic data

Solve using basis pursuit

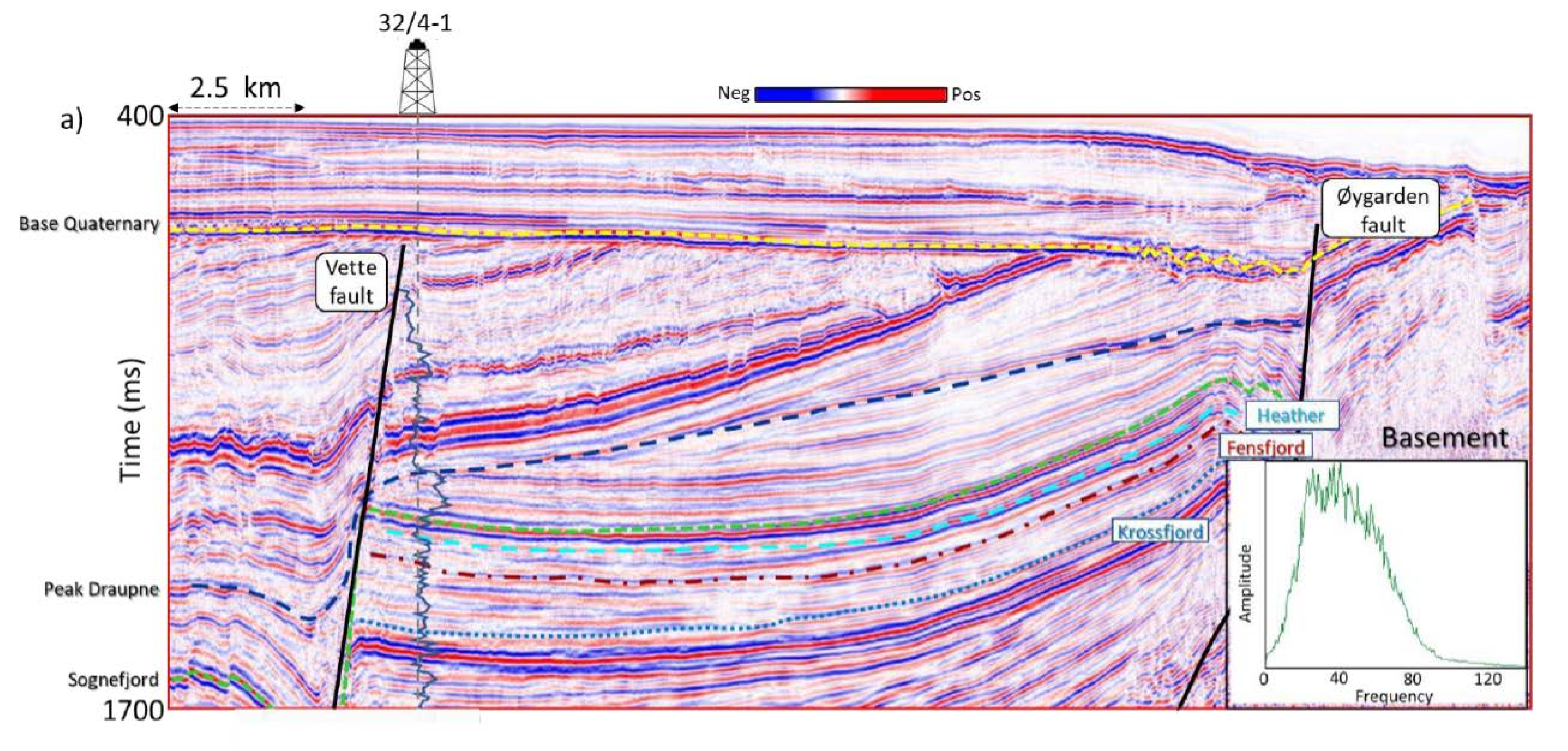
# Bandwidth extension based on thin-bed reflectivity inversion






(Chopra et al., 2023)

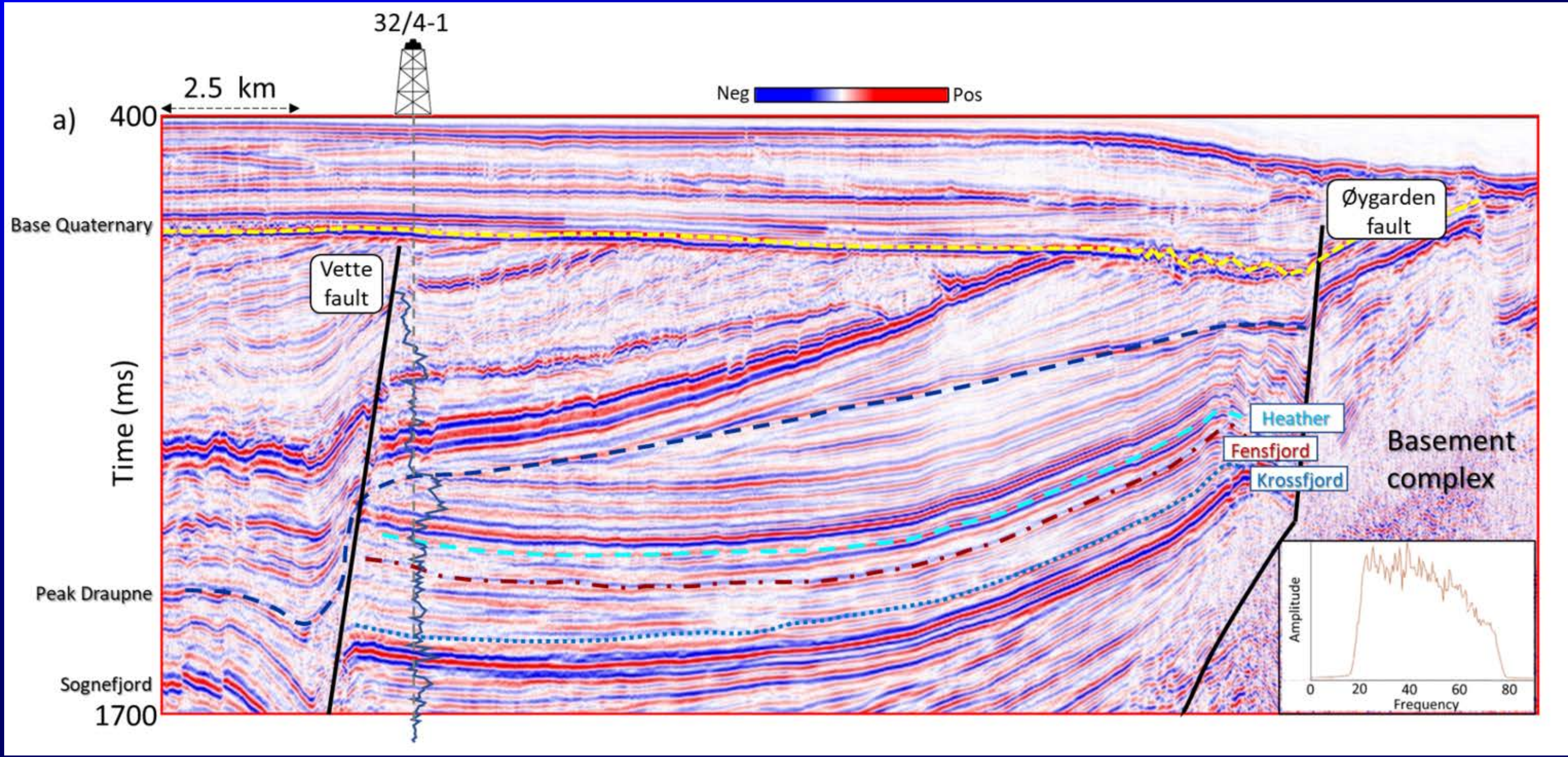
# Original data





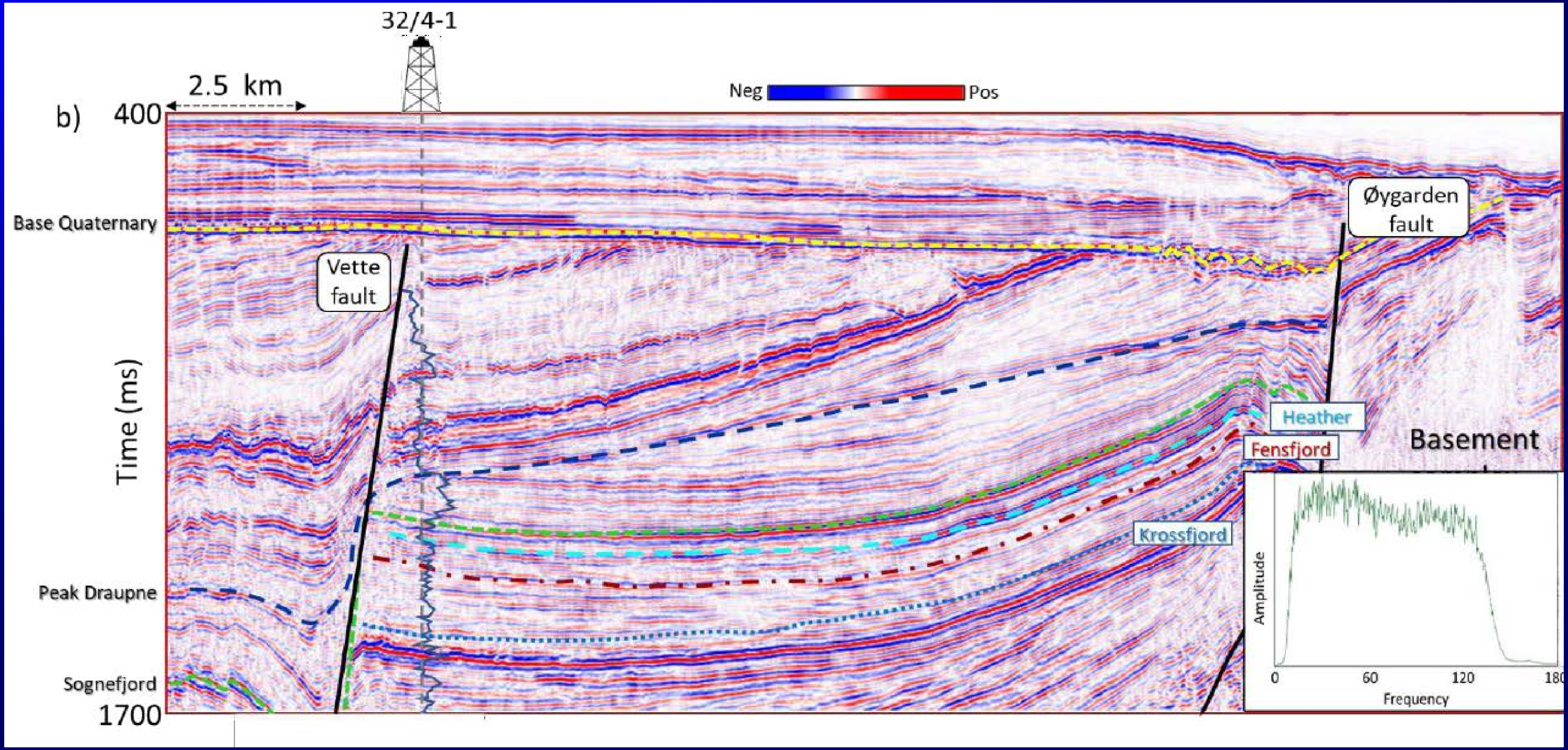

(Chopra et al., 2023)

# Data after spectral balancing




(Chopra et al., 2023)

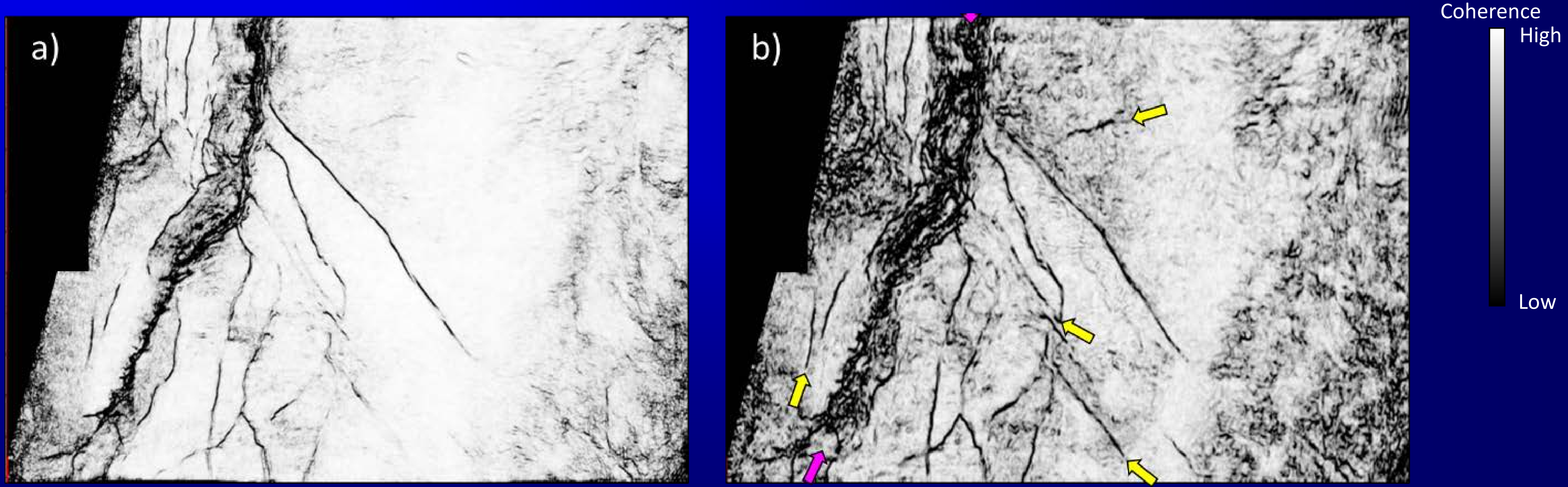
# Data after inversion for doublets and bandwidth extension




(Chopra et al., 2023)

## Coherence on original data

## Coherence after bandwidth extension






(Chopra et al., 2023)

# Post Migration Poststack Data Conditioning – Spectral Balancing

## In Summary:

- Spectral balancing based on time-variant laterally constant operators results in amplitude friendly filters that do not negatively impact impedance inversion that use different wavelets for targets at different depths
- There are several bandwidth extension algorithms in the marketplace. Most provide cosmetically appealing images that increase the bandwidth of resolved horizons but do not improve the resolution of thin layers that exhibit tuning phenomena
- At present, it appears that model-based bandwidth extension algorithms using basis pursuit algorithms are the only ones that provide improved resolution of thin beds