Spectral Recomposition in Stratigraphic Interpretation*

Yihua Cai[1], Sergey Fomel[2], and Hongliu Zeng[2]

Search and Discovery Article #41376 (2014)**
Posted June 30, 2014

*Adapted from oral presentation given at Geoscience Technology Workshop, Deepwater Reservoirs, Houston, Texas, January 28-29, 2014

[1]Shell, Houston, TX (yihua.cai@shell.com)
[2]University of Texas at Austin, Austin, TX

Abstract

Spectral recomposition splits the seismic spectrum into Ricker components. It provides a tool for imaging and mapping temporal bed thicknesses and geologic discontinuities. We propose separable nonlinear least-squares estimation in spectral recomposition. Employing the Gauss-Newton method, separable nonlinear least-squares approach estimates fundamental signal parameters: peak frequencies and amplitudes.

References Cited

Chakraborty, A., and D. Akaya, 1995, Frequency-time decomposition of seismic data using wavelet-based methods: Geophysics, v. 60/6, p. 1906-1916.

Chen, G., G. Matteucci, B. Fahmy, and C. Finn, 2008, Spectral-decomposition response to reservoir fluids from a deepwater West Africa reservoir: Geophysics, v. 73/6, p. C23-C30.

Chopra, S., and K.J. Marfurt, 2007, Volumetric curvature attributes adding value to 3D seismic data interpretation: The Leading Edge, v. 26, p. 856-867.

Spectral Recomposition in Stratigraphic Interpretation

Yihua Cai*, Sergey Fomel, and Hongliu Zeng

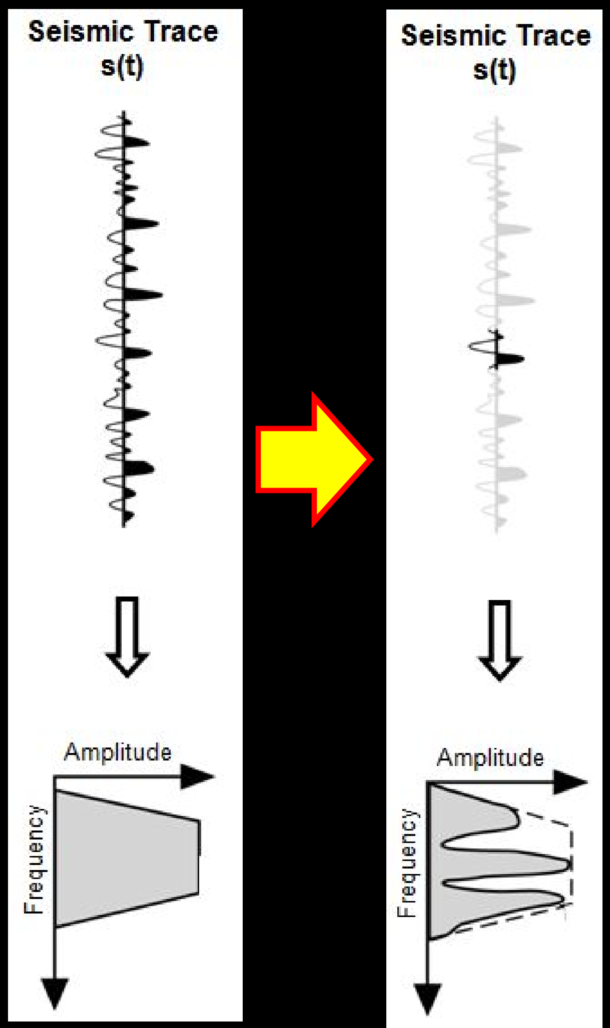
University of Texas at Austin

* Currently with Shell

Outline

- ❑ Motivation and Background
  - ❑ Spectral Analysis
  - ❑ Spectral Recomposition
- ❑ Theory and Numerical Method
  - ❑ Theory
  - ❑ Numerical Method – Separable Nonlinear Least Squares Estimation
  - ❑ Synthetic and Real Data Examples
- ❑ Application of Spectral Recomposition
  - ❑ Seismic Data Display
  - ❑ Stratal Slice Imaging and RGB Color Blending Plot
  - ❑ Time-frequency Analysis Estimation
- ❑ Summary

Spectral Analysis



Long Window **Short Window**

❑ Spectral analysis:

1. Long window vs. short window;
2. Spectral decomposition for short window analysis.

❑ Spectral decomposition is helpful because:

1. Unpredictable geology and whitened spectrum in a long window;
2. In short window analysis, local geology filters wavelet and overprints it in frequency domain.

❑ Some difficulties in spectral decomposition:

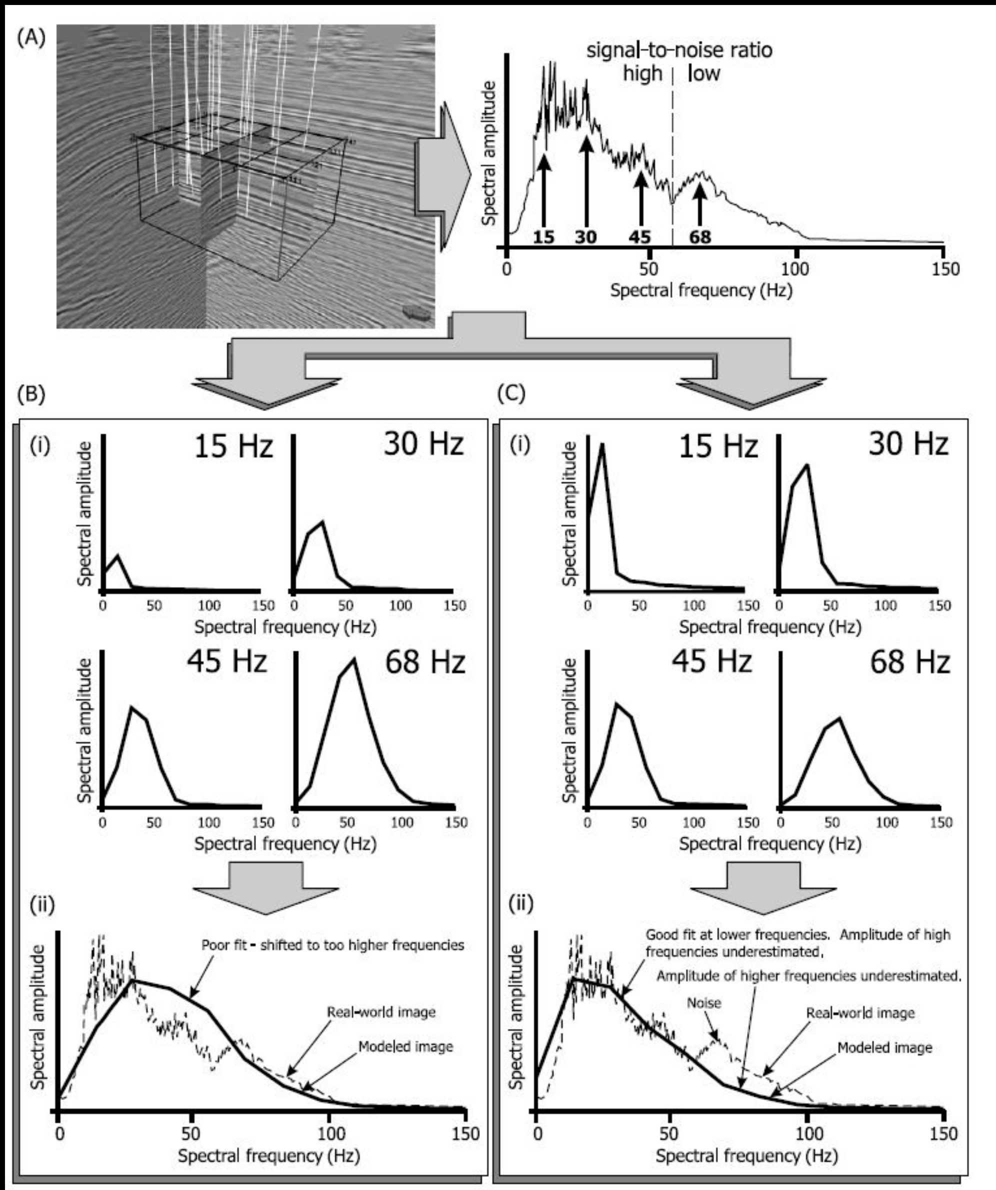
(Greg Partyka, James Gridley, and John Lopez, 1999)

1. Time-frequency resolution limit;
2. Residuals in “frequency gathers”.

(Chakraborty and Okaya, 1995)

(Chen, 2008)

Spectral Recomposition



1. Manually select component frequencies;
2. Compute spectrum of each component;
3. Scale amplitude spectrum of each component;
4. Sum components up.

(Mark Tomasso, Renaud Bouroullec and David Pyles, 2010)

Theory

Model: $$d(f) \approx \sum_{i=1}^{n} a_i \Psi_i(m_i, f)$$

$d(f)$ is the spectrum of seismic data;

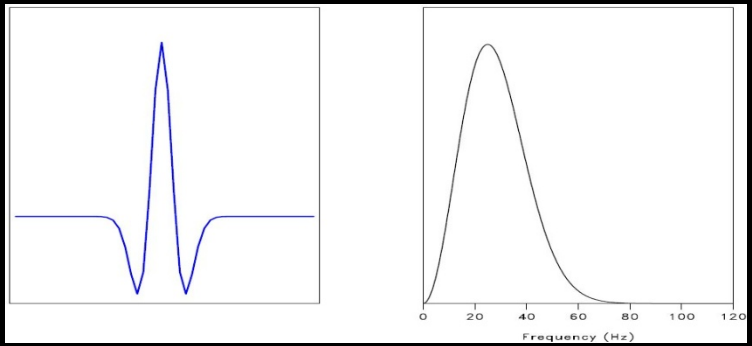
a_i and m_i are the amplitude and peak frequency of the i-th Ricker component.

Ricker spectrum: $$R(f) = a\Psi(m, f) = a\frac{f^2}{m^2}\exp(-\frac{f^2}{m^2})$$

To estimate a seismic spectrum, we need:

$$\mathbf{a} = \{a_1, a_2, \cdots, a_n\}$$ and $$\mathbf{m} = \{m_1, m_2, \cdots, m_n\}$$

Each component has its own amplitude and peak frequency terms.



Numerical Method – Separable Nonlinear Least Squares

Let $$r_j(\mathbf{a},\mathbf{m}) = d(f_j) - \sum_{i=1}^{n} a_i(\mathbf{m})\Psi_i(m_i, f_j)$$

Optimal least-squares estimation requires:

$$\min_{\mathbf{a},\mathbf{m}} \left\| \mathbf{r}(\mathbf{a},\mathbf{m}) \right\|_2^2$$

Linear and nonlinear parts are solved ***separately*** by least squares method.

(Scolnik, 1972)

The variable projection algorithm has been used. Assuming **m**, we have:

$$\mathbf{a} = \Psi(\mathbf{m})^\dagger \mathbf{d}$$

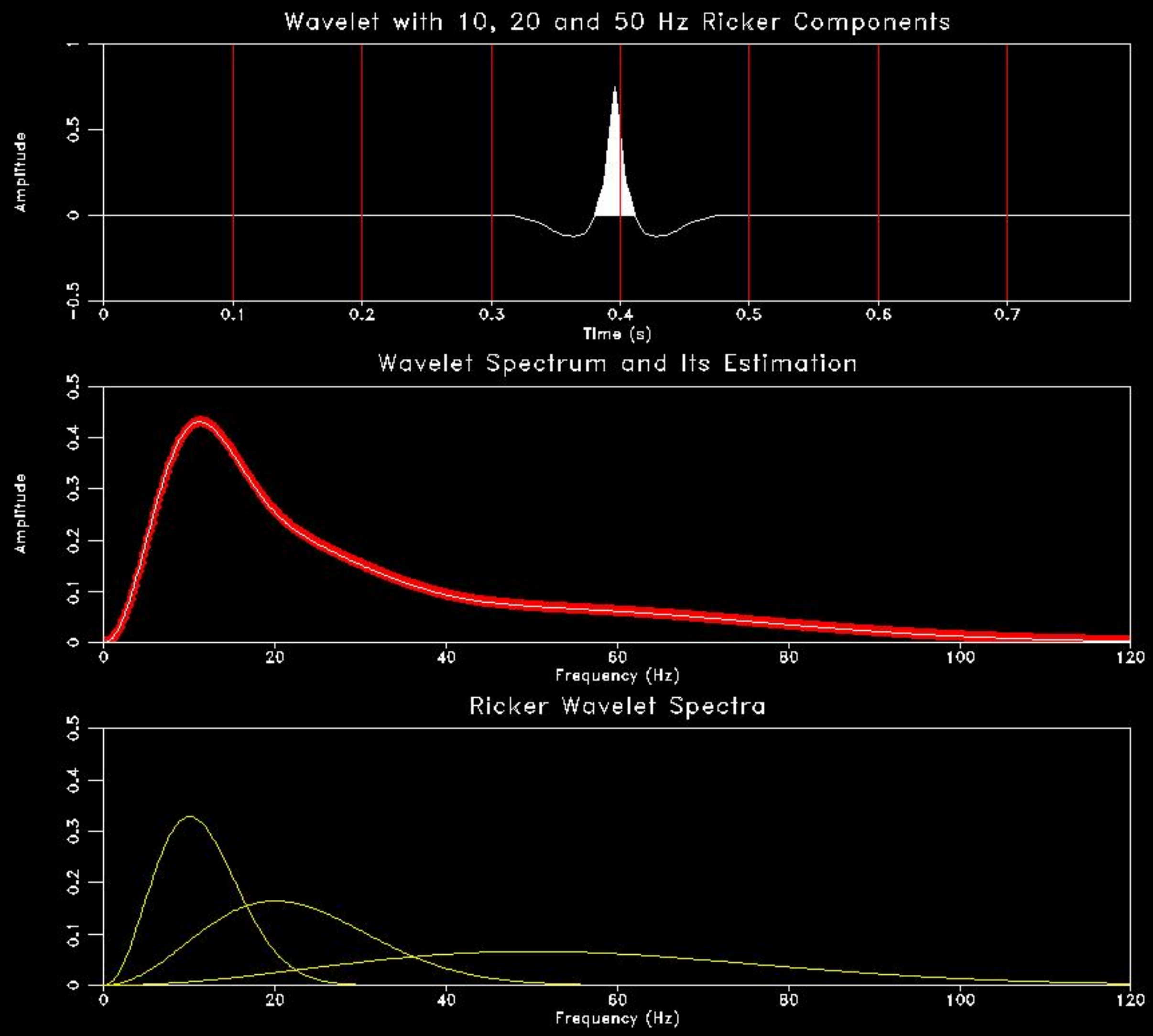
where $\Psi(\mathbf{m})$ is the matrix composed of $\Psi_i(m_i, f_j)$ (Golub & Pereyra, 1973)

Having **a** solved, we then need to solve $$\min_{\mathbf{m}} \left\| (\mathbf{I} - \Psi(\mathbf{m})\Psi(\mathbf{m})^\dagger)\mathbf{d} \right\|_2^2$$

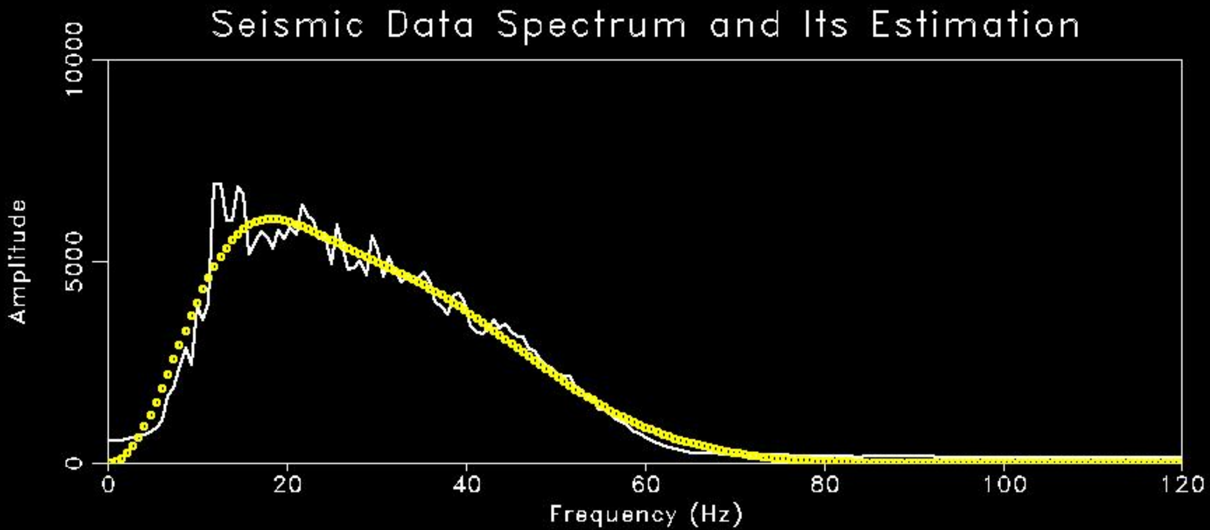
Gauss-Newton method has been used, hence

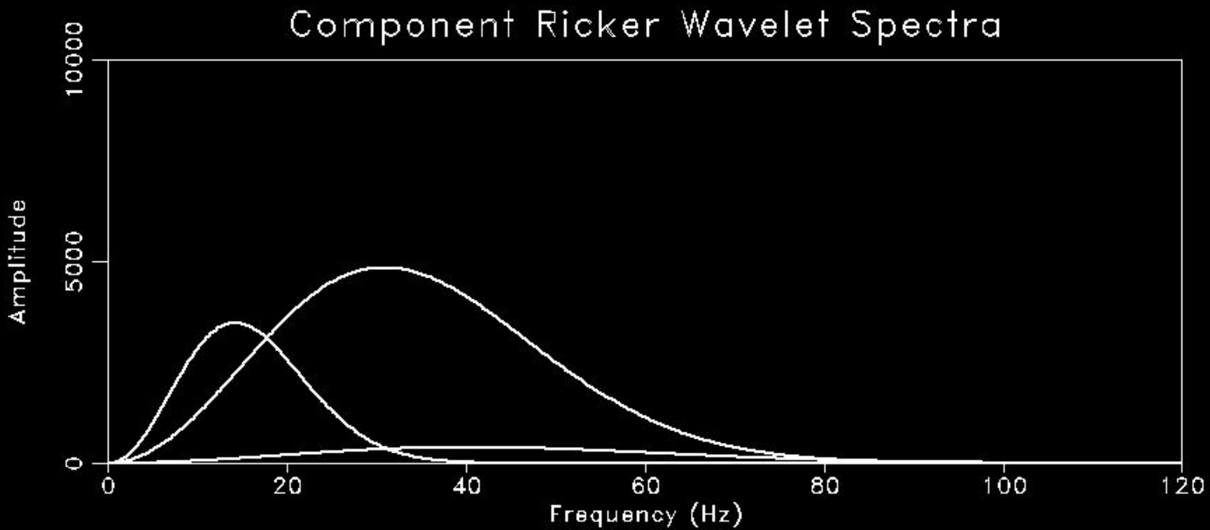
$$\begin{aligned} d(f_j) &\approx \sum_i r_j(m_i, f_j) + \sum_i \frac{\partial r_j}{\partial m_i} \Delta m_i \\ &\approx \sum_i a_i \Psi(m_i, f_j) + \sum_i [a_i' \Psi(m_i, f_j) + a_i \Psi'(m_i, f_j)] \Delta m_i \end{aligned}$$

Spectral Recomposition – Synthetic Data

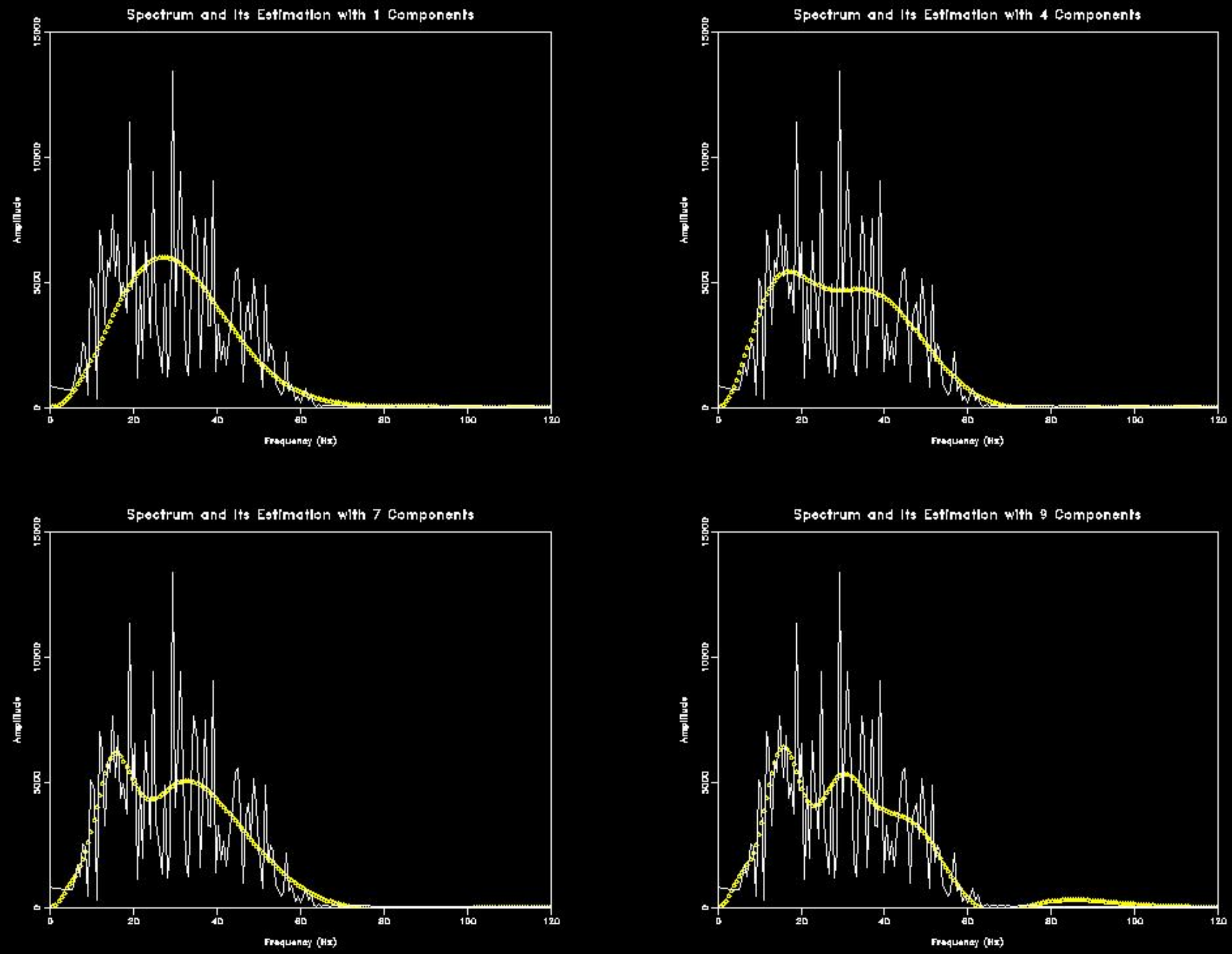


Spectral Recomposition – Real Data Example

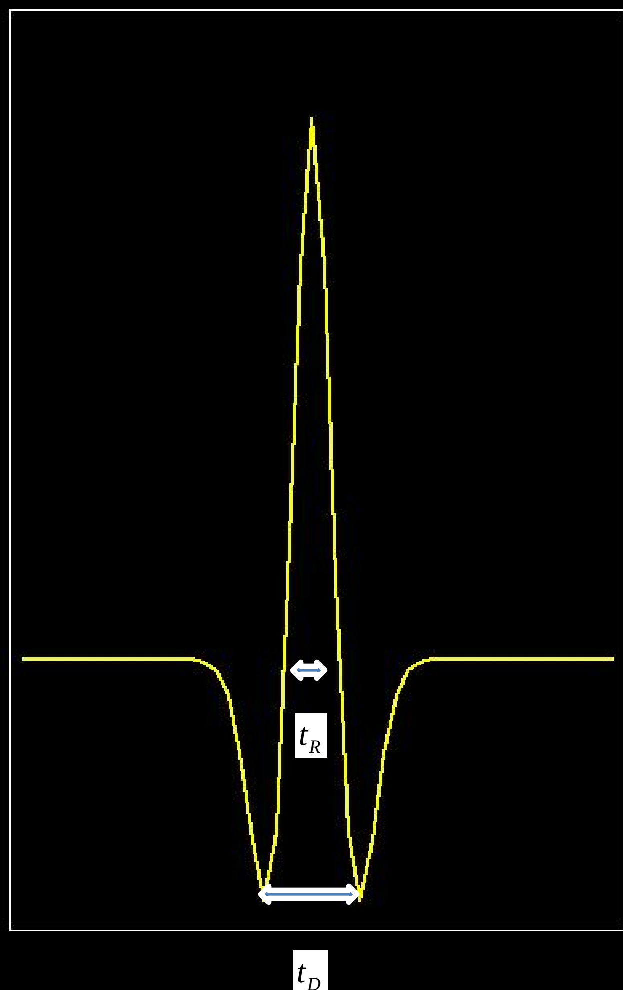




Spectral Recomposition – Data Fitting Example

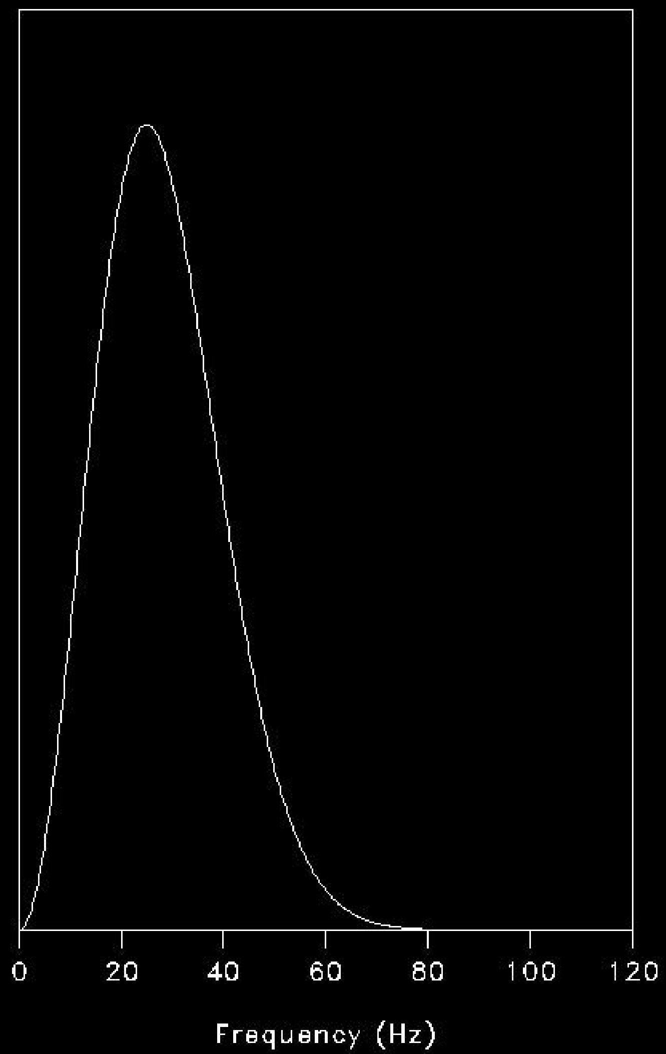


Frequency Band Picking



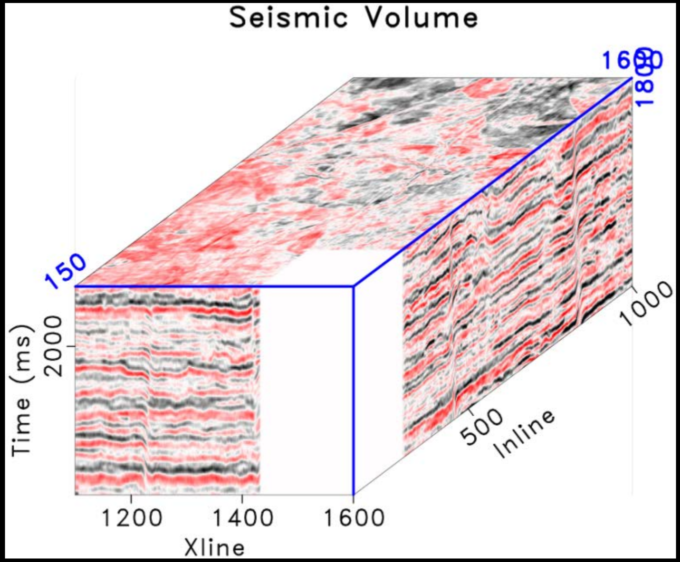
$t_R = t_D / \sqrt{3}$

$t_D = \sqrt{6} / f_m \pi$

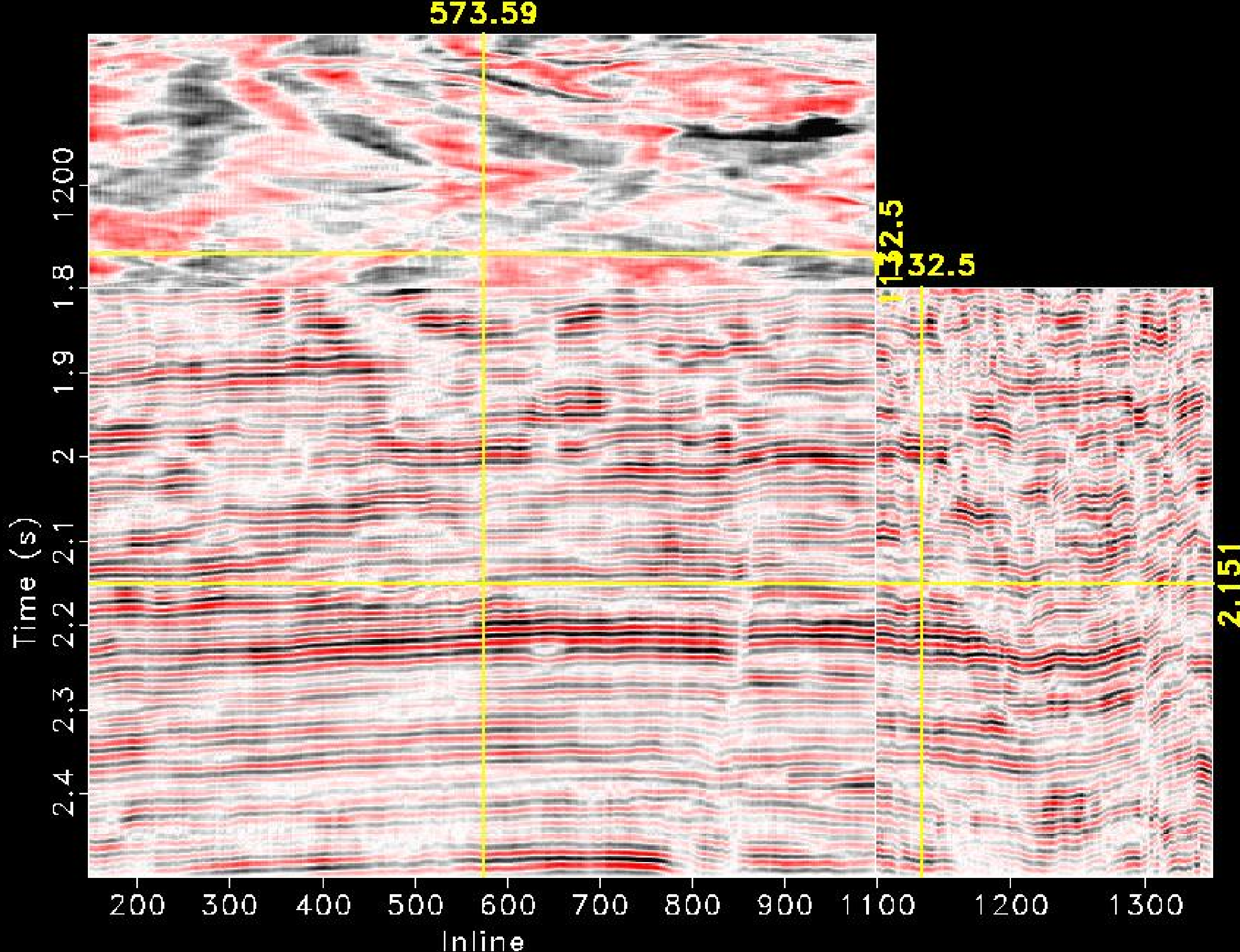


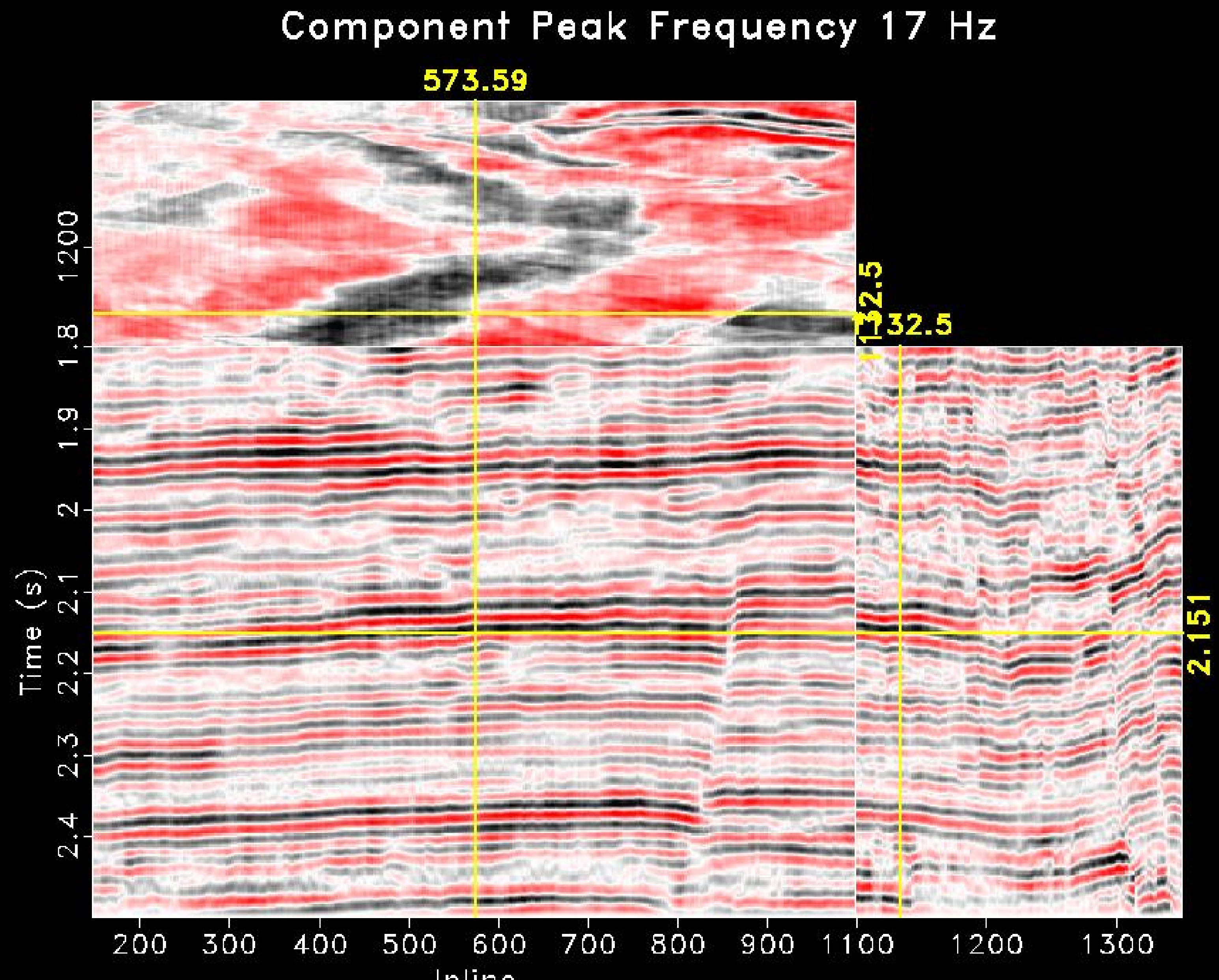
Application of Spectral Recomposition Using SNLS

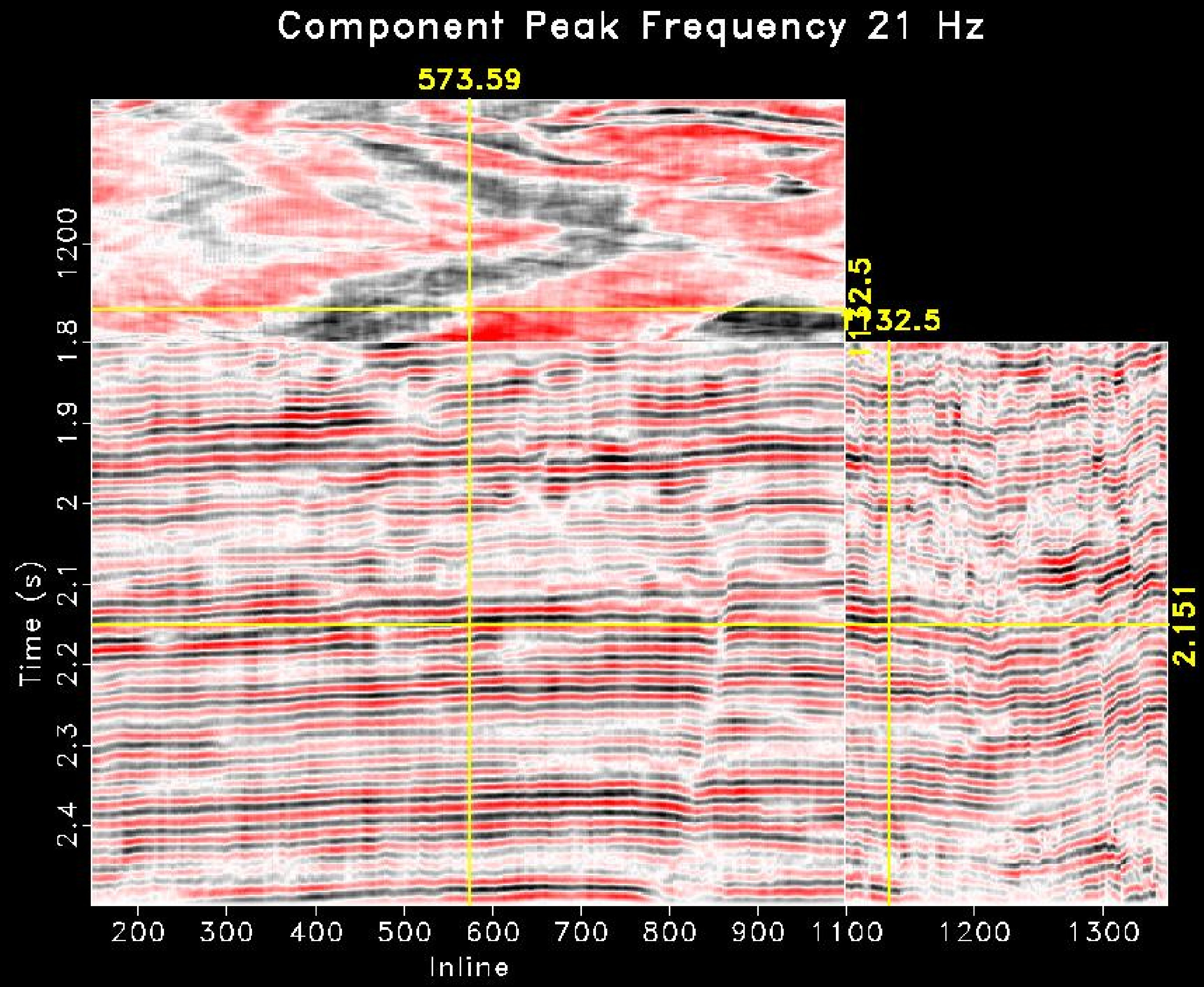
- Seismic image display
- Stratal slice imaging and RGB color blending
- Time-frequency analysis simulation



Component Peak Frequency 30 Hz

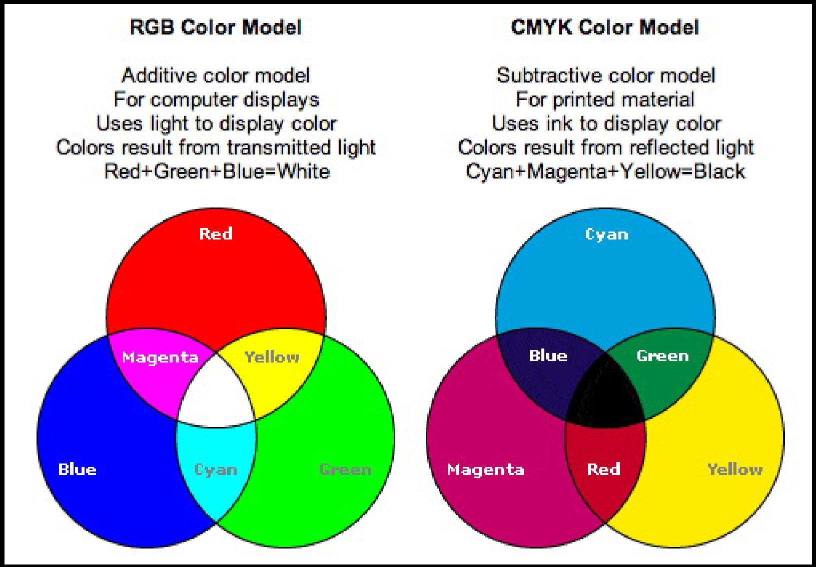



Component Peak Frequency 17 Hz
573.59
1132.5
1132.5
2.151
1200
1.8
1.9
2
2.1
2.2
2.3
2.4
Time (s)
200
300
400
500
600
700
800
900
1100
1200
1300
Inline


Component Peak Frequency 21 Hz
573.59
1132.5
1132.5
2.151
1200
1.8
1.8
1.9
2
2.1
2.2
2.3
2.4
Time (s)
200
300
400
500
600
700
800
900
1100
1200
1300
Inline

RGB Color Blending Plot

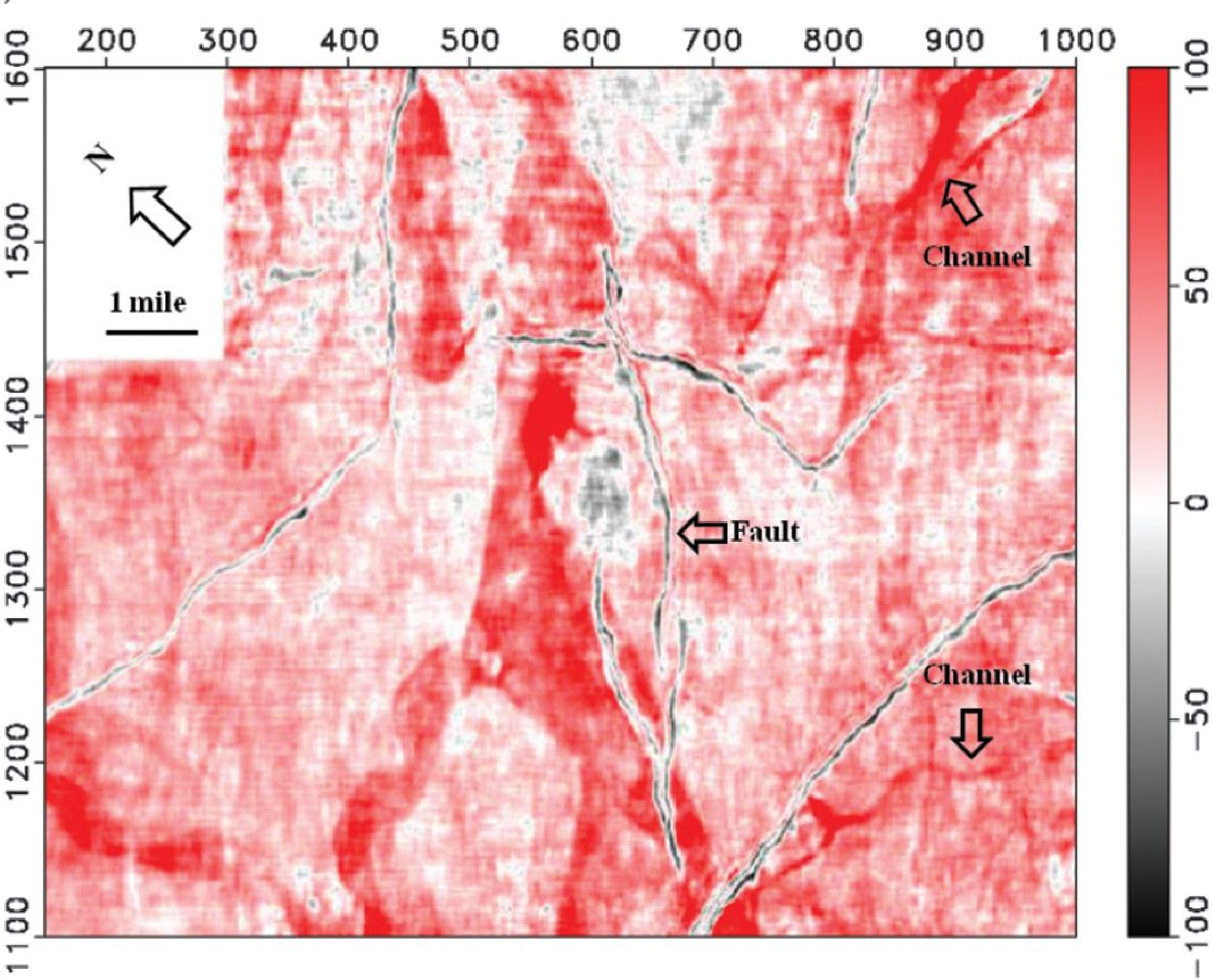
- RGB color model: an additive color model in which red, green, and blue are added together to produce a broad array of colors.

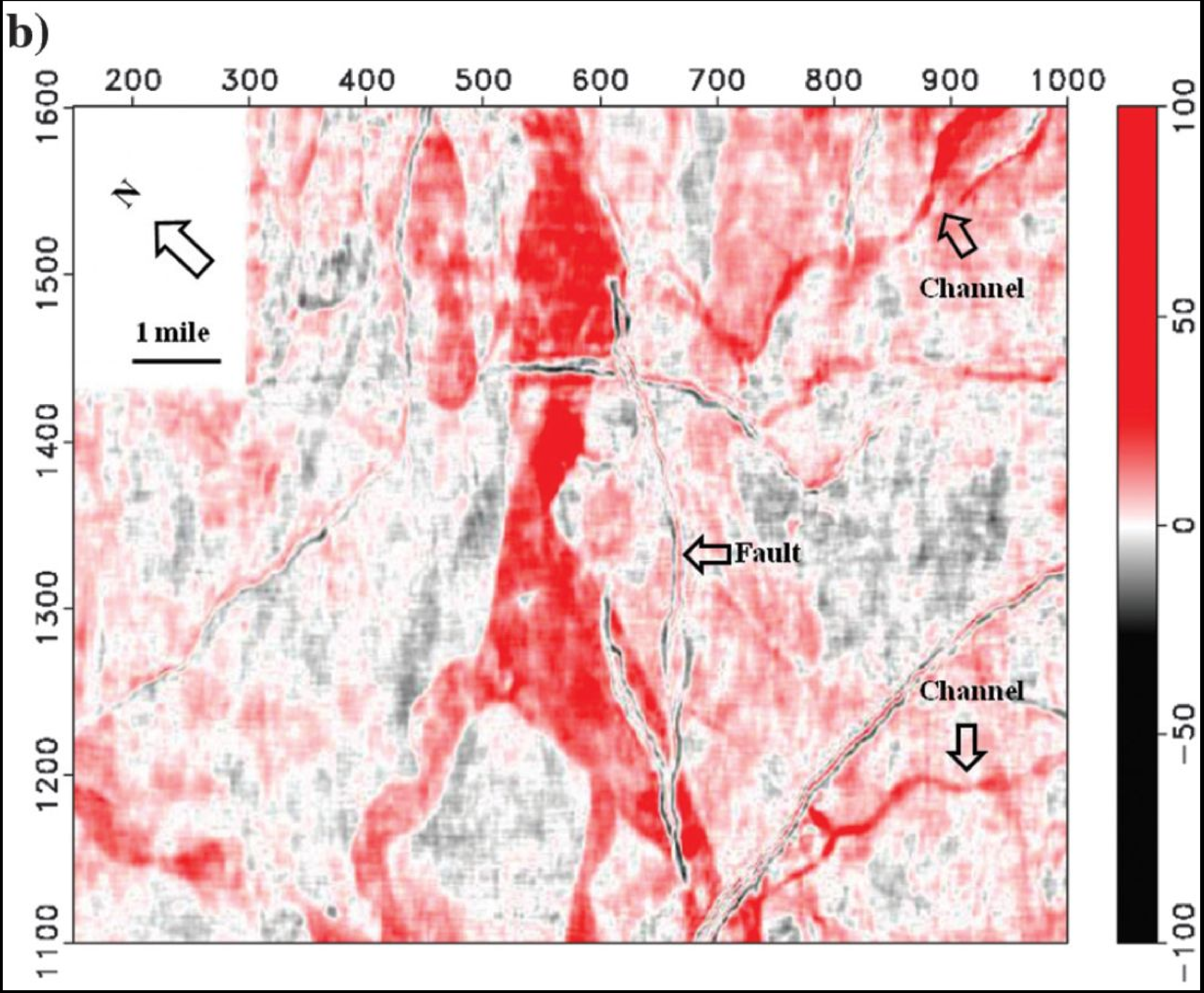


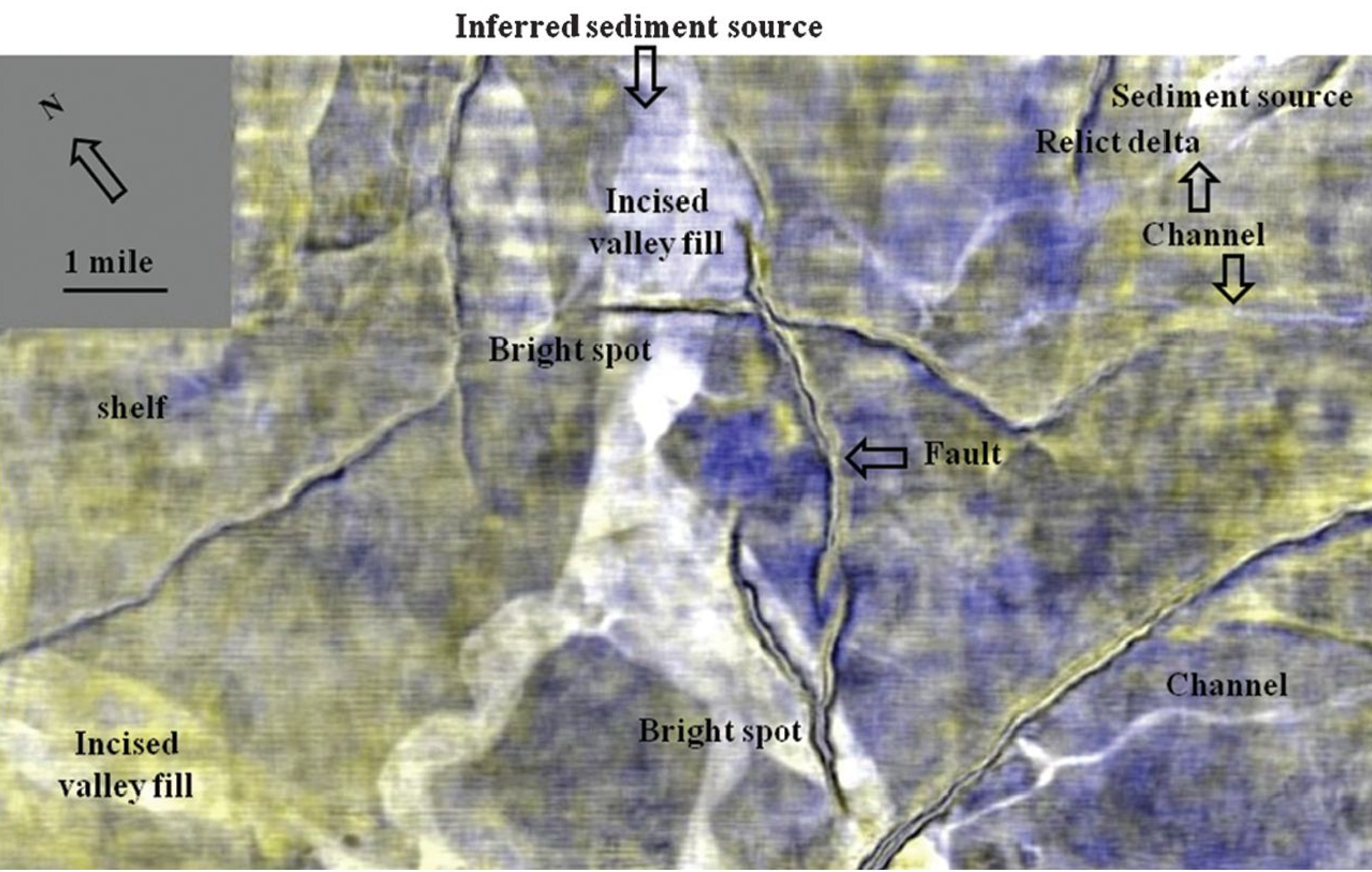
- Using color blending plot, we can visualize subtle geologic features
- Various color blending plots based on various types of seismic attributes

(Chopra and Marfurt, 2007)

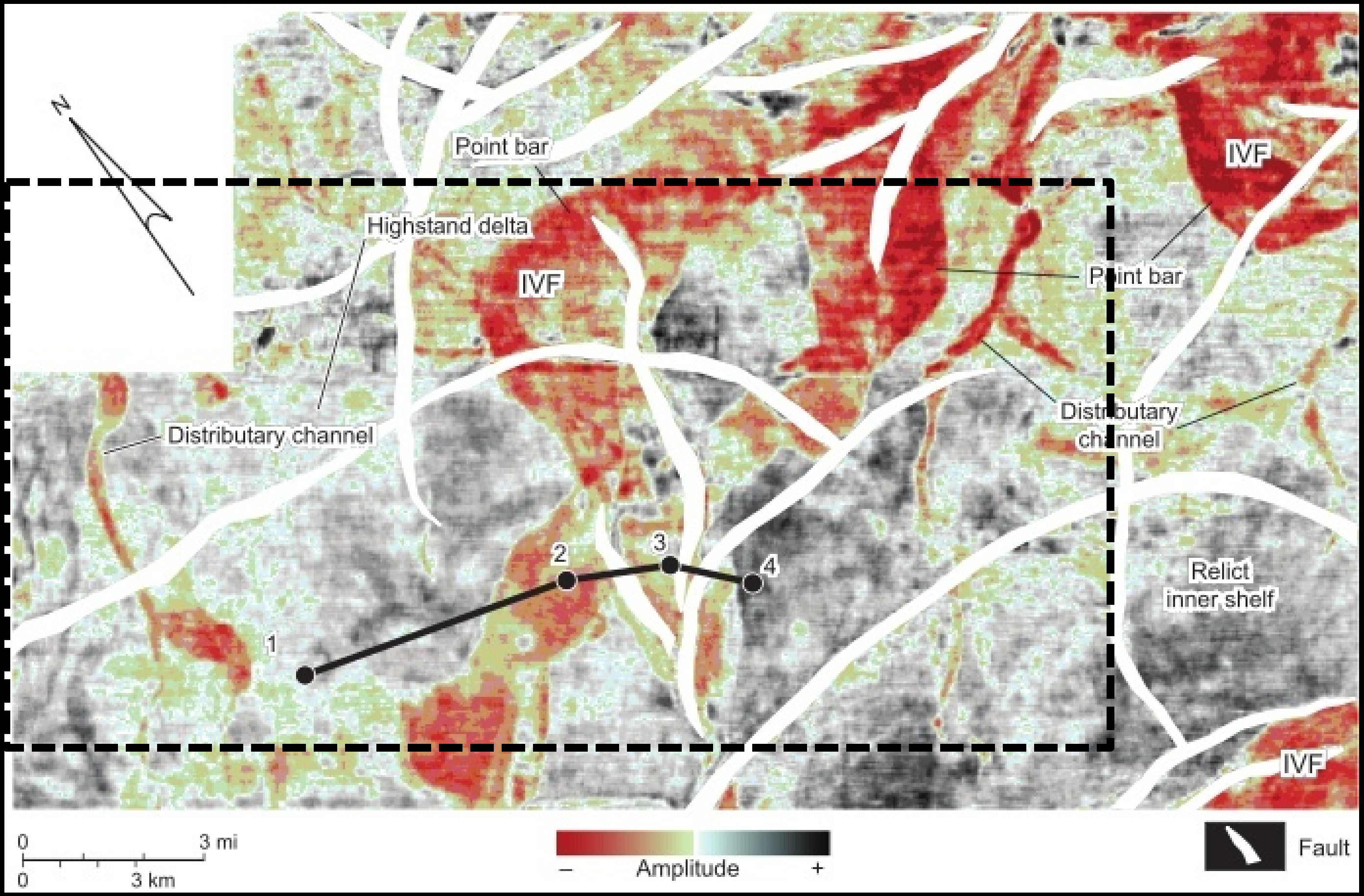
a)


200
300
400
500
600
700
800
900
1000
1600
1500
1400
1300
1200
1100
N
1 mile
Channel
Fault
Channel
100
50
0
−50
−100


b)
200
300
400
500
600
700
800
900
1000
1600
1500
1400
1300
1200
1100
N
1 mile
Channel
Fault
Channel
100
50
0
−50
−100

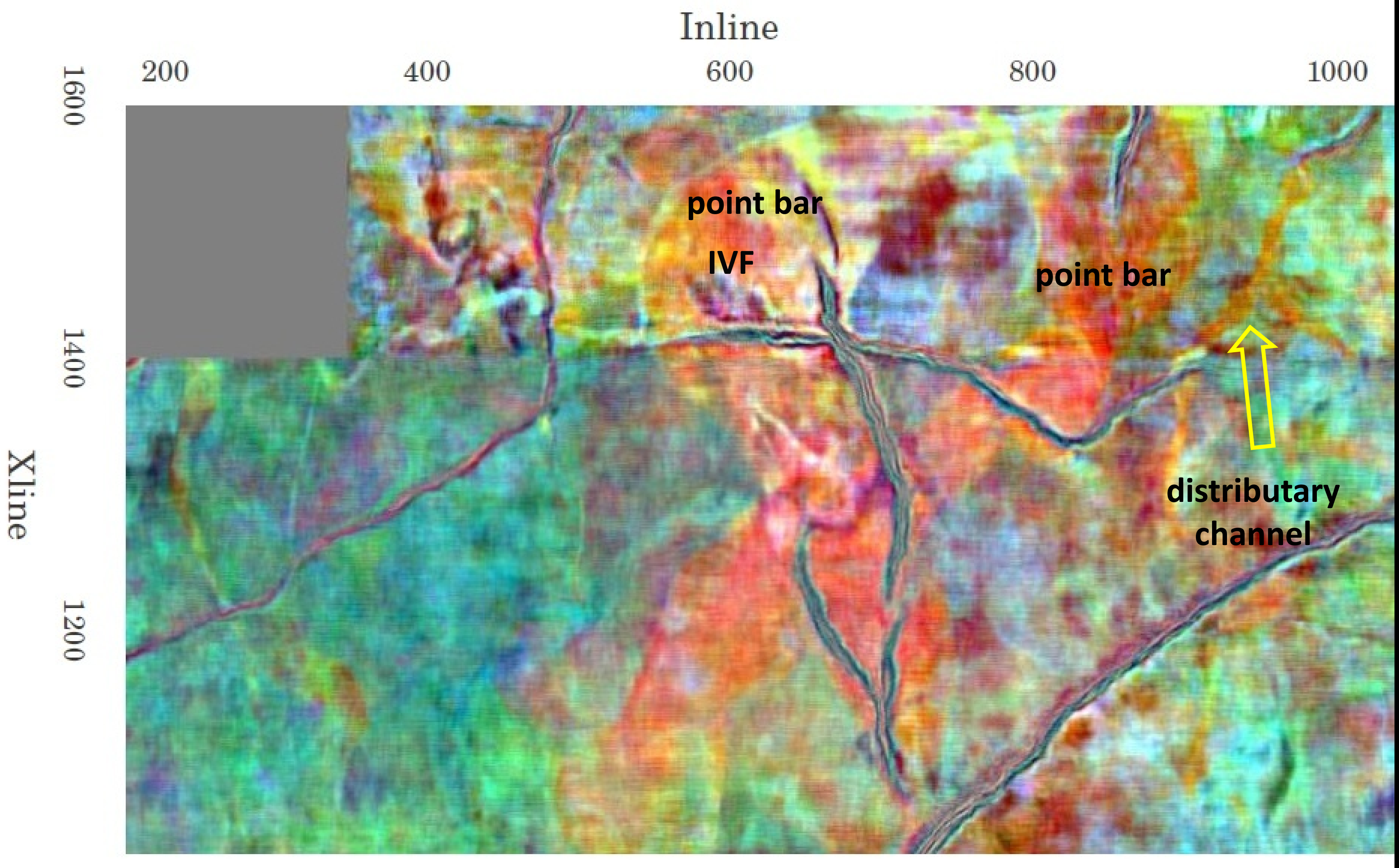

Inferred sediment source
N
1 mile
Incised
valley fill
Sediment source
Relict delta
Channel
Bright spot
shelf
Fault
Channel
Bright spot
Incised
valley fill

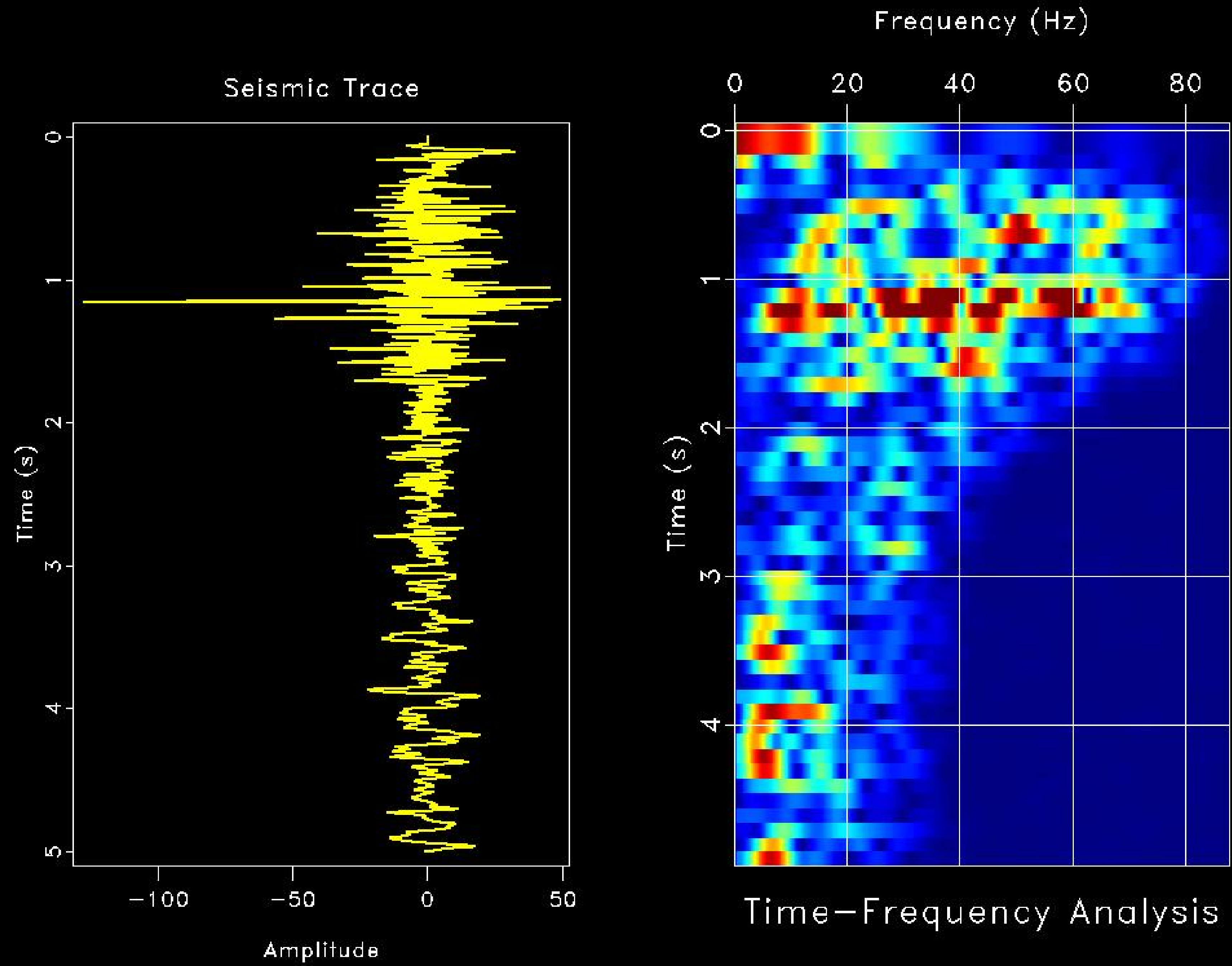
Stratal Slice

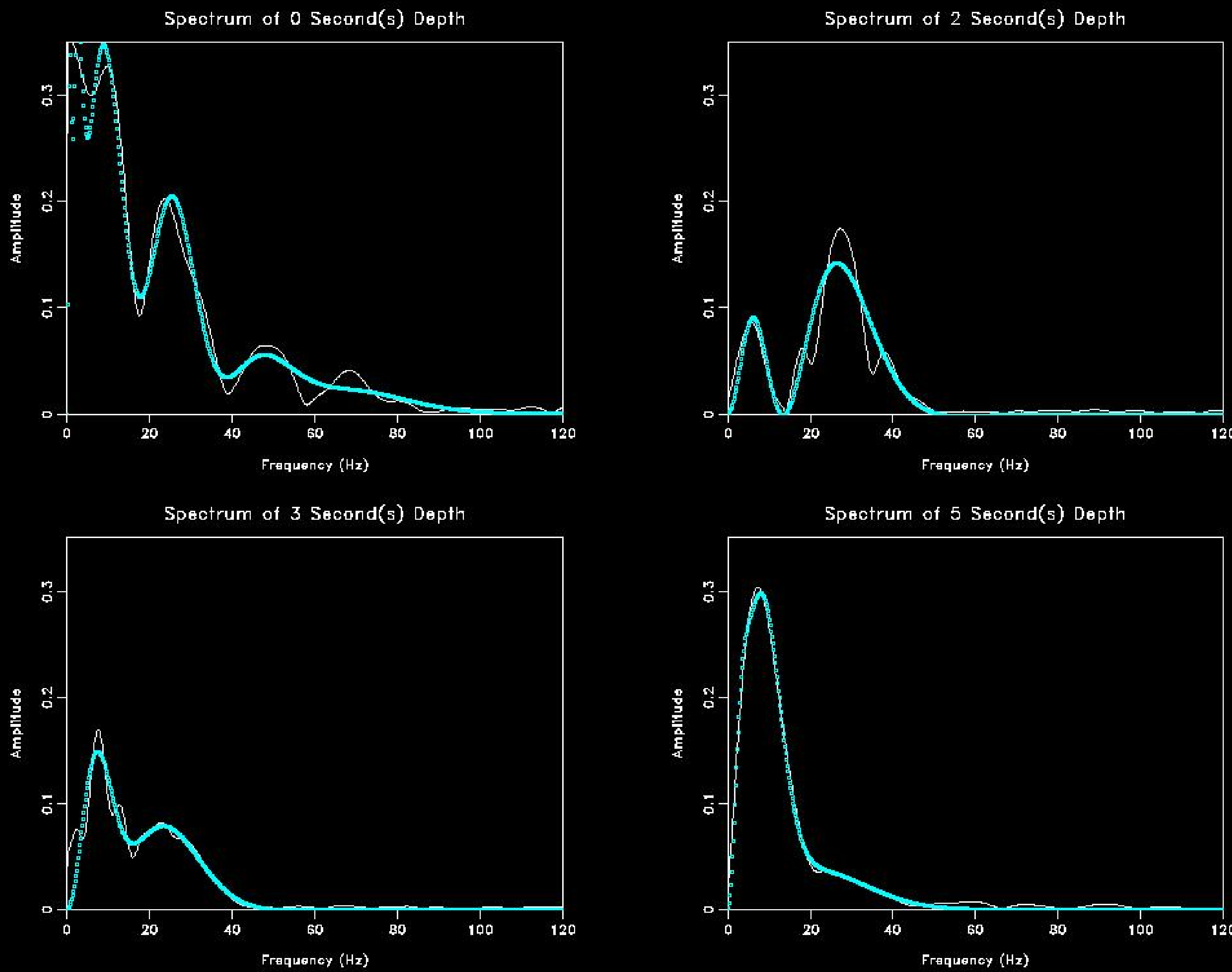


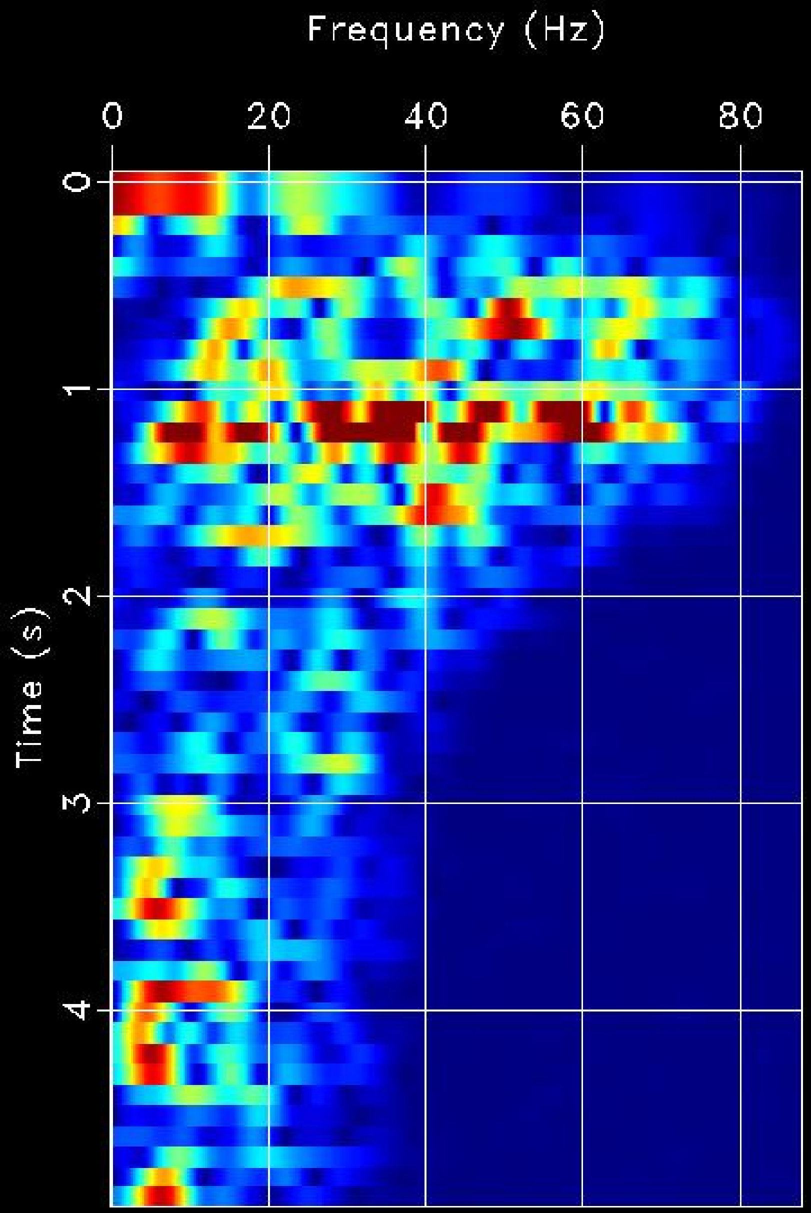
(Hongliu Zeng, and Tucker Hentz, 2004)

RGB Color Blending Plot with Significant Components

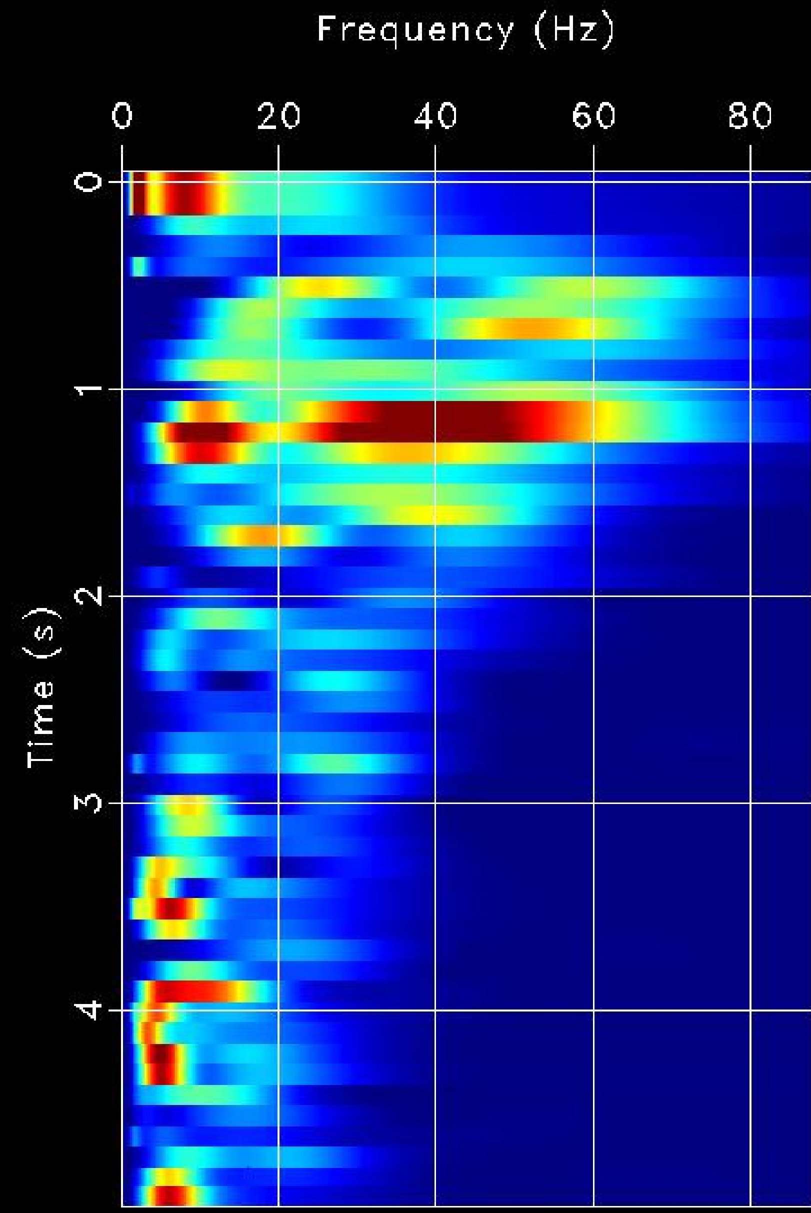



Seismic Trace
Time (s)
0
1
2
3
4
5
−100
−50
0
50
Amplitude
Frequency (Hz)
0
20
40
60
80
Time (s)
0
1
2
3
4
Time−Frequency Analysis


Spectrum of 0 Second(s) Depth
Spectrum of 2 Second(s) Depth
Spectrum of 3 Second(s) Depth
Spectrum of 5 Second(s) Depth
Amplitude
Frequency (Hz)
0
0.1
0.2
0.3
0
20
40
60
80
100
120



Time-Frequency Analysis



Spectral Recomposition

Summary

- Spectral recompostion as a new approach of spectral analysis
  - extracts significant component frequencies and their amplitudes
  - reconstructs seismic spectrum accurately and efficiently
  - improves seismic display, color blending plot and t-f analysis
  - can be used in inversion, reservoir characterization, etc.
- SNLS in spectral recomposition
  - converges to local minimum quickly
  - allows interpreter to choose number of components in estimation

Golub, G.H., and V. Pereyra, 1973, The differentiation of pseudoinverses and nonlinear least squares problems whose variables separate: SIAM Journal on Numerical Analysis, v. 10, p. 413-432.

Partyka, G., J. Gridley, and J. Lopez, 1999, Interpretational applications of spectral decomposition in reservoir characterization: The Leading Edge, v. 18/3, p. 353-360.

Scolnik, H.D., 1972, On the solution of non-linear least squares problems: IFIP Congress, IFIP Congress, p. 1258-1265.

Tomasso, M., R. Bouroullec, and D.R. Pyles, 2010, The use of spectral recomposition in tailored forward seismic modeling of outcrop analogs: AAPG Bulletin, v. 94/4, p. 457-474.

Zeng, H., and T.F. Hentz, 2004, High-frequency sequence stratigraphy from seismic sedimentology: Applied to Miocene, Vermilion Block 50, Tiger Shoal area, offshore Louisiana: AAPG Bulletin, v. 88/2, p. 153-174.