Seismic Attributes - from Interactive Interpretation to Machine Learning

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Geometric Attributes – Amplitude Gradients, Laplacians, and Amplitude Curvature

Geometric Attributes that map continuity, amplitude changes and textures

1. Coherence
2. Amplitude gradients and amplitude curvature
3. GLCM textures

Thin channels, fractures

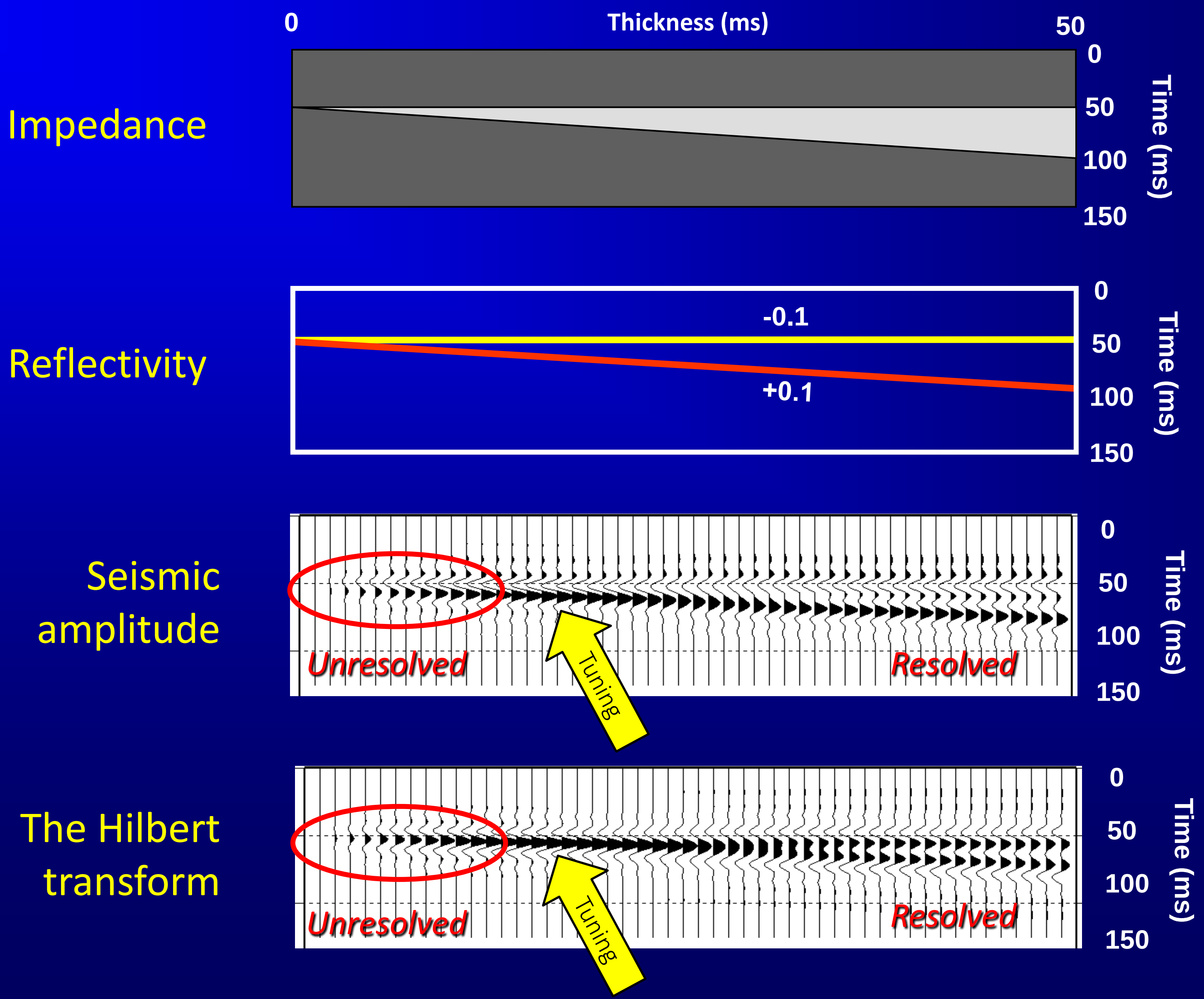
Coherence

After this section you will be able to:

- use amplitude gradients and amplitude curvature to highlight lateral changes in thickness that fall below tuning, and

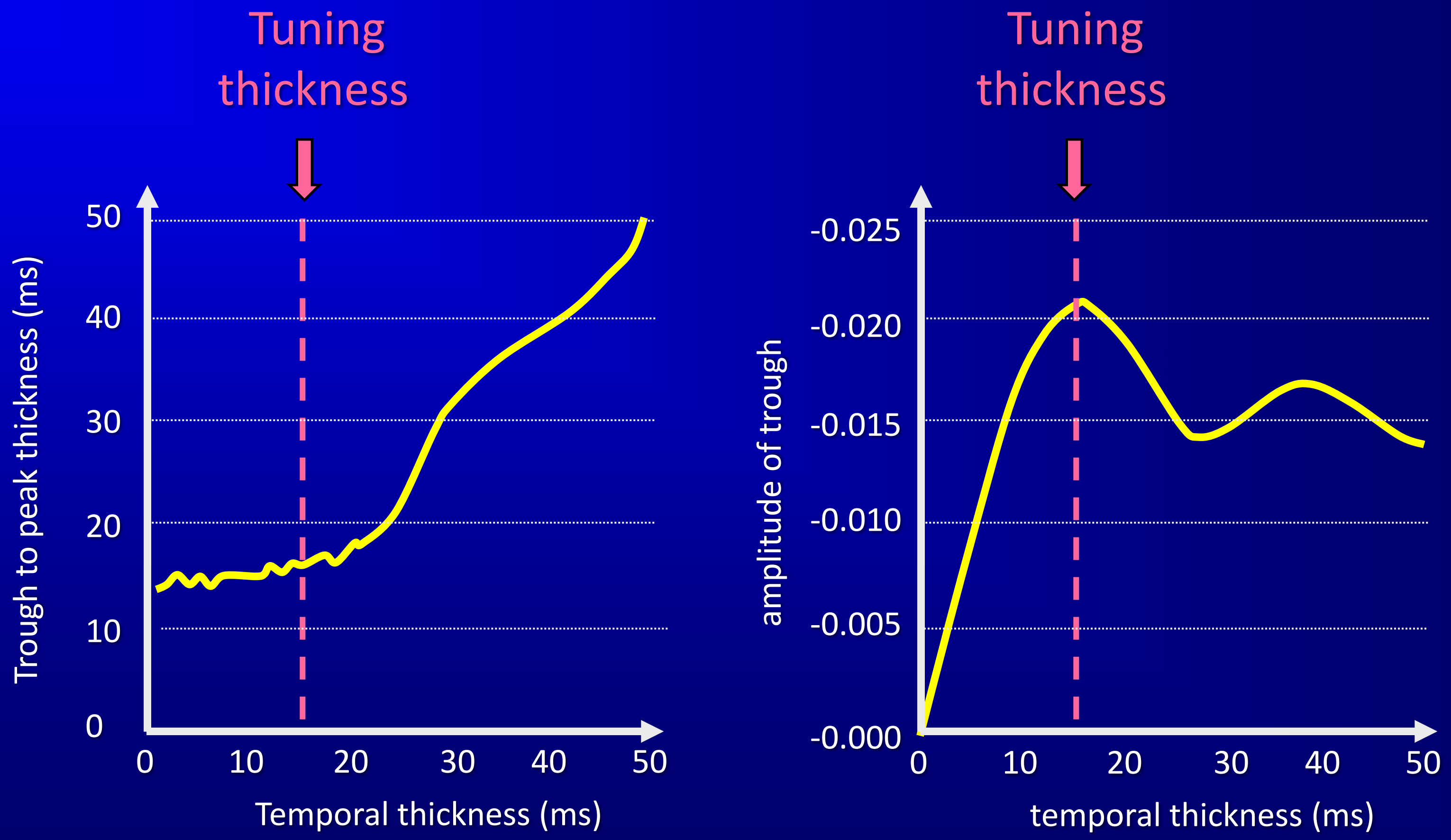
- use amplitude gradients and amplitude curvature to highlight lateral changes in reflectivity, such as diagenetically altered joints and fractures.

Thin bed tuning and the wedge model



(Partyka, 2001)

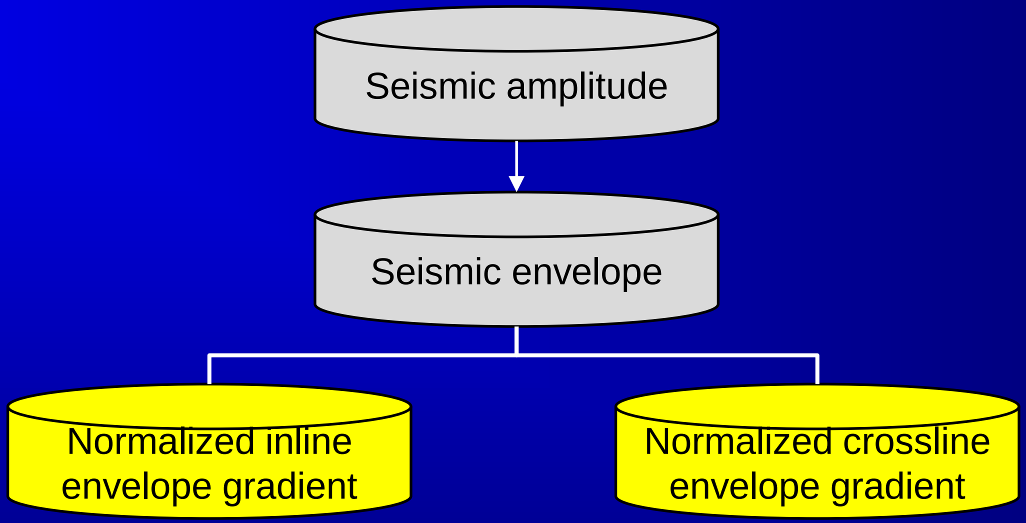
Thin bed tuning and the wedge model



$$u(t+\Delta T/2)-u(t-\Delta T/2)\approx \Delta T\frac{\partial u}{\partial T}$$

(Partyka, 2001; Widess, 1973)

Attributes based on volumetric amplitude, envelope, or energy gradients

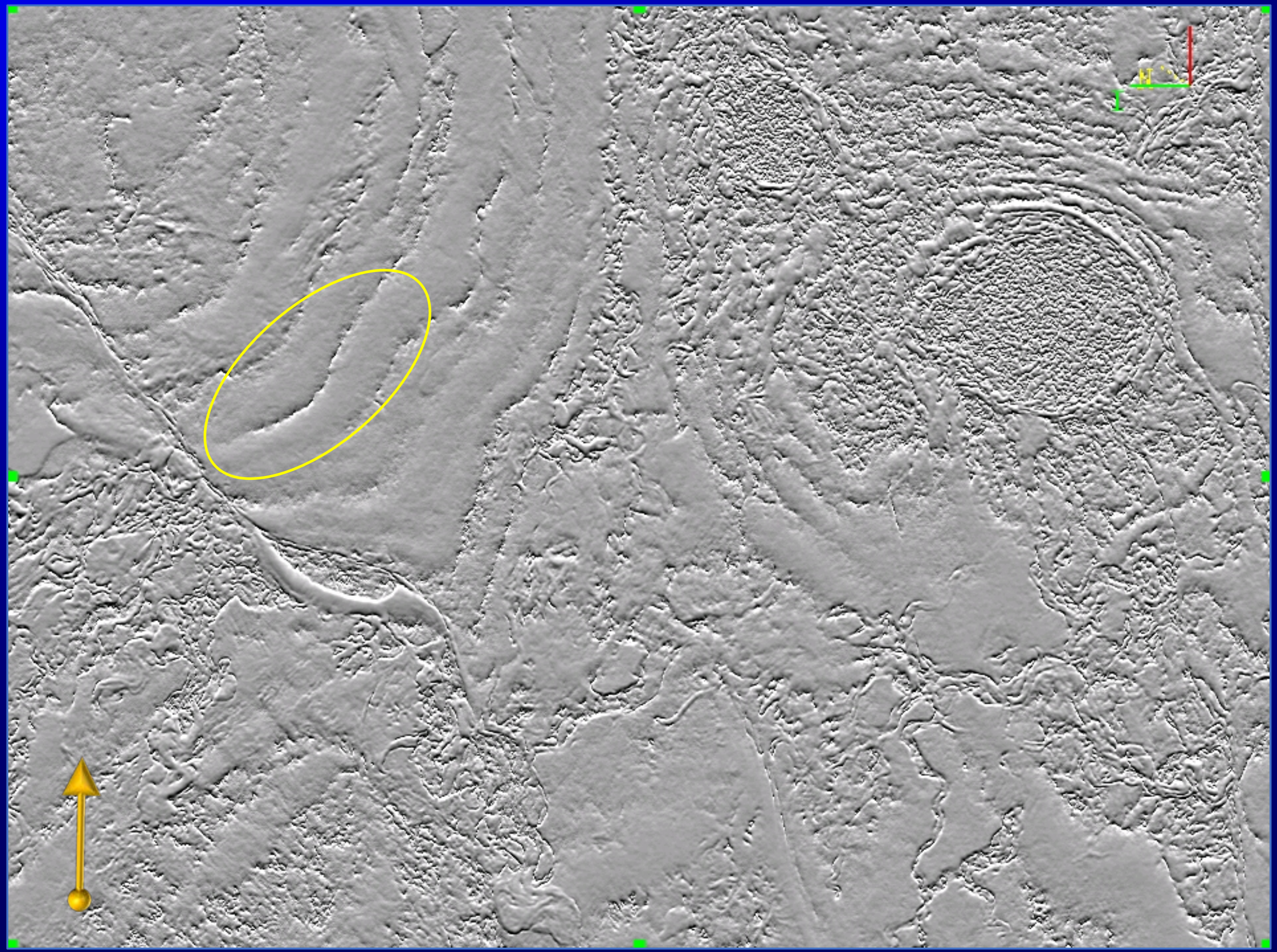


$$g_x = \frac{1}{e(t)} \frac{\partial e(t)}{\partial x}$$

$$g_y = \frac{1}{e(t)} \frac{\partial e(t)}{\partial y}$$

Artifacts on a simple NS gradient

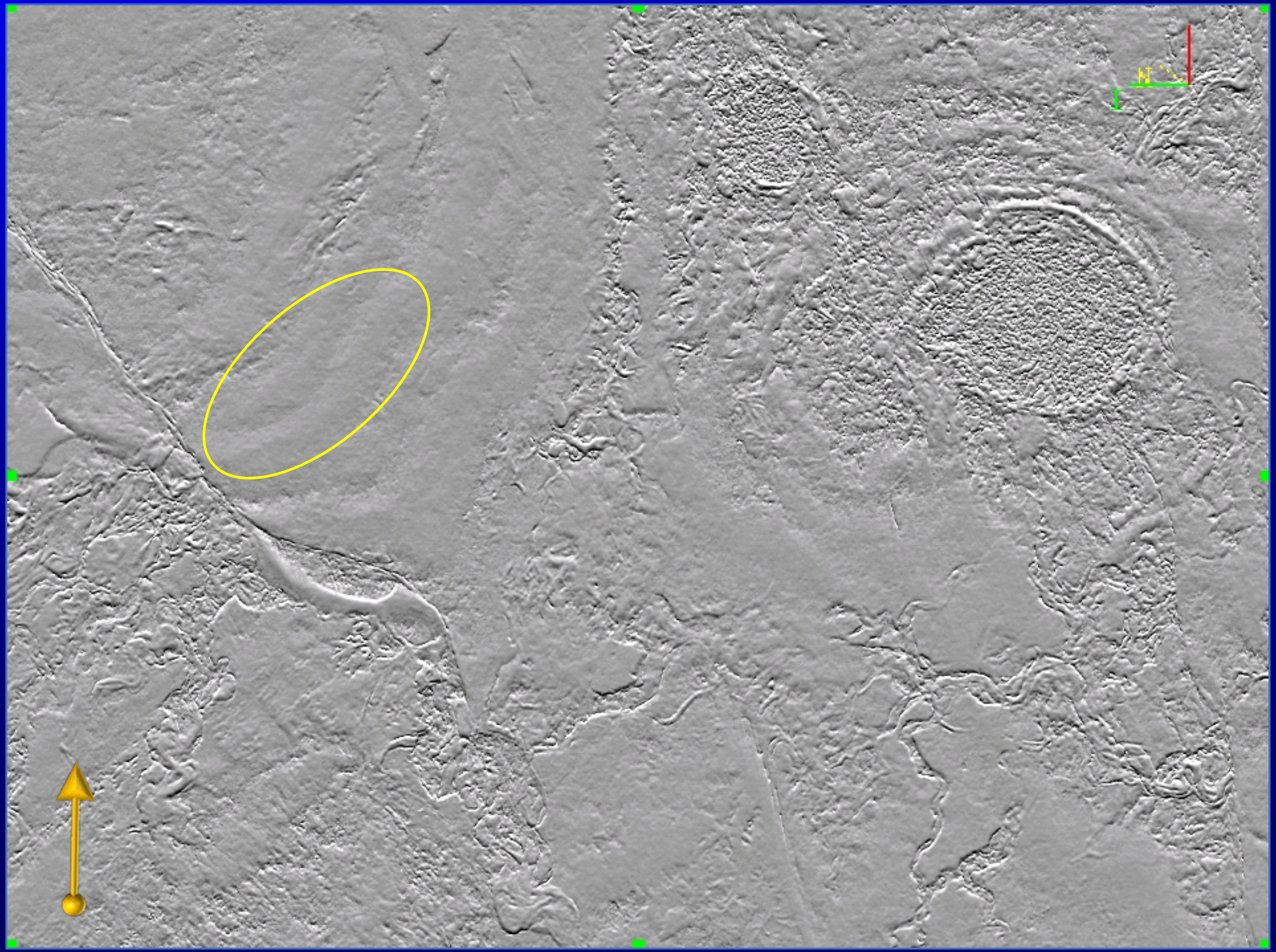
$$g_y = \frac{1}{e(t)} \frac{\partial e(t)}{\partial y}$$



(Barnes, 2011)

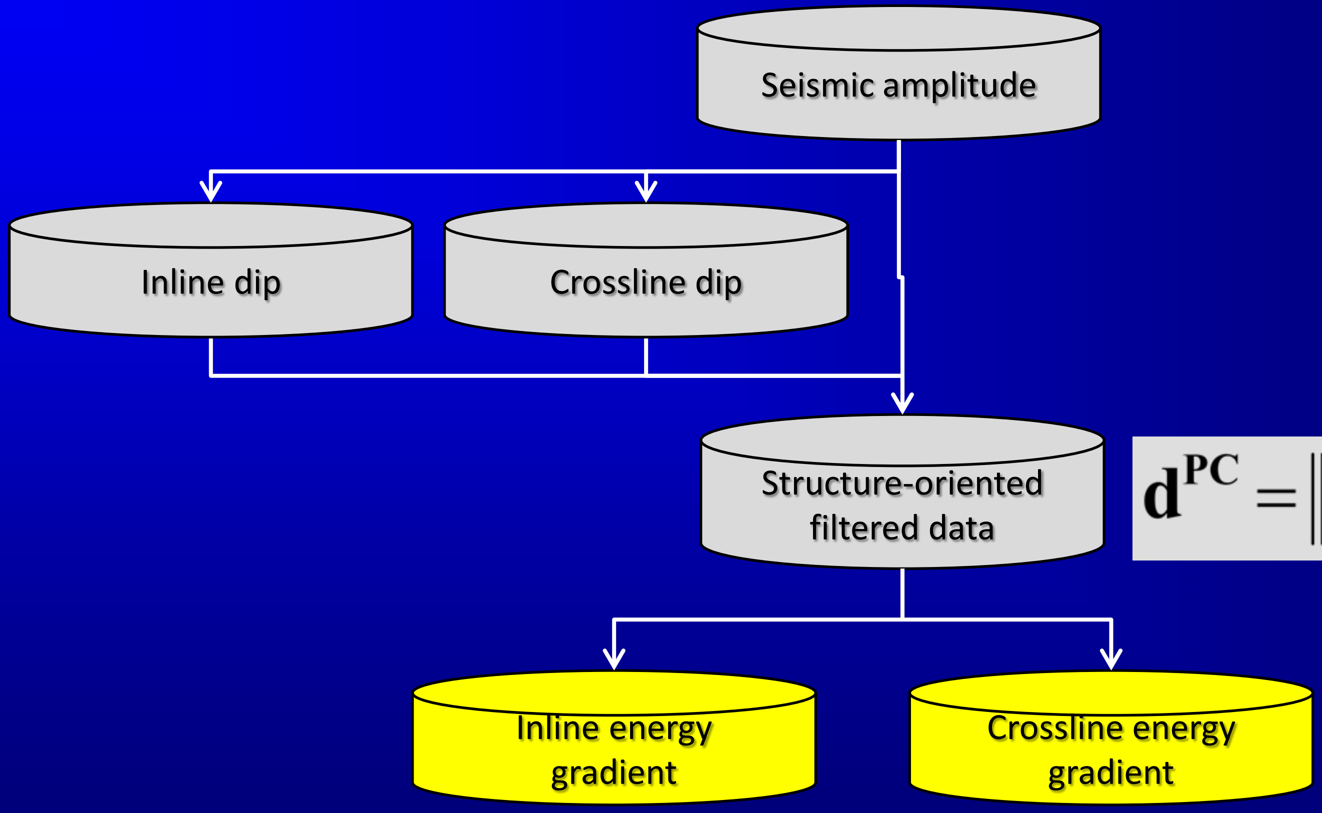
Artifacts suppressed using a median filter

$$g_y = \frac{1}{e(t)} \frac{\partial e(t)}{\partial y}$$



(Barnes, 2011)

Eigenvalues vs. eigenvectors



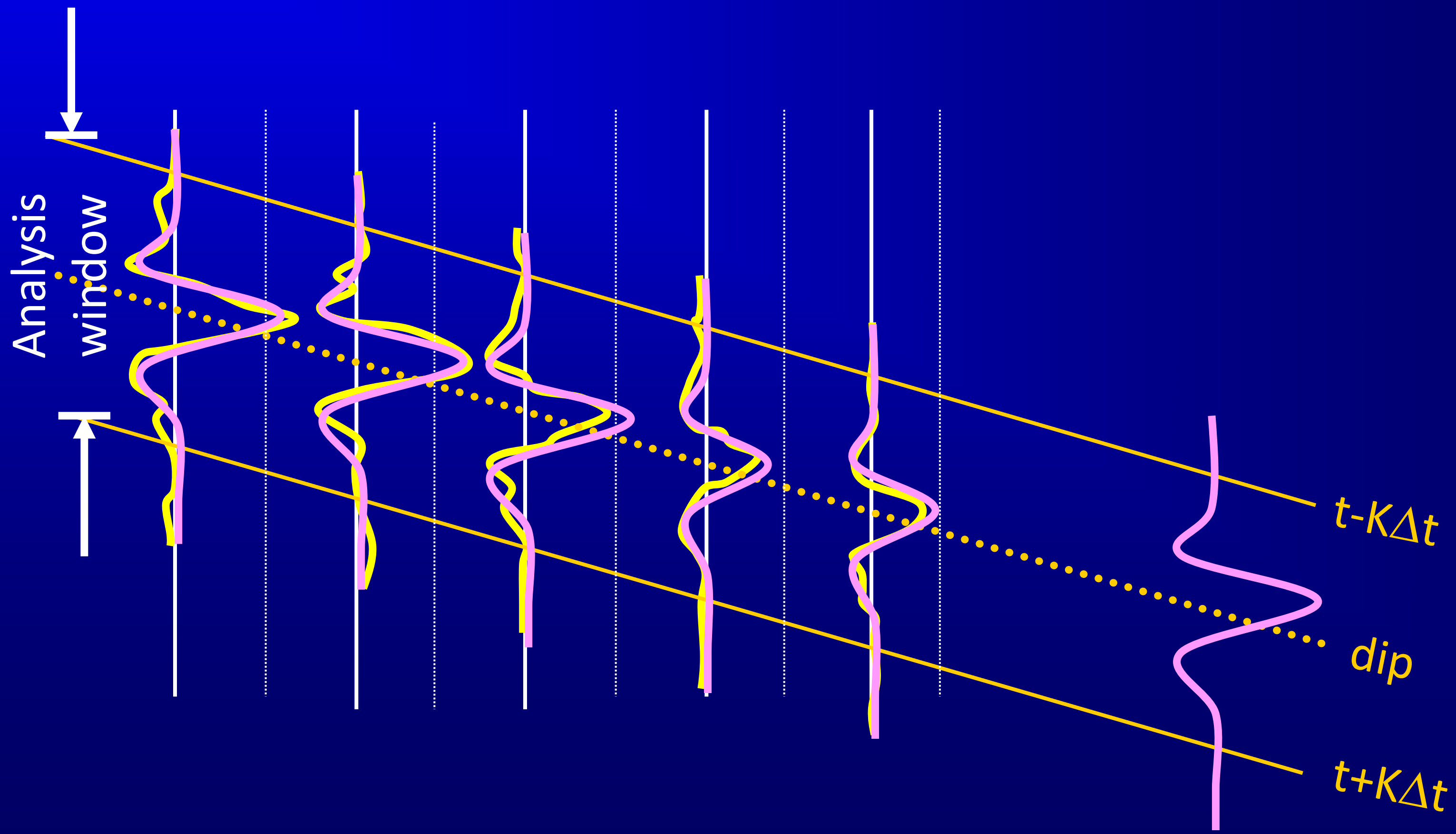
$$\mathbf{d}^{\mathbf{PC}} = \left\| \mathbf{d} \cdot \mathbf{v} \right\| \mathbf{v}$$

$$g_x = \left\| \mathbf{d} \cdot \mathbf{v} \right\| \frac{\partial v}{\partial x}$$

$$g_y = \left\| \mathbf{d} \cdot \mathbf{v} \right\| \frac{\partial v}{\partial y}$$

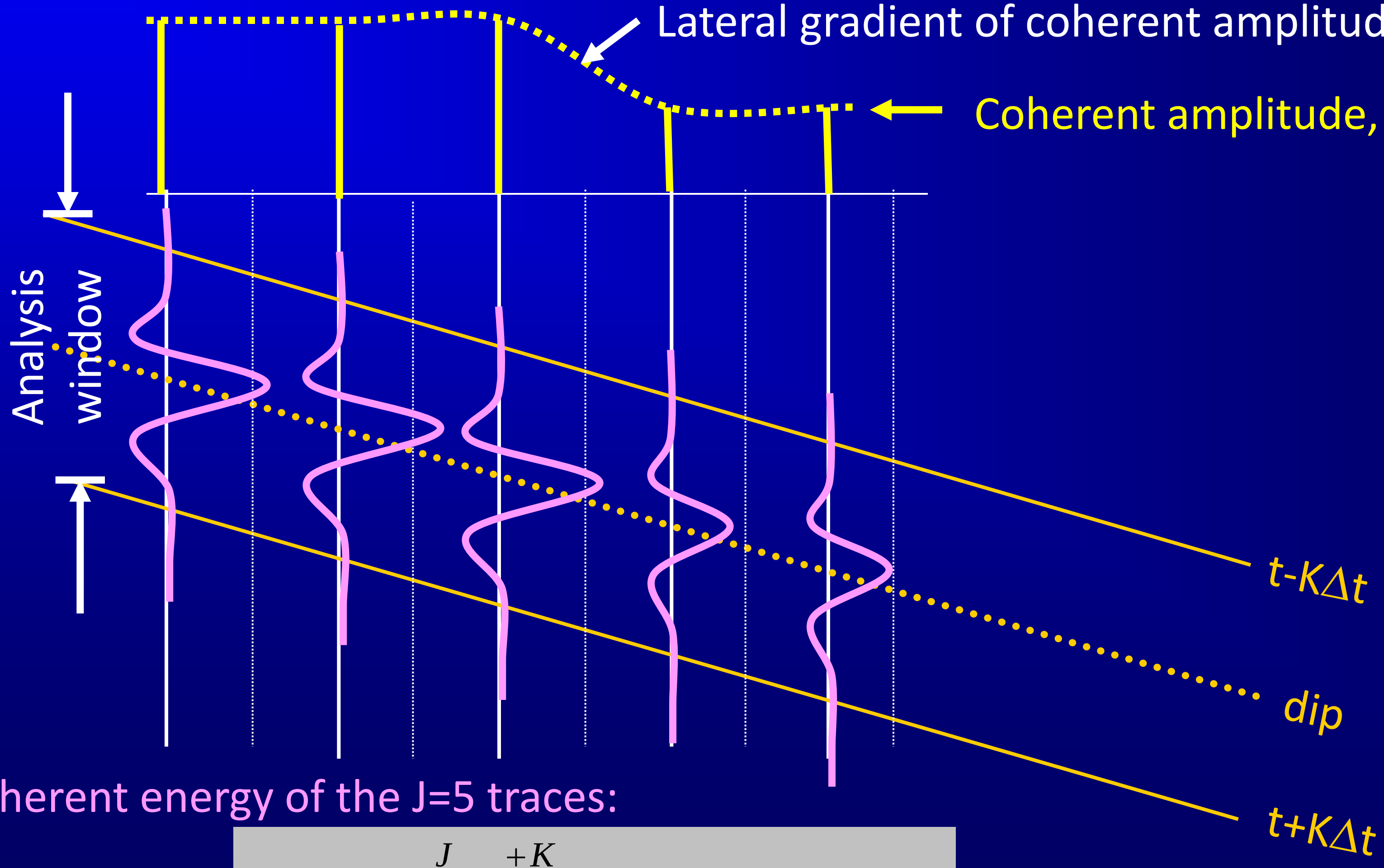
Energy-weighted coherent amplitude gradients

1. Calculate the wavelet that best represents the vertical variation of the data within the analysis window.



(Marfurt, 2006)

2. Fit the coherent wavelet to the data within the analysis window. This represents the 'coherent component' of the seismic data.



Coherent energy of the J=5 traces:

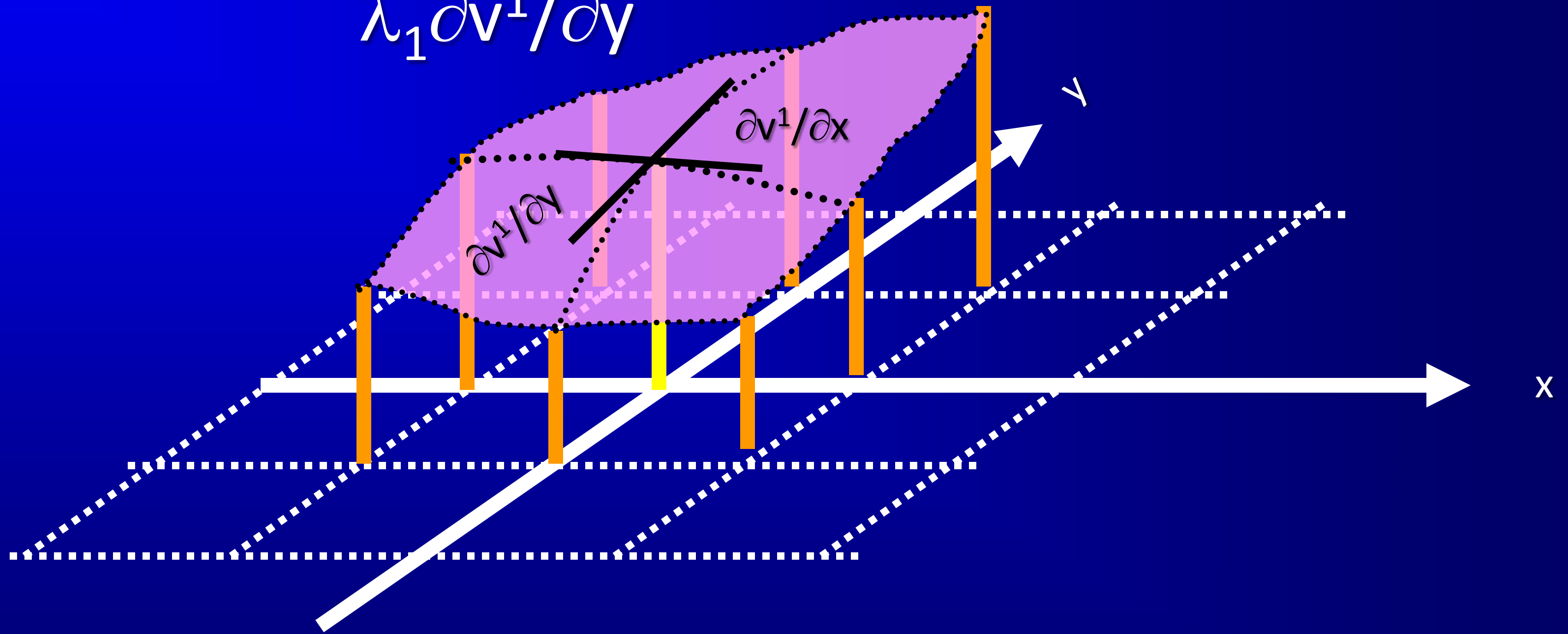
$$e_c(t) = \sum_{j=1}^{J} \sum_{k=-K}^{+K} u_c^2(t+k\Delta t,\, j\Delta x)$$

(Marfurt, 2006)

Energy-weighted coherent amplitude gradients

$\lambda_1 \partial v^1/\partial x$

$\lambda_1 \partial v^1/\partial y$

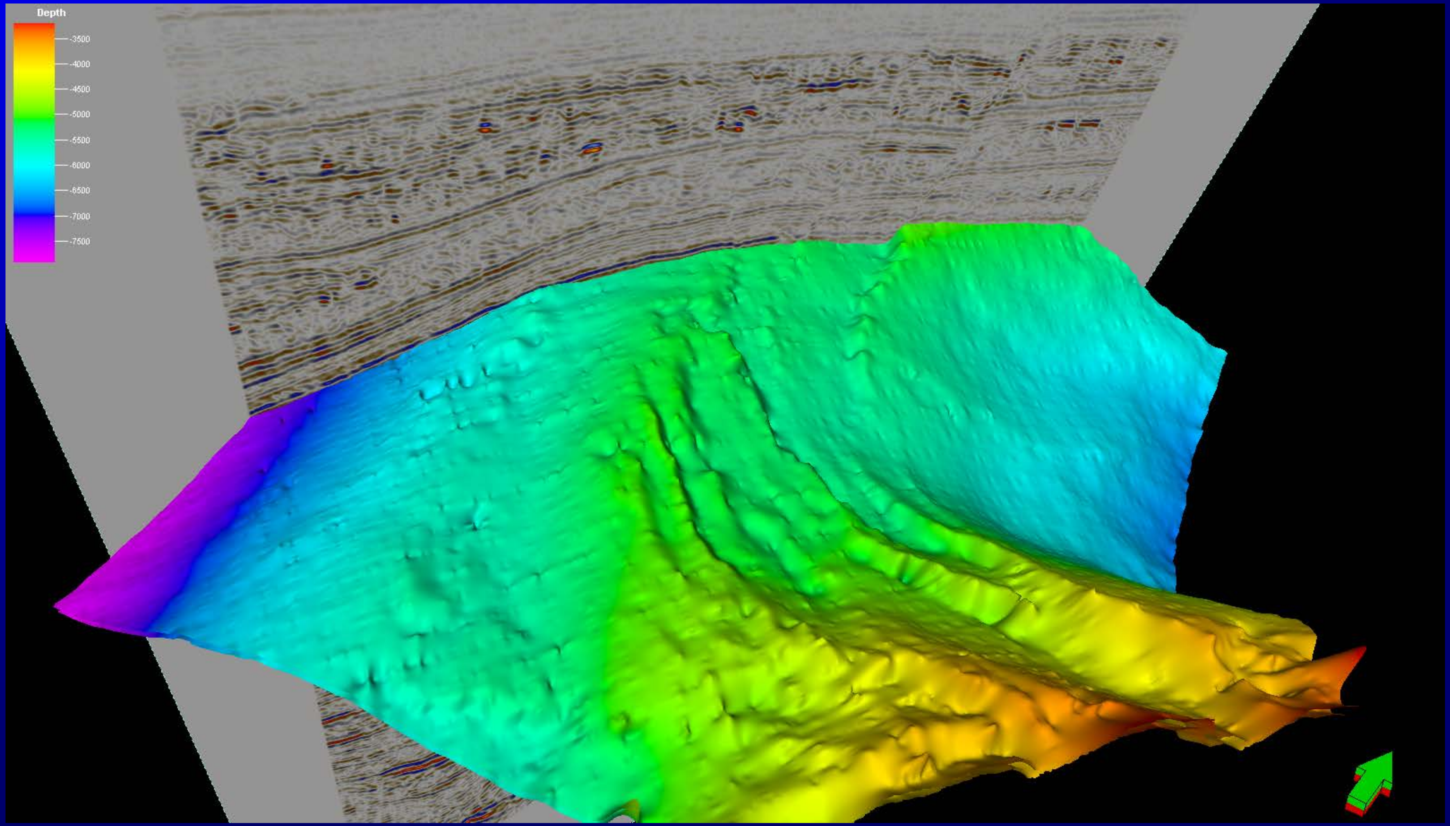


9 Components of eigenvector, v^1, describe the amplitude variation of the coherent wavelet along a local surface, v(x,y)

(Marfurt, 2006)

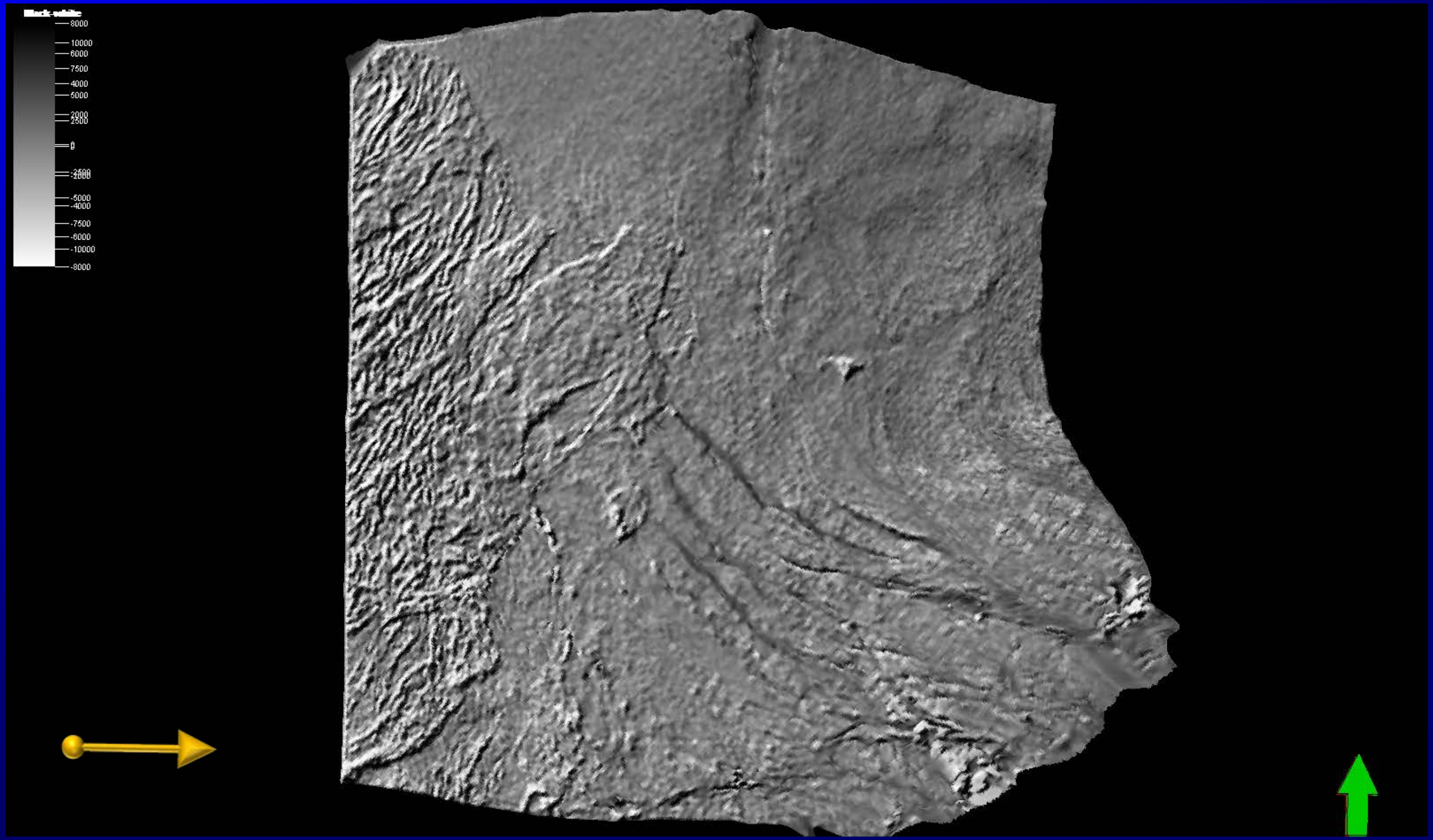
Time-structure map of horizon A - 120 ft

(a phantom horizon)



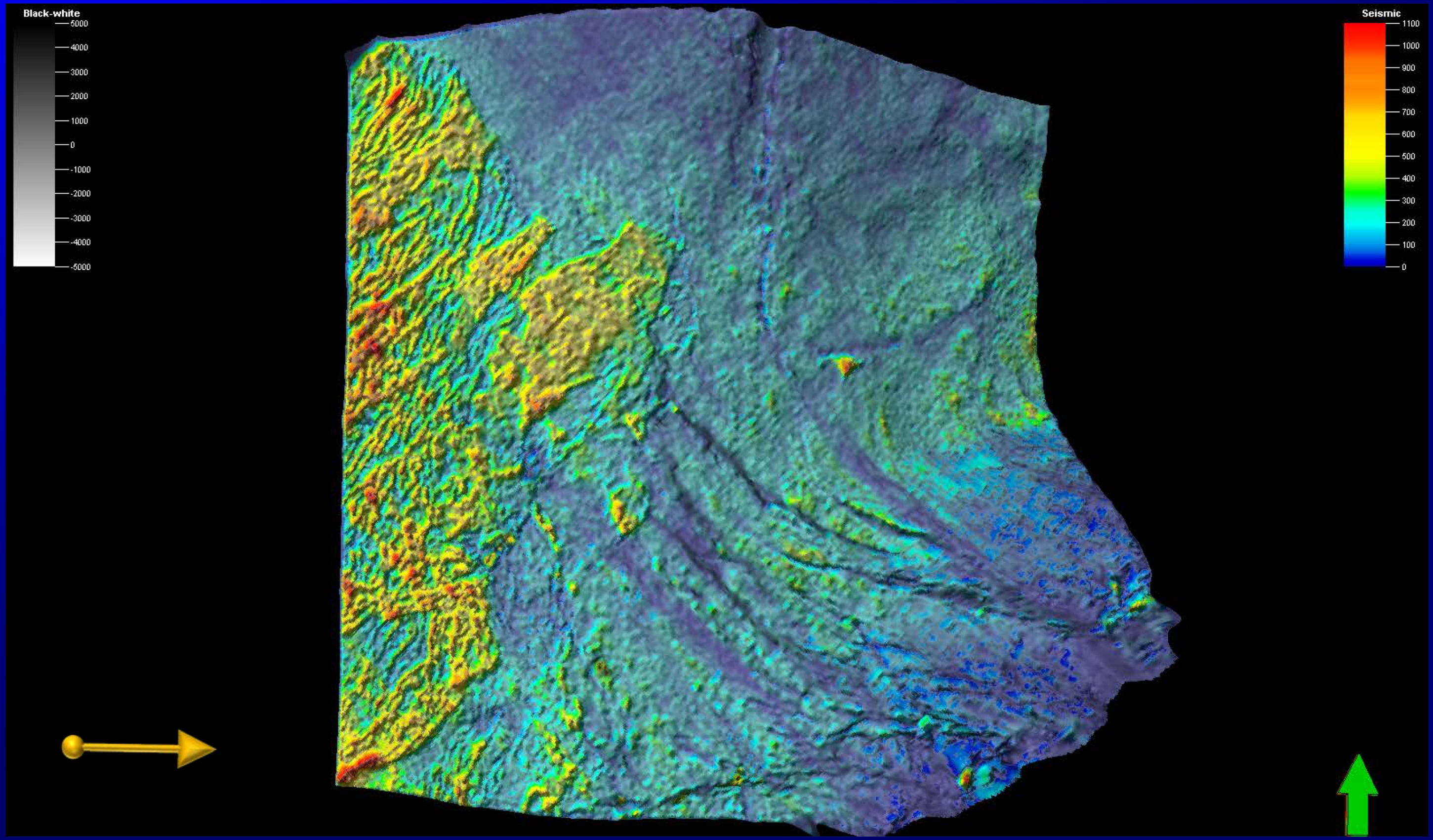
(Sarkar et al. 2009)

Phantom horizon slice through the EW coherent energy gradient



(Sarkar et al. 2009)

Phantom horizon slice through co-rendered coherent energy and EW coherent energy gradient



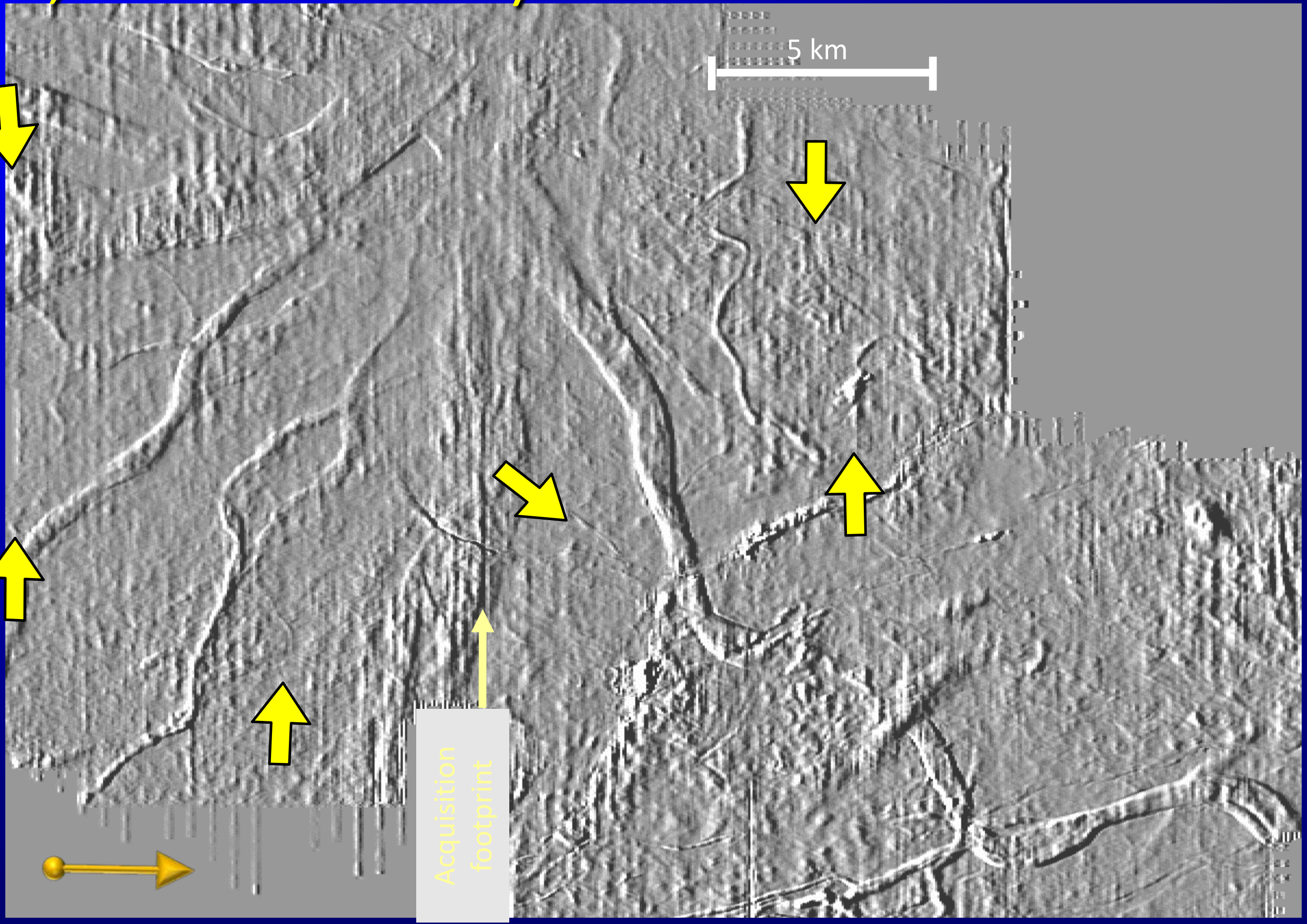
(Sarkar et al. 2009)

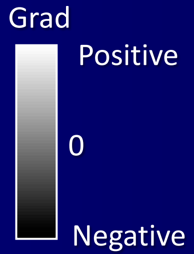
Horizon slice through amplitude coherence
(So. Marsh Island, Gulf of Mexico)

Coherence

(Marfurt et al.,1998)

Horizon slice through amplitude gradient
(So. Marsh Island, Gulf of Mexico)

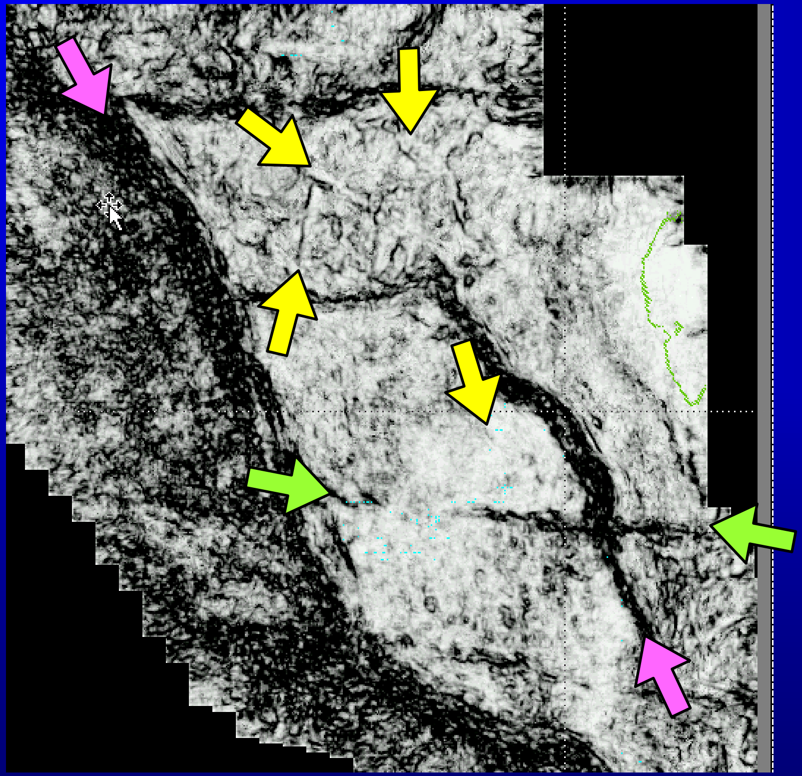




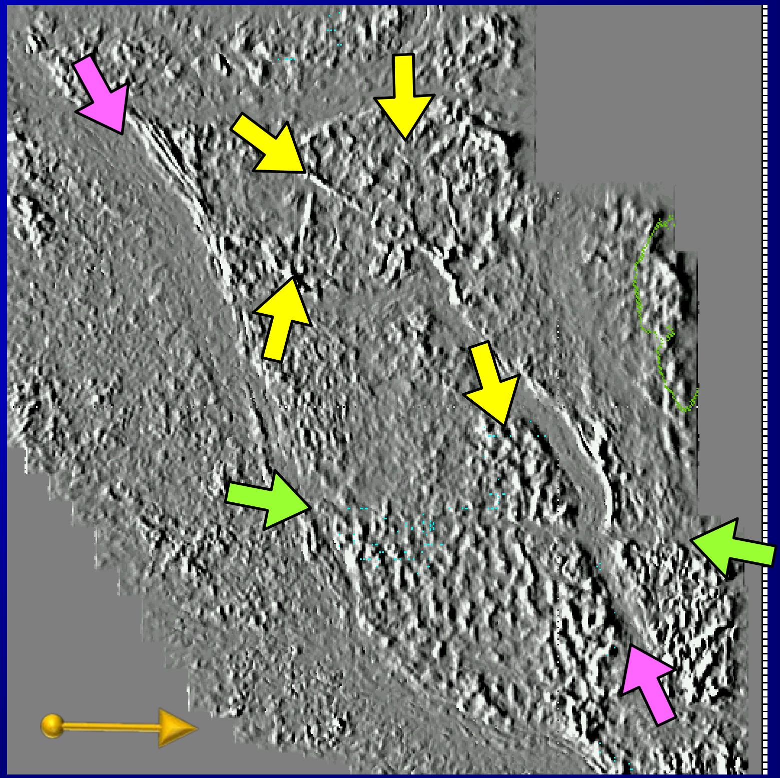
EW component energy-weighted coherent amplitude gradient

(Marfurt et al.,1998)

Central Basin Platform, Texas, USA
(Devonian Thirtyone Horizon)



coherence

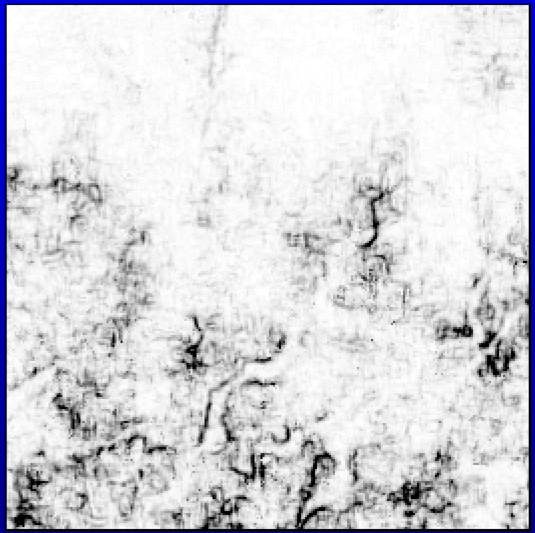


EW coherent energy gradient

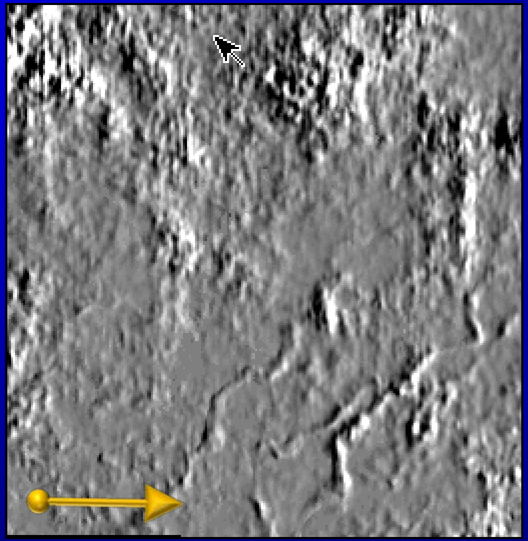
(Blumentritt et al.,1998)

Midcontinent, USA
Time slices

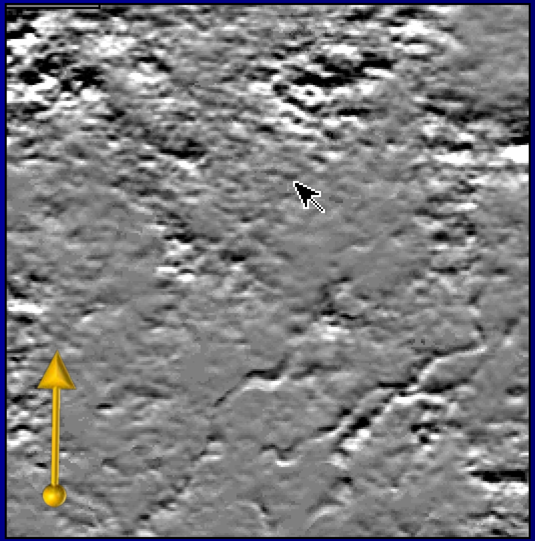
2 km



coherence



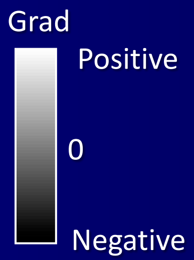
EW coherent energy gradient



NS coherent energy gradient

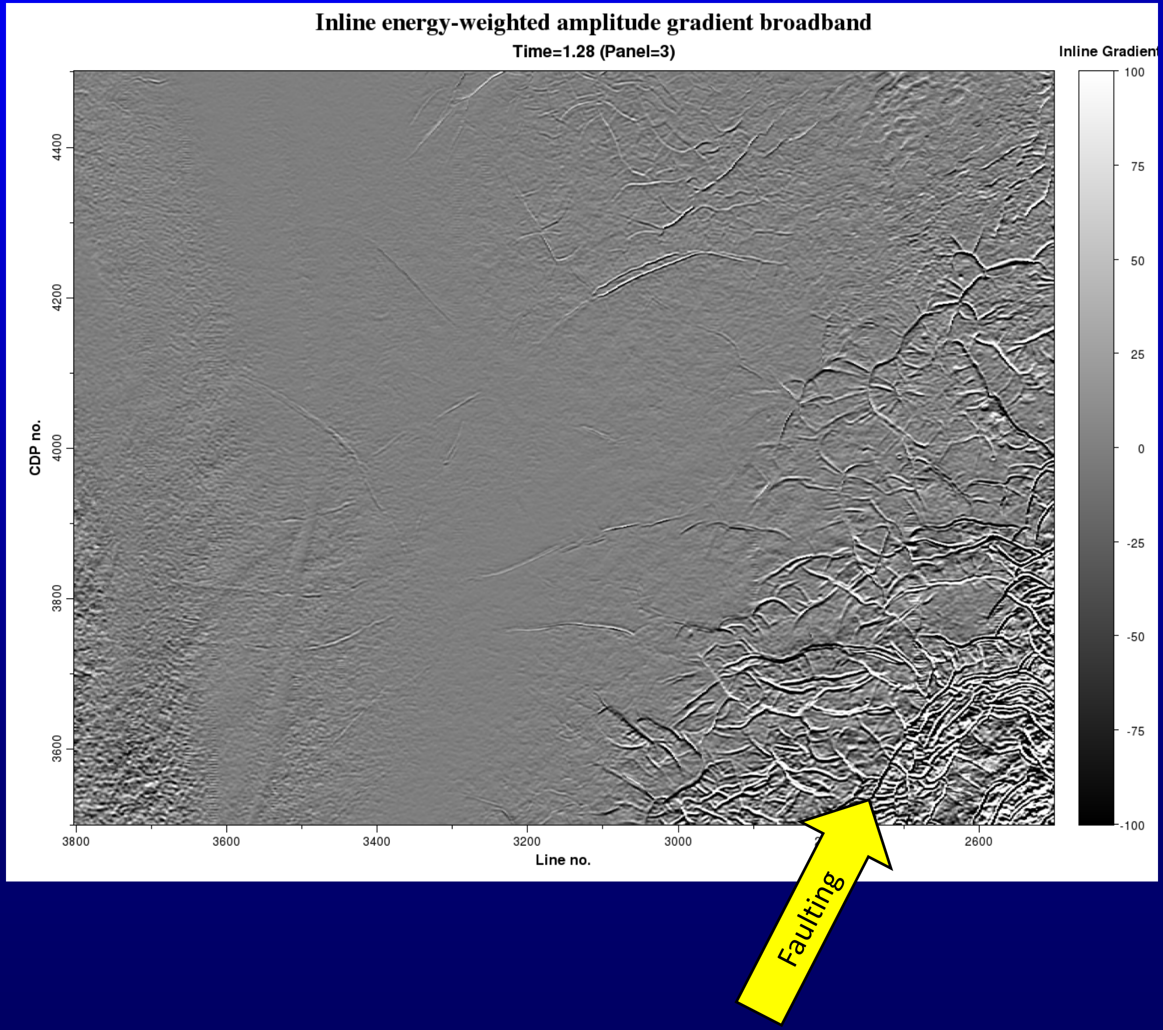
Grad
Positive
0
Negative

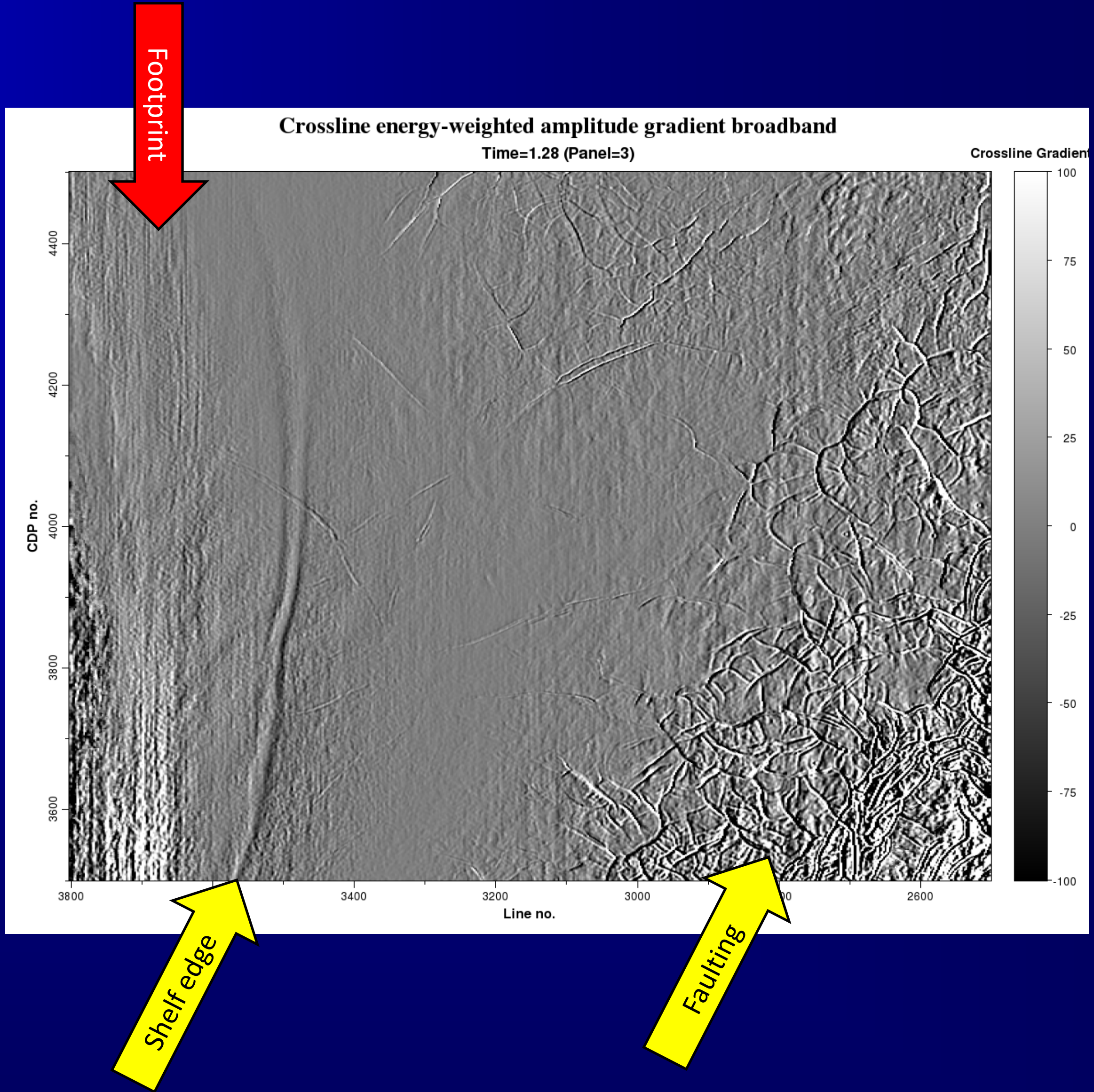
Energy-weighted coherent amplitude gradients
(So. Marsh Island, Gulf of Mexico, USA)



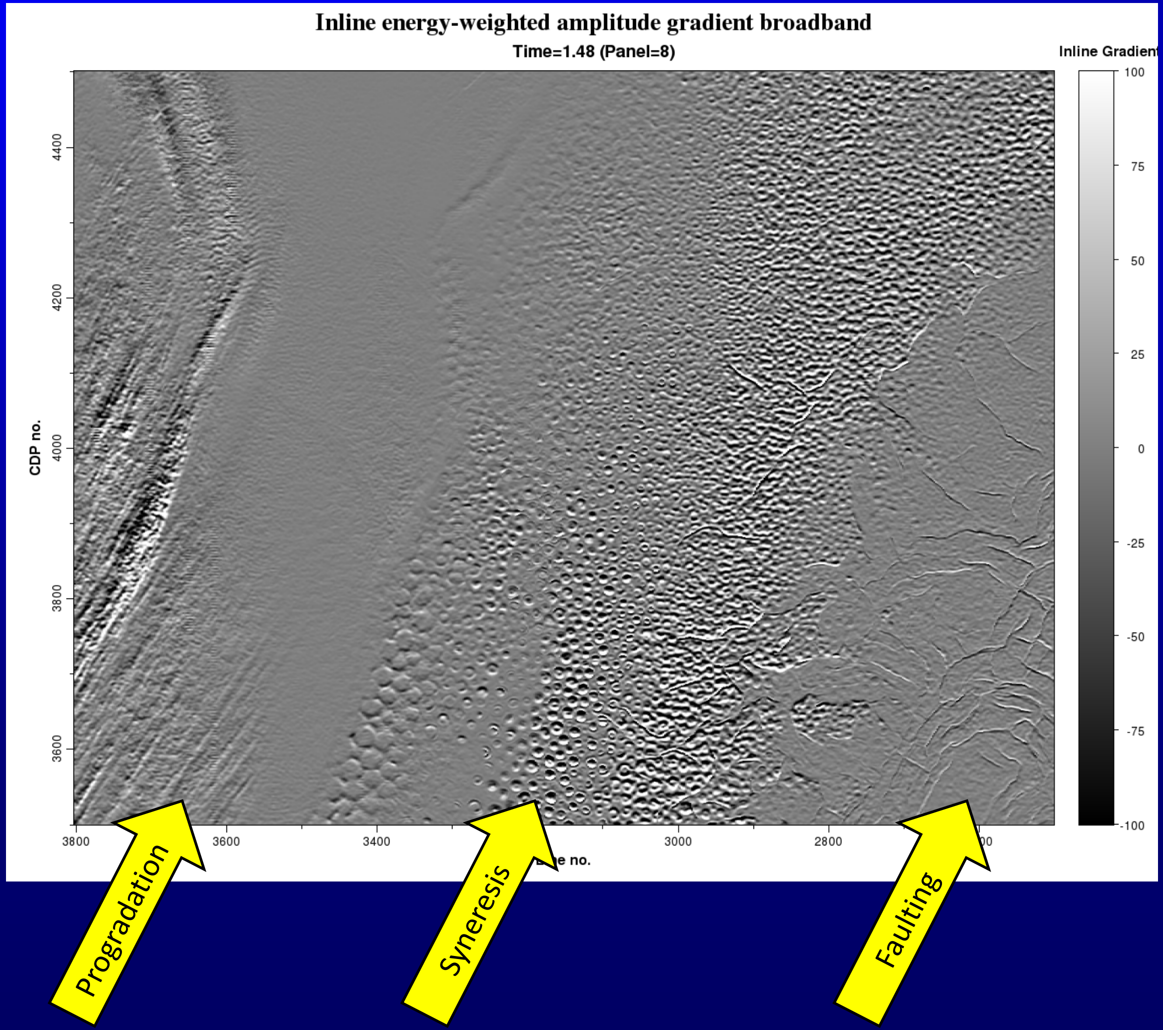
(Data courtesy of Fairfield)

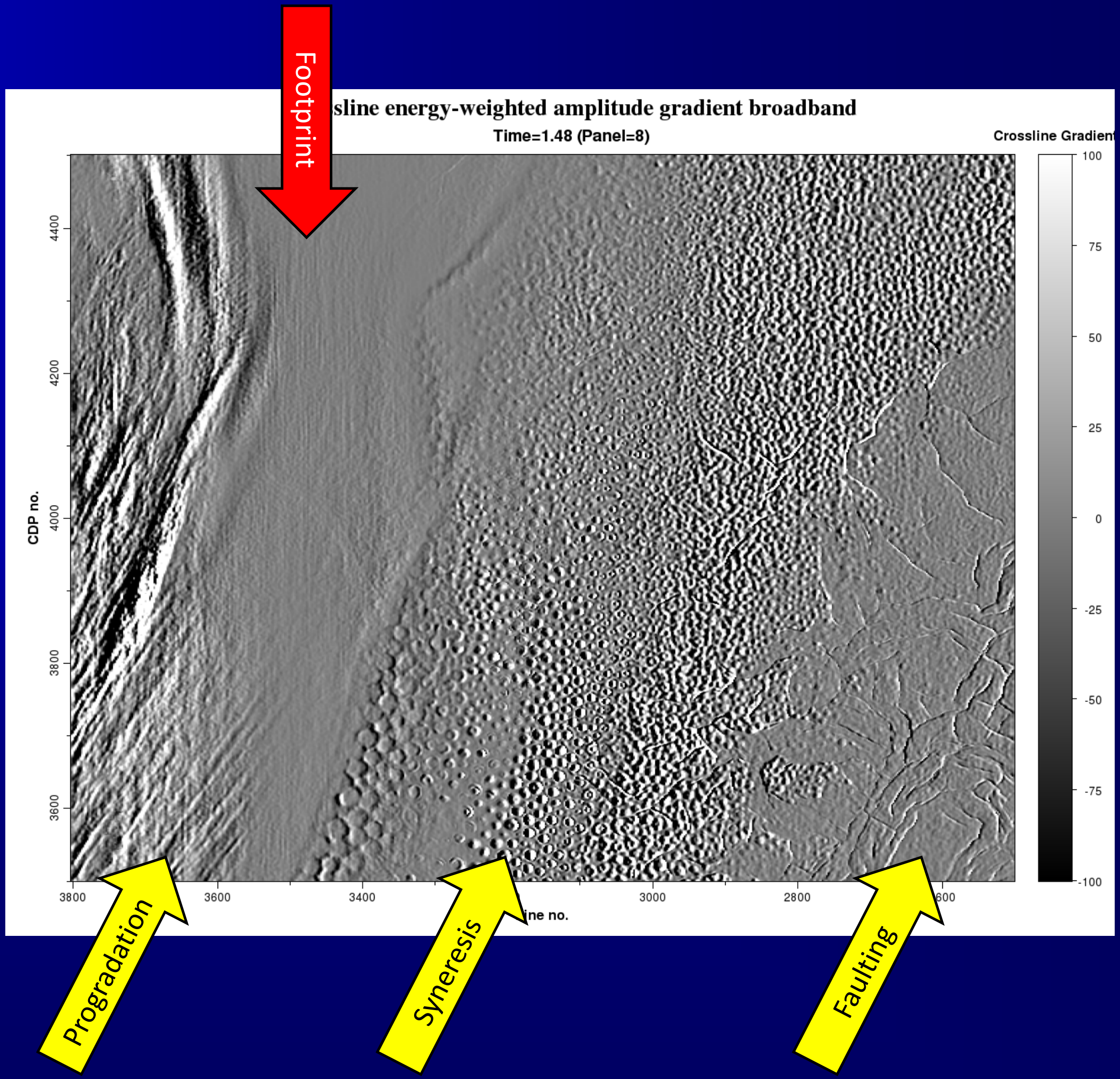
Energy-weighted coherent amplitude gradients
(Great South Basin, New Zealand)



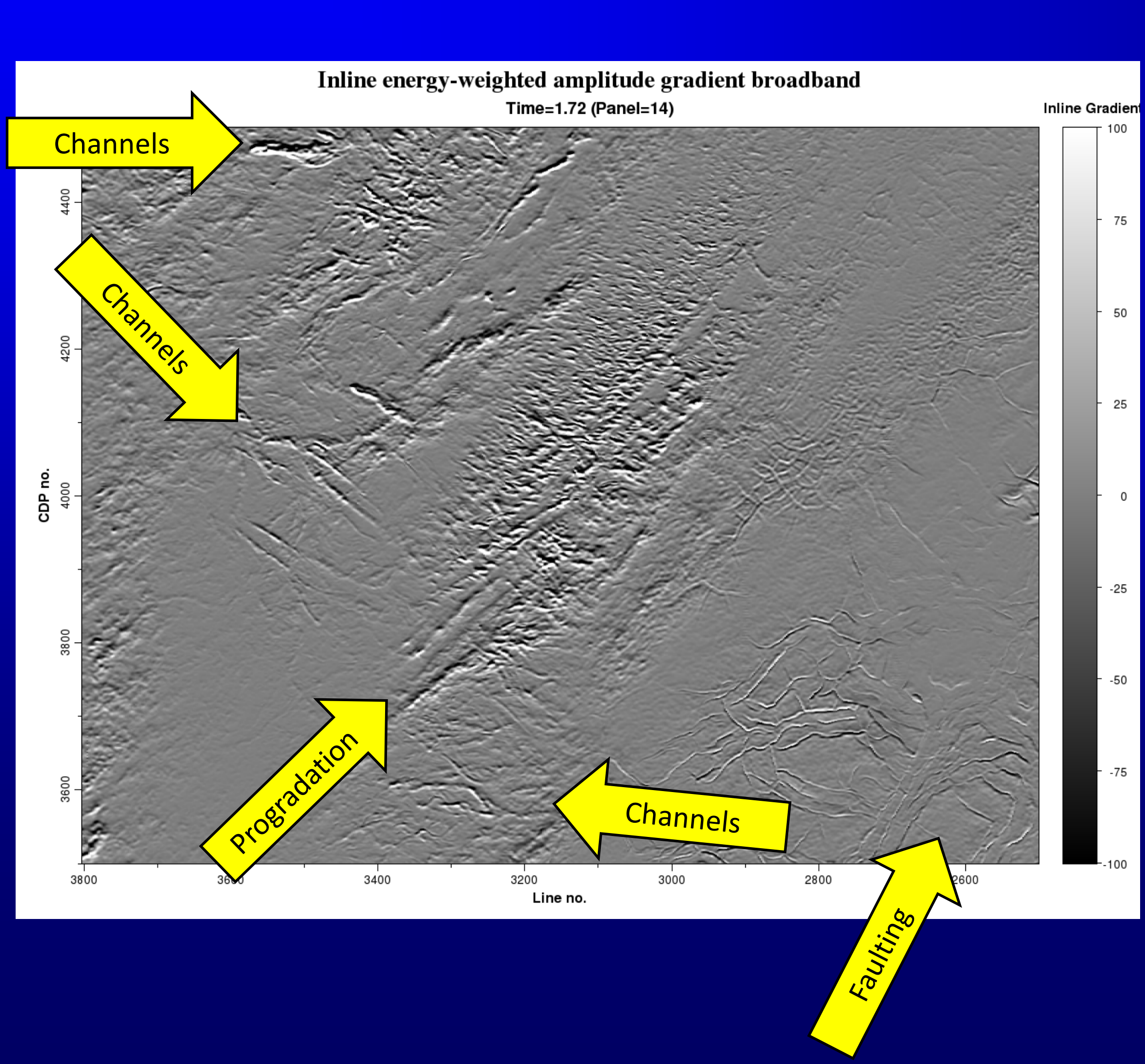


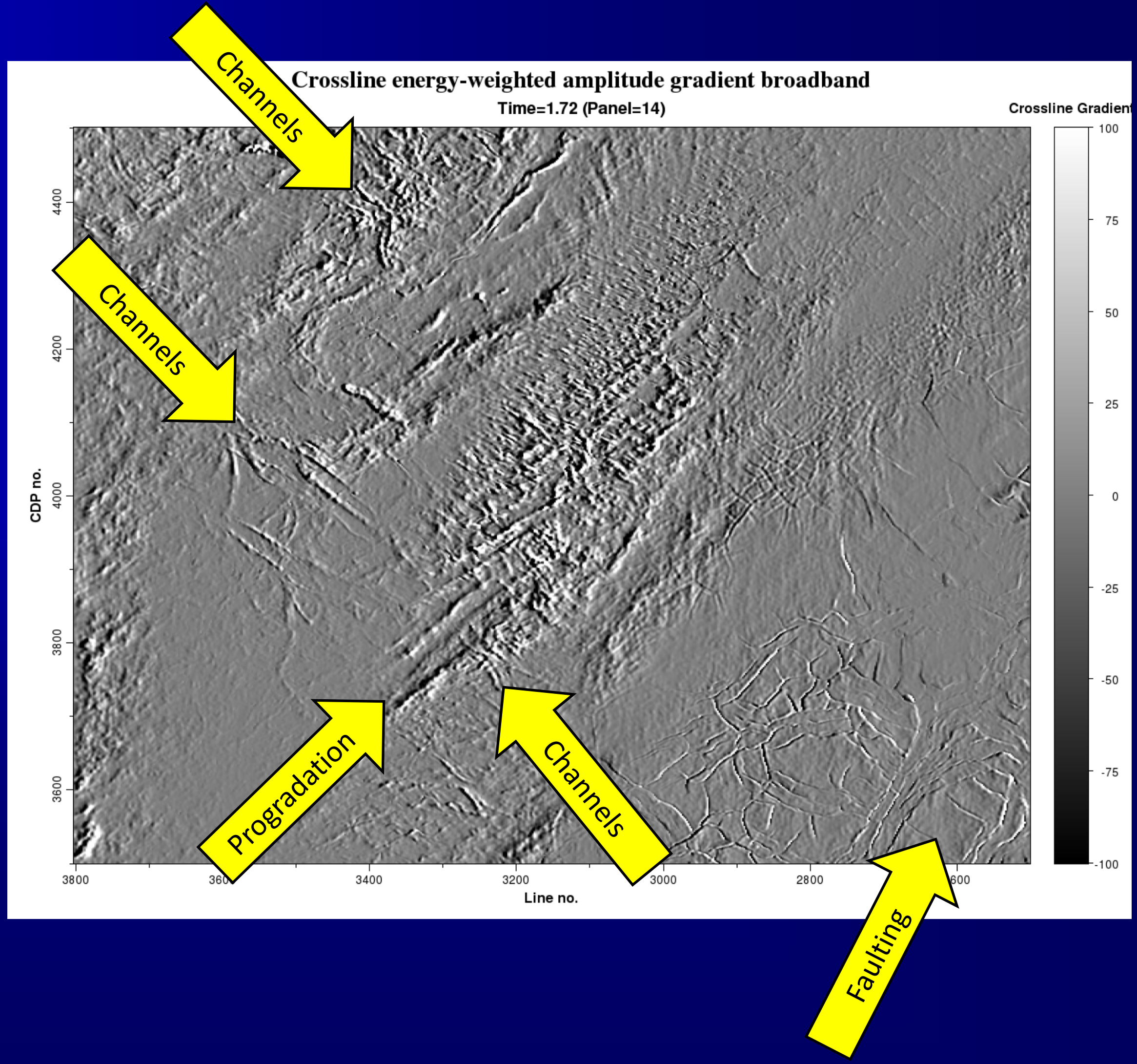
Energy-weighted coherent amplitude gradients
(Great South Basin, New Zealand)



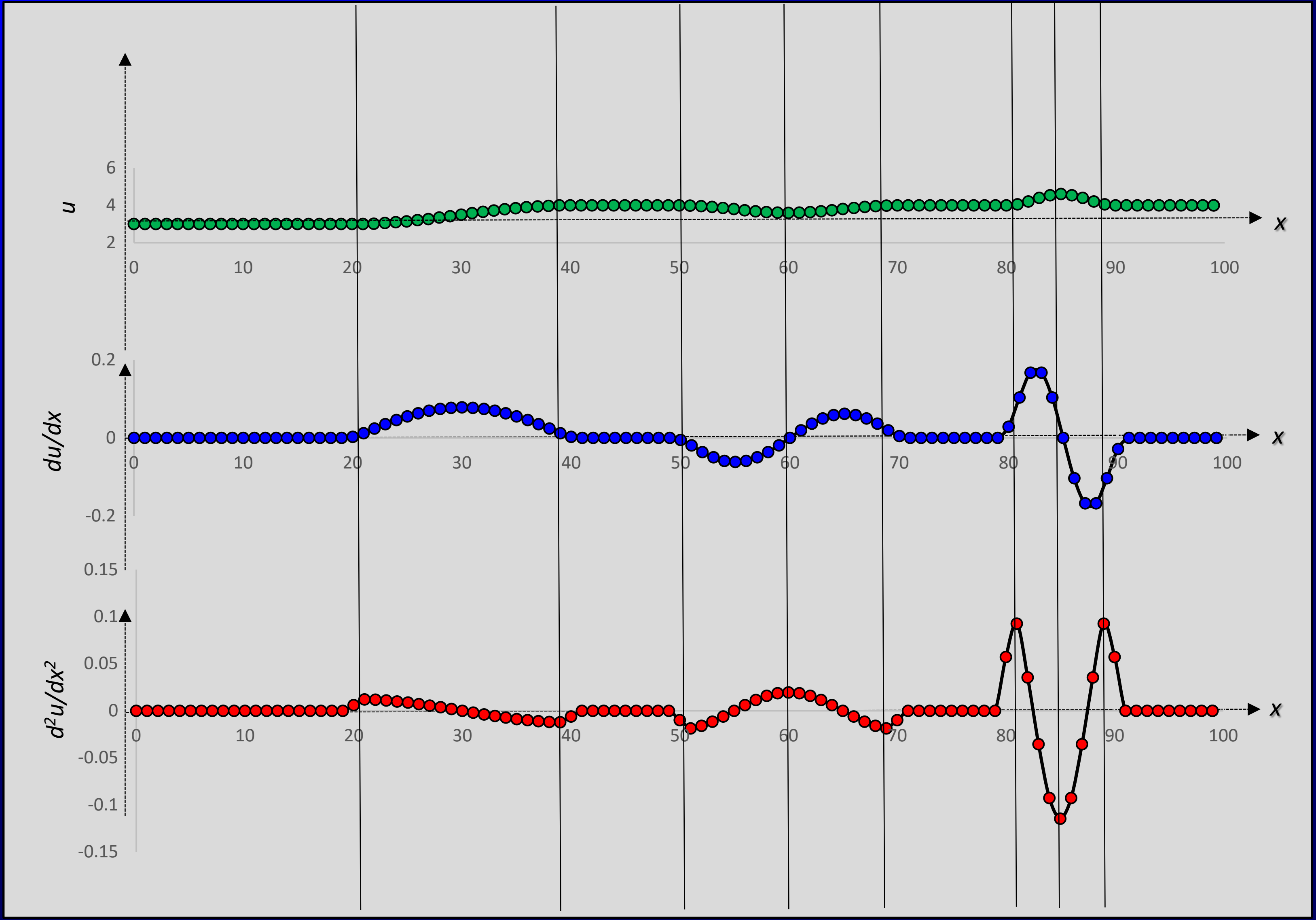


Energy-weighted coherent amplitude gradients
(Great South Basin, New Zealand)





Derivatives of an RMS amplitude, energy, or impedance profile

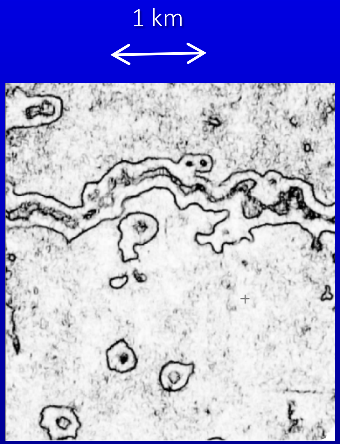


Amplitude profile

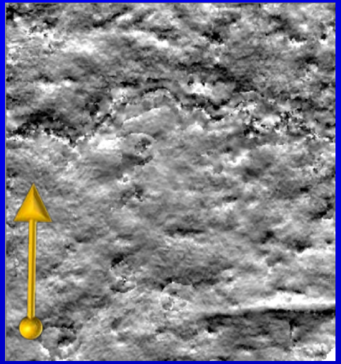
1st derivative profile

2nd derivative profile

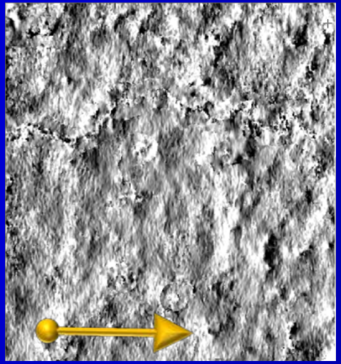
Structural curvature versus Amplitude curvature



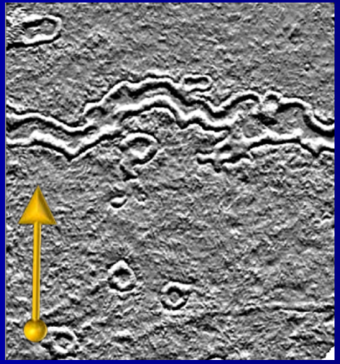
Coherence



Inline (NS) dip

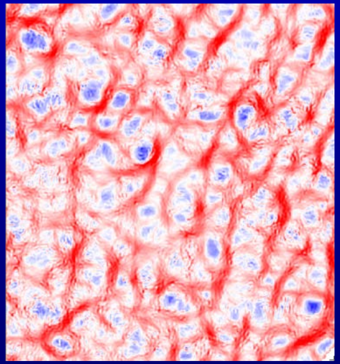


Crossline (EW) dip

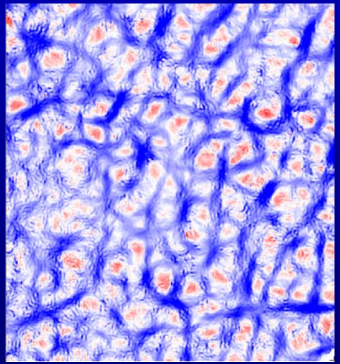


Inline (NS) energy gradient

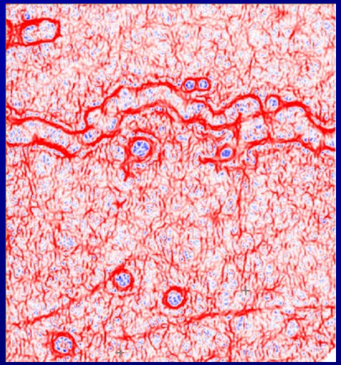
Crossline (EW) energy gradient



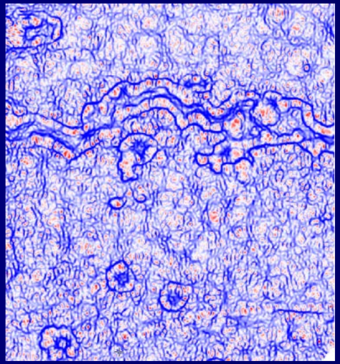
Principal structural positive curvature (LW)



Principal structural negative curvature (LW)



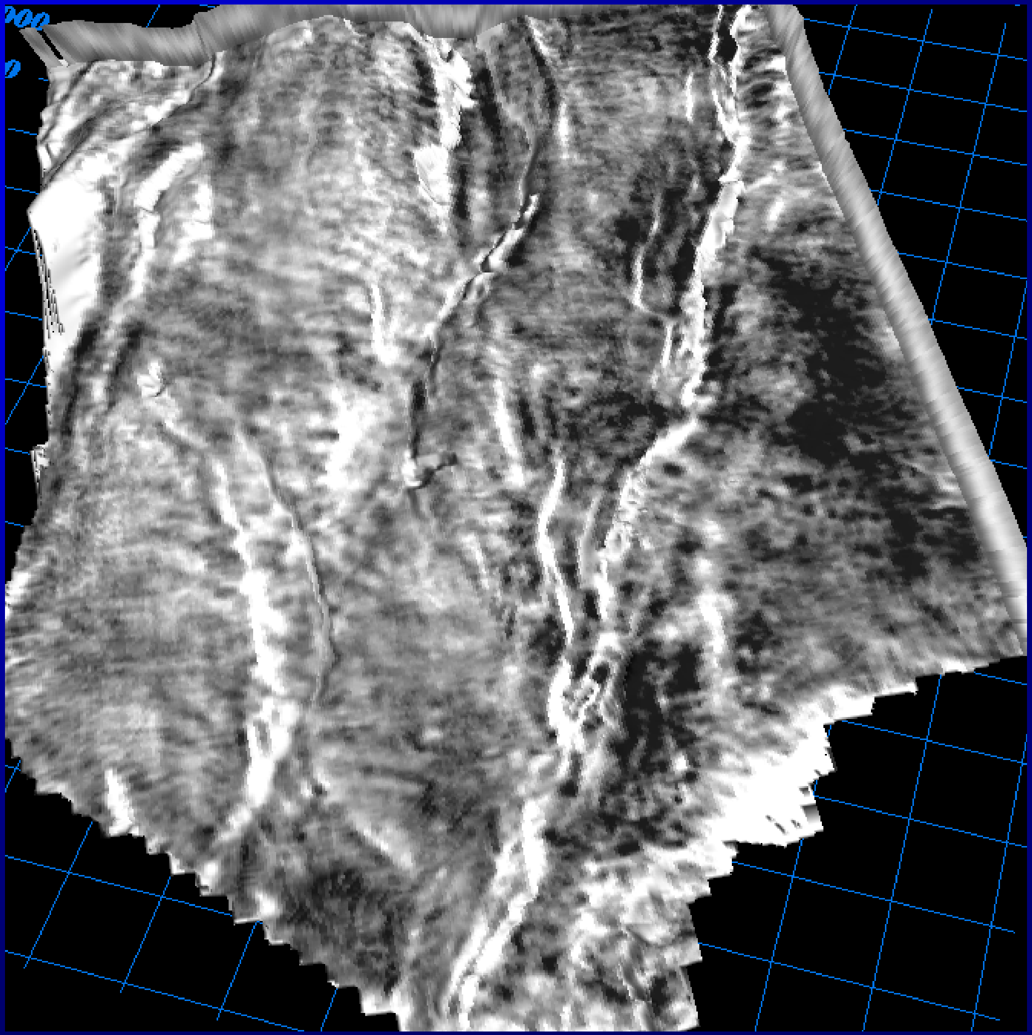
Amplitude positive curvature (LW)



Amplitude negative curvature (LW)

(Chopra and Marfurt, 2011;' Data courtesy: Fairborne Energy Ltd., Calgary)

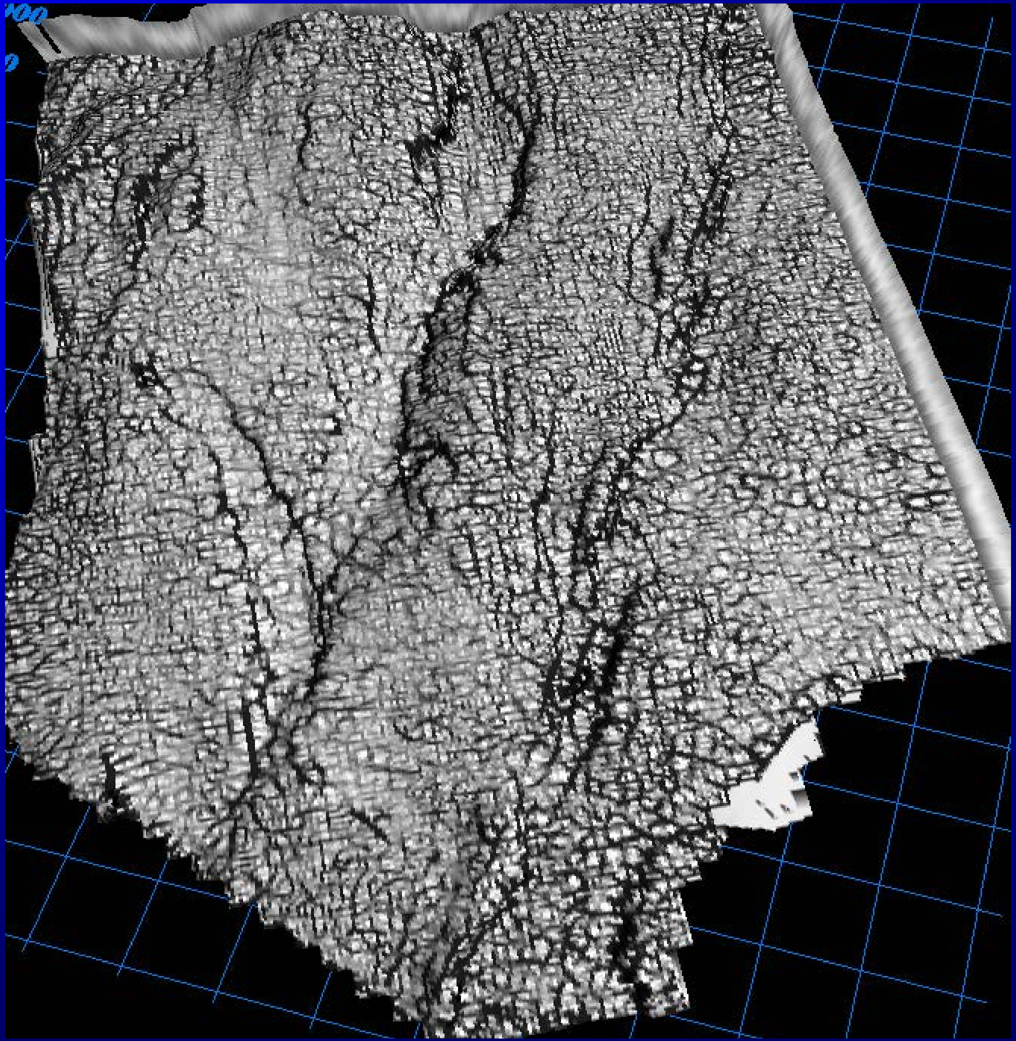
Amplitude curvature



Horizon slice through the seismic amplitude volume

(Chopra and Marfurt, 2007)

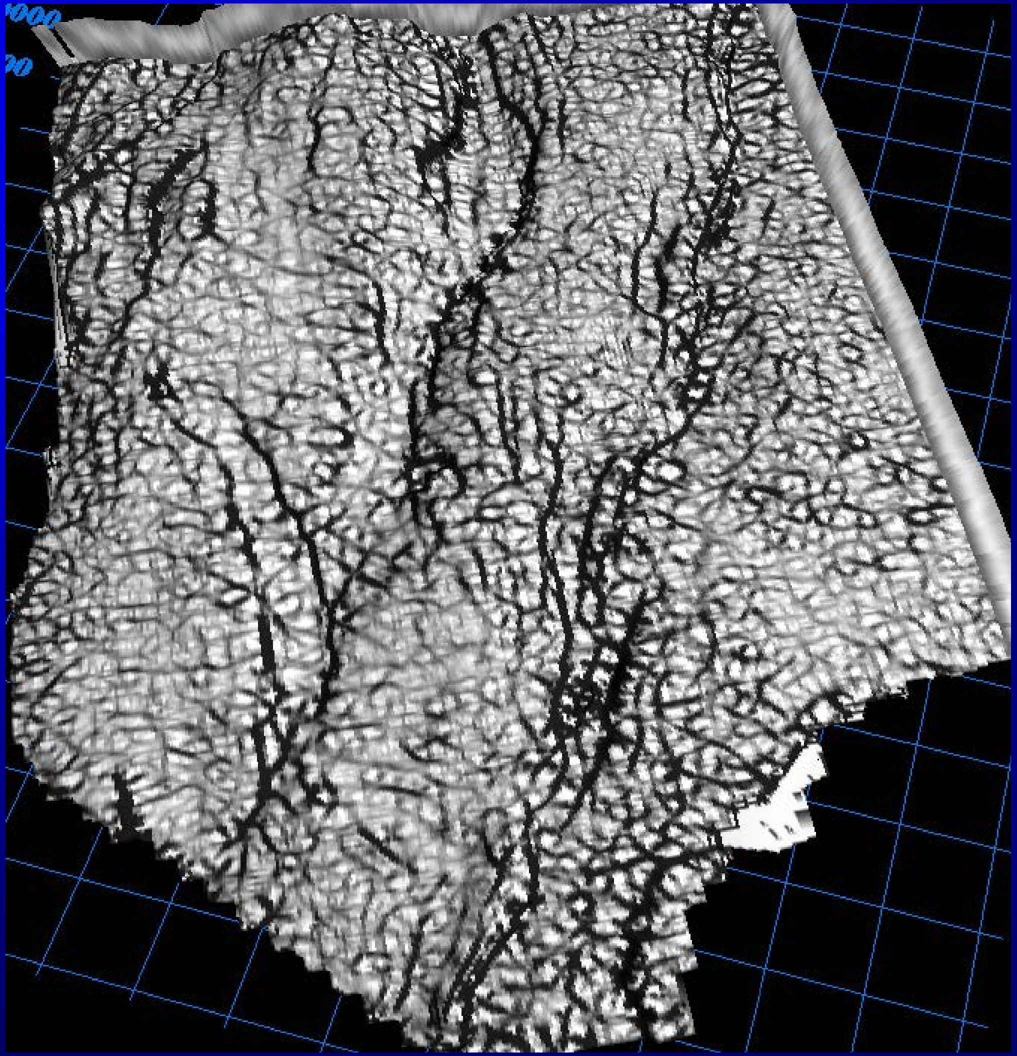
Amplitude curvature



Short wavelength most-positive amplitude curvature, e_{pos}

(Chopra and Marfurt, 2007)

Amplitude curvature



Long wavelength most-positive amplitude curvature, e_{pos}

(Chopra and Marfurt, 2007)

Horizon slice along top Ellenburger Dolomite, Fort Worth Basin, TX

Most-positive structural curvature, k_1

Most-negative structural curvature, k_2

Small, isolated collapse

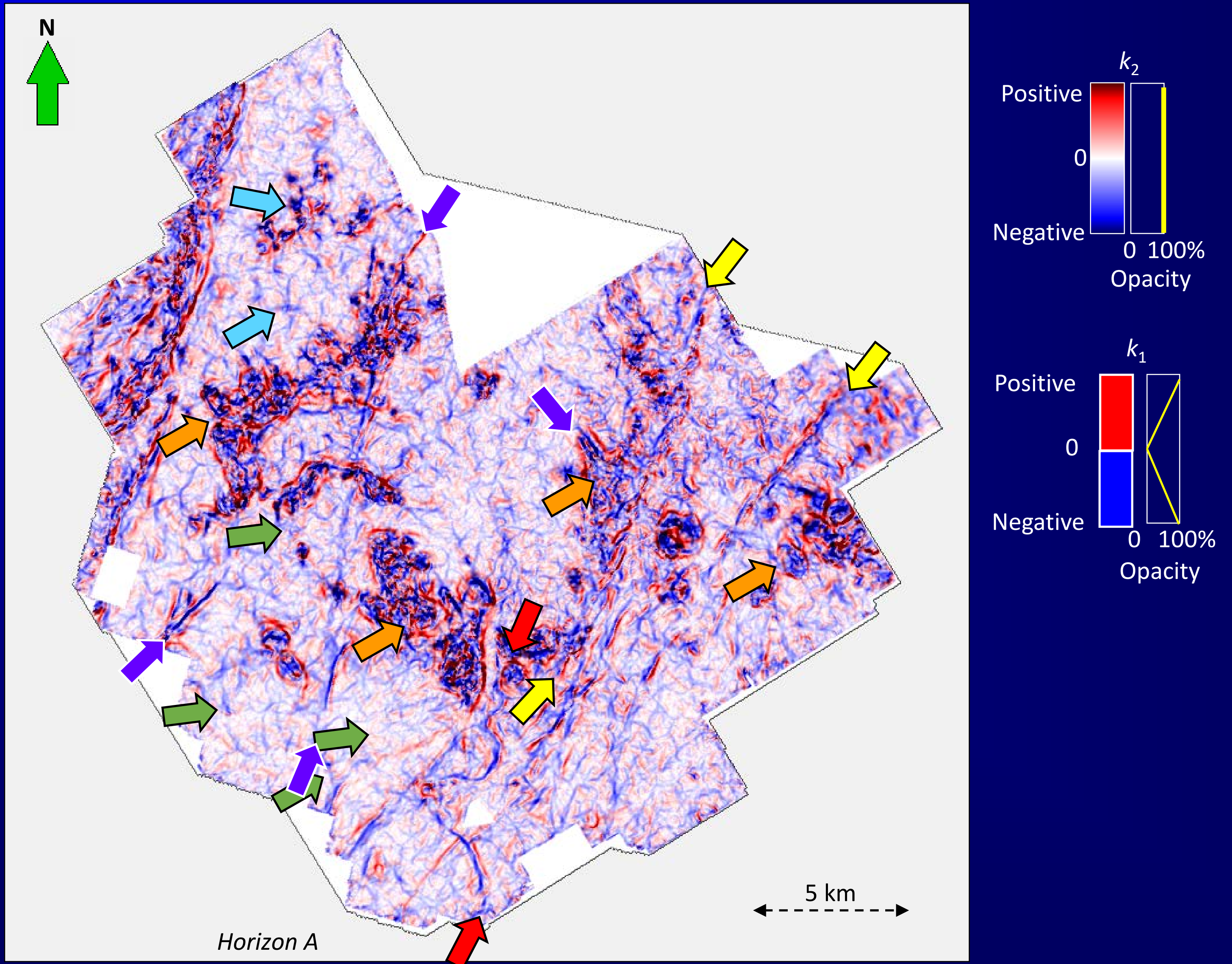
Collapse at intersection of joints

Small, collapse in structurally deformed area

Discrete, linear edges

Channel seen only on structural curvature

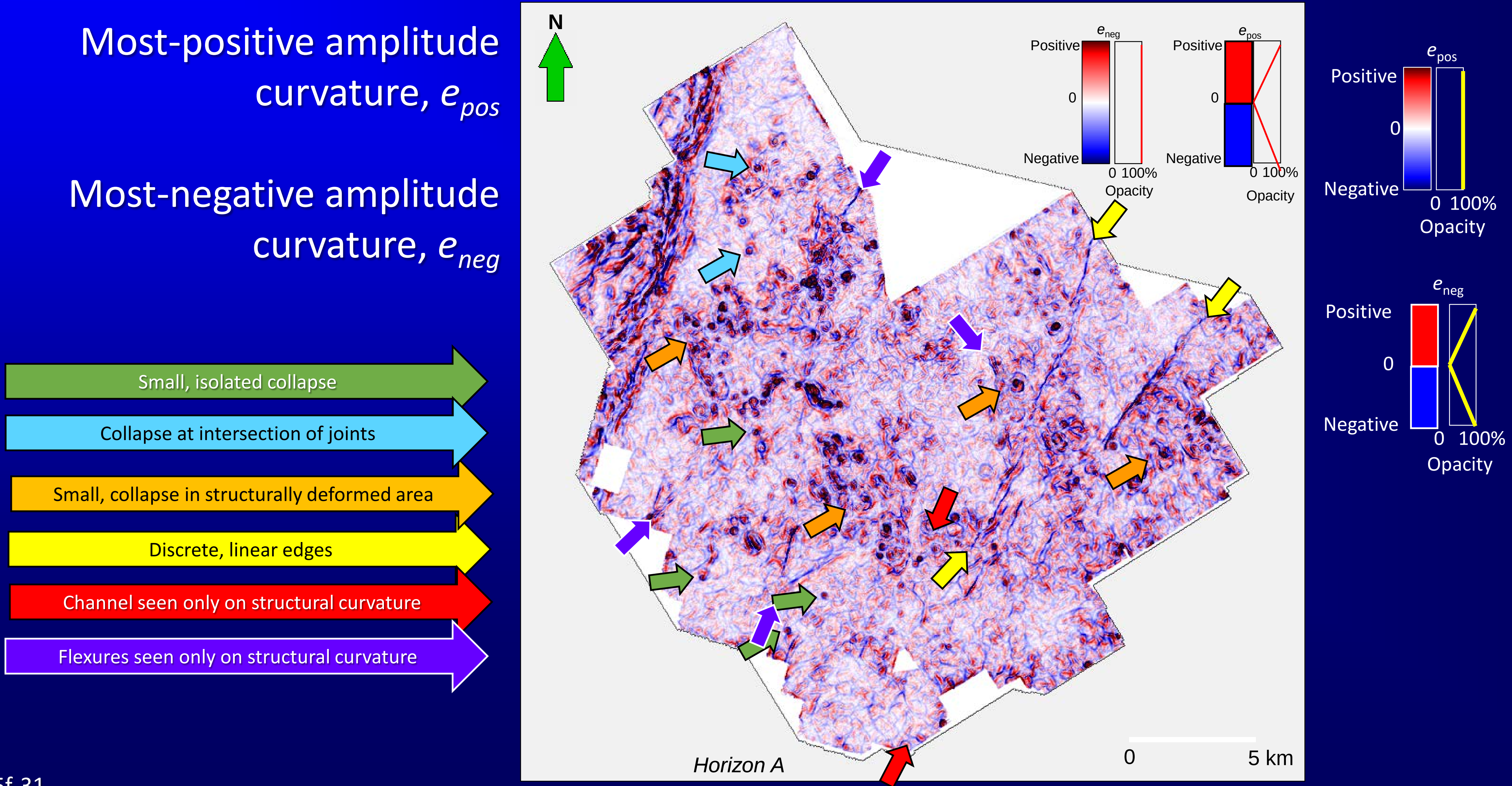
Flexures seen only on structural curvature



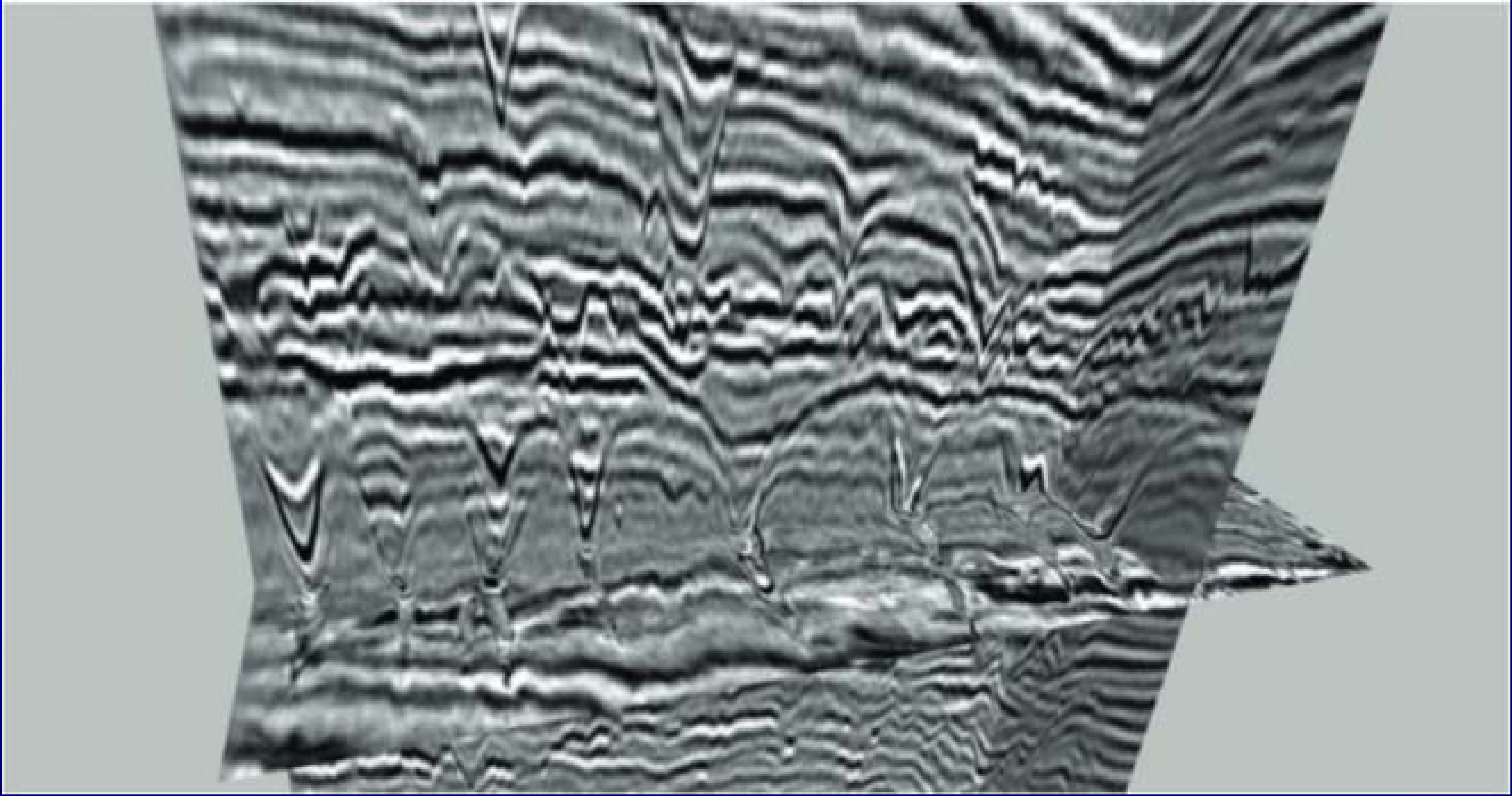
Horizon slice along top Ellenburger Dolomite, Fort Worth Basin, TX

Most-positive amplitude curvature, e_{pos}

Most-negative amplitude curvature, e_{neg}



Amplitude curvature to delineate channels (Taranaki Basin)



Chair display of amplitude data

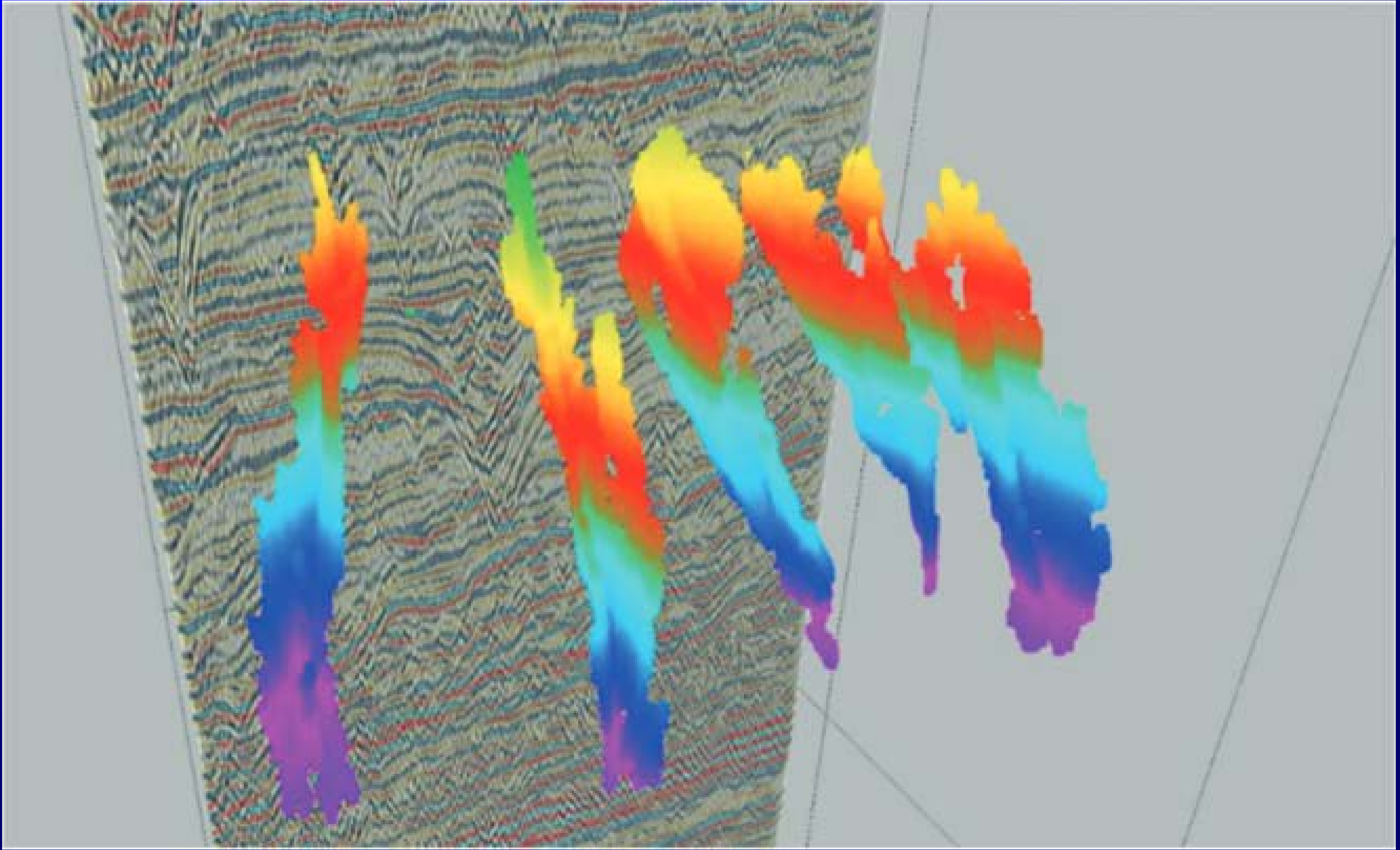
(DeGroot et al., 2021)

Amplitude curvature to delineate channels (Taranaki Basin)

Chair display of 2nd derivative of amplitude (amplitude curvature) in the crossline direction

(DeGroot et al., 2021)

Amplitude curvature to delineate channels (Taranaki Basin)



The results of dGB's "thalweg tracker"

(DeGroot et al., 2021)

Lateral Changes in Amplitude and Texture Analysis

In Summary:

- Lateral changes in coherent amplitude are mathematically independent of eigenstructure coherence, dip/azimuth, and curvature
- Lateral changes in total amplitude as measured by semblance and the Sobel filter are sensitive to both thin bed tuning and changes in waveform
- Lateral changes in coherent amplitude are often associated with thin bed tuning – helping us map channels and paleo topographic features below the tuning thickness where eigenstructure coherence fails