Seismic Attributes - from Interactive Interpretation to Machine Learning

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Geometric Attributes that Map Reflector Configuration

Curvature and Aberrancy

Geometric attributes that map reflector configuration

1. Dip magnitude and dip azimuth
2. Reflector convergence
3. Reflector nonparallelism
4. Curvature and aberrancy
5. Shape index and curvedness

Volumetric curvature

After this section you will be able to:

- Use most-positive and most-negative principal curvatures to map folds, flexures, and faults that separate blocks exhibiting a lateral change of dip,
- Use aberrancy to define the axes of flexures that may be aligned with faults that exhibit offsets that fall below the limits of seismic resolution, and
- Use the strike of curvature or the azimuth of aberrancy to construct hypothesized fault or fold sets

Alternative volumetric measures of curvature

1. 3D derivatives of volumetric vector dip estimates
    - Long wavelength estimates obtained by applying a k_x-k_y filter to the derivative operator
2. 2D derivatives of a surface fit to local dip
    - Long wavelength estimates obtained by fitting the quadratic surface to nine more distant points
    - Long wavelength estimates obtained by fitting the quadratic surface to all points in a larger patch

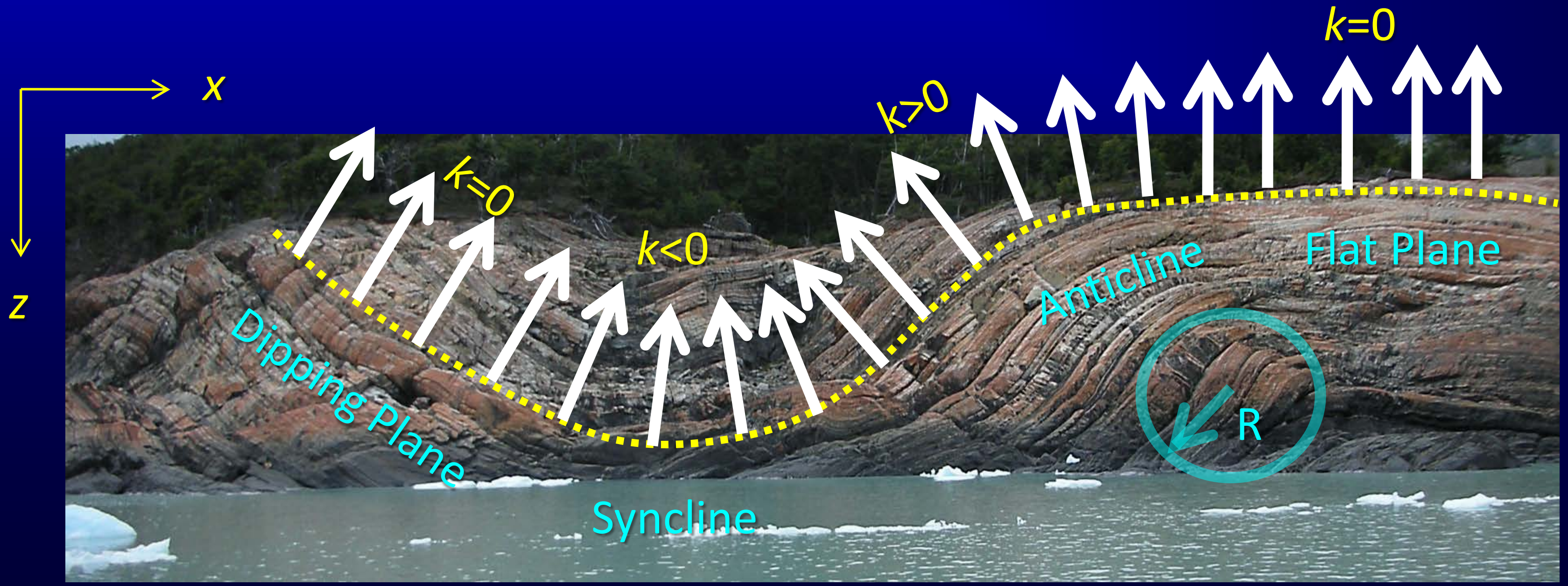
Sign convention for 2D curvature attributes:

Anticline: $k > 0$

Plane: $k = 0$

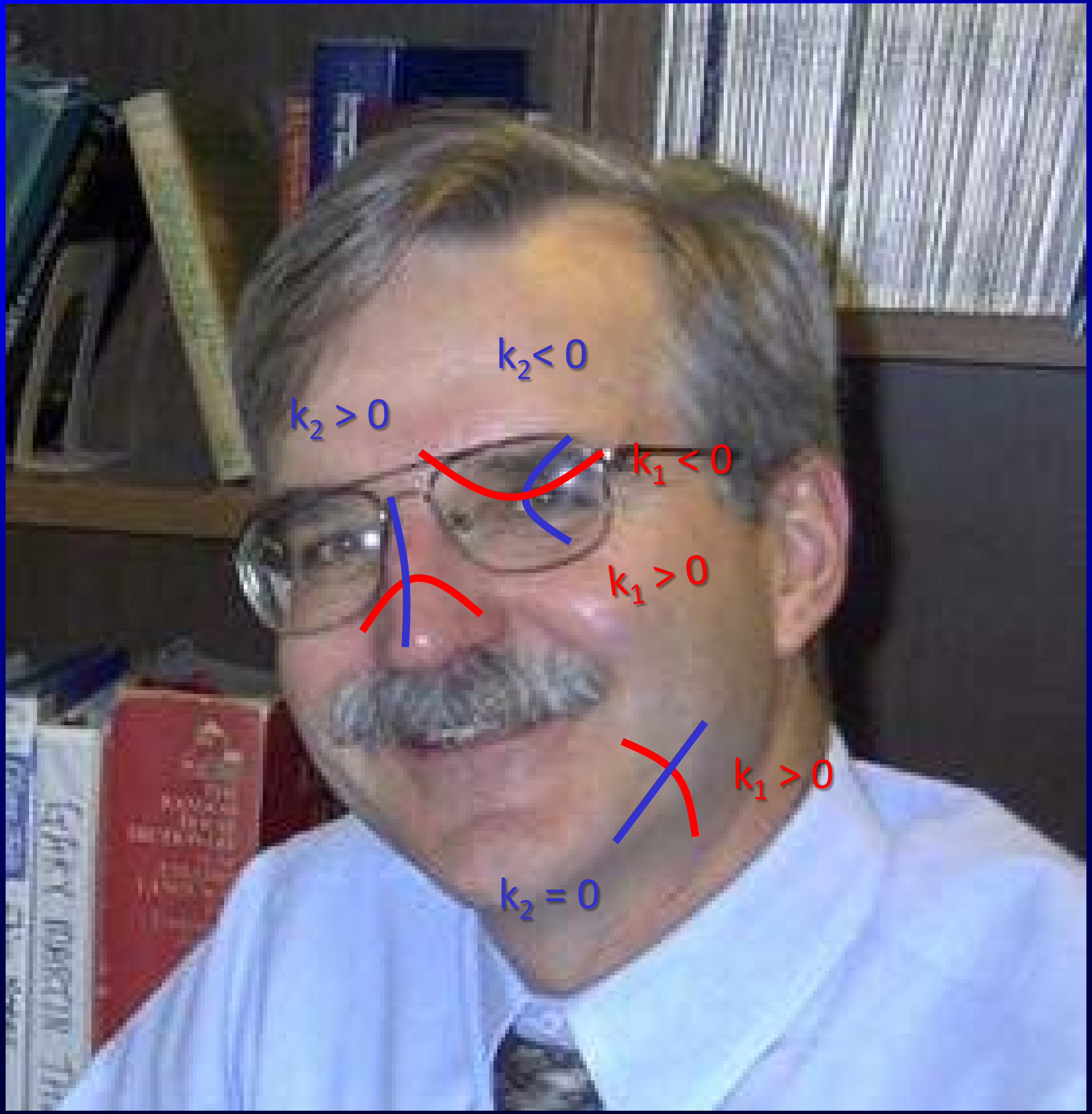
Syncline: $k < 0$

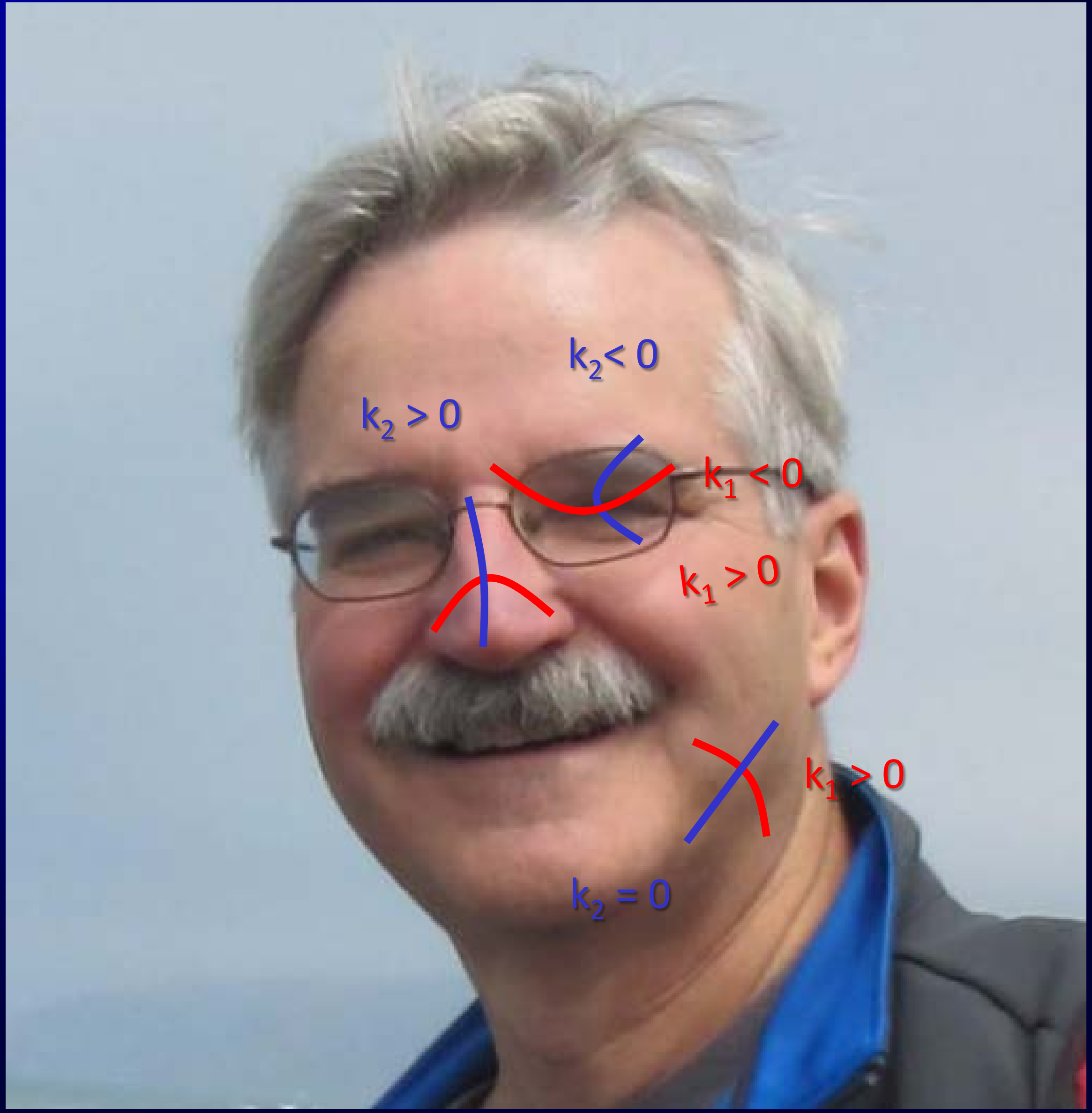
$$k = \frac{1}{R} = \frac{d\theta}{ds} = \frac{\dfrac{d^2 z}{dx^2}}{\left[1+\left(\dfrac{dz}{dx}\right)^2\right]^{3/2}}$$



(Marfurt, 2018)

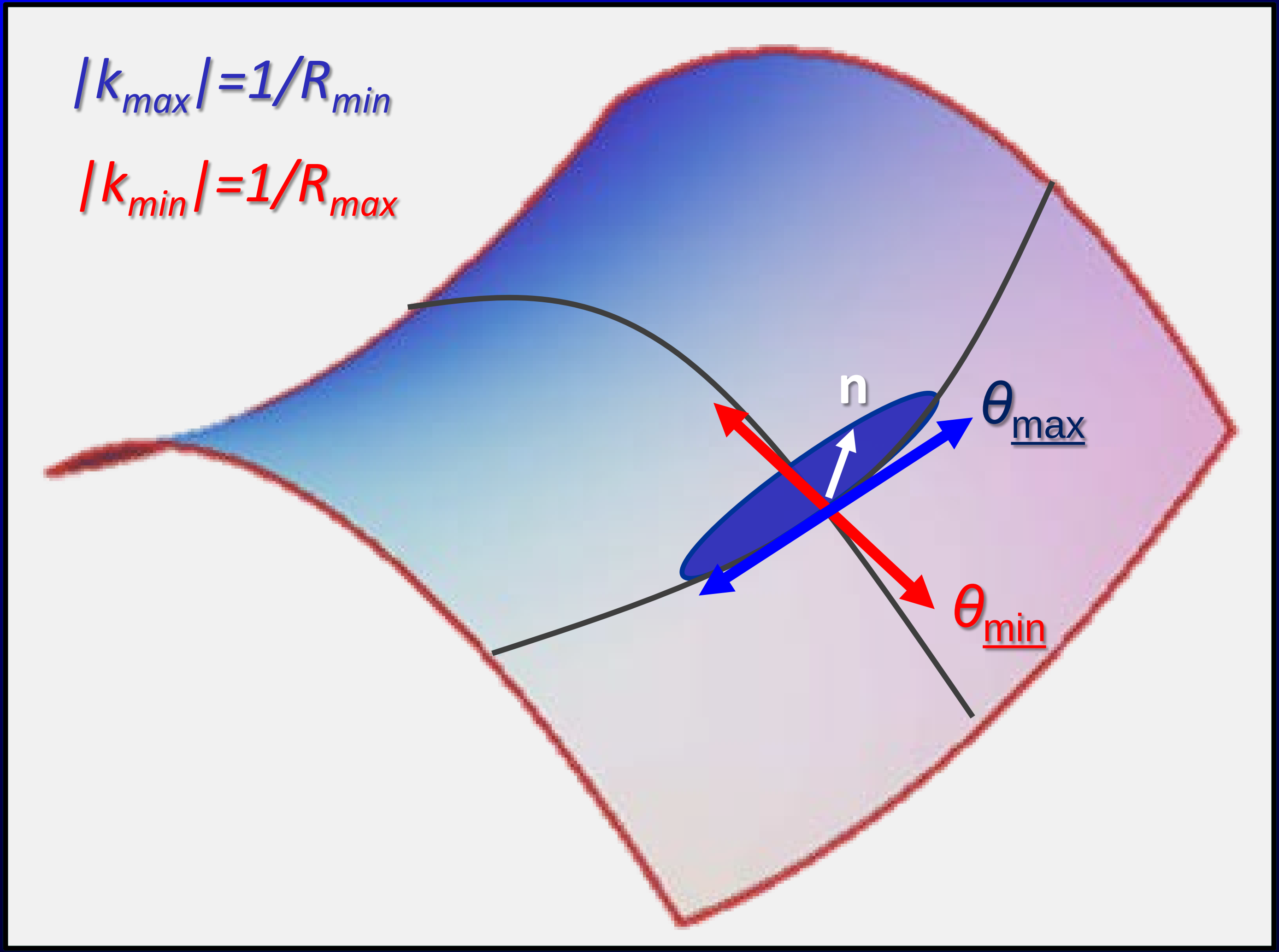
3D Curvature and Biometric Identification of Suspicious Travelers





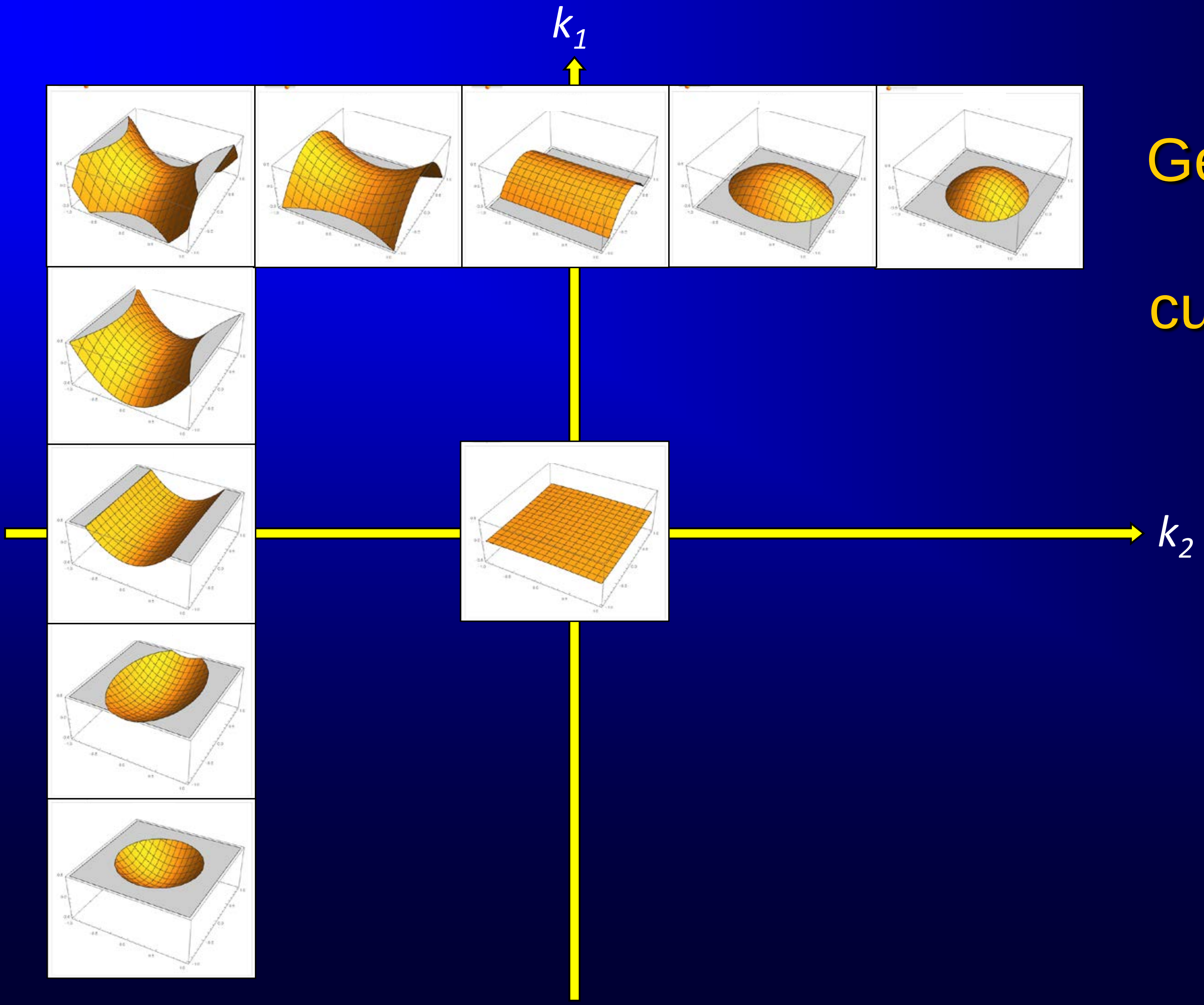
(Marfurt, 2018)

Circles in perpendicular planes tangent to a quadratic surface

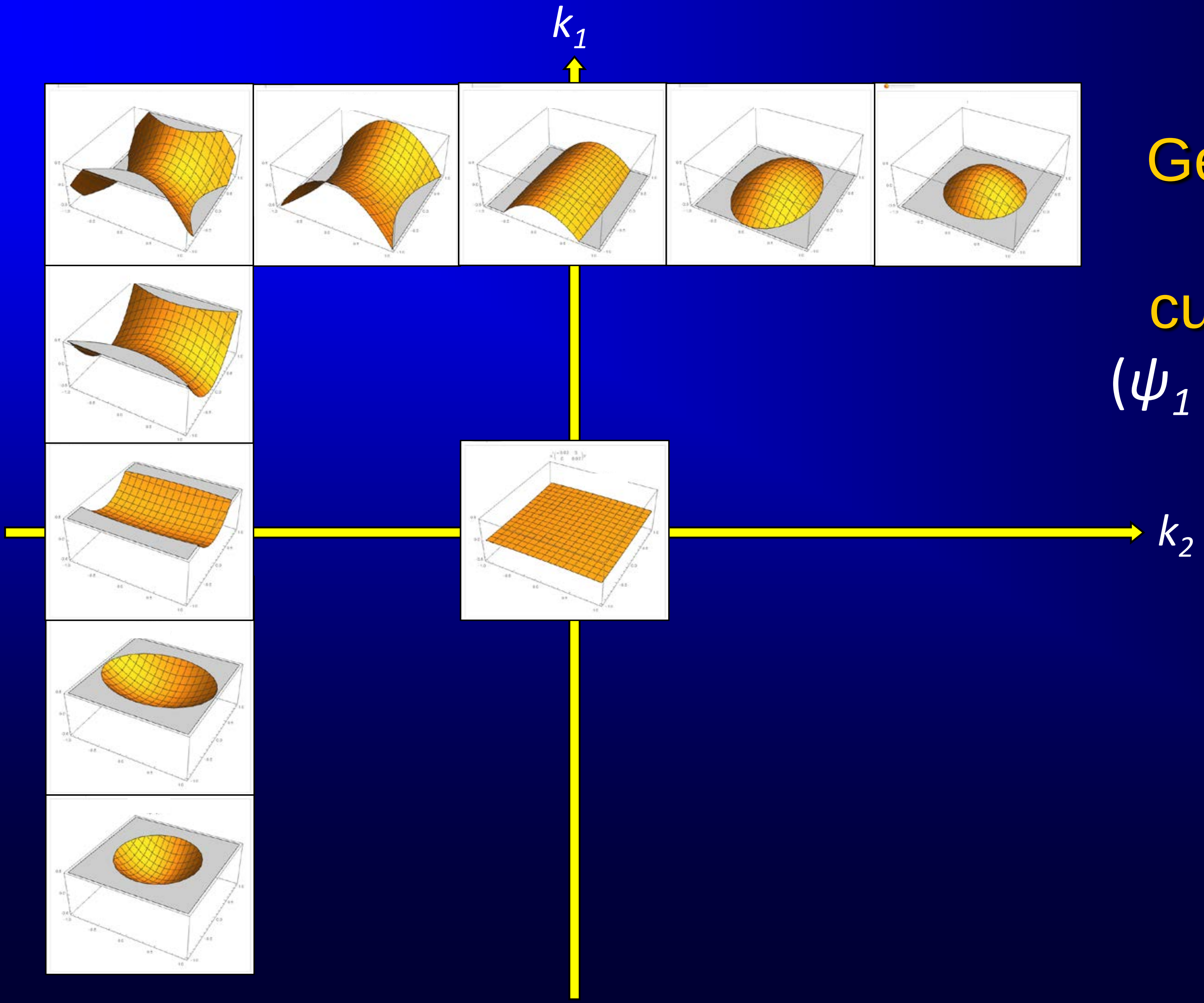


(Mai et al., 2009)

Geometry defined by the two principal curvatures, k_1 and k_2



(Marfurt, 2018)



Geometry defined by the two principal curvatures, k_1 and k_2

(ψ_1 and ψ_2 rotated by 90°)

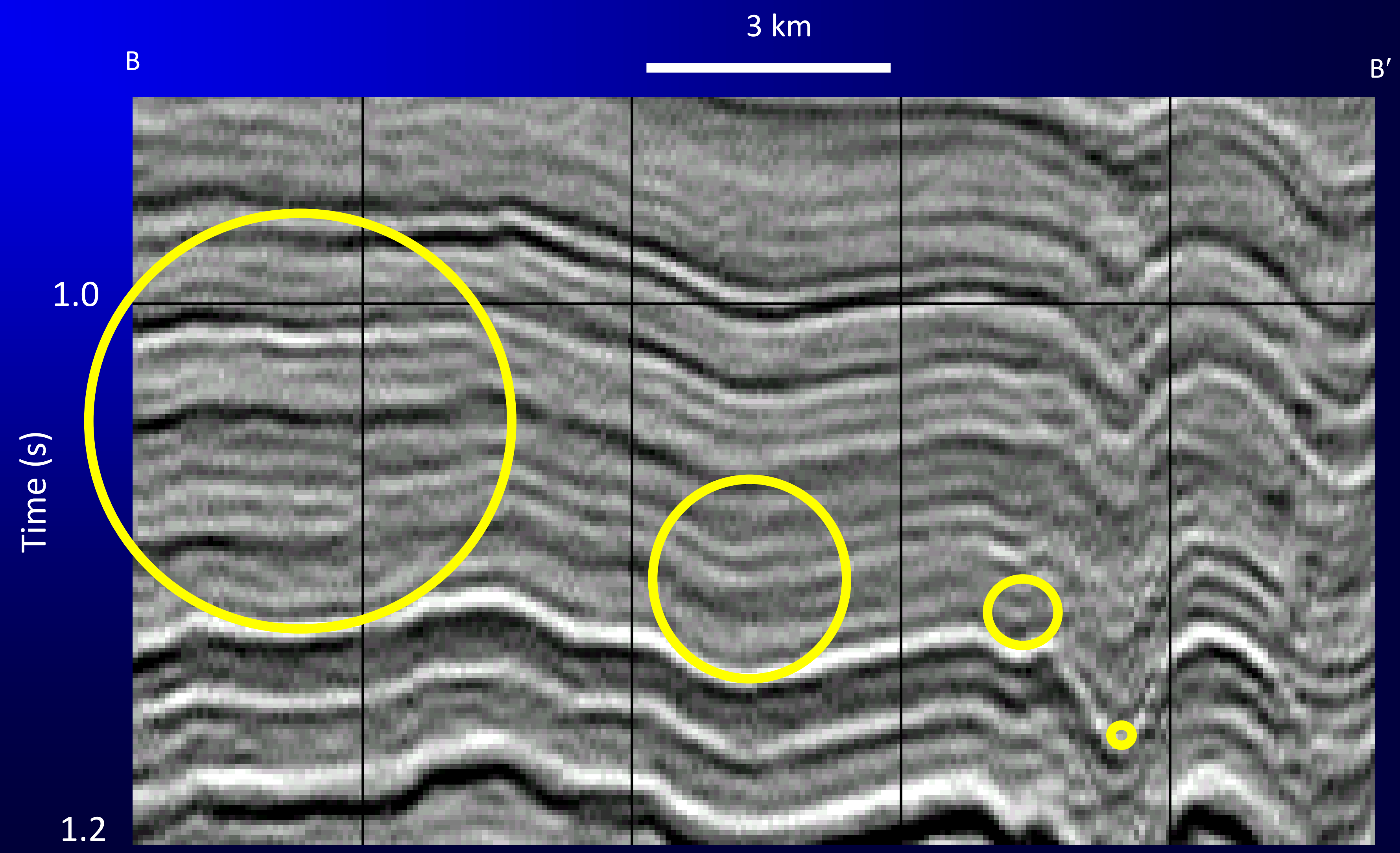
(Marfurt, 2018)

A deeper look:

The value of volumetric vs. horizon-based attributes

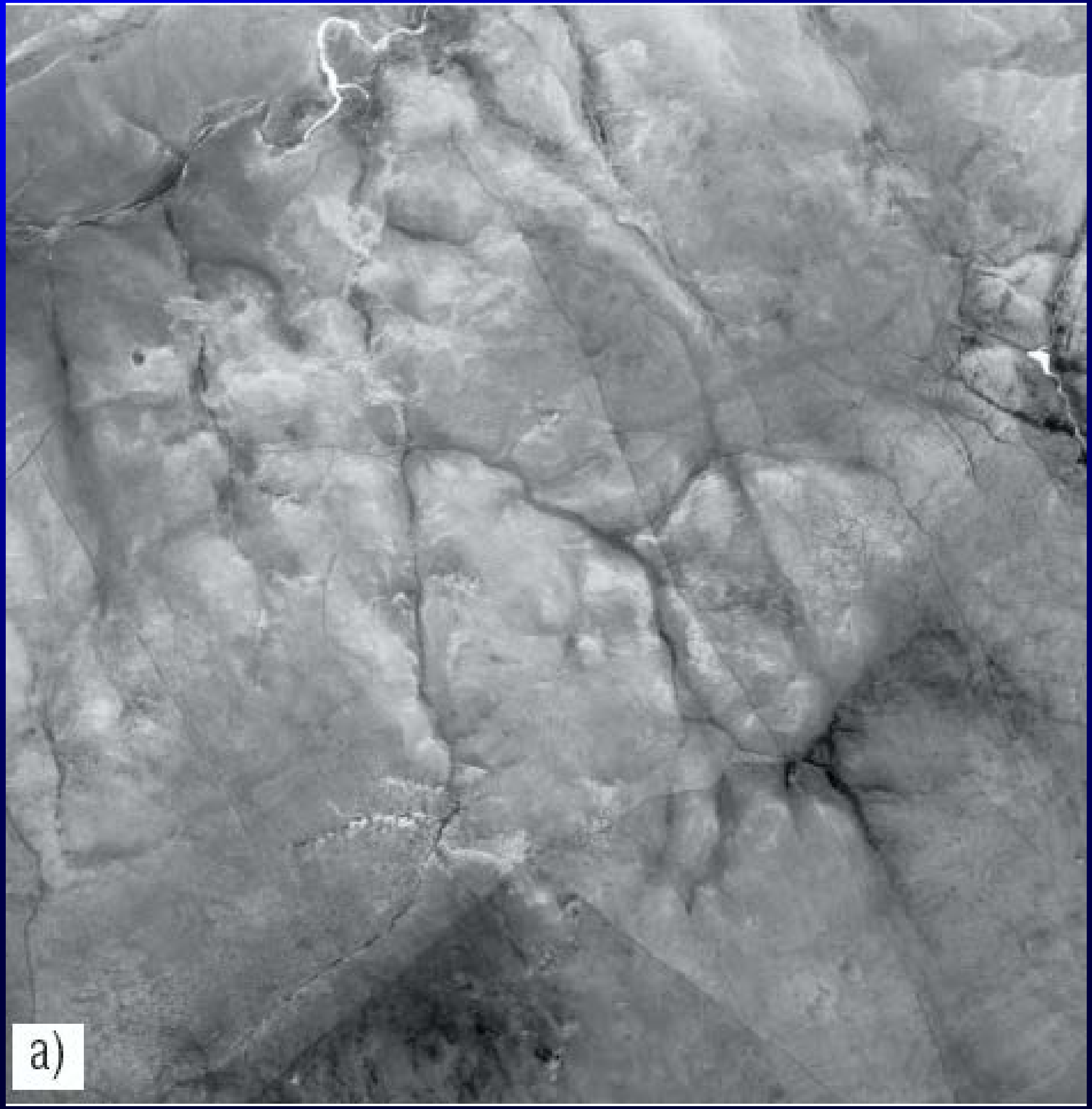
The value of long-wavelength vs. short-wavelength computations

Radius of Curvature



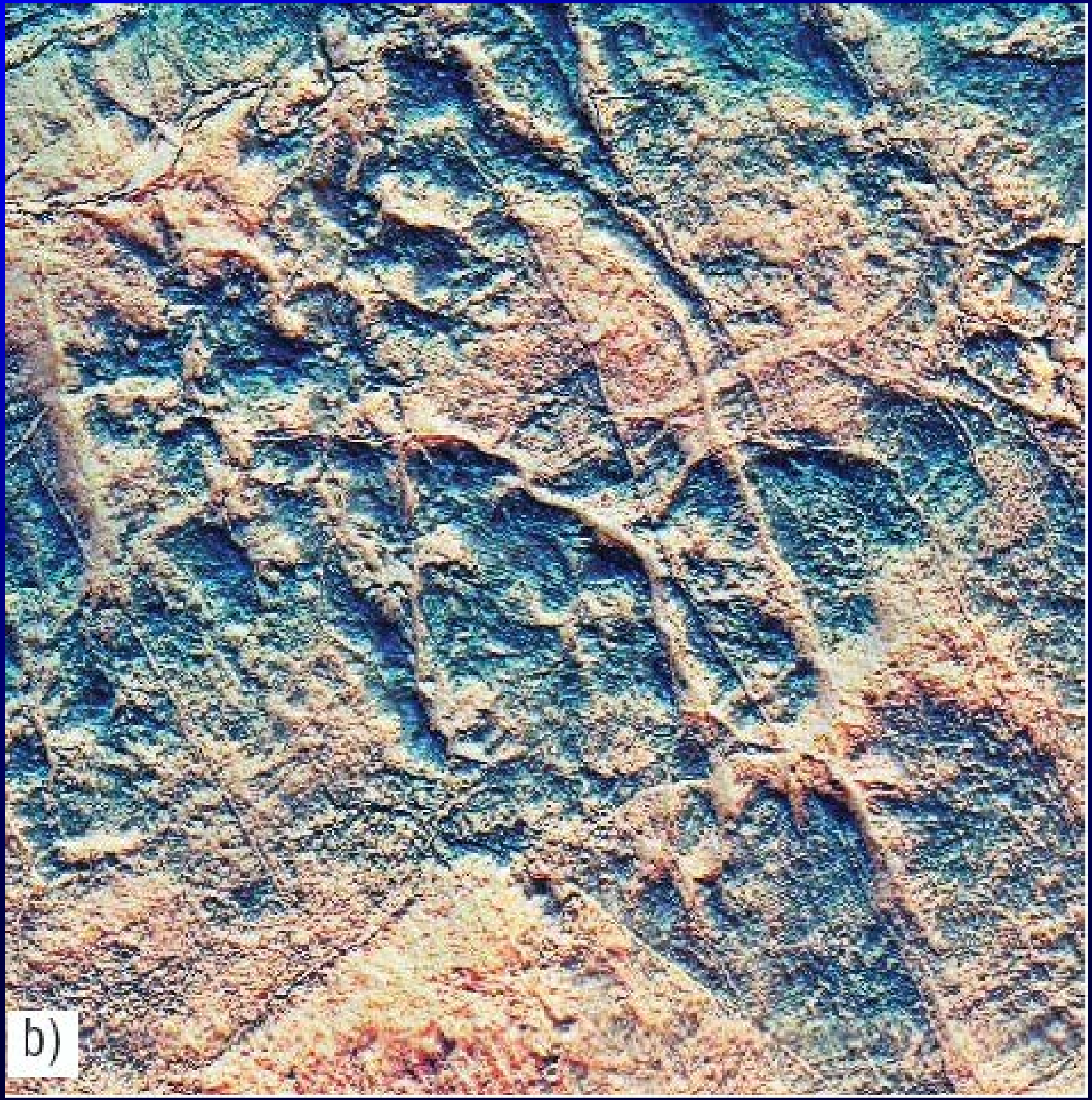
(Chopra and Marfurt, 2007)

Thermal imagery with sun-shading



(Cooper and Cowan, 2003)

Fractional derivatives with sun-shading



Red=0.75
Green=1.00
Blue=1.25

(Cooper and Cowan, 2003)

Volumetric curvature can be computed using first derivatives of the dip components, *p* and *q*:

$$\frac{\partial^2 z}{\partial x^2} = \frac{\partial p}{\partial x}$$

$$\frac{\partial^2 z}{\partial x \partial y} = \frac{1}{2}\left(\frac{\partial p}{\partial y} + \frac{\partial q}{\partial x}\right)$$

$$\frac{\partial^2 z}{\partial y^2} = \frac{\partial q}{\partial y}$$

Will fractional derivatives of p and q provide more useful results?

(Cooper and Cowan, 2003)

Early estimates of long wavelength curvature: Fractional derivatives

1st derivative

$$dp/dx = F^{-1}[\, ik_x F(p) \,]$$

Fractional derivative

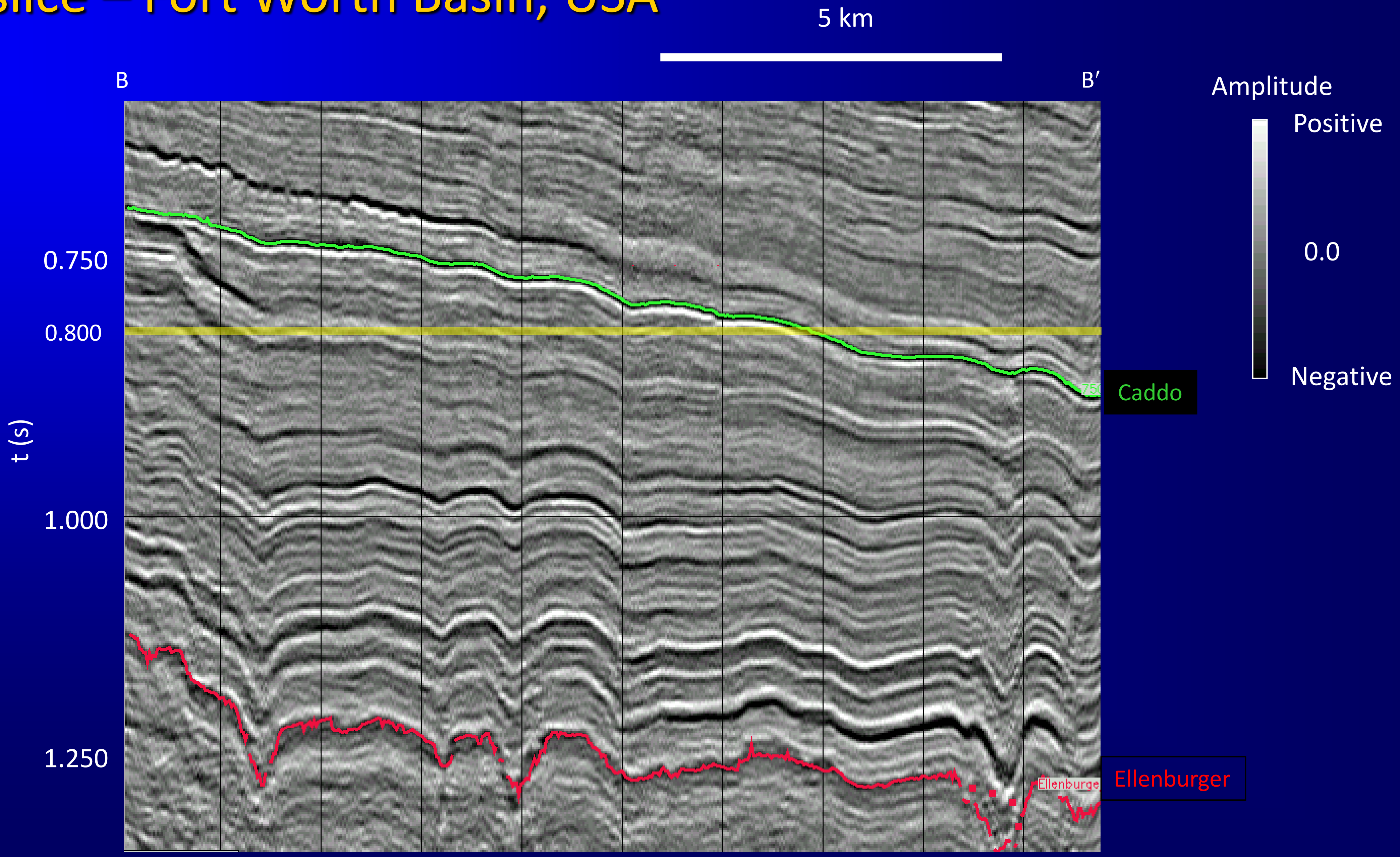
(or 1st derivative followed by a low pass filter)

$$d^{\alpha}p/dx^{\alpha} \approx F^{-1}[i(k_x)^{\alpha} F(p)\,]$$

(al-Dossary and Marfurt, 2006)

Attributes extracted along a geological horizon

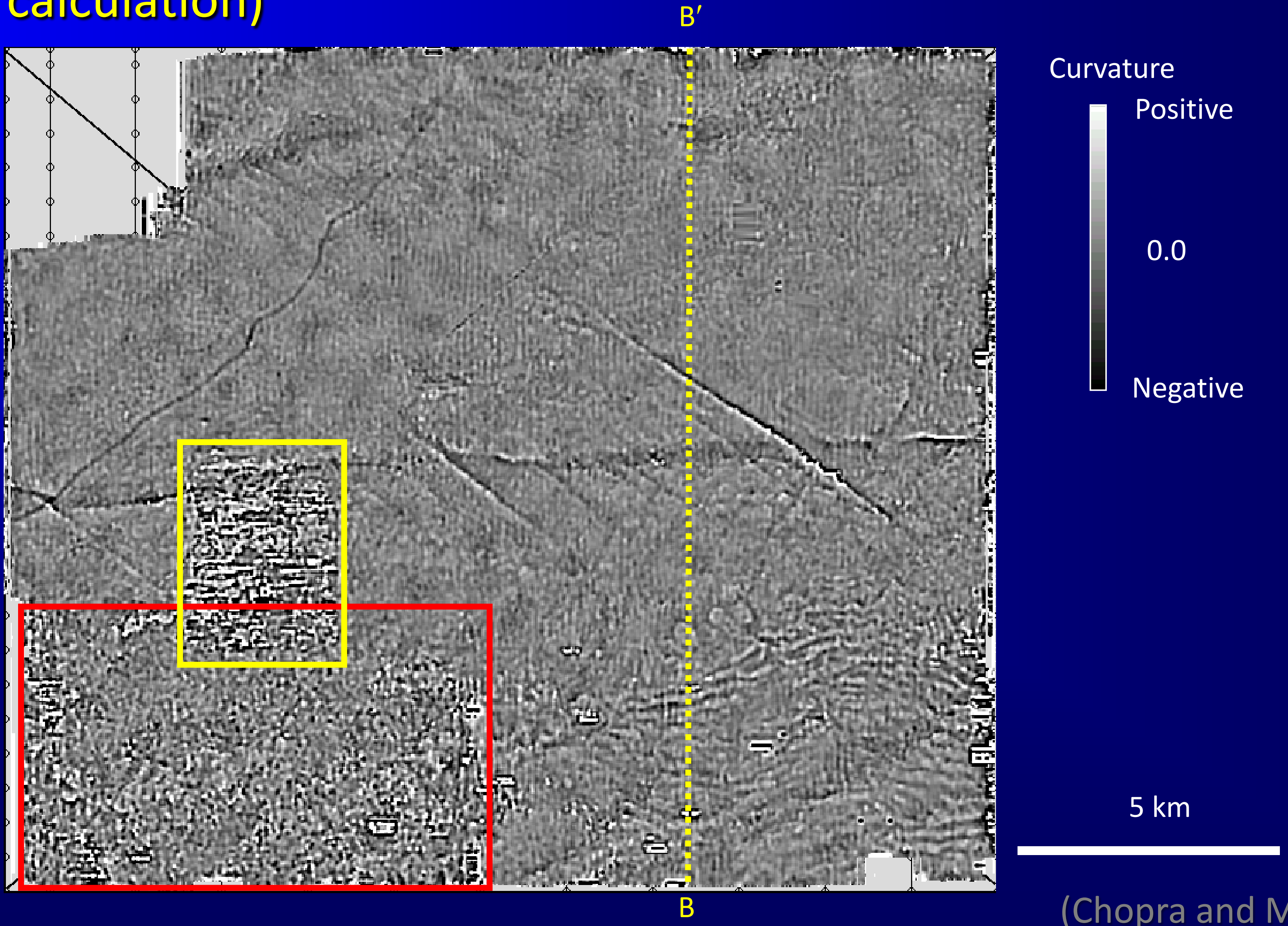
Vertical slice – Fort Worth Basin, USA



(al-Dossary and Marfurt, 2006)

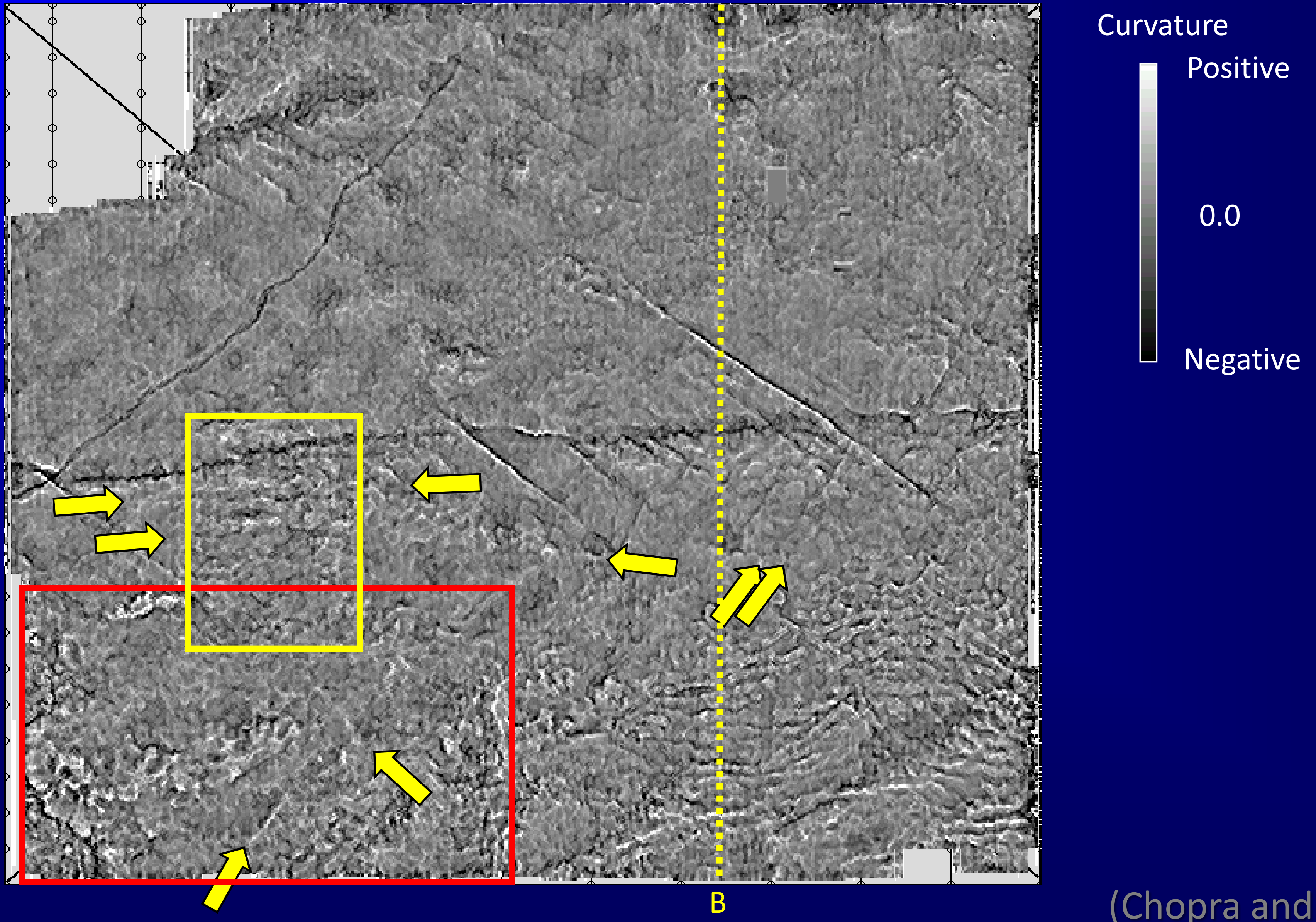
$k_{mean}=1/2(d^2T/dx^2+d^2T/dy^2)$

(Caddo horizon calculation)



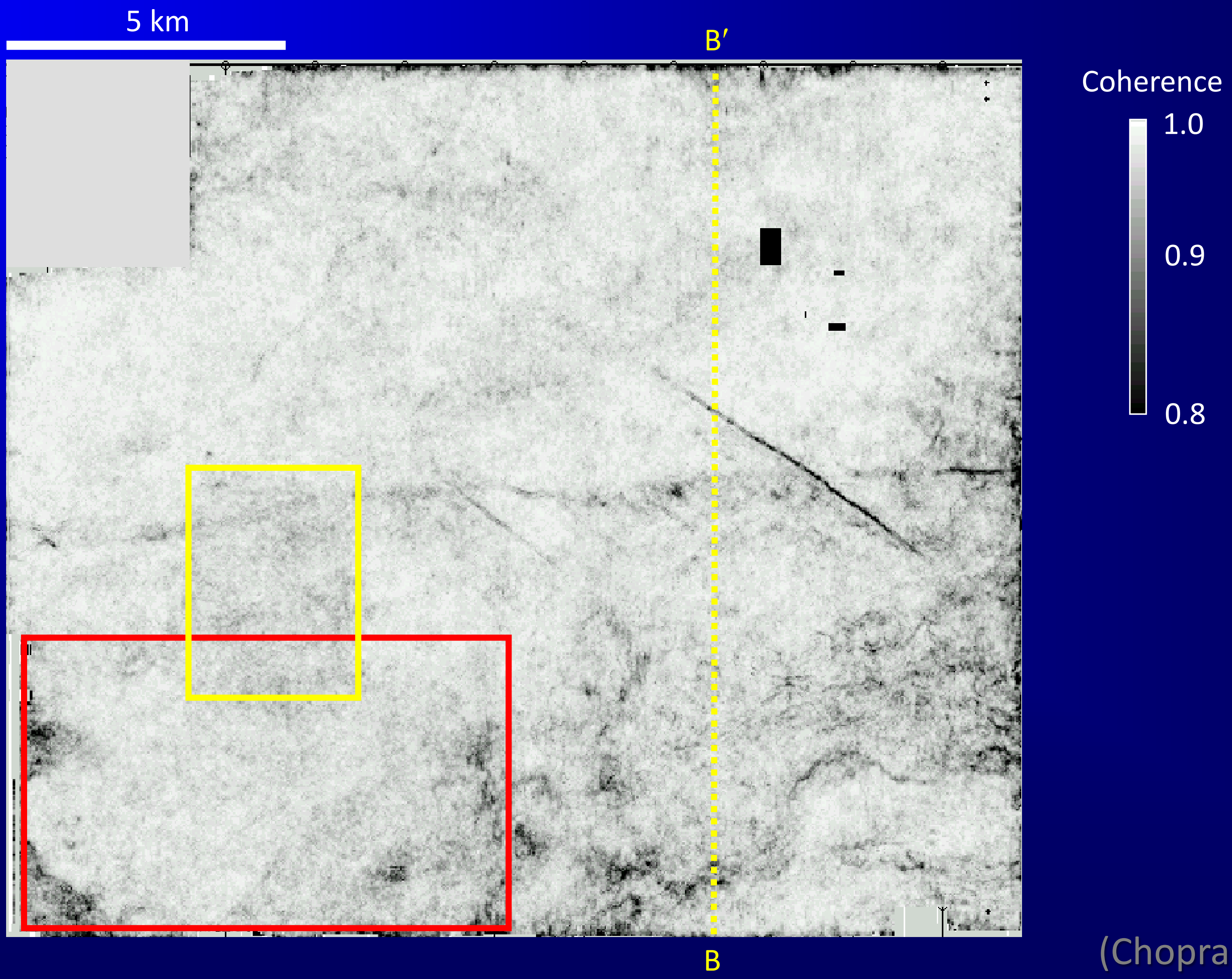
(Chopra and Marfurt, 2007)

k_{mean}=1/2(dp/dx+dq/dy)
(Caddo horizon slice through volumetric calculation)



(Chopra and Marfurt, 2007)

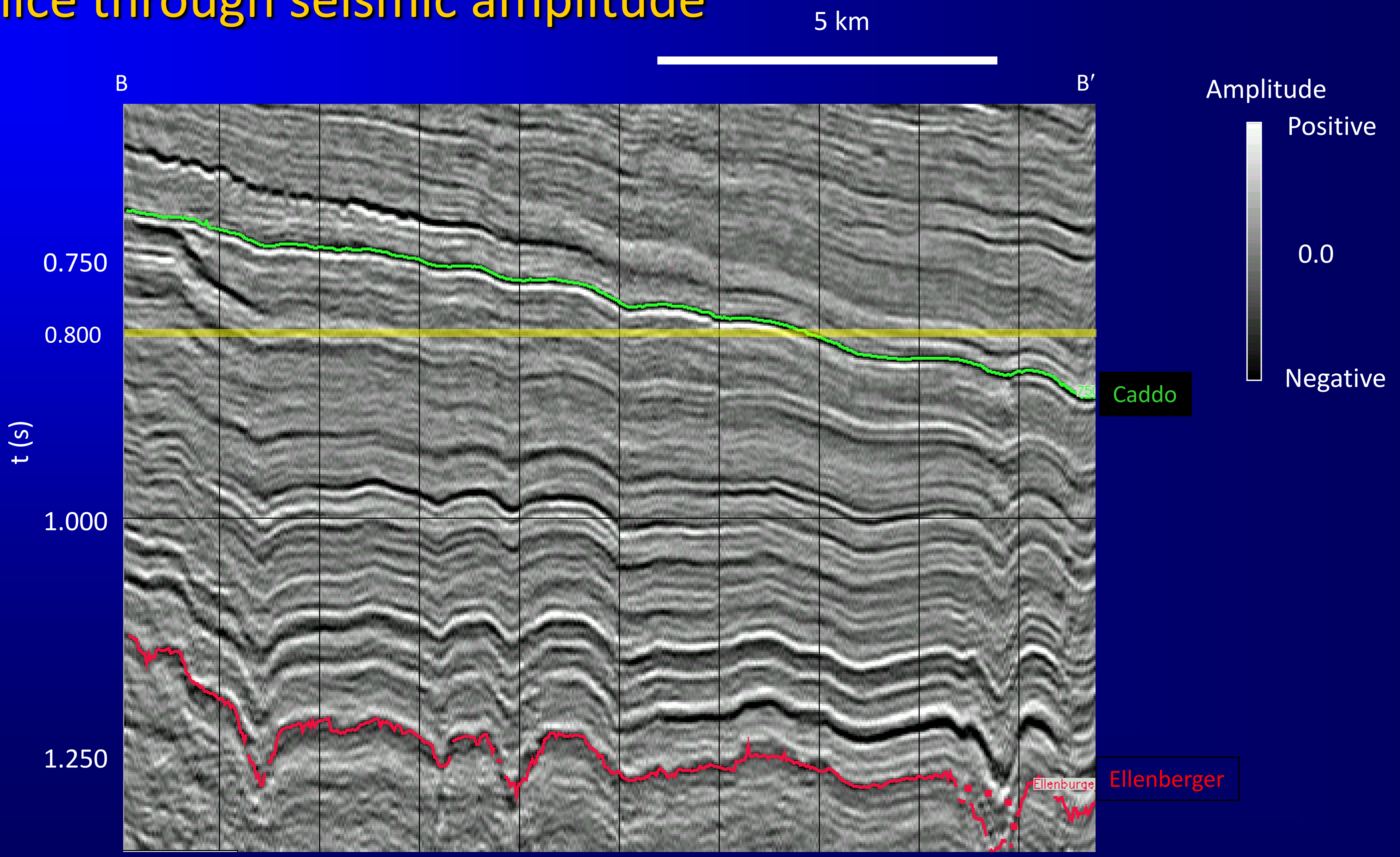
Caddo horizon slice through coherence volume



(Chopra and Marfurt, 2007)

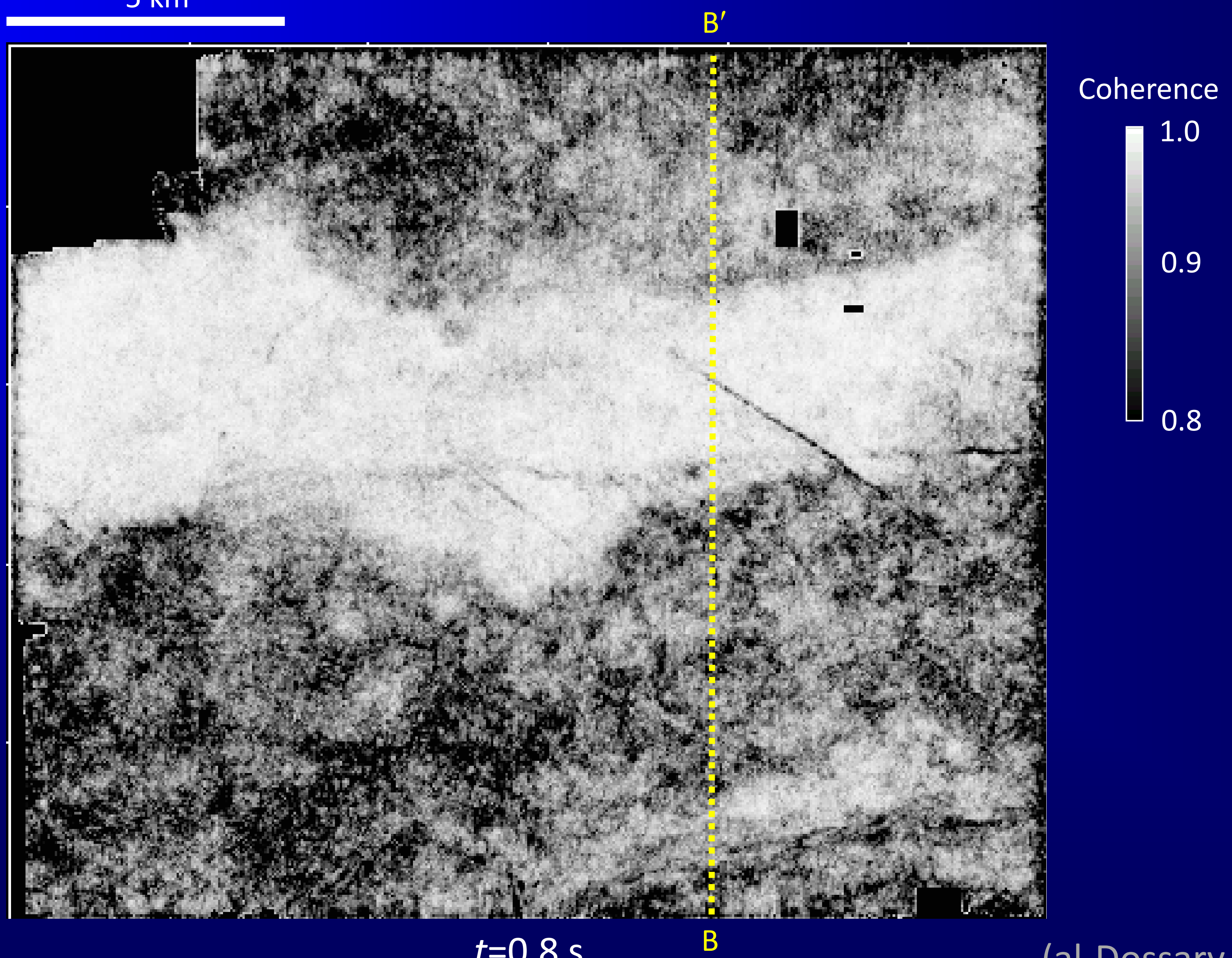
Attributes extracted along time slices

Vertical slice through seismic amplitude



(al-Dossary and Marfurt, 2006)

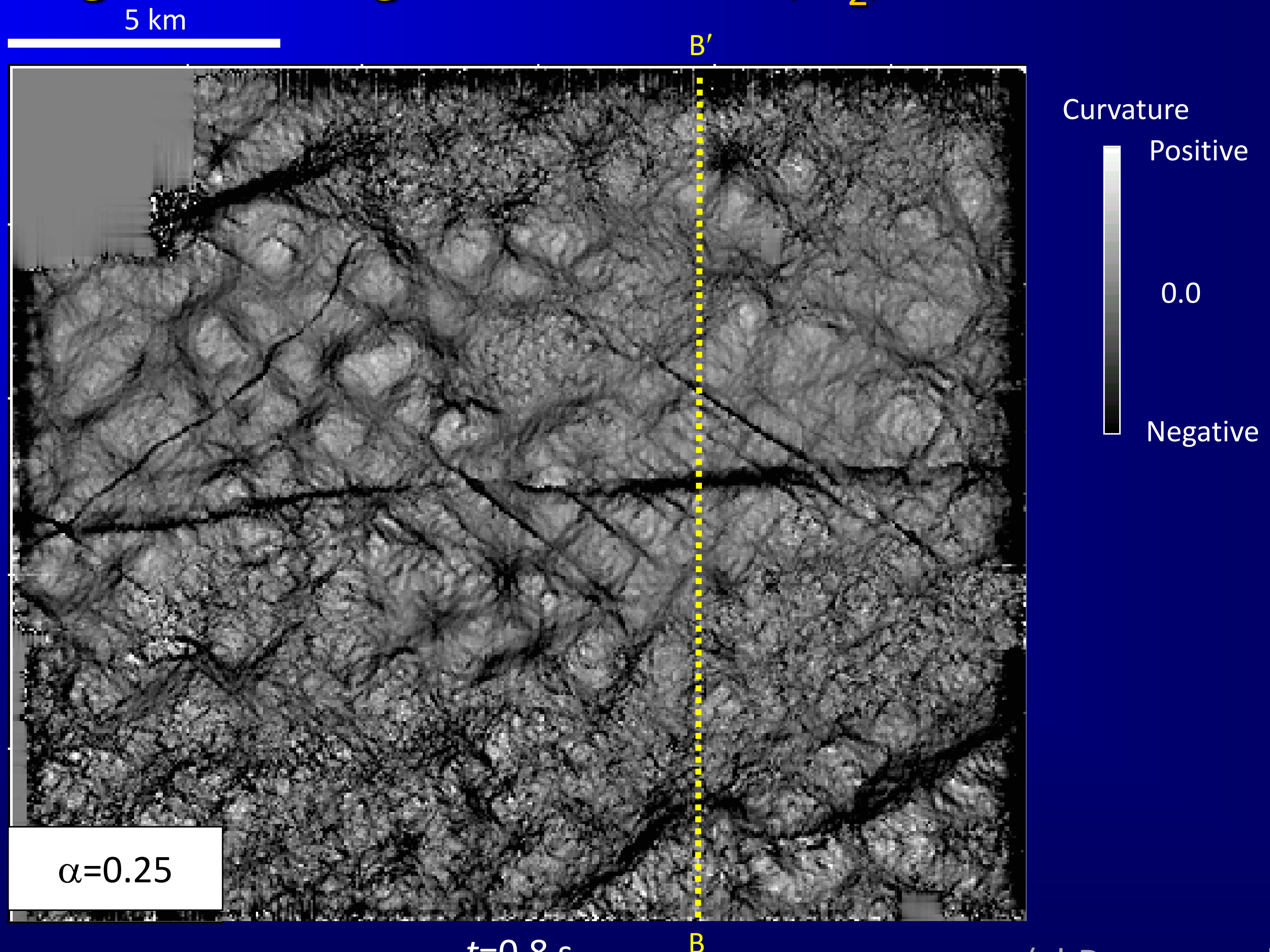
Time slice through coherence



t=0.8 s

(al-Dossary and Marfurt, 2006)

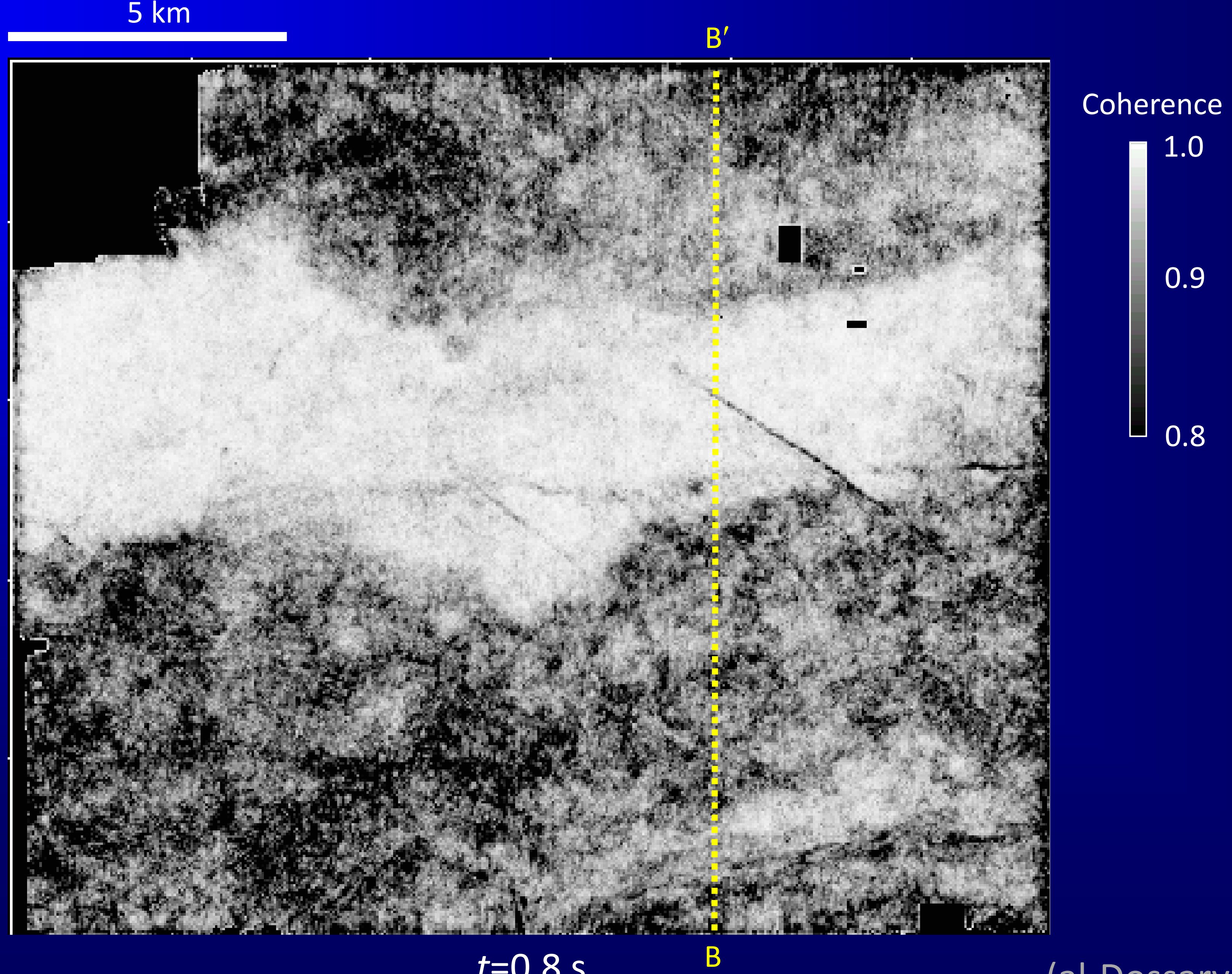
Time slices through most-negative curvature, k_2, at different wavelengths



t=0.8 s

(al-Dossary and Marfurt, 2006)

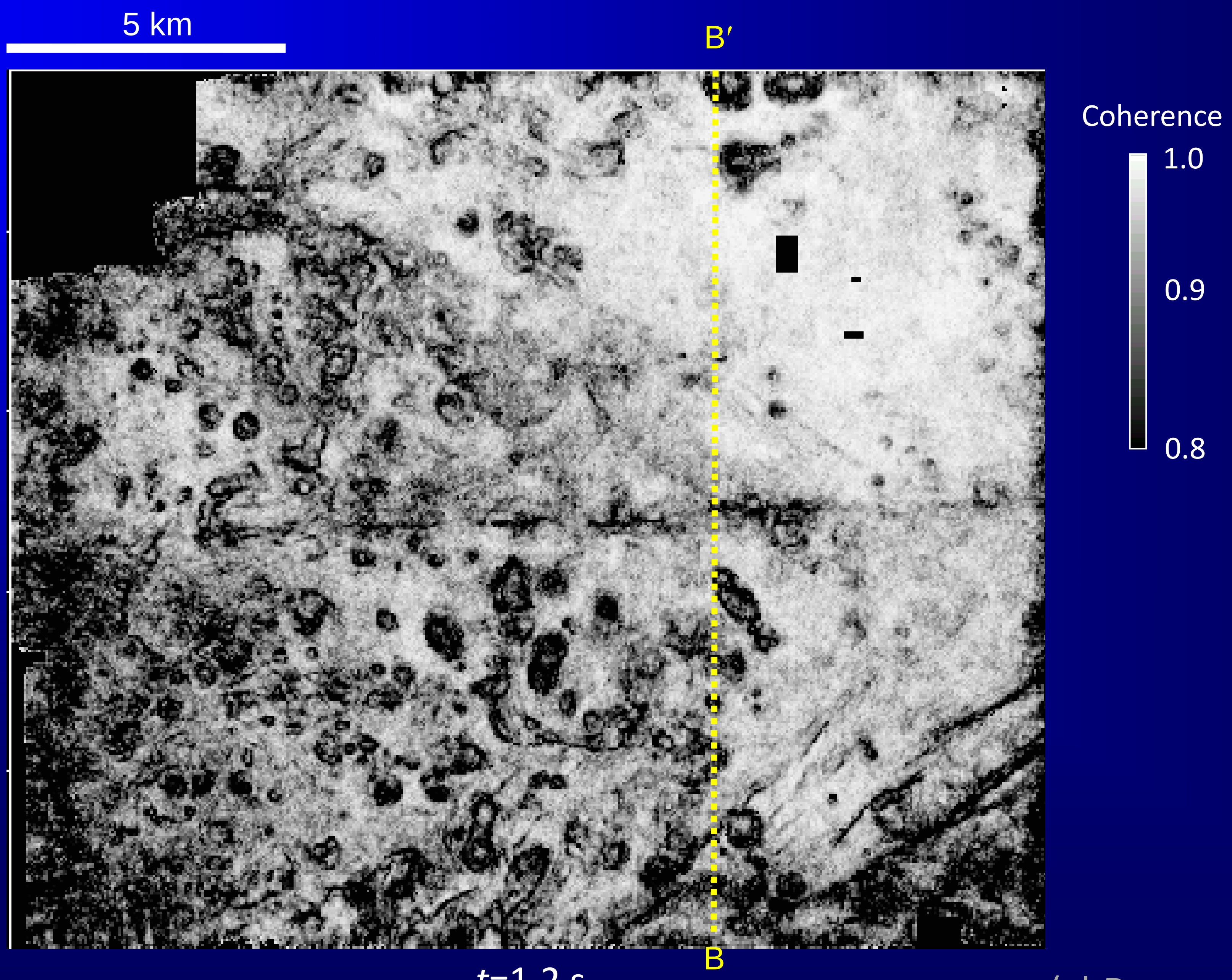
Time slice through coherence



t=0.8 s

(al-Dossary and Marfurt, 2006)

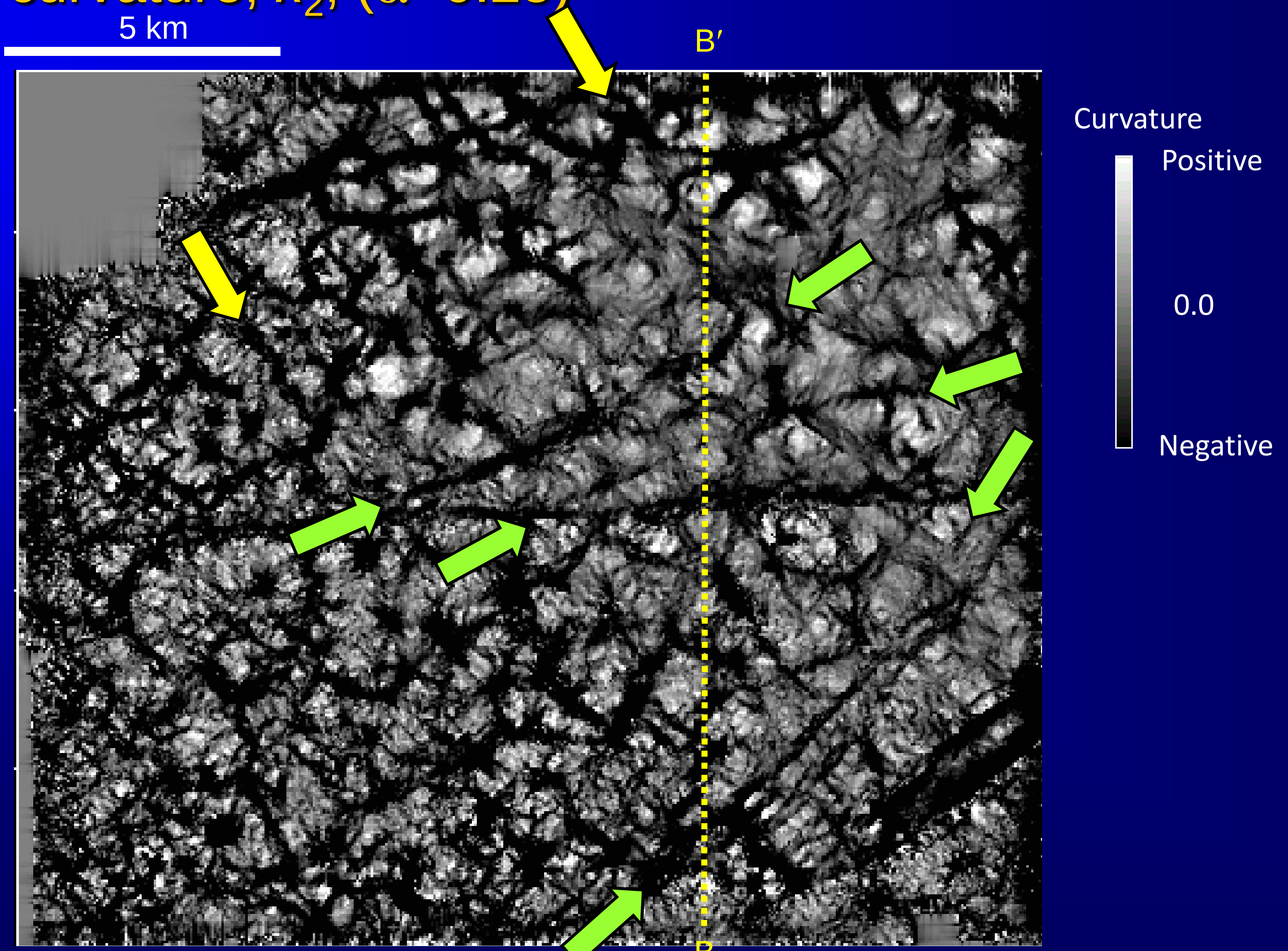
Coherence



t=1.2 s

(al-Dossary and Marfurt, 2006)

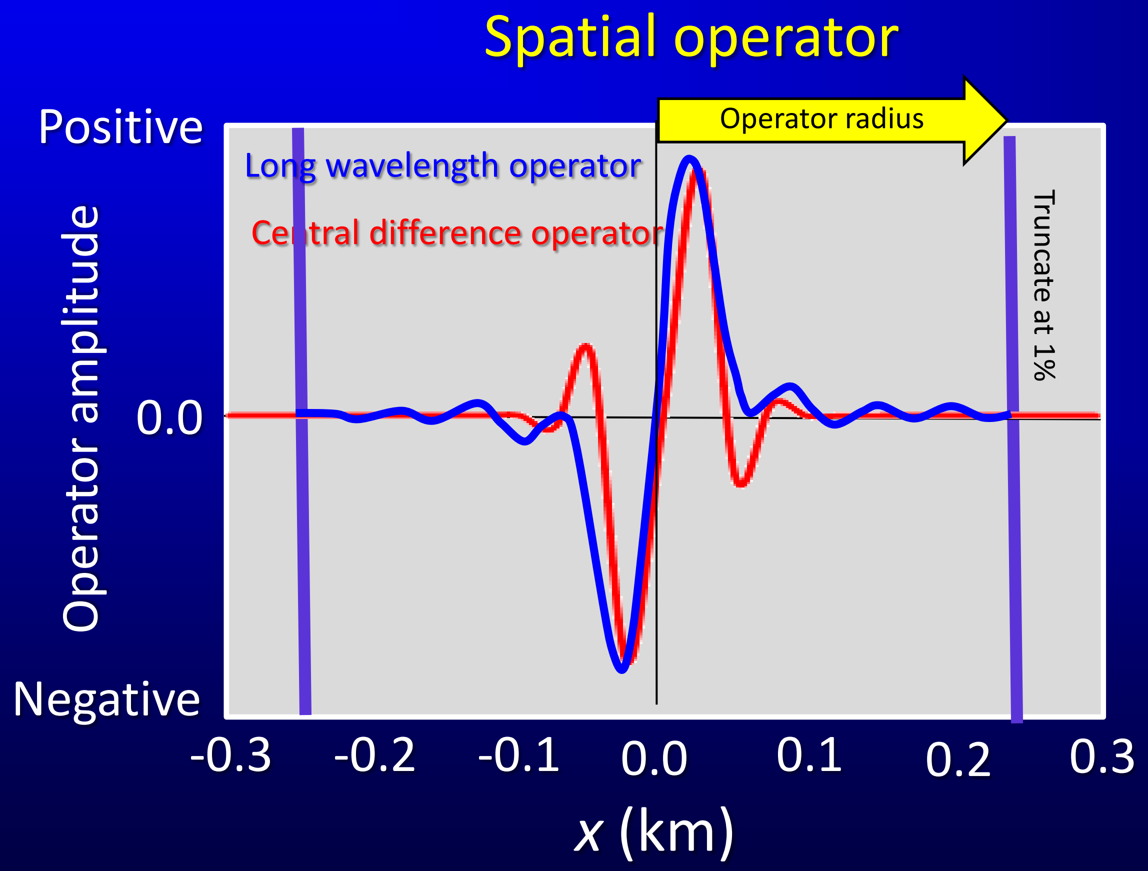
Most negative curvature, k_2, (α=0.25)

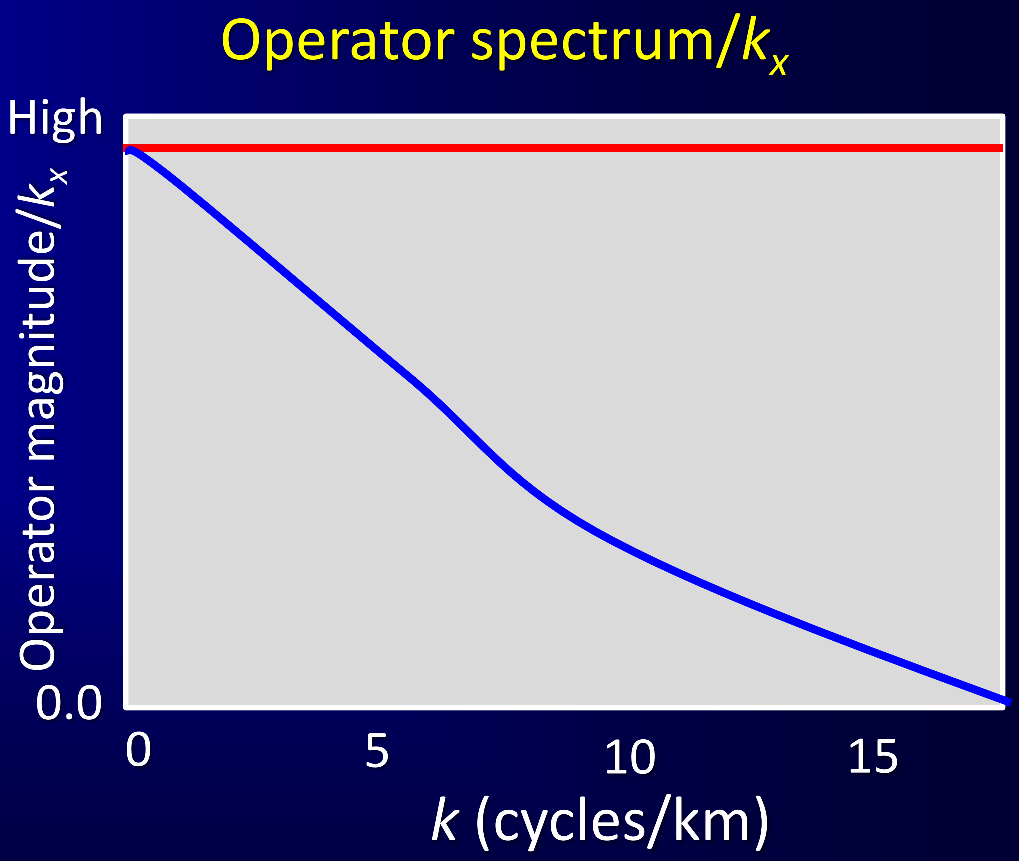


t=1.2 s

(al-Dossary and Marfurt, 2006)

Later long wavelength curvature operator: Define a filter

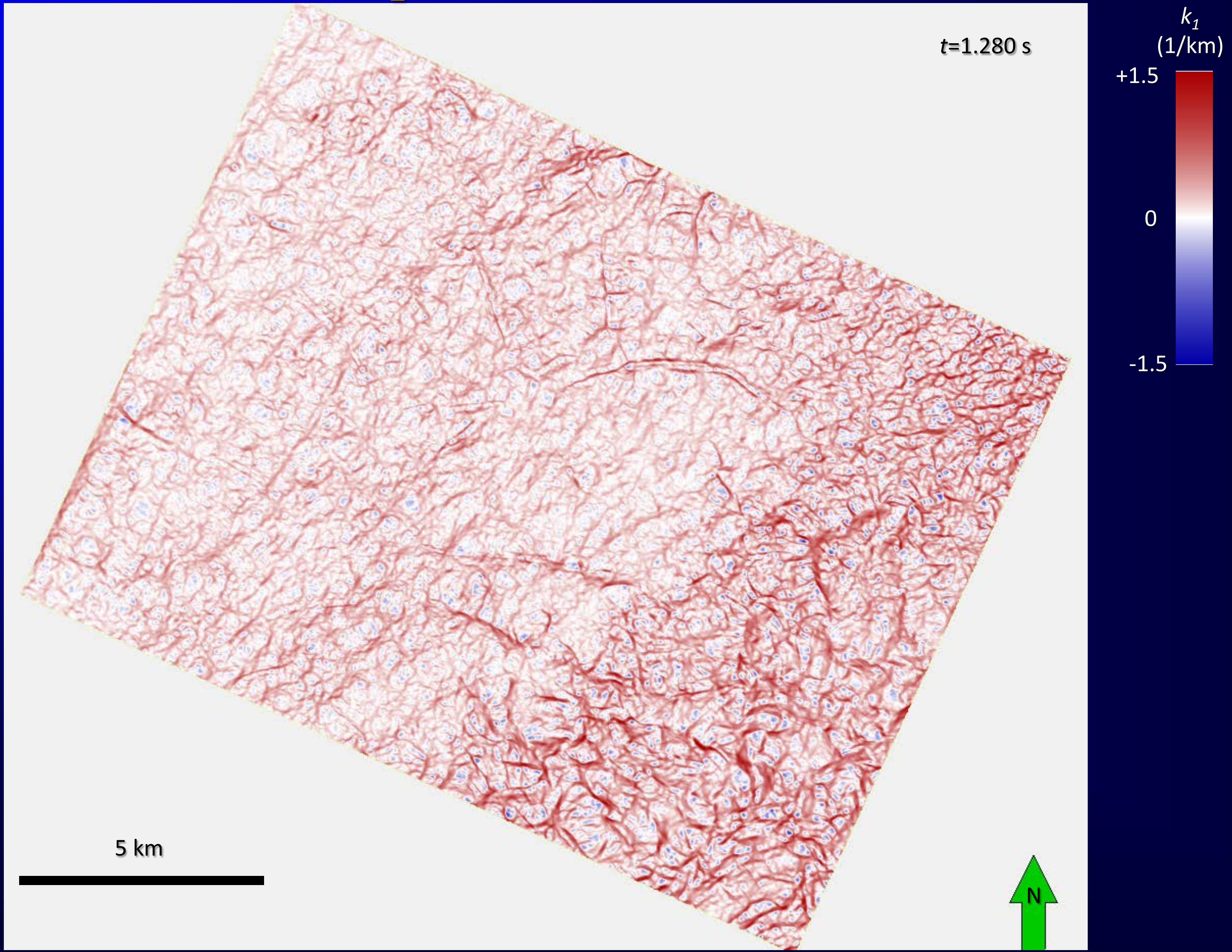




(Marfurt, 2018)

Most-positive principal curvature k_1

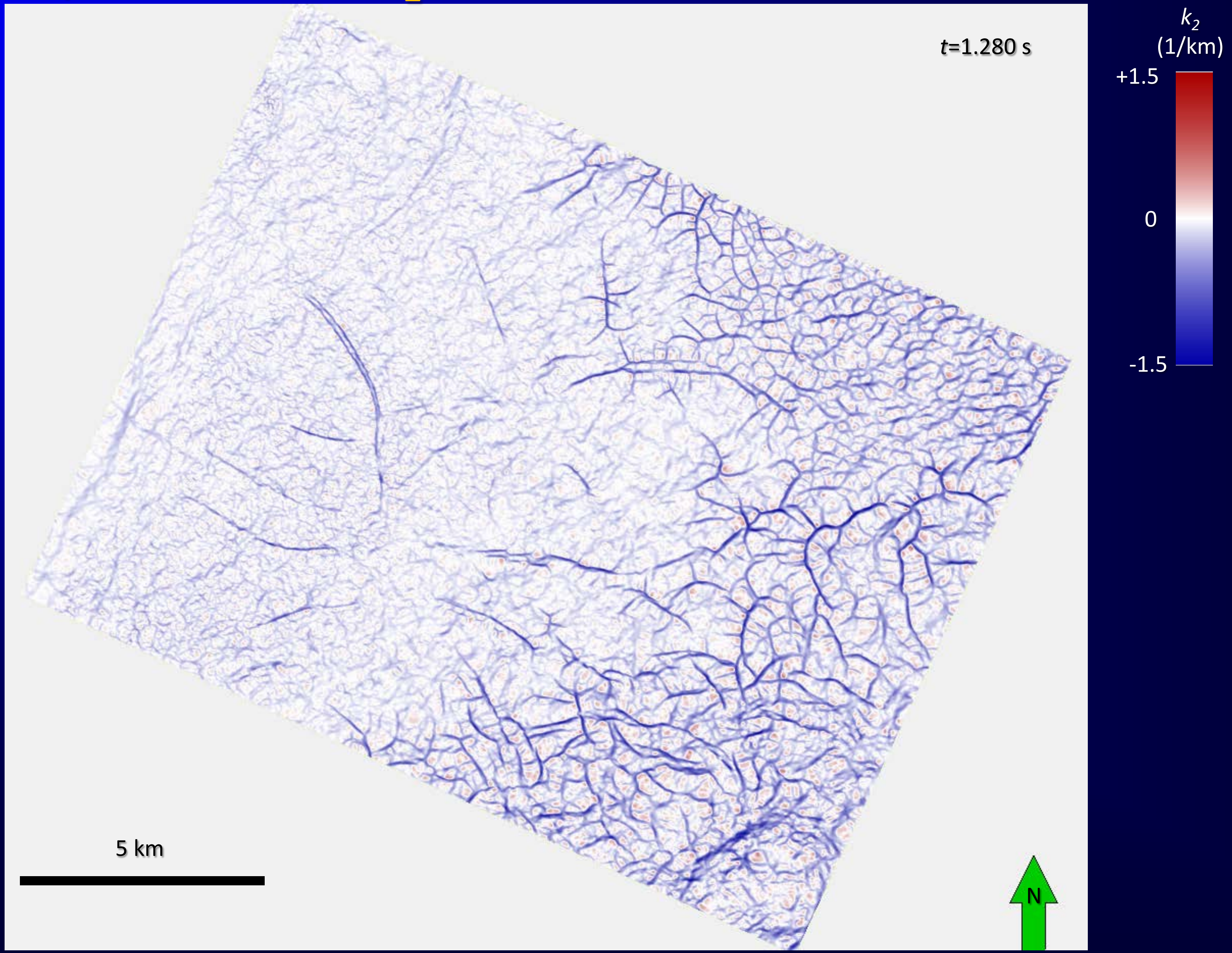
Great South Basin, NZ



(Marfurt, 2018)

Most-negative principal curvature k_2

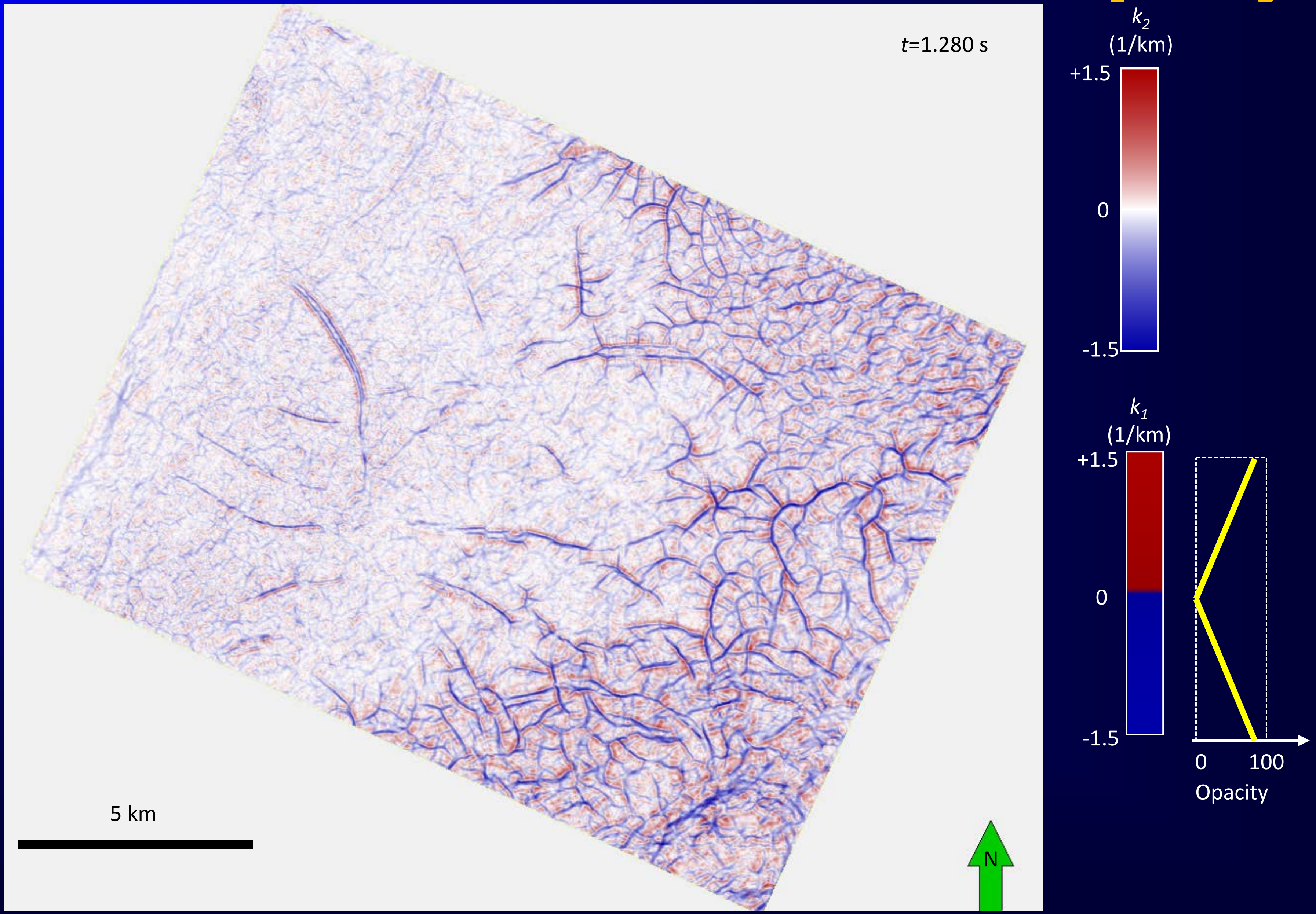
Great South Basin, NZ



(Marfurt, 2018)

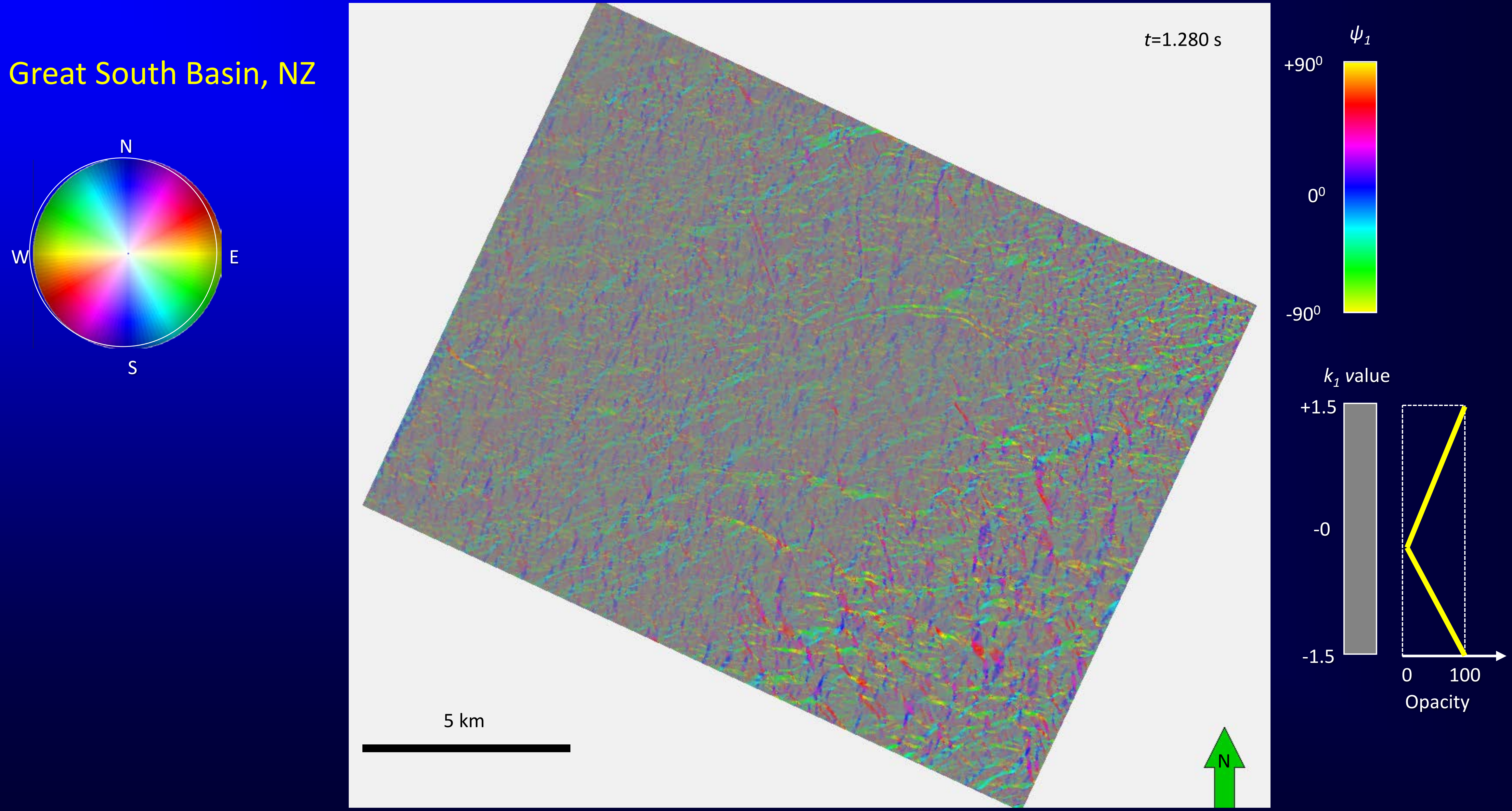
Co-rendered most-positive and most-negative principal curvatures k_1 and k_2

Great South Basin, NZ



(Marfurt, 2018)

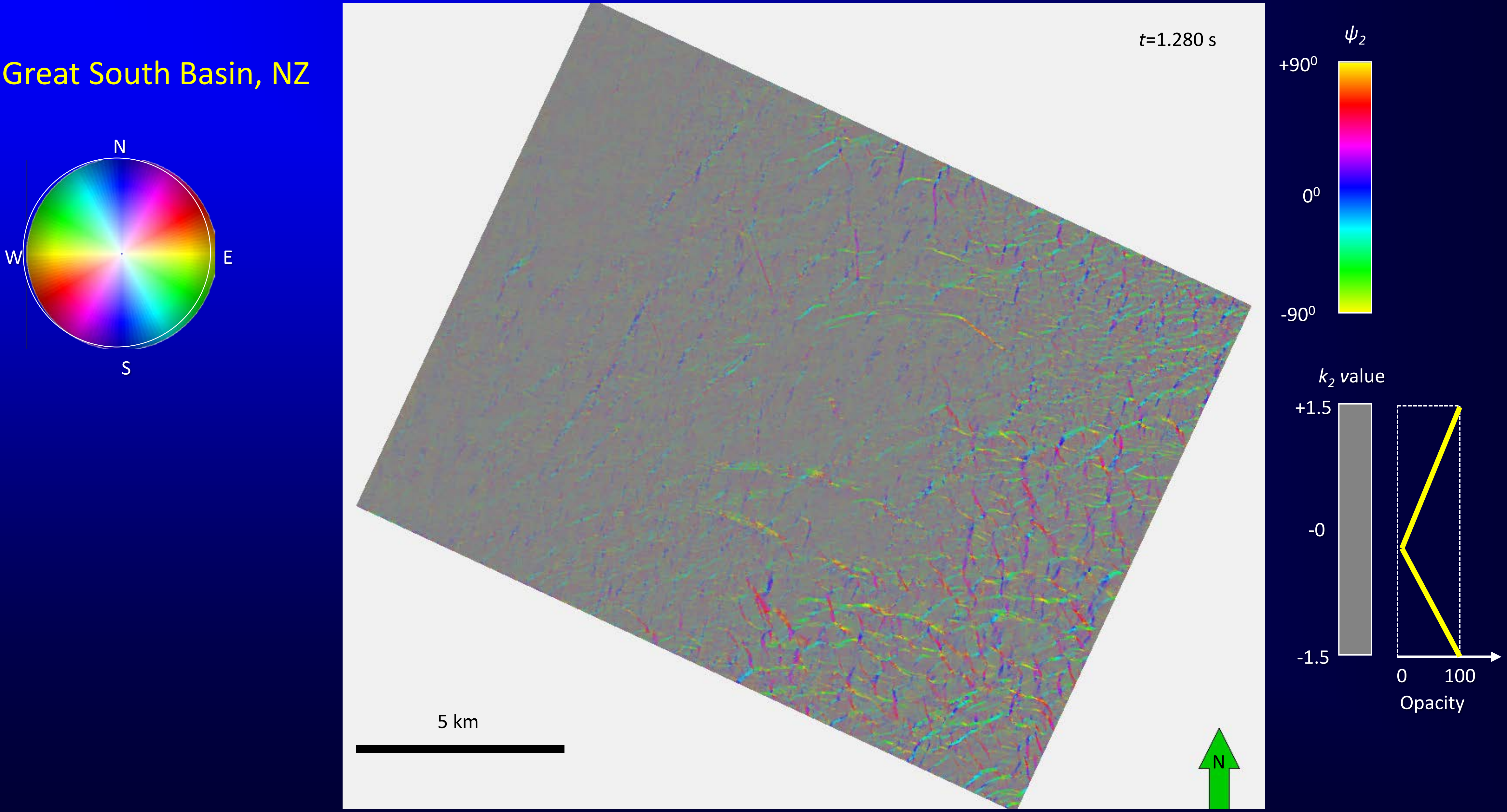
Co-rendered strike ψ_1 and value of most positive curvature k_1



(Marfurt, 2018)

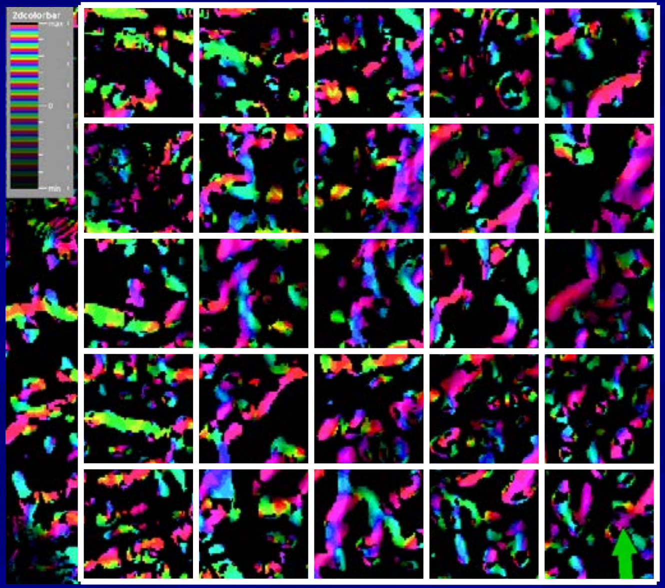
Co-rendered strike ψ_2 and value of most negative curvature k_2

Great South Basin, NZ

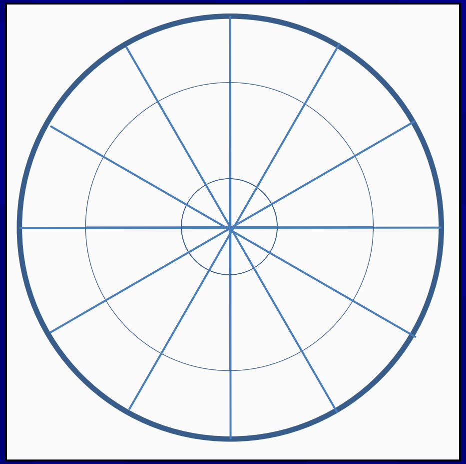


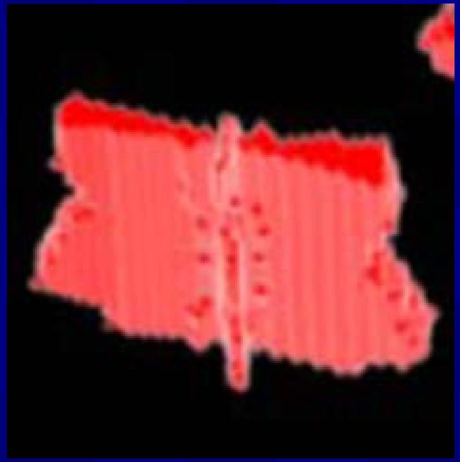
(Marfurt, 2018)

Generating rose diagrams of curvature and aberrancy lineaments



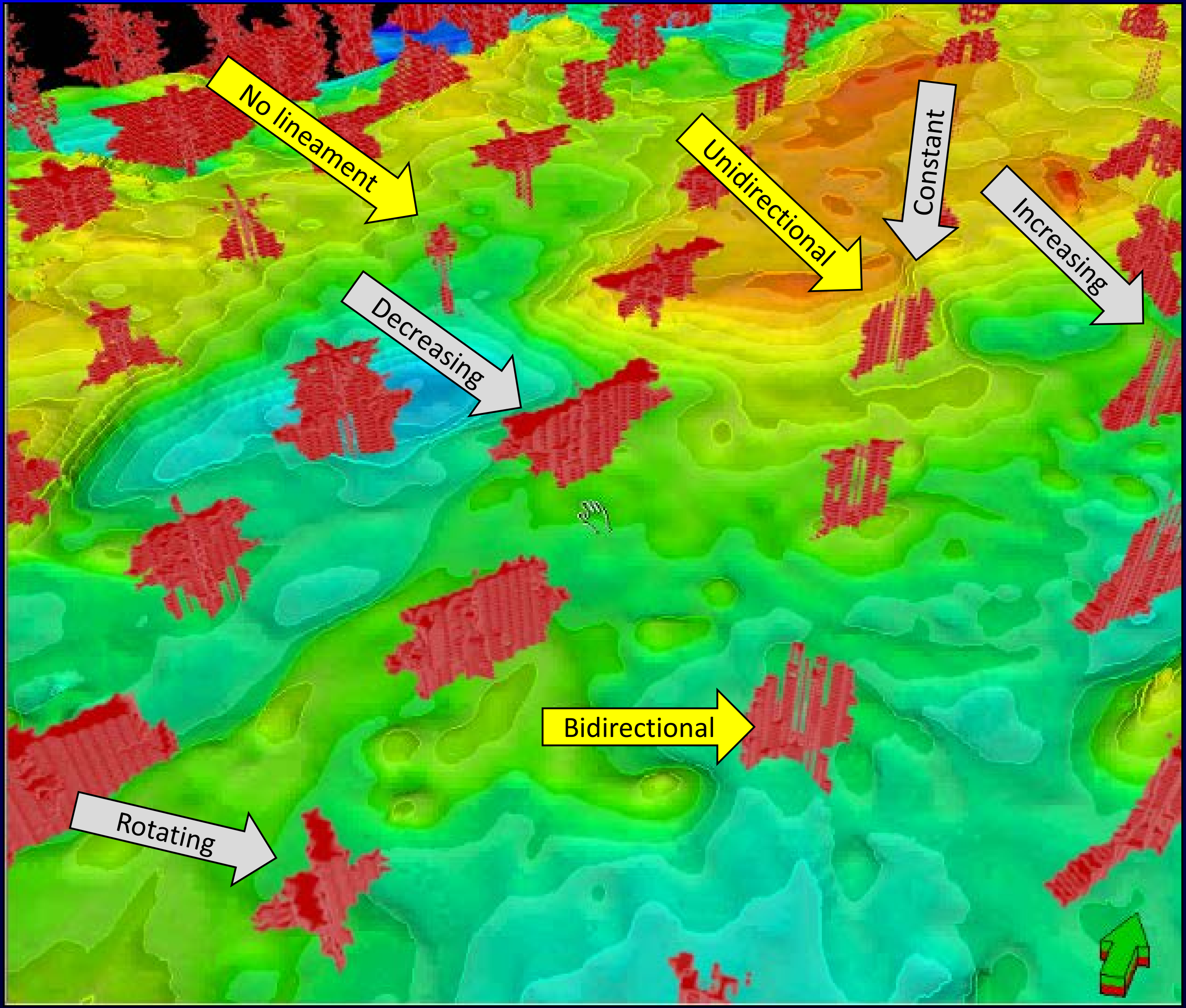
1. Compute curvature lineaments
2. Create grids
3. Examine each grid one at a time
4. Map voxels to a rose diagram
5. Represent the rose using the voxels in the grid
6. Export in seismic format





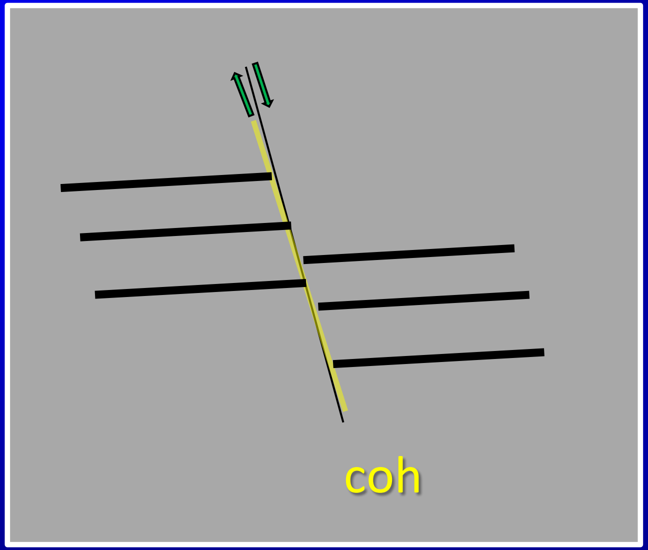
(Mai, 2010)

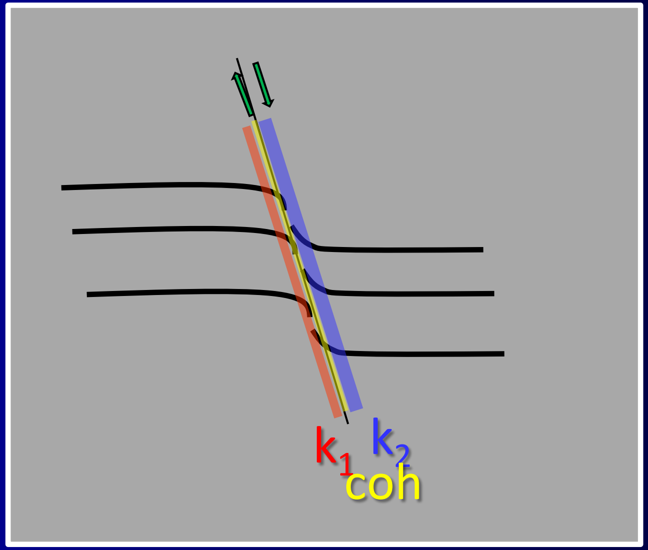
Interpreting rose diagrams of curvature and aberrancy lineaments



Fault expression on attributes

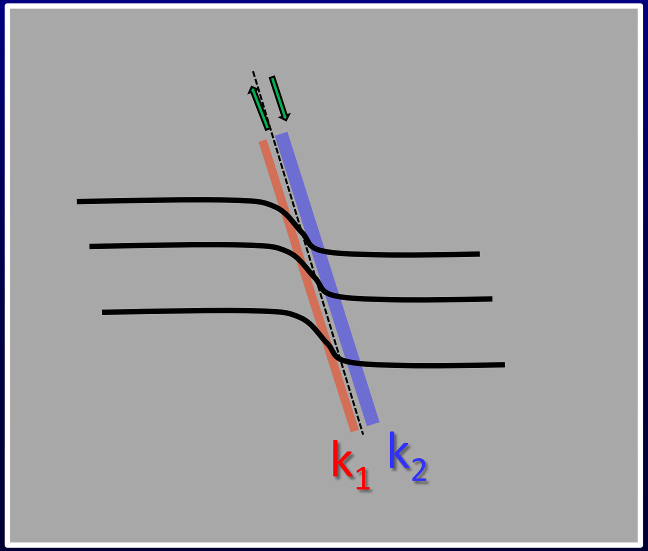
Fault offset only, well imaged

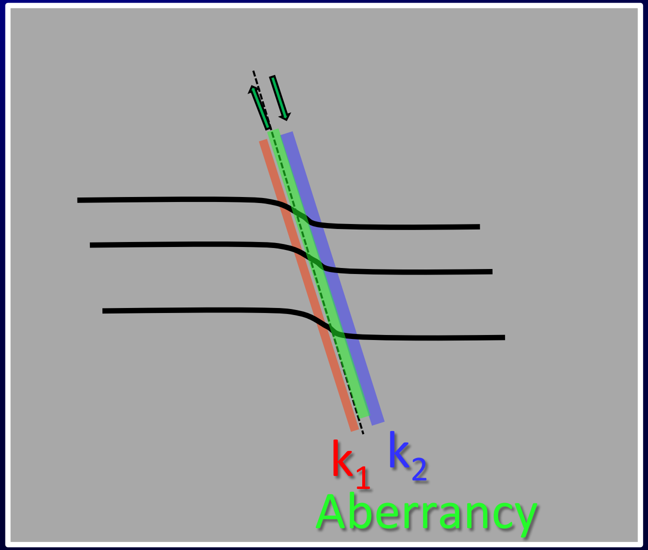




Fault offset with conjugate faulting or poor imaging

Fault offset (if any) below resolution





Fault offset (if any) below resolution

(Qi and Marfurt, 2018)

Aberrancy: The third derivative of a time-structure map

SCIENCES MATHÉMATIQUES

PURES ET APPLIQUÉES.

A.

ABE

ABERRATION. (*Astr.*) Les formules d'aberration en ascension droite et en déclinaison énoncées dans le premier volume de ce dictionnaire (pag. 10), bien qu'elles soient sous une forme très-simple, ne sont cependant pas celles dont les astronomes font ordinairement usage pour construire des tables particulières ou générales; voici une application fort élémentaire du calcul différentiel et de la géométrie aux trois dimensions qui conduit à ces dernières formules de la manière la plus directe.

ABE

$$x = r \cos A . \cos D, \quad y = r \sin A . \cos D, \quad z = r \sin D;$$

d'où l'on tire..... (2)

$$\text{tang } A = \frac{y}{x}, \quad x^2 + y^2 + z^2 = r^2.$$

Astronomy – change in acceleration resulting in a deviation from an elliptical orbit

Aberrancy: The third derivative of a time-structure map

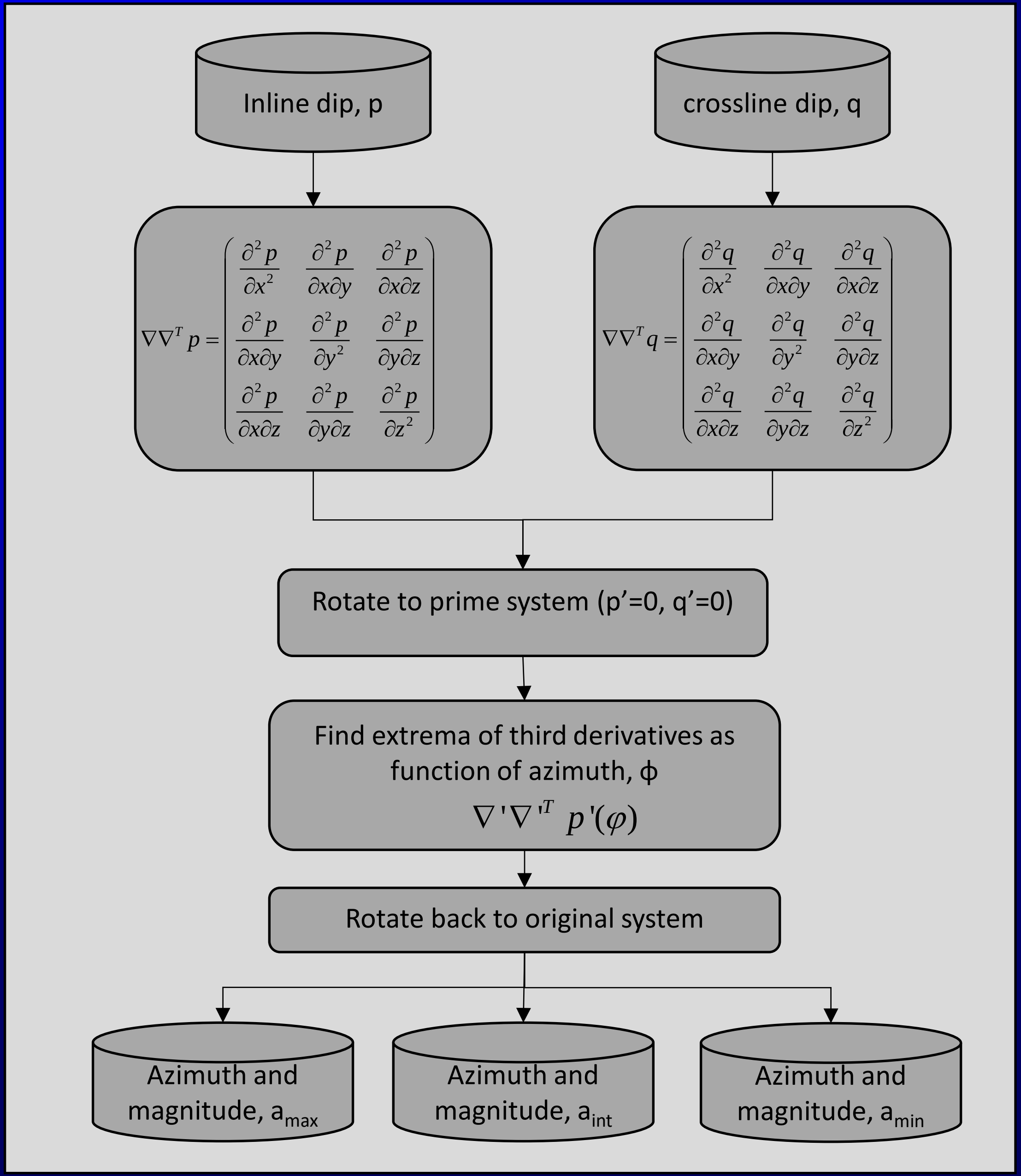
$$\text{location} = s$$

$$\text{velocity} = \frac{ds}{dt}$$

$$\text{acceleration} = \frac{d^2 s}{dt^2}$$

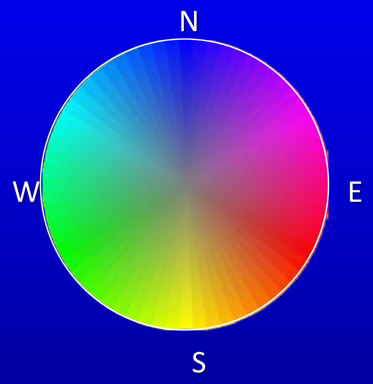
$$\text{jerk} = \frac{d^3 s}{dt^3}$$

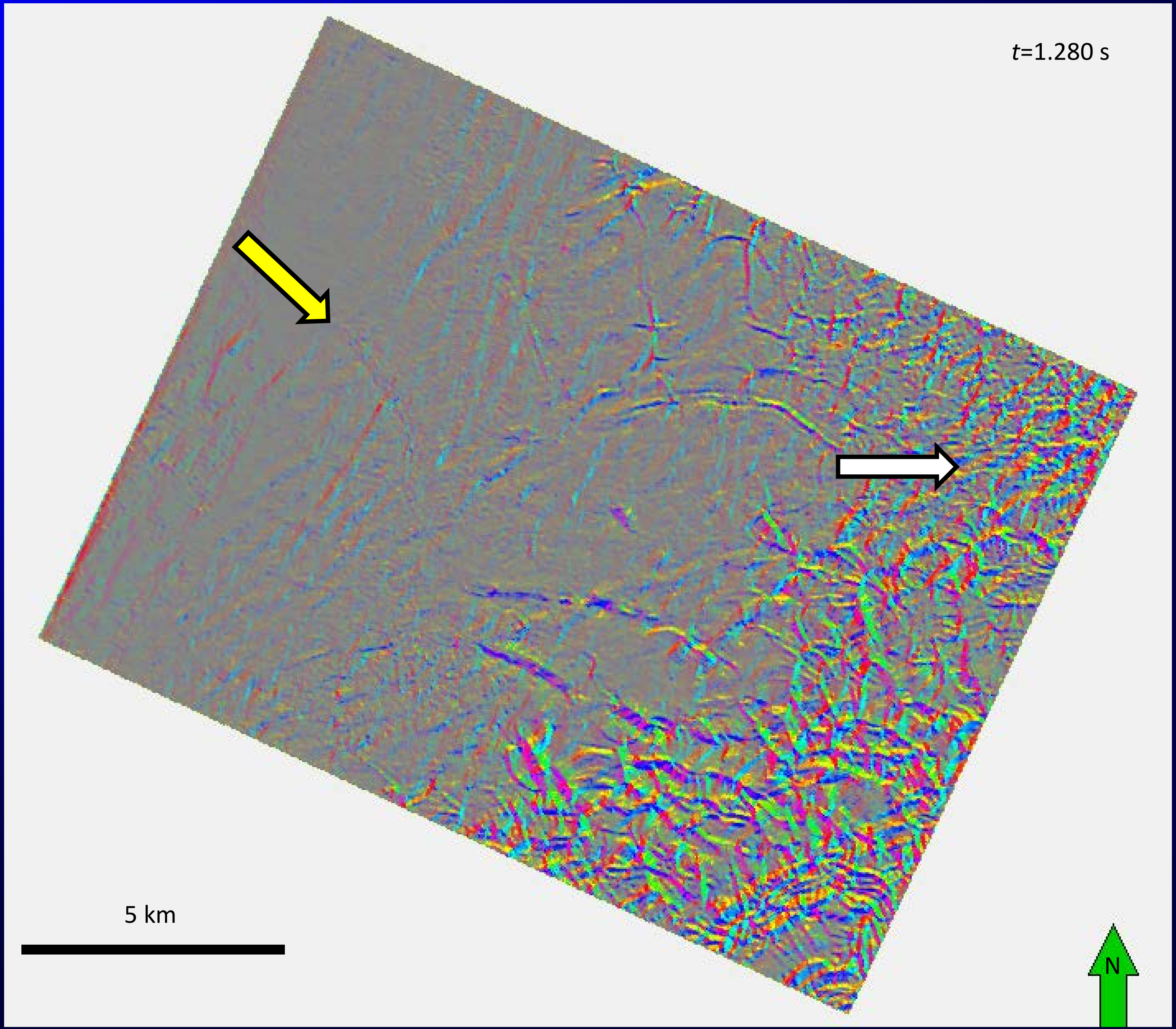
Internal steps in aberrancy computation

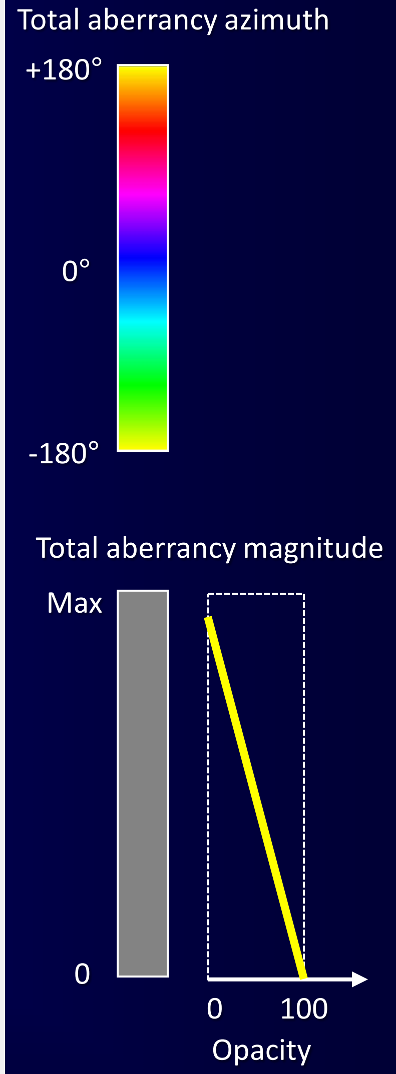


(Qi and Marfurt, 2018

Co-rendered azimuth and magnitude of total aberrancy

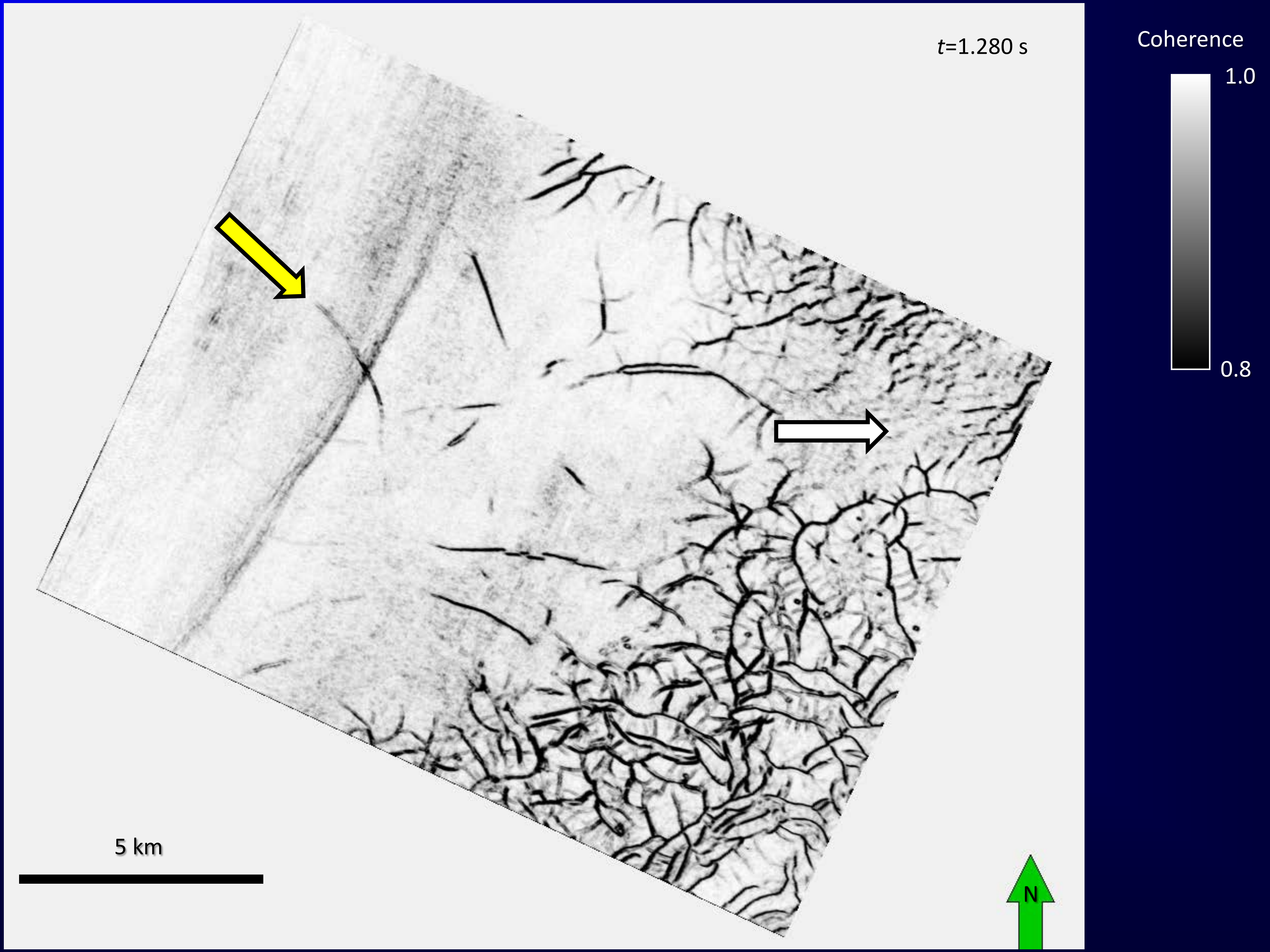






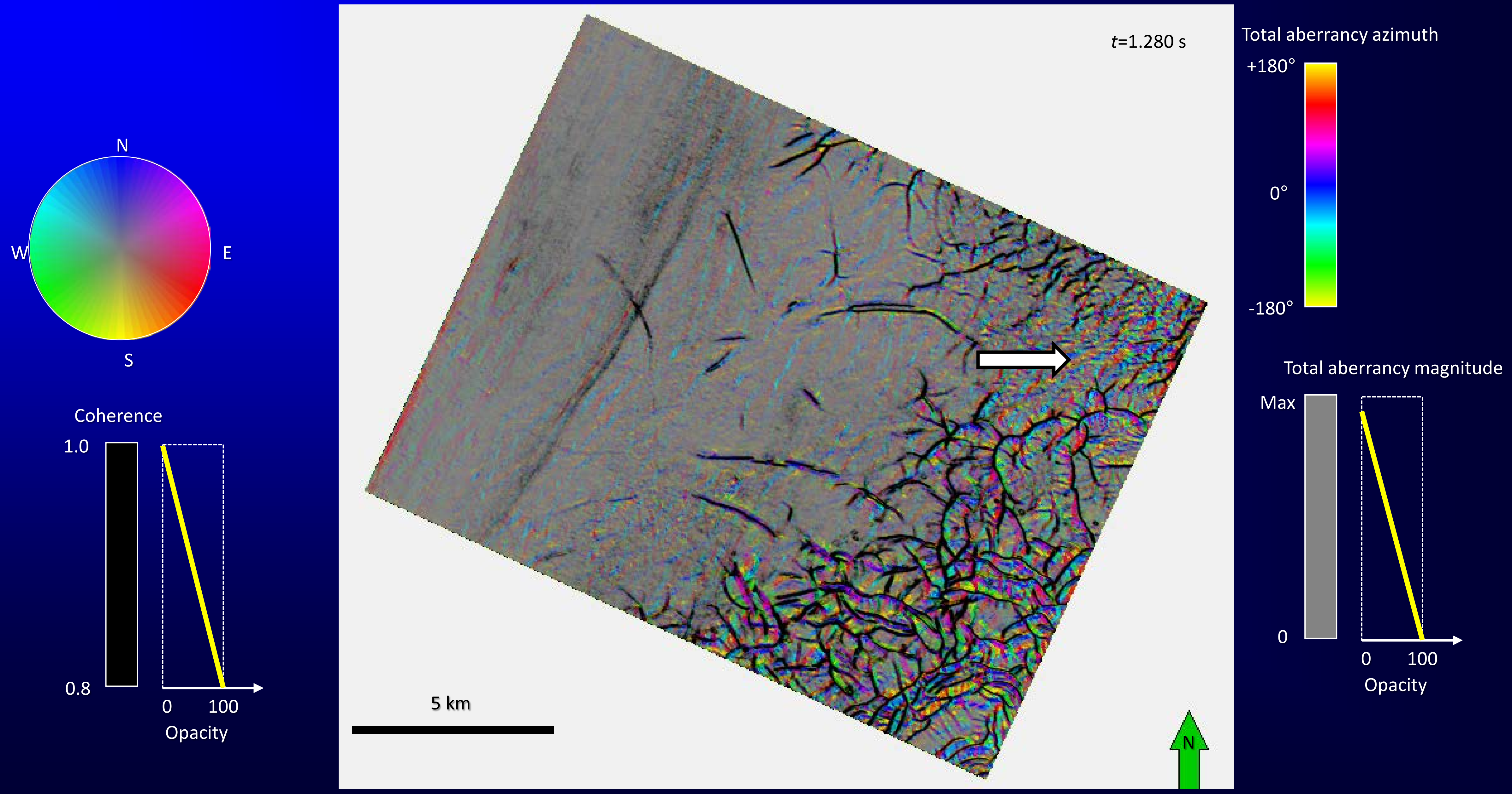
(Marfurt, 2018)

Energy ratio coherence



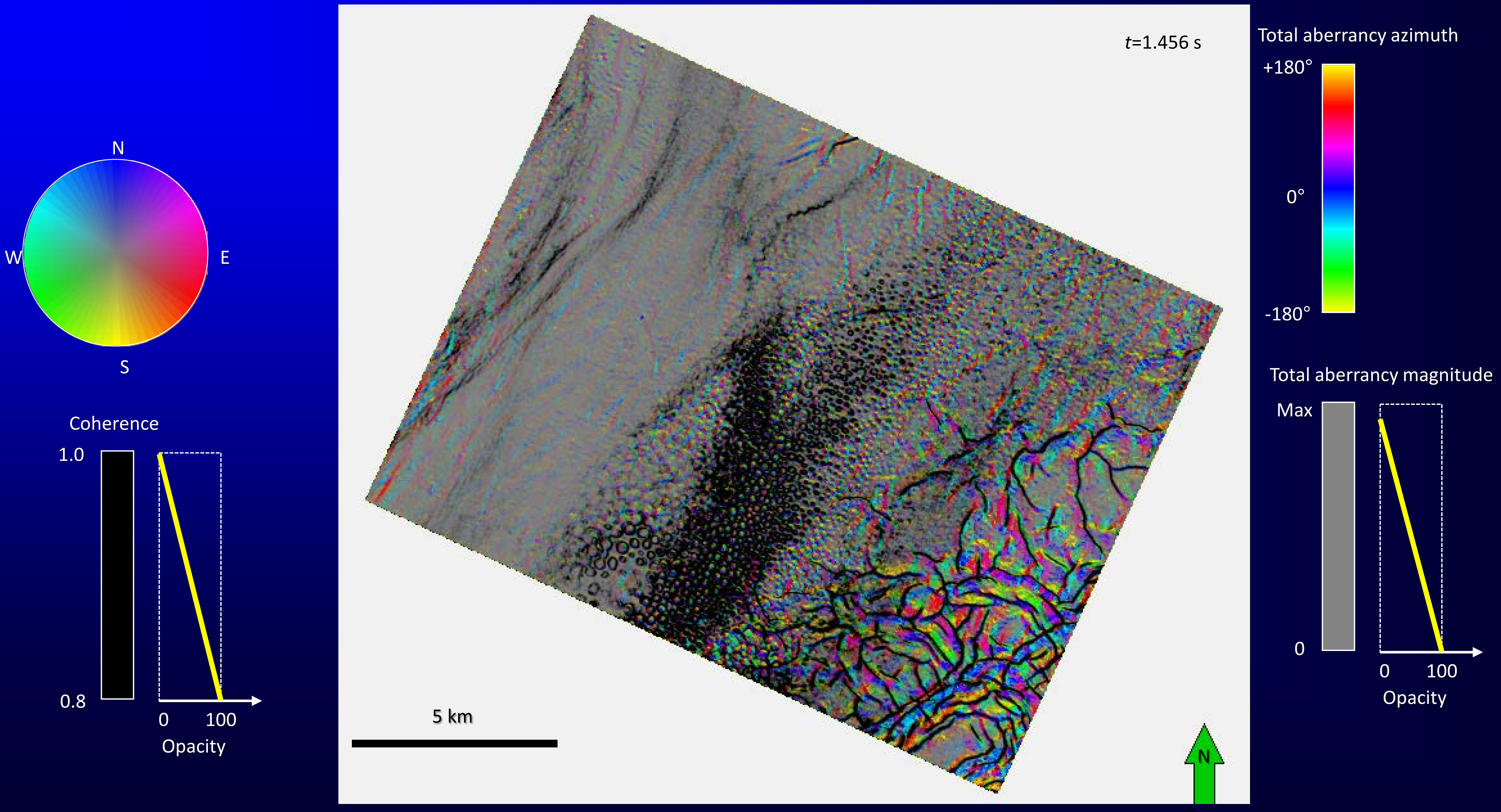
(Marfurt, 2018)

Total aberrancy vector co-rendered with energy ratio coherence



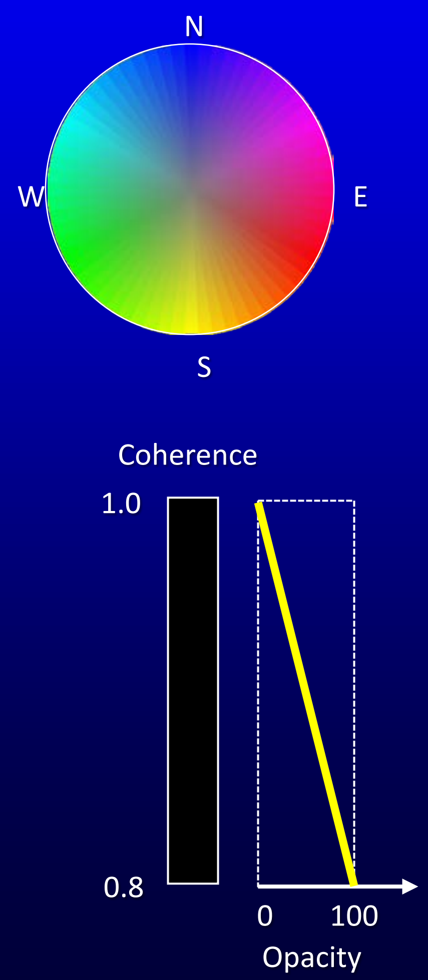
(Marfurt, 2018)

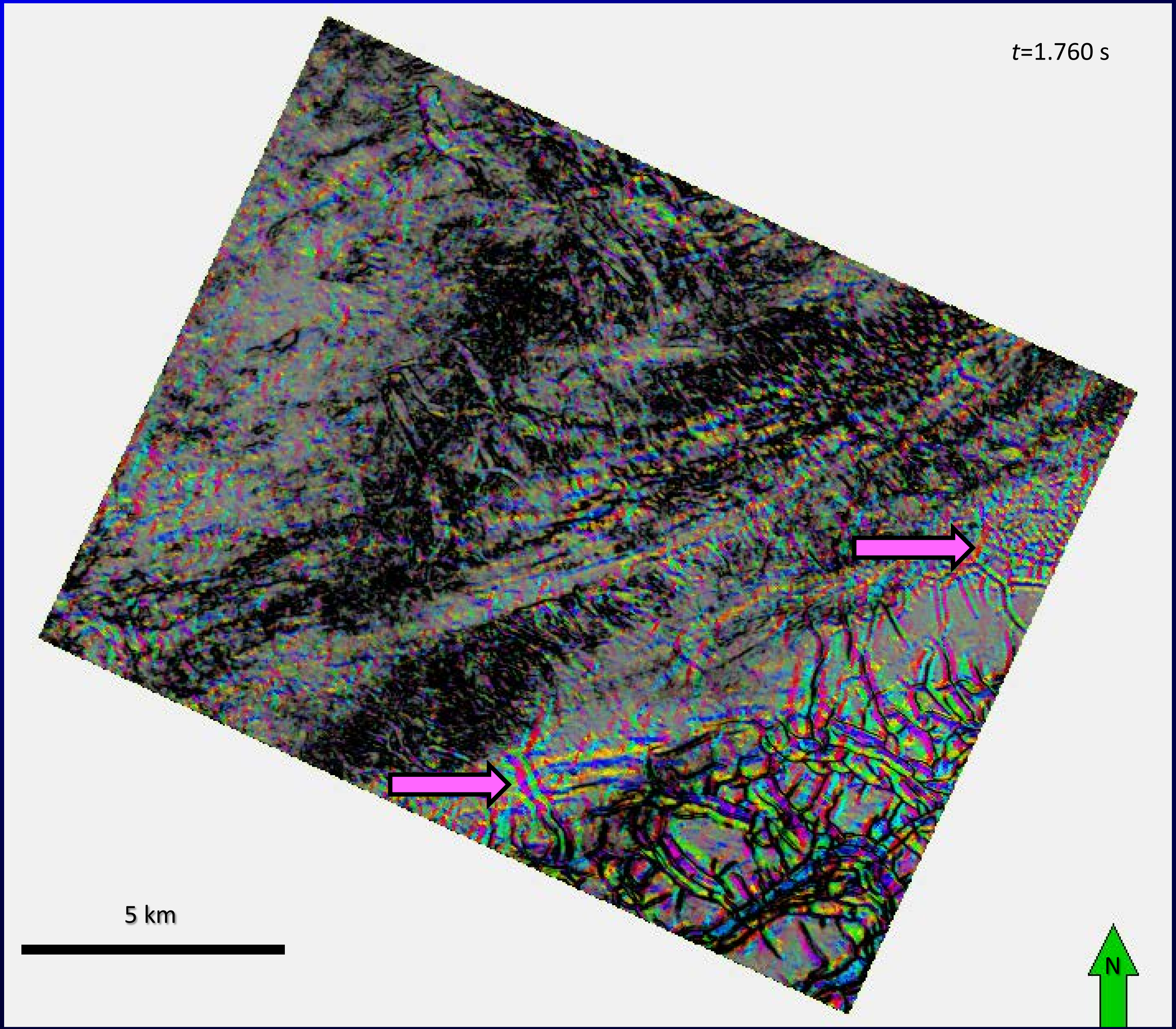
Total aberrancy vector co-rendered with energy ratio coherence

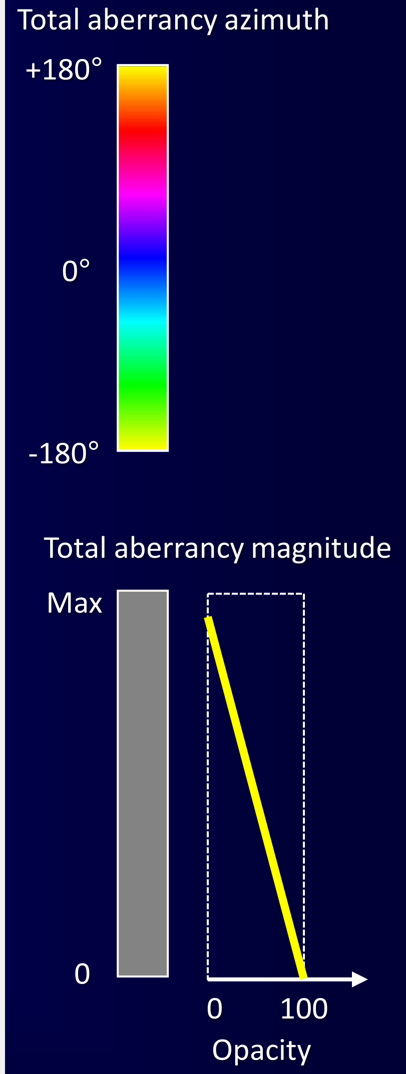


(Marfurt, 2018)

Total aberrancy vector co-rendered with energy ratio coherence

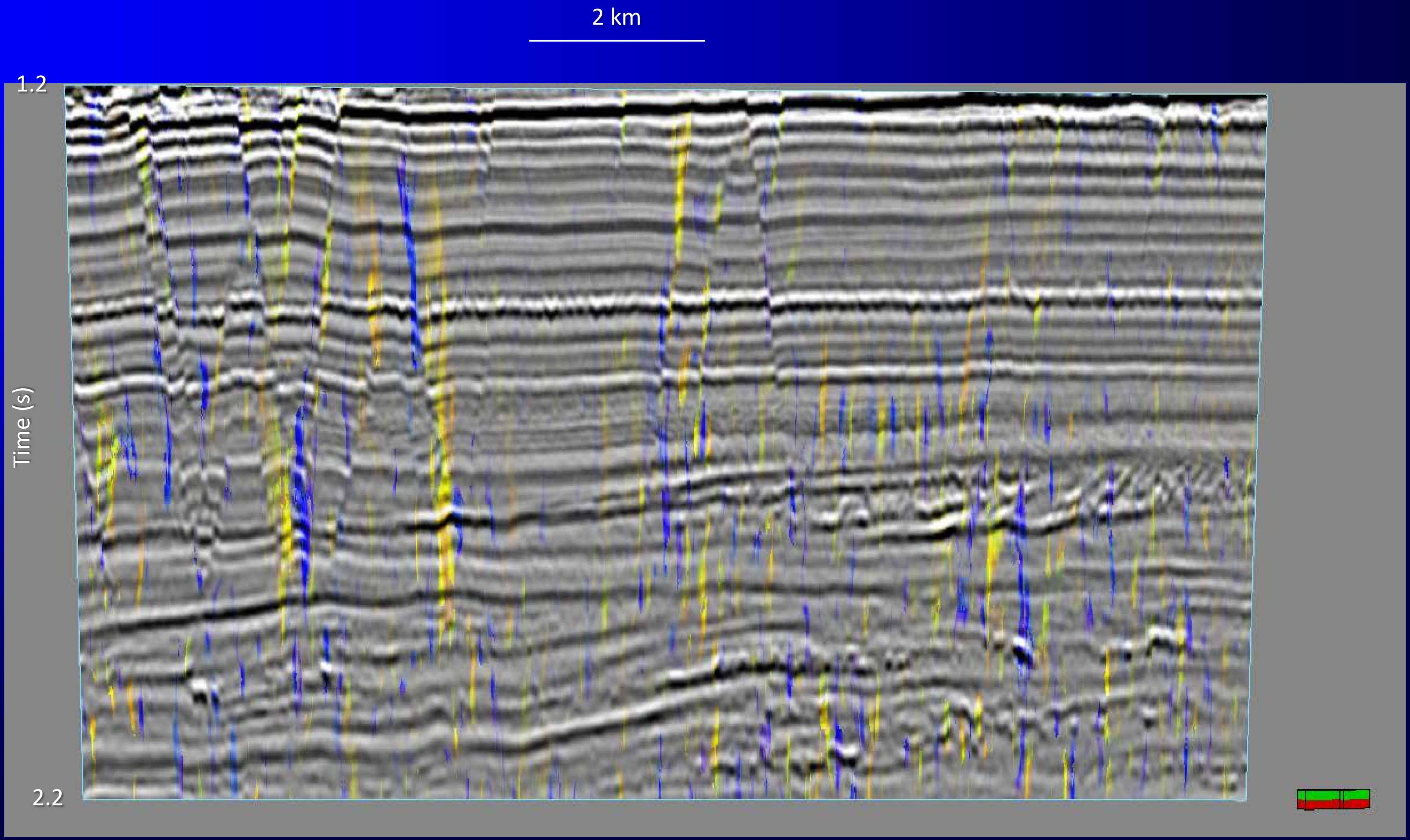


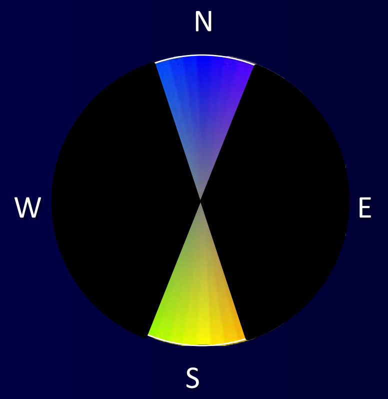


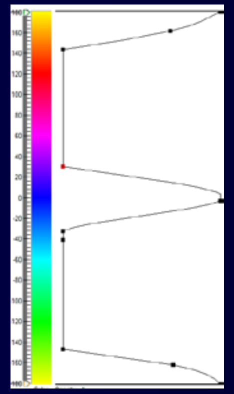


(Marfurt, 2018)

Azimuthally-limited (or apparent) aberrancy

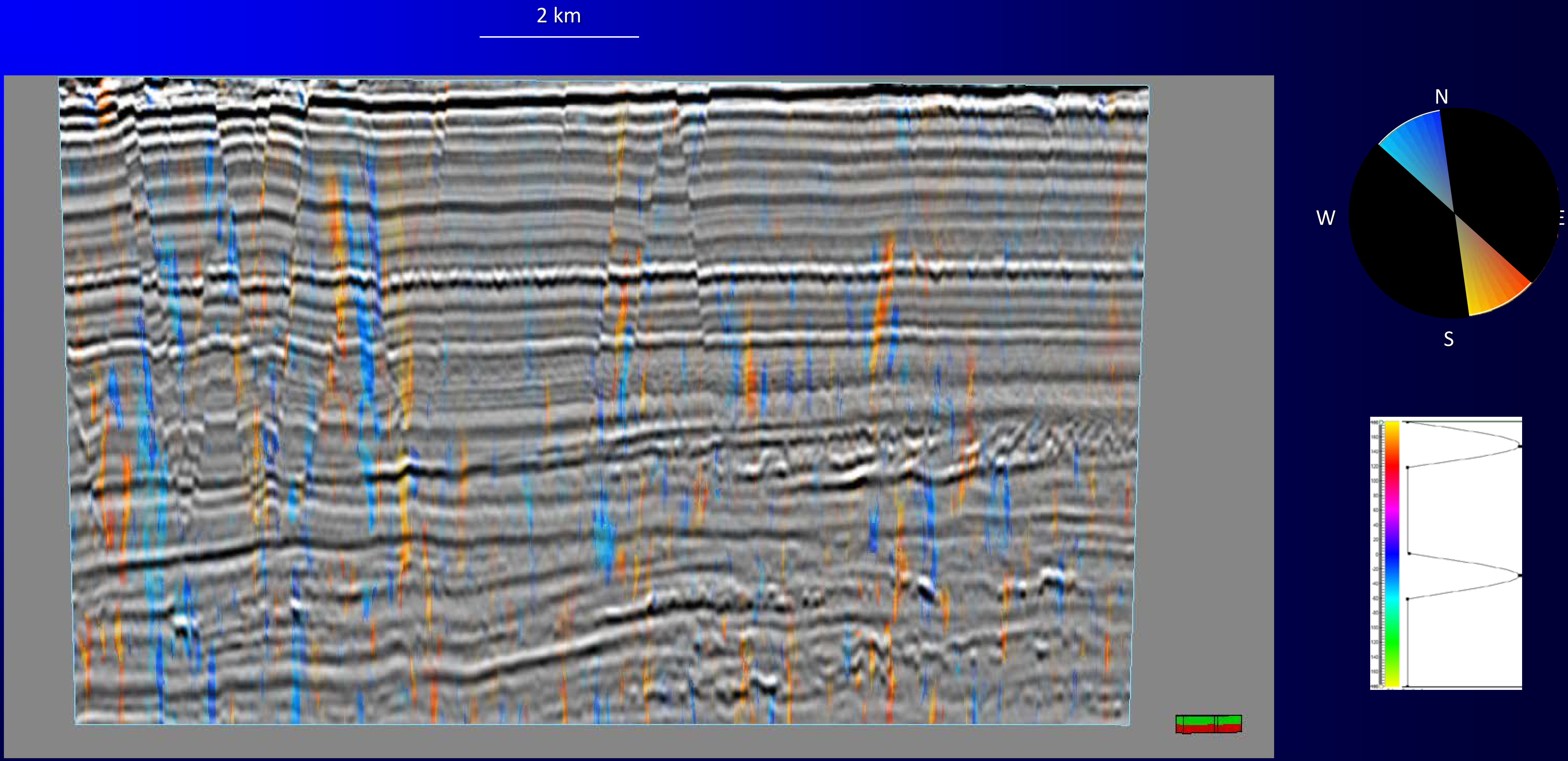






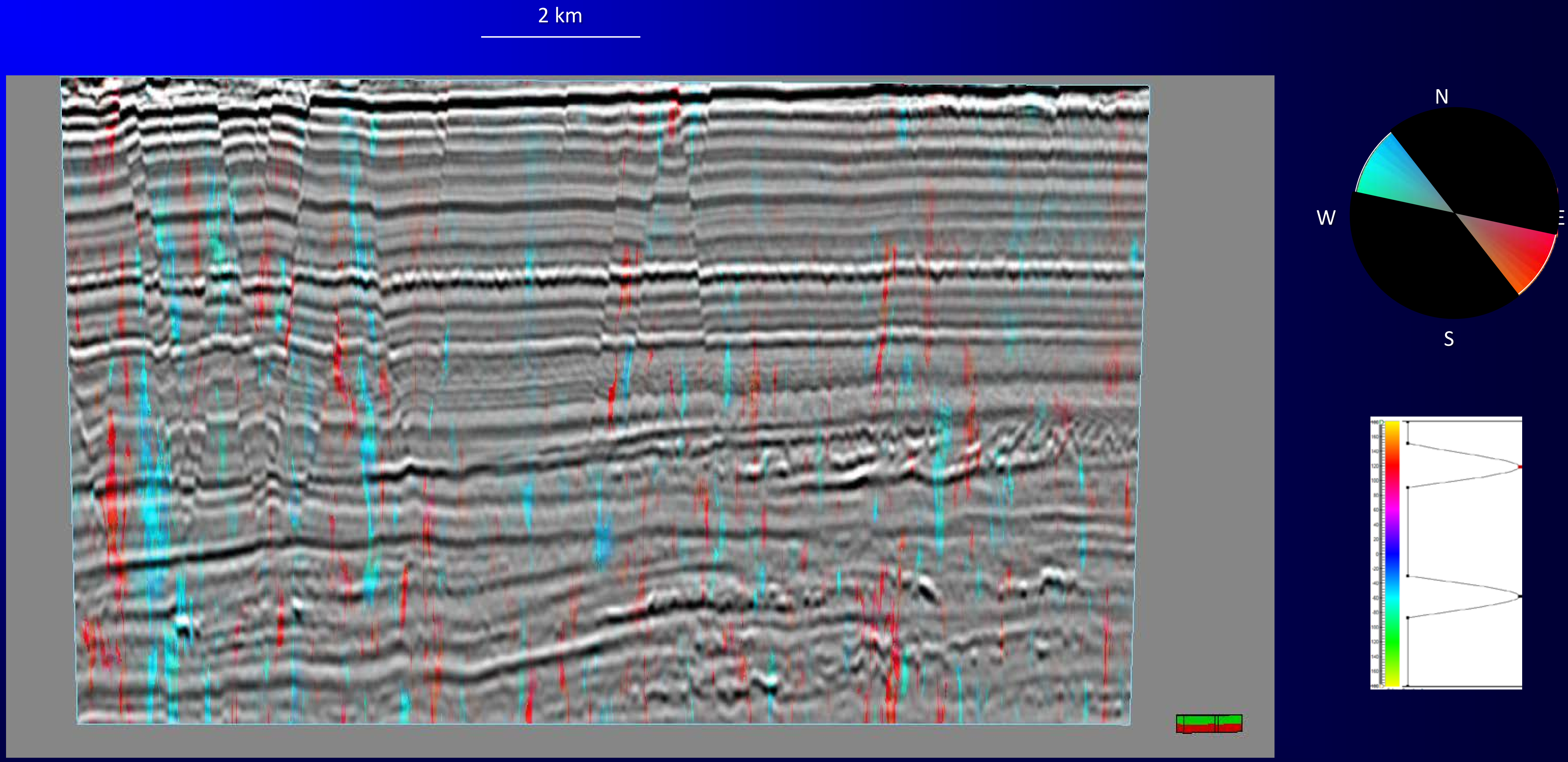
(Marfurt, 2018)

Azimuthally-limited (or apparent) aberrancy



(Marfurt, 2018)

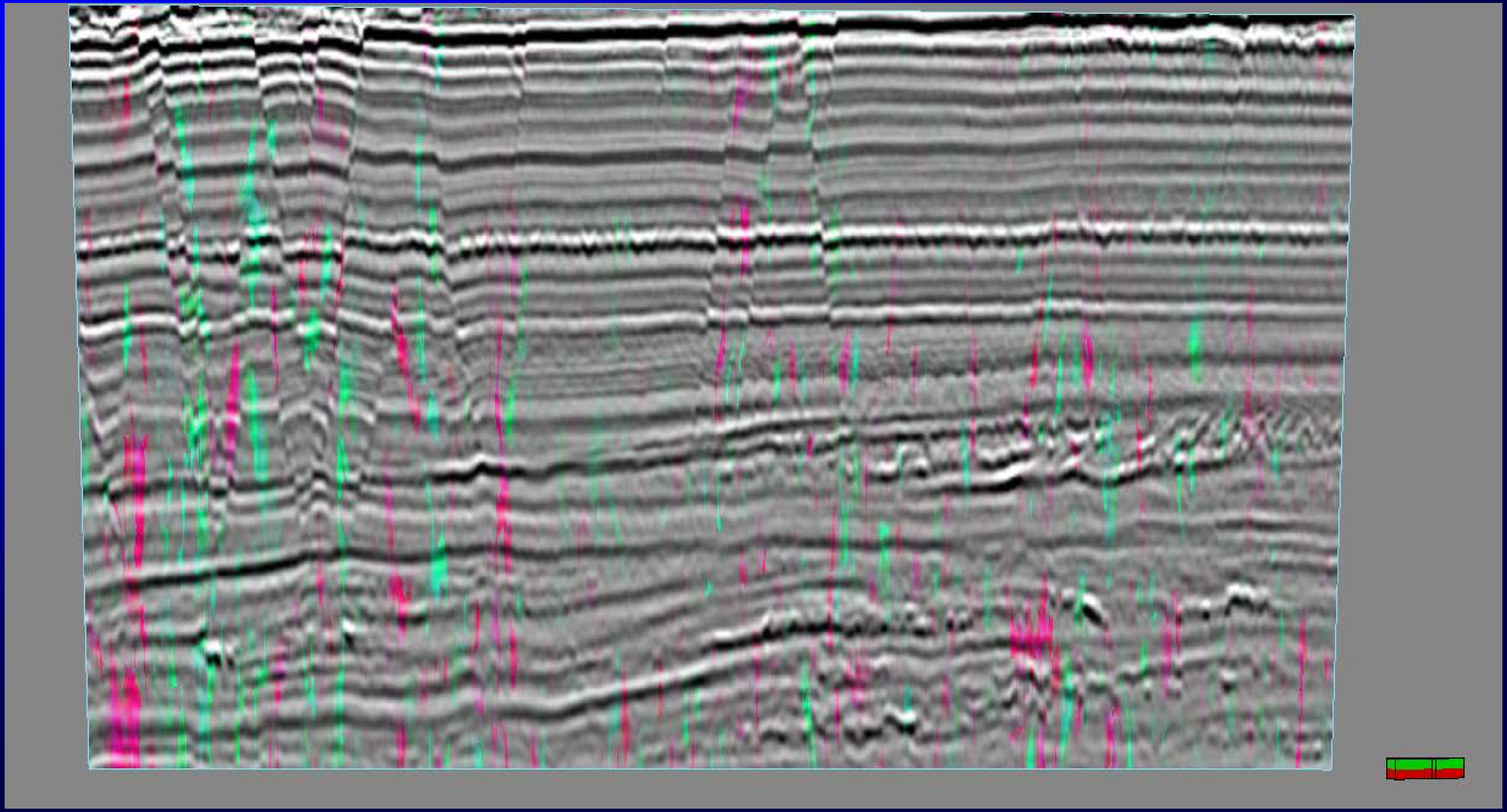
Azimuthally-limited (or apparent) aberrancy

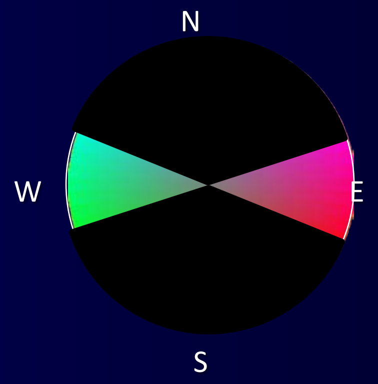


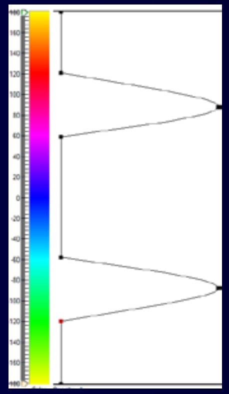
(Marfurt, 2018)

Azimuthally-limited (or apparent) aberrancy

2 km



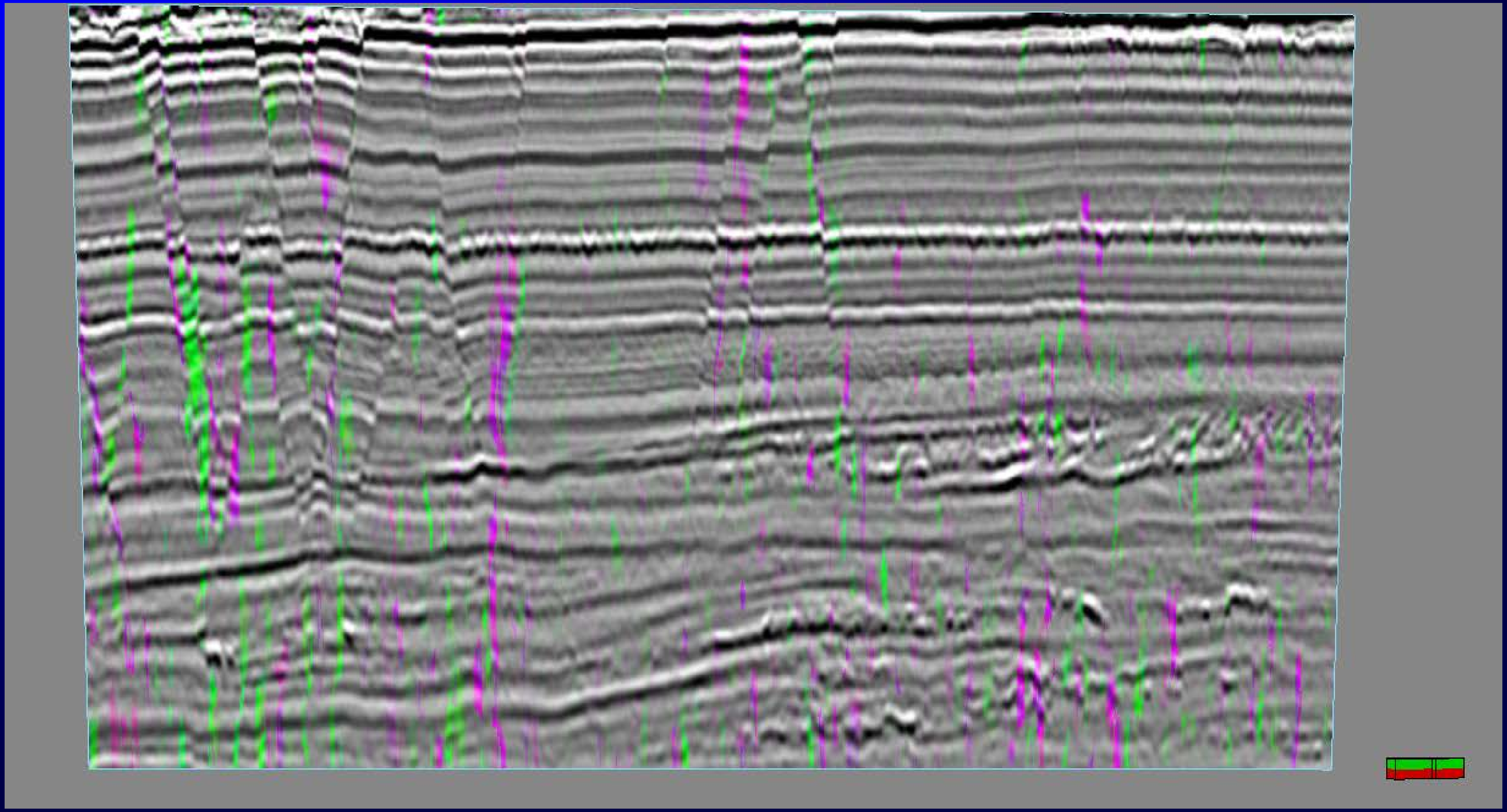


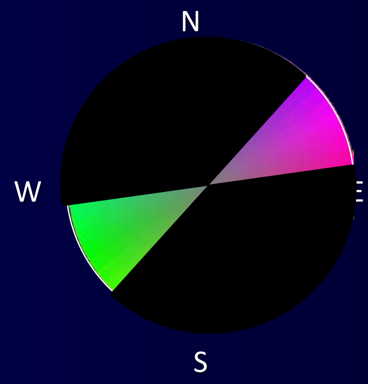


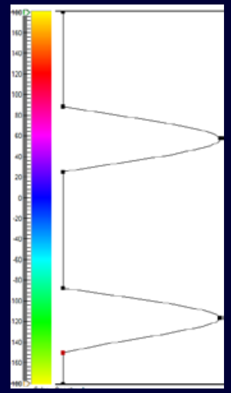
(Marfurt, 2018)

Azimuthally-limited (or apparent) aberrancy

2 km



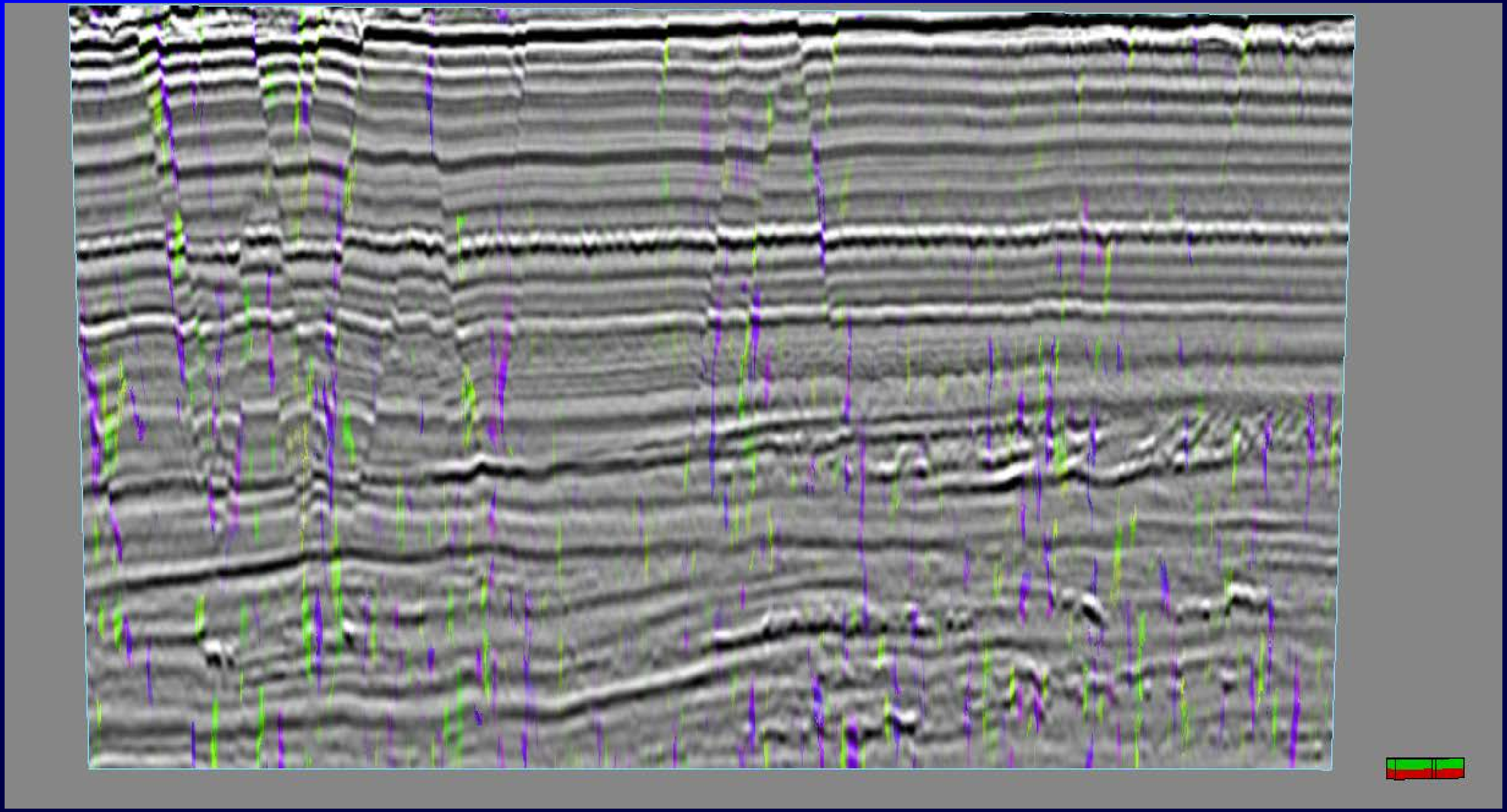


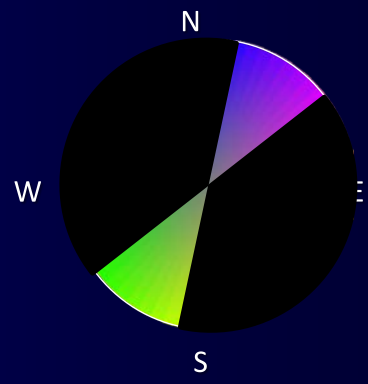


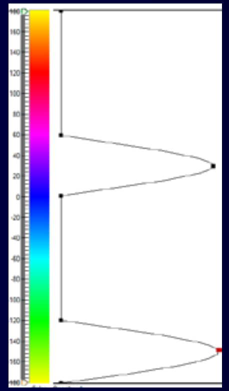
(Marfurt, 2018)

Azimuthally-limited (or apparent) aberrancy

2 km



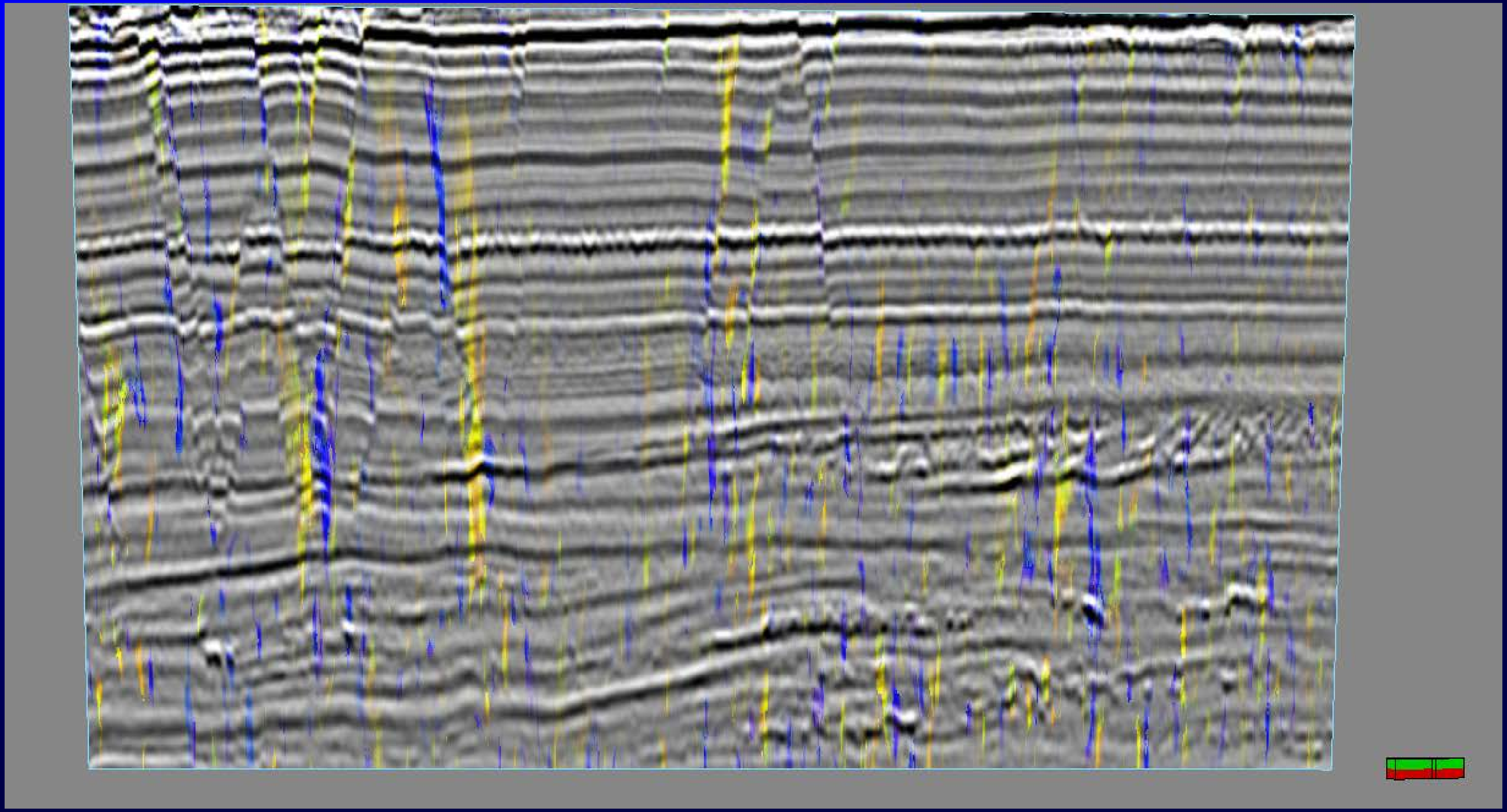


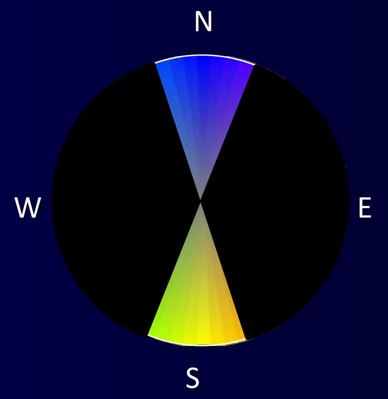


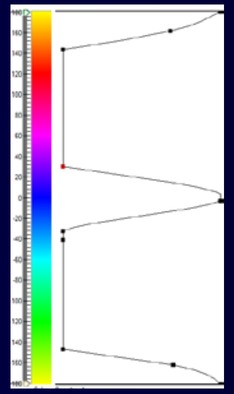
(Marfurt, 2018)

Azimuthally-limited (or apparent) aberrancy

2 km

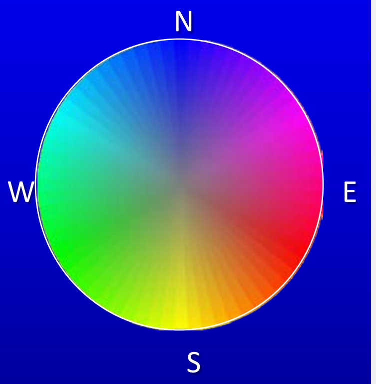


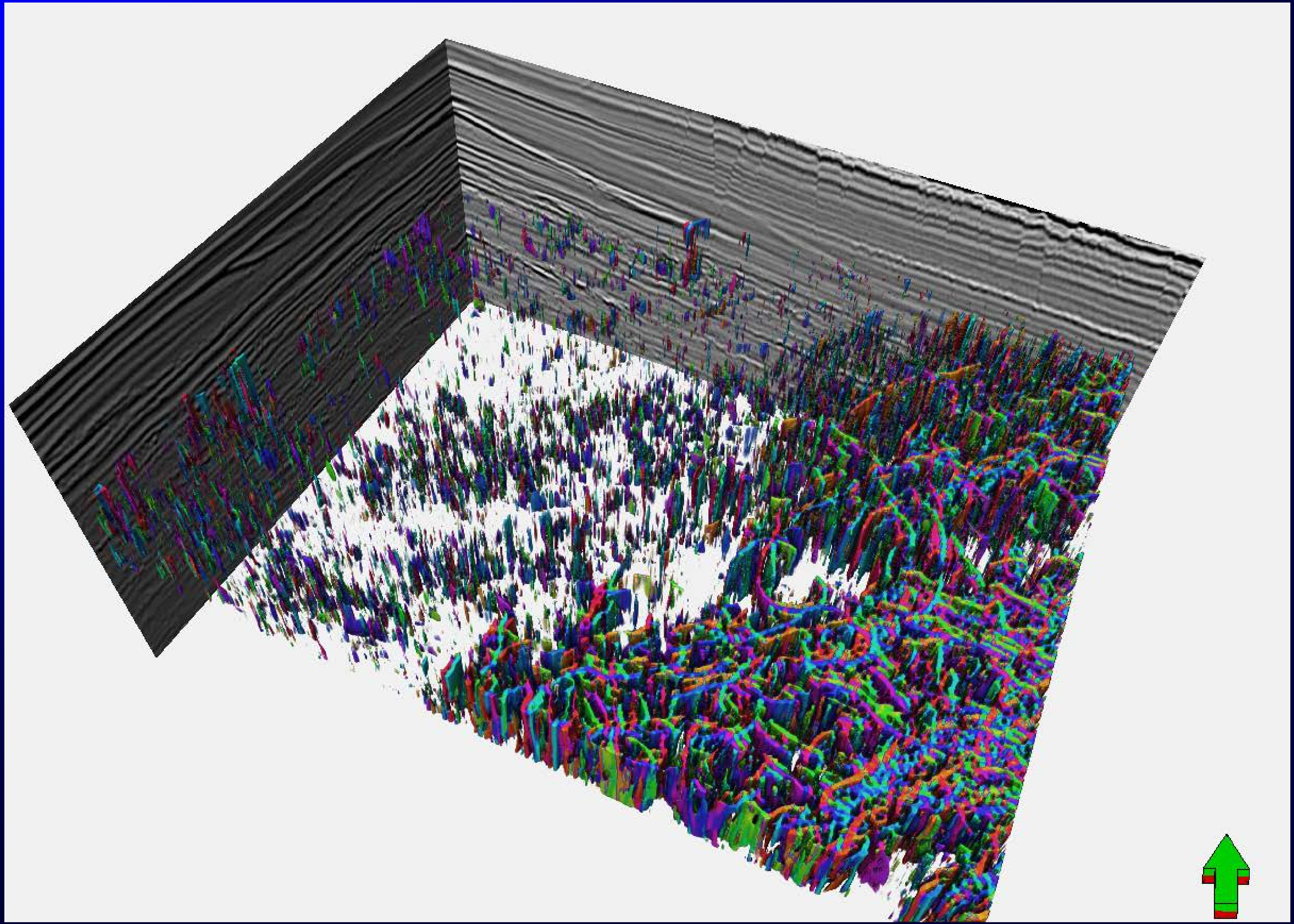




(Marfurt, 2018)

3D Visualization of Polygonal Faults using Aberrancy

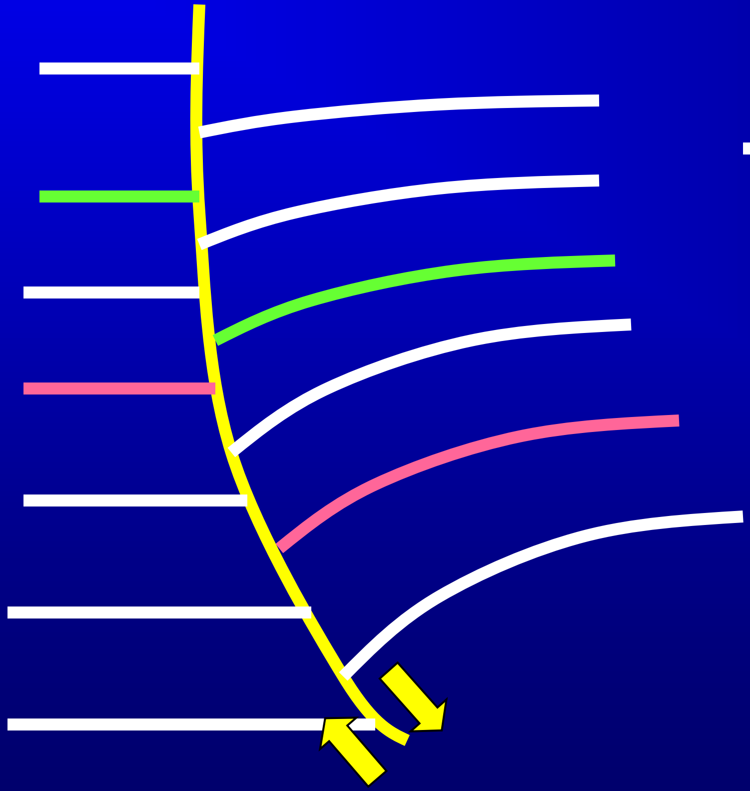




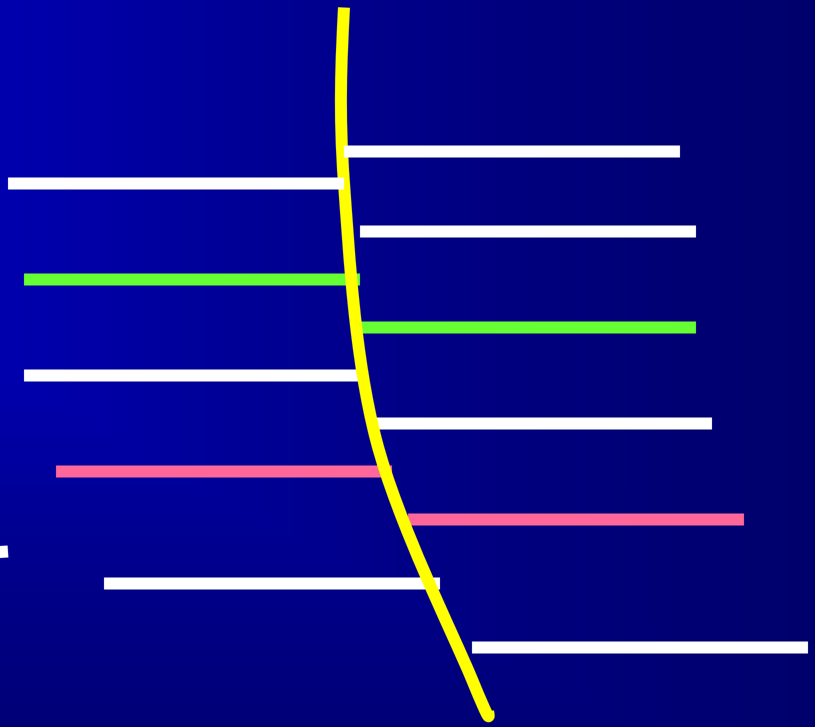
(Marfurt, 2018)

Pitfalls and algorithm limitations

Differences between volume- and horizon-based curvature



Normal fault seen by curvature

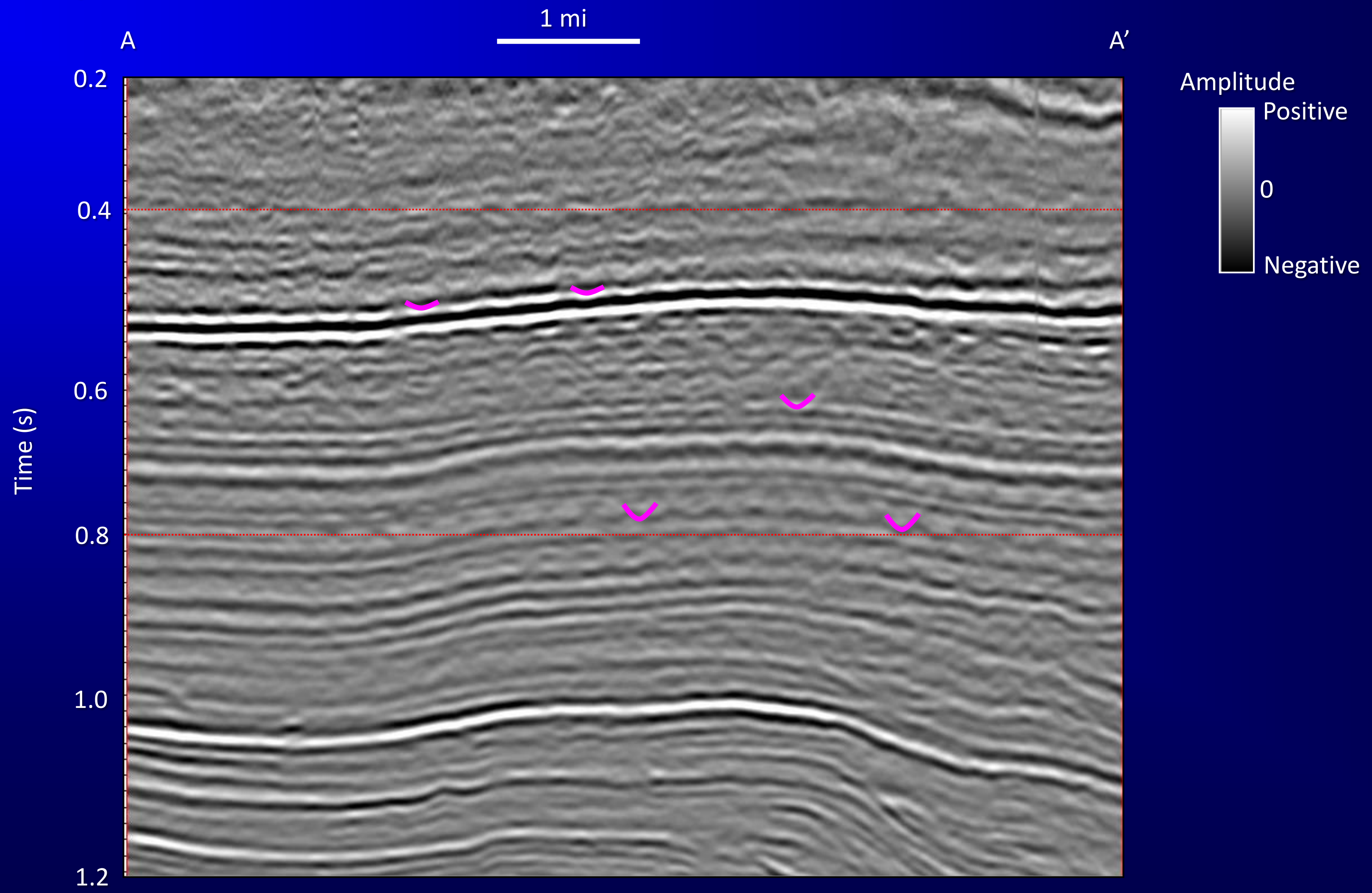


Strike slip fault not seen by curvature

(Chopra and Marfurt, 2008)

Pitfalls and algorithm limitations

Acquisition footprint

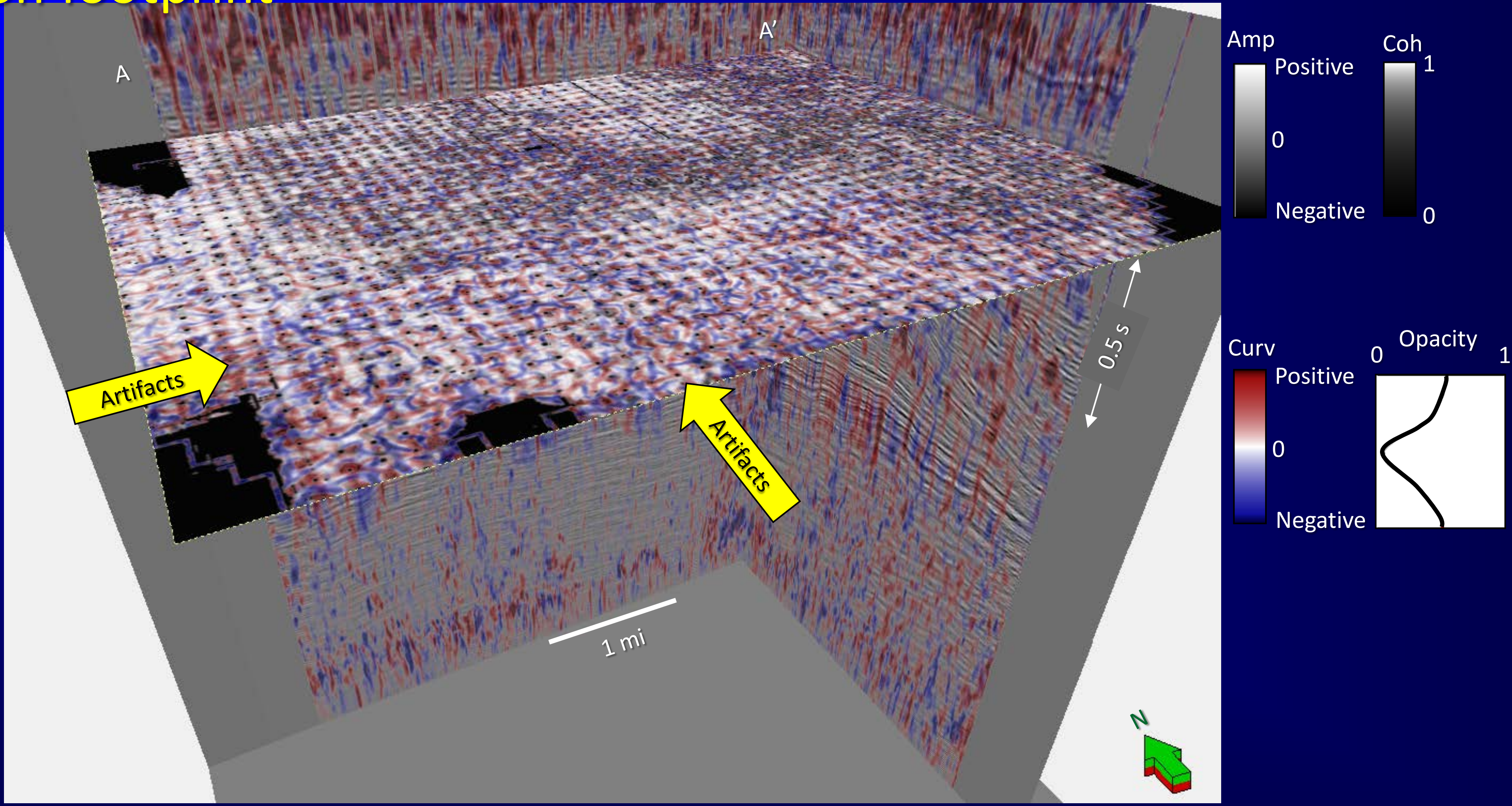


“U-shape” anomalies probably caused by overcorrecting with velocity that is too slow for far offsets

(Marfurt and Alvez, 2015)

Pitfalls and algorithm limitations

Acquisition footprint

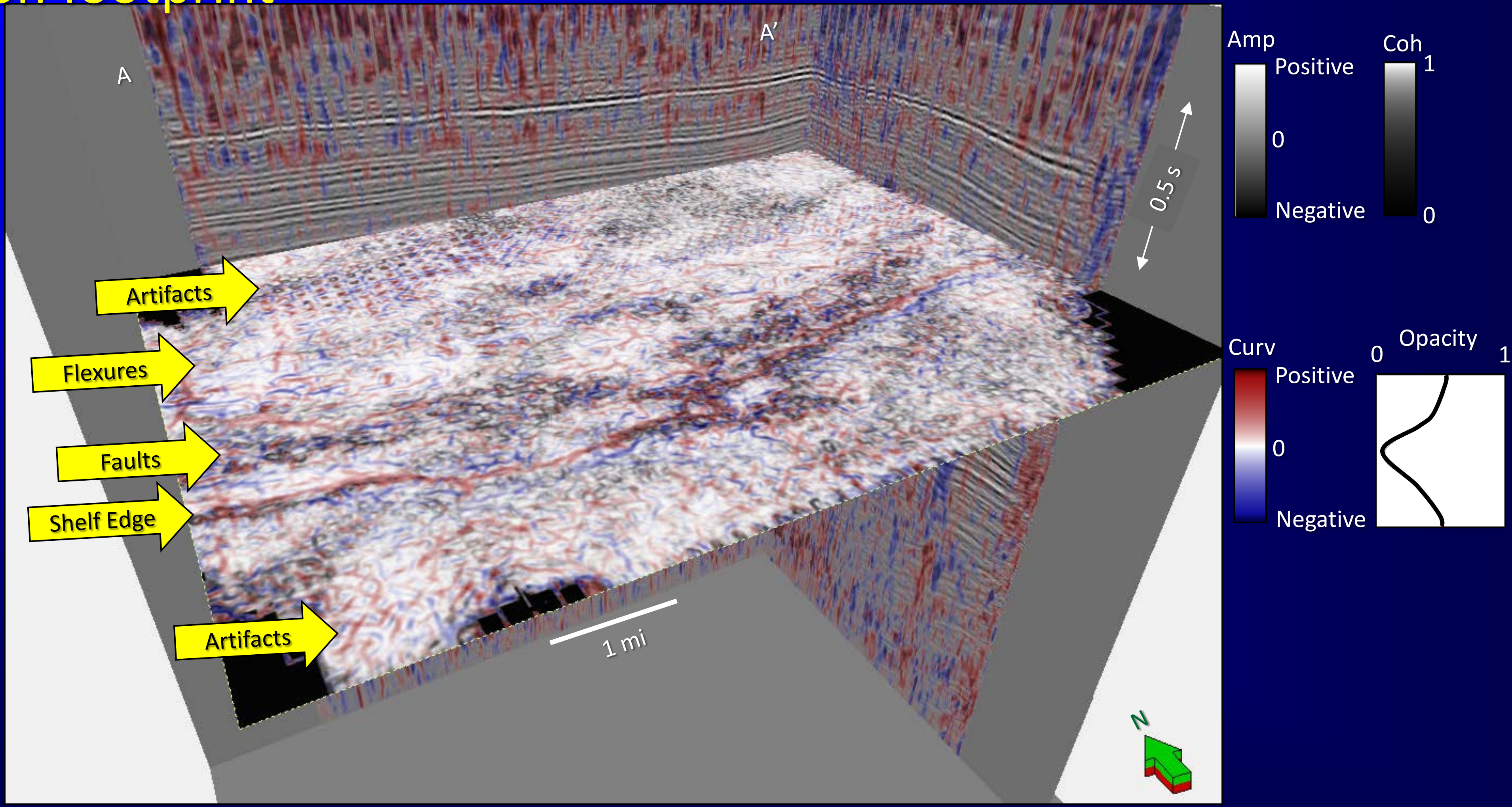


Footprint dominates shallow section at *t*=0.4 s

(Marfurt and Alvez, 2015)

Pitfalls and algorithm limitations

Acquisition footprint

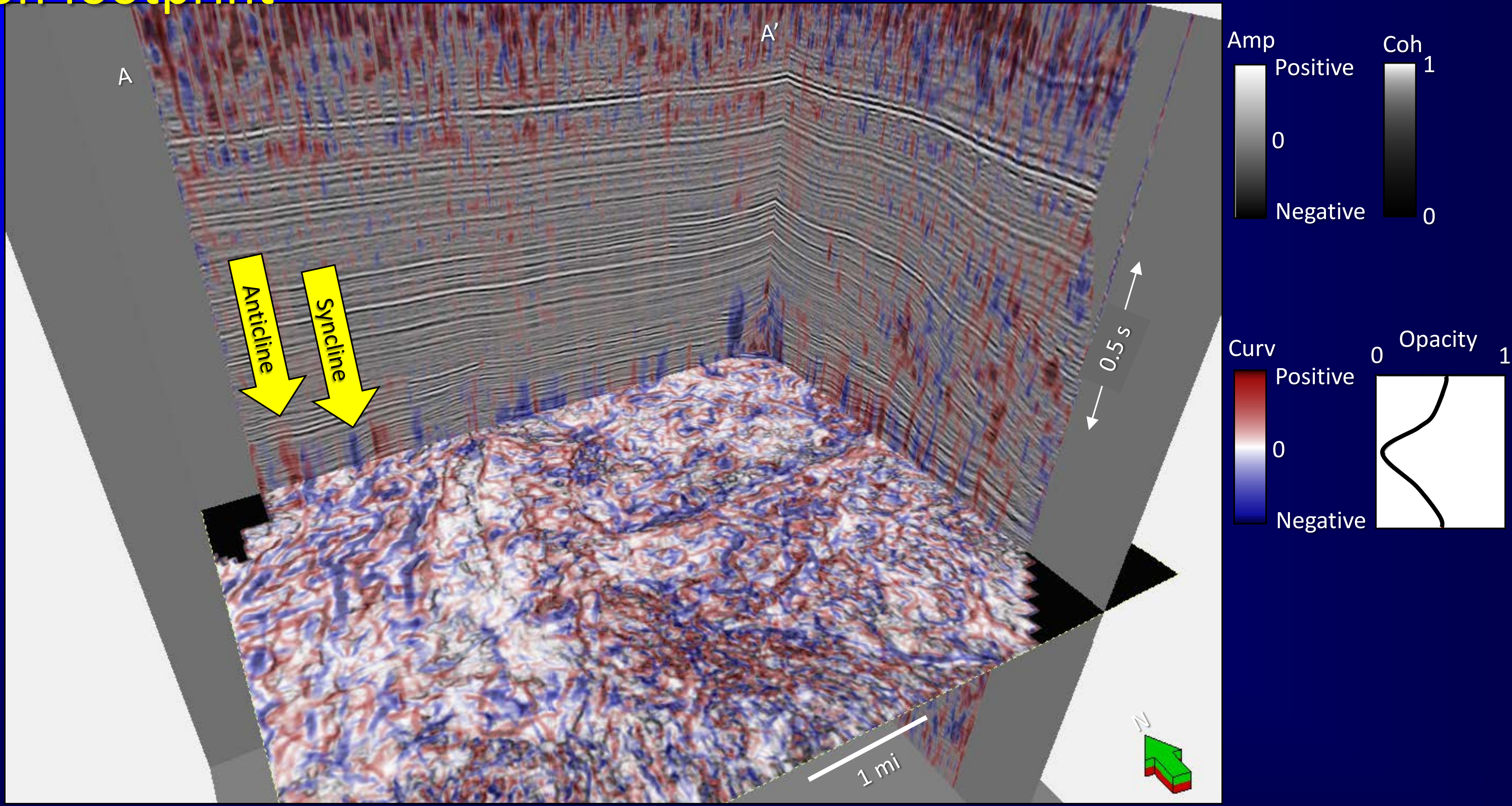


Footprint contaminates geology at Yates level at t=0.8 s

(Marfurt and Alvez, 2015)

Pitfalls and algorithm limitations

Acquisition footprint

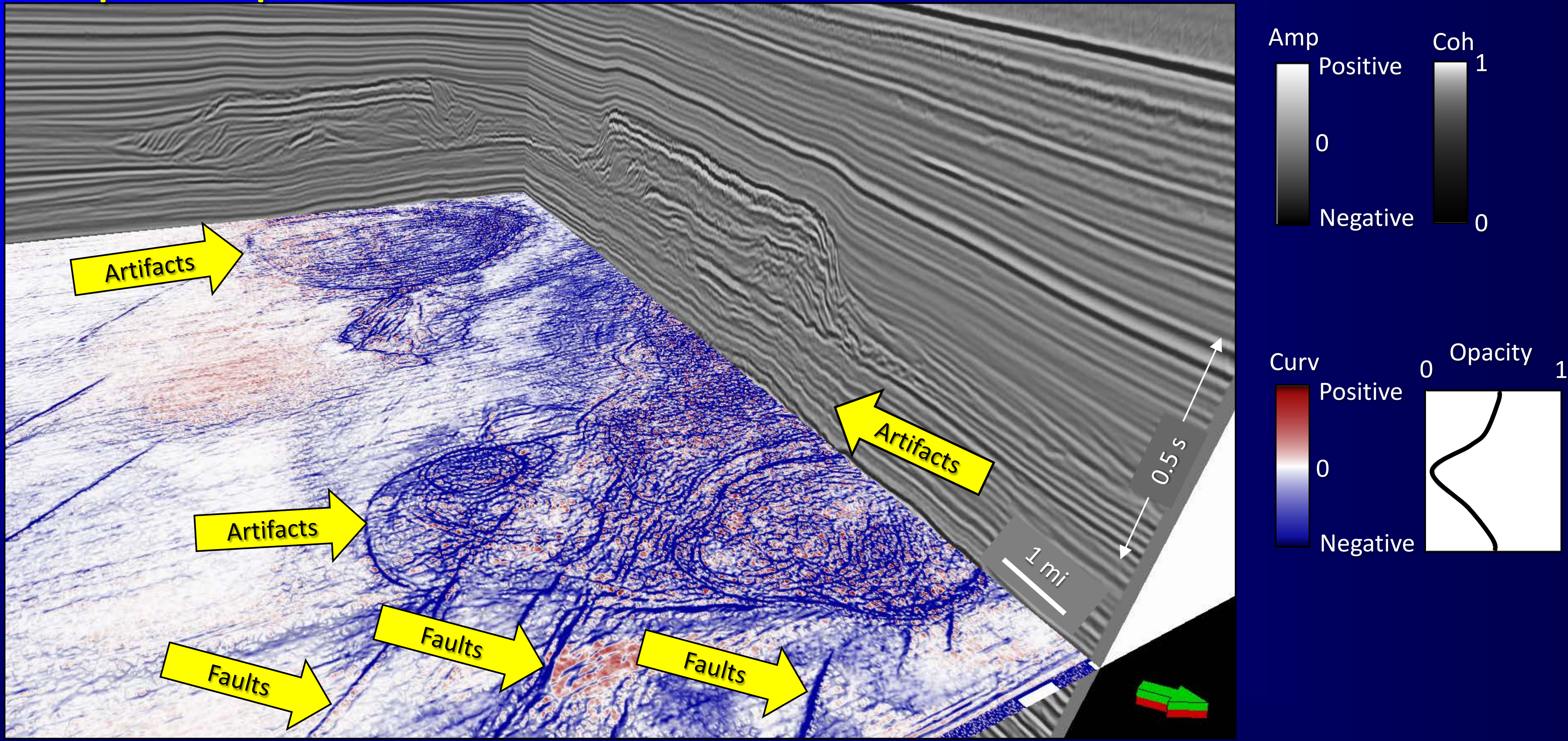


Geologic deformation unaffected by footprint deep in the section at t=1.724 s

(Marfurt and Alvez, 2015)

Pitfalls and algorithm limitations

Velocity pullup and pushdown



Overlying high velocity carbonate reefs give rise to false structure

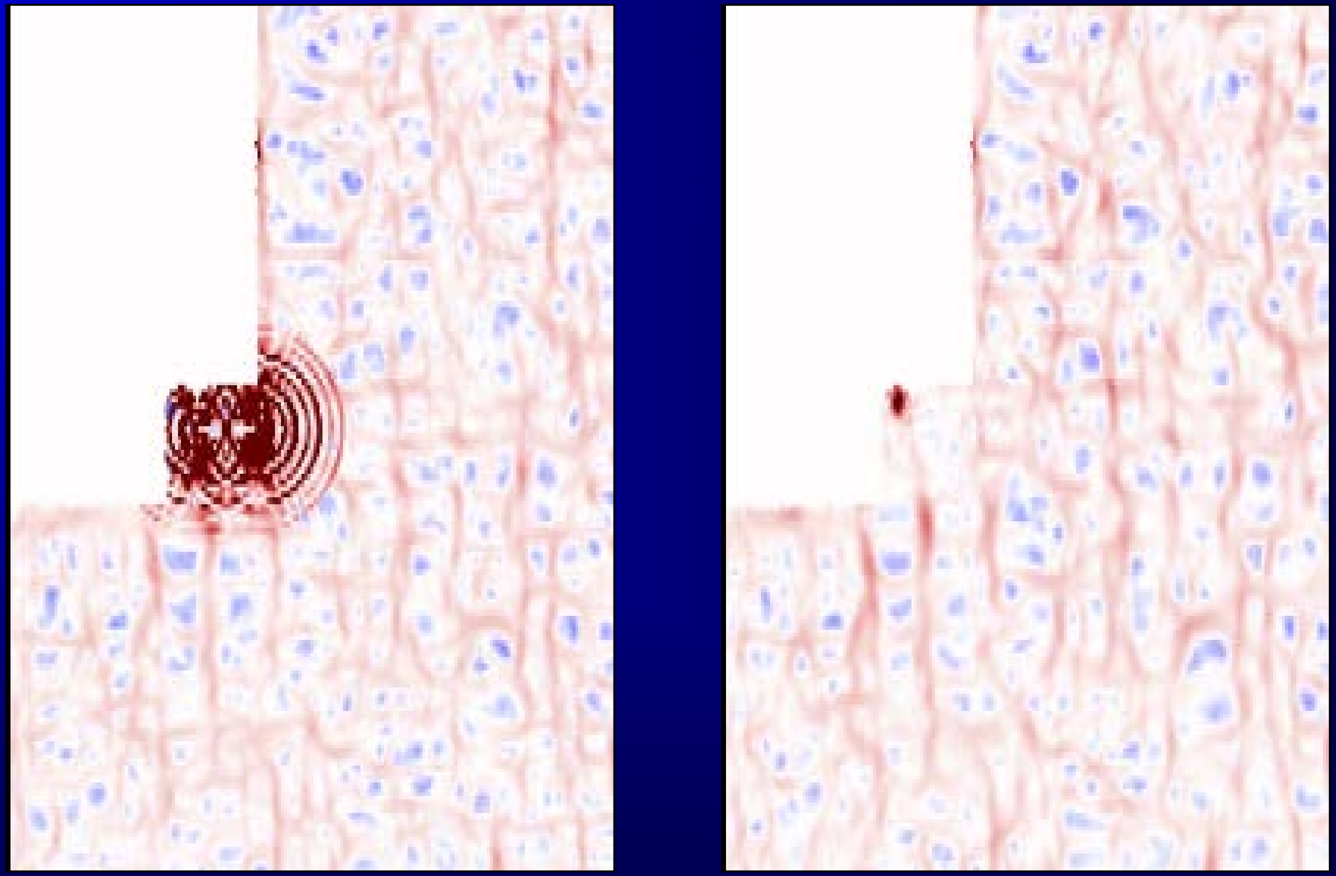
Figure 3a

(Marfurt and Alvez, 2015)

Pitfalls and algorithm limitations

Errors introduced in conversion to 8-bit data

1. 32-bit zeroes are not converted to a non-zero 8-bit value
2. In the absence of headers in interpretation software, dead traces cannot be flagged and mutes cannot be set
3. There is rapid change in dip from the live data zone to the dead data zone
4. Such rapid changes give rise to a curvature impulse response



1 km

(Chopra and Marfurt, 2024)

Curvature and Aberrancy

In Summary:

- The most negative and most positive principal curvatures appear to be the most unambiguous of the curvature images in illuminating folds and flexures.
- Curvature and aberrancy measure strain, and are a good indicator of paleo rather than present-day stress regimes.
- Open fractures are a function of the strike of curvature and aberrancy lineaments and the strike of minimum horizontal stress.
- Curvature and aberrancy are vectors, allowing the interpreter to define hypothesized fault and fold systems.