Seismic Attributes - from Interactive Interpretation to Machine Learning

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Geometric Attributes that Map Reflector Configuration

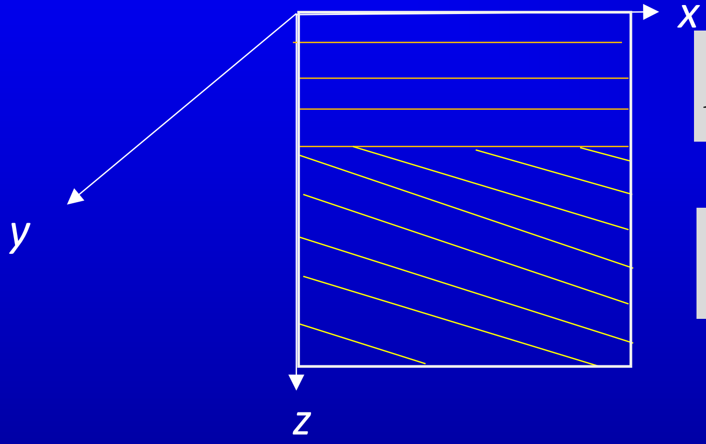
Nonparallelism and Reflector Convergence

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

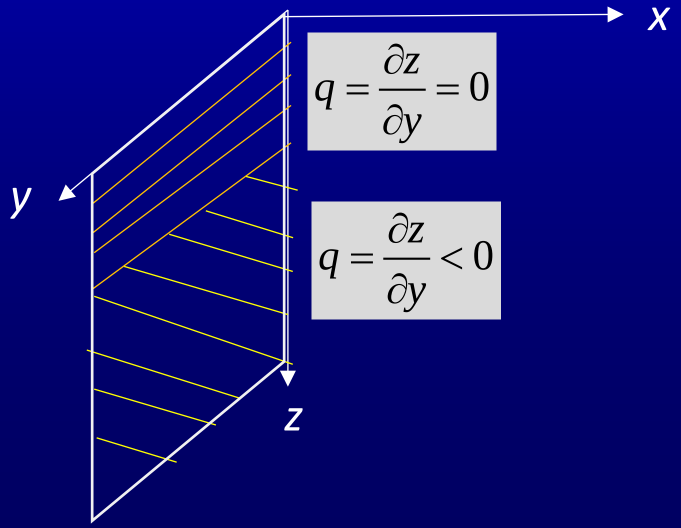
Reflector convergence

(Changes in dip perpendicular a relatively flat stratigraphic trend)



$$p = \frac{\partial z}{\partial x} = 0$$

$$p = \frac{\partial z}{\partial x} > 0$$



$$q = \frac{\partial z}{\partial y} = 0$$

$$q = \frac{\partial z}{\partial y} < 0$$

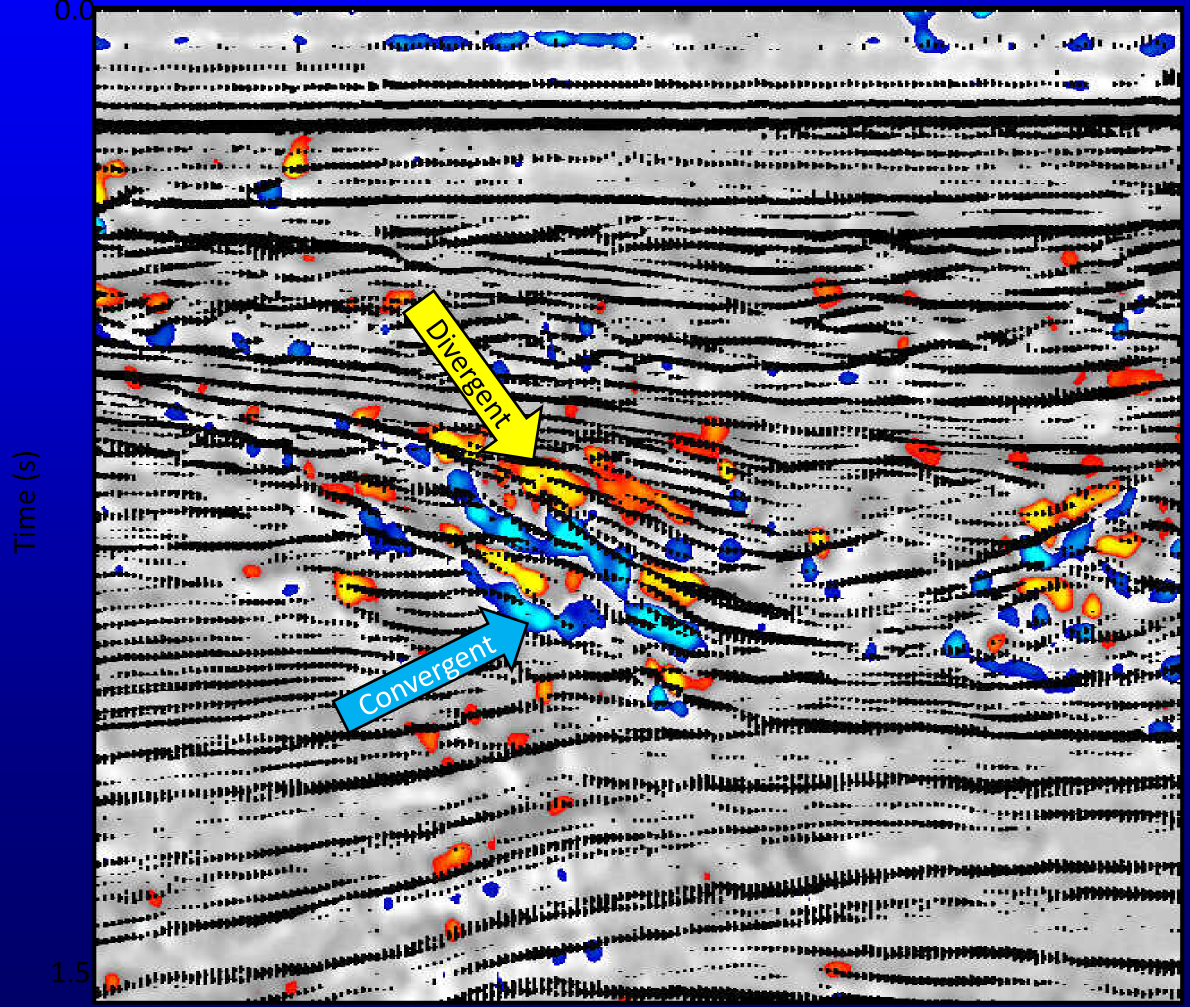
$$c_x = \frac{\partial p}{\partial z}$$

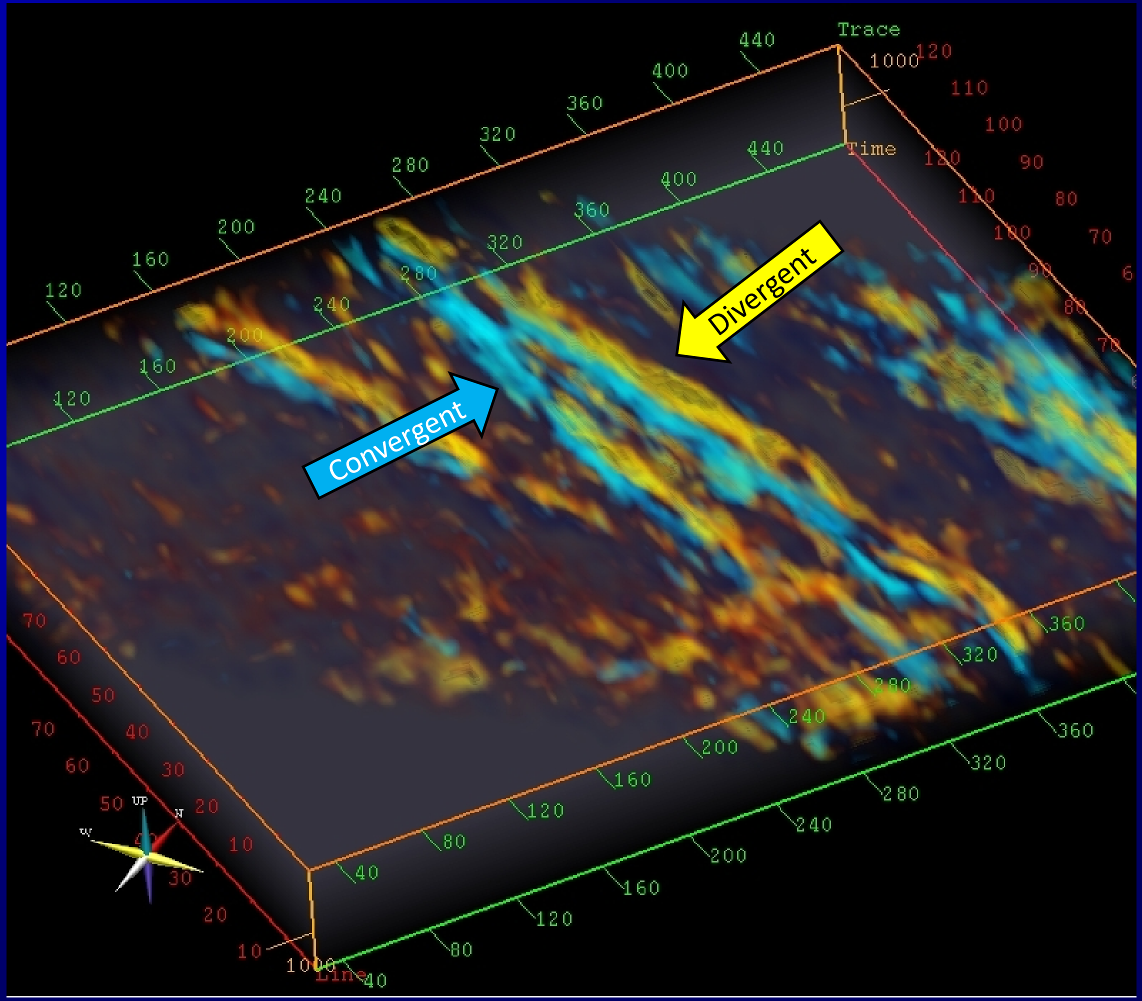
Apparent dip in x

$$c_y = \frac{\partial q}{\partial z}$$

Apparent dip in y

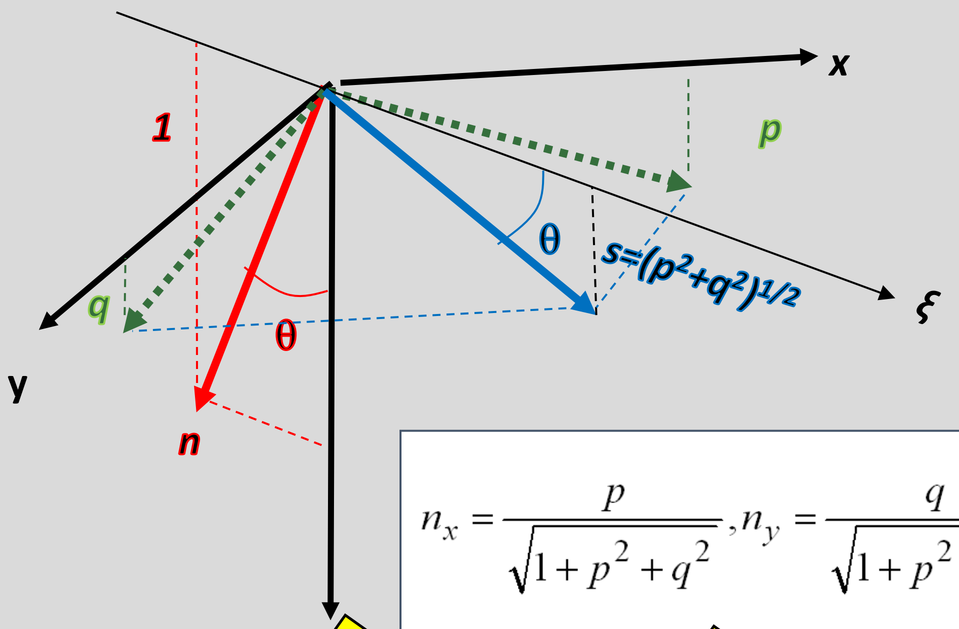
Volumetric mapping of angular unconformities (lack of conformance)





(Barnes, 2002)

Computing the normal from apparent dip components *p* and *q*



$$n_x = \frac{p}{\sqrt{1+p^2+q^2}}, n_y = \frac{q}{\sqrt{1+p^2+q^2}}, n_z = \frac{1}{\sqrt{1+p^2+q^2}},$$

Rotation about the x axis

Rotation about the y axis

Rotation about the z axis

$$\boldsymbol{\psi} = \nabla \times \mathbf{n} = \hat{\mathbf{x}}\left(\frac{\partial n_y}{\partial z} - \frac{\partial n_z}{\partial y}\right) + \hat{\mathbf{y}}\left(\frac{\partial n_z}{\partial x} - \frac{\partial n_x}{\partial z}\right) + \hat{\mathbf{z}}\left(\frac{\partial n_x}{\partial y} - \frac{\partial n_y}{\partial x}\right),$$

(Marfurt and Rich, 2010)

Arithmetic for mapping angular unconformities

Compute rotations about the average normal, ñ

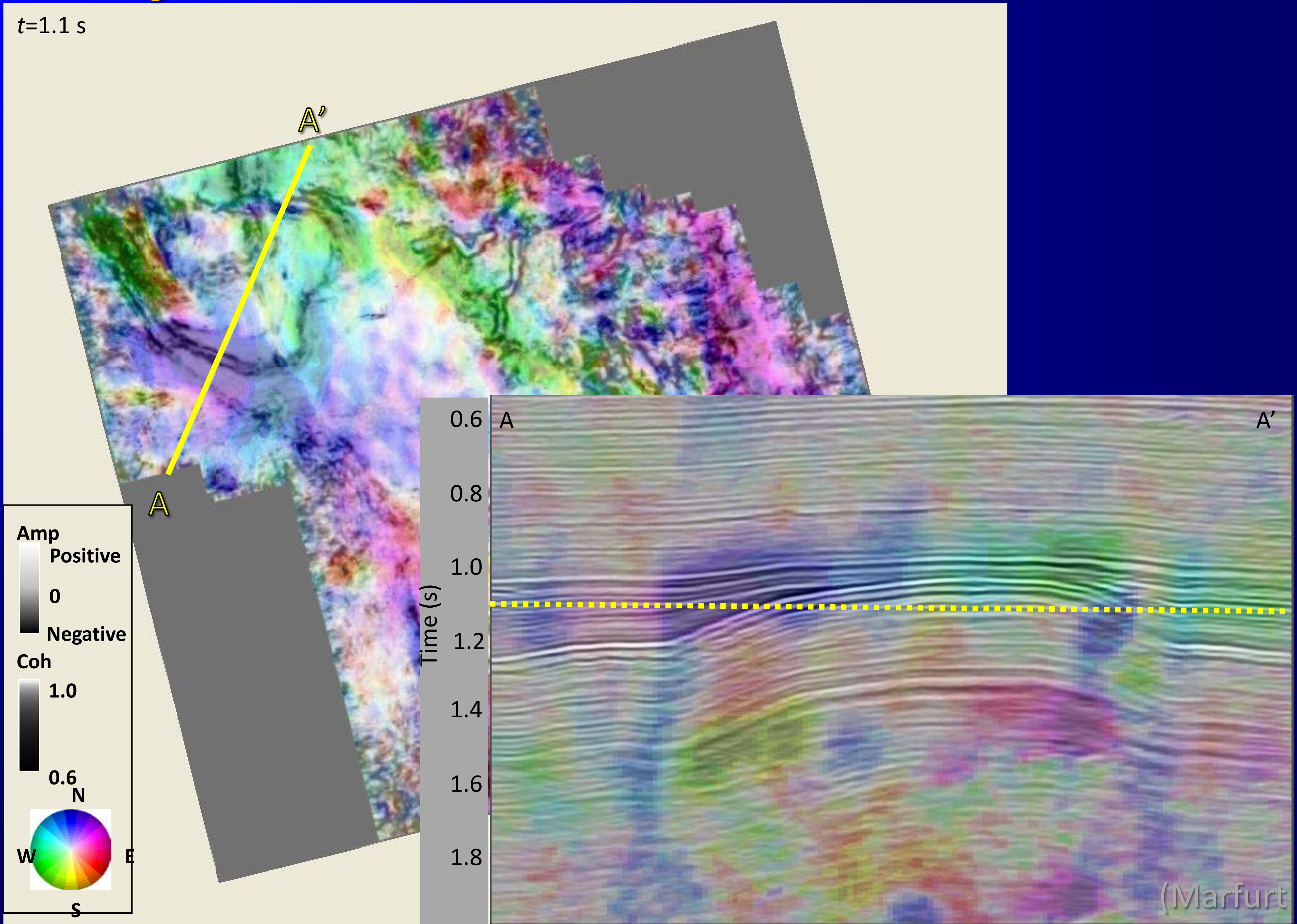
$$\mathbf{c} = \tilde{\mathbf{n}} \times \boldsymbol{\psi} = \hat{\mathbf{x}}\left[\tilde{n}_y\left(\frac{\partial n_x}{\partial y} - \frac{\partial n_y}{\partial x}\right) - \tilde{n}_z\left(\frac{\partial n_y}{\partial z} - \frac{\partial n_z}{\partial y}\right)\right]$$

$$+\hat{\mathbf{y}}\left[\tilde{n}_z\left(\frac{\partial n_y}{\partial z} - \frac{\partial n_z}{\partial y}\right) - \tilde{n}_x\left(\frac{\partial n_x}{\partial y} - \frac{\partial n_y}{\partial x}\right)\right]$$

$$+\hat{\mathbf{z}}\left[\tilde{n}_x\left(\frac{\partial n_z}{\partial x} - \frac{\partial n_x}{\partial z}\right) - \tilde{n}_y\left(\frac{\partial n_y}{\partial z} - \frac{\partial n_z}{\partial y}\right)\right]$$

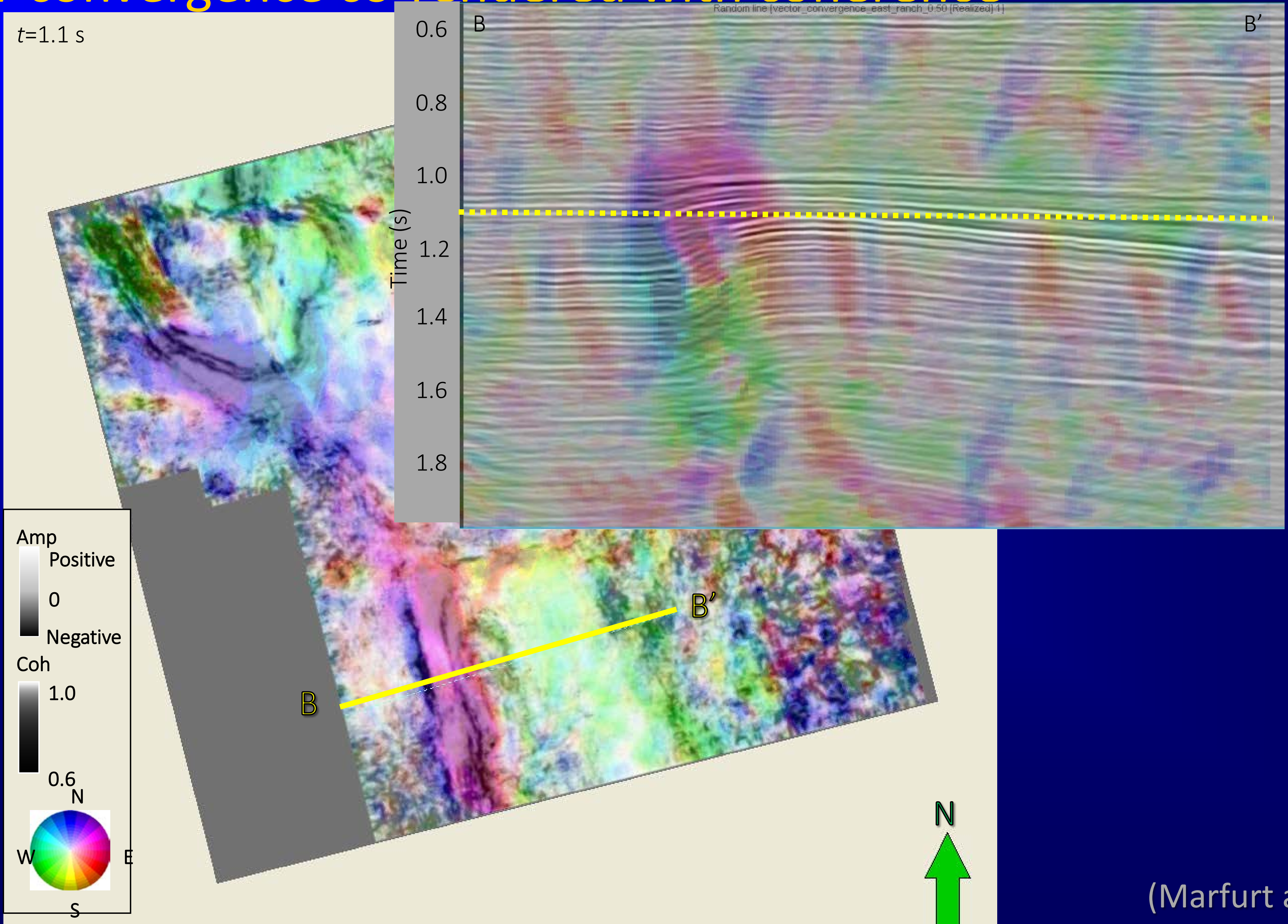
(Marfurt and Rich, 2010)

Reflector convergence co-rendered with coherence



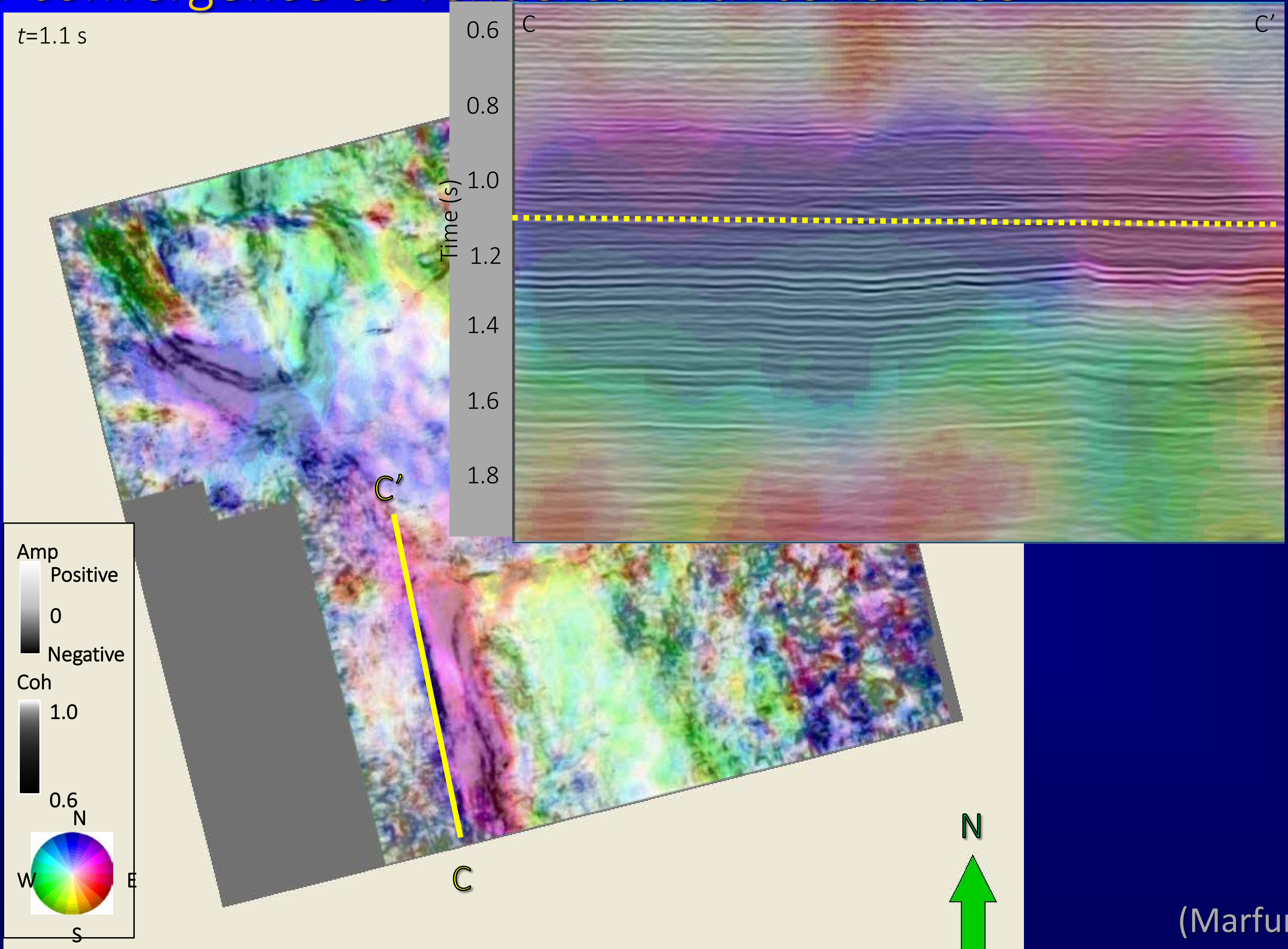
(Marfurt and Rich, 2010)

Reflector convergence co-rendered with coherence



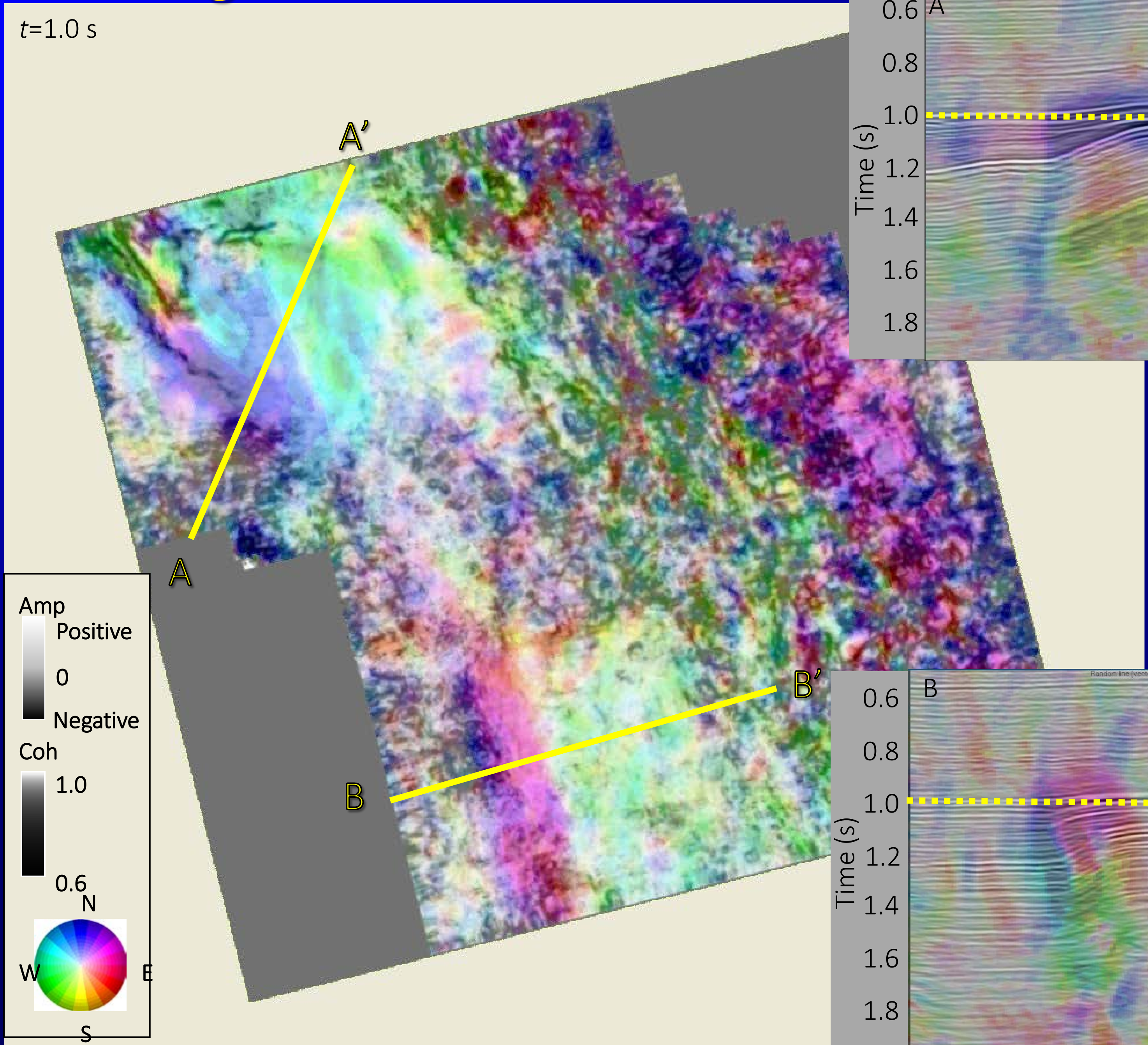
(Marfurt and Rich, 2010)

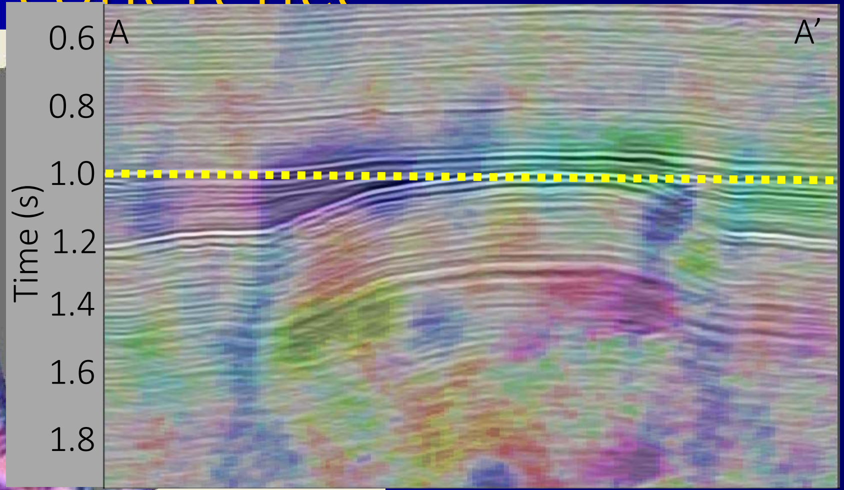
Reflector convergence co-rendered with coherence

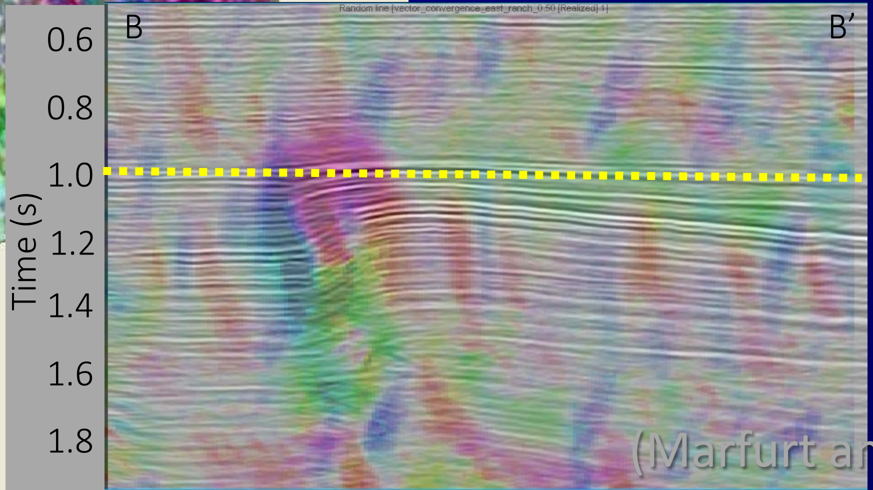


(Marfurt and Rich, 2010)

Reflector convergence co-rendered with coherence

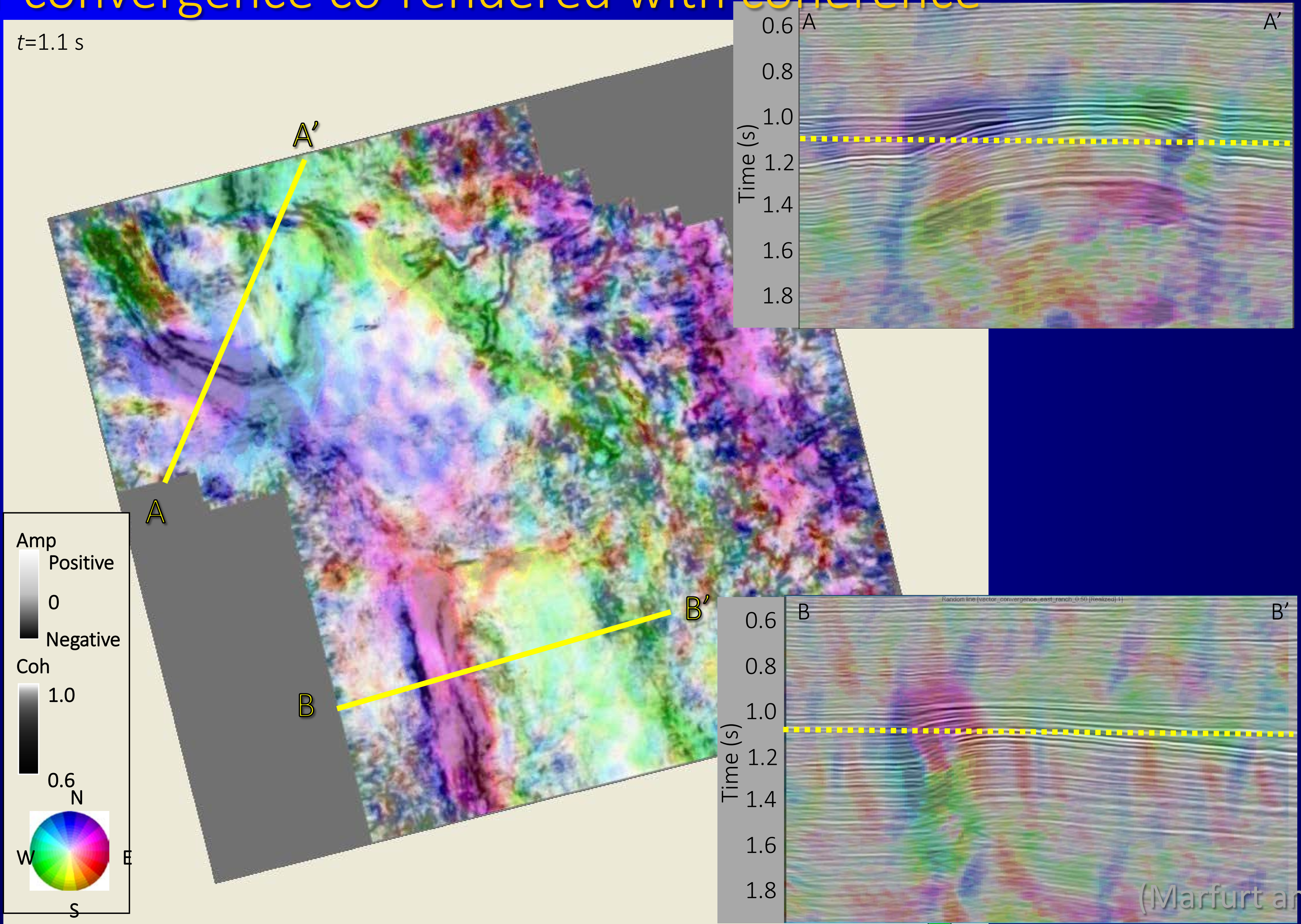






(Marfurt and Rich, 2010)

Reflector convergence co-rendered with coherence



(Marfurt and Rich, 2010)

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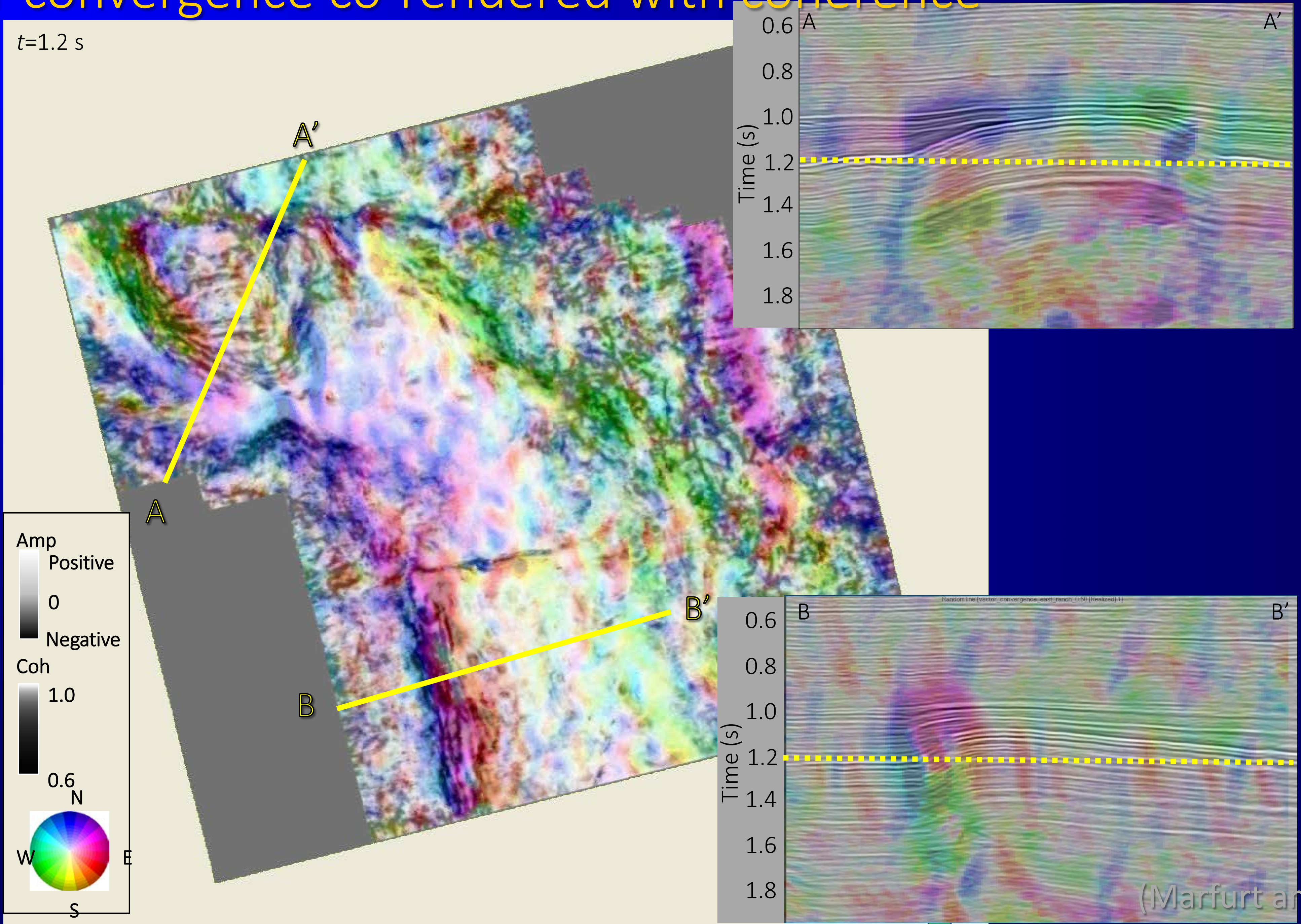
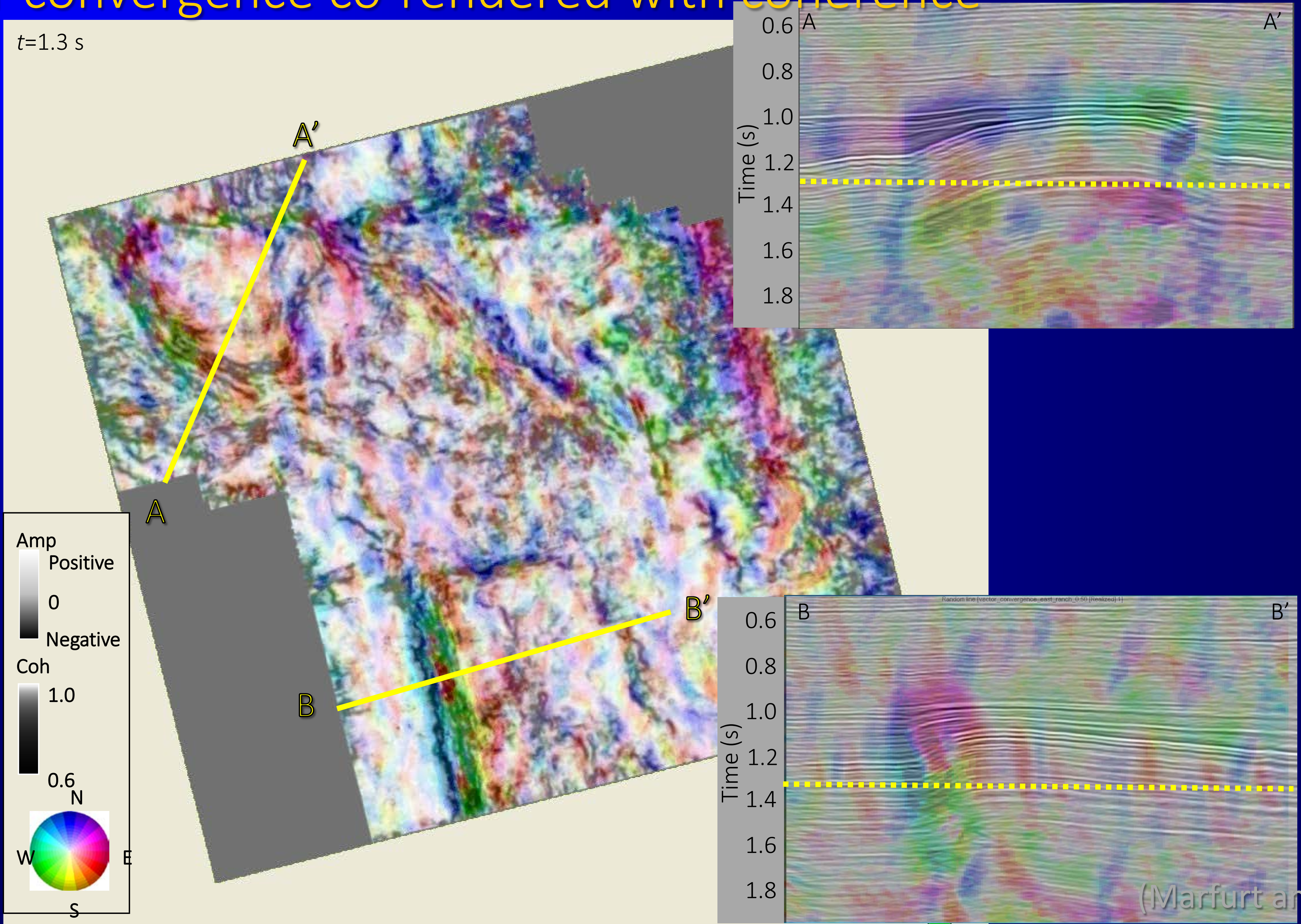


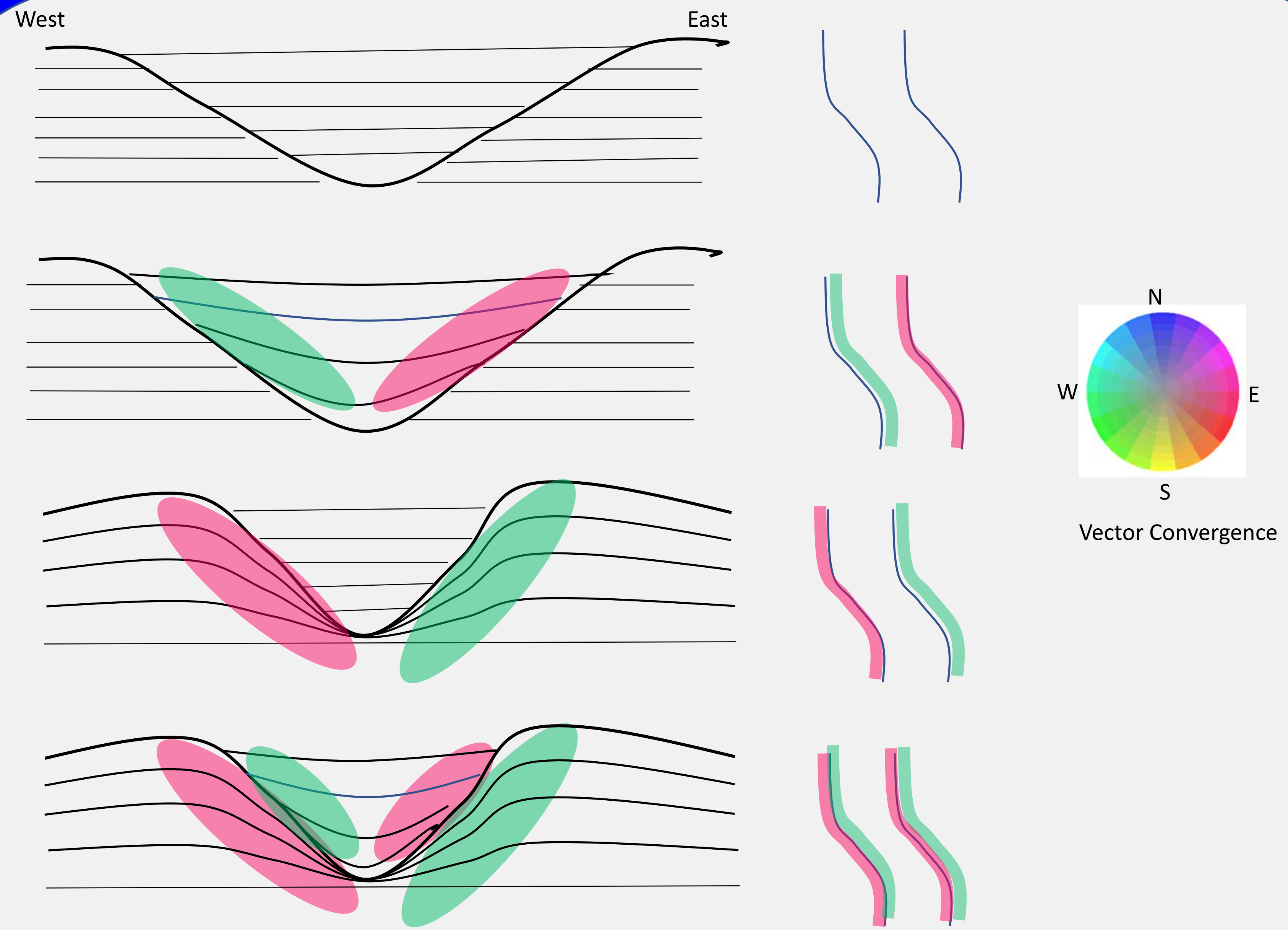
(Marfurt and Rich, 2010)

Reflector convergence co-rendered with coherence



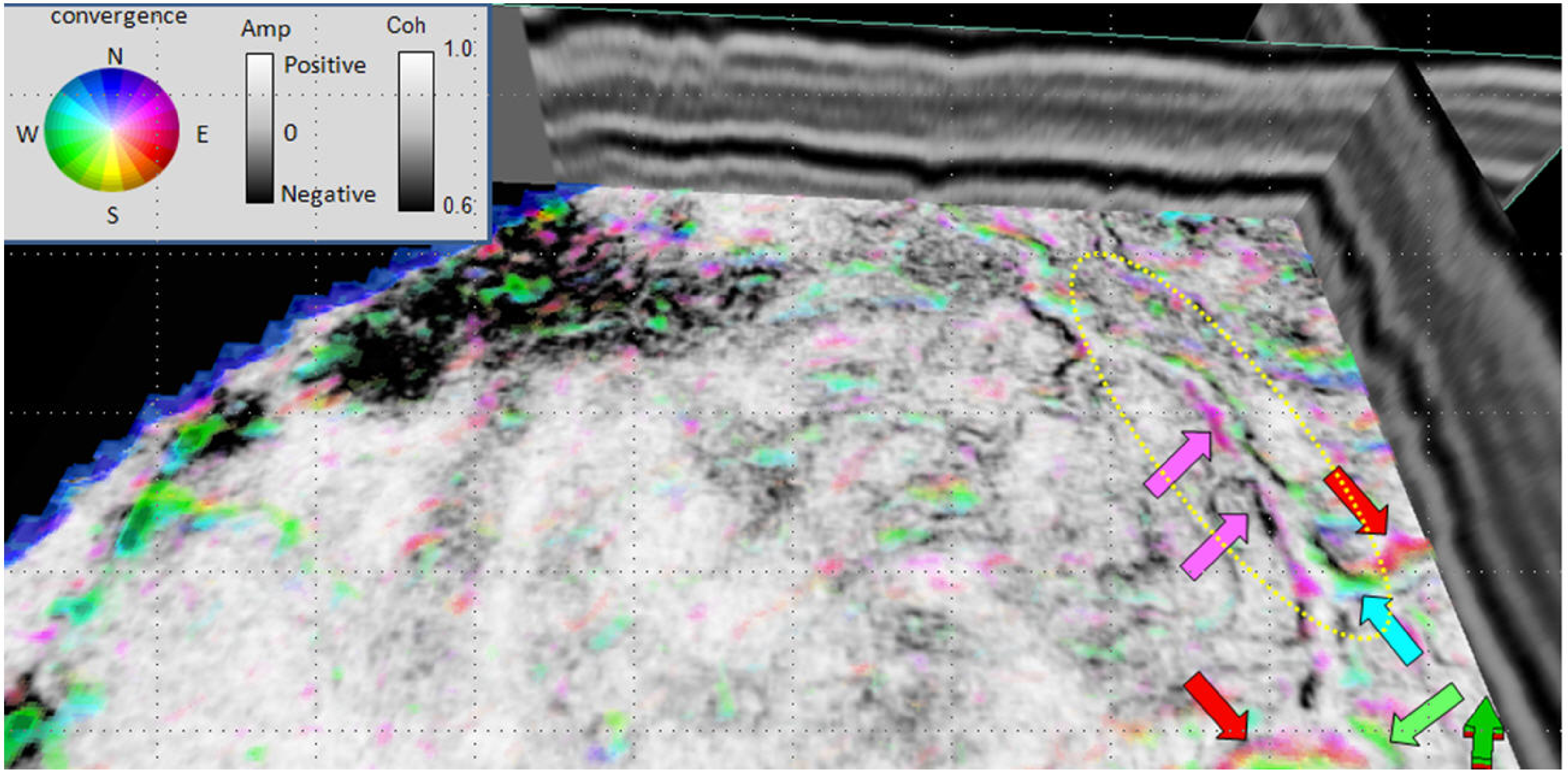
(Marfurt and Rich, 2010)

Reflector convergence about channel edges



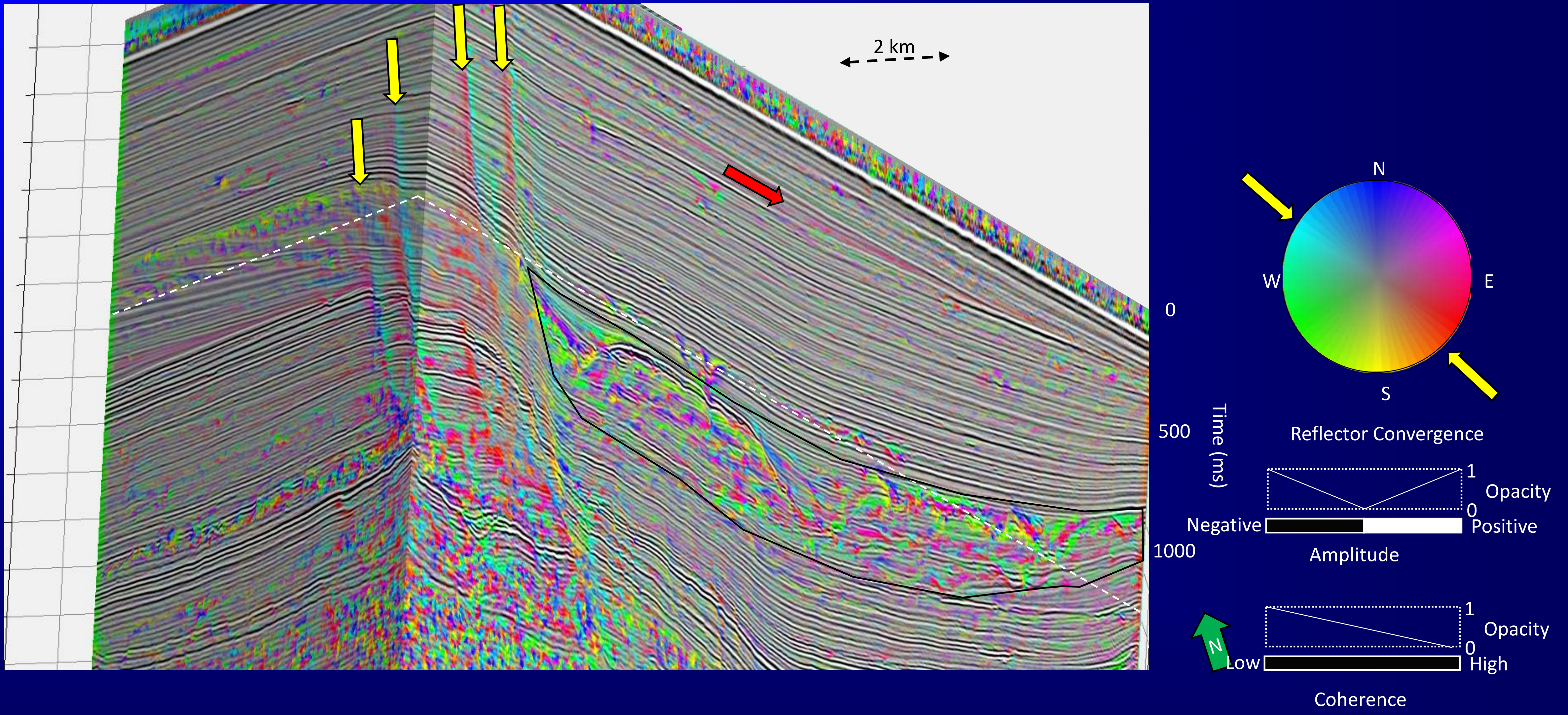
(Chopra and Marfurt, 2011)

Reflector convergence co-rendered with coherence (Distributary system in Alberta)



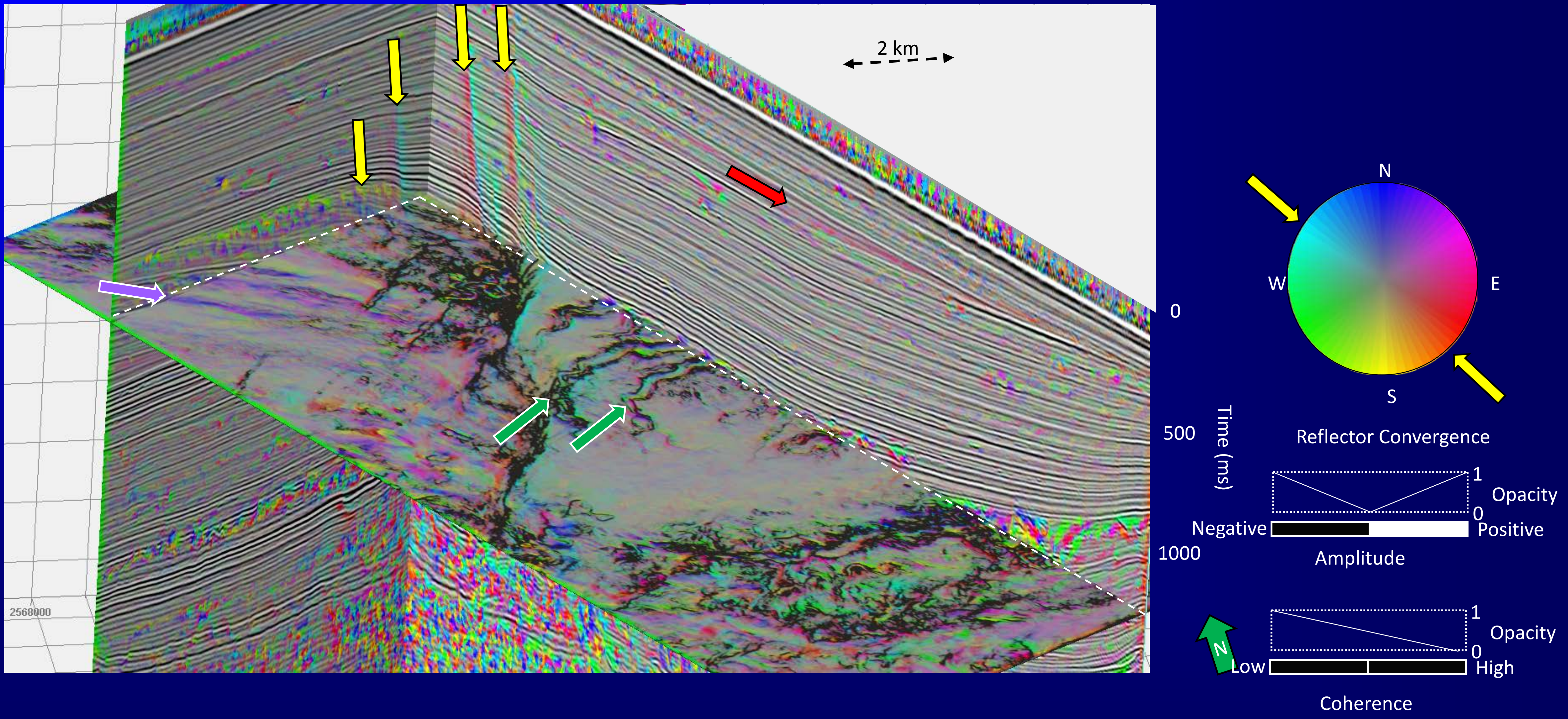
(Chopra and Marfurt, 2011)

Reflector convergence co-rendered with seismic amplitude (Faults, relay ramps, and turbidites in Taranaki Basin, NZ)



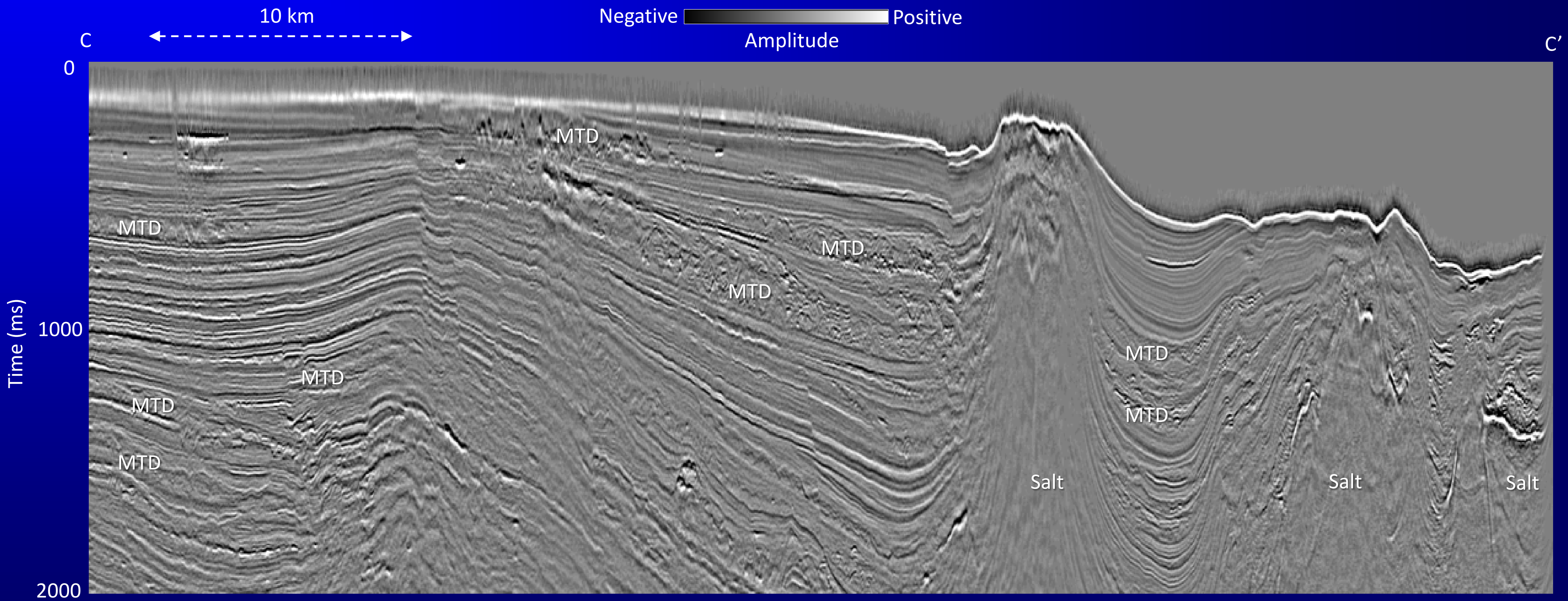
(Chopra and Marfurt, 2024)

Reflector convergence co-rendered with seismic amplitude (Faults, relay ramps, and turbidites in Taranaki Basin, NZ)



(Chopra and Marfurt, 2024)

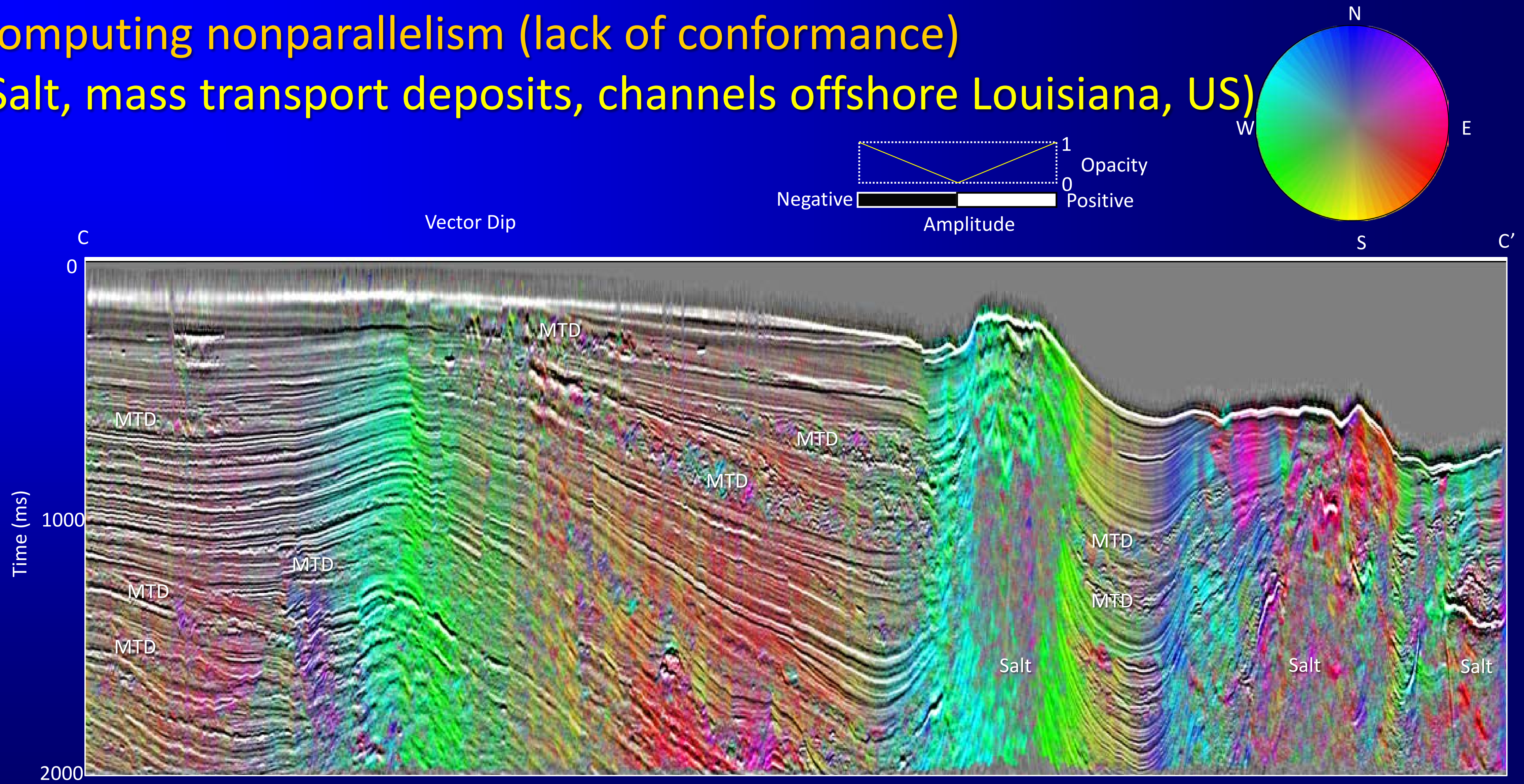
Computing nonparallelism (lack of conformance)
(Salt, mass transport deposits, channels offshore Louisiana, US)



Seismic Amplitude

(Chopra and Marfurt, 2024)

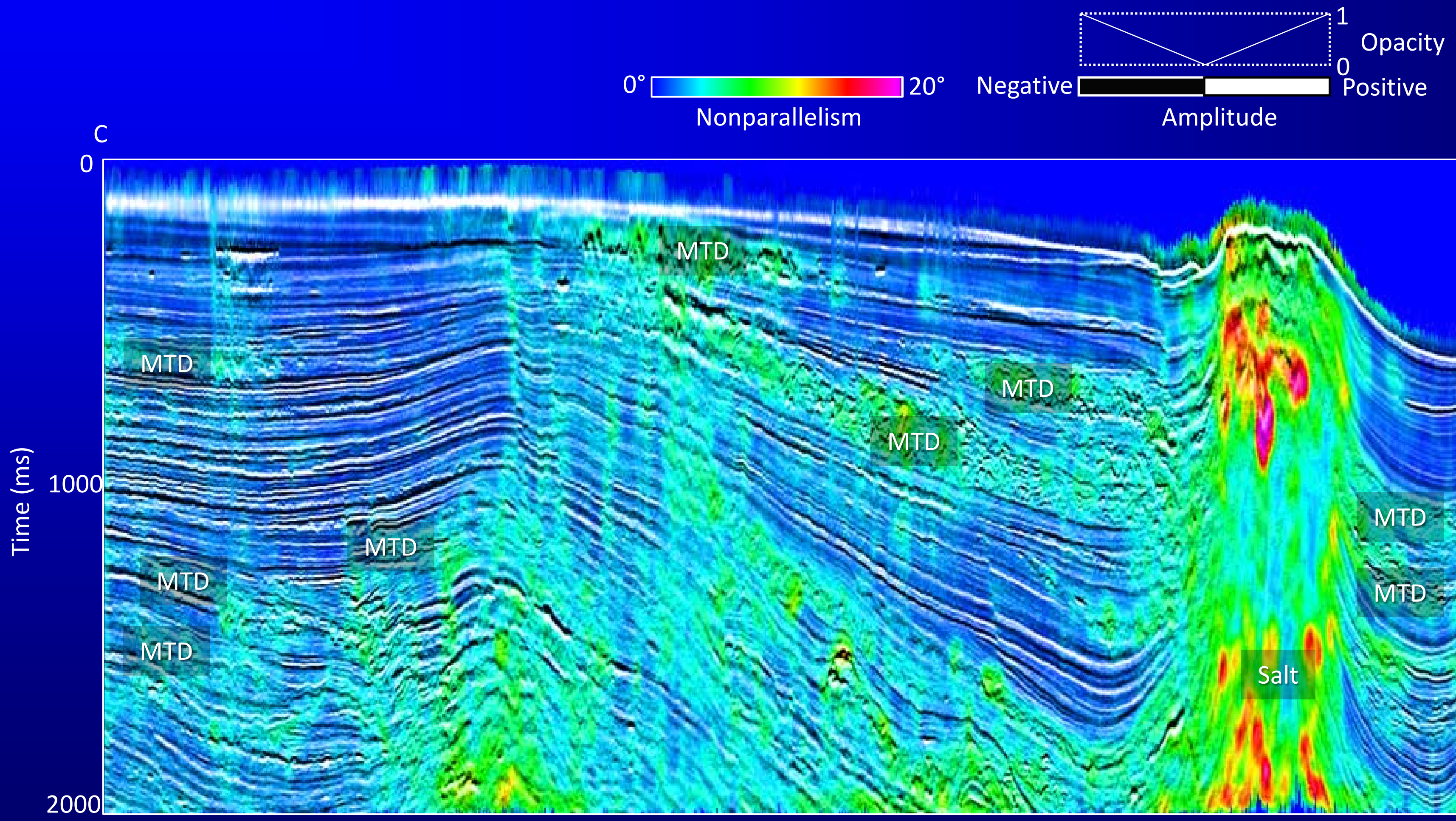
Computing nonparallelism (lack of conformance)
(Salt, mass transport deposits, channels offshore Louisiana, US)



Corendered Dip Magnitude and Dip Azimuth

(Chopra and Marfurt, 2024)

Computing nonparallelism (lack of conformance)
(Salt, mass transport deposits, channels offshore Louisiana, US)

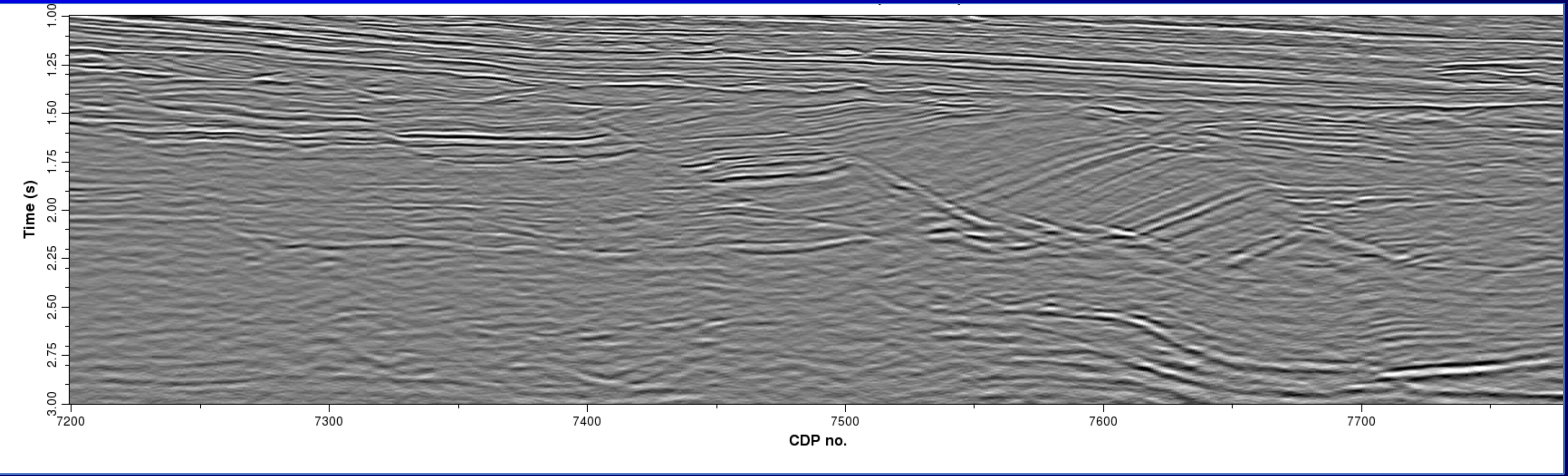


Nonparallelism computed in a 150 m radius by 80 ms vertical analysis aligned with the average structural dip.

(Chopra and Marfurt, 2024)

Mapping changes in dip across listric faults
(Land acquisition, northern Gulf of Mexico)

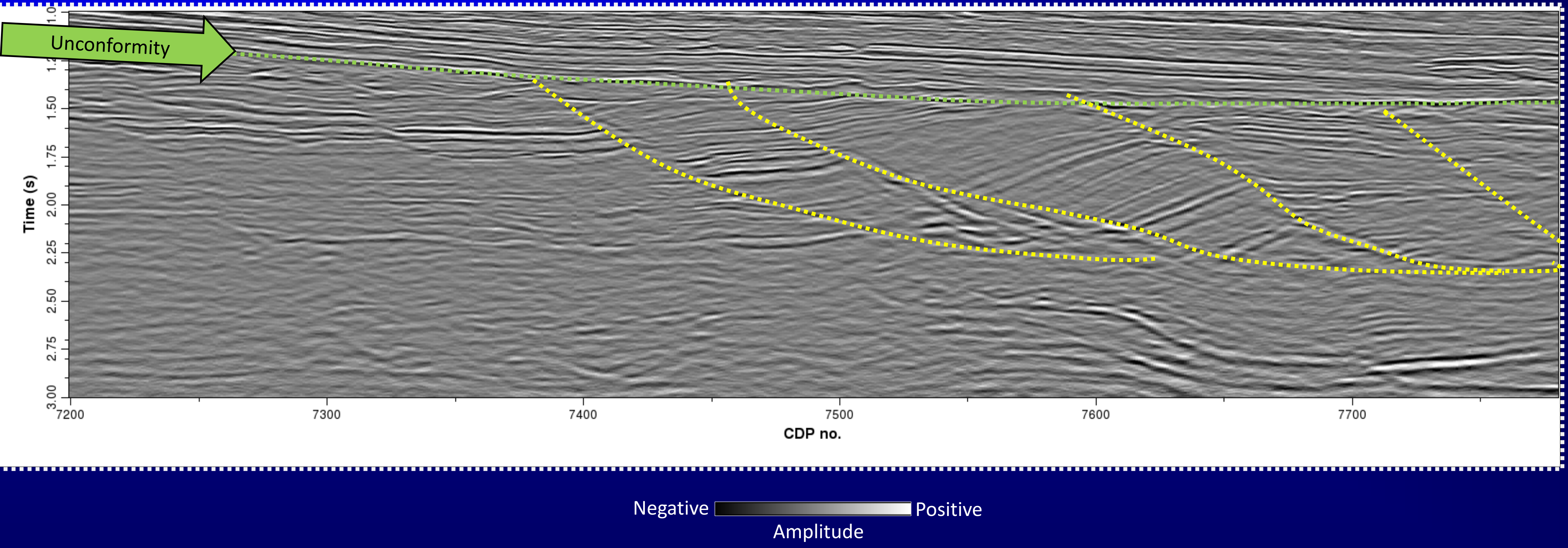
Seismic amplitude



Negative Positive
Amplitude

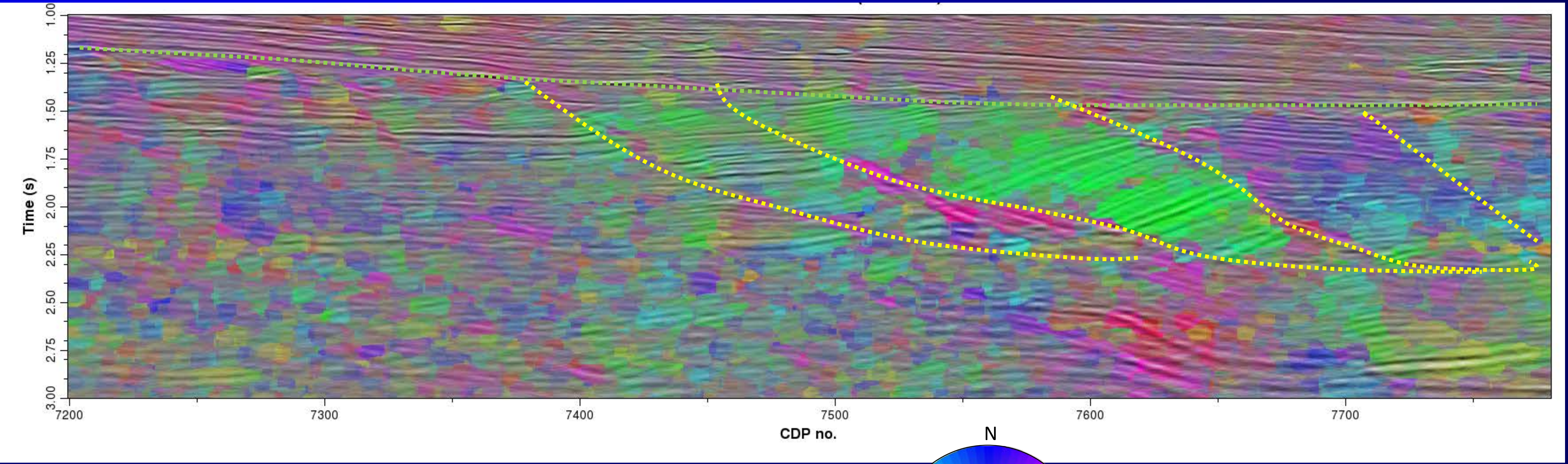
Mapping changes in dip across listric faults
(Land acquisition, northern Gulf of Mexico)

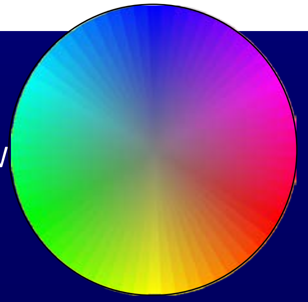
Seismic amplitude



Mapping changes in dip across listric faults
(Land acquisition, northern Gulf of Mexico)

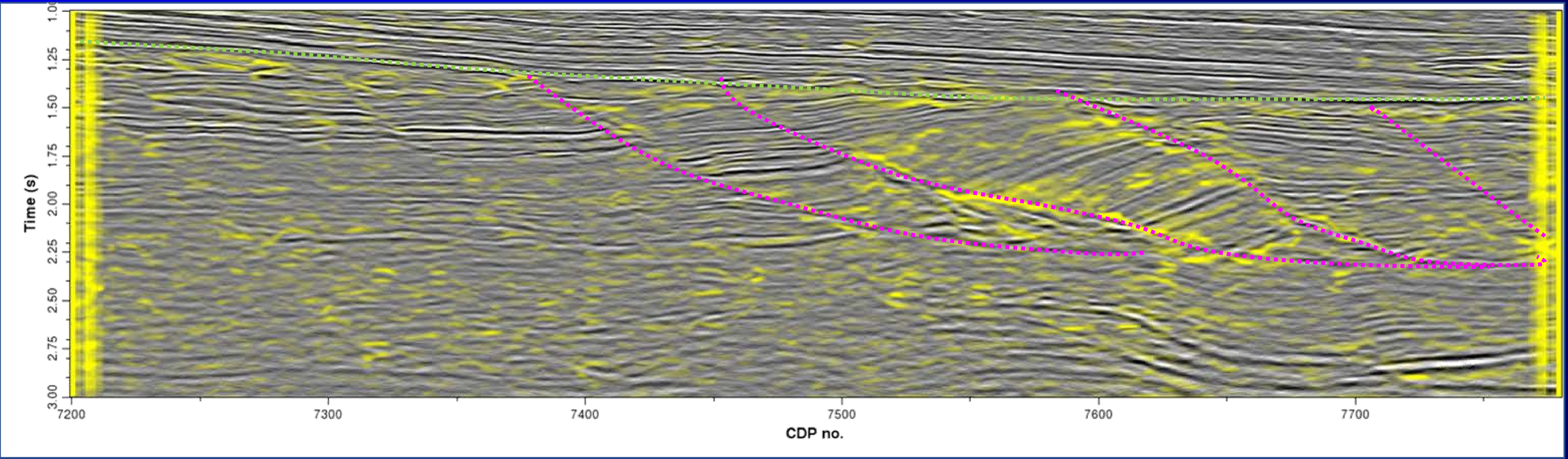
Vector dip corendered with amplitude





Mapping changes in dip across listric faults
(Land acquisition, northern Gulf of Mexico)

Reflector convergence magnitude corendered with amplitude



Nonparallelism and reflector convergence

In Summary:

- The reflector convergence vector measures the intensity and orientation of pinchouts and can be used to map reflector configurations associated with progradations, lateral changes in accommodation space, channel fill, levees, fans, and angular unconformities
- Nonparallelism provides a statistical measure as to whether the bedding within an analysis window are conformal, contorted, or even random
- Nonparallelism provides limited value in interactive interpretation but is quite useful in machine learning driven facies classification