3D Seismic Attributes for Prospect Identification and Reservoir Characterization

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Attribute Expression of Tectonic Deformation

Course Outline

Introduction
Complex Trace, Horizon, and Formation Attributes
Multiattribute Display
Spectral Decomposition

Geometric Attributes
Attribute Expression of Geology
- Tectonic Deformation
- Clastic Depositional Environments
- Carbonate Deposition Environments
- Shallow Stratigraphy and Drilling Hazards
- Igneous and Intrusive Reservoirs and Seals

Impact of Acquisition and Processing on Attributes
Attribute Prediction of Fractures and Stress
Data Conditioning
Inversion for Acoustic and Elastic Impedance
Image Enhancement and Object Extraction

Interactive Multiattribute Analysis
Statistical Multiattribute Analysis
Unsupervised Multiattribute Classification
Supervised Multiattribute Classification

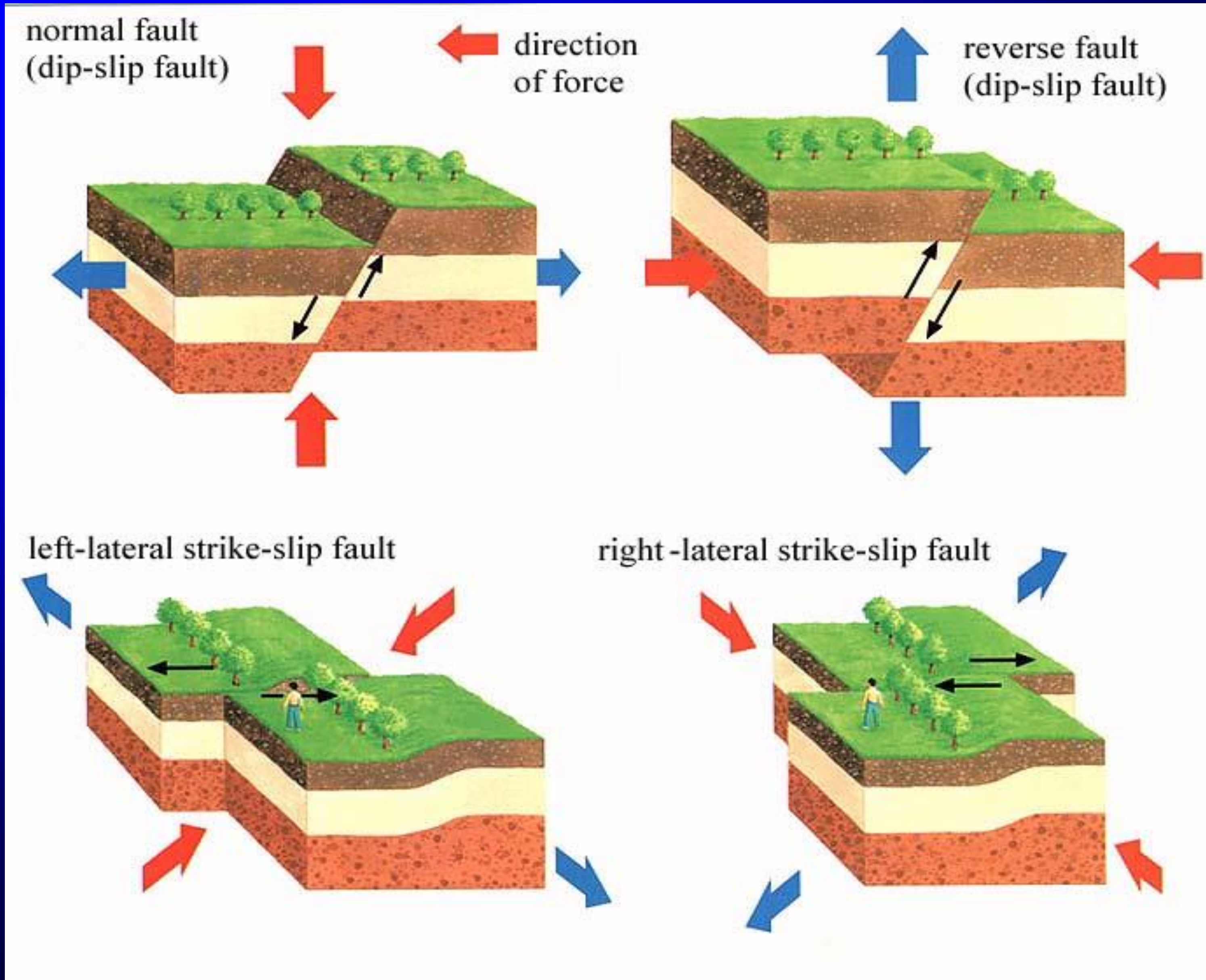
Attributes and Hydraulic Fracturing of Shale Reservoirs
Attribute Expression of the Mississippi Lime

Attribute expression of tectonic deformation

After this section you should be able to:

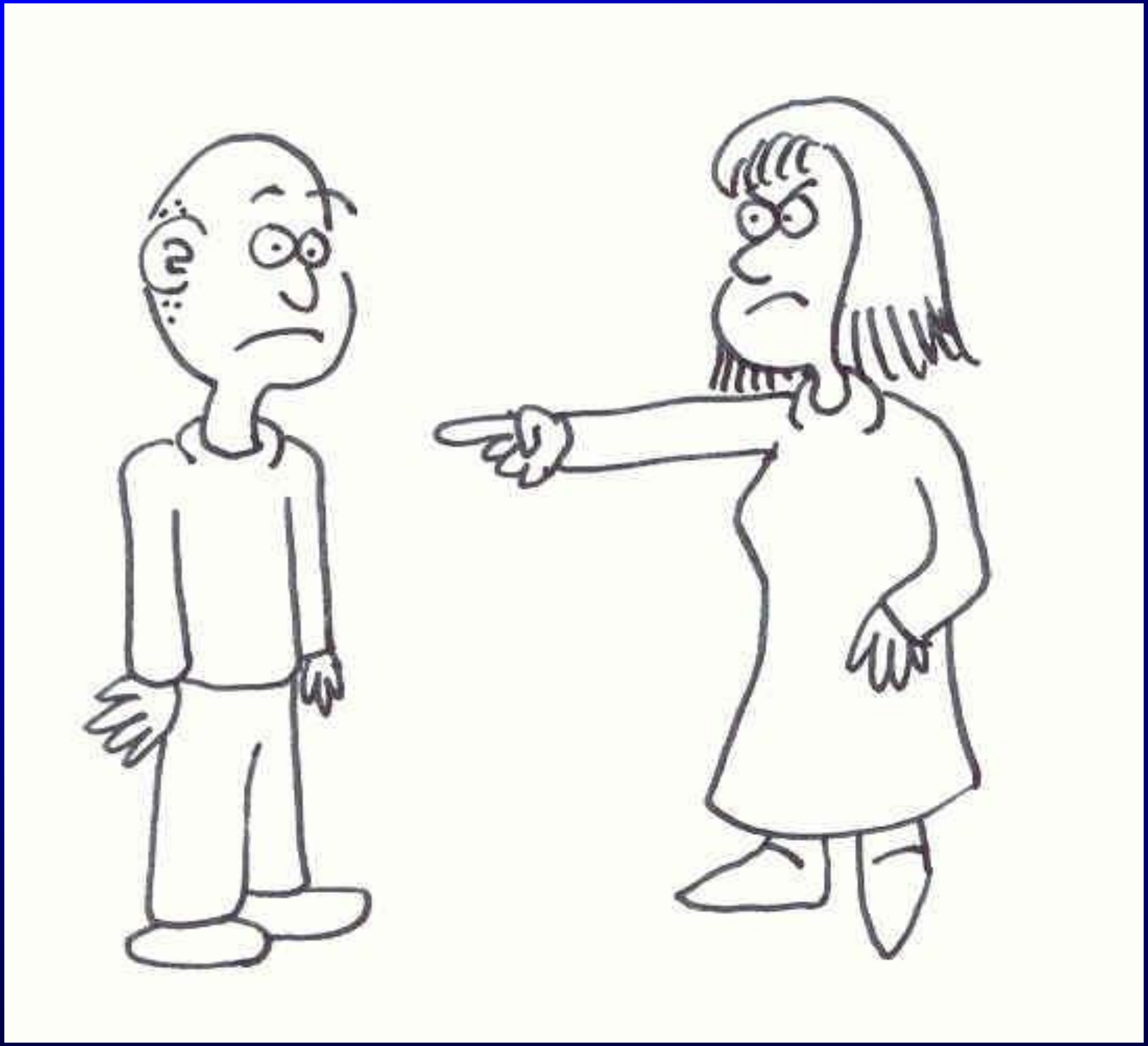
- Use coherence to accelerate the interpretation of faults on 3-D volumes,
- Use volumetric attributes to provide a preliminary interpretation across multiple surveys having different amplitude and phase,
- Identify the appearance and structural style of salt and shale diapirs on geometric attributes,
- Use curvature to define axial planes, and
- Use coherence and curvature as an aid to predicting fractures.

The three most important faults



(http://www.hp1039.jishin.go.jp/eqchreng/figures/af1-2.jpg)

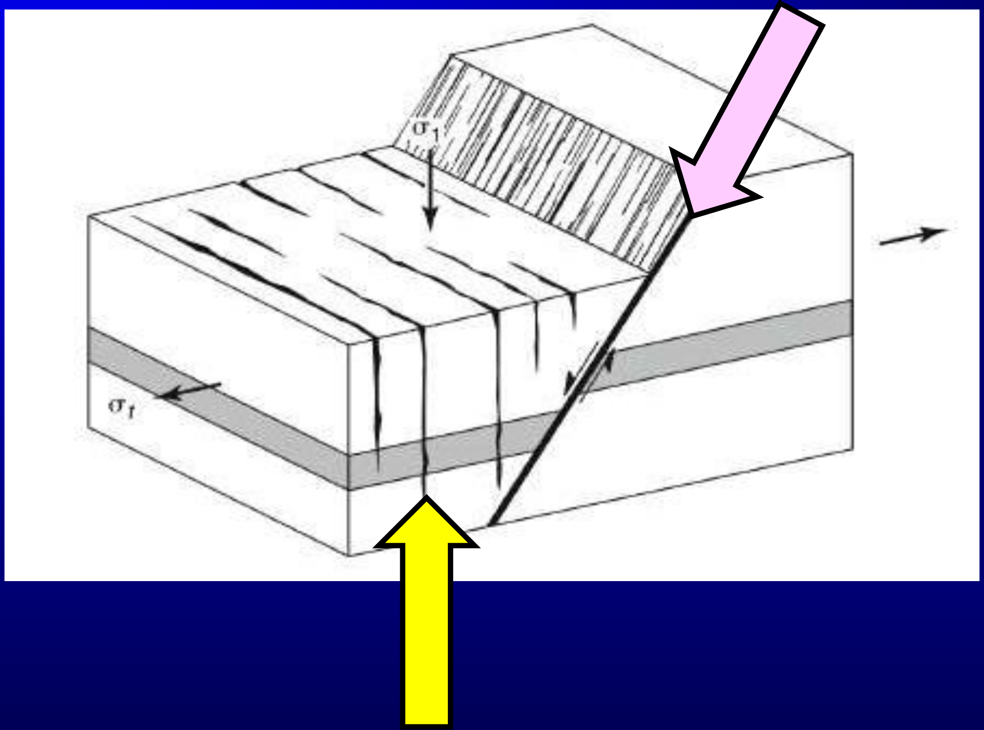
Review: the normal fault



(http://www.nvcc.edu/home/cbentley/geoblog/pix/normal_fault.jpg)

Faults and fractures on seismic data

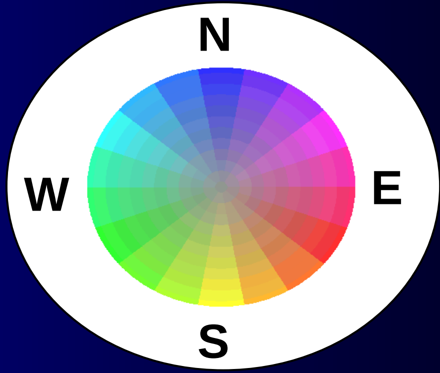
Reflector offset – seen on 3D seismic data

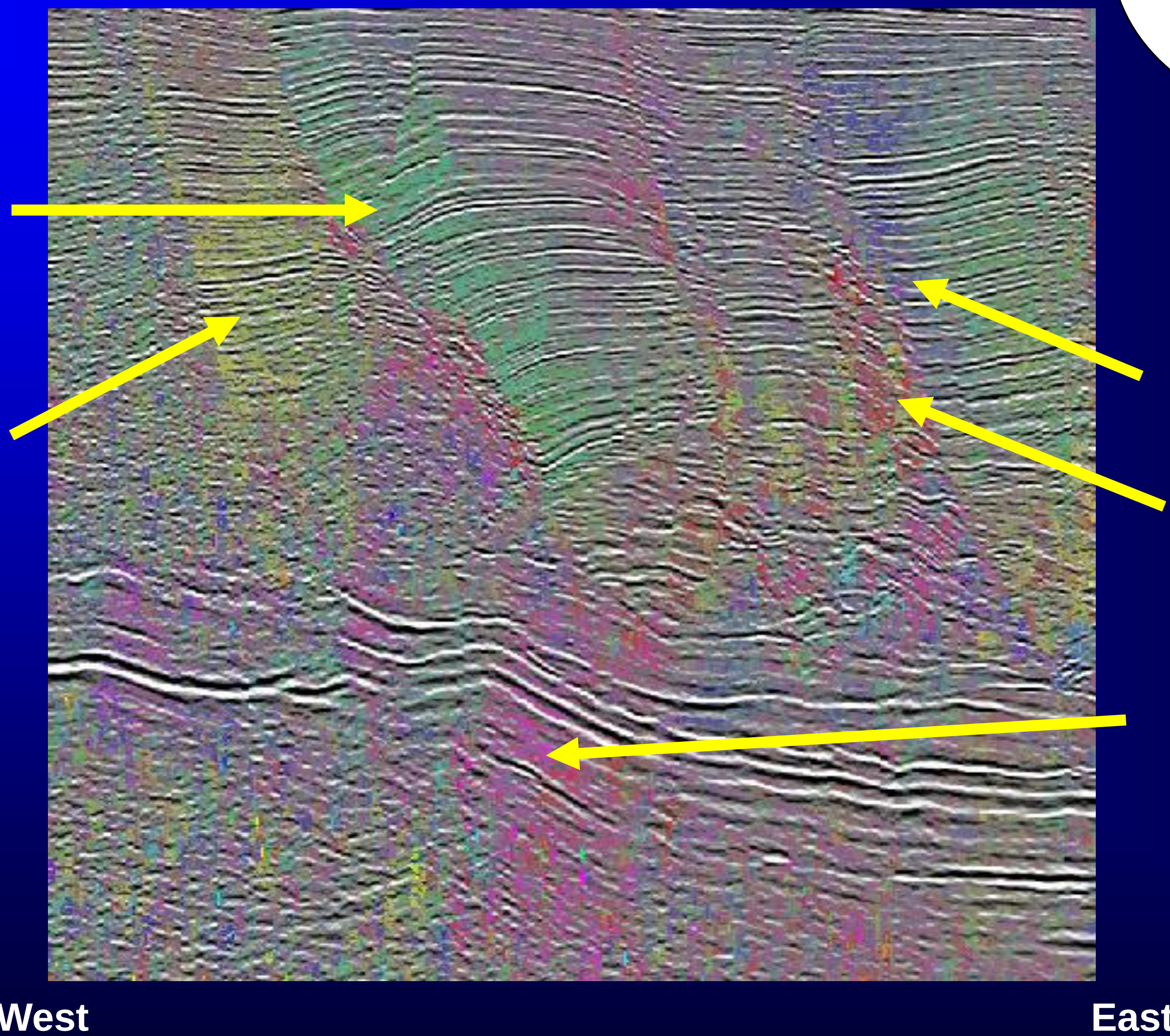


No reflector offset – probably *not* seen on 3D seismic data

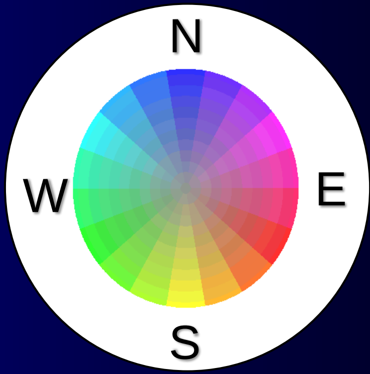
We *infer* fractures from knowledge of lithology and a structural deformation model

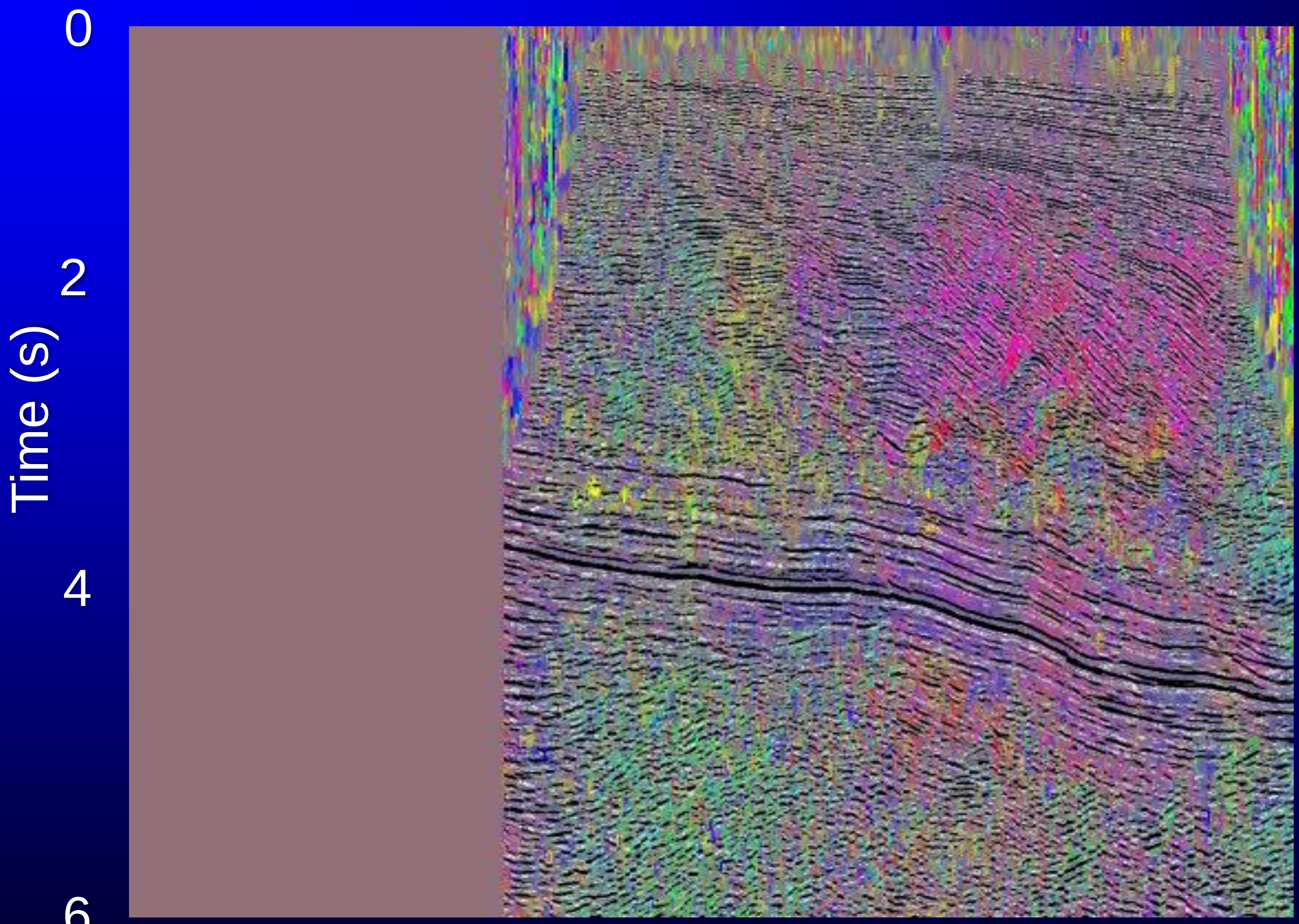
Growth faults, Gulf of Mexico





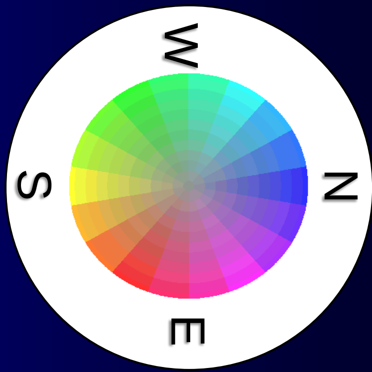
Growth faults, on-shore Gulf of Mexico (co-rendered with amplitude)

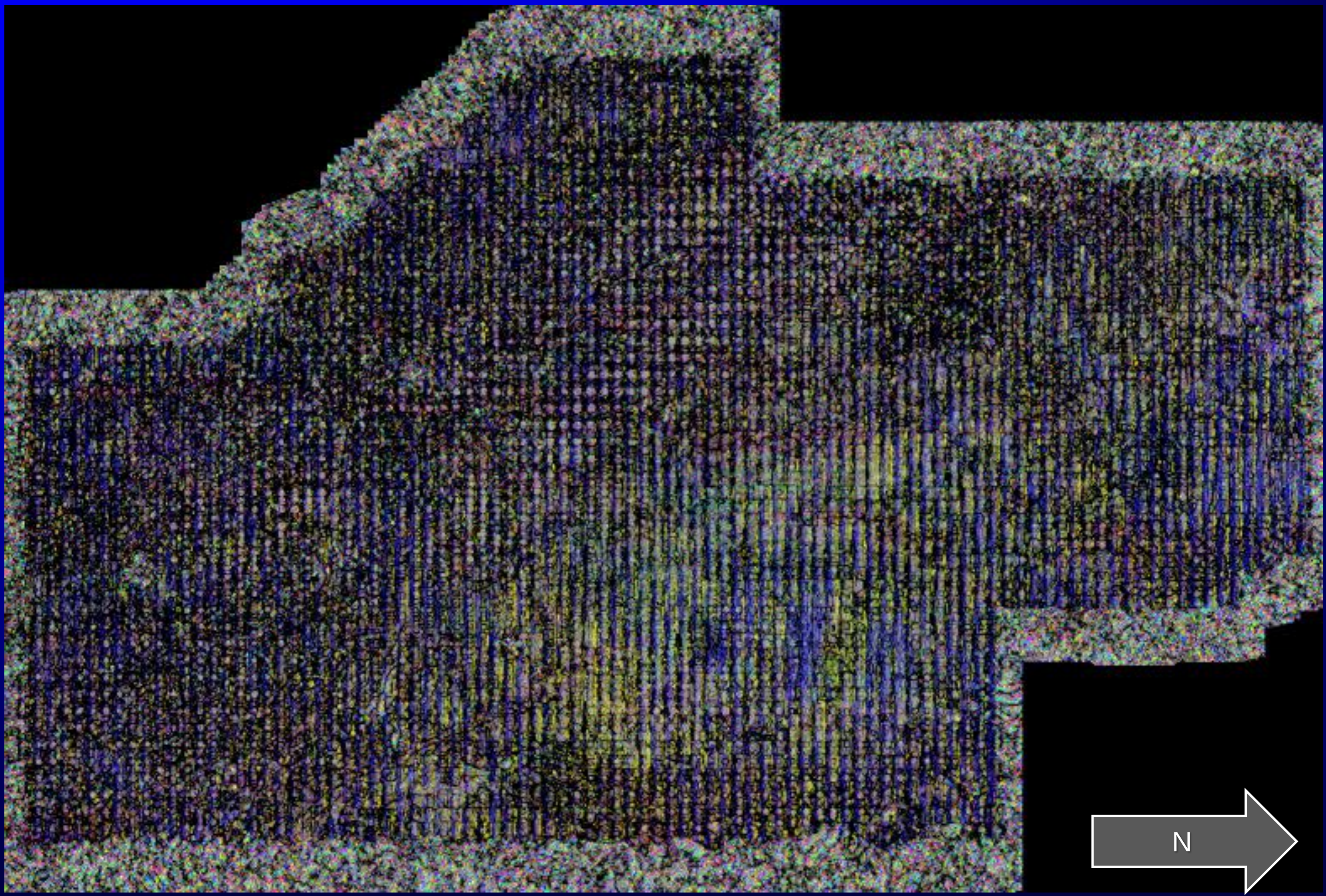




6a-8

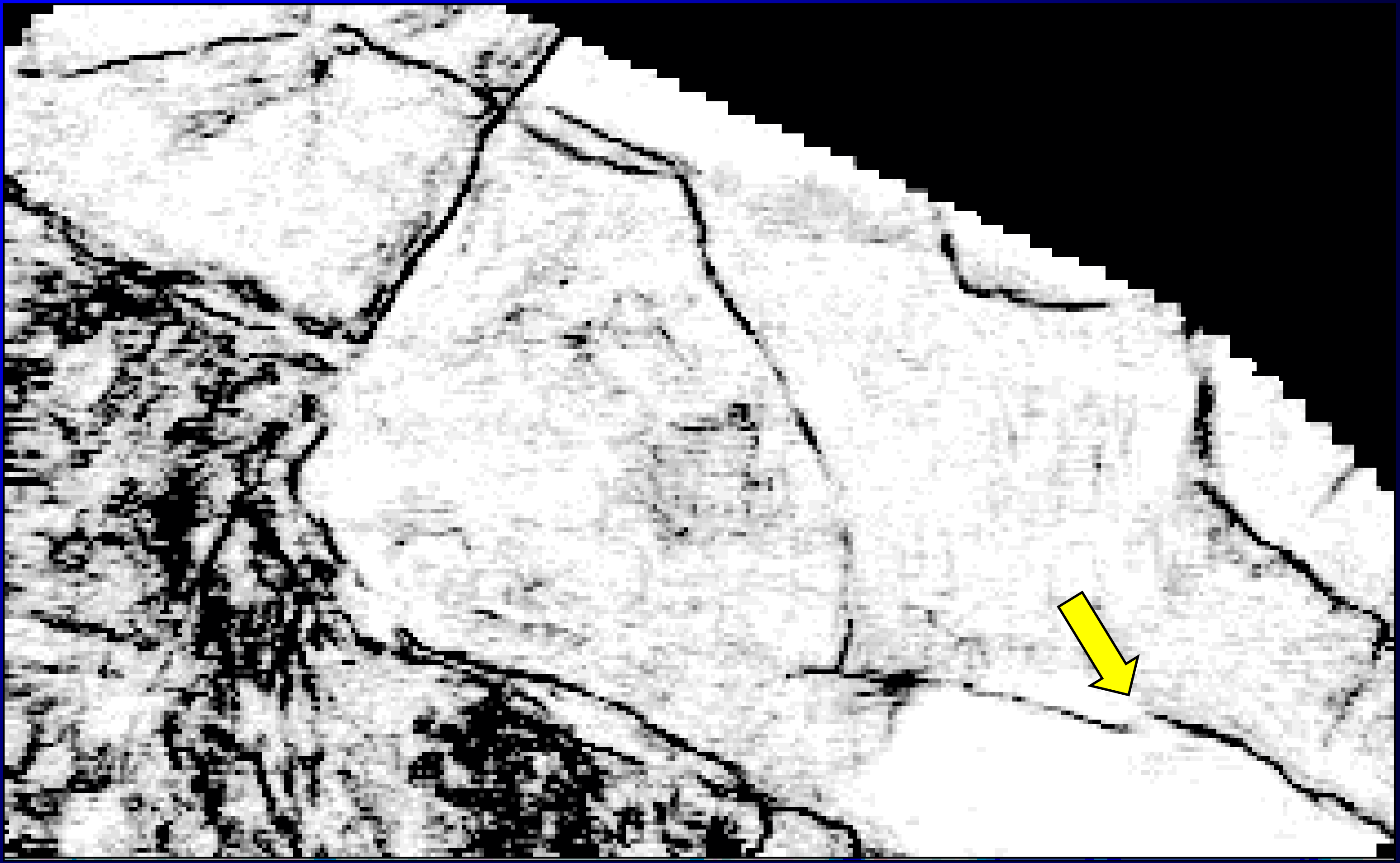
Growth faults, on-shore Gulf of Mexico (co-rendered with coherence)



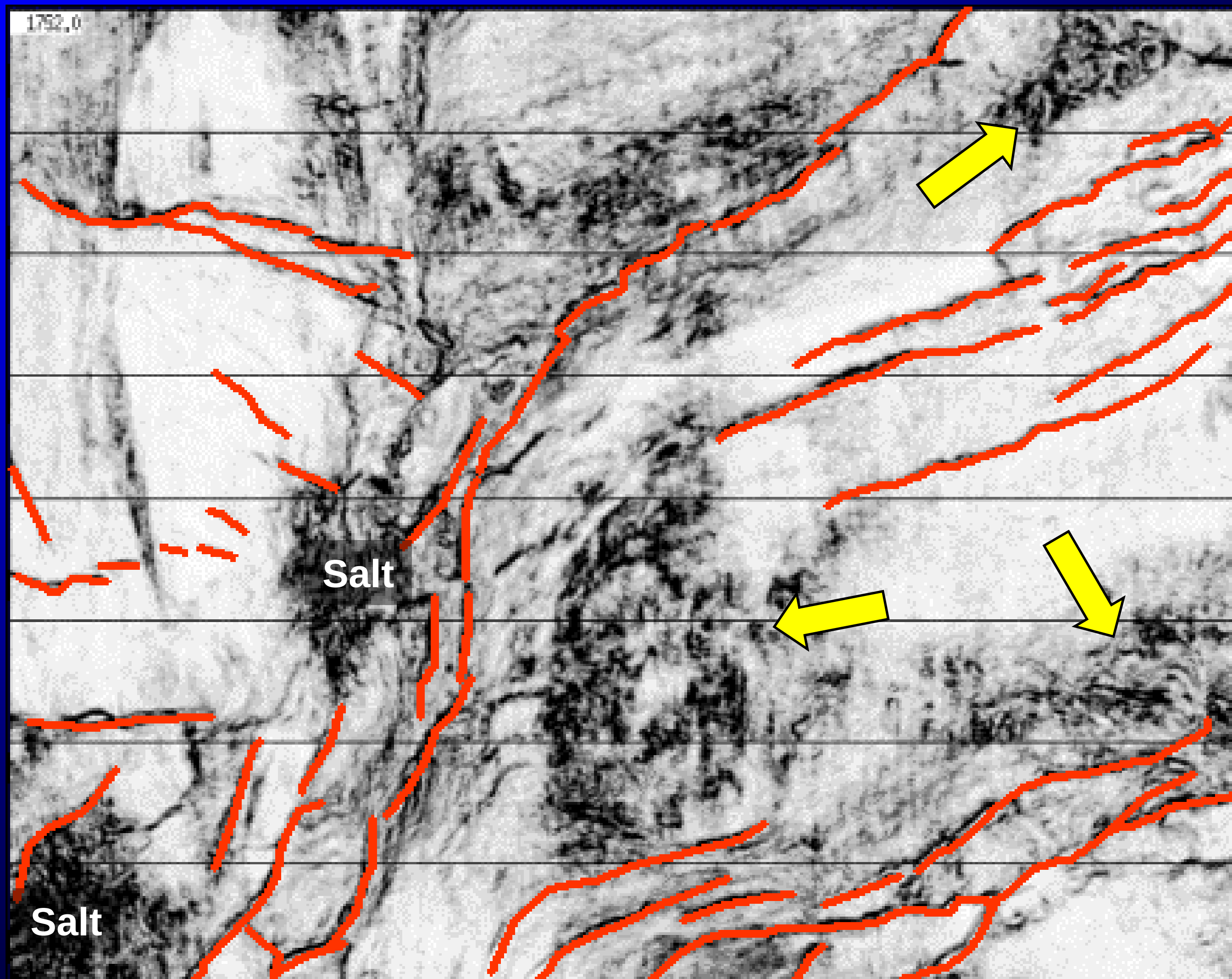


Time slices at 0.1 s increment

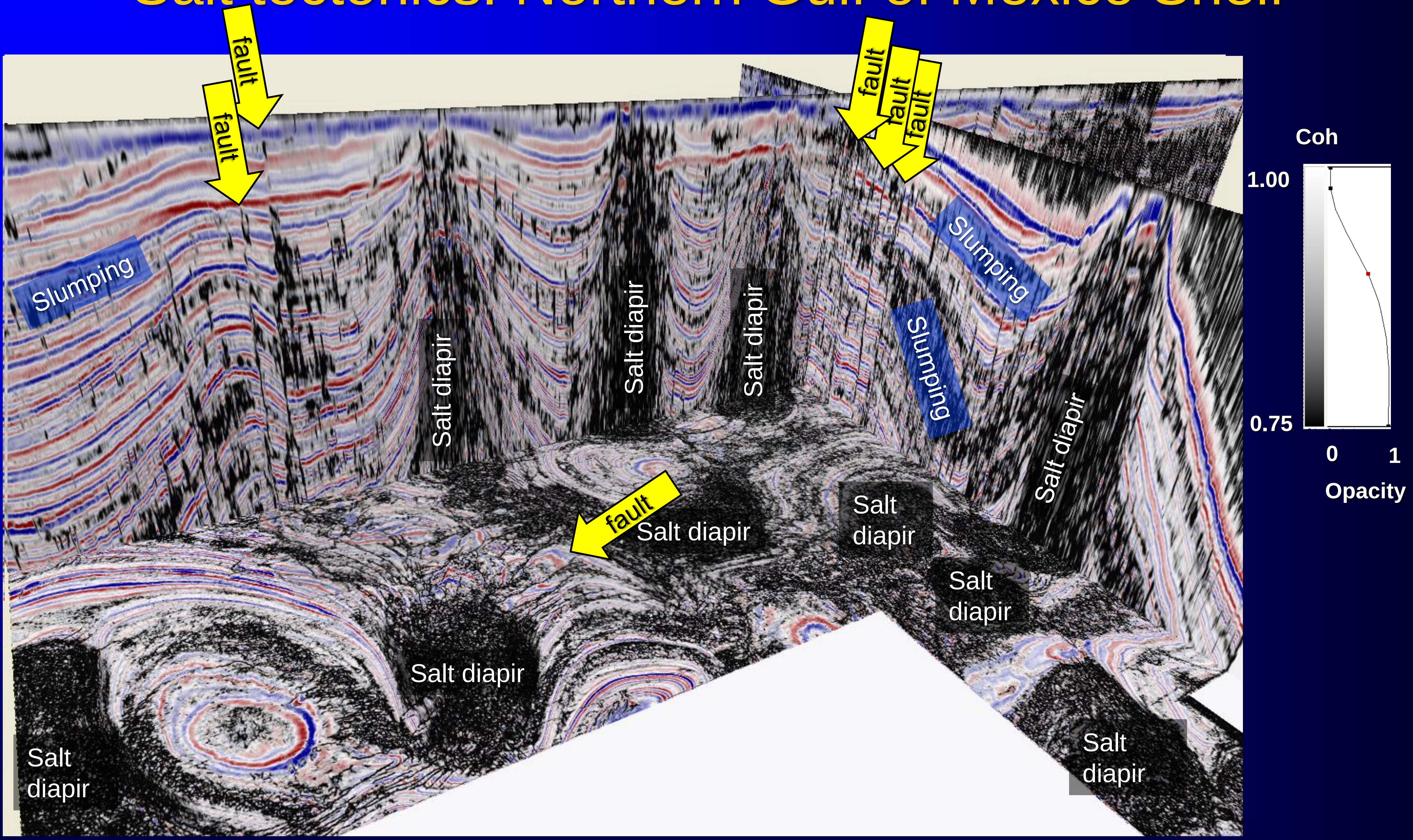
Identification of faults (Alberta, Canada)



Identification of faults (Gulf of Mexico, USA)



Salt tectonics. Northern Gulf of Mexico Shelf



(Data courtesy of PGS)

The first application of curvature to mapping fracture-enhanced production: the Bakken formation!

1968

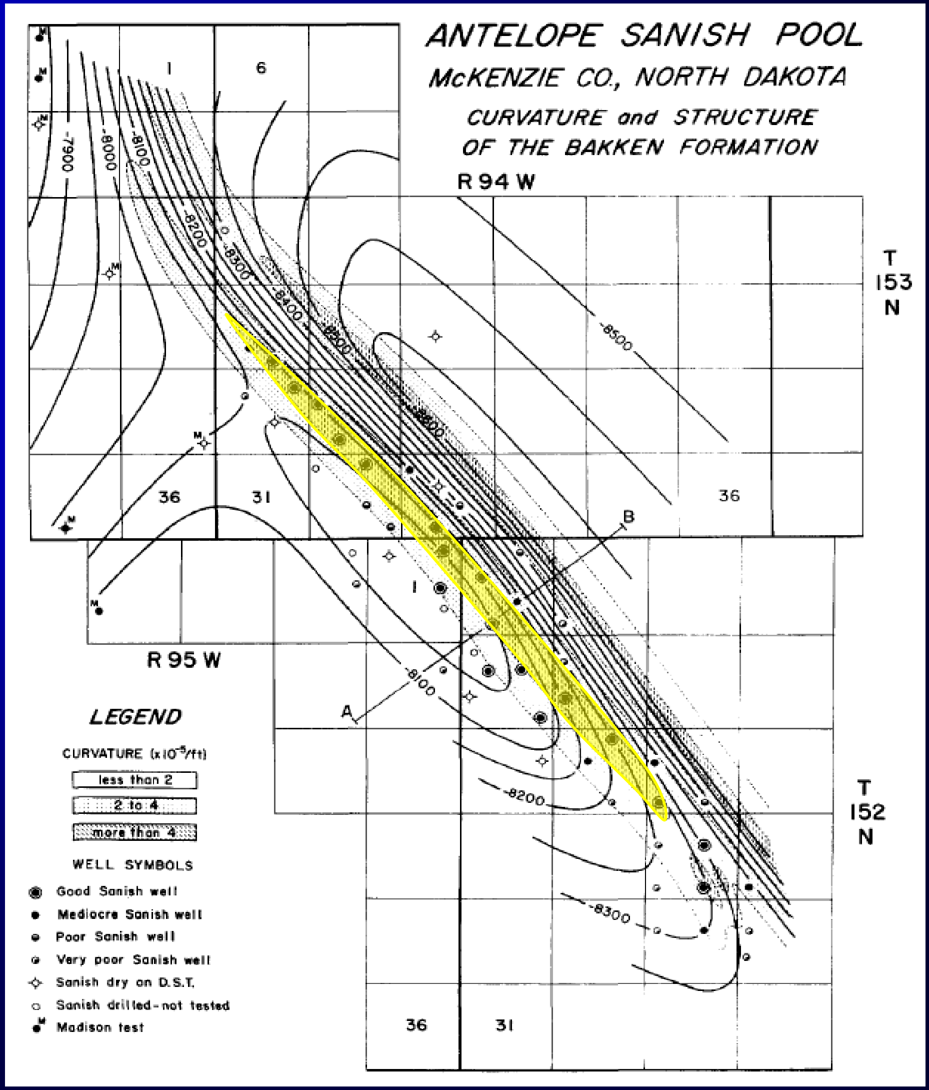
THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS BULLETIN
VOL. 52, NO. 1 (JANUARY, 1968), P. 57-65, 5 FIGS., 1 TABLE

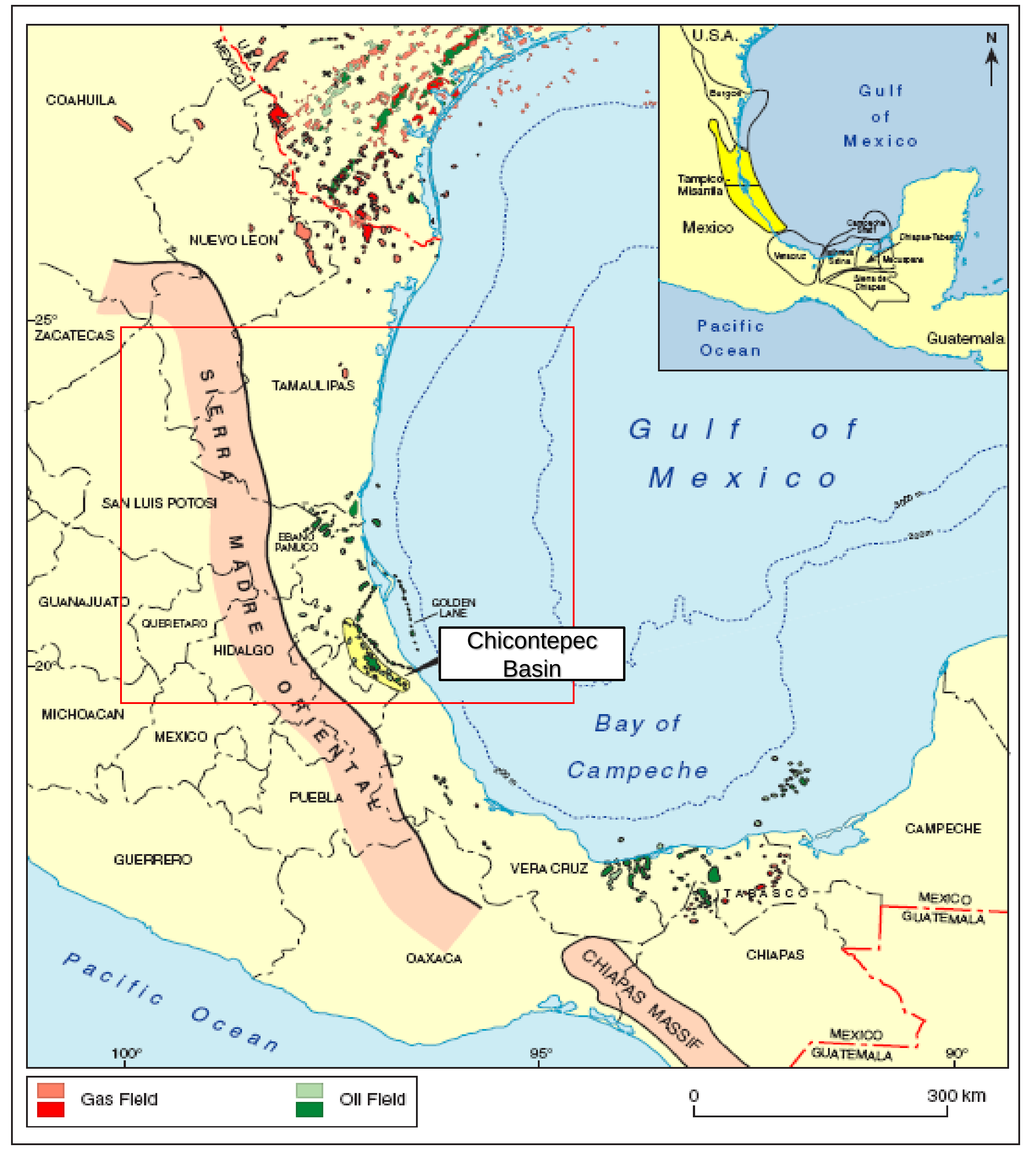
QUANTITATIVE FRACTURE STUDY—SANISH POOL, McKENZIE COUNTY, NORTH DAKOTA[1]

GEORGE H. MURRAY, JR.[2]
Billings, Montana 59102

ABSTRACT

The Dev· ·ian Sanish pool of the Antelope field has several unusual characteristics which make it almost ur· · in the Williston basin. Some of these are: (1) high productivity of several wells from a nebulou· ·fined reservoir; (·) association with the steepest dip in the central part of the basi· (3) ver· ·ial reservoir p· ·ure; · · (4) almost complete absence of water produ· ·ish productivity is a fun· ·n of





Attribute expression of complex structure: the Chincontepec Basin, Mexico.

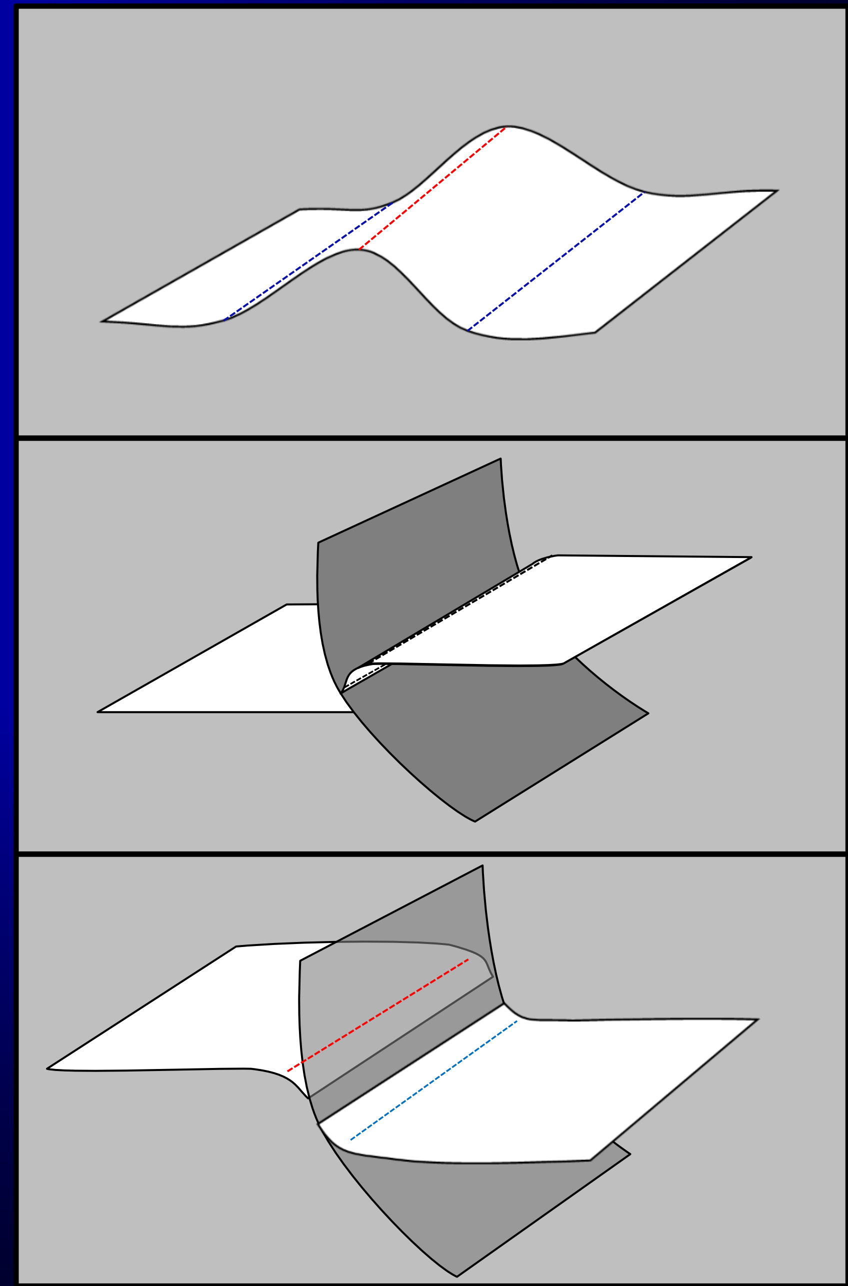
(Salvador, 1991)

Attribute expression of some common structural features

Folds

Reverse faults

Normal faults



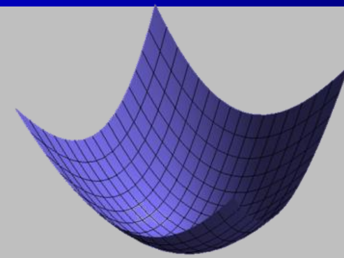
(Mai et al., 2009a)

Definition of shape index, s

$$s = -\frac{2}{\pi}\,\mathbf{ATAN}\left(\frac{k_2 + k_1}{k_2 - k_1}\right)$$

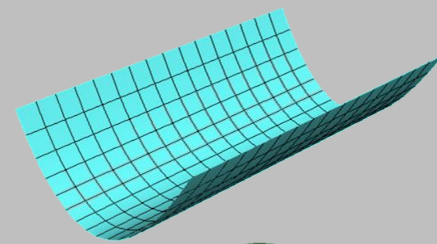
$$k_1 \geq k_2$$

Principal curvatures



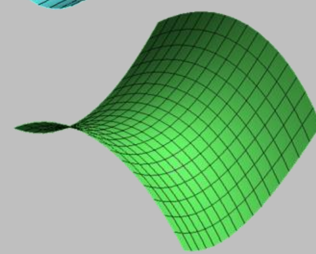
s=-1.0 **Bowl**

$k_1 < 0$ and $k_2 < 0$



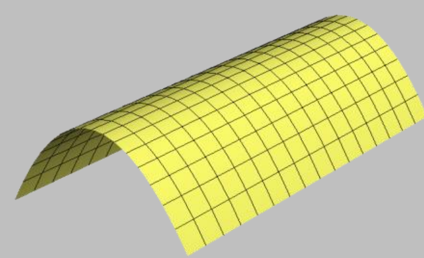
s=-0.5 **Valley**

$k_1 = 0$ and $k_2 < 0$



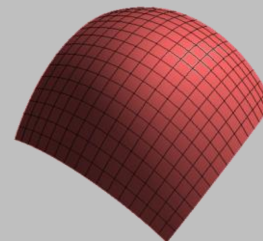
s=0.0 **Saddle**

$k_1 > 0$ and $k_2 < 0$



s=+0.5 **Ridge**

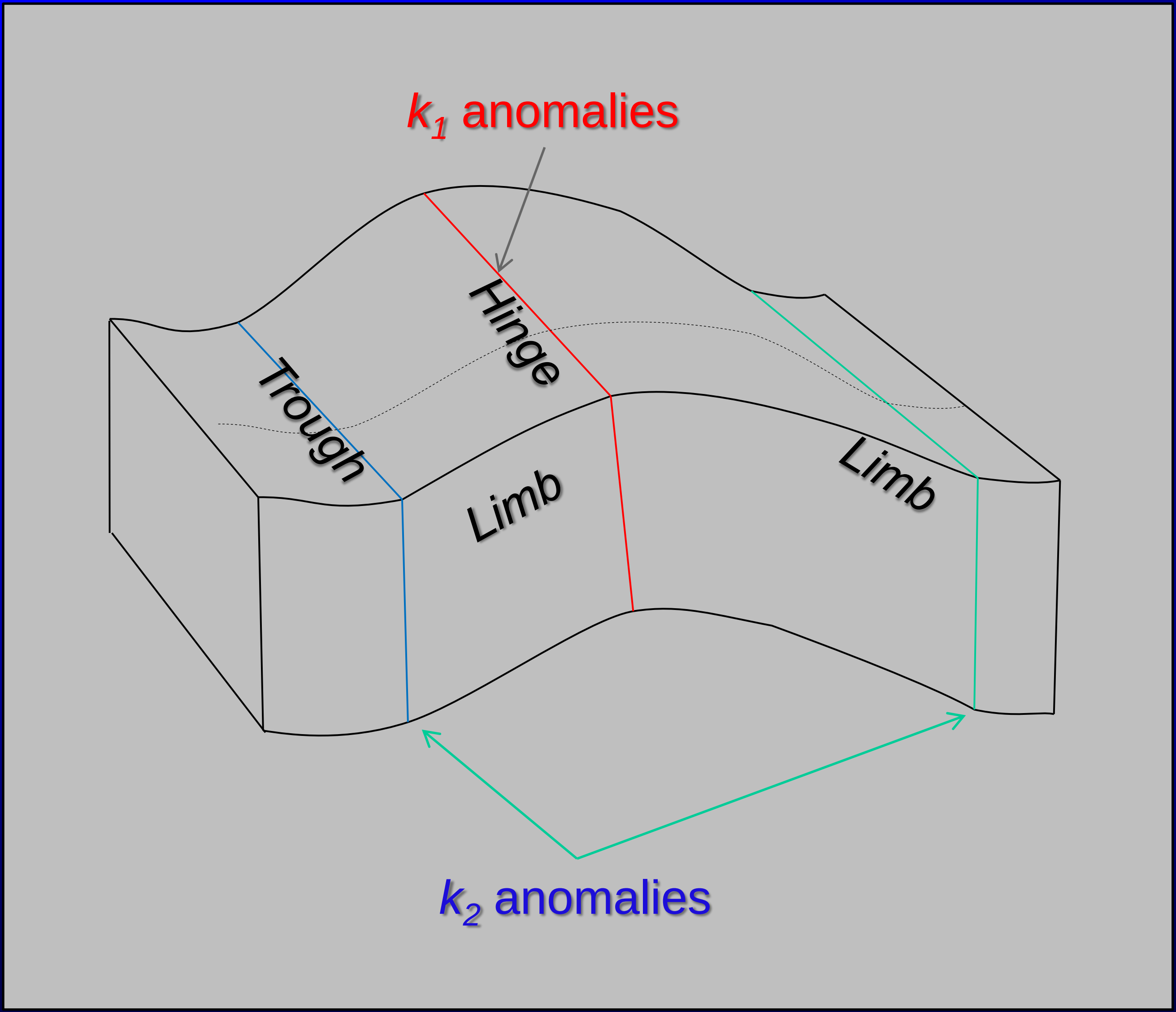
$k_1 > 0$ and $k_2 = 0$



s=+1.0 **Dome**

$k_1 > 0$ and $k_2 > 0$

Fold - Anticline

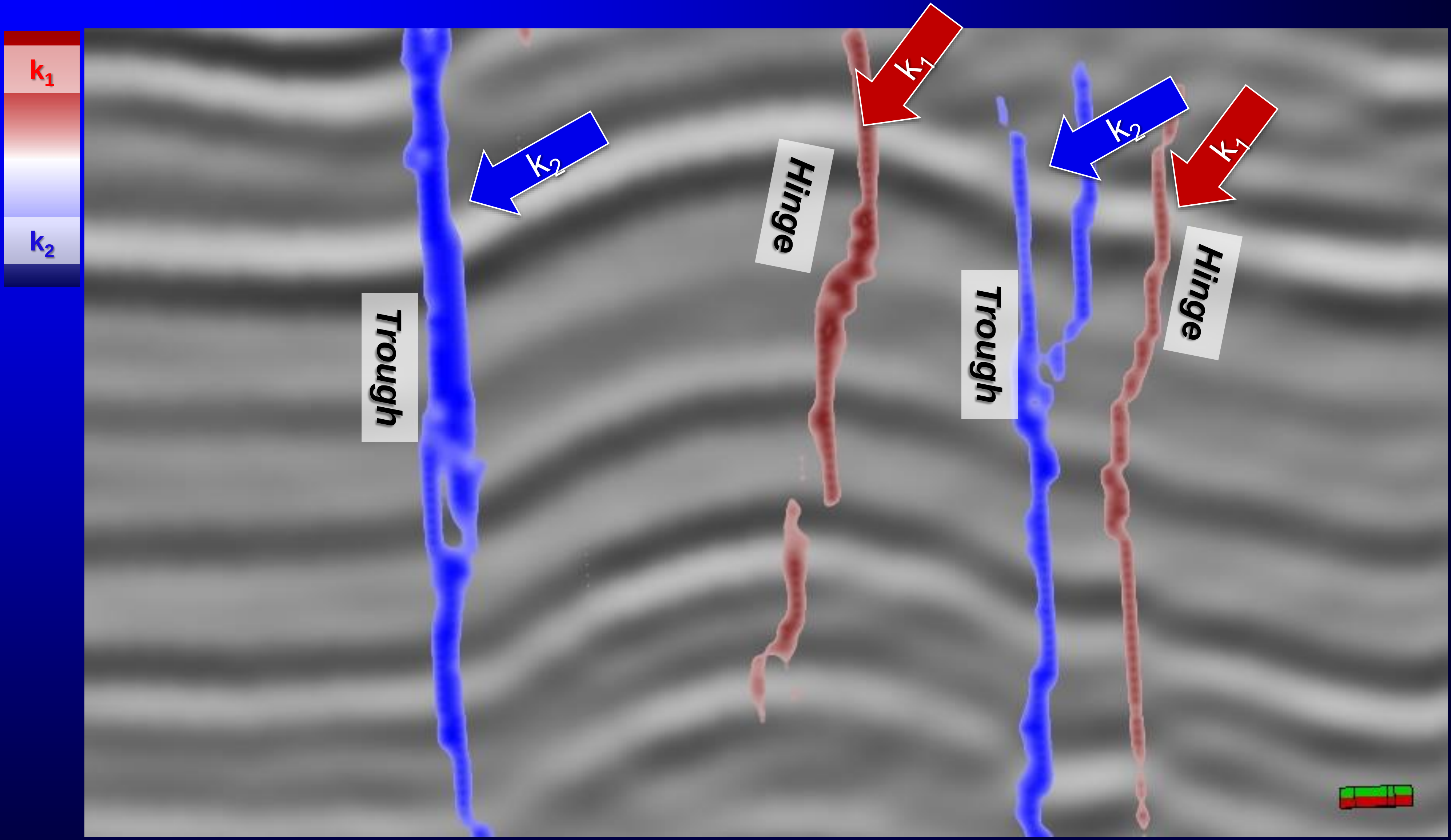


The k_2 most-negative principal curvature features (blue) delineate the two limbs of the fold.

The k_1 most-positive principal curvature (red) delineate the axial plane. There are no significant coherence anomalies.

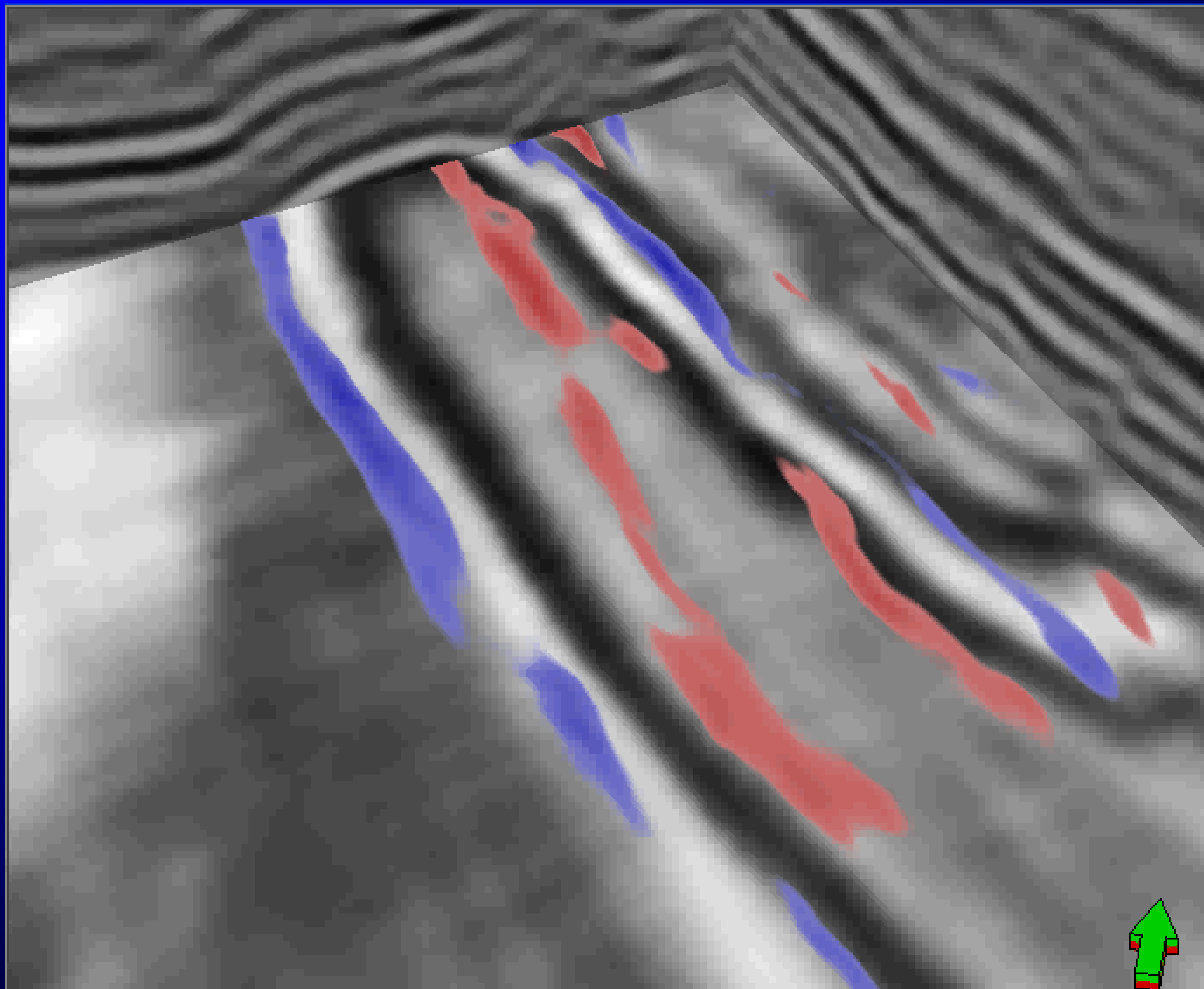
(Mai et al., 2009)

Anticlinal feature



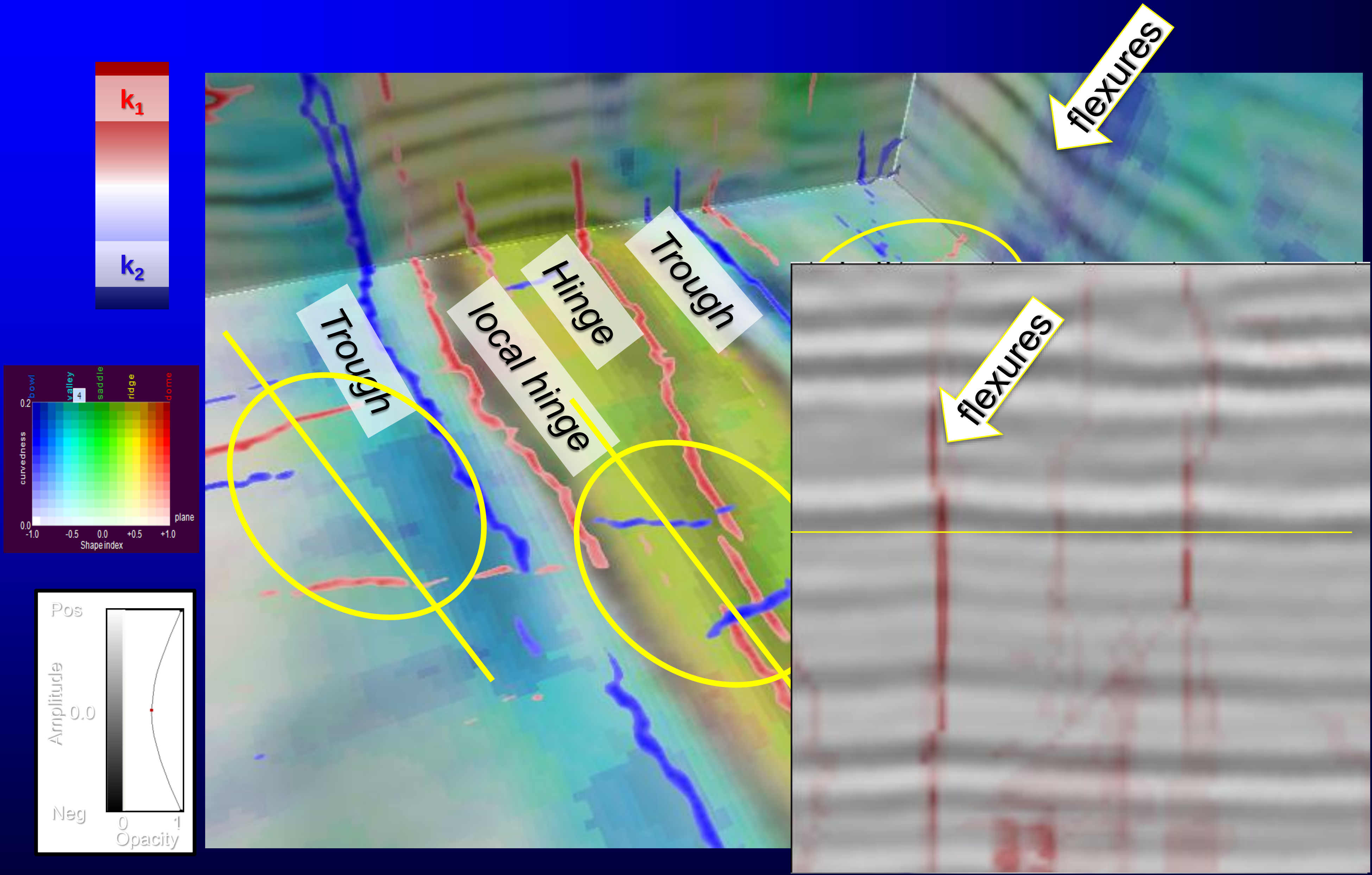
(Mai et al., 2009a)

Anticlinal feature



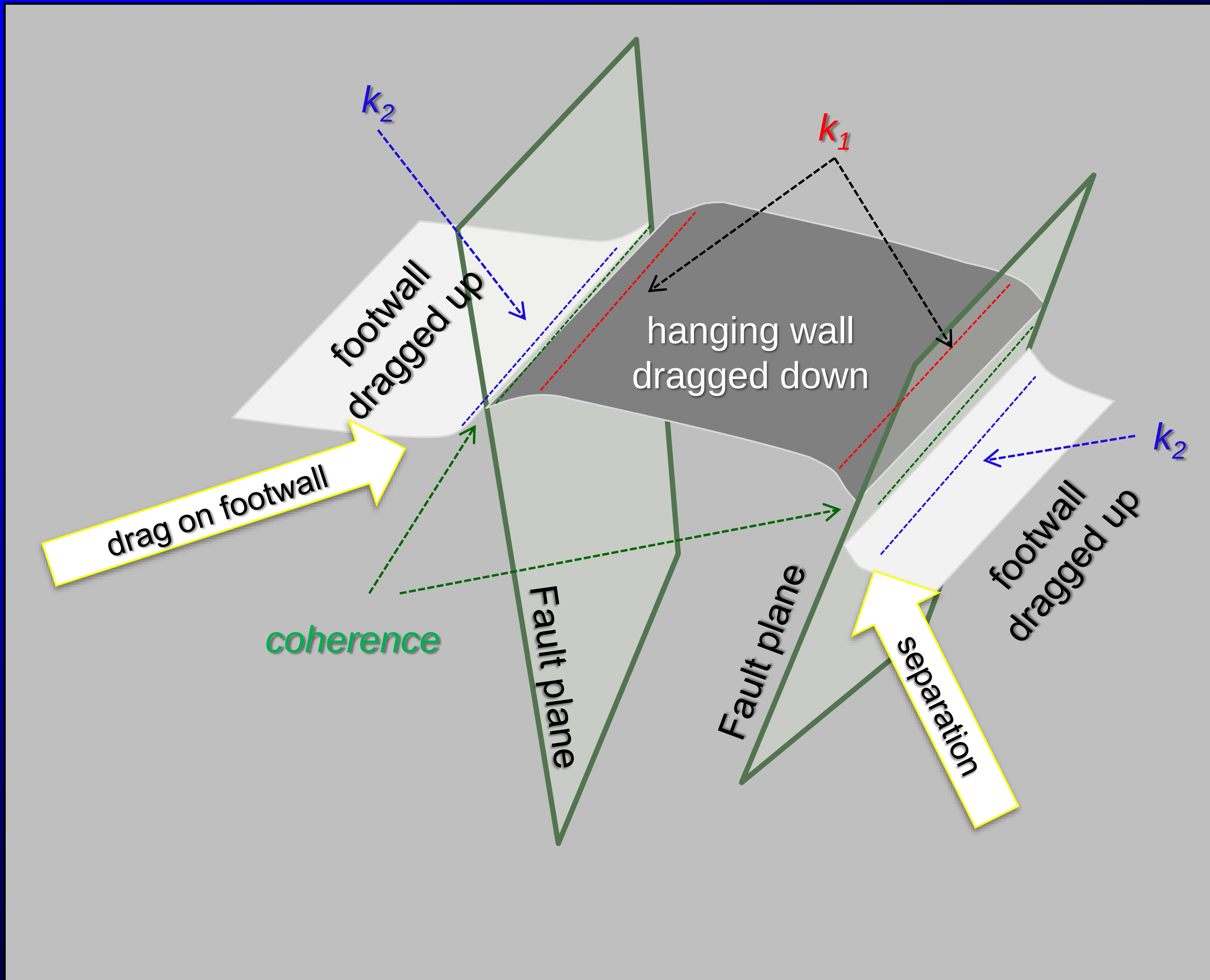
(Mai et al., 2009a)

Anticlinal feature



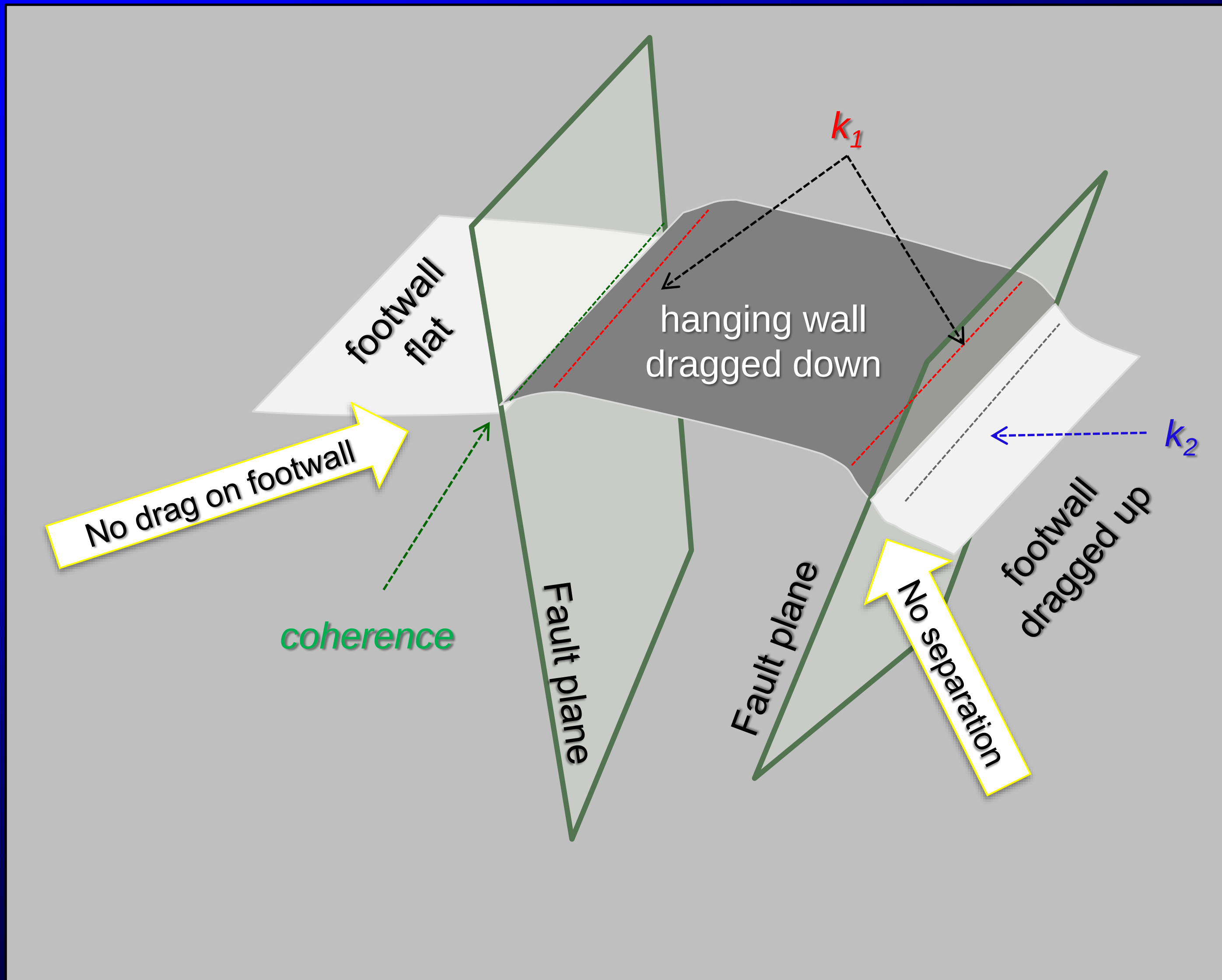
(Mai et al., 2009a)

Reverse fault feature – case1



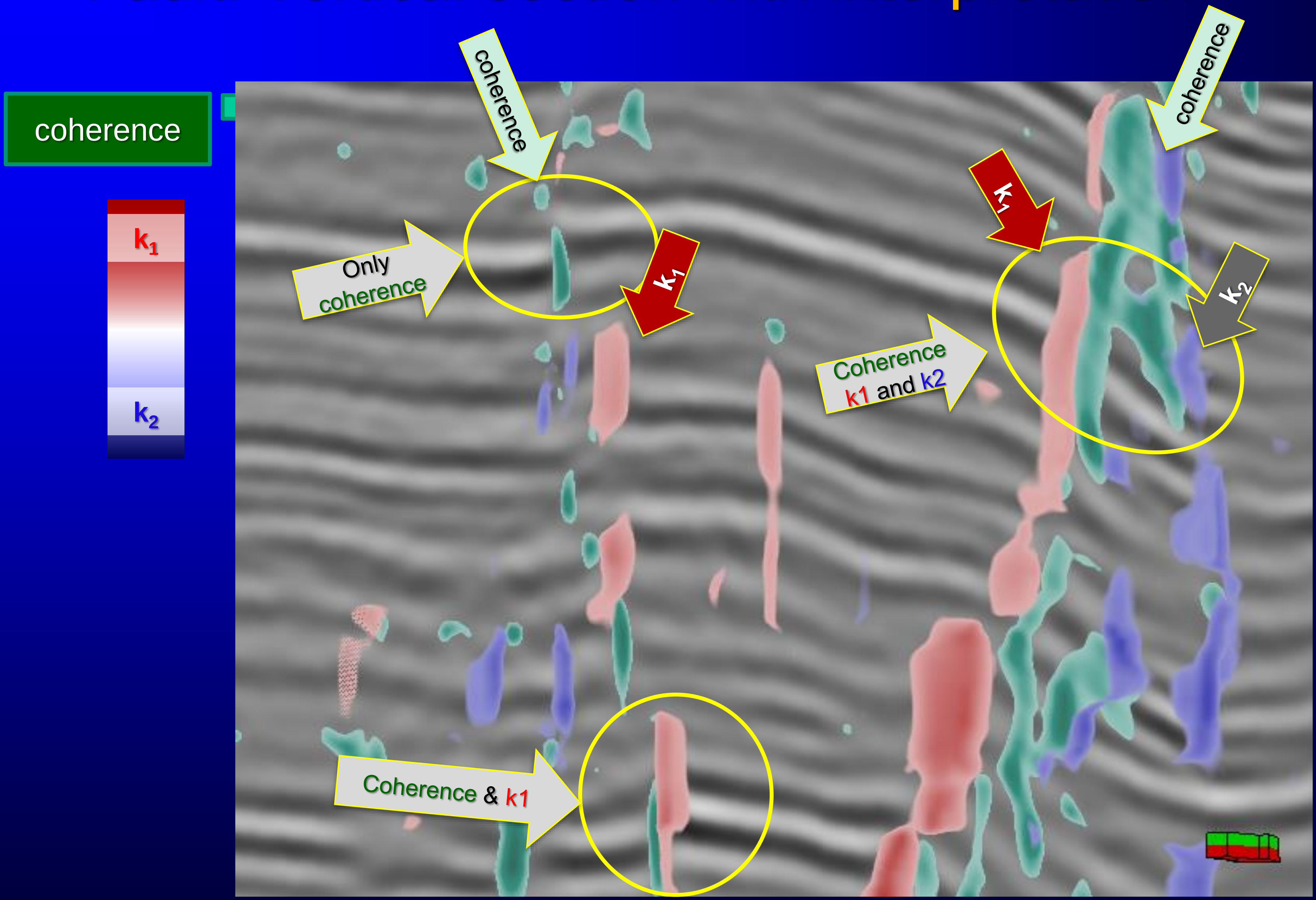
(Mai et al., 2009a)

Reverse fault feature – case 2



(Mai et al., 2009a)

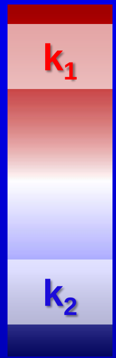
Fault: Vertical section with interpretation

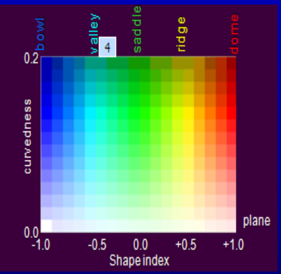


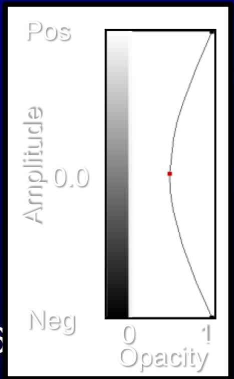
(Mai et al., 2009a)

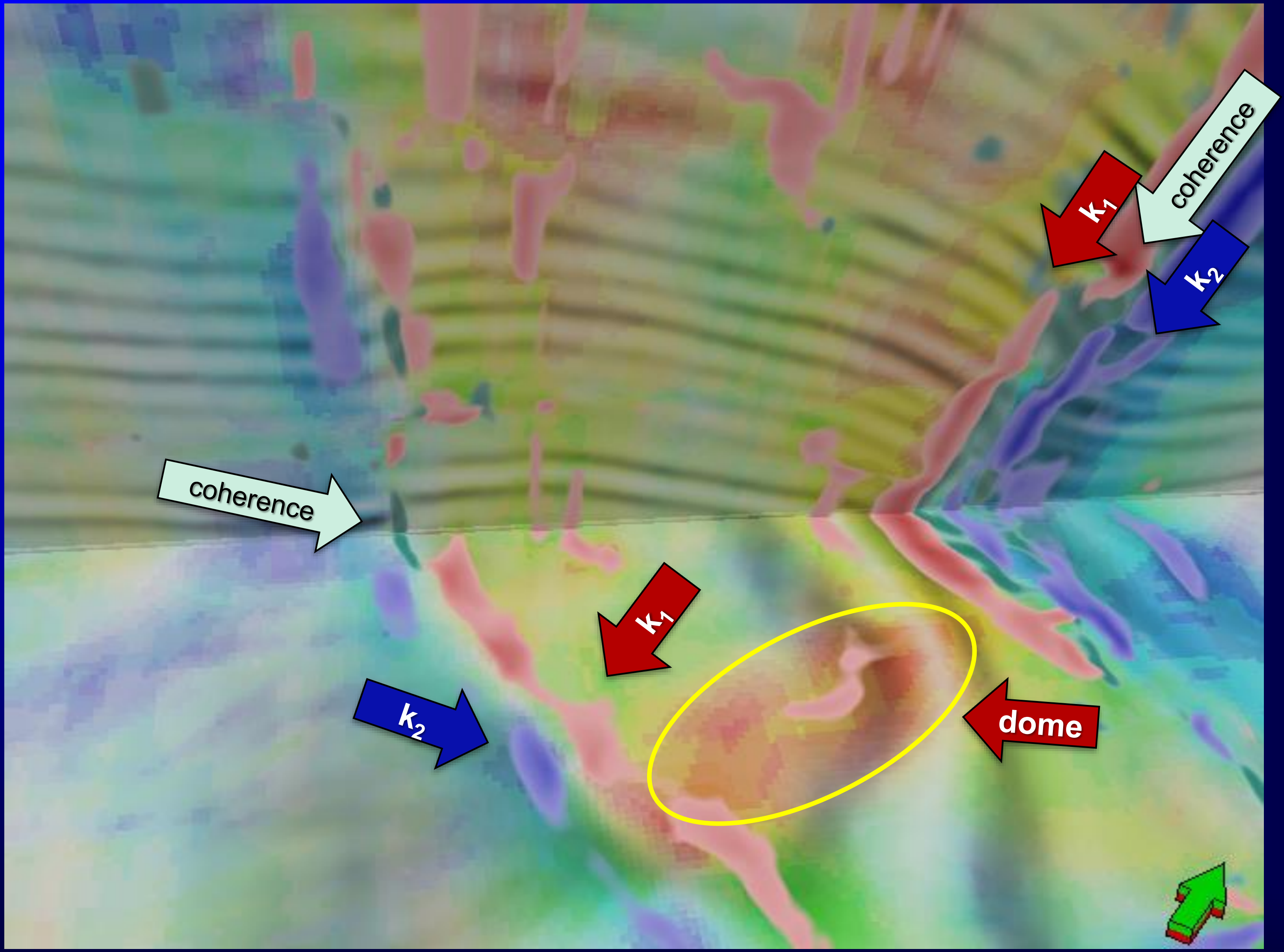
Fault: Seismic volume with interpretation

coherence



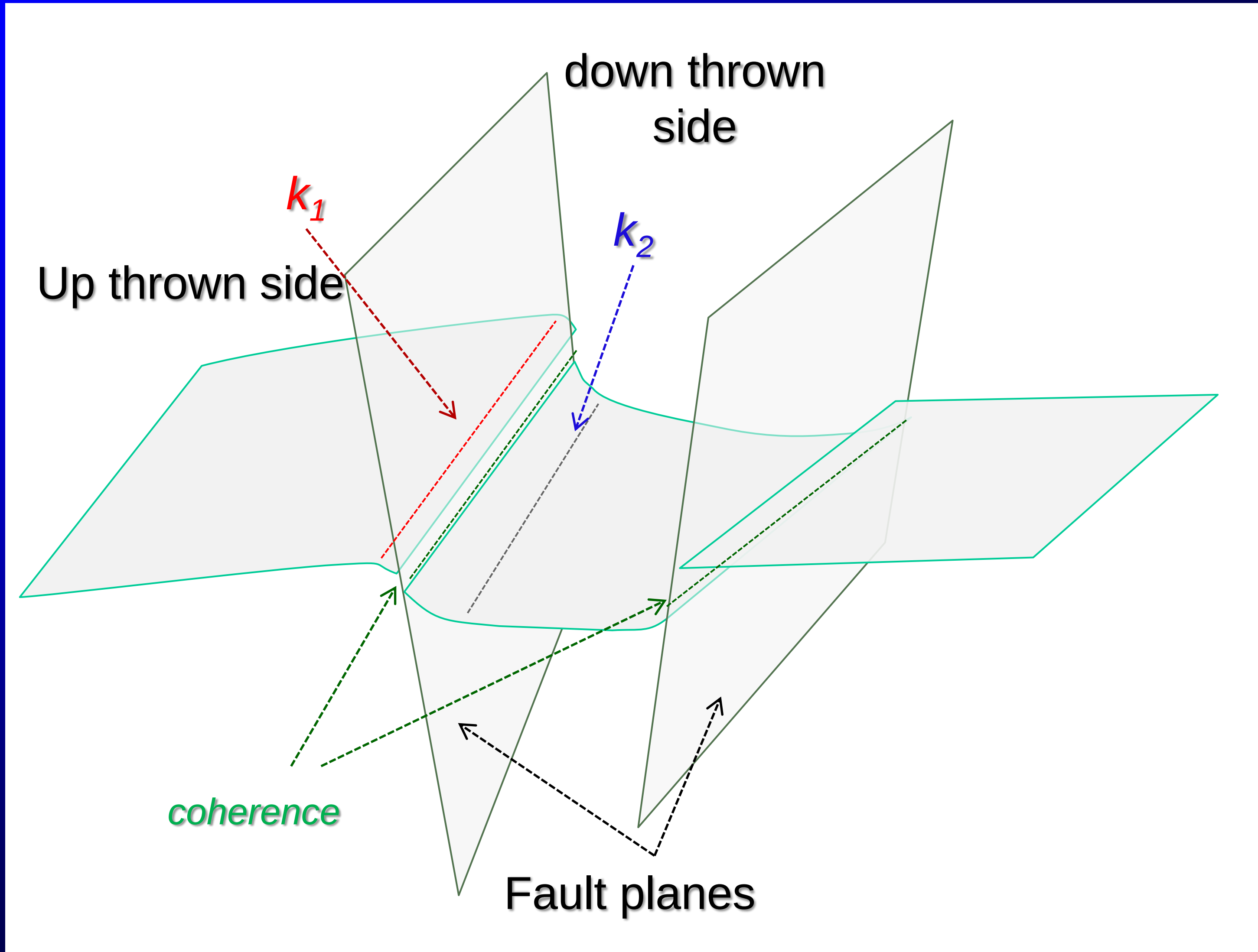






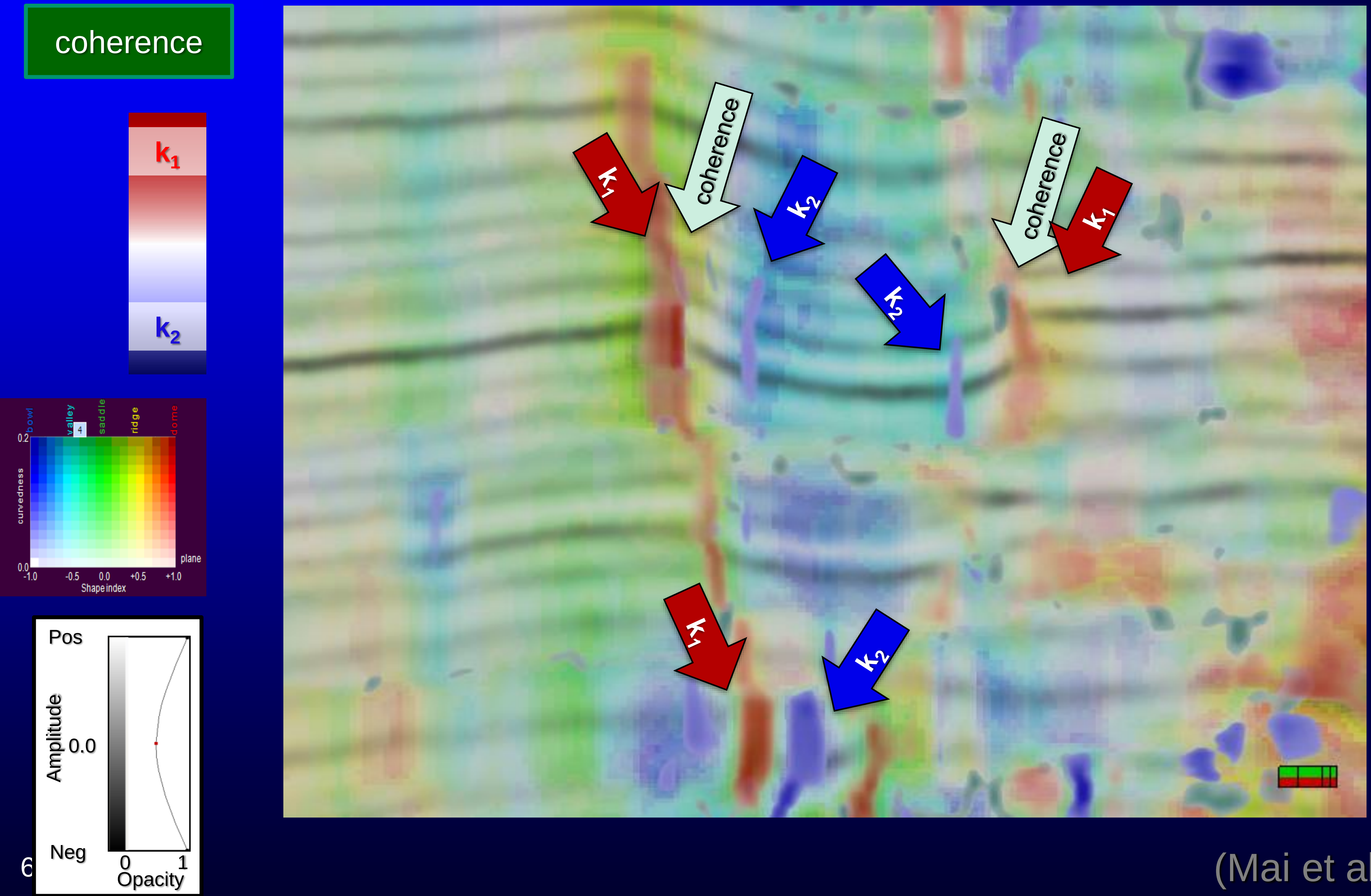
(Mai et al., 2009a)

Normal fault



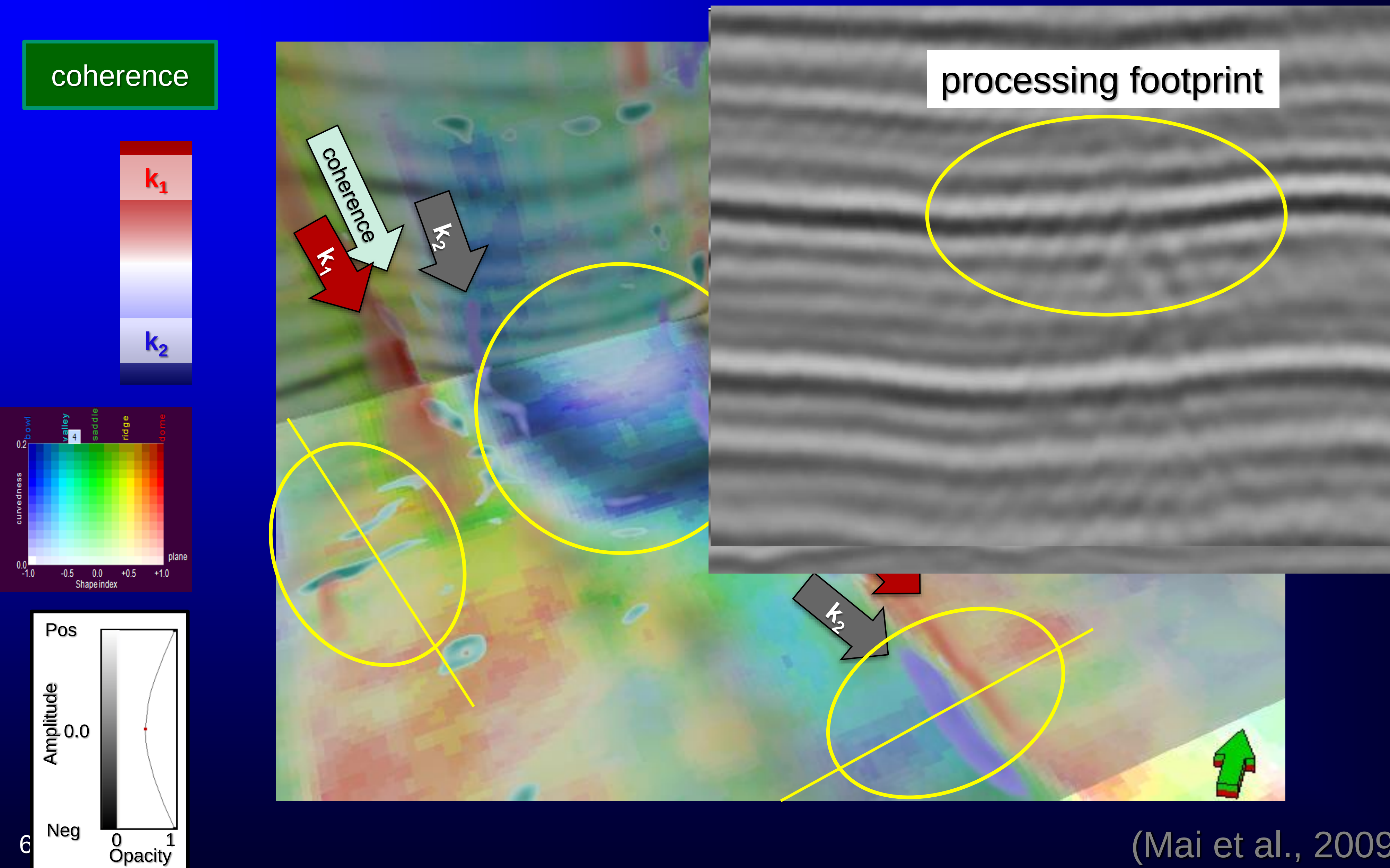
(Mai et al., 2009a)

Fault: Vertical section with interpretation



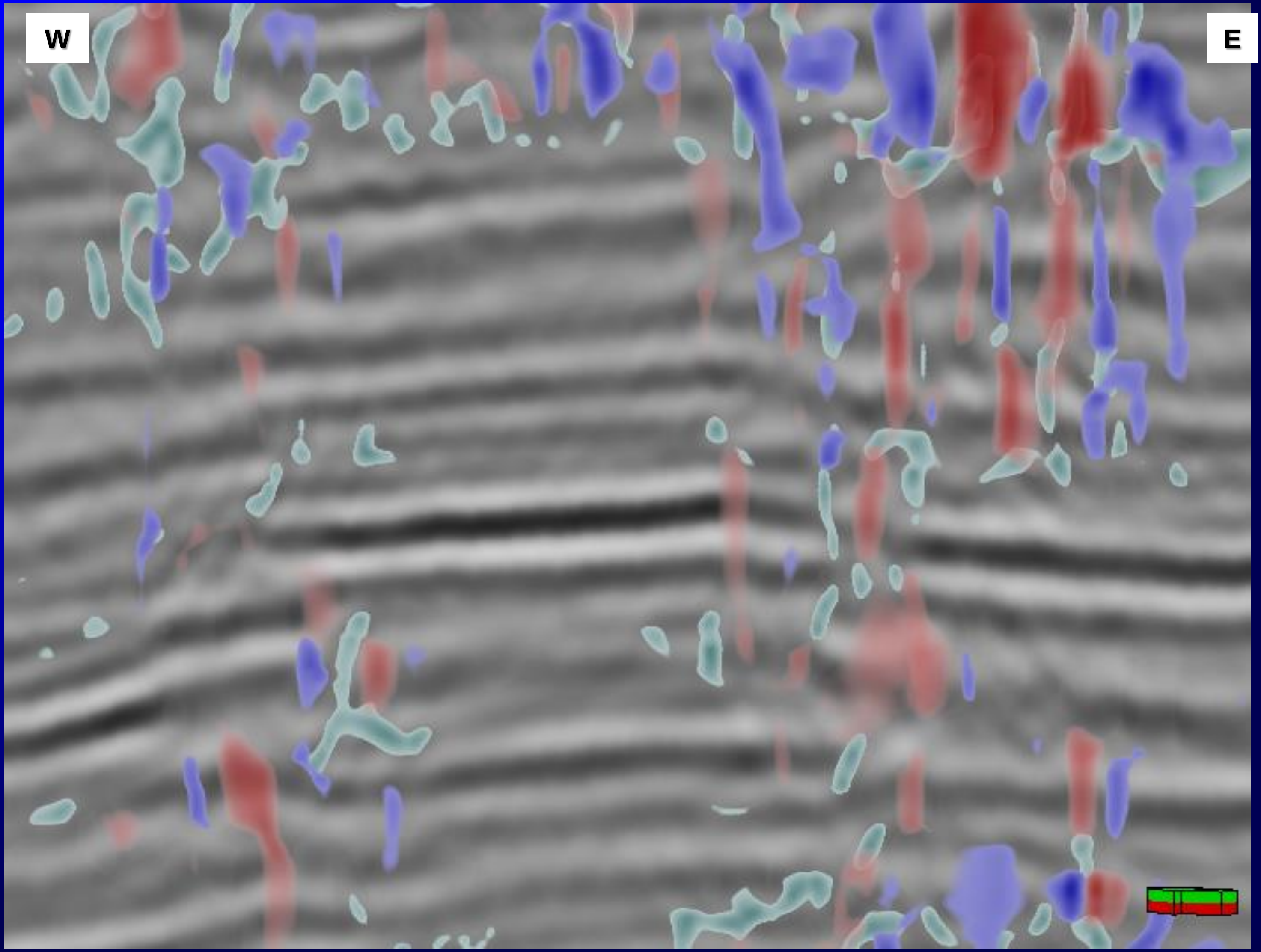
(Mai et al., 2009a)

Fault: Seismic volume with interpretation

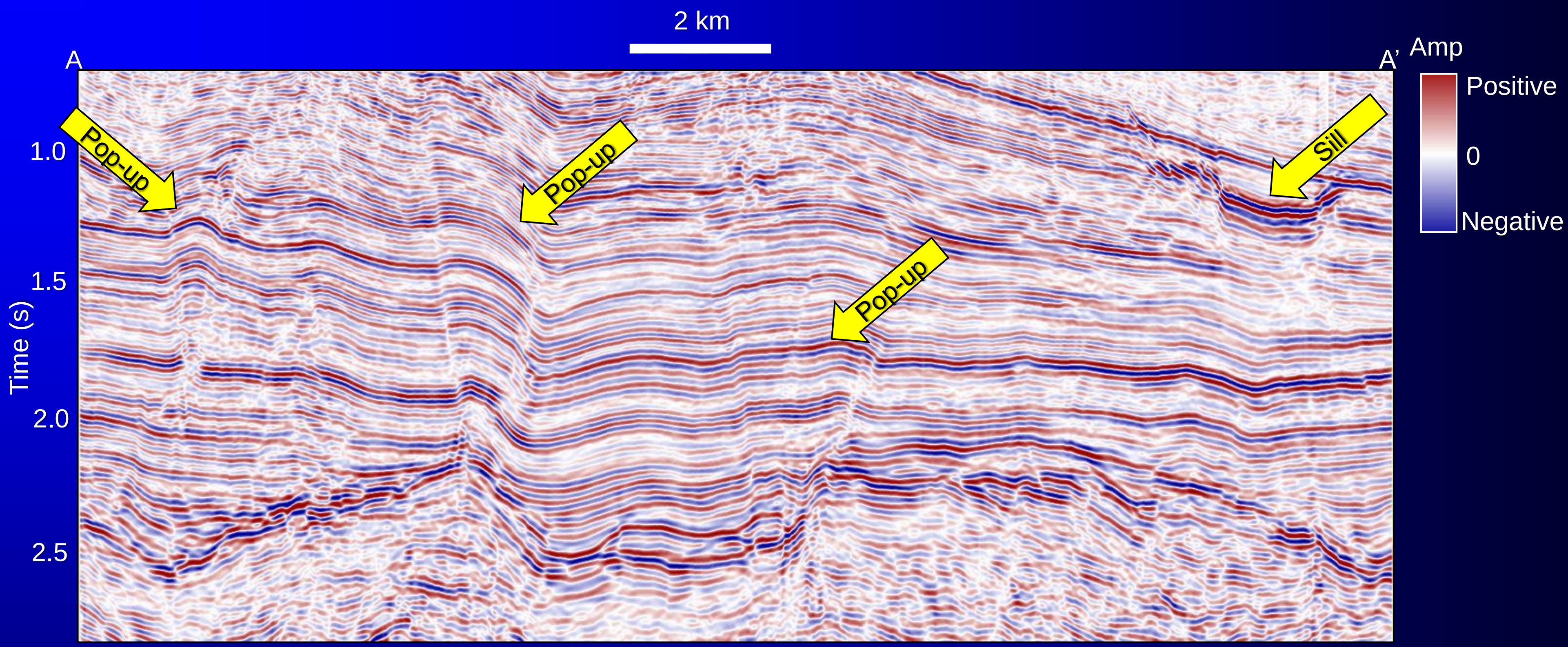


(Mai et al., 2009a)

Effect of processing artifacts

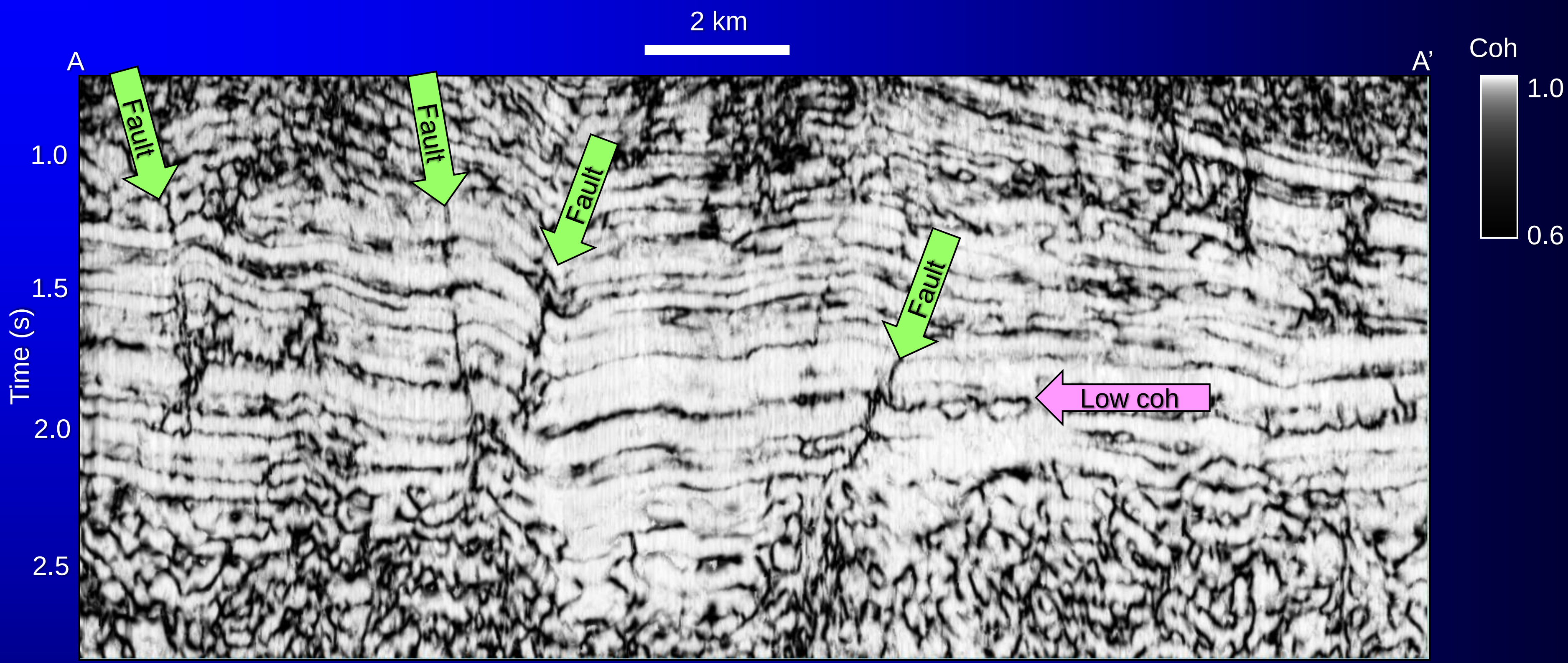


(Mai et al., 2010)



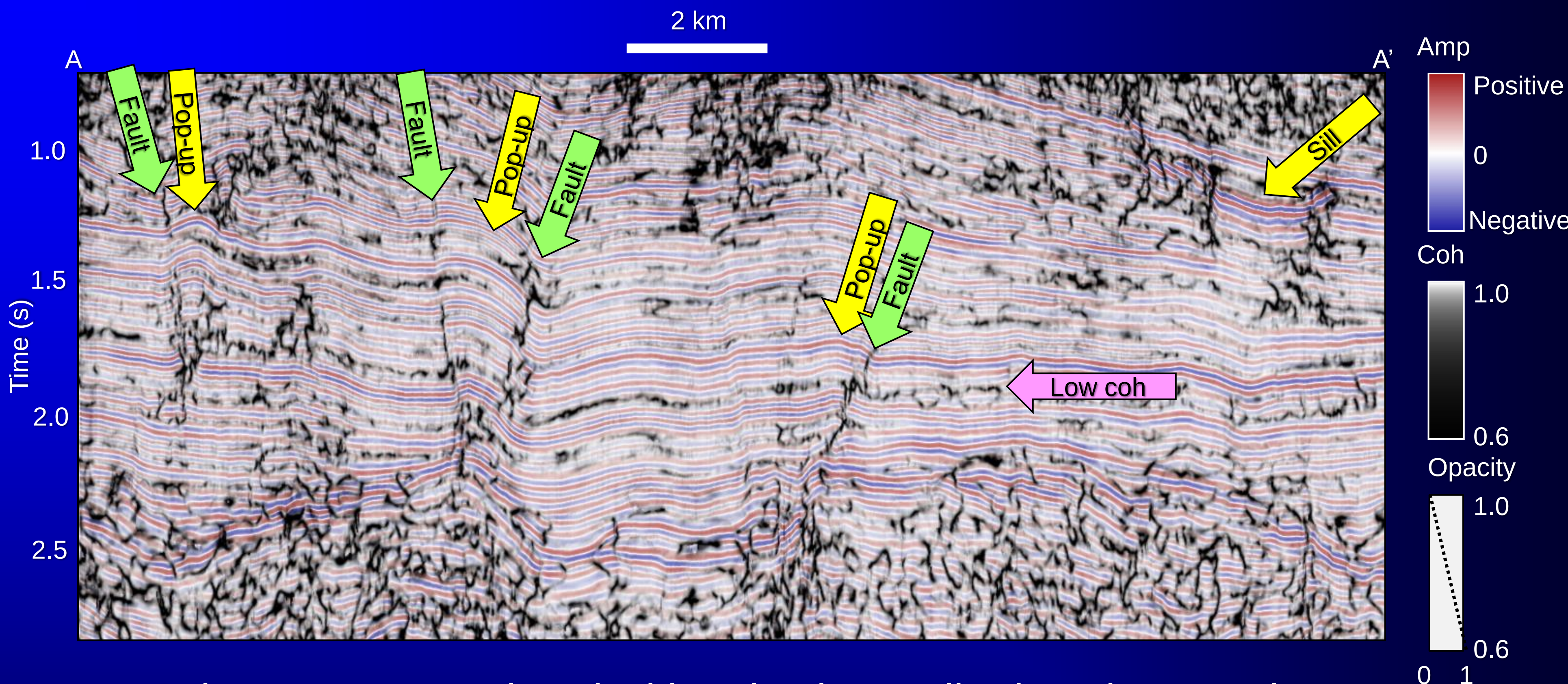
Seismic amplitude

(Mai et al., 2010)



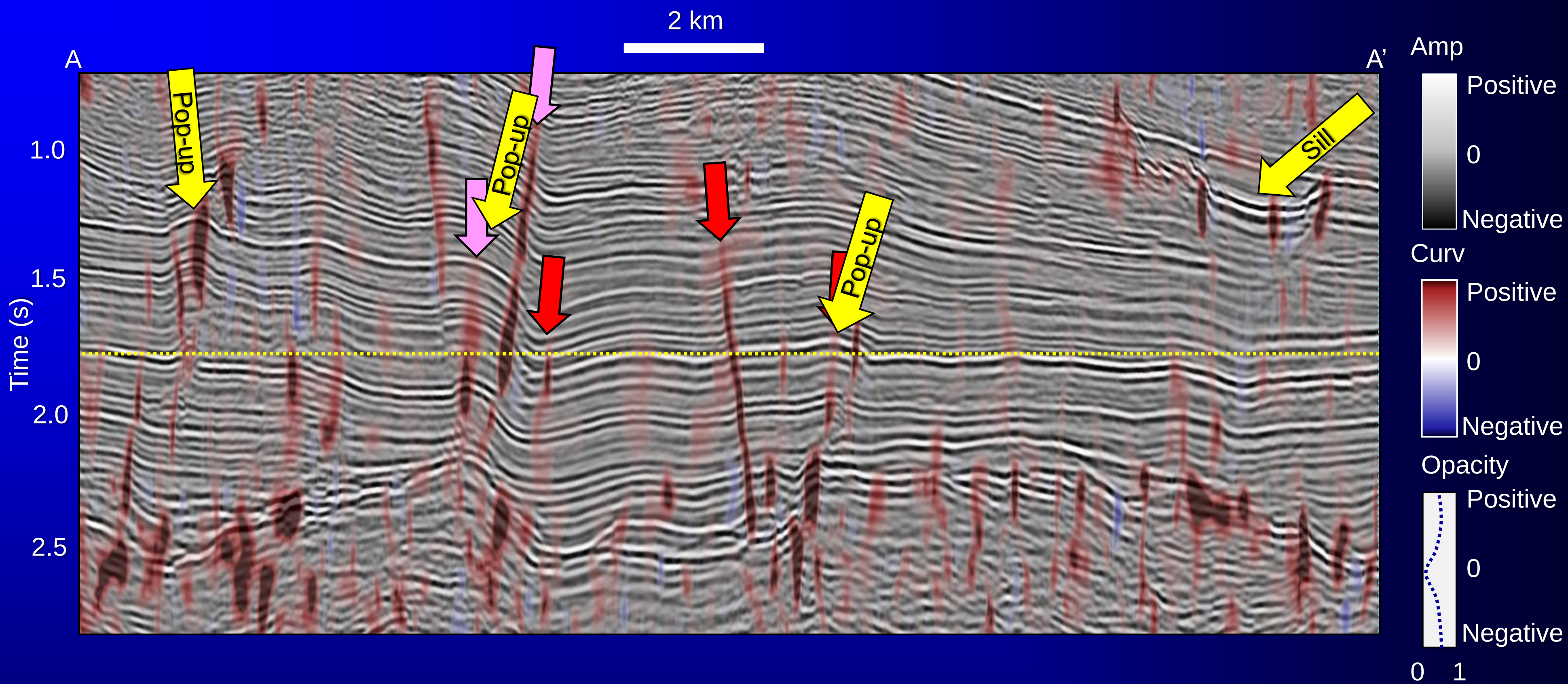
Coherence

(Mai et al., 2010)



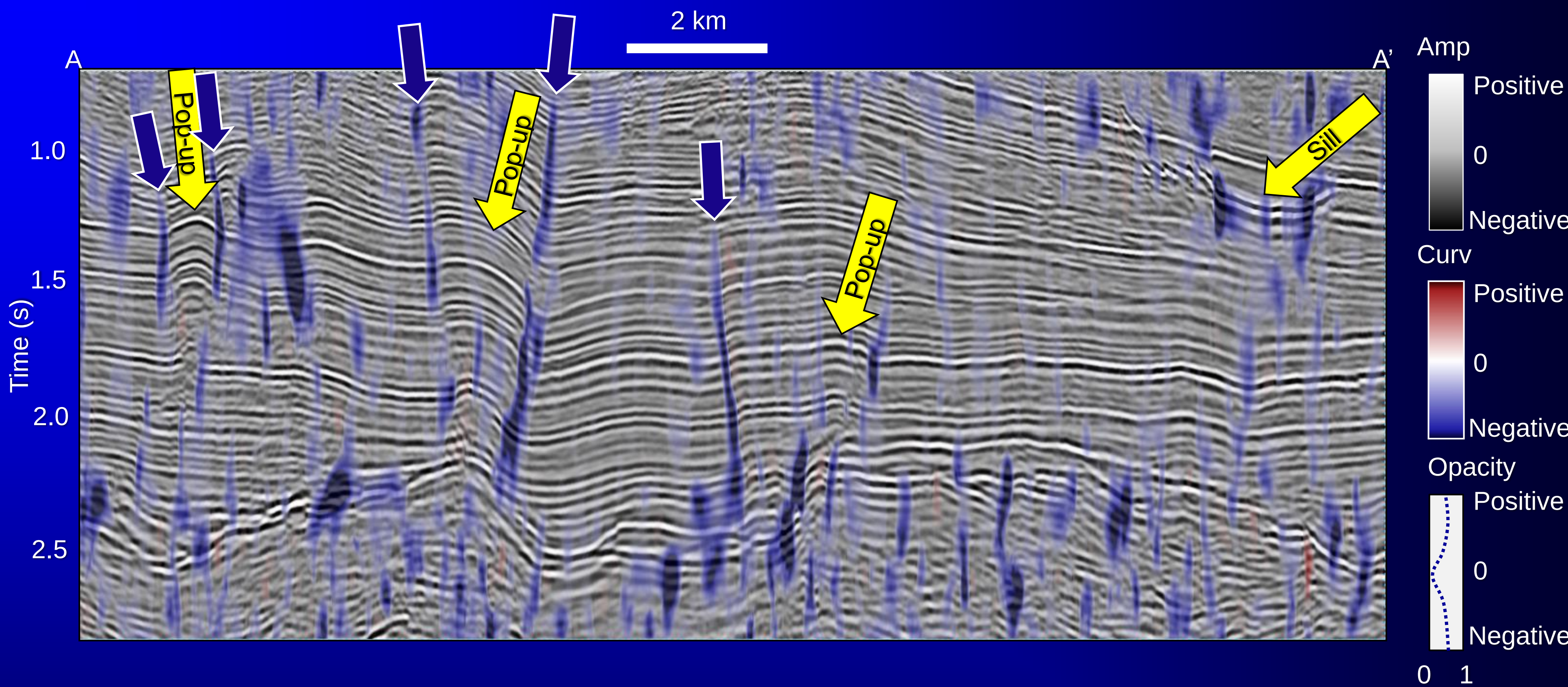
Coherence co-rendered with seismic amplitude using opacity

(Mai et al., 2010)



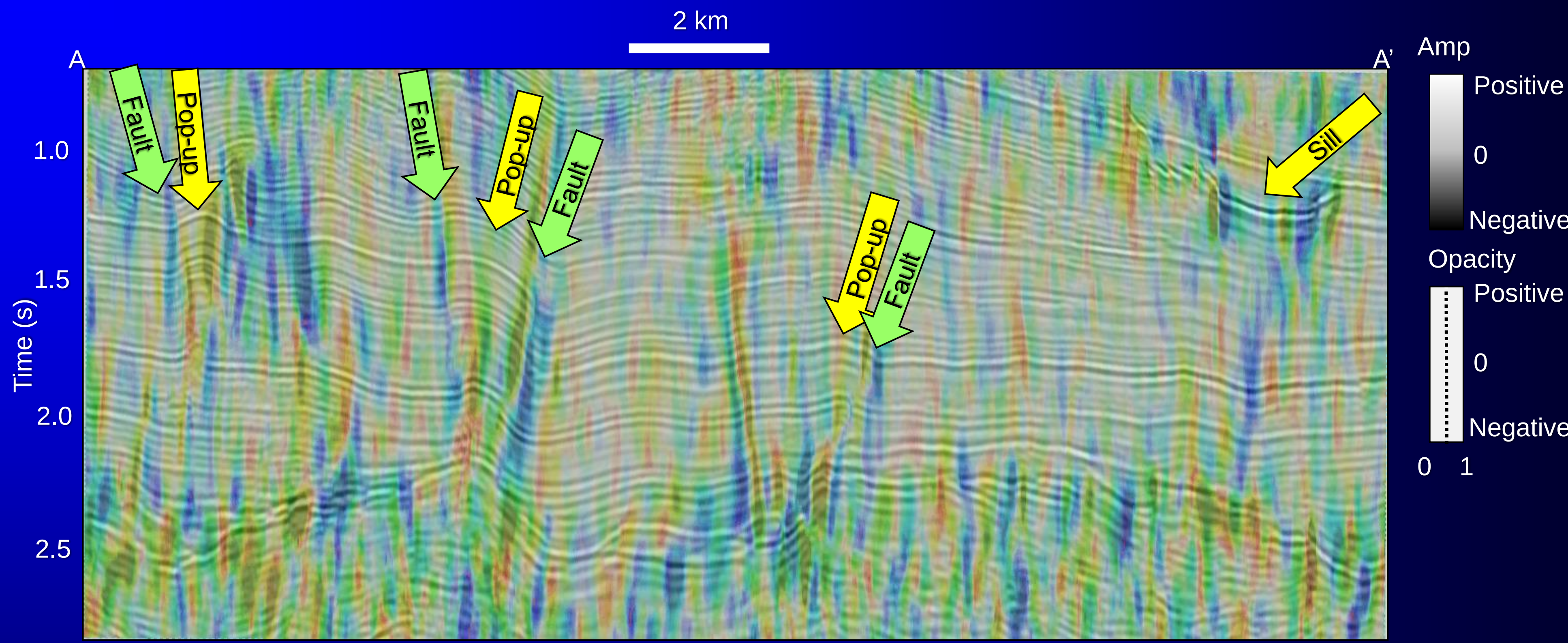
k_1 most-positive principal curvature co-rendered with seismic amplitude using opacity

(Mai et al., 2010)

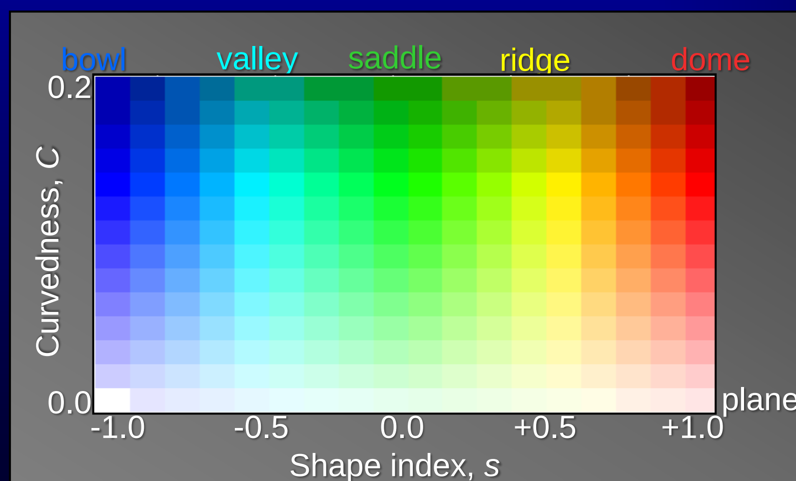


k_2 most-negative principal curvature co-rendered with seismic amplitude using opacity

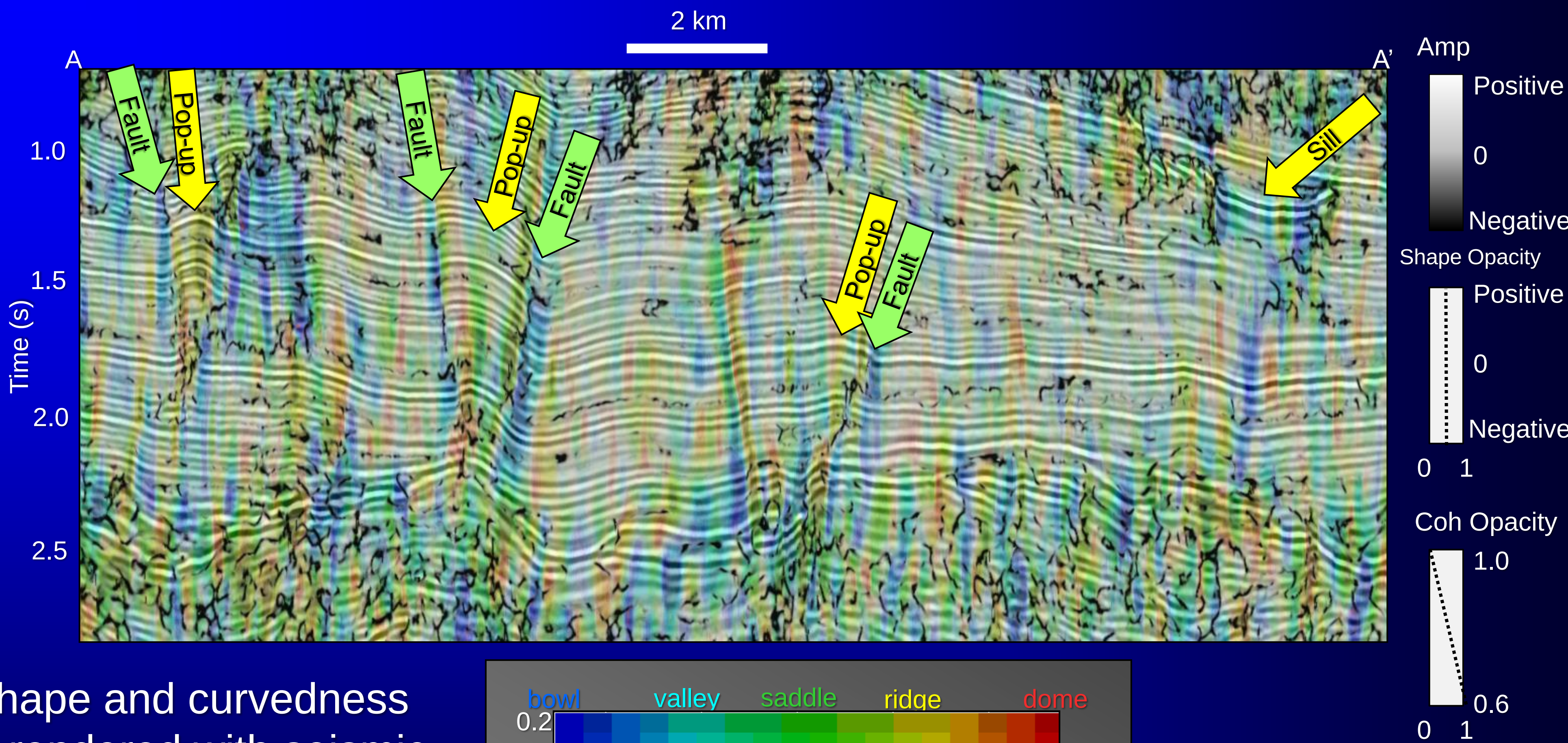
(Mai et al., 2010)



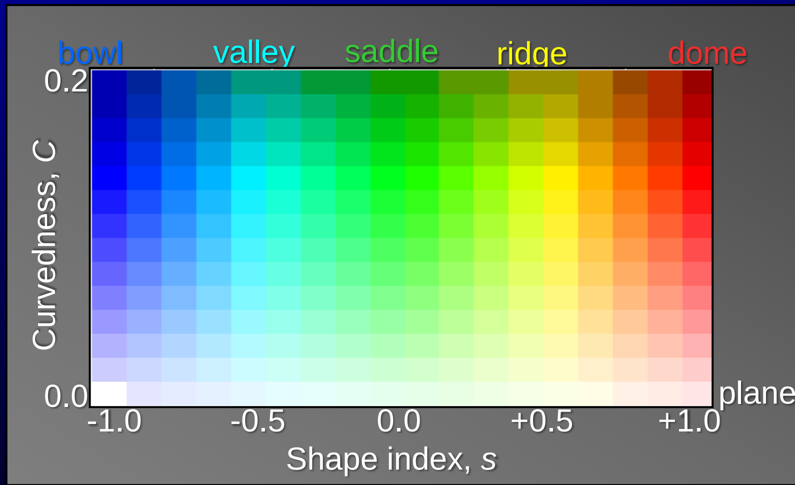
Shape and curvedness co-rendered with seismic amplitude using opacity



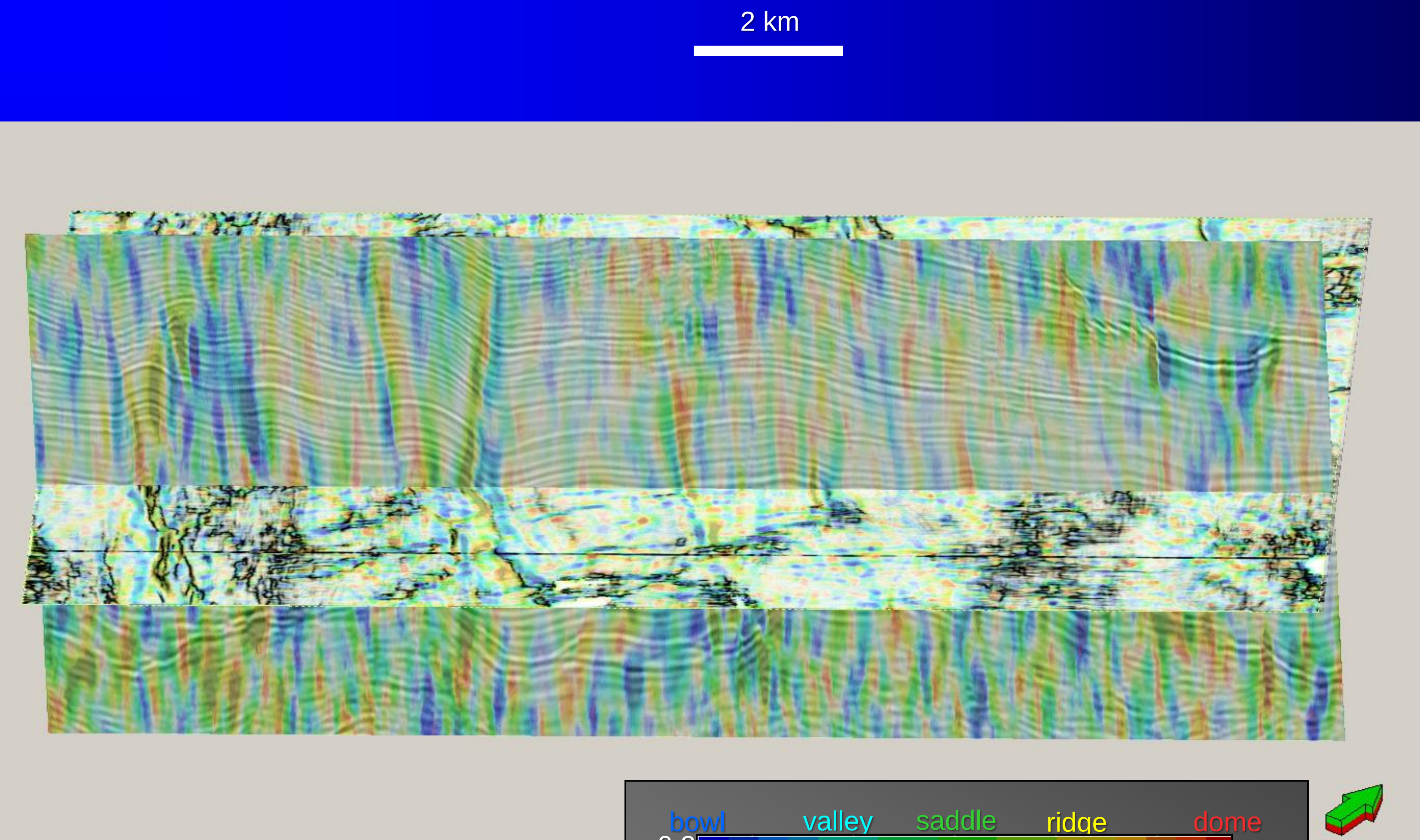
(Mai et al., 2010)

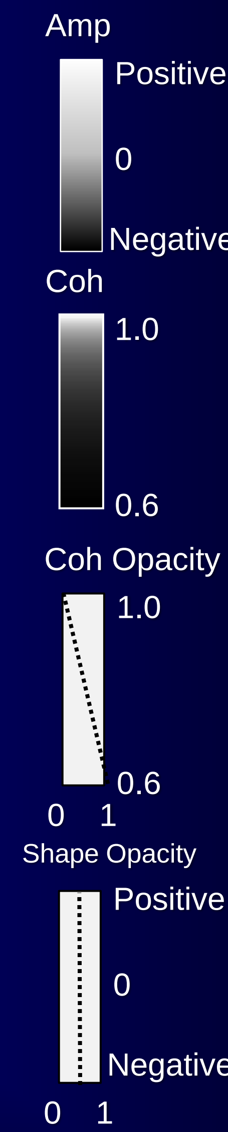


Shape and curvedness co-rendered with seismic amplitude and coherence using opacity

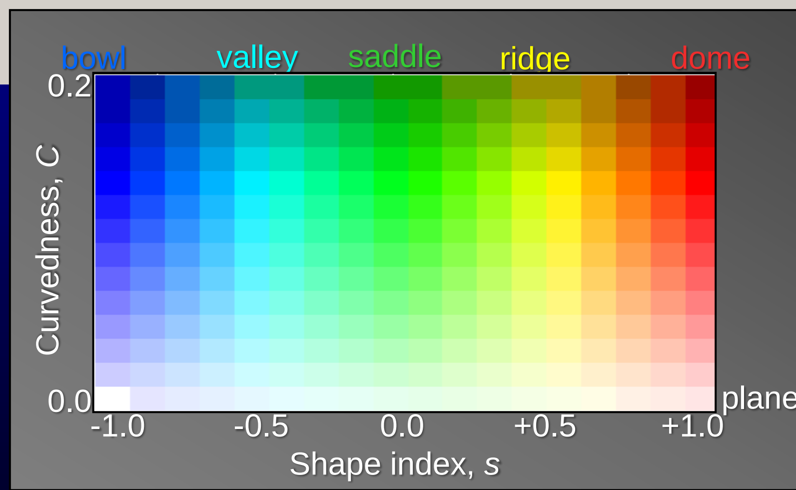


(Mai et al., 2010)

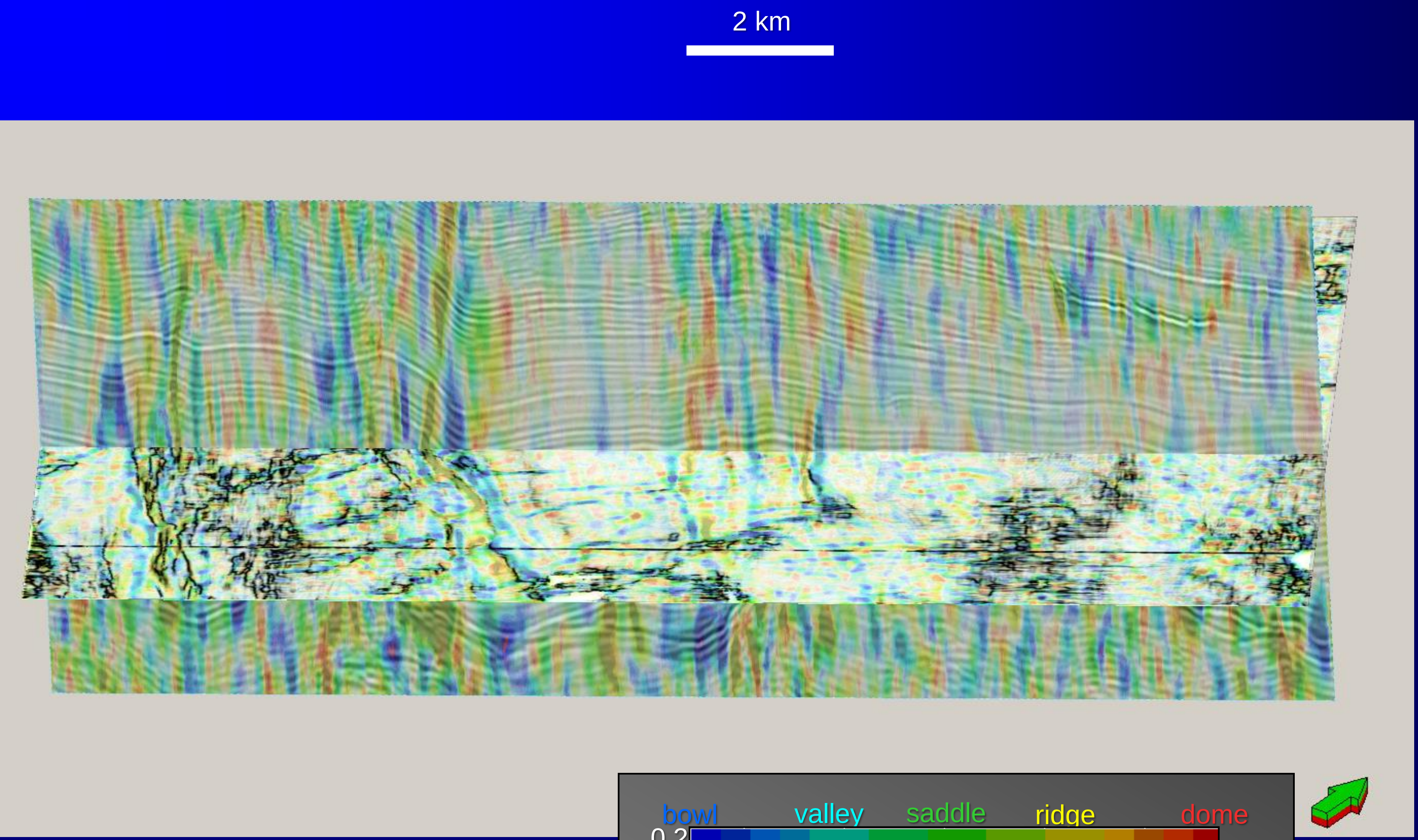


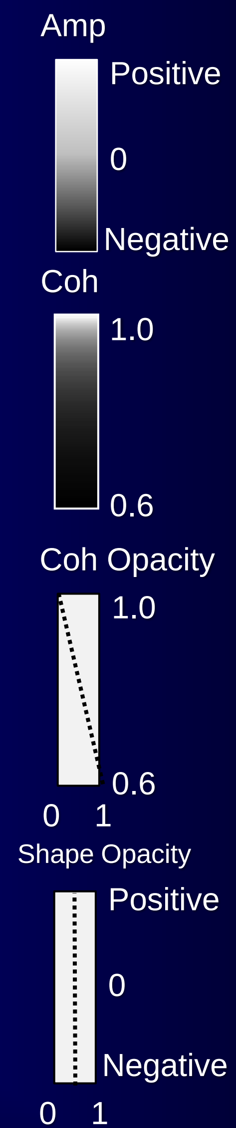


Time slice at t=1.75 s through shape modulated by curvedness co-rendered with coherence.

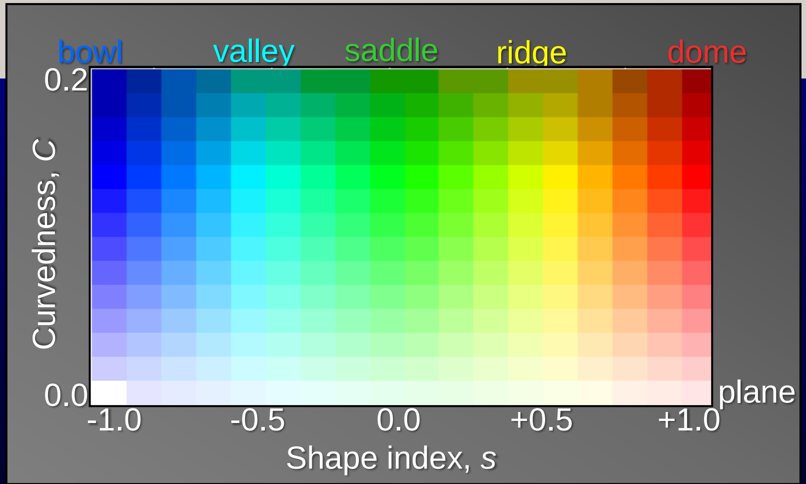


(Mai et al., 2010)





Time slice at t=1.75 s through shape modulated by curvedness co-rendered with coherence.

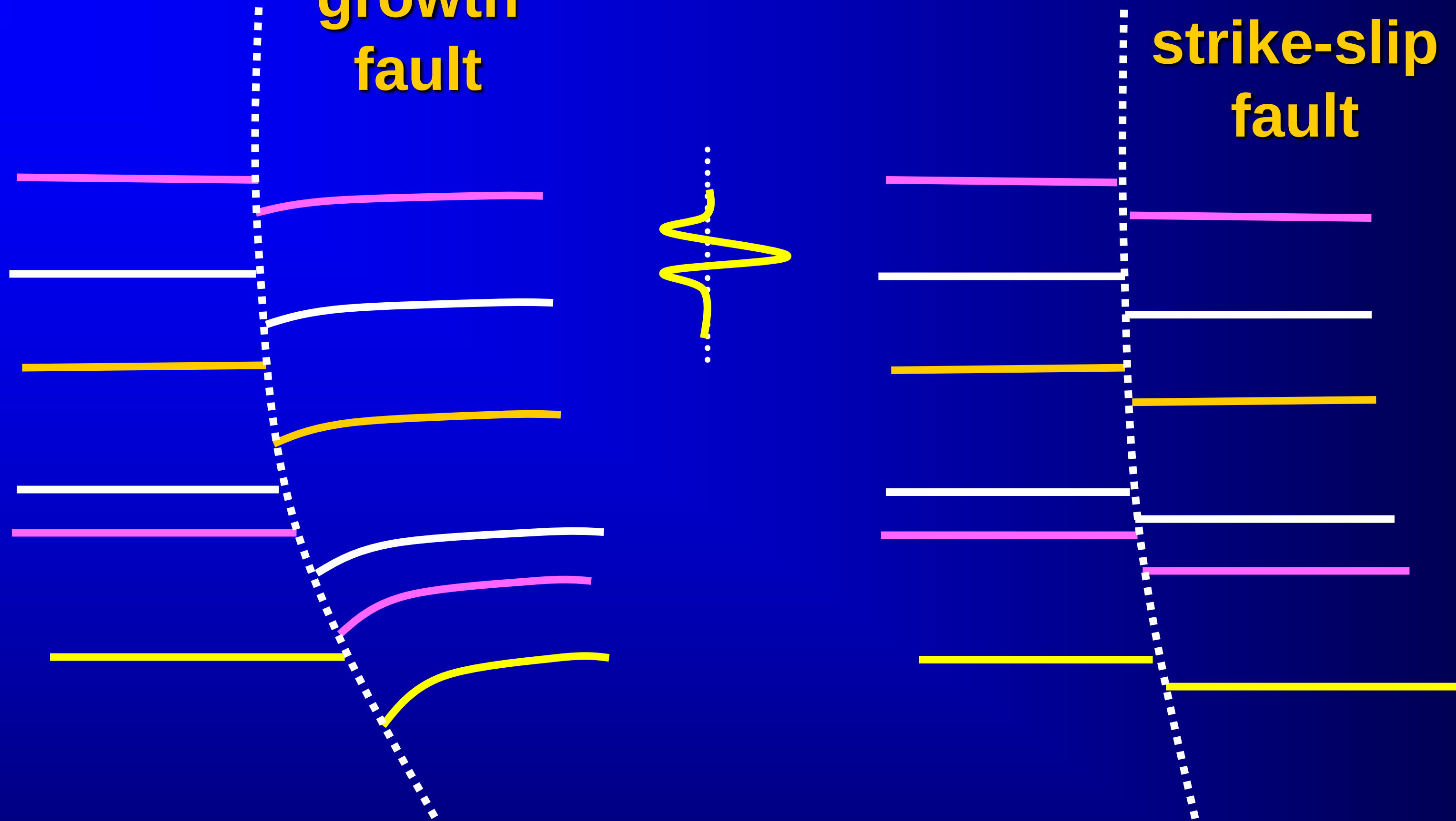


(Mai et al., 2010)

Attribute imaging of faults and flexures

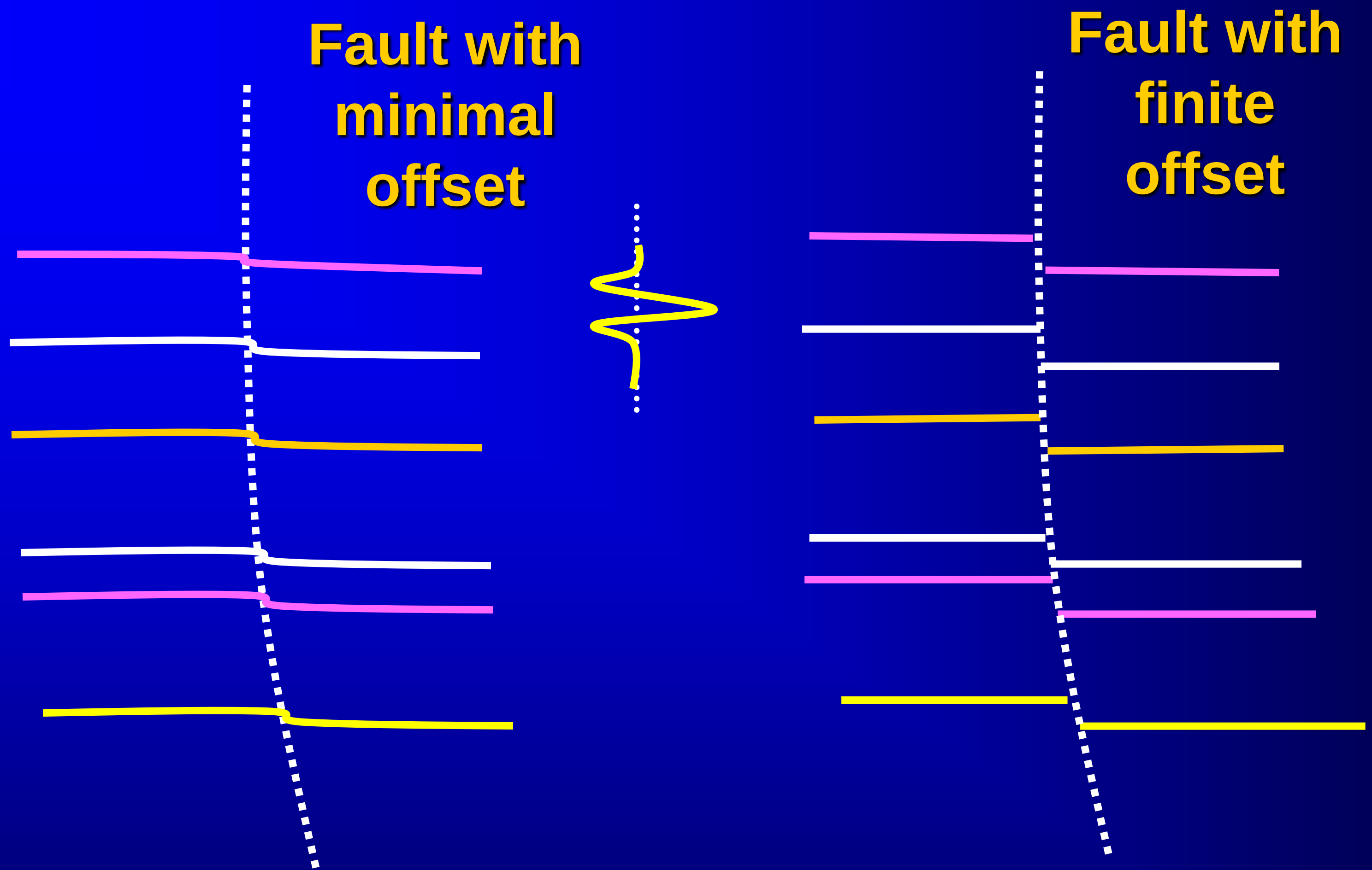
Idealized growth fault

Idealized strike-slip fault



Fault seen on curvature. Seen on coherence.

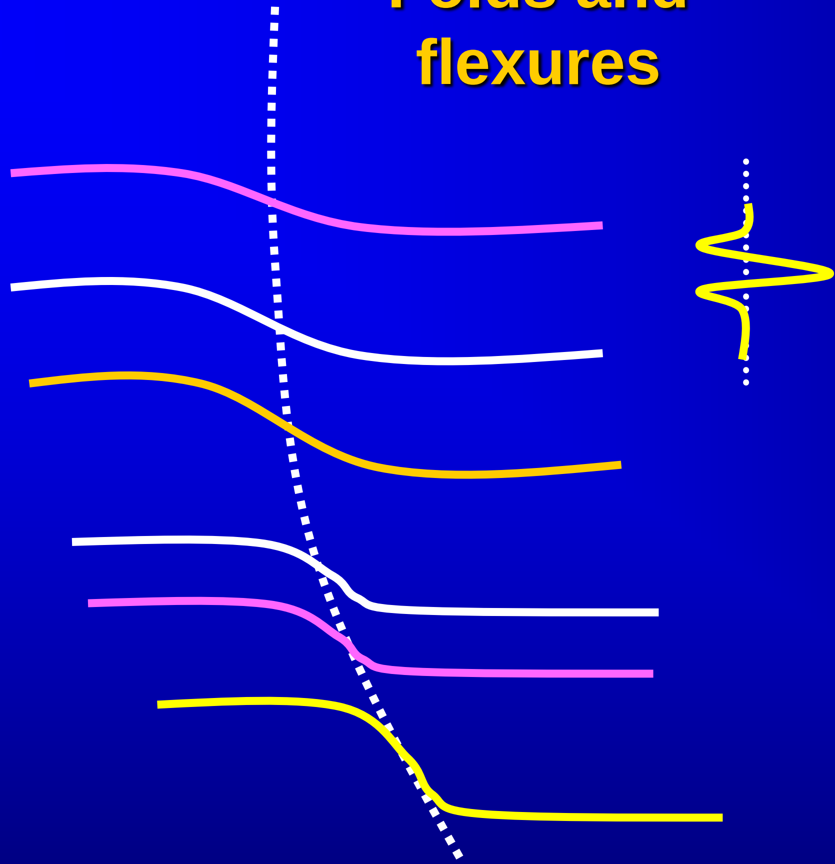
Fault not seen on curvature. Seen on coherence.



Fault seen on curvature. Not seen on coherence.

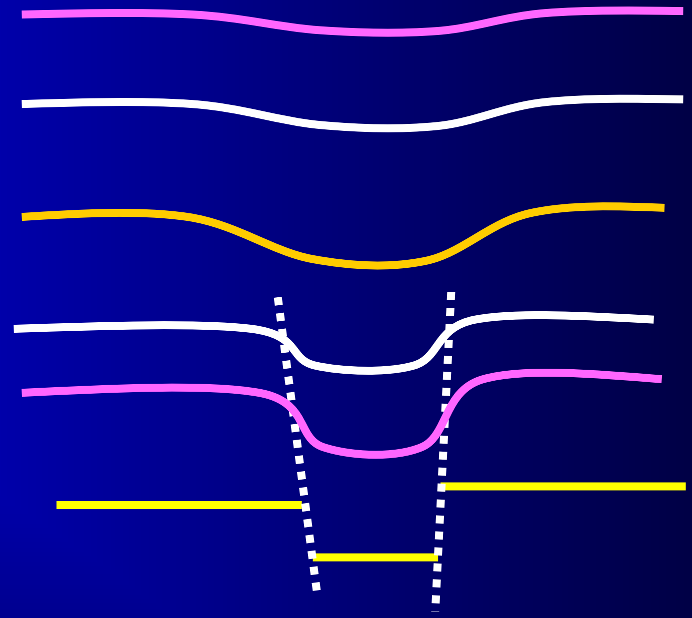
Fault seen on coherence. Not seen on curvature.

Folds and flexures



‘Fault’ seen on curvature. Not seen on coherence.

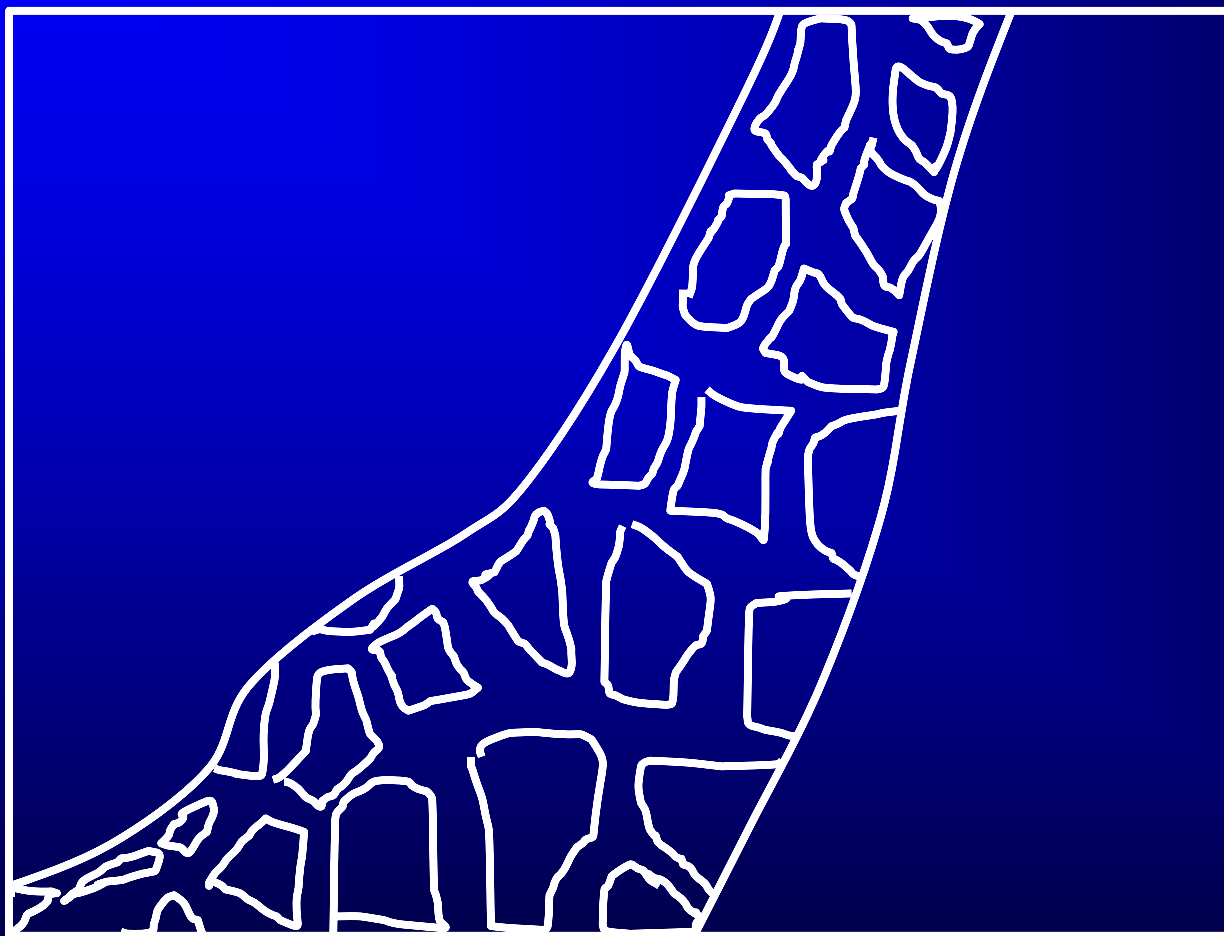
Infilled grabens



Fault seen on coherence at depth. Infill/collapse seen on curvature shallow.

Basinwide Regional Interpretation across Heterogeneous Seismic Surveys

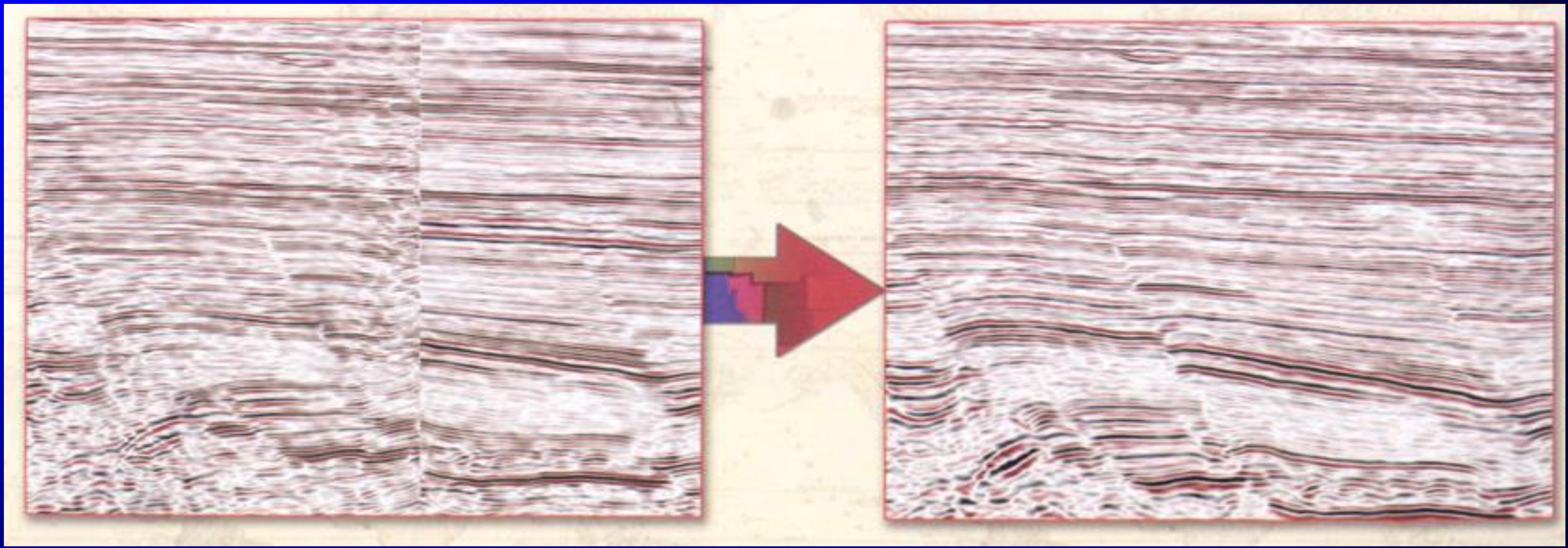
What do you see?



Merged surveys

Before merge

After merge



Merging includes:

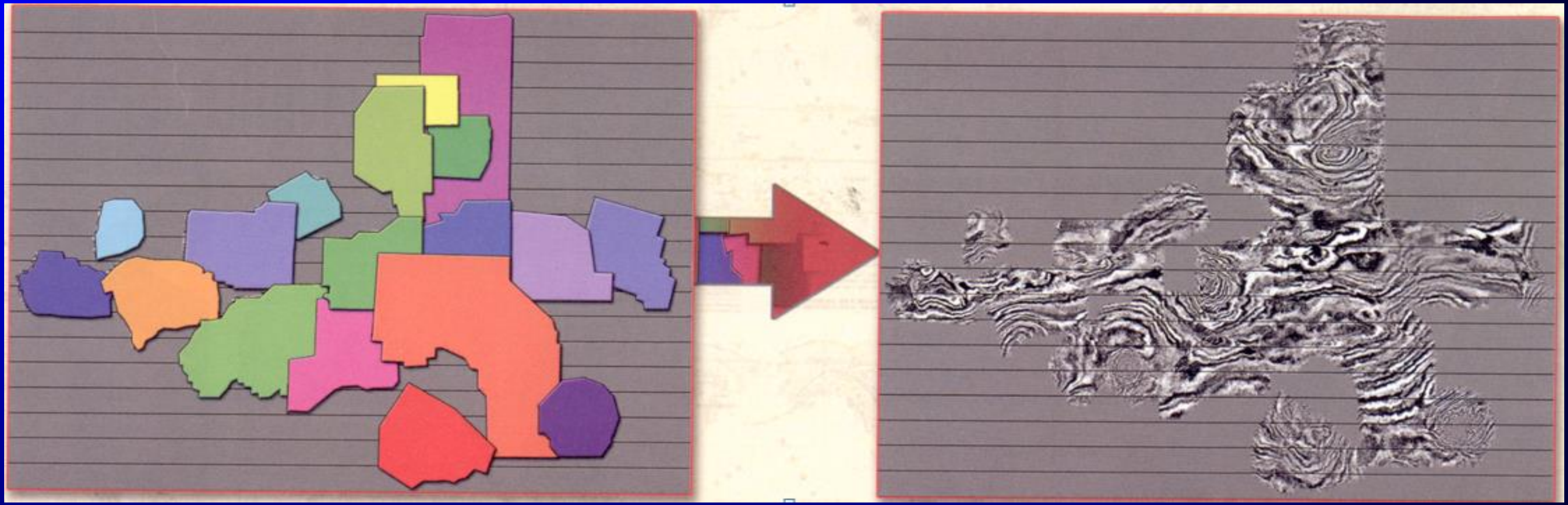
- Phase matching
- Common static solution
- Amplitude balancing
- Increased migration aperture

(Fairfield advertisement, 2008)

Merged surveys

Before merge

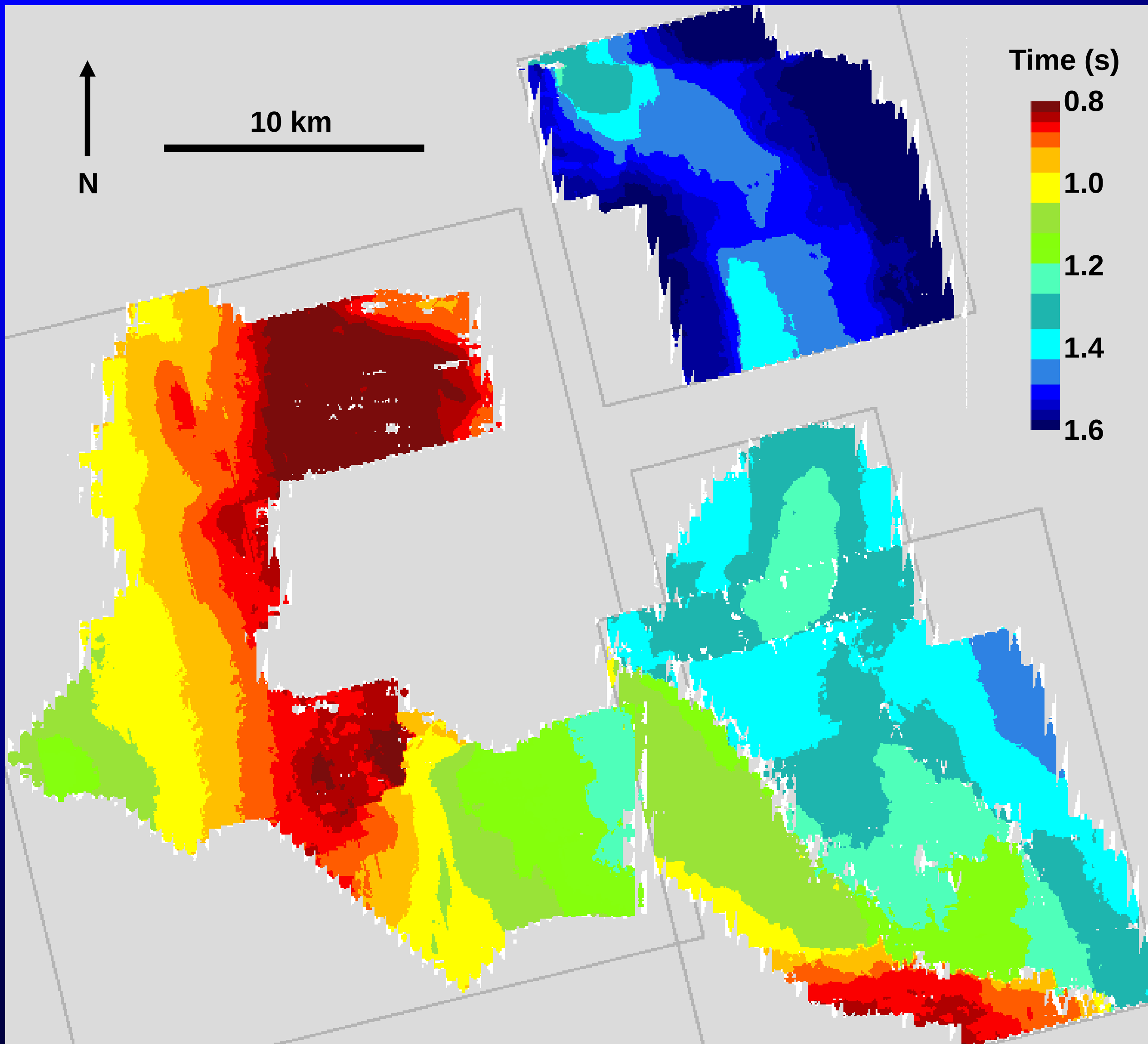
After merge



18 separate surveys!

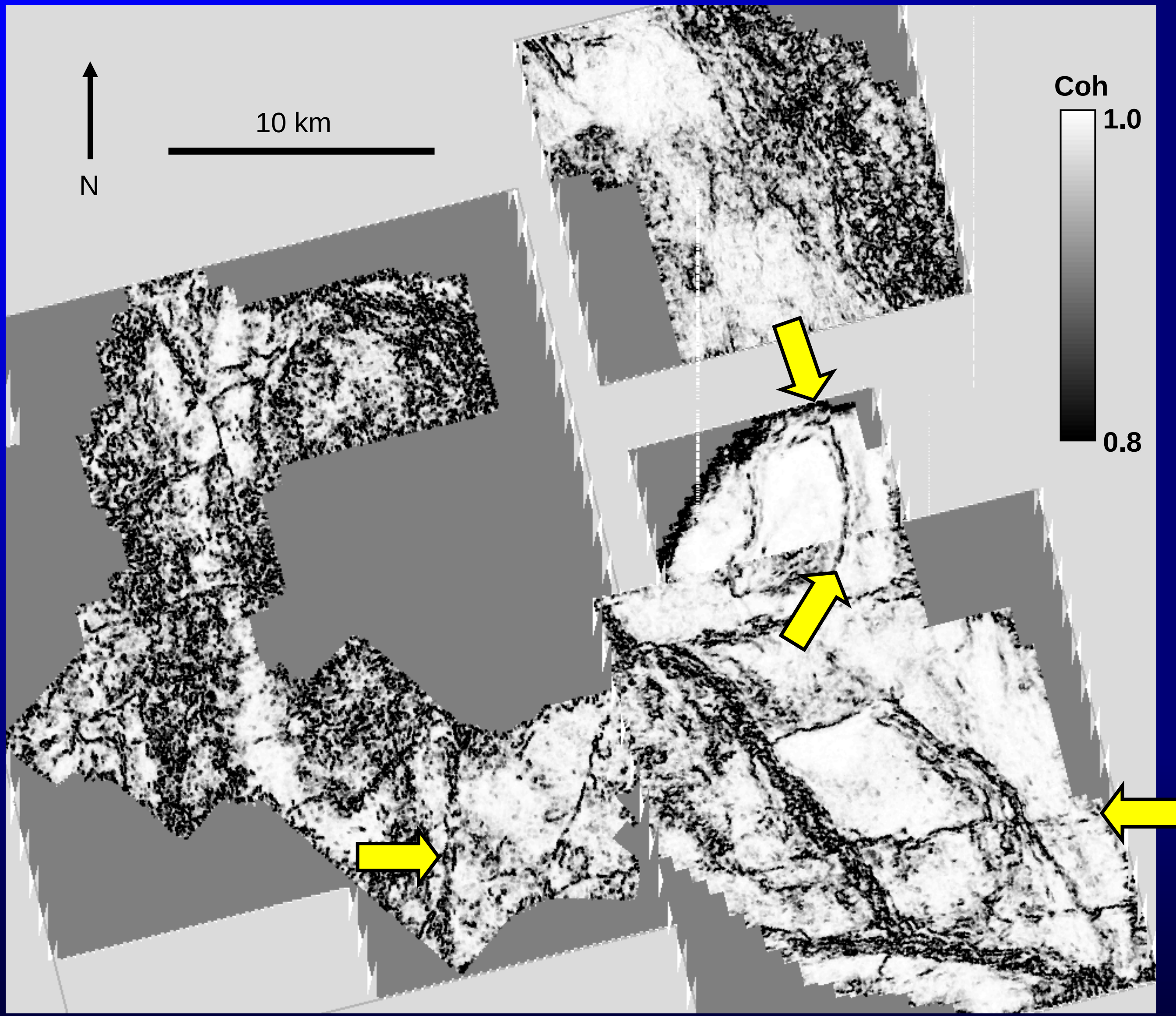
(Fairfield advertisement, 2008)

Time/structure map of heterogeneous surveys



Central Basin Platform, Texas, USA Top Devonian

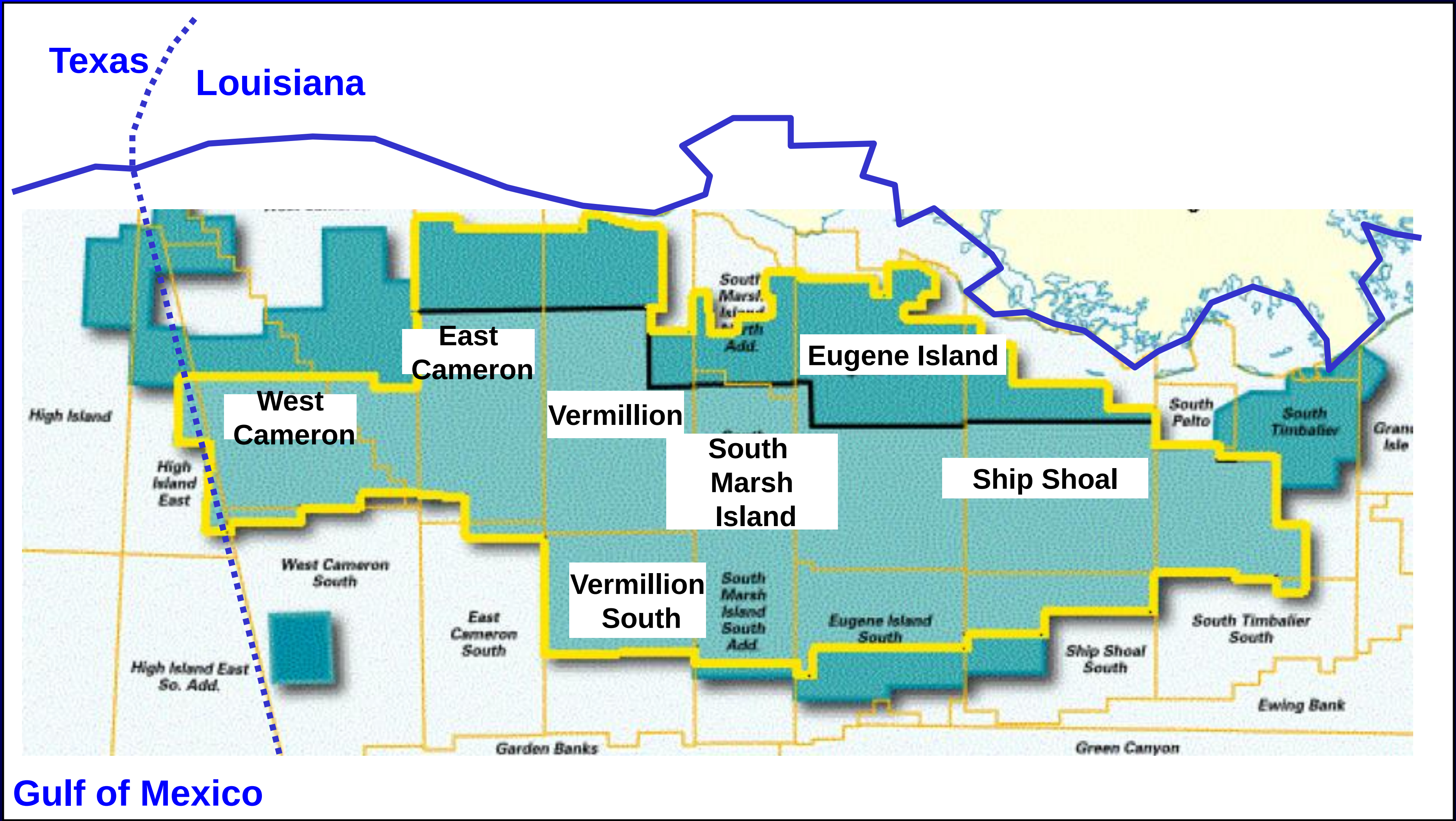
Coherence time slice on heterogeneous surveys



Central Basin Platform, Texas, USA
t=1.0 s

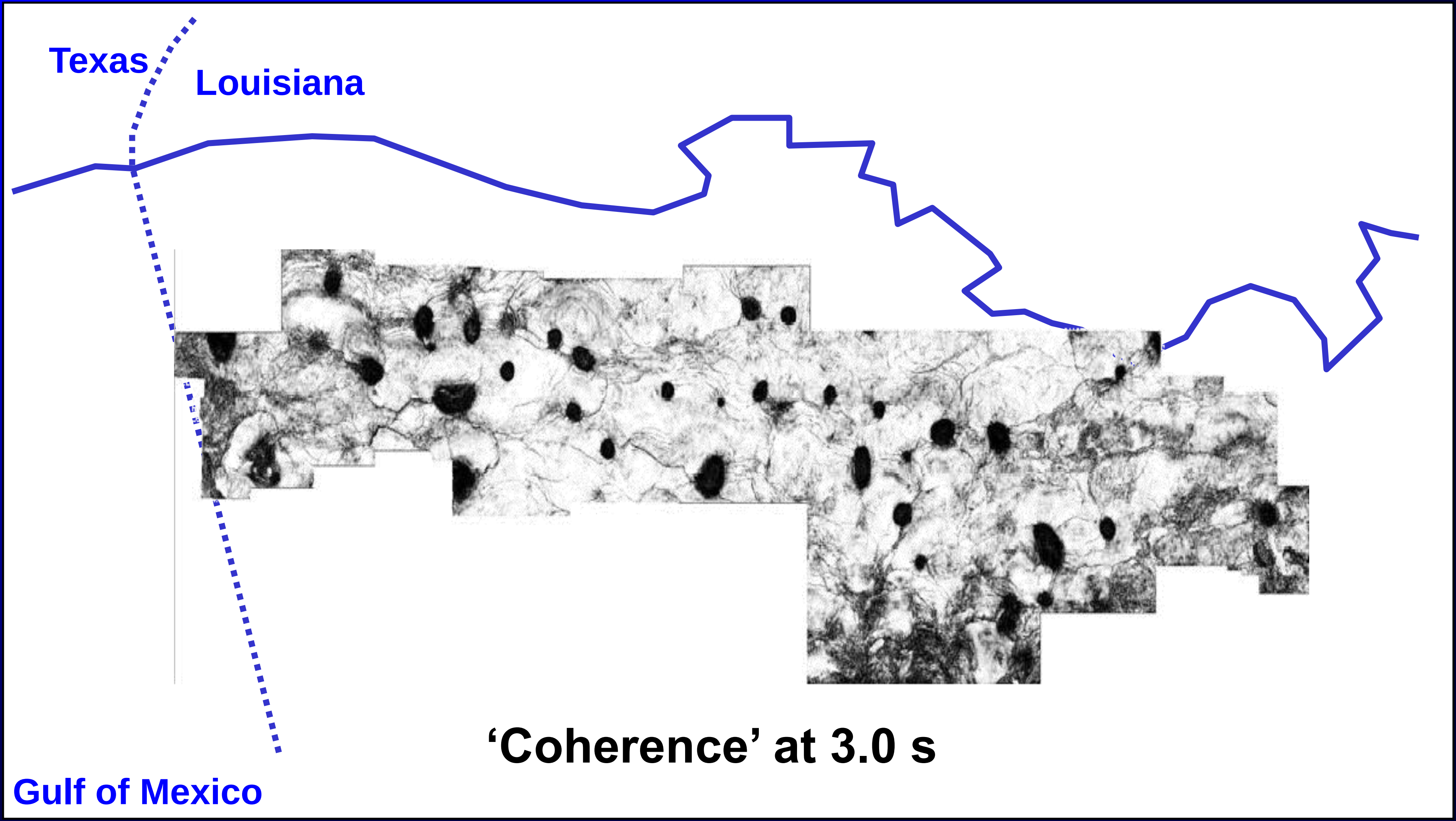
(Data courtesy of BP, OXY, Burlington)

A large regional survey



(Biles et al, 2003)

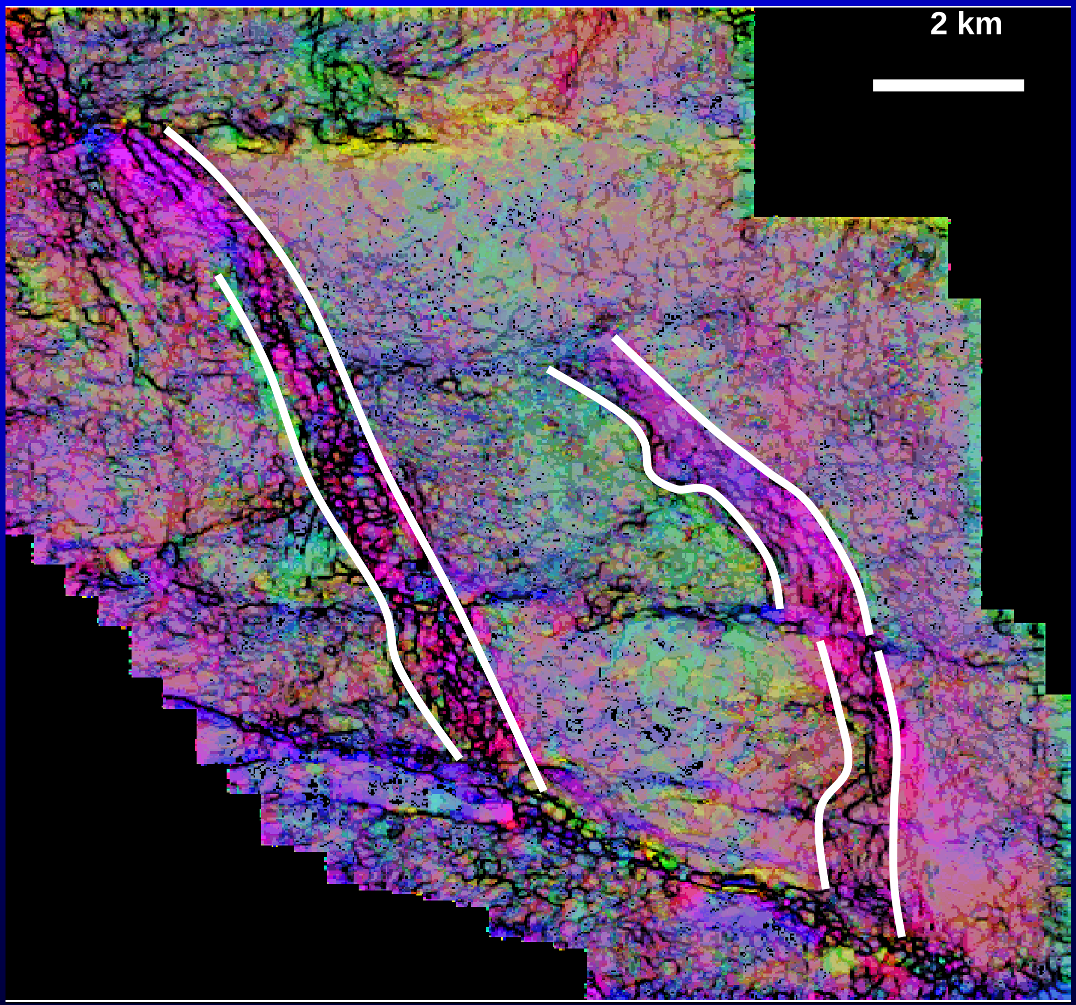
Use of coherence to interpreter a large regional survey

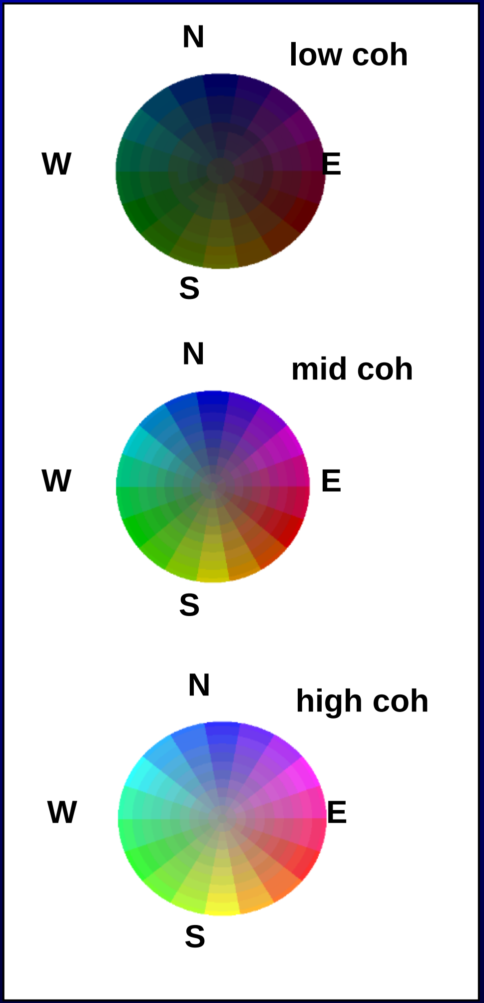


(Biles et al, 2003)

Interpretation Workflows

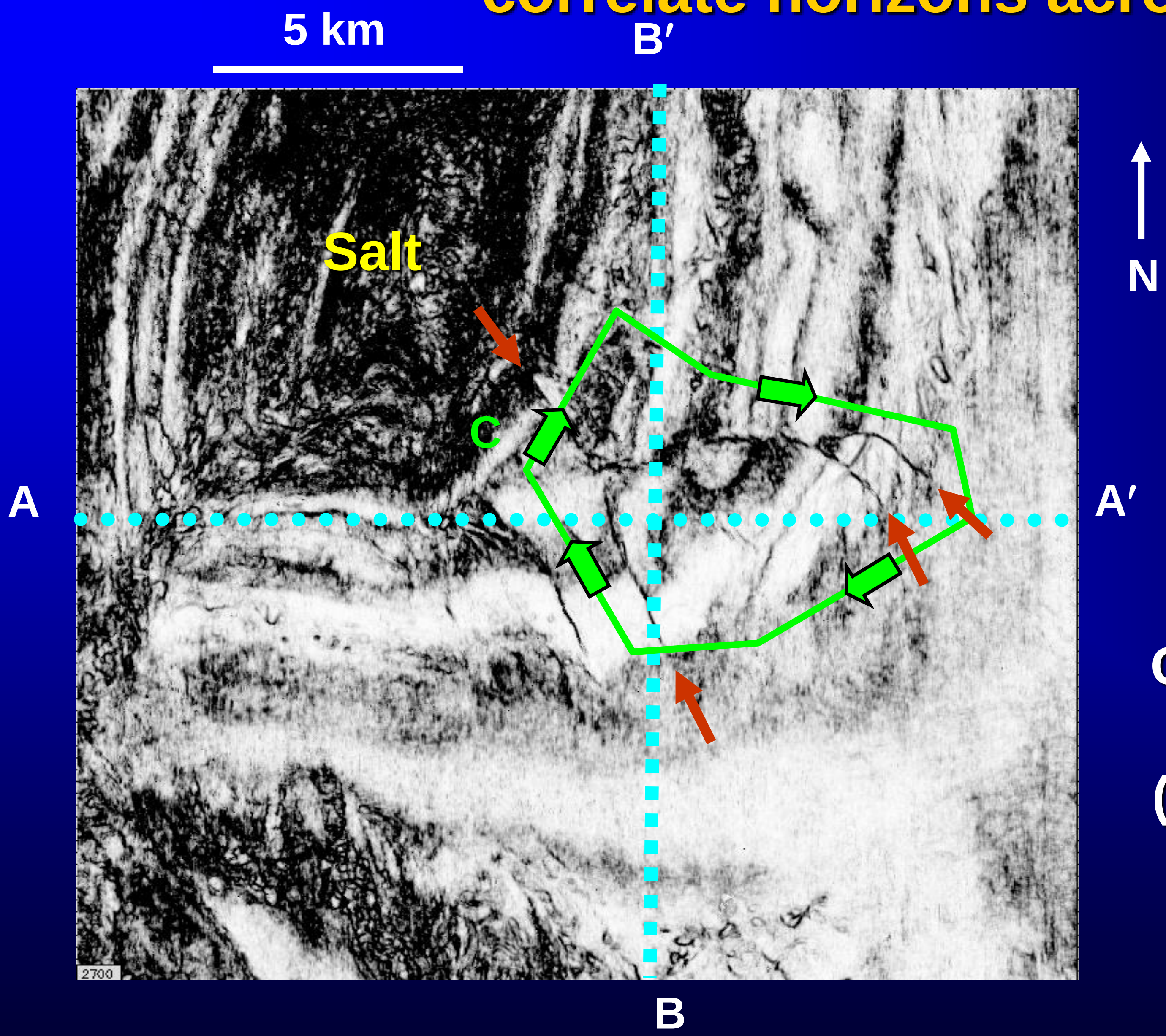
Workflow#1: Using attribute to delineate limits of fault *zones*





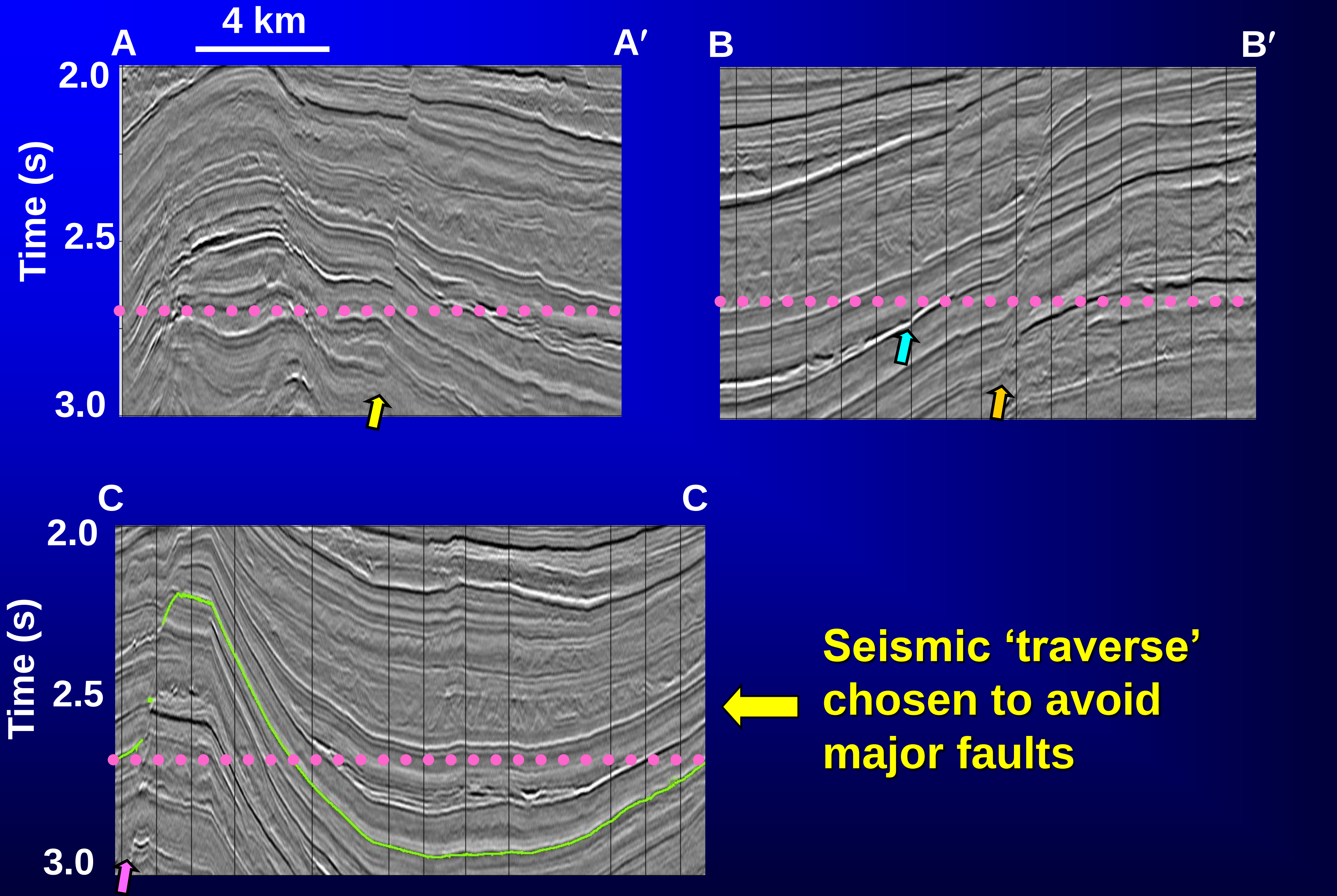
(Data courtesy of OXY)

Workflow#2: Using attribute time slices to help correlate horizons across faults



Pick an arbitrary line that runs around faults

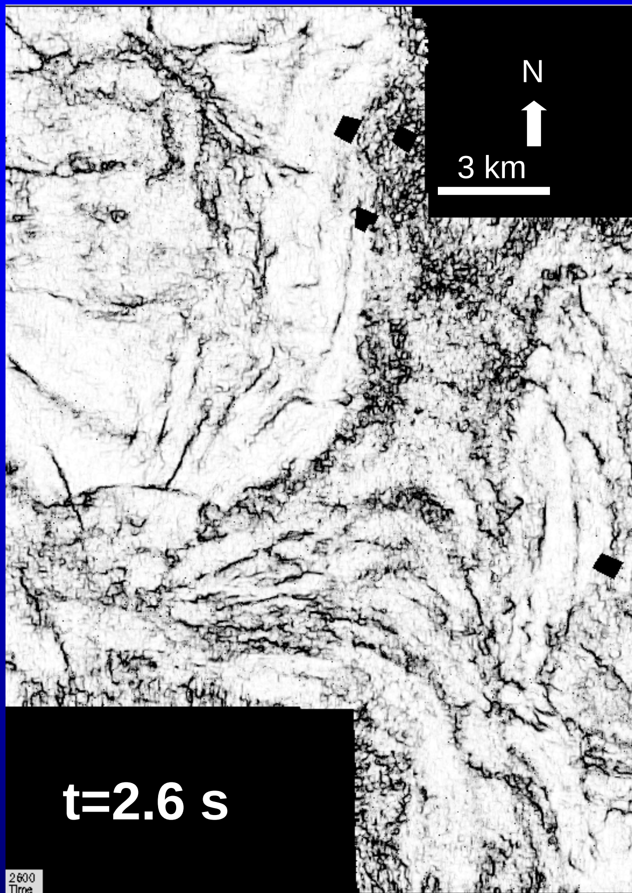
Coherence time slice. T=2.7 s (Green Canyon, GOM, USA)



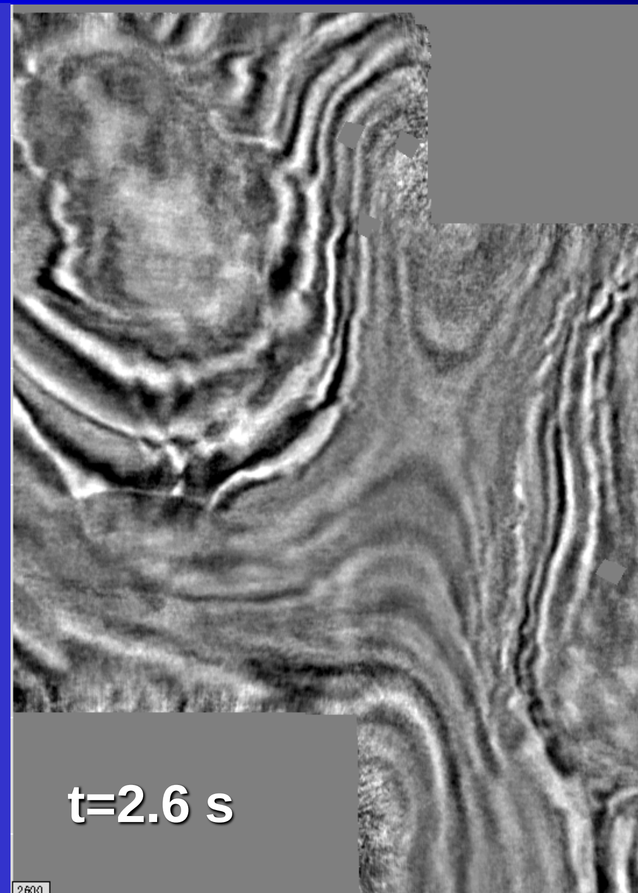
Seismic ‘traverse’ chosen to avoid major faults

(Data courtesy of BP)

Workflow #3: Using attributes to help fault naming and correlation



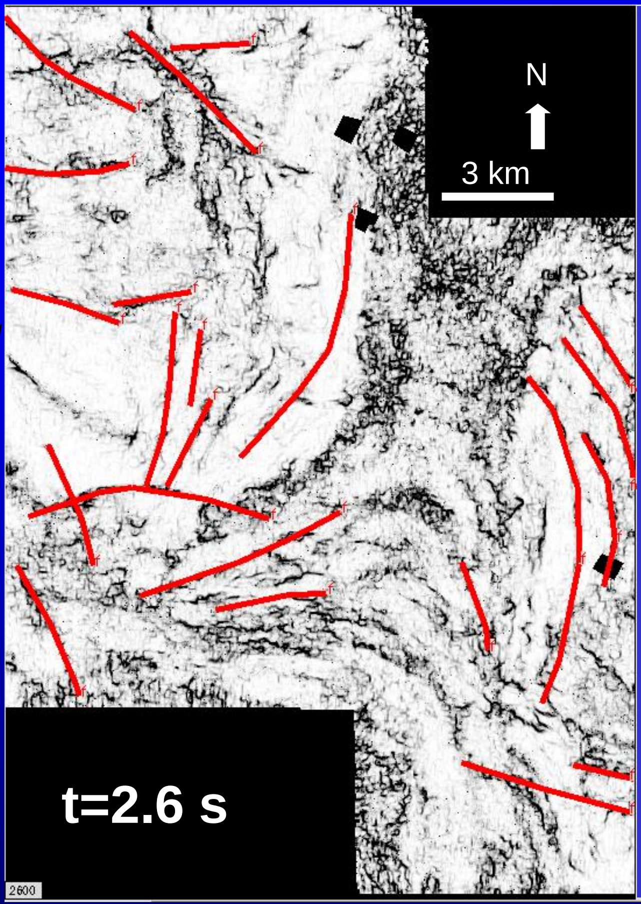
coherence

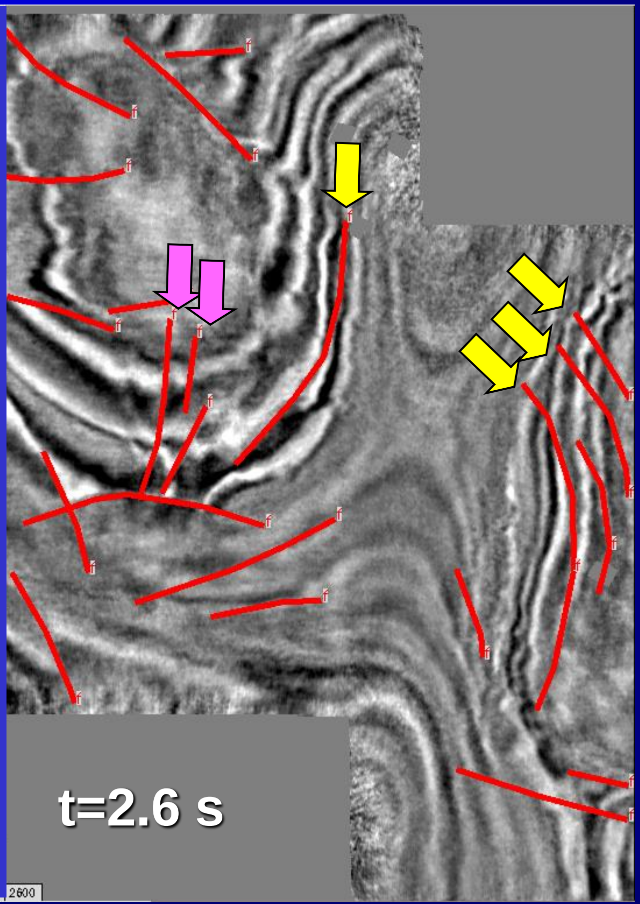


seismic

Northwest Louisiana, USA

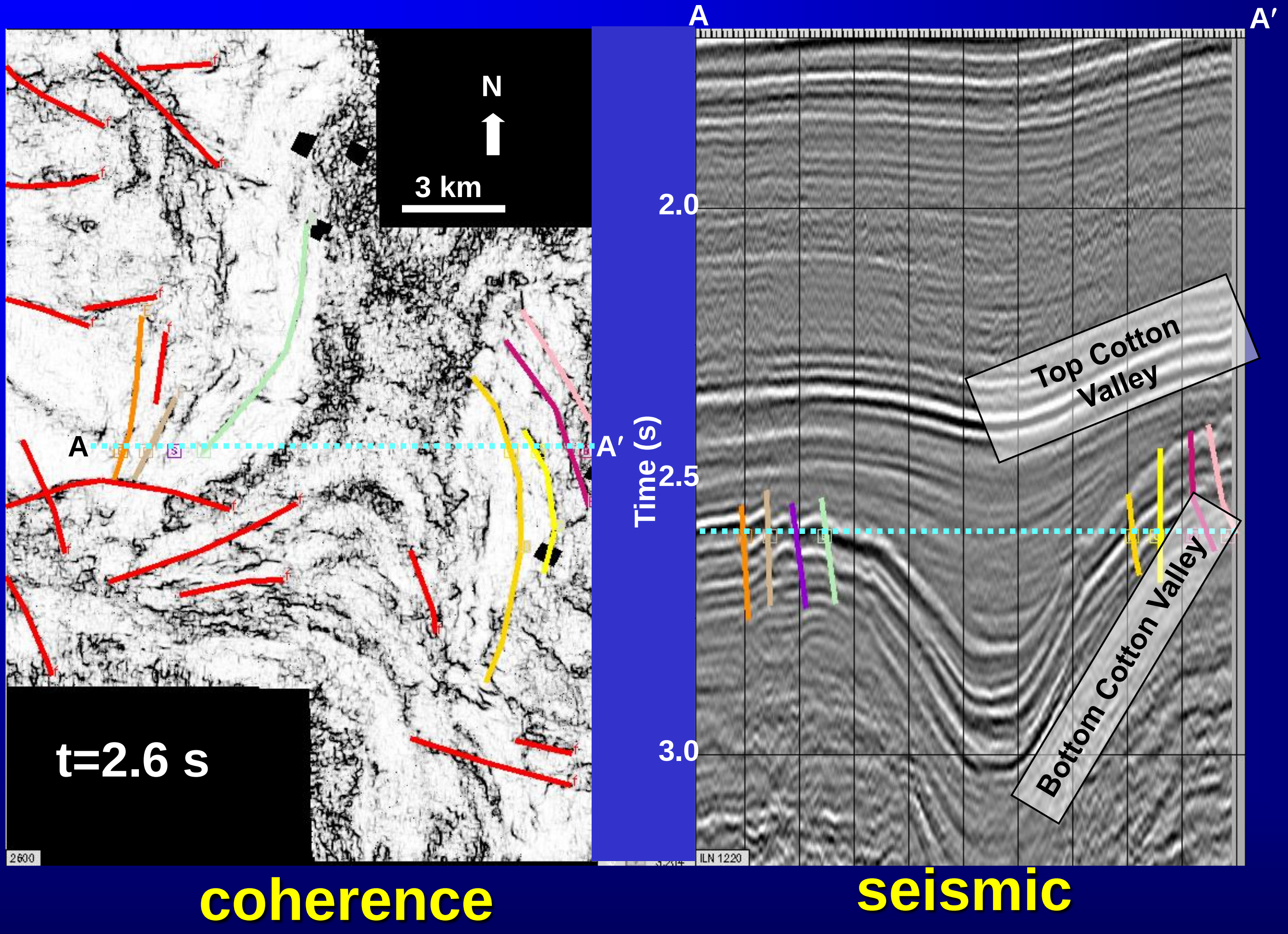
(Data courtesy of Seitel)





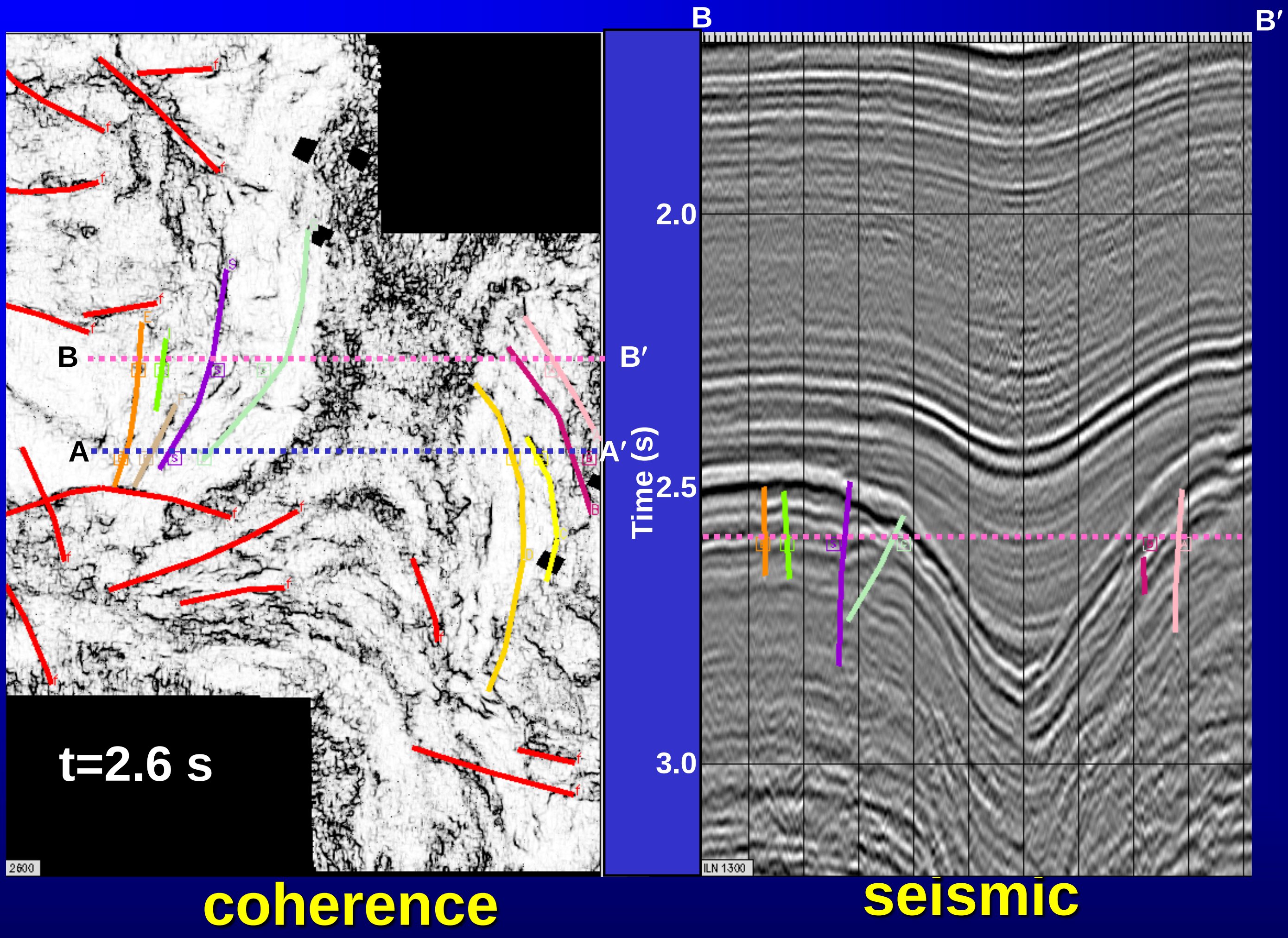
1) Pick on coherence using seismic time slice as a guide. Try to avoid stratigraphic discontinuities and unconformities

(Data courtesy of Seitel)



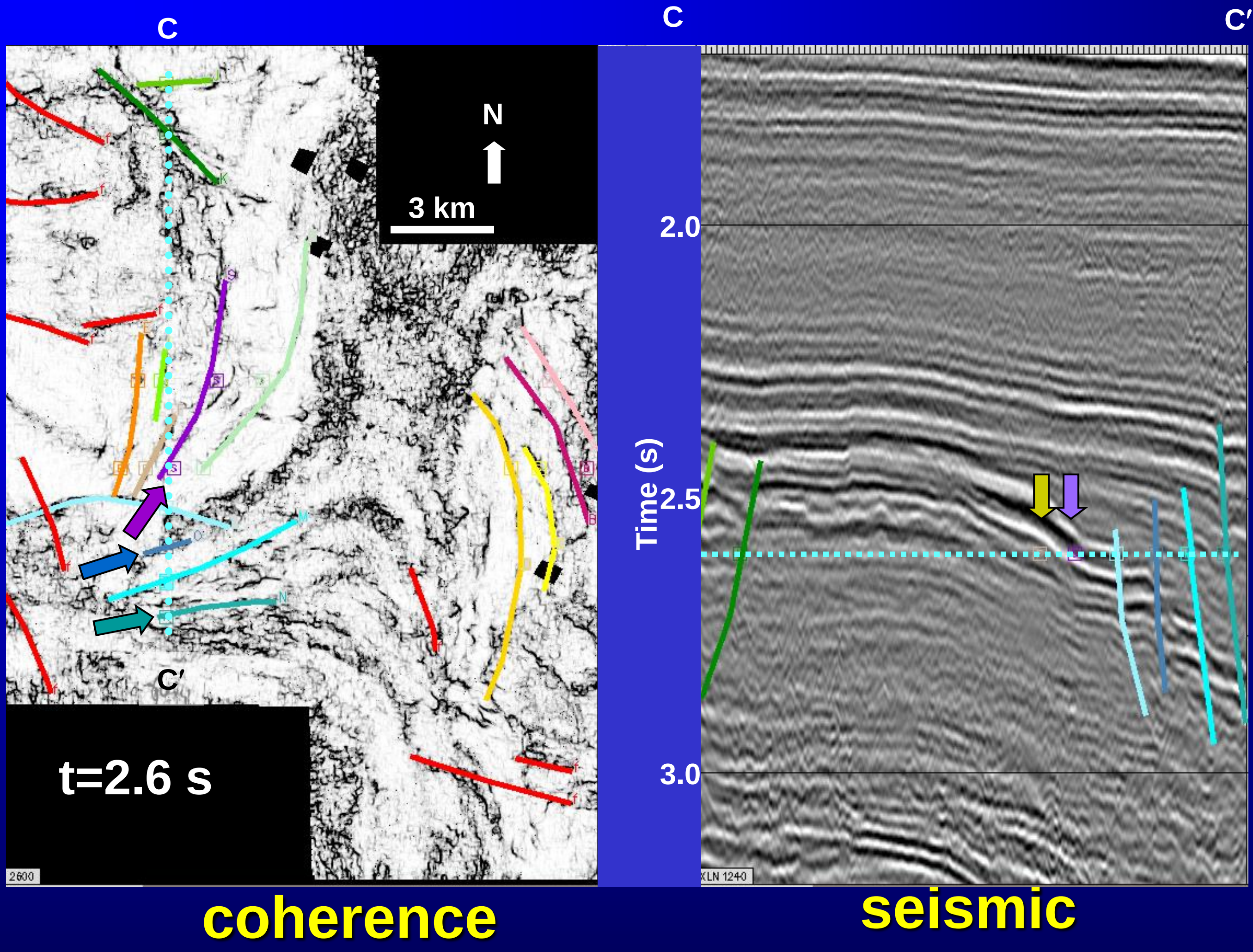
2) Choose a seismic line perpendicular to the fault traces. Pick and assign faults as you normally would.

(Data courtesy of Seitel)



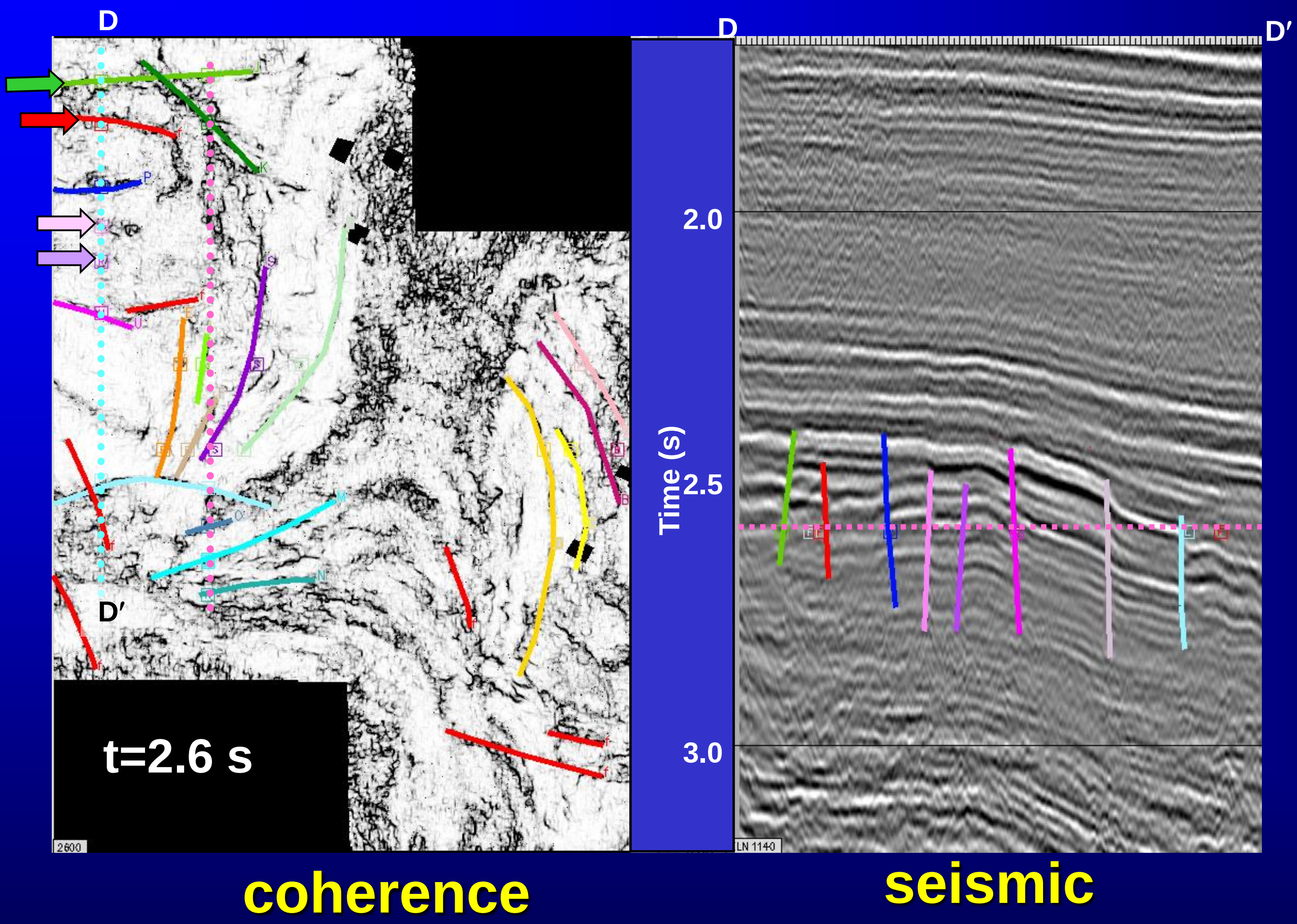
3) Choose a 2nd EW seismic line further down the fault trace to begin forming a coarse fault grid.

(Data courtesy of Seitel)



4) Pick a NS line and continue the process. If subtle discontinuities seen to be faults on seismic, track them on coherence.

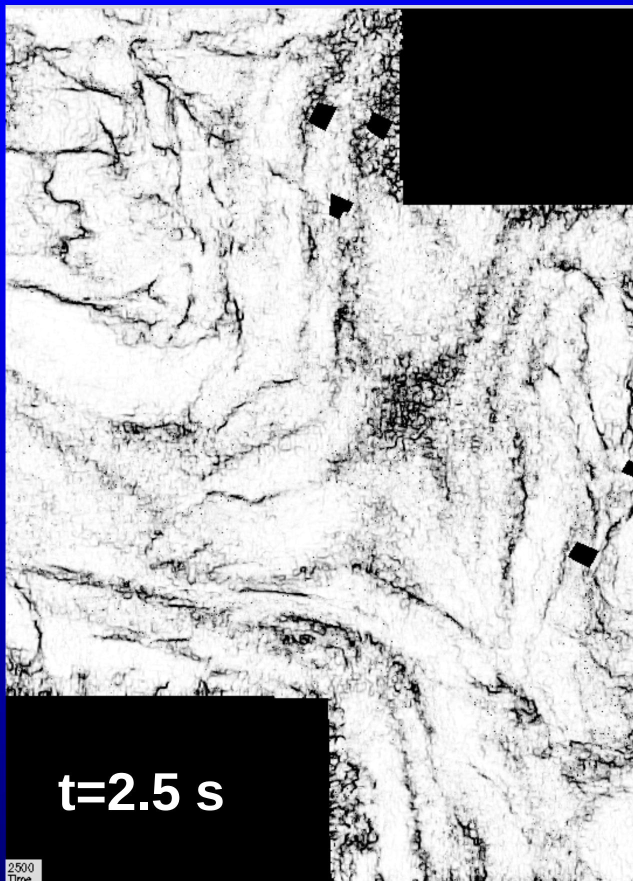
(Data courtesy of Seitel)



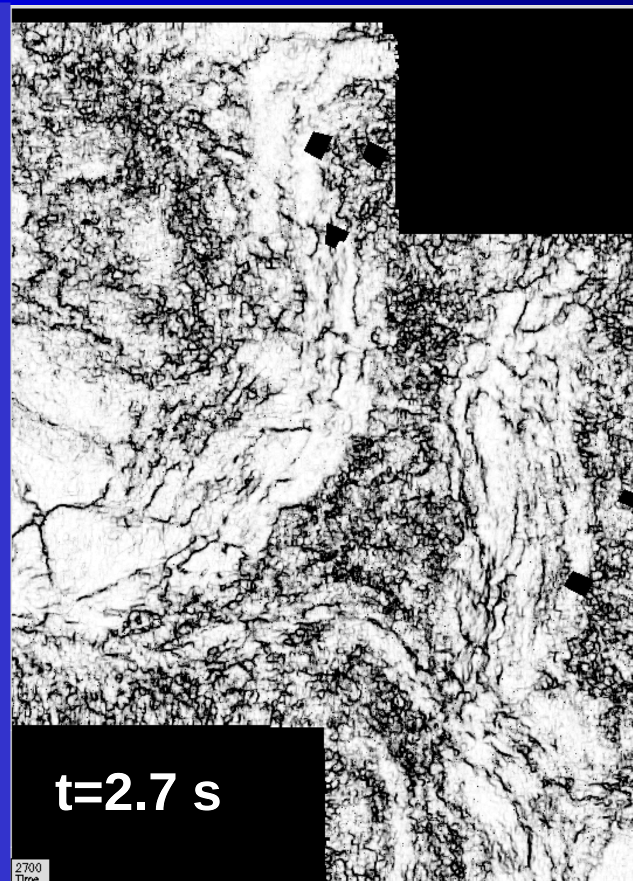
5) Pick additional NS lines and continue the process, forming a coarse grid.

(Data courtesy of Seitel)

6) Pick a new time slice through the coherence volume

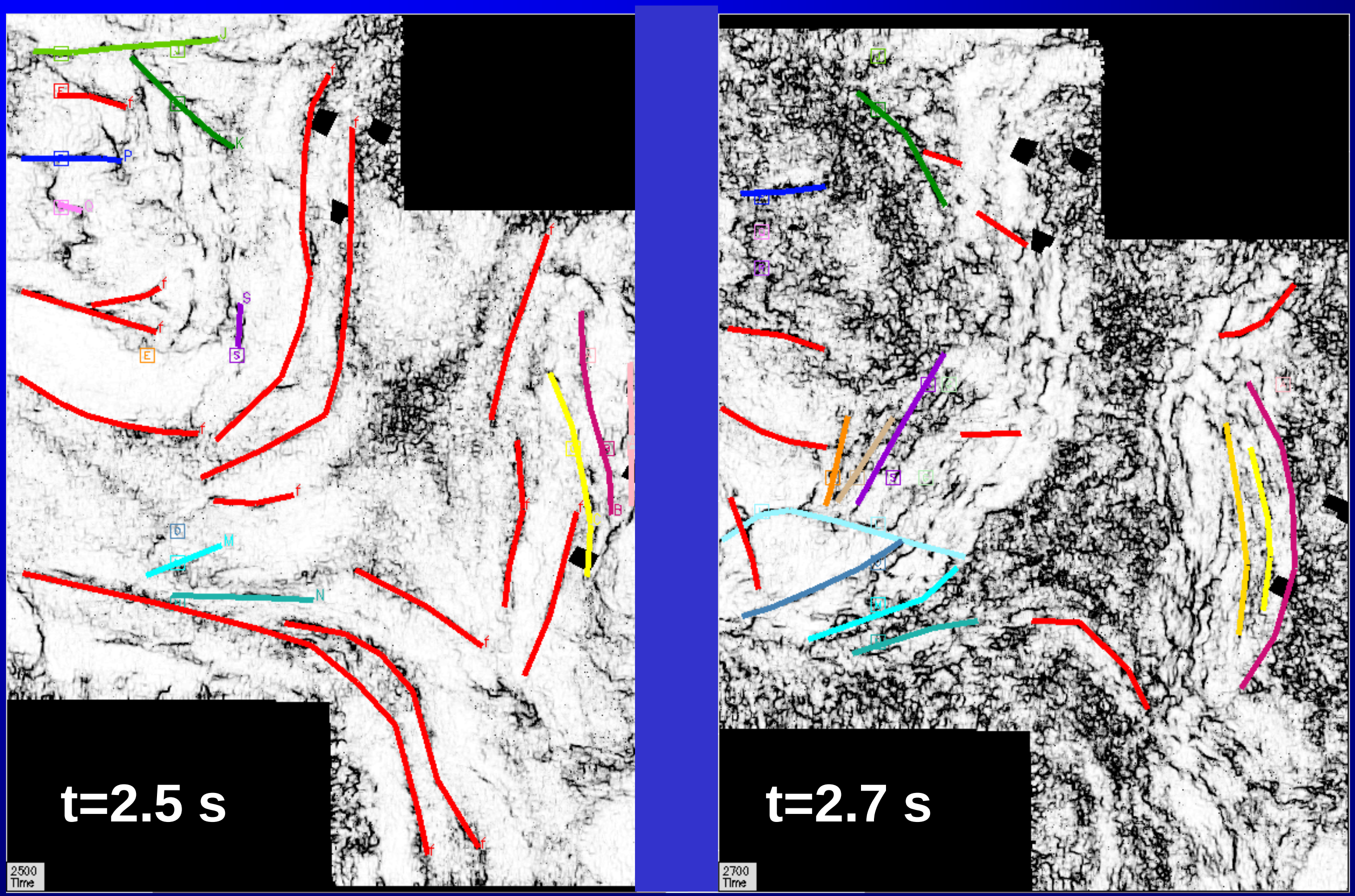


coherence



coherence

(Data courtesy of Seitel)



coherence

coherence

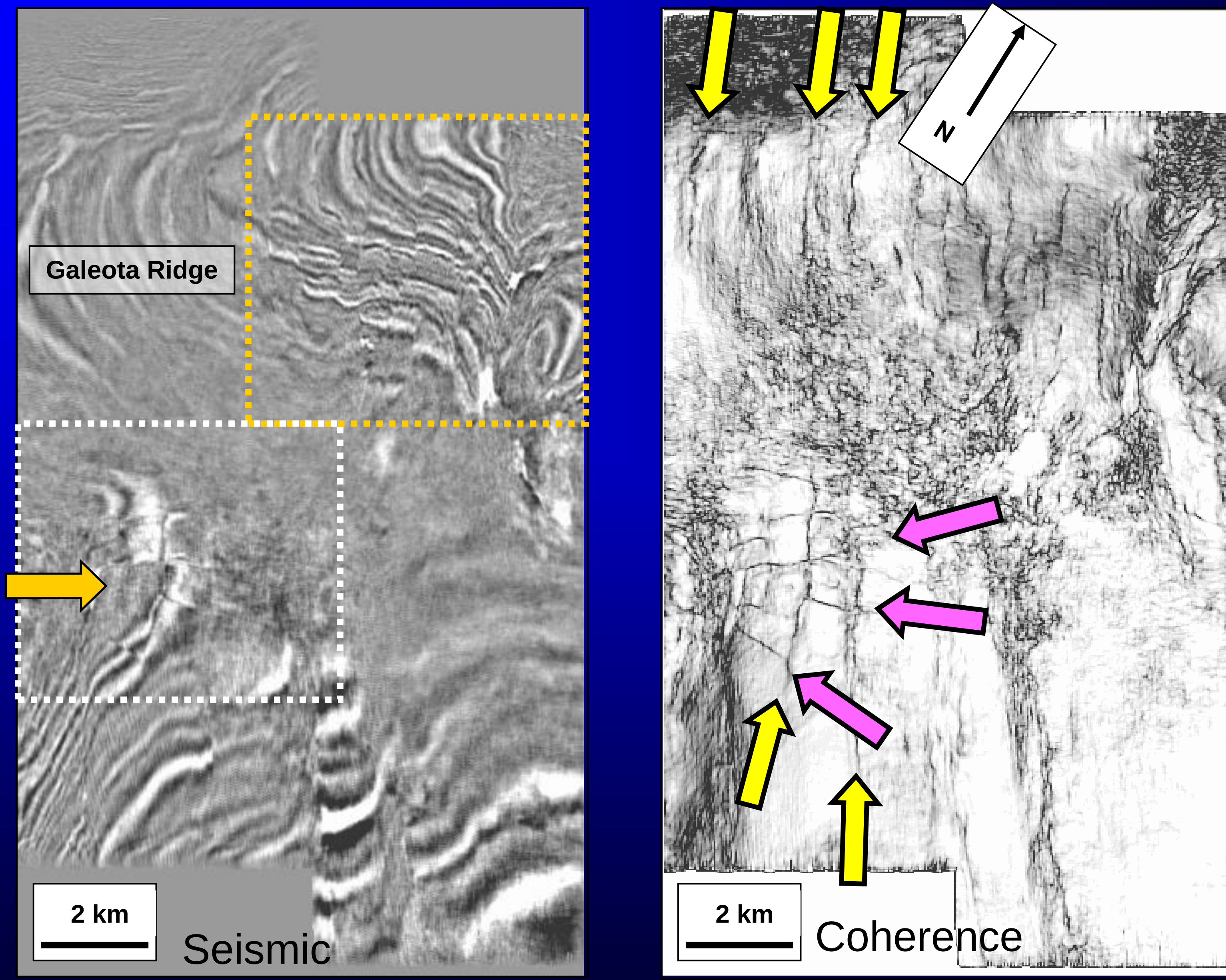
7) Use the cross-posted fault picks from the vertical seismic to guide your interpretation on the seismic coherence slices

(Data courtesy of Seitel)

Structural Deformation

Offshore Trinidad Time Slice (t=1.2 s)

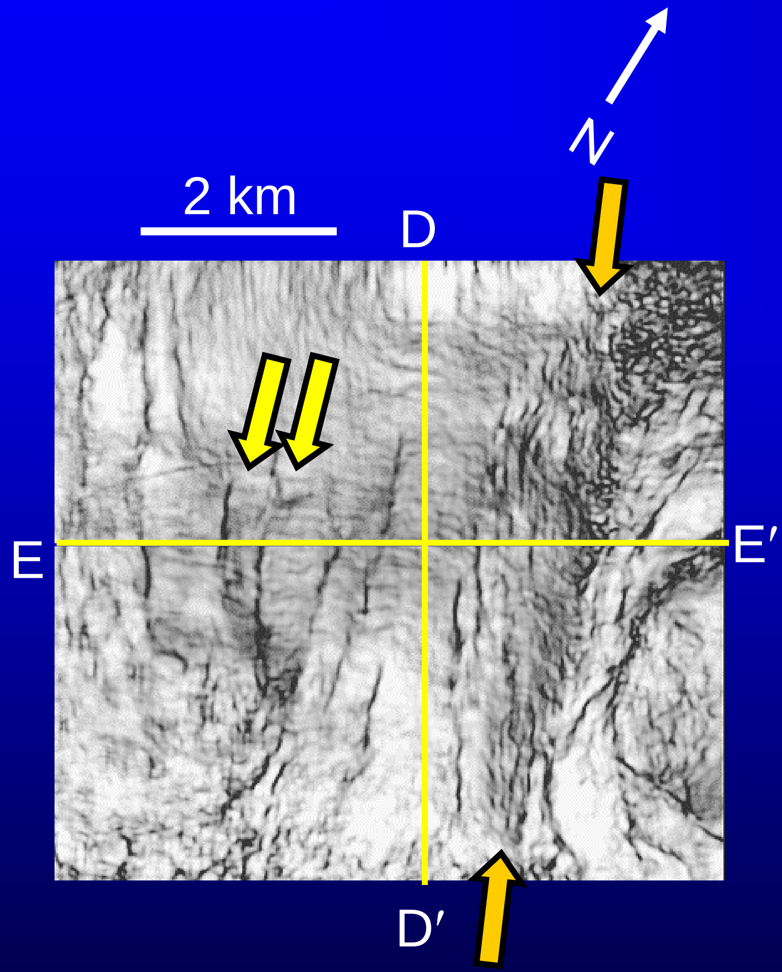
Complex faulting difficult to detect on seismic

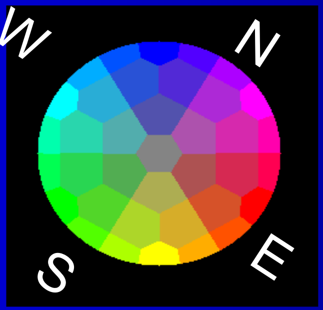


Coherence shows lateral continuity of faults

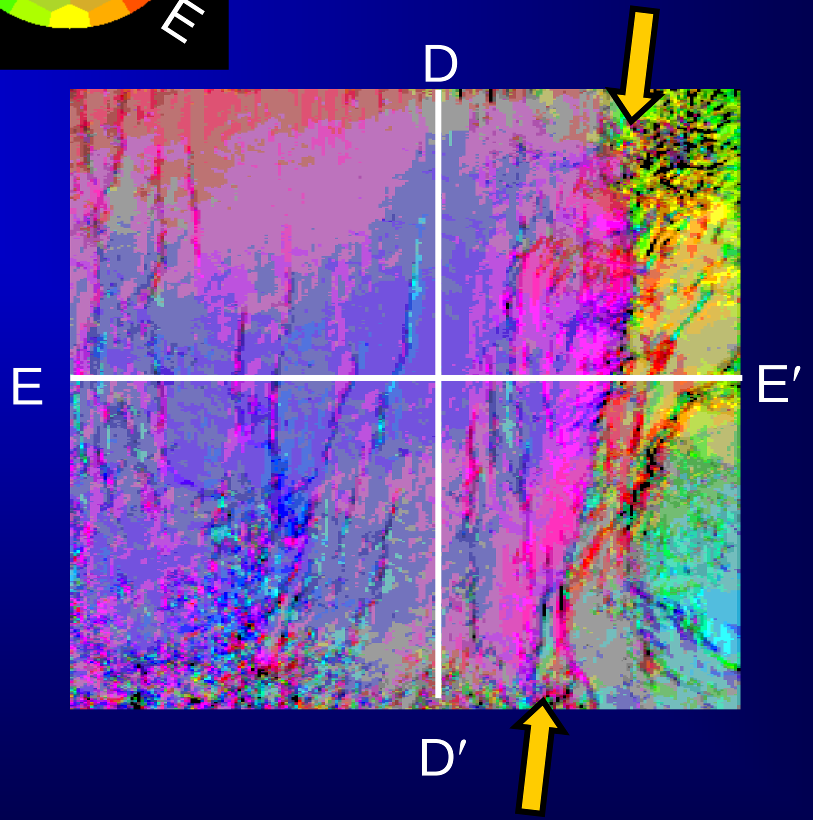
(Gersztenkorn et al., 1999)

Coherence Time Slice (1.1 s)



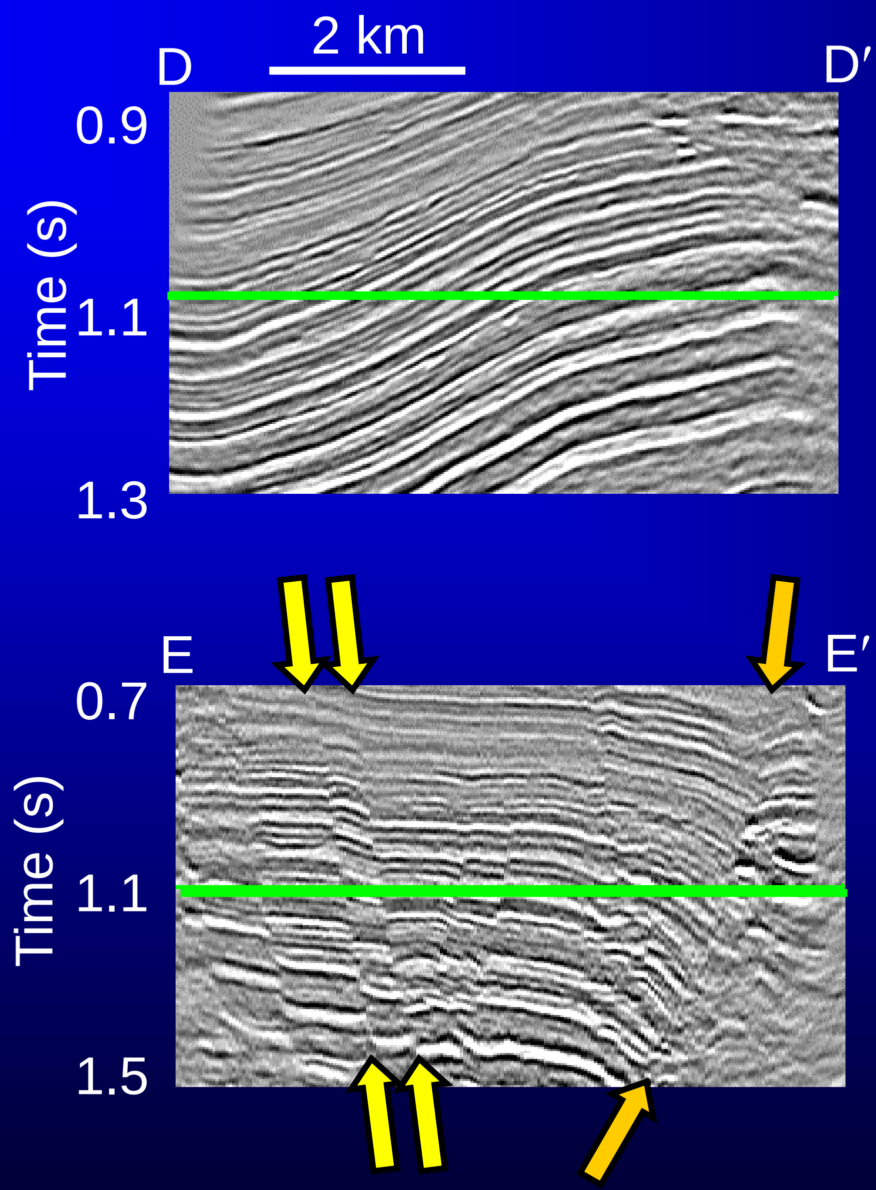


Dip / Azimuth Time Slice (1.1 s)



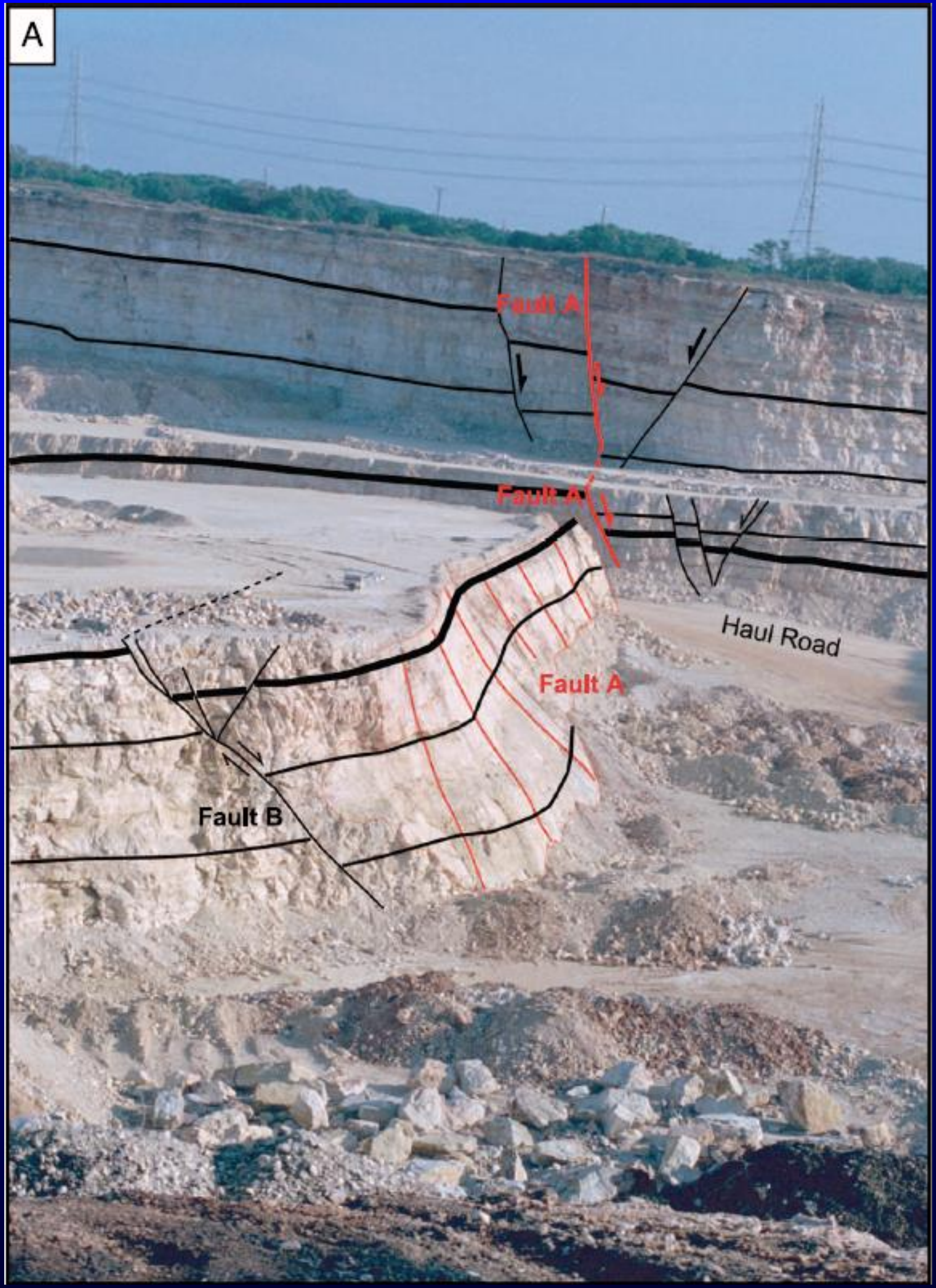
(Gersztenkorn et al., 1999)

Seismic Data



6a-65

(Gersztenkorn et al., 1999)

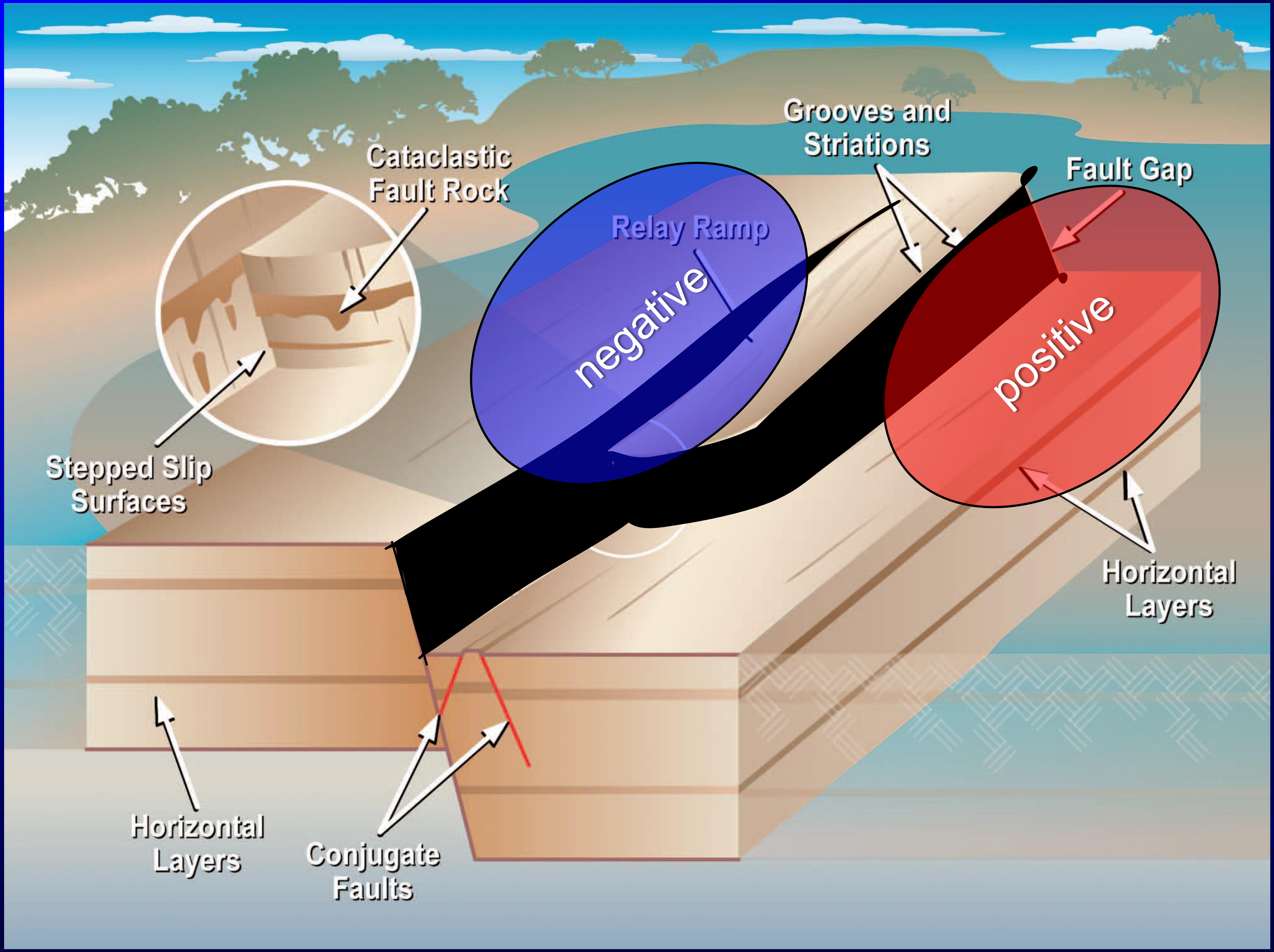


Deformation of Brittle Rocks

(A field study from Beckman Quarry, Georgetown, TX)

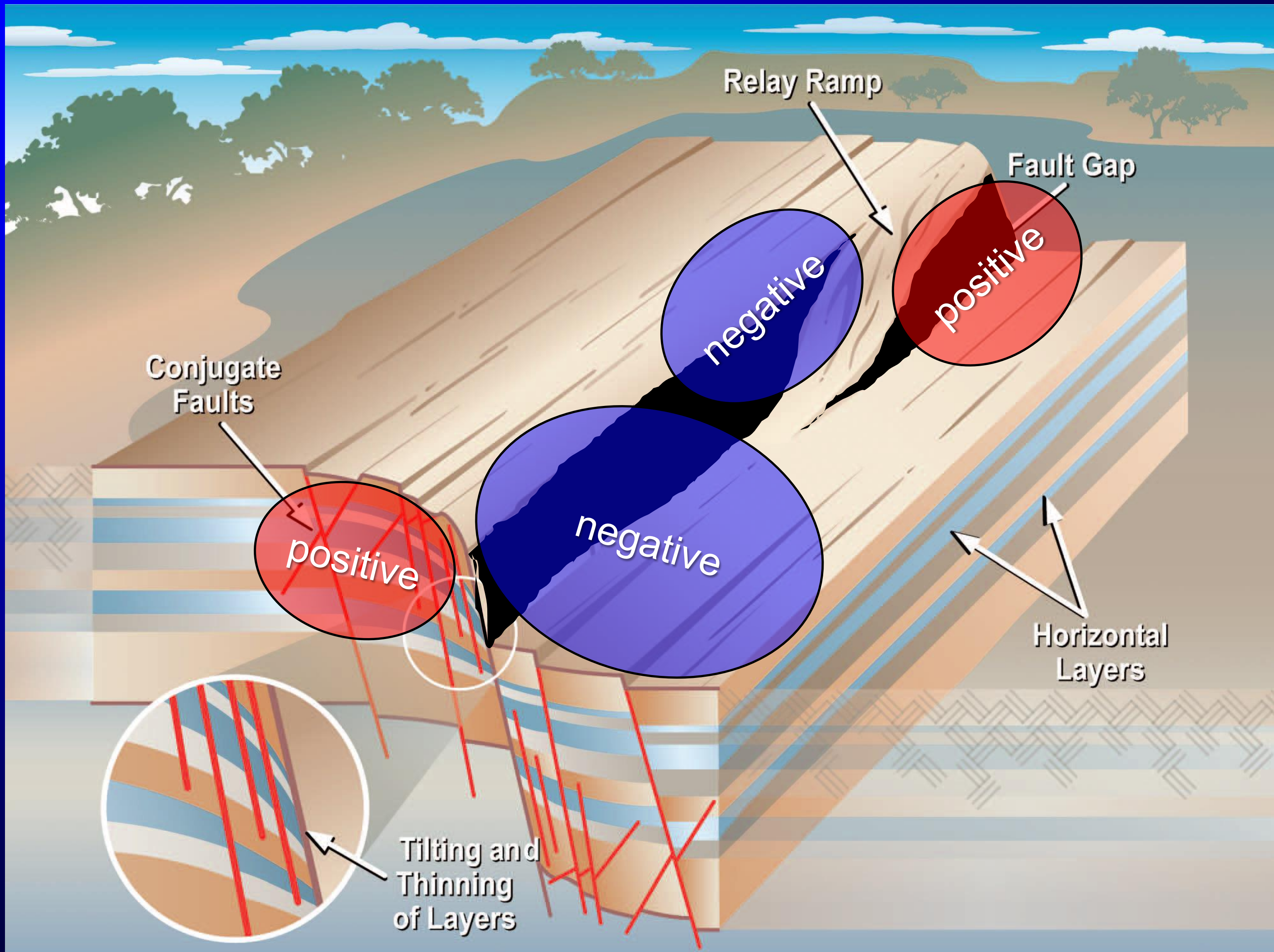
(Ferrill and Morris, 2008)

Deformation of highly competent rocks (Edwards Group)



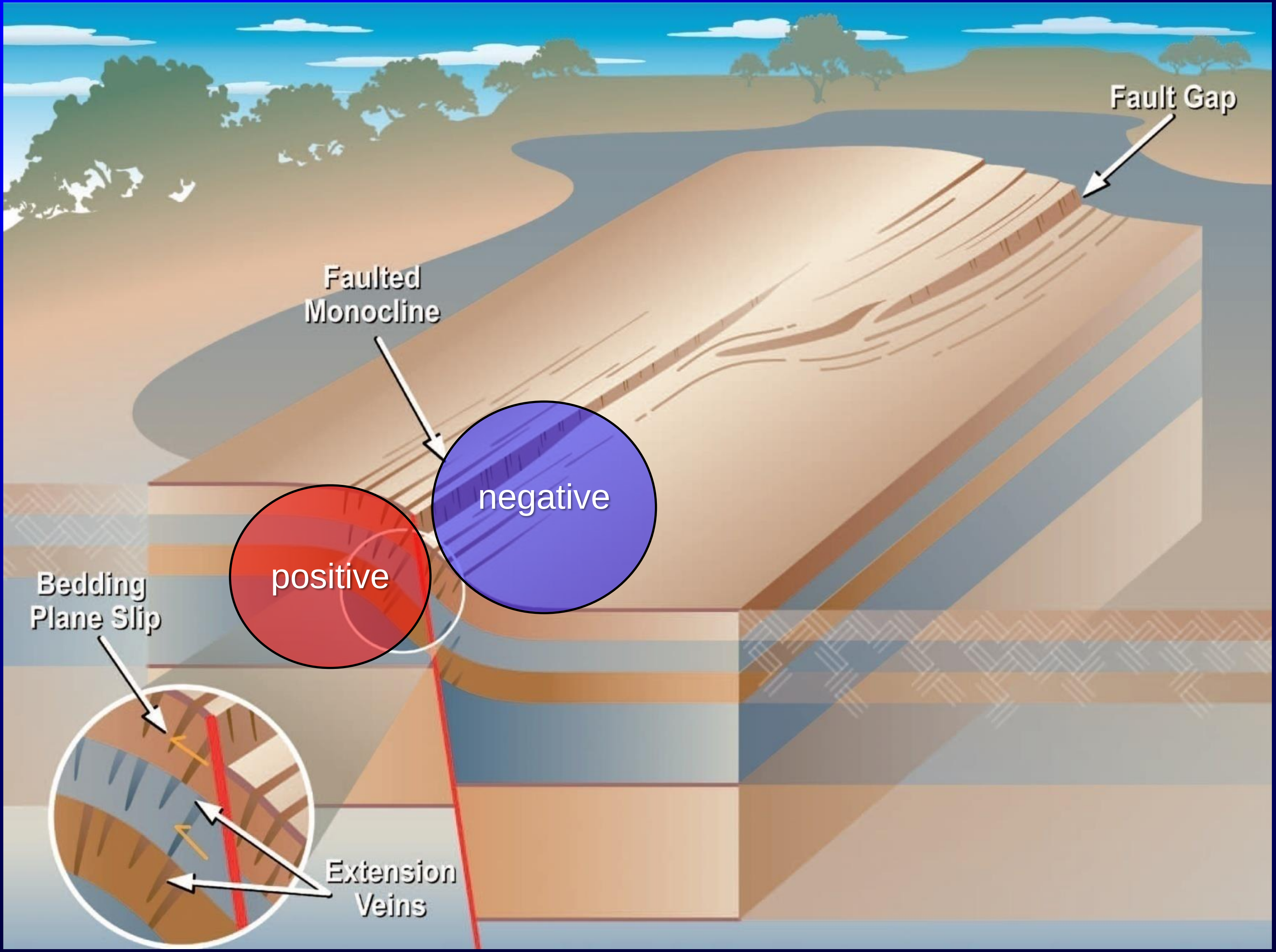
(Ferrill and Morris, 2008)

Deformation of mixed competency rocks (Glen Rose fm)



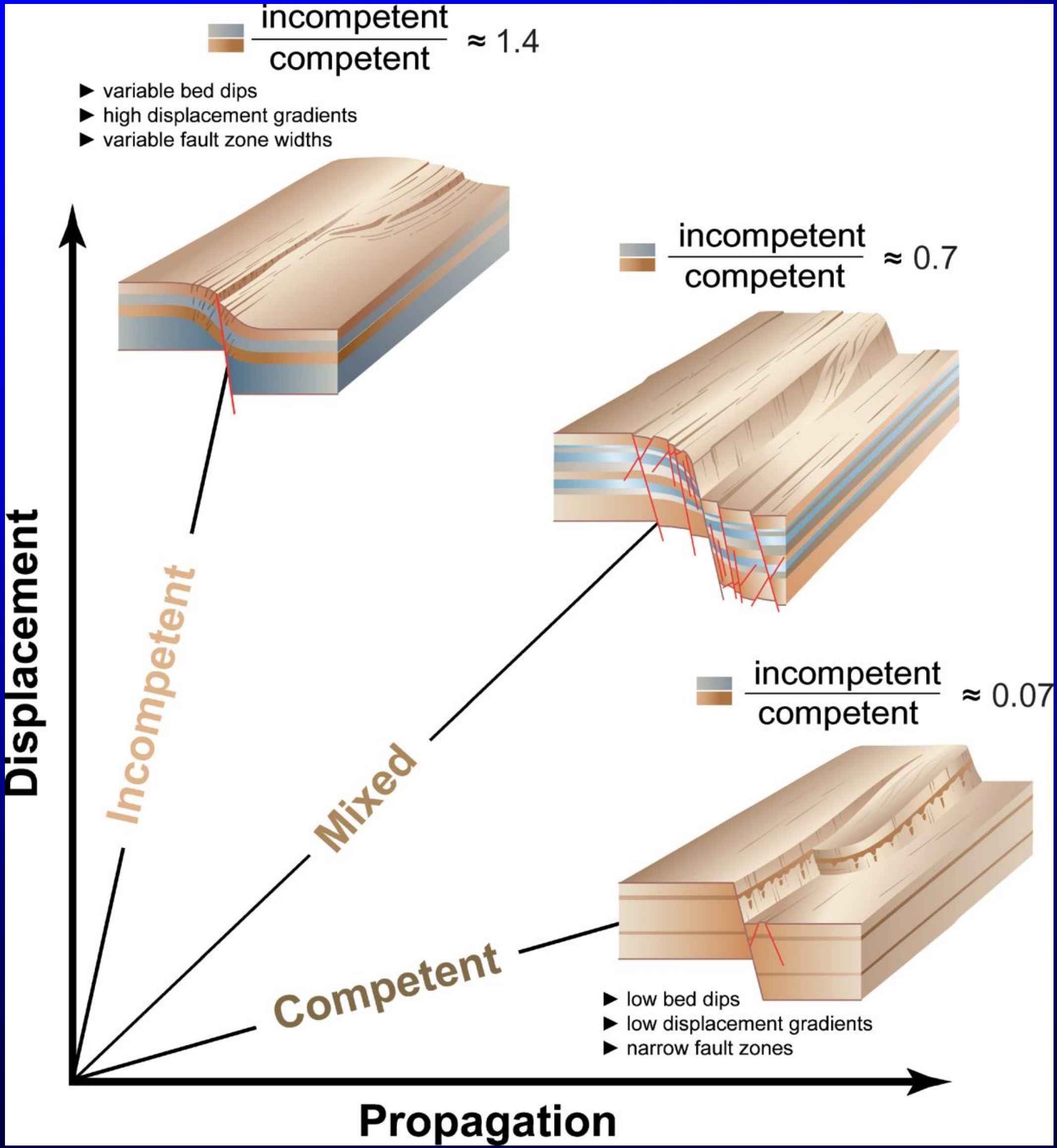
(Ferrill and Morris, 2008)

Deformation of less competent rocks (e.g. Eagleford fm)

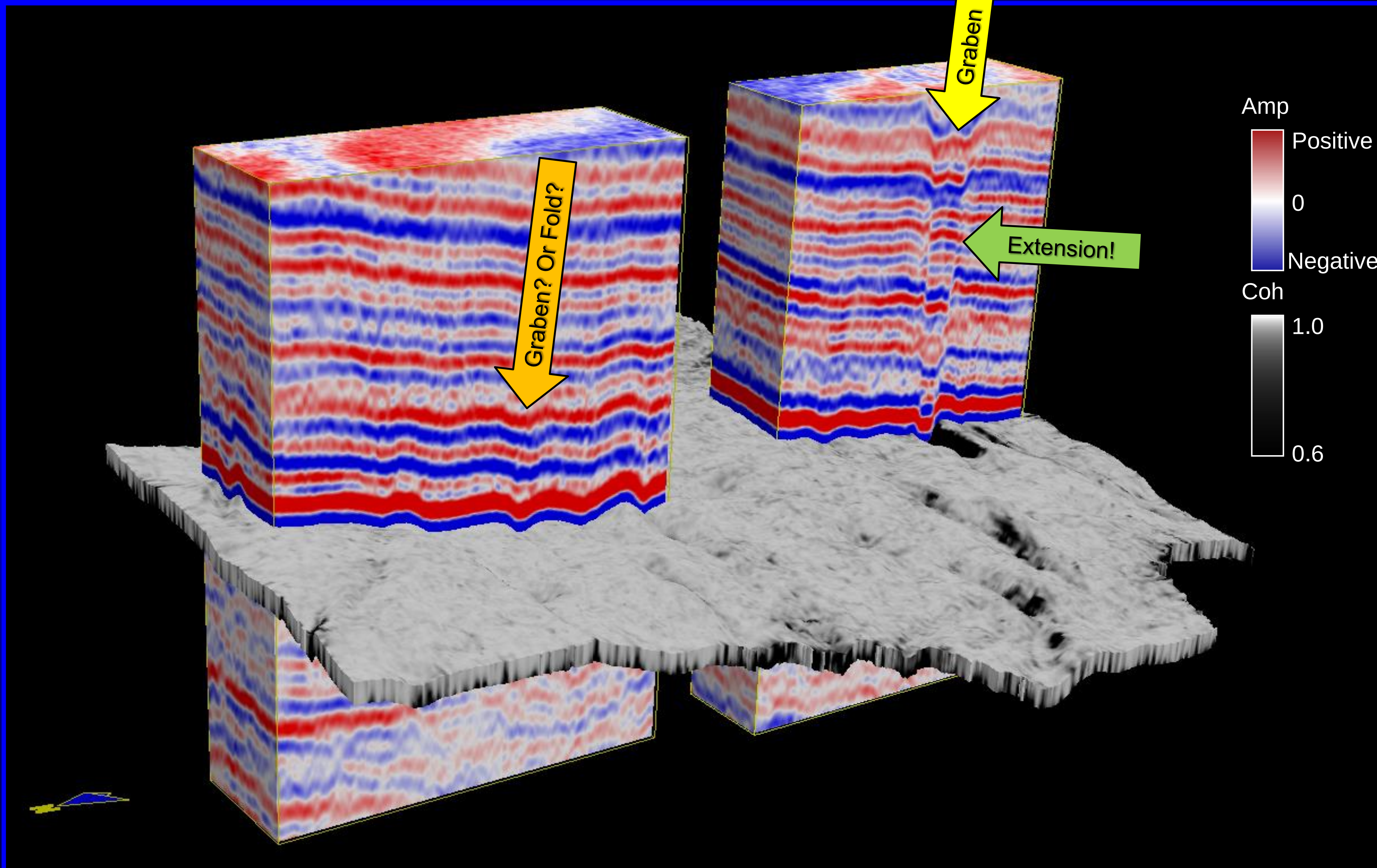


(Ferrill and Morris, 2008)

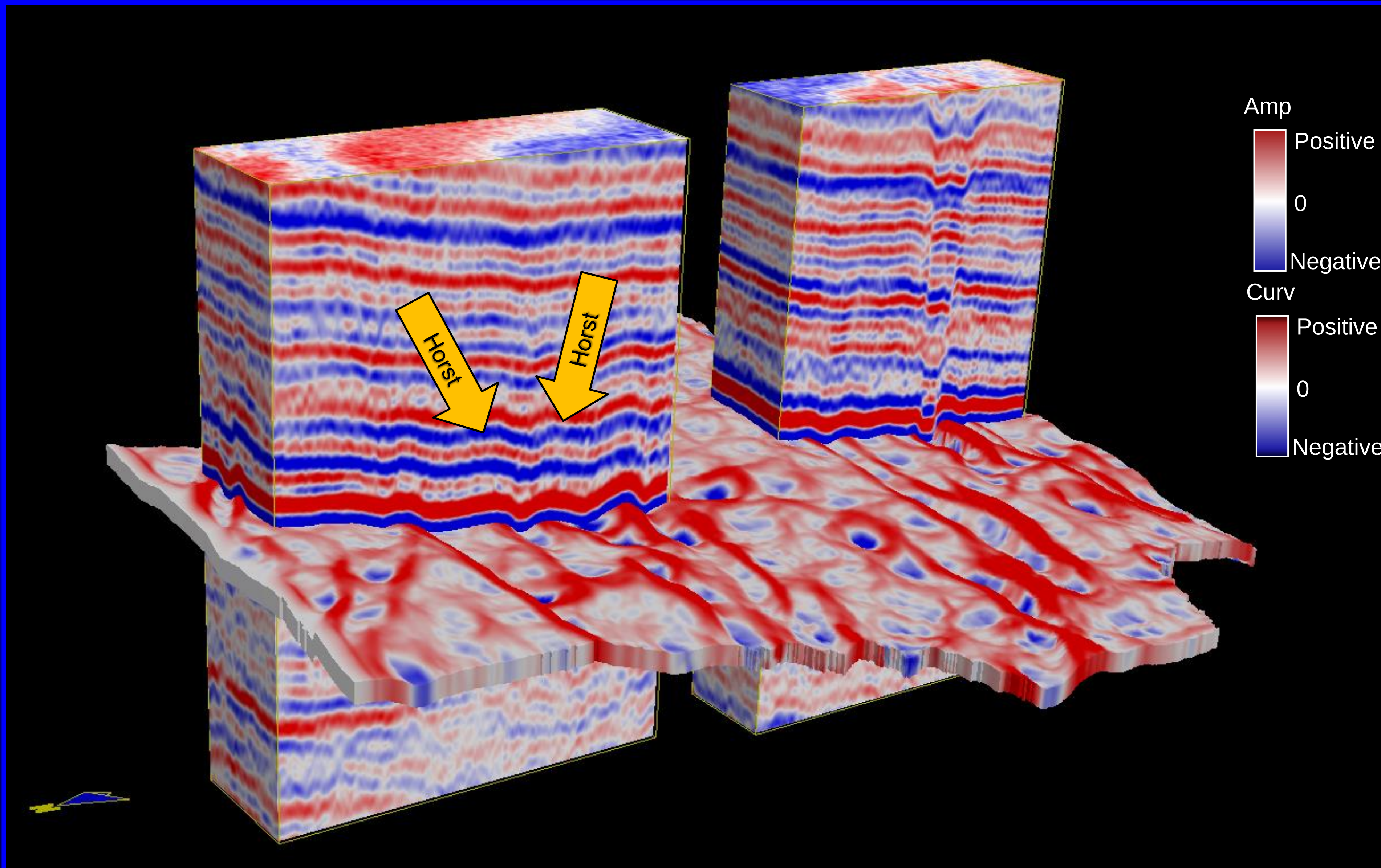
Summary of deformation of carbonate strata



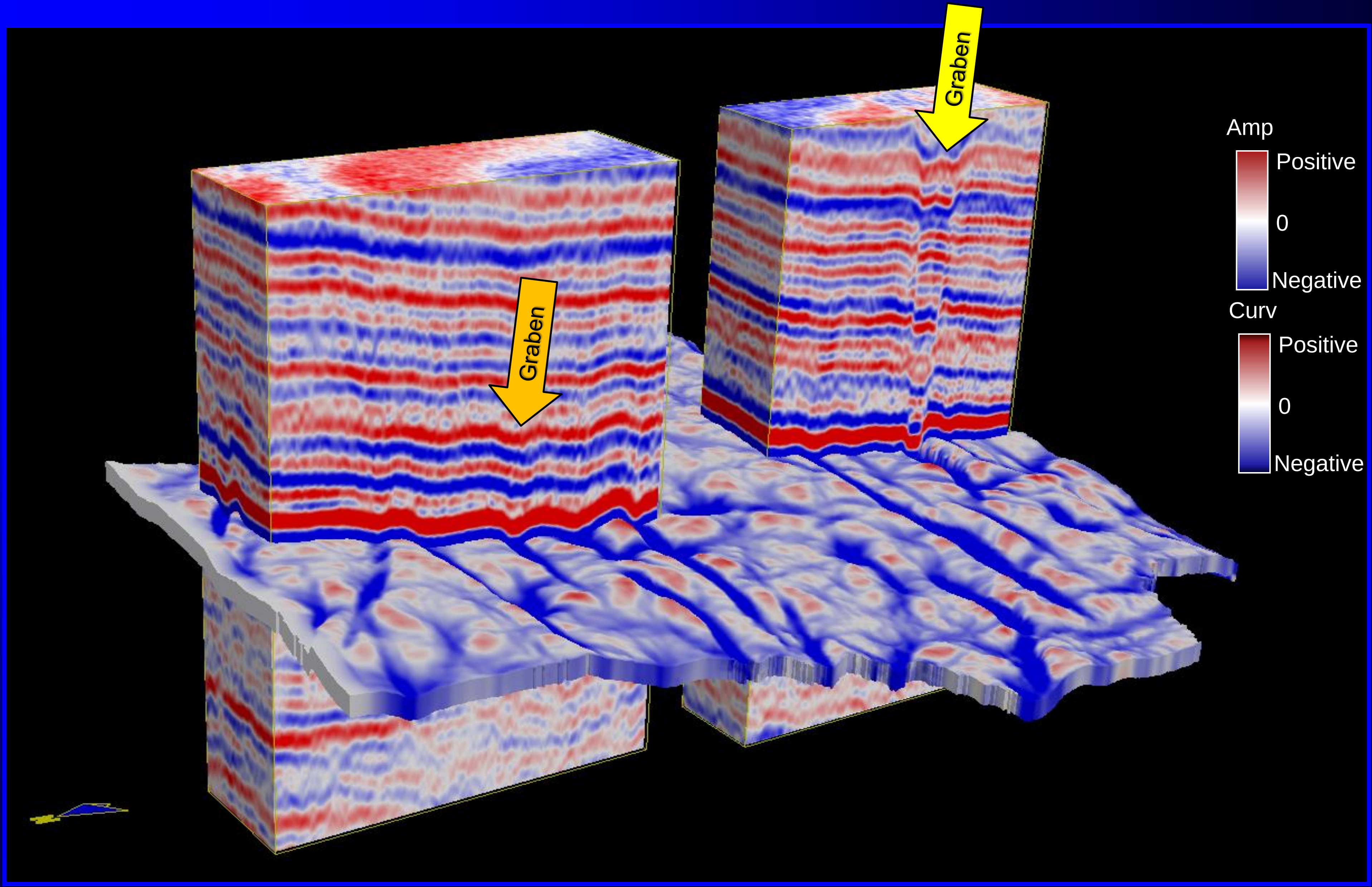
(Ferrill and Morris, 2008)



Coherence stratal-slice shown correlated with seismic sub-volumes

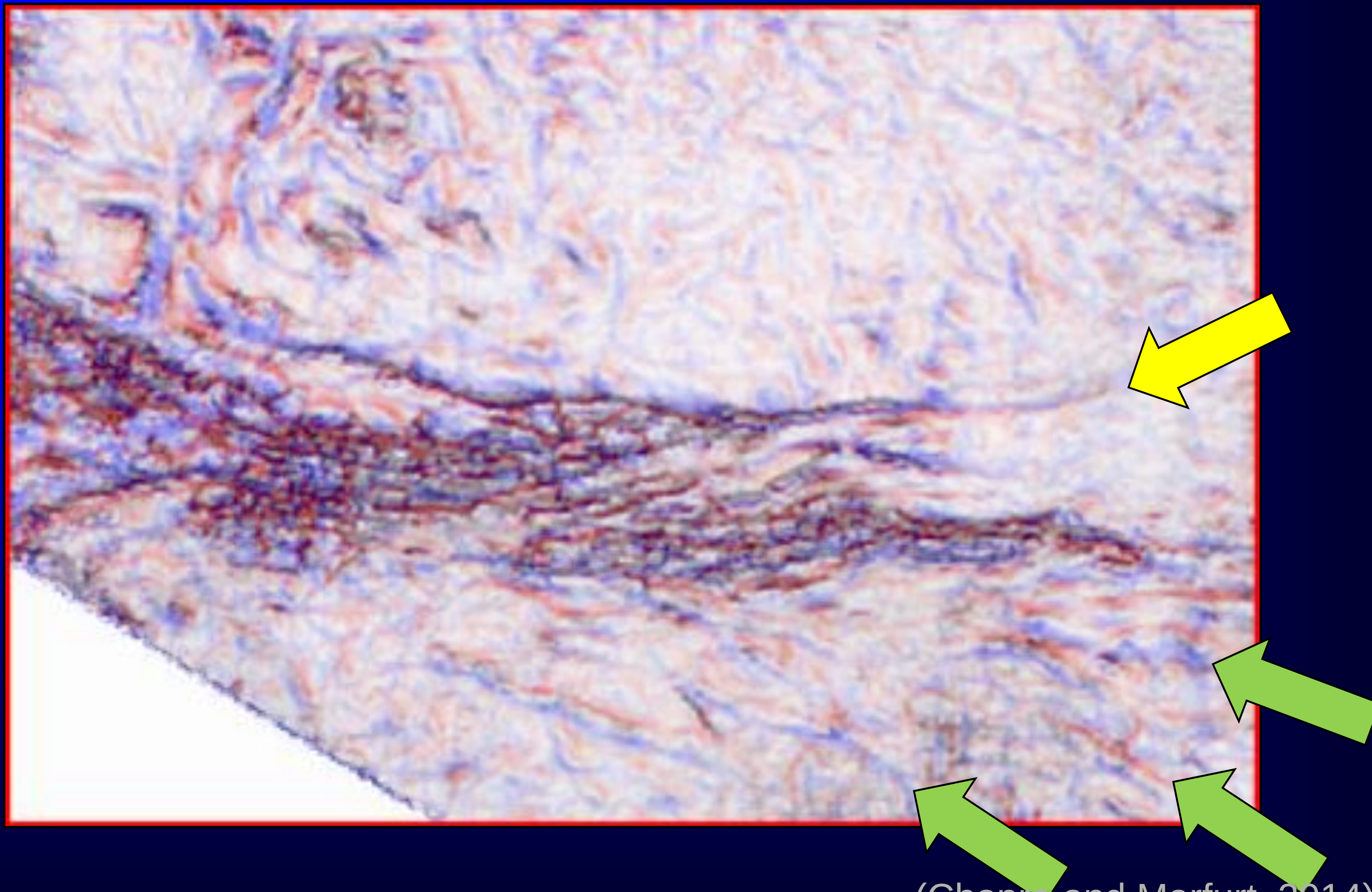


Most-positive curvature stratal-slice shown correlated with seismic sub-volumes



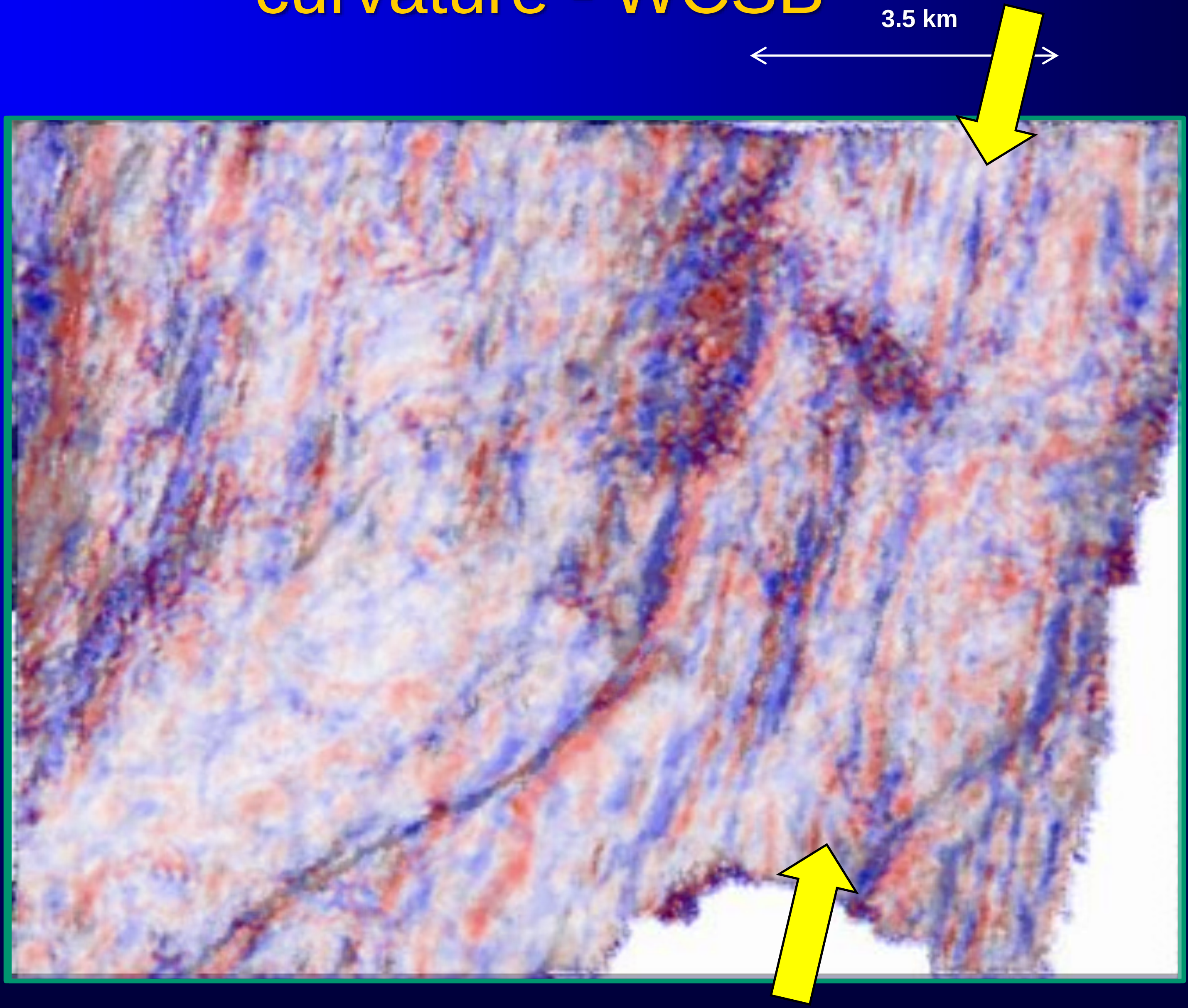
Most-negative curvature stratal-slice shown correlated with seismic sub-volumes

Co-rendering coherence and curvature - WCSB



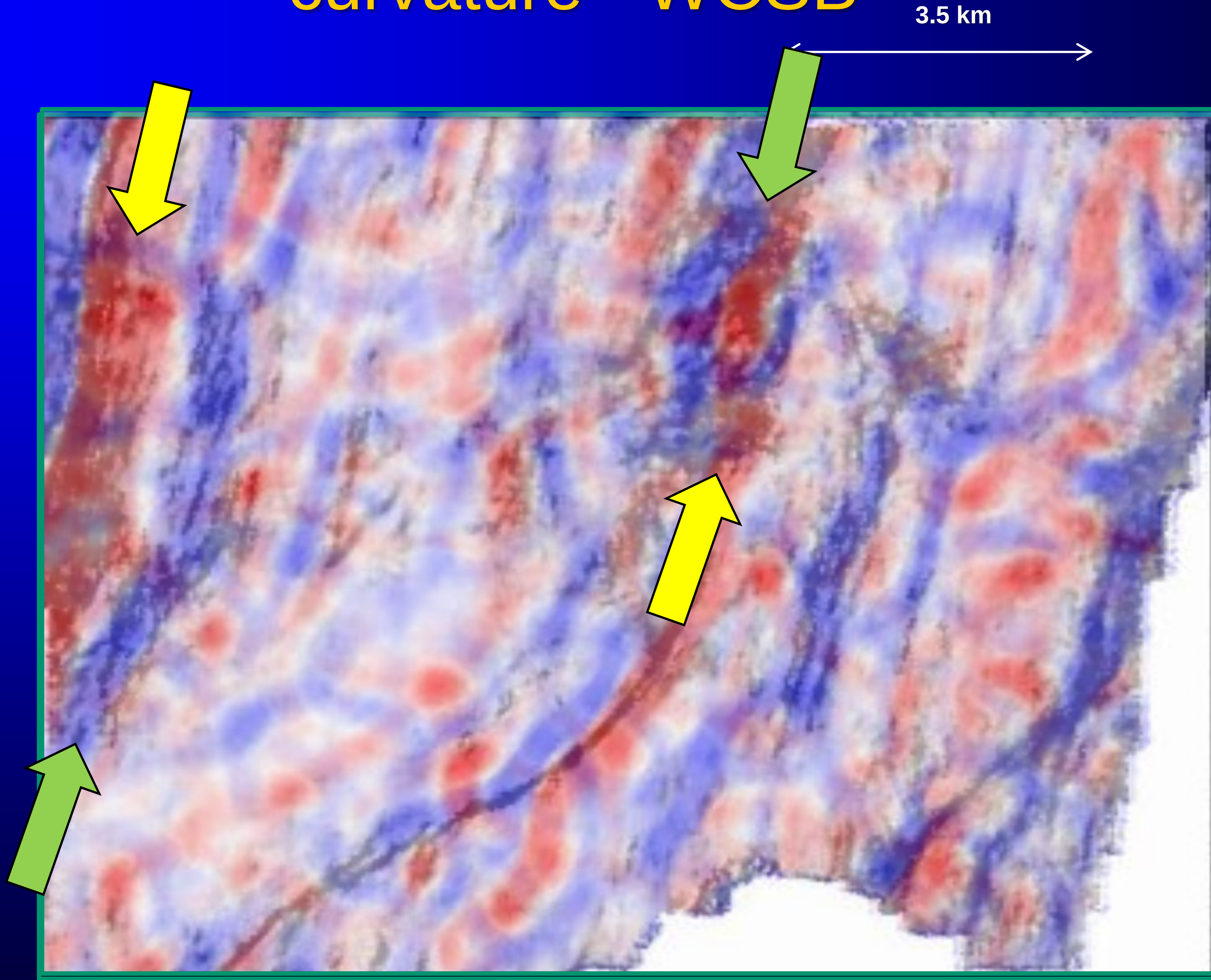
(Chopra and Marfurt, 2014)

Co-rendering coherence and short-wavelength curvature - WCSB



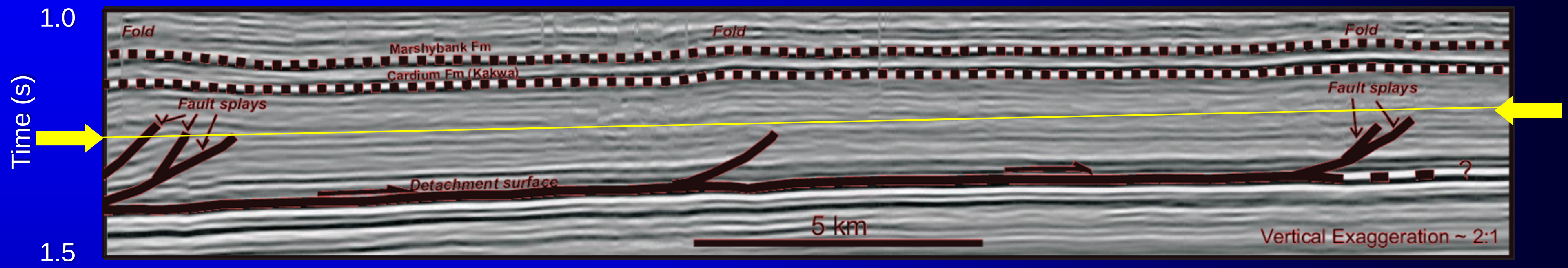
(Chopra and Marfurt, 2015)

Co-rendering coherence and long-wavelength curvature - WCSB



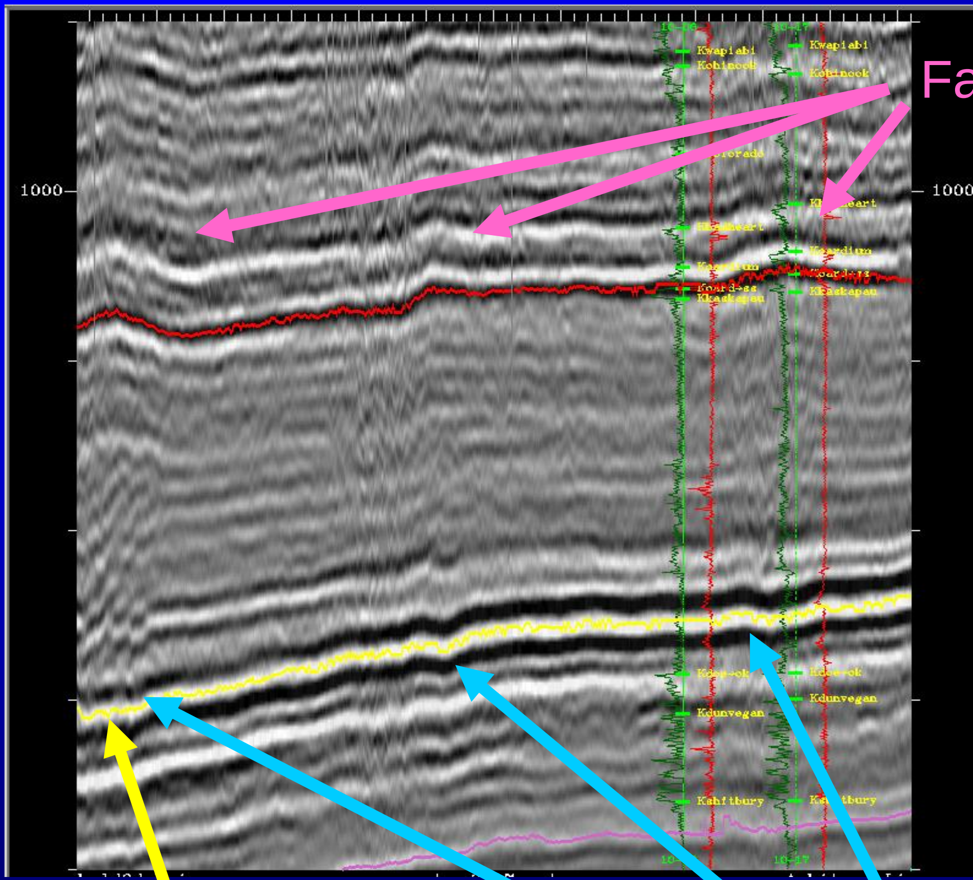
(Chopra and Marfurt, 2015)

Reverse faulting

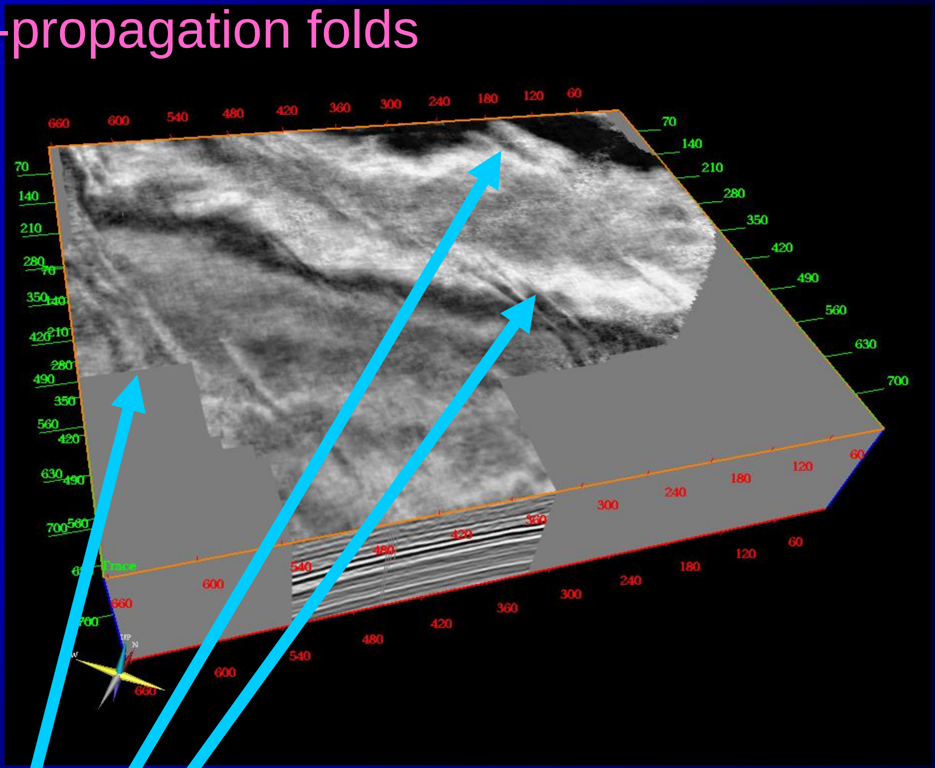


(Hart et al., 2007)

Cross-section view



Cube/timeslice view

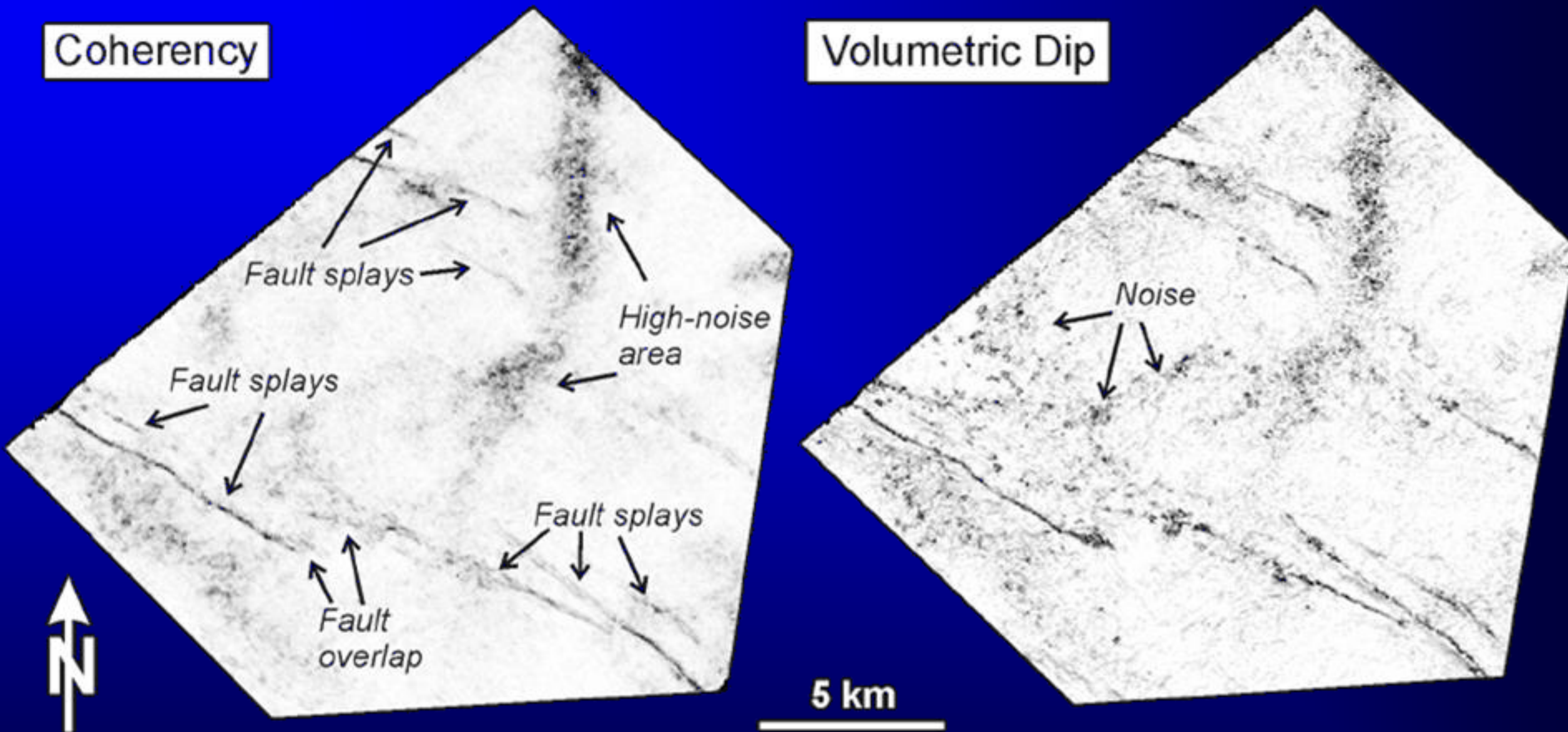


Fault-propagation folds

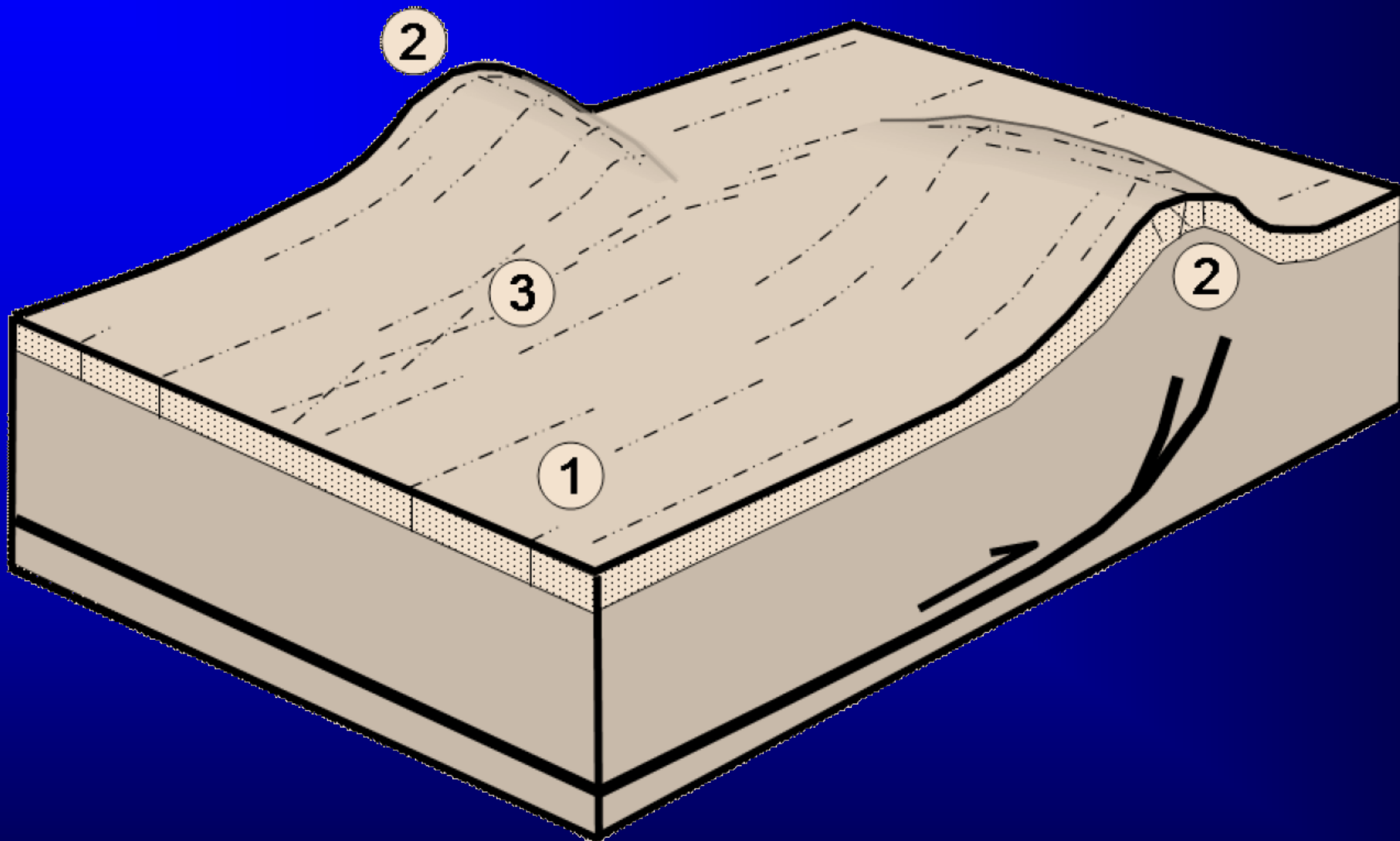
Faults do not extend below yellow horizon – detachment surface?

Small thrust faults

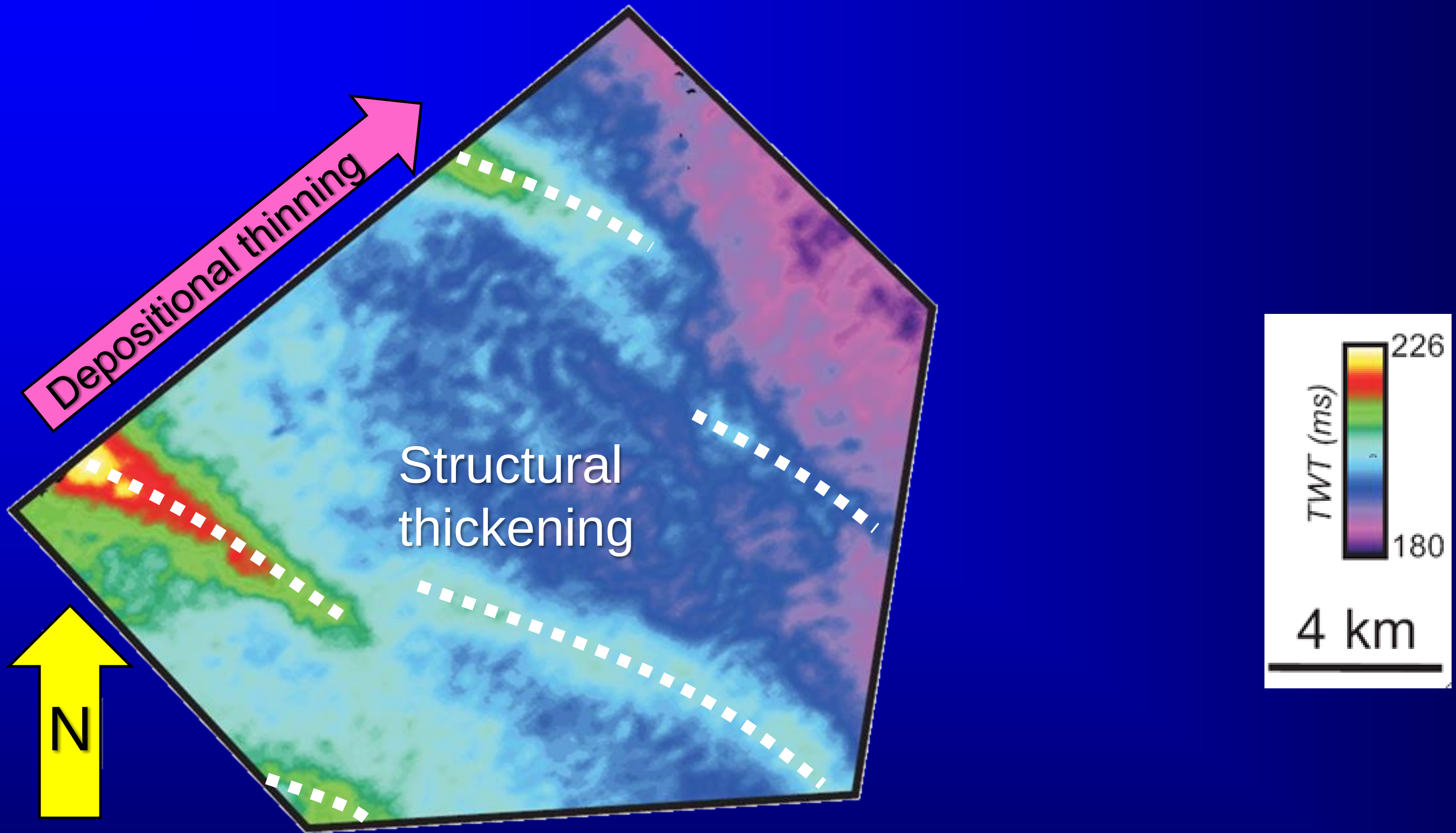
(Hart et al., 2007)



(Hart et al., 2007)

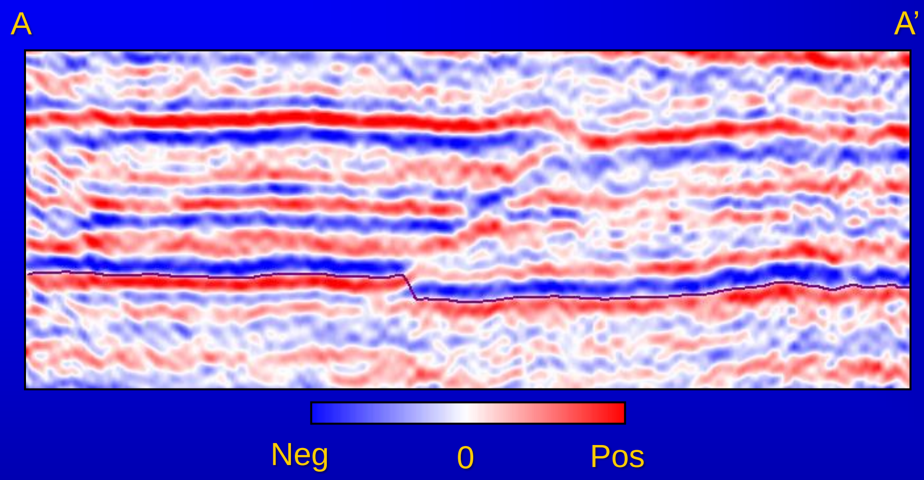


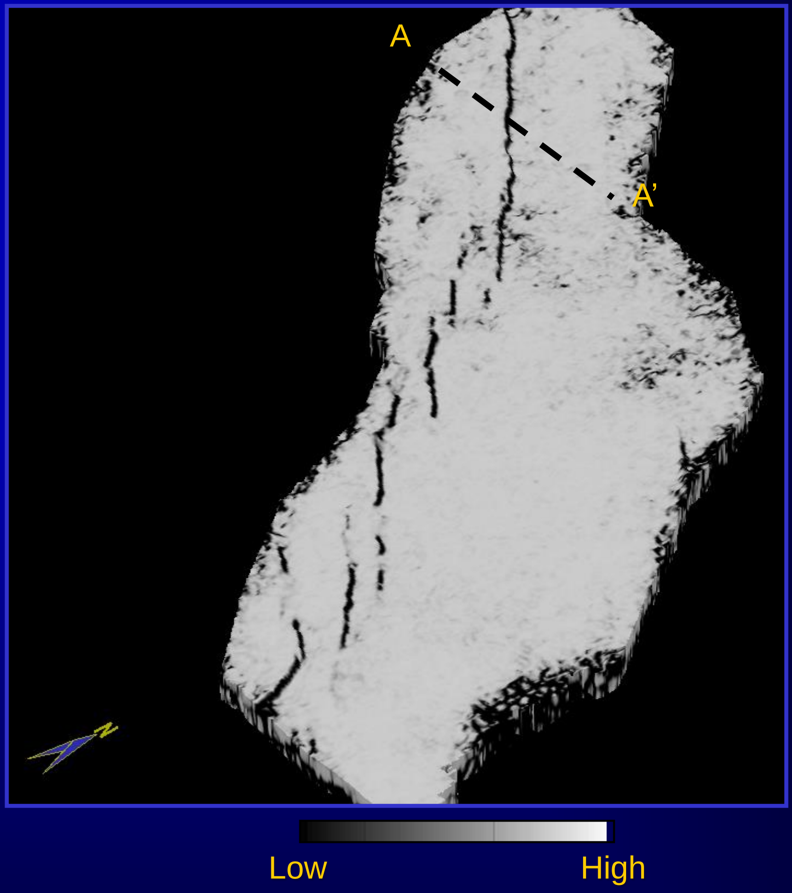
(Hart et al., 2007)



(Hart et al., 2007)

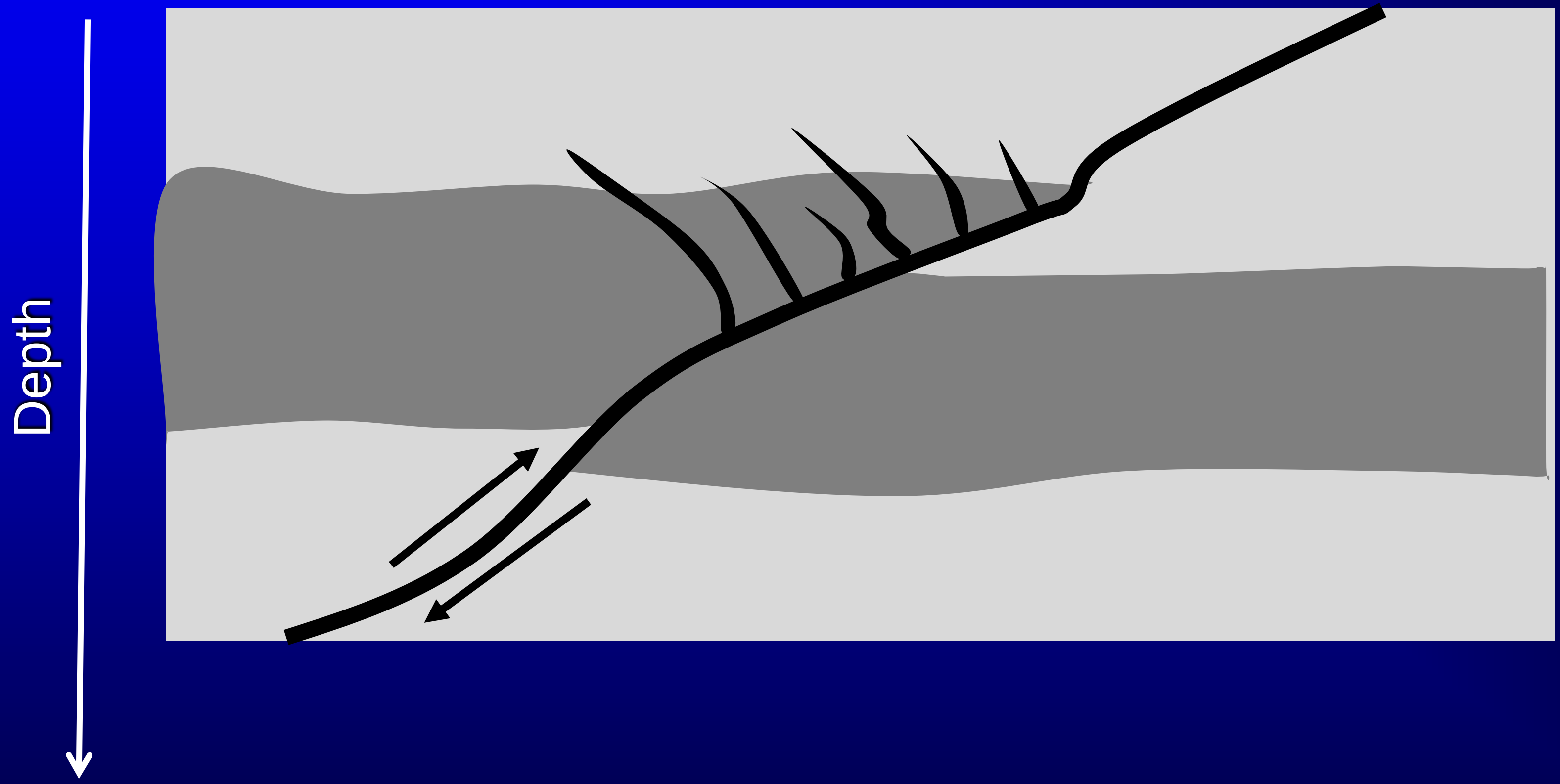
Reverse Faulting (Alberta, Canada)



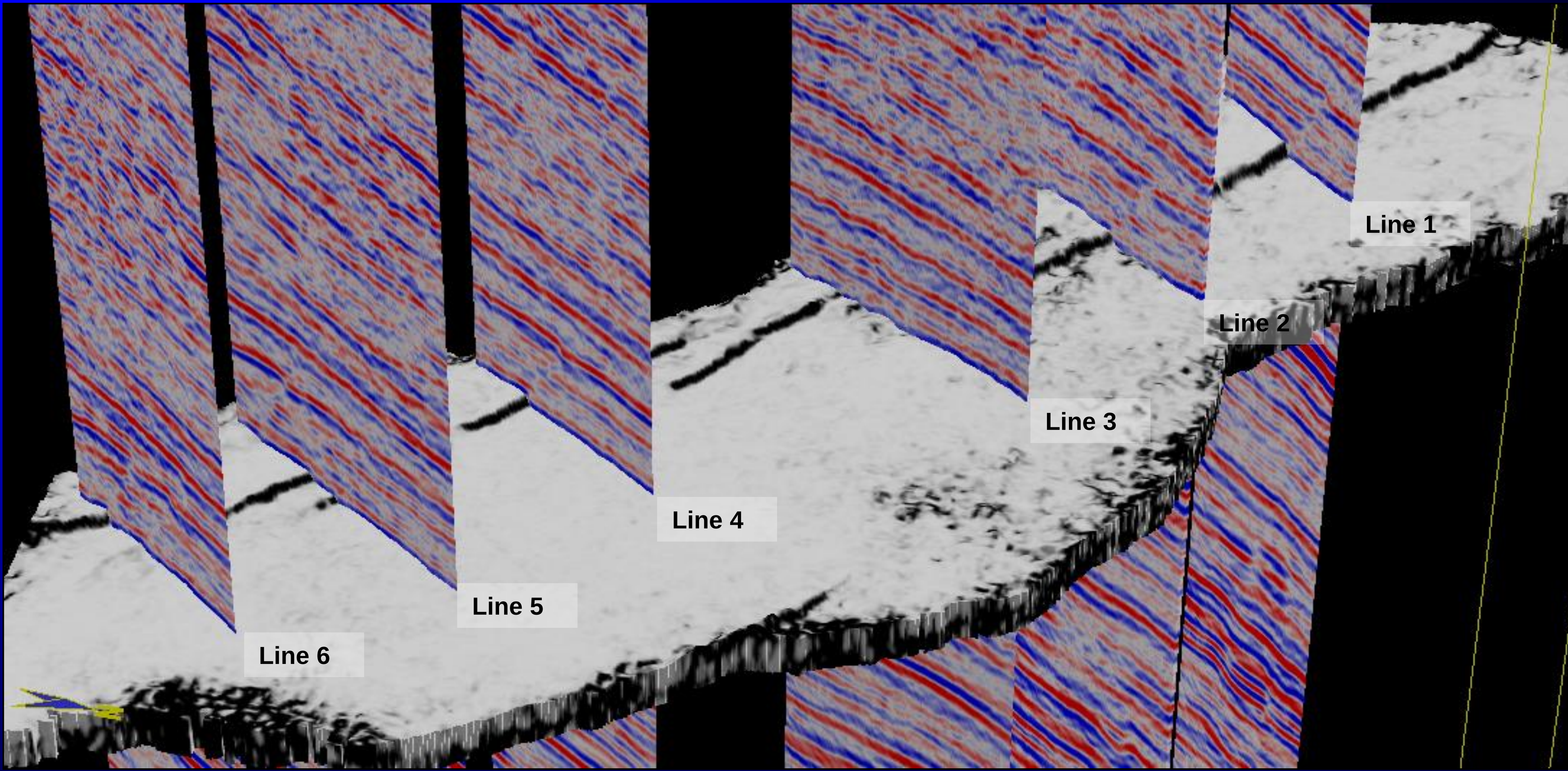


(Chopra and Marfurt, 2007b)

Fractures associated with non-planar faults

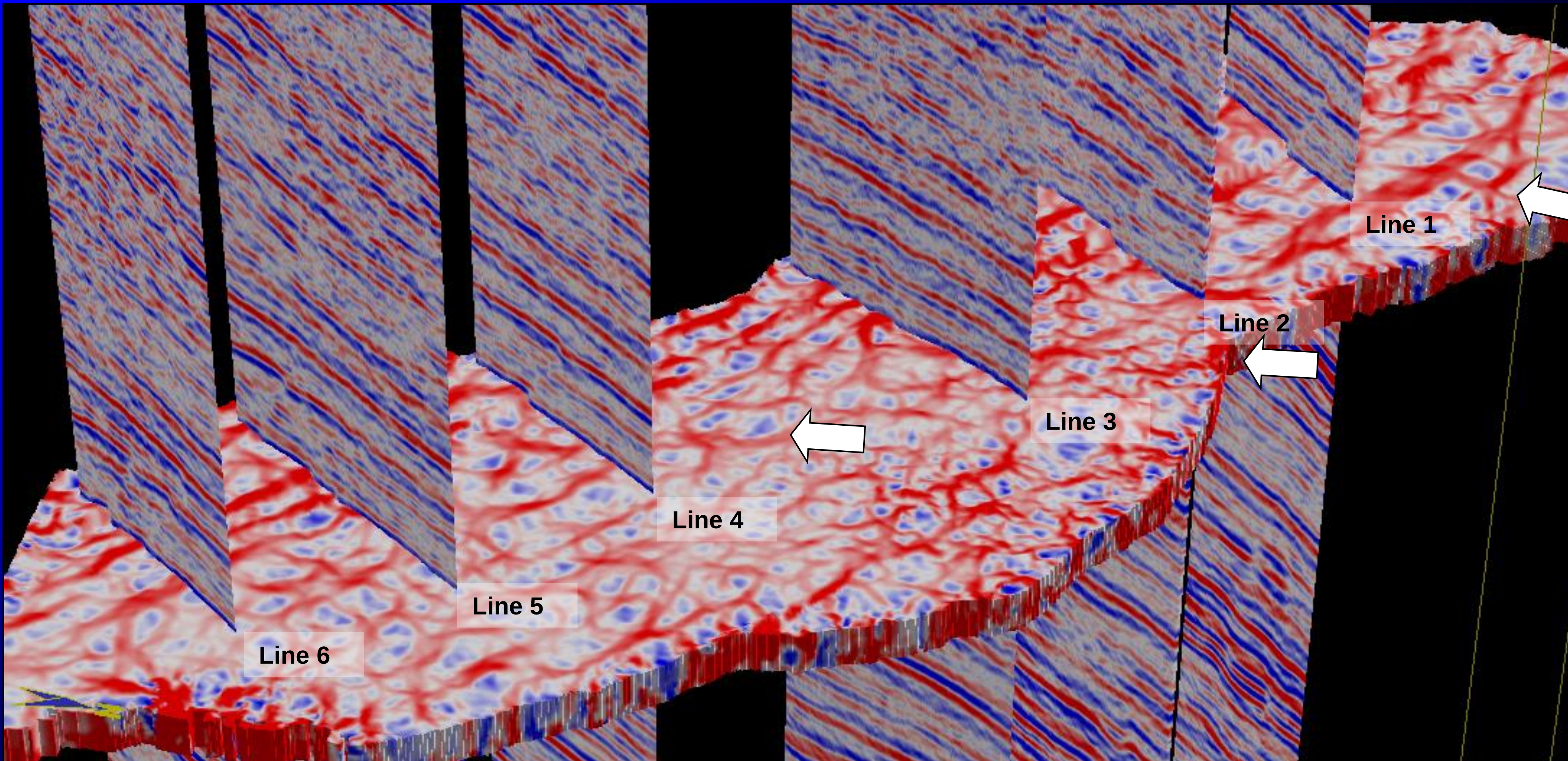


Coherence Strat Slices



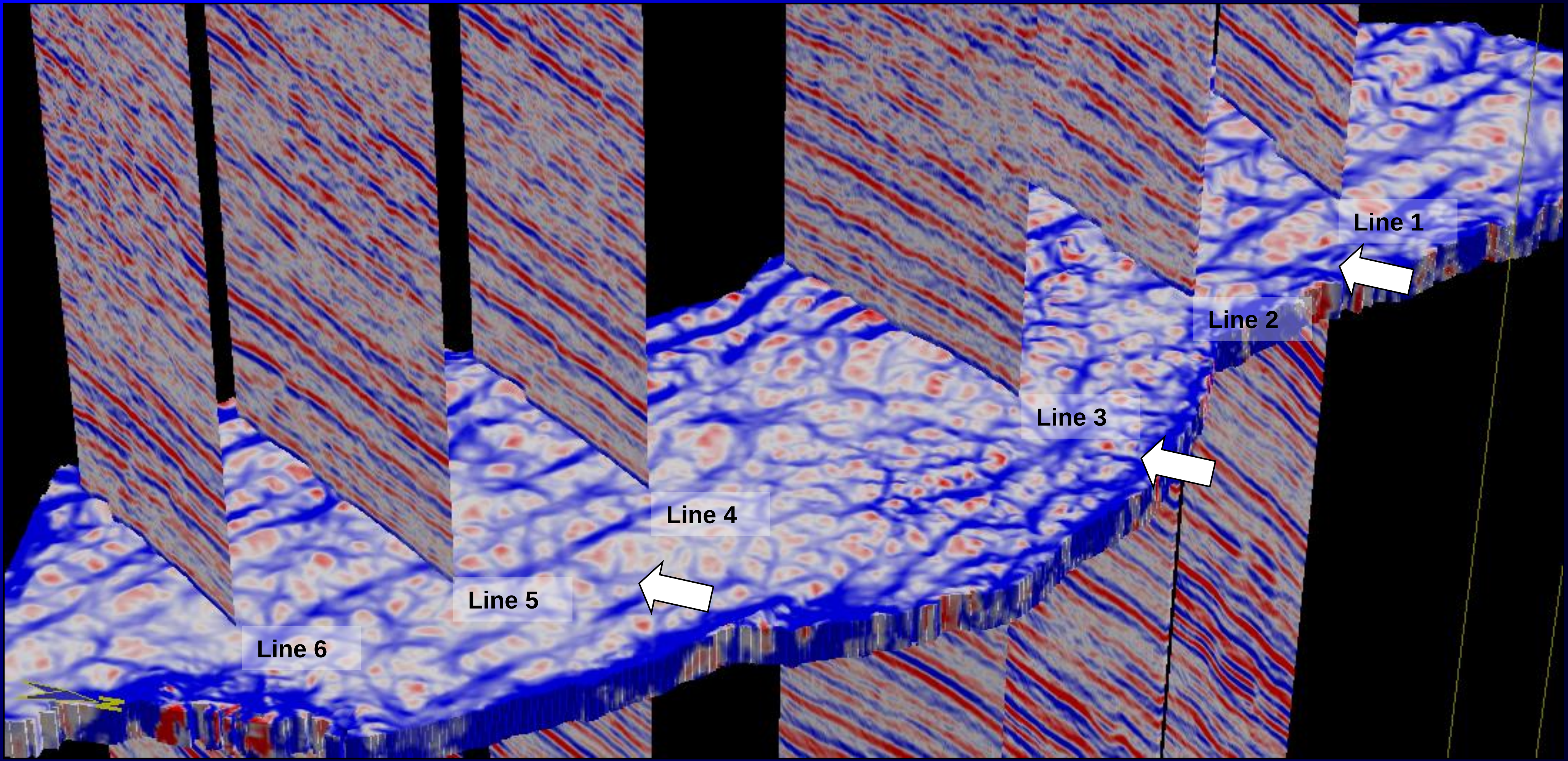
(Chopra and Marfurt, 2007b)

Most-Positive Curvature Strat Slices



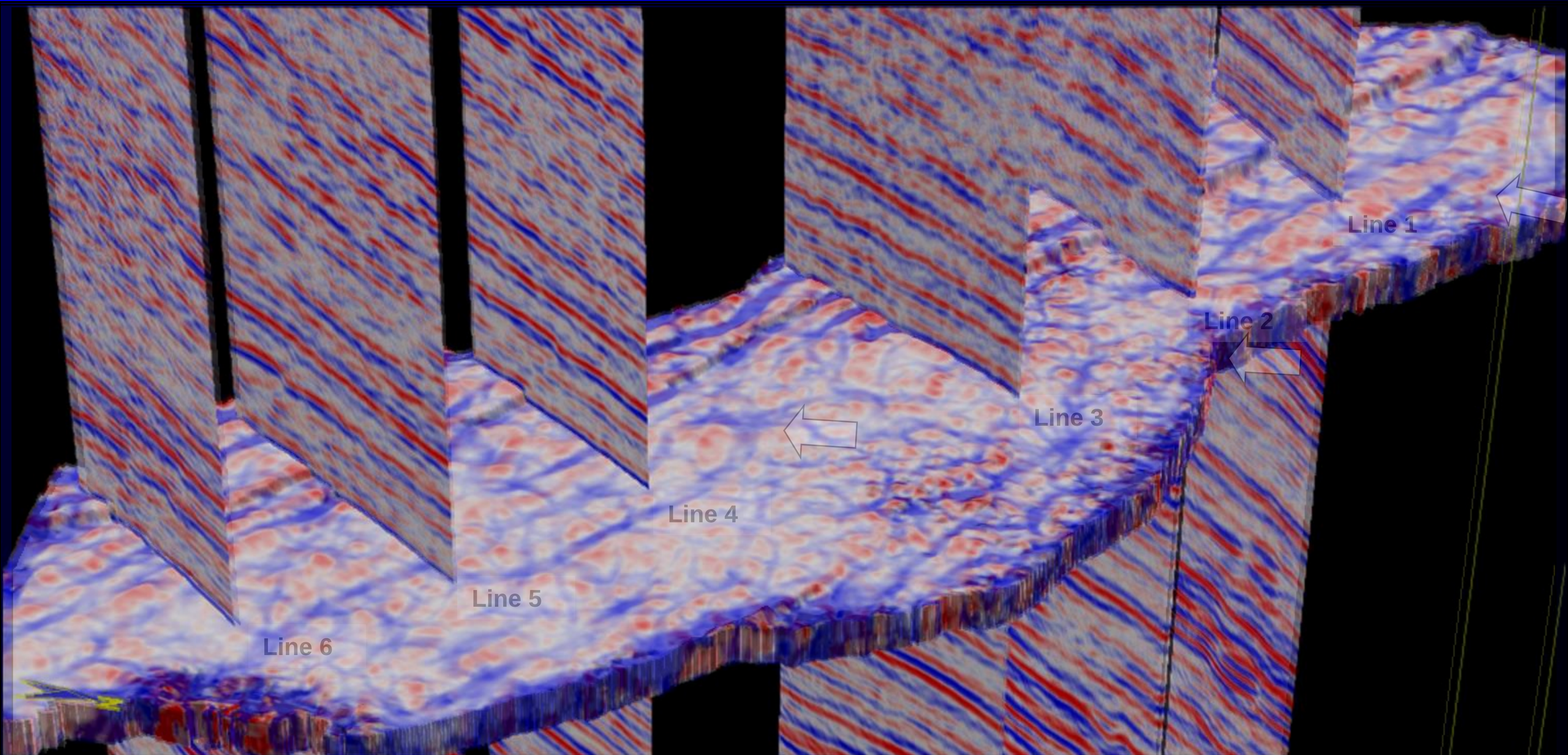
(Chopra and Marfurt, 2007b)

Most-Negative Curvature Strat Slices

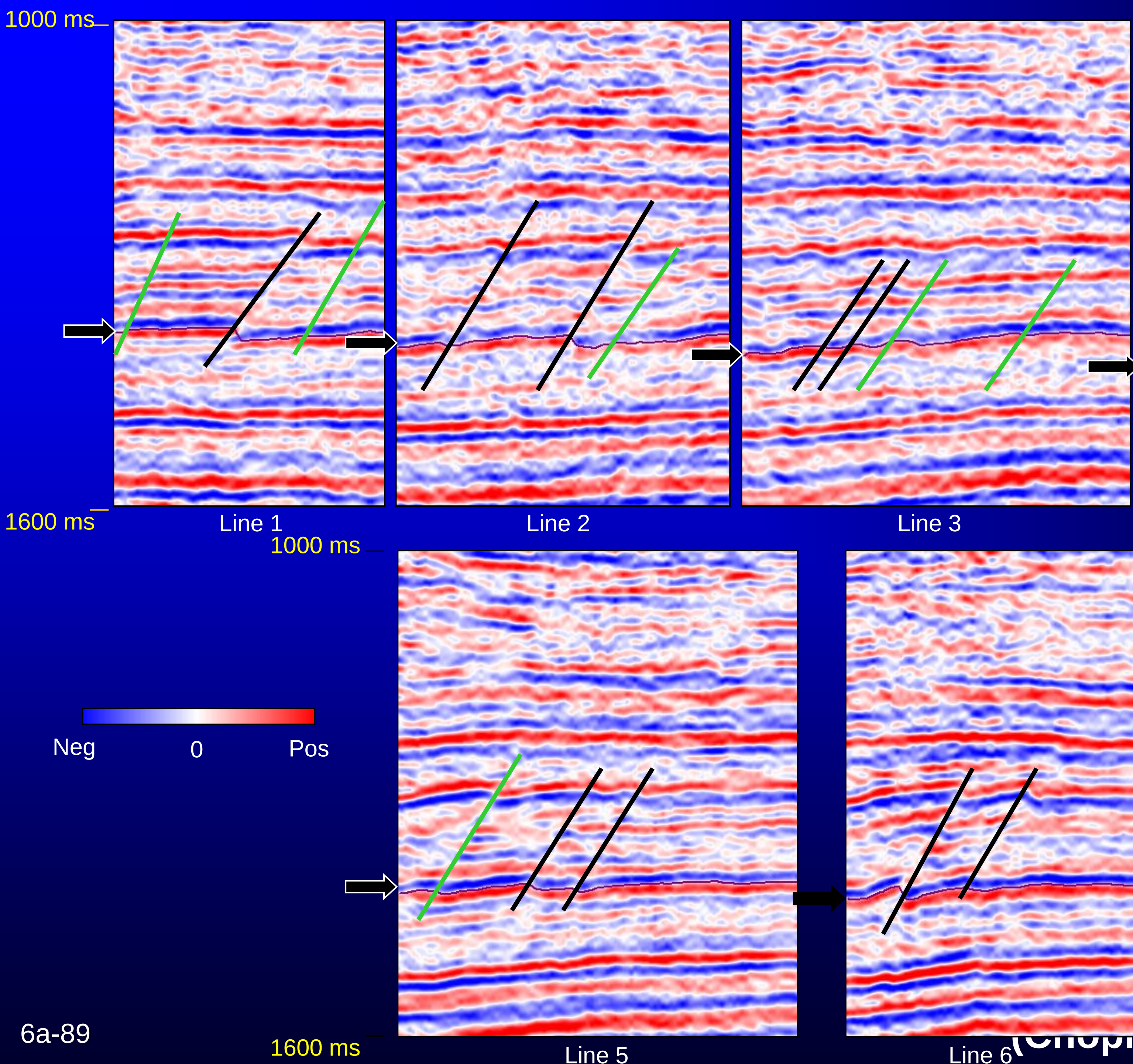


(Chopra and Marfurt, 2007b)

Coherence Strat Slices



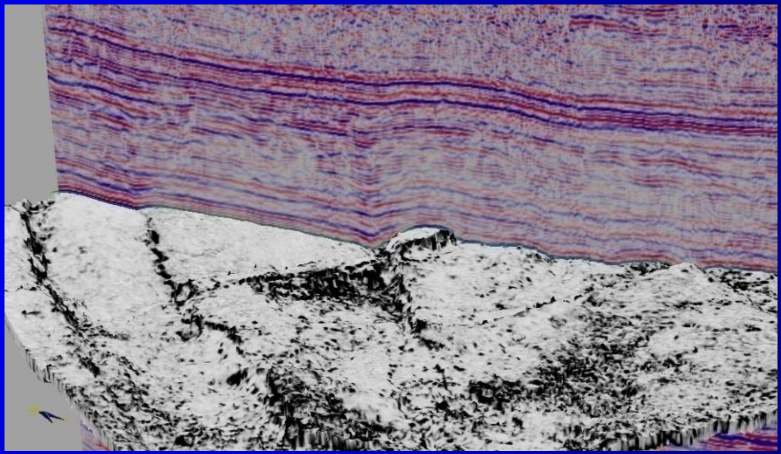
(Chopra and Marfurt, 2007b)



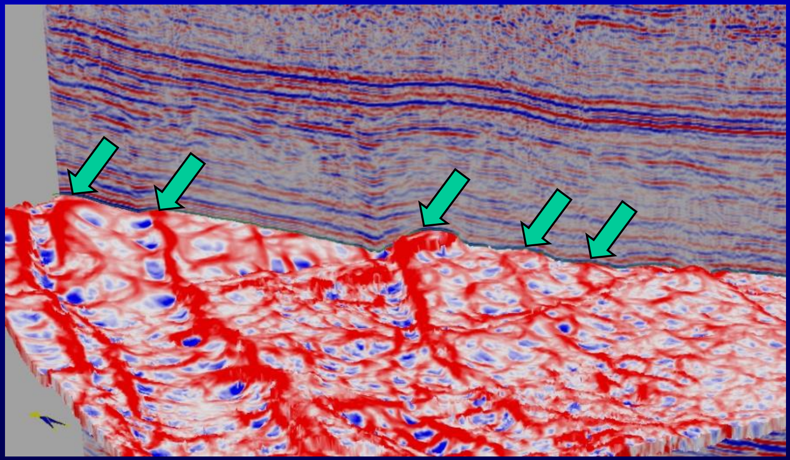
Faults that appear as discontinuities (seen on both coherence and curvature horizon slices)

Flexures seen on most positive curvature horizon slice that *do not* appear coherence slice

(Chopra and Marfurt, 2007b)

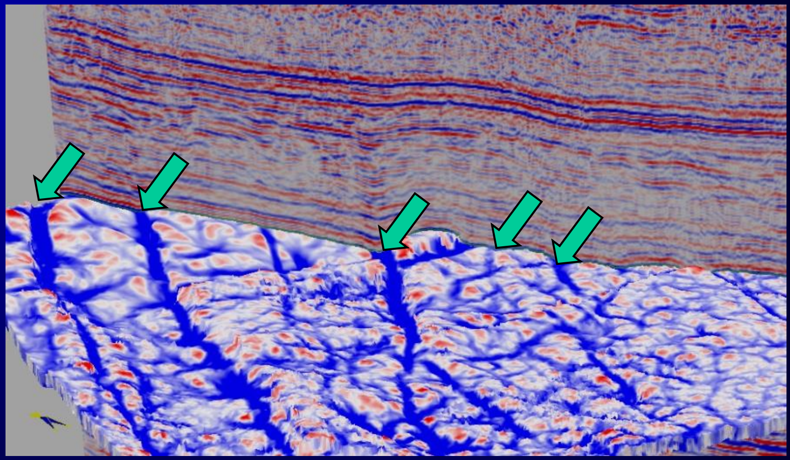


Coherence

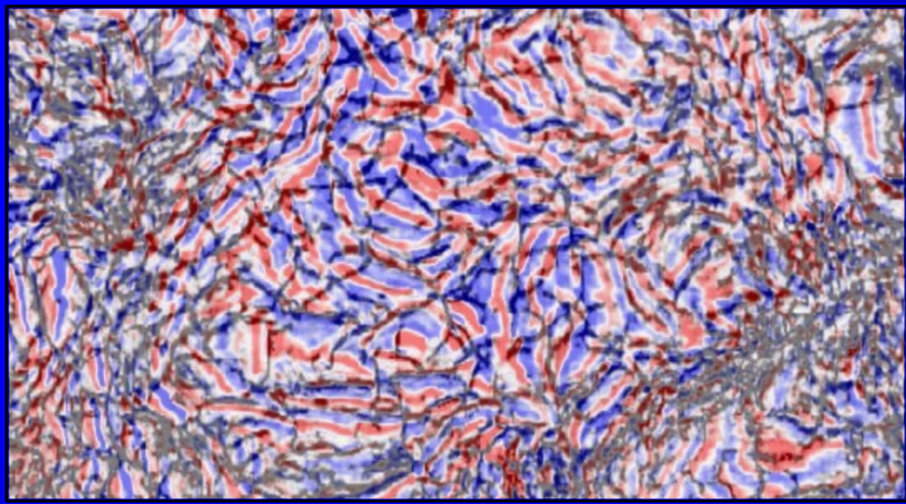


Most-positive curvature
(Long-wavelength)

Most-negative curvature
(Long-wavelength)



(Chopra and Marfurt, 2007c)



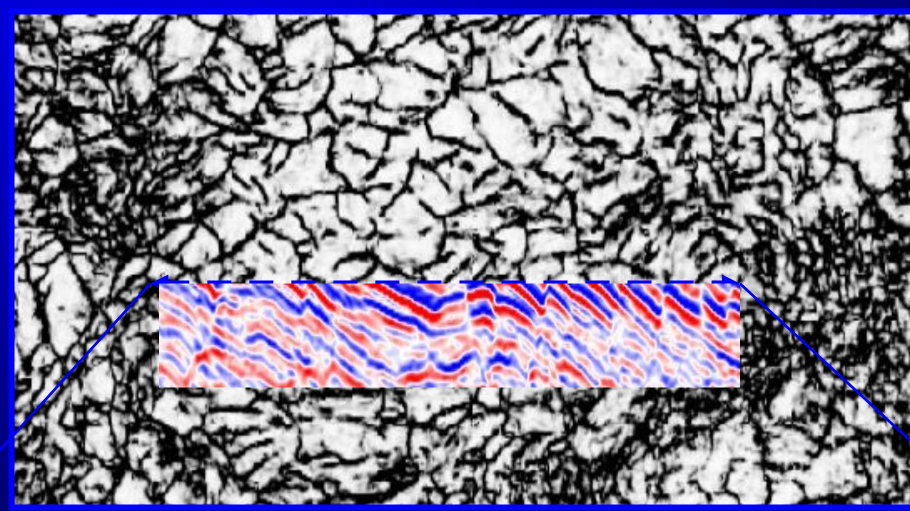
Seismic

Time slices (1240 ms)

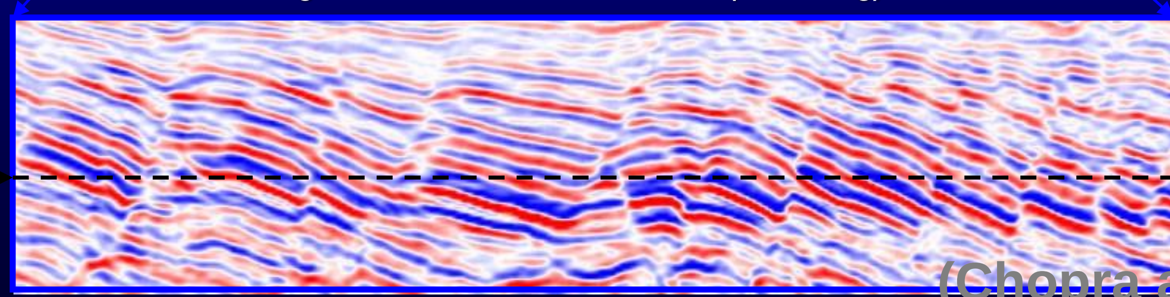
Semblance coherence without dip-steering

Neg 0 Pos

Low High



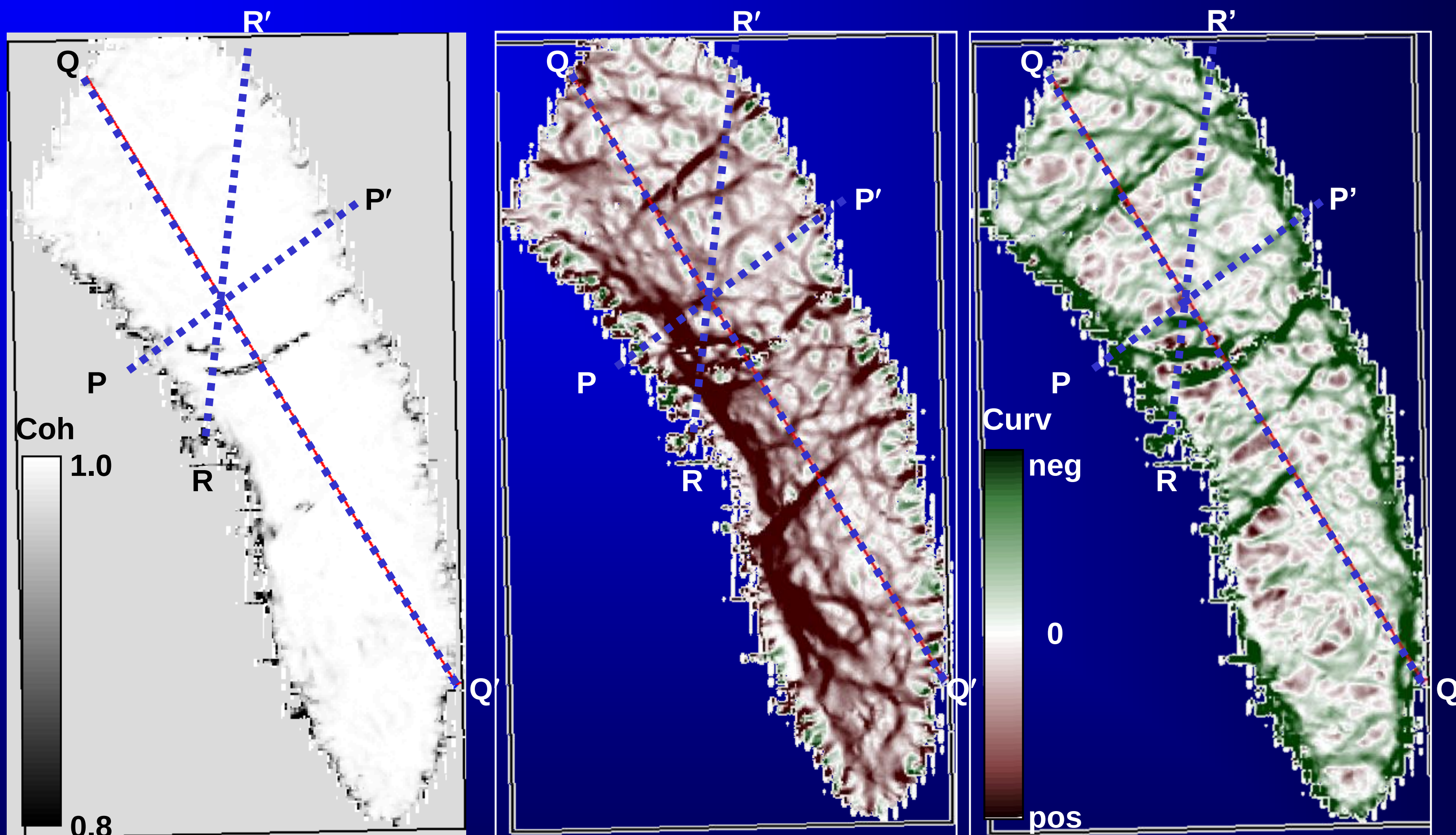
Eigenstructure coherence with dip-steering)



(Data courtesy: OILEXCO, Calgary)

(Chopra and Marfurt, 2008)

Teapot Dome (WY, USA)

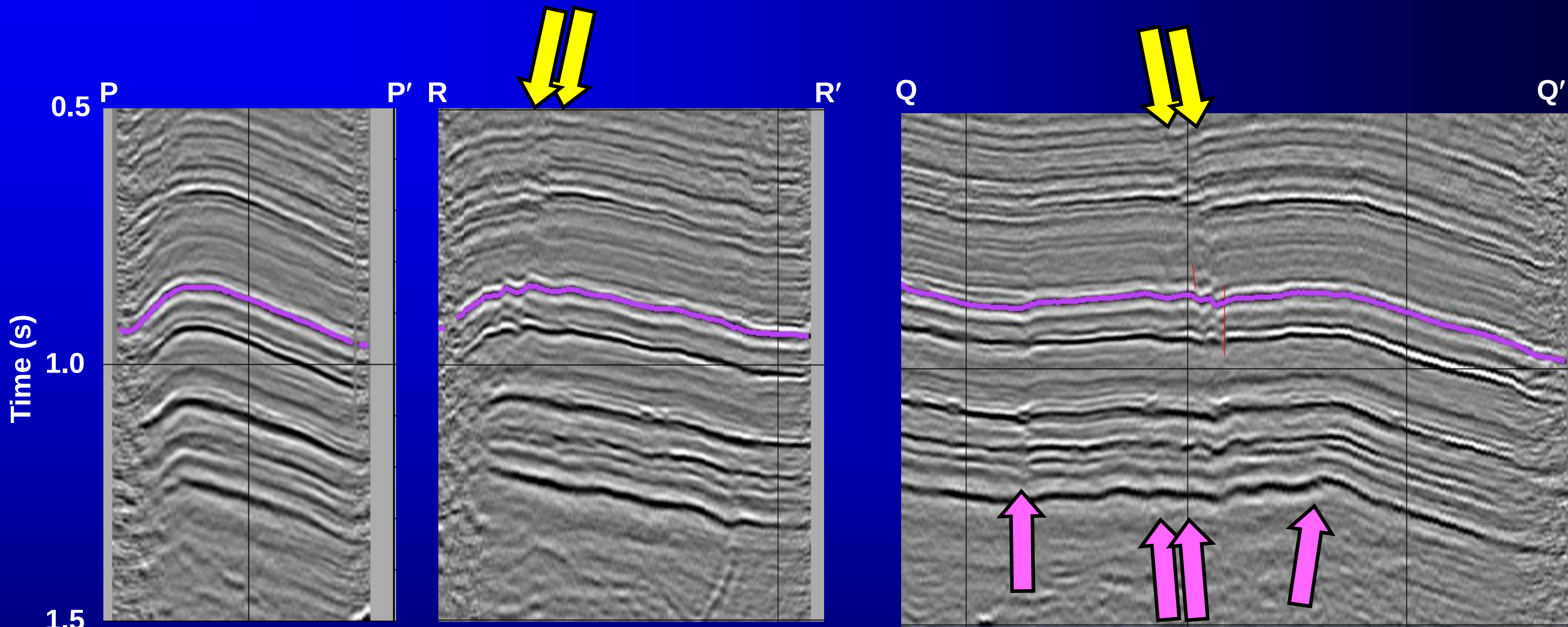


Coherence

Most Positive Curvature

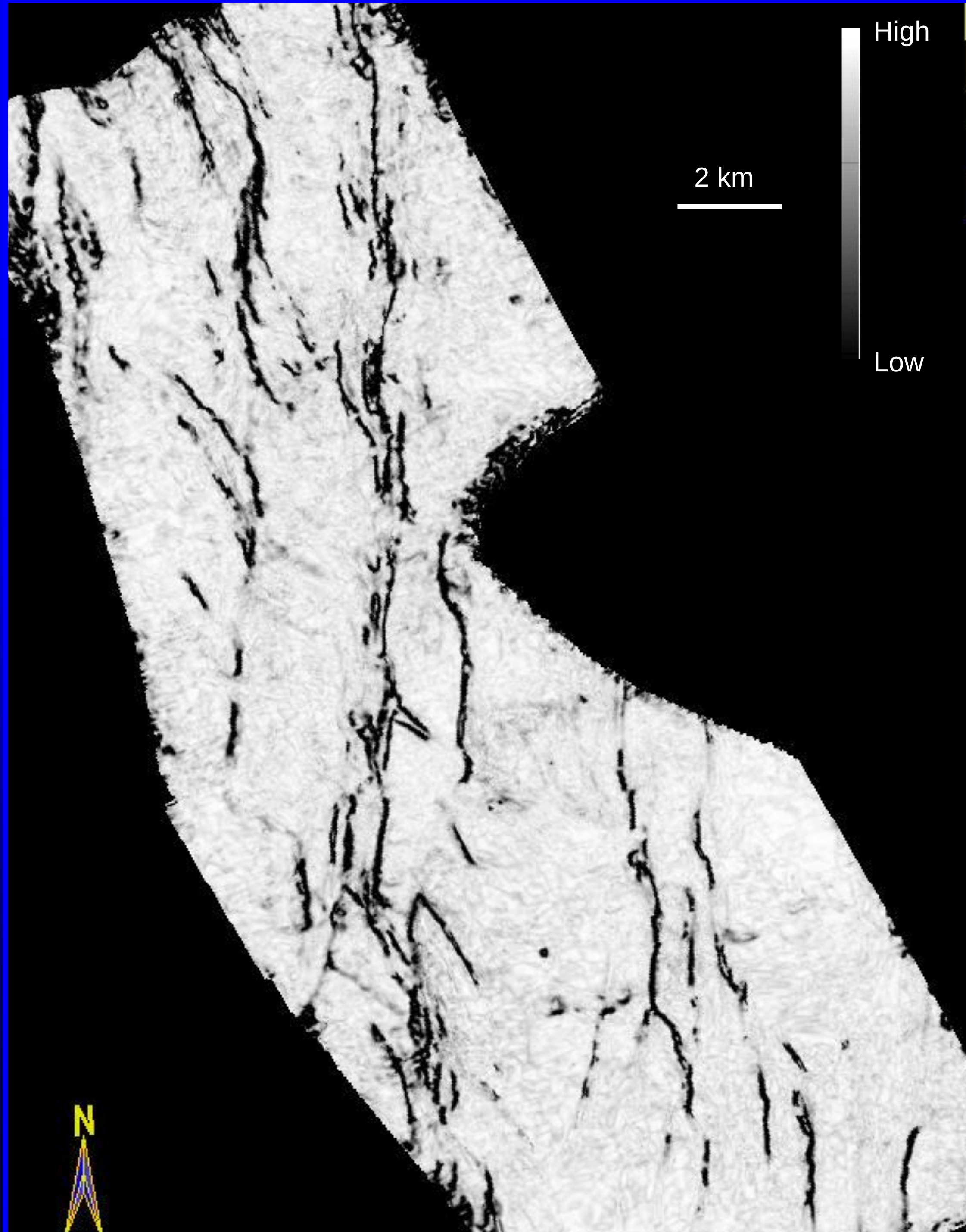
Most Negative Curvature

Teapot Dome (WY, USA)



(Data courtesy of RMTOC)

Horizon slice through the coherence volume

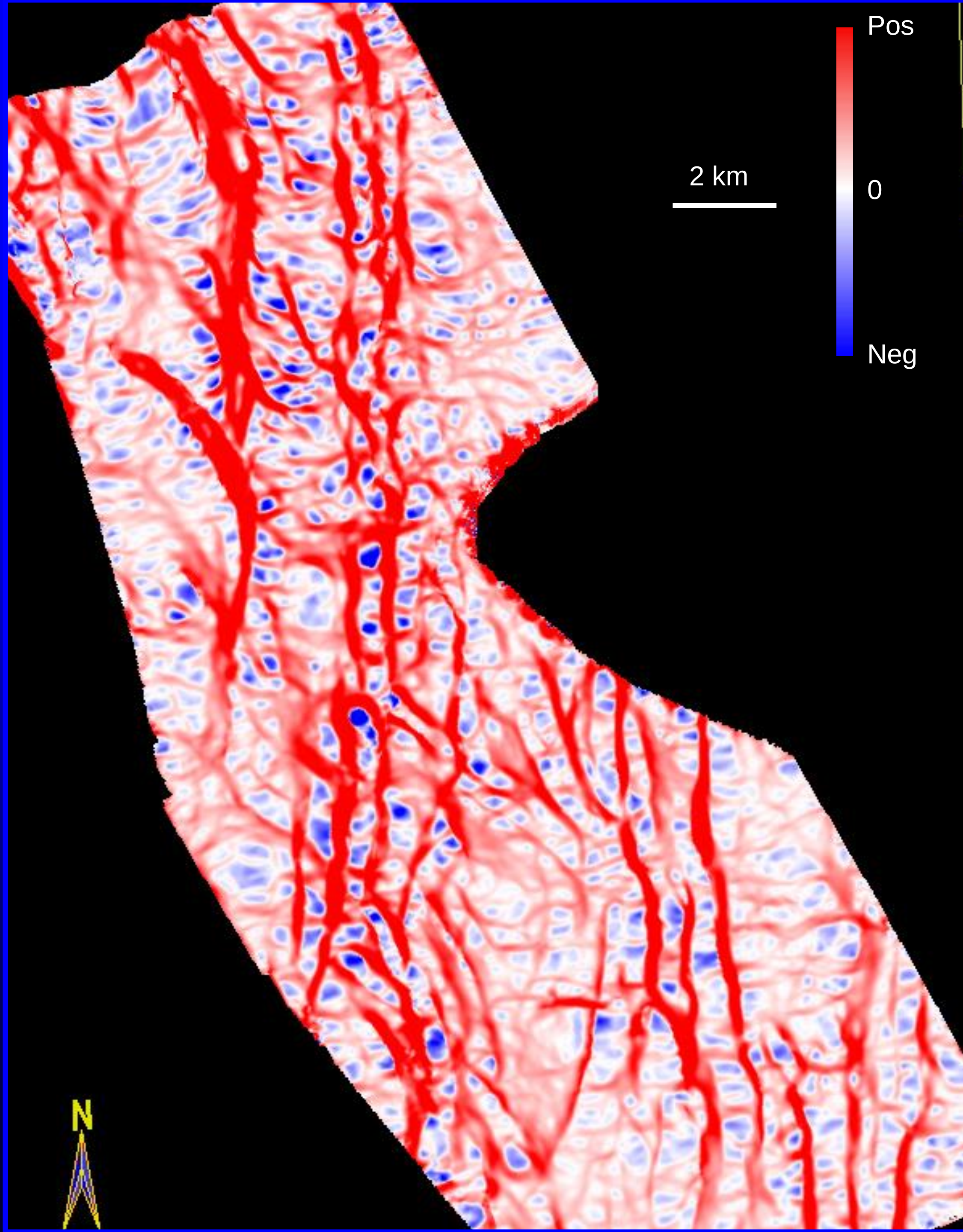


2-94

6a-94

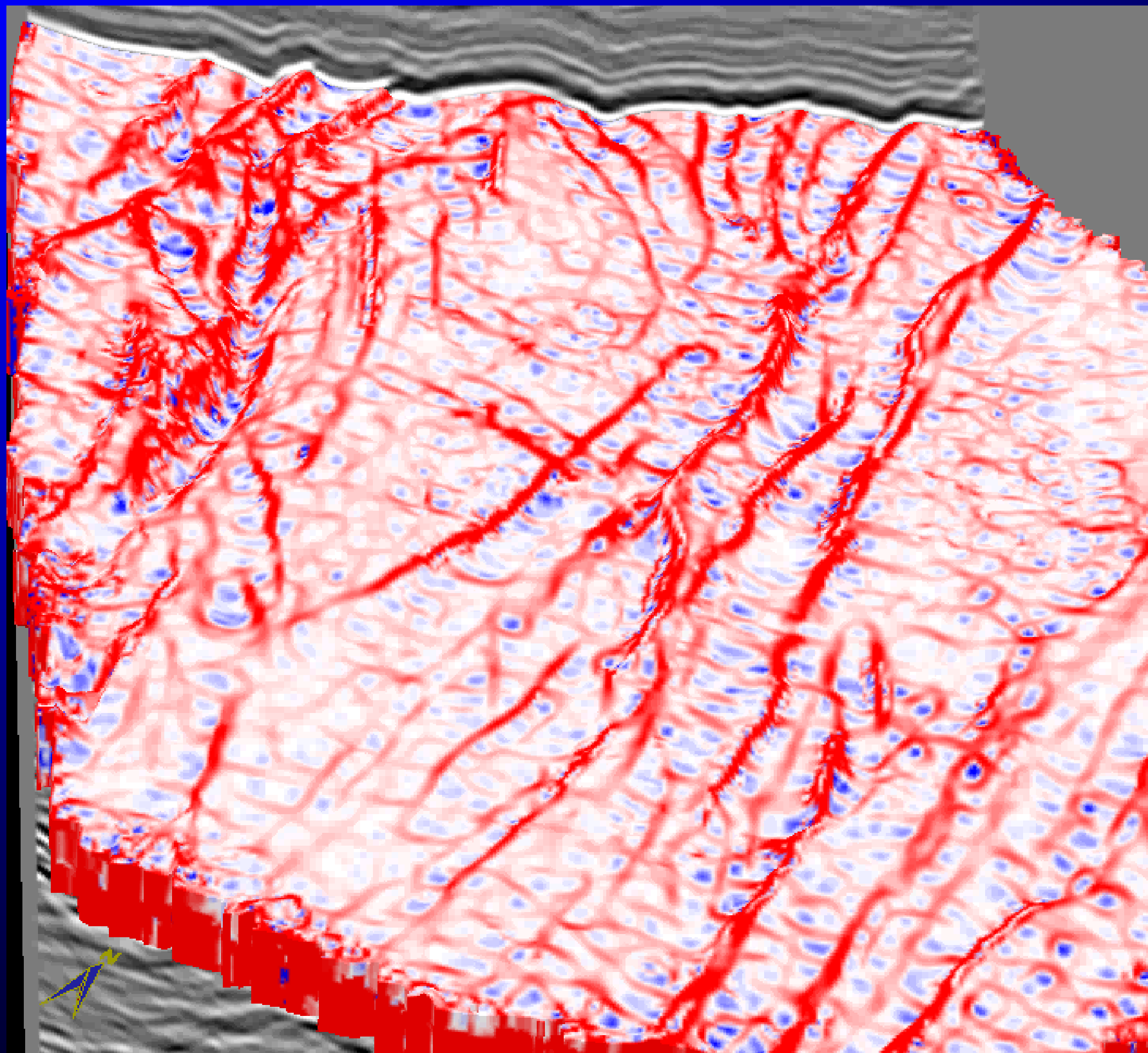
(Chopra and Marfurt, 2010)

Horizon slice through the most-positive curvature volume

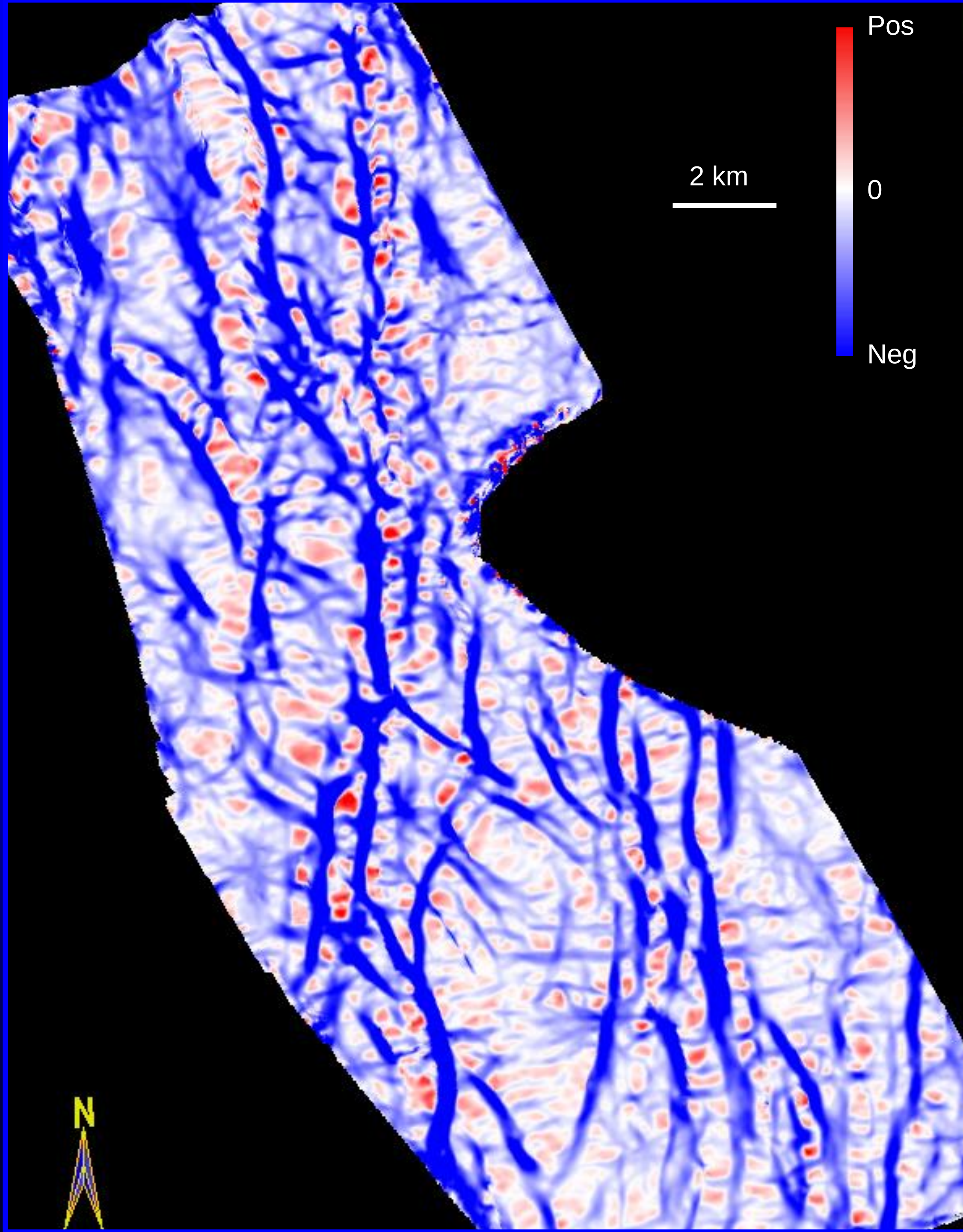


(Chopra and Marfurt, 2010)

Animation of vertical seismic data with most-positive curvature – Alberta, Canada

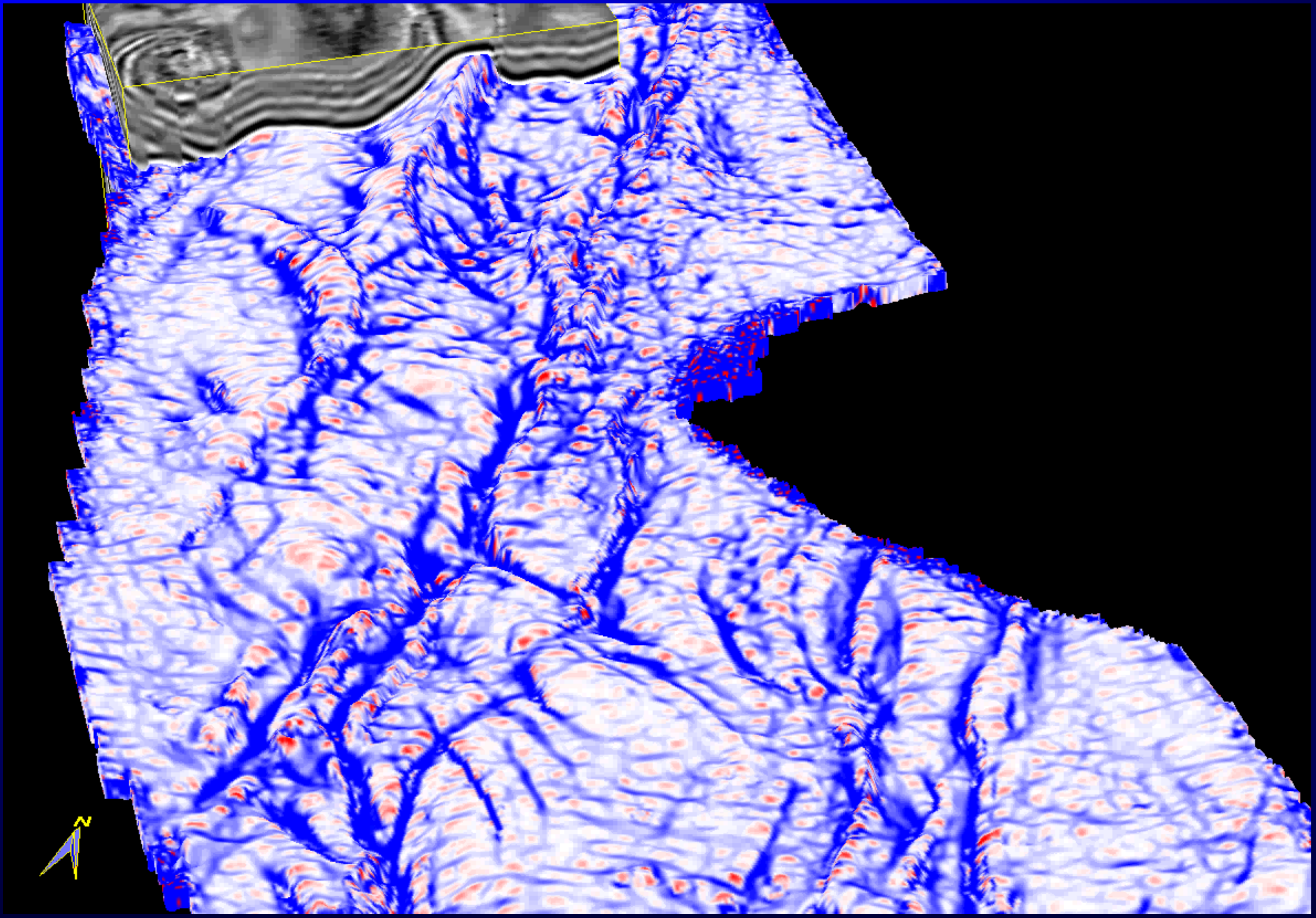


Horizon slice through the most-negative curvature volume

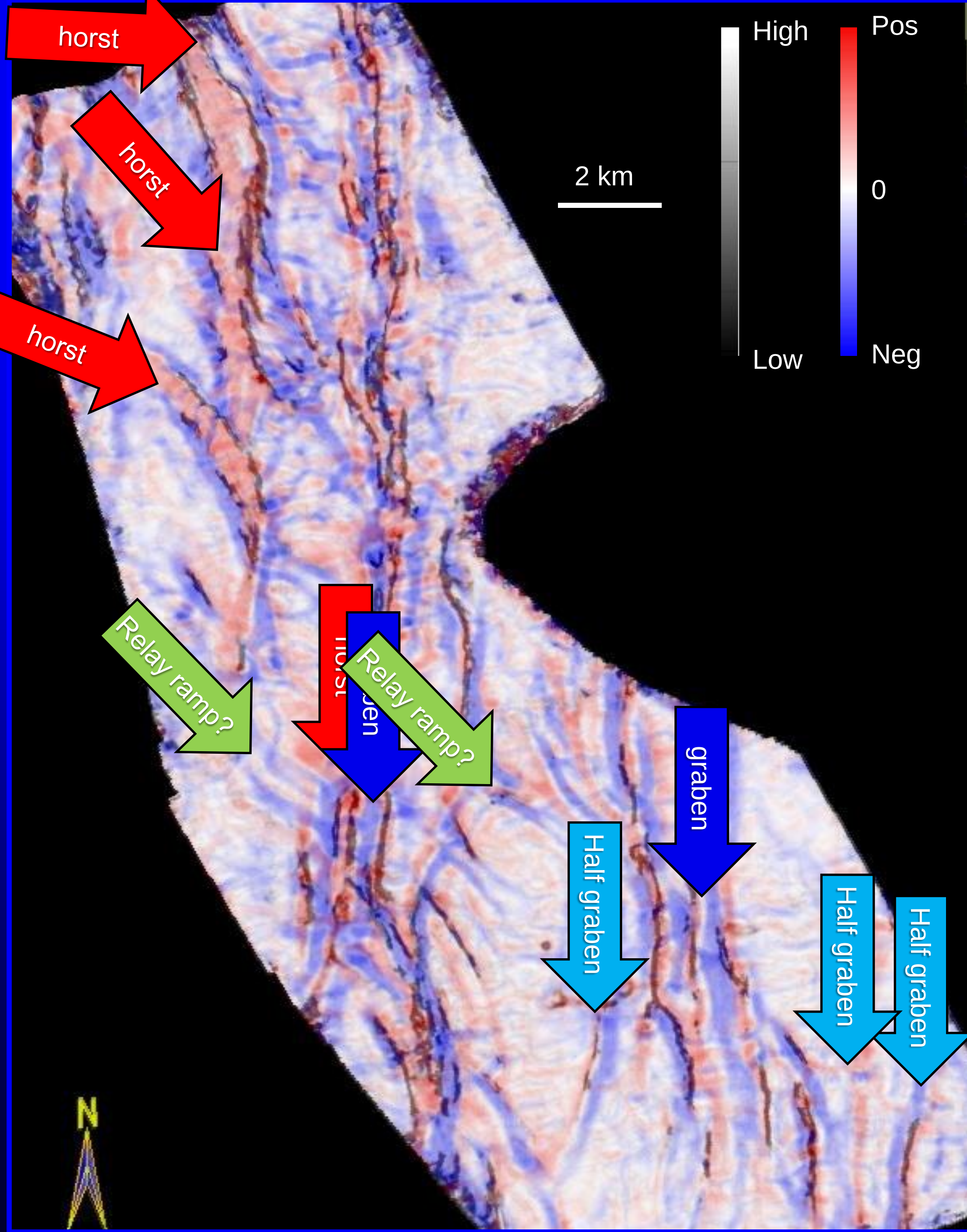


(Chopra and Marfurt, 2010)

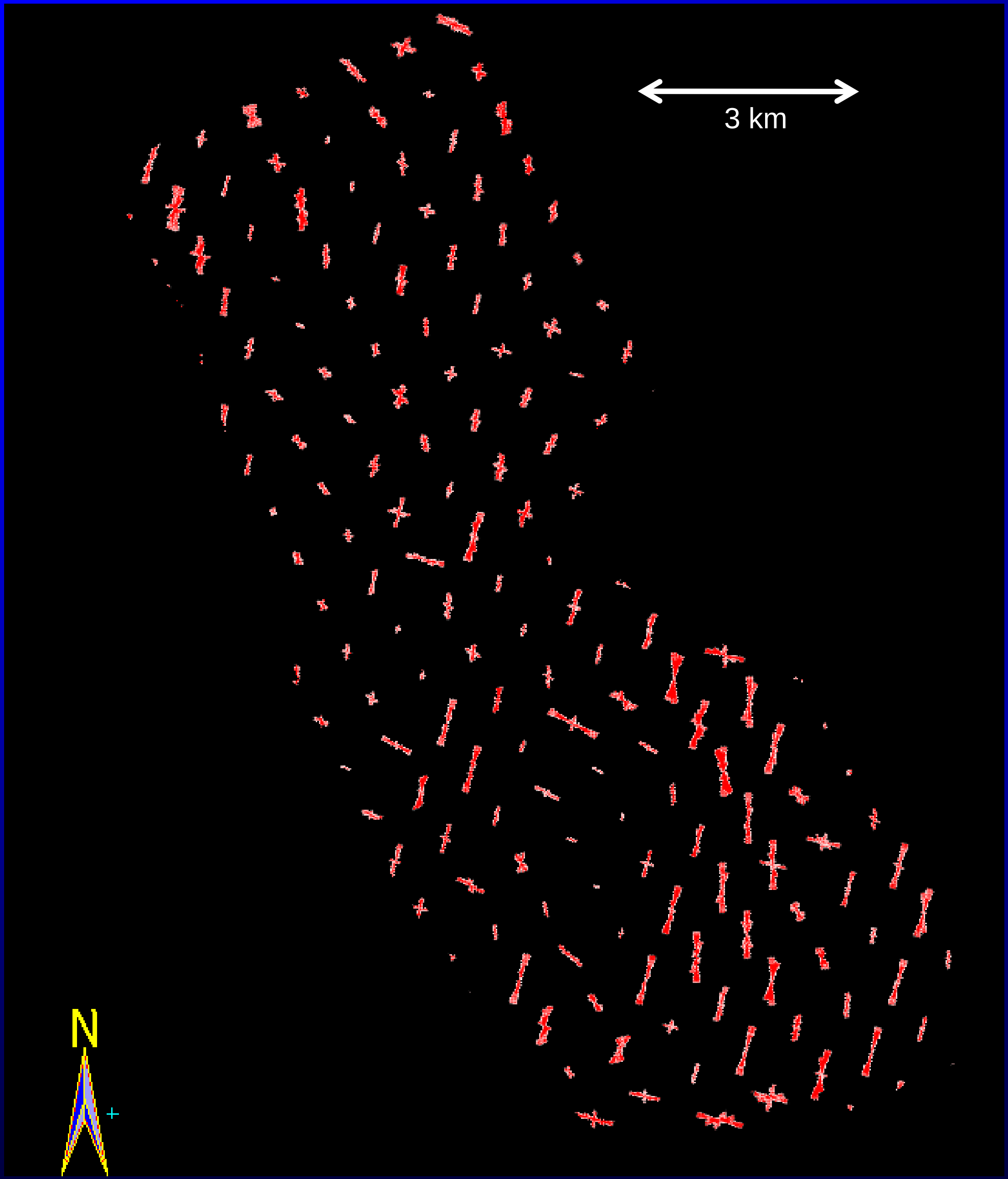
Animation of vertical seismic data with most-negative curvature – Alberta, Canada



Color stack of coherence, most-positive curvature, and most negative curvature

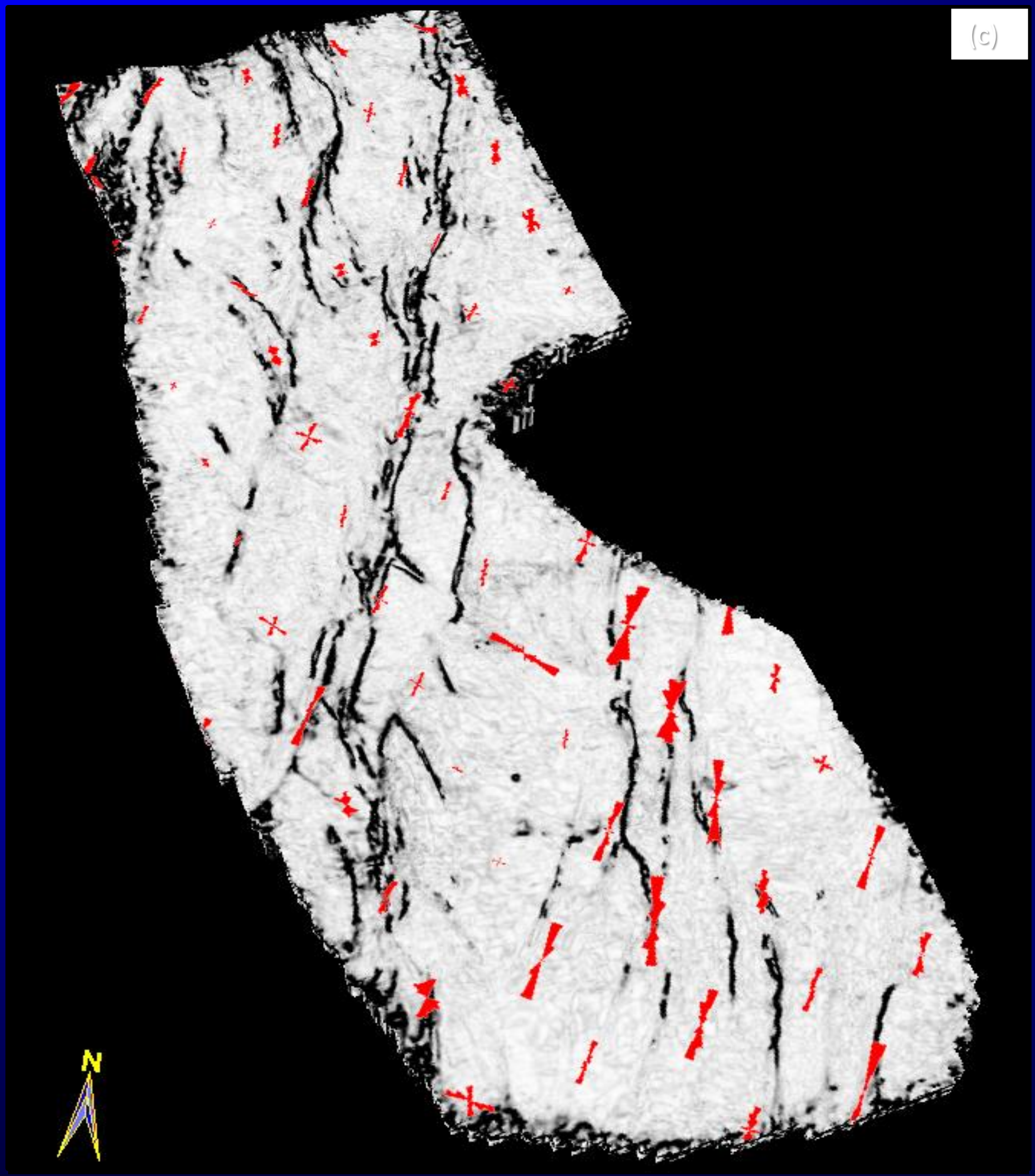


(Chopra and Marfurt, 2010)

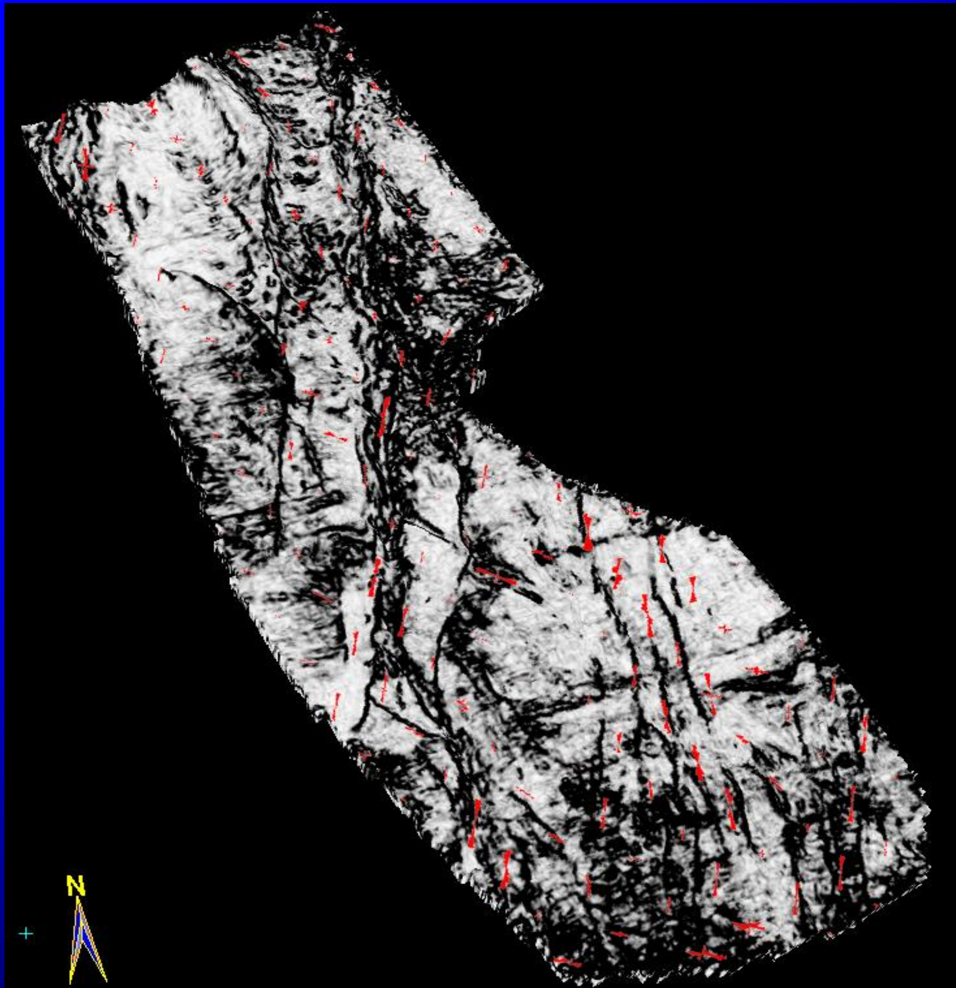


Rose diagrams displayed 40 ms above a marker horizon

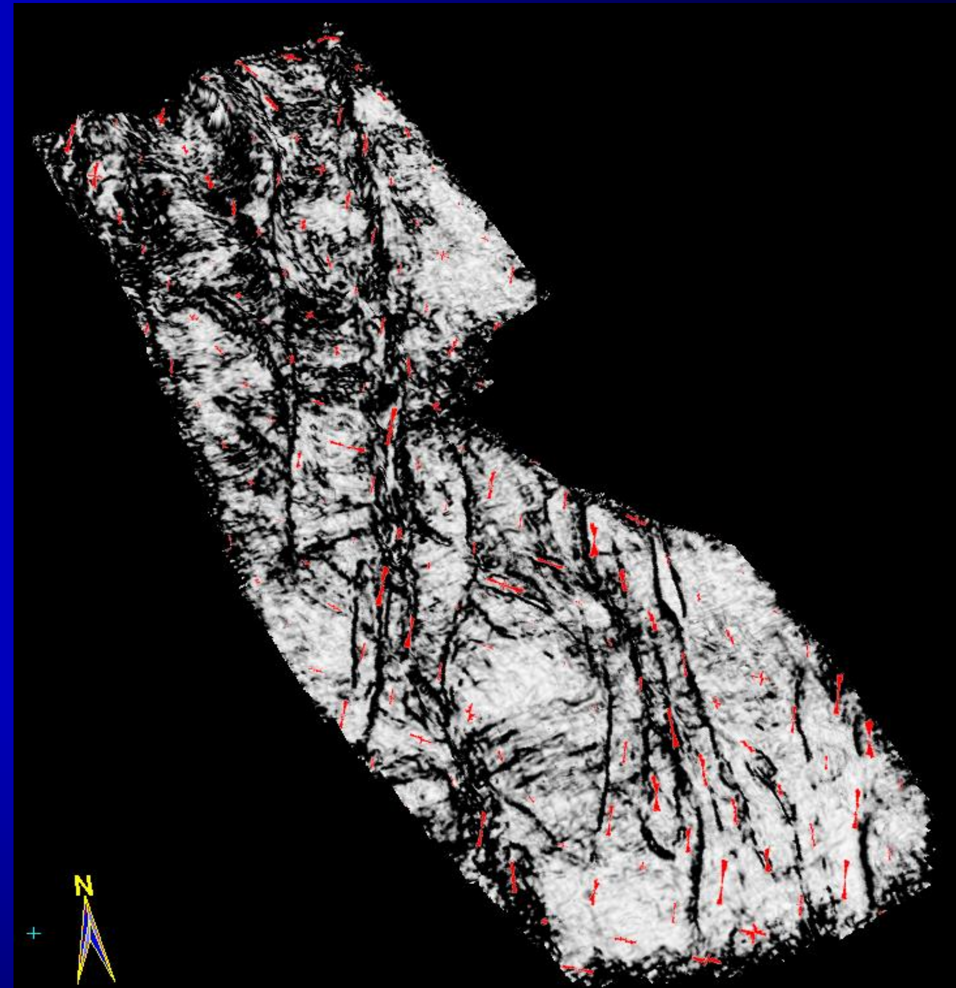
(Chopra et al., 2009)



(Chopra et al., 2009)



Display 50 ms below a marker horizon

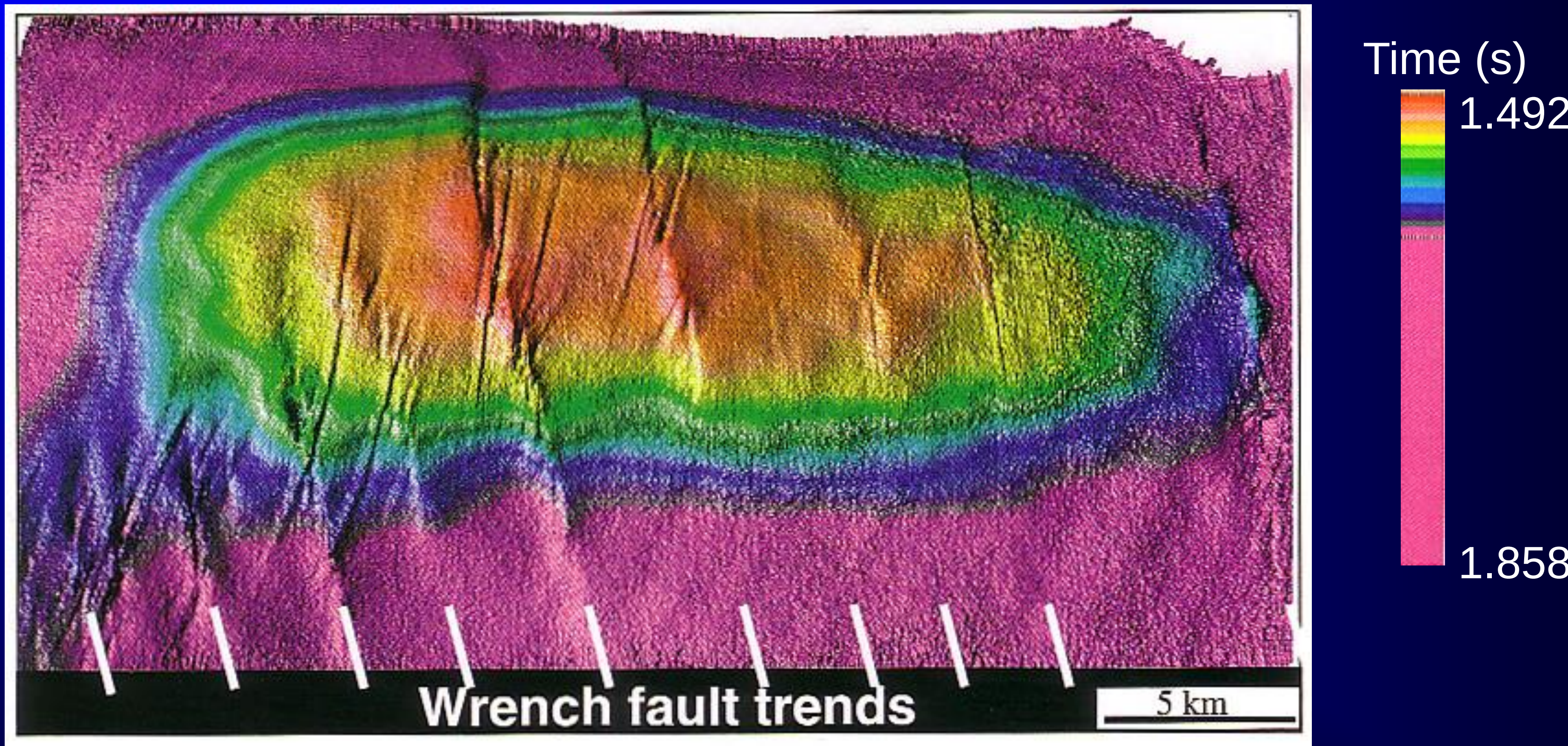


Display 100 ms below a marker horizon

Roses generated with valley attribute and radius 600 m

(Chopra et al., 2009)

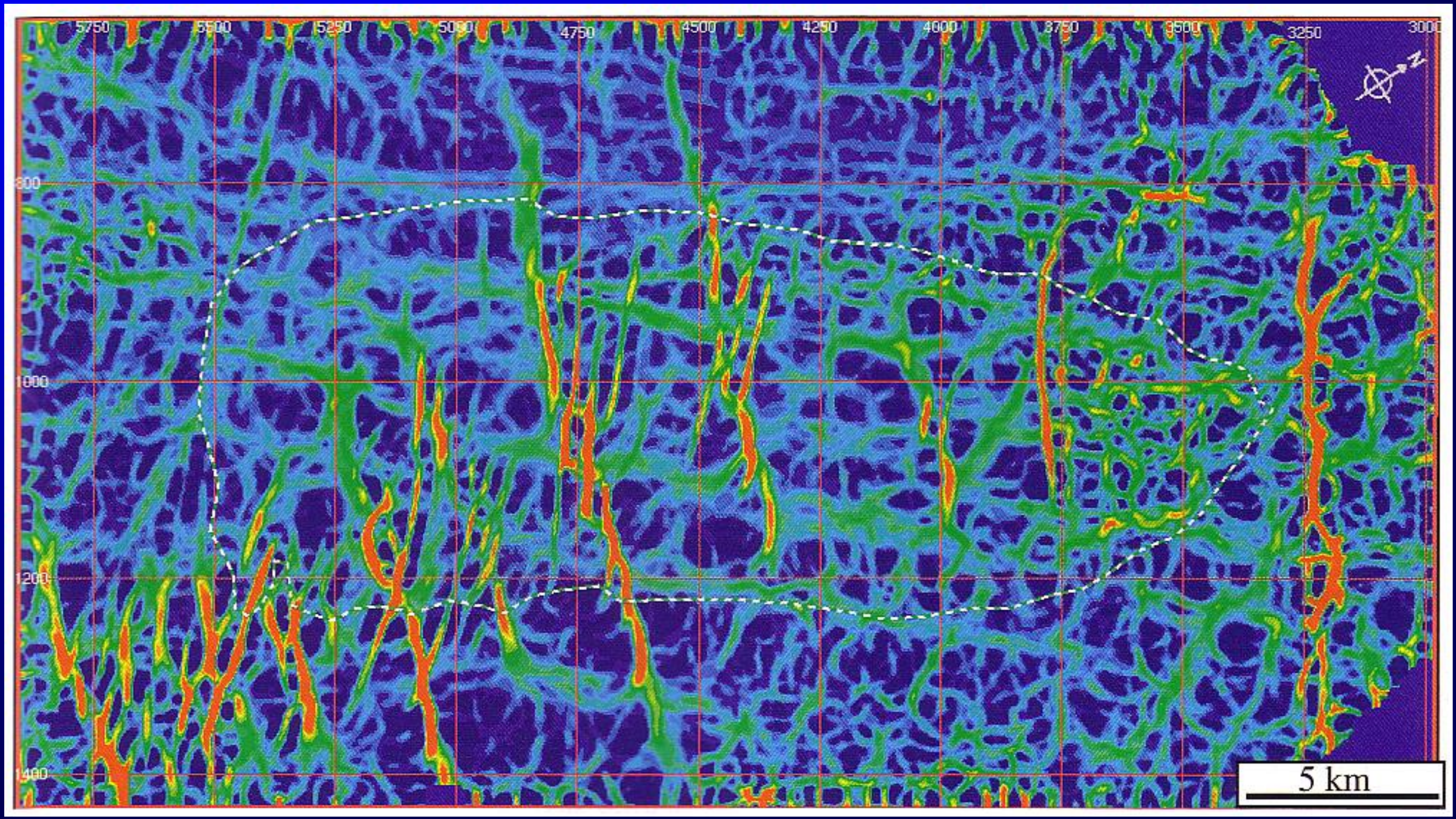
Wrench faulting (U.A.E.)



3D visualization of horizon surface

(Melville et al., 2004)

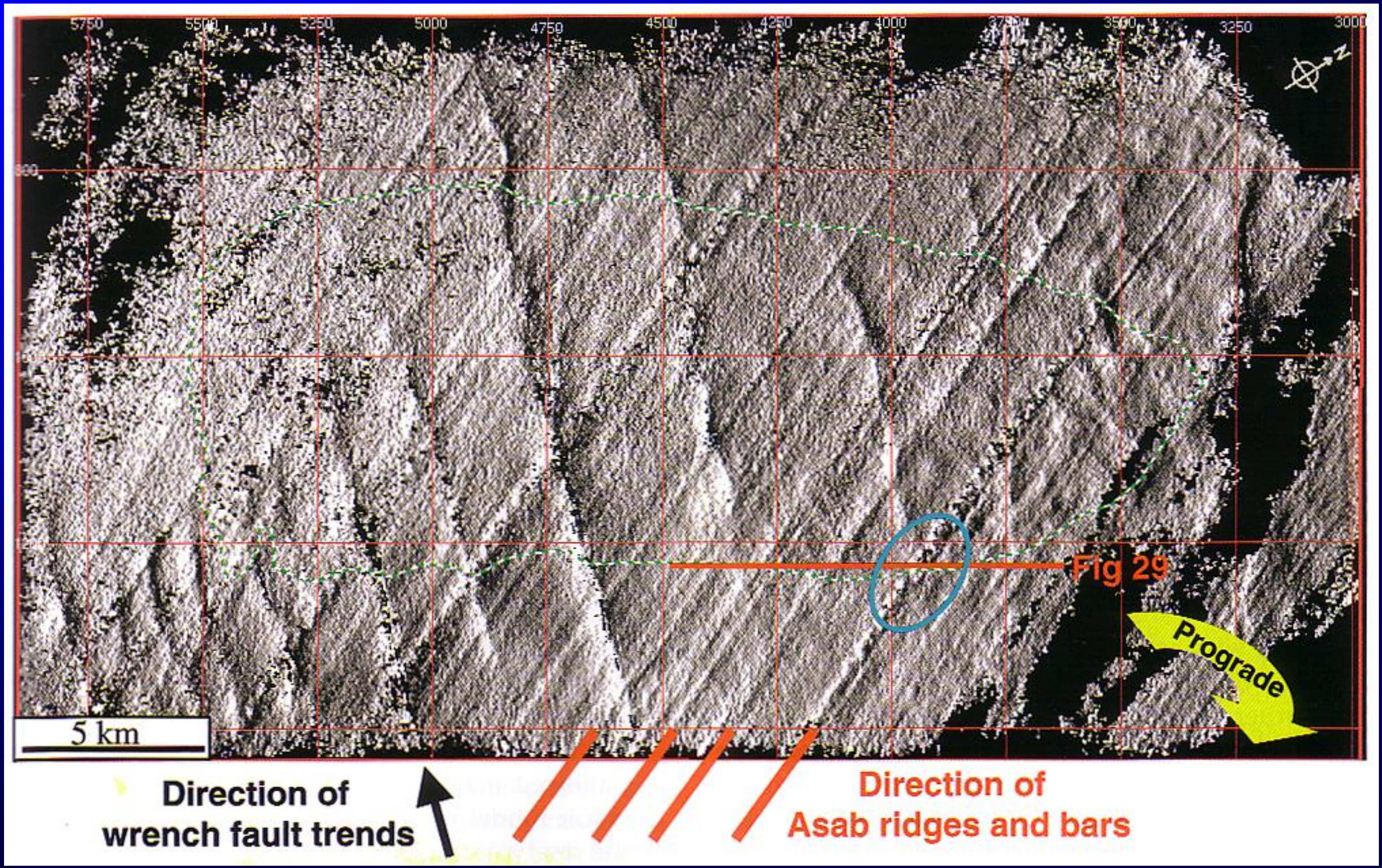
Wrench faulting (U.A.E.)



Maximum curvature of horizon surface

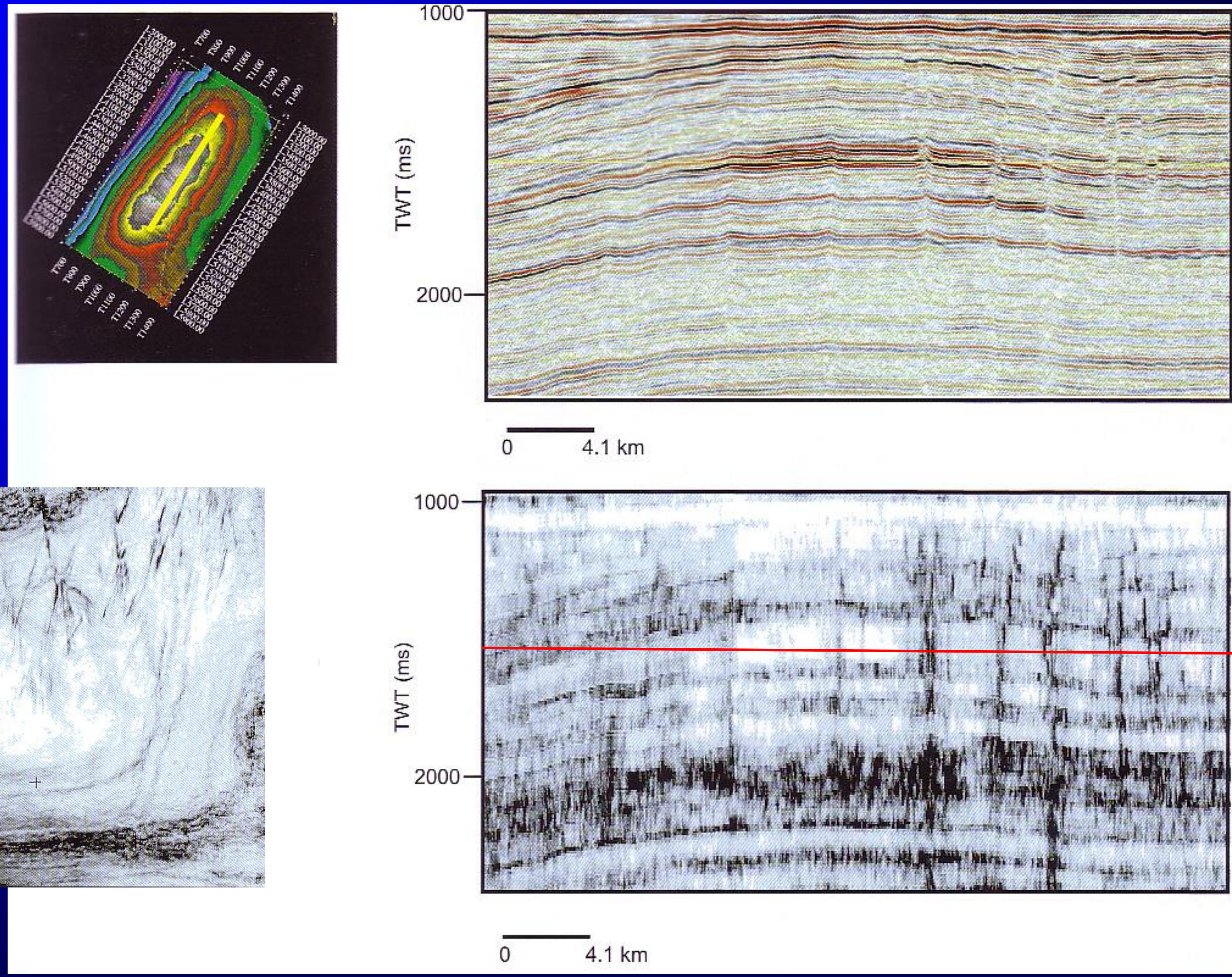
(Melville et al., 2004)

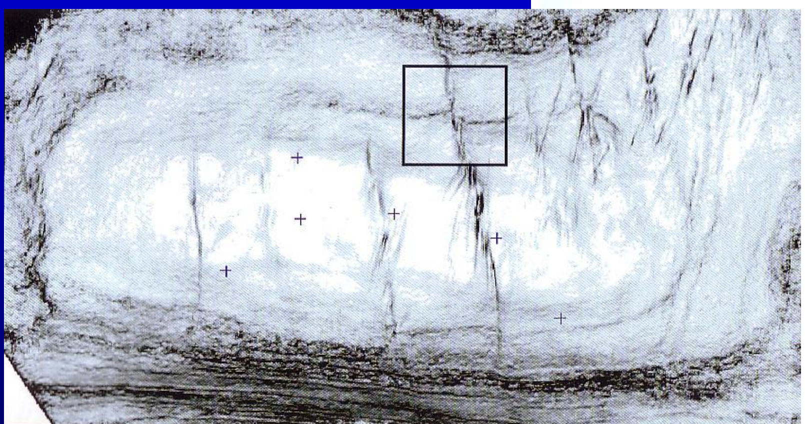
Wrench faulting (U.A.E.)



(Melville et al., 2004)

Wrench faulting (U.A.E.)



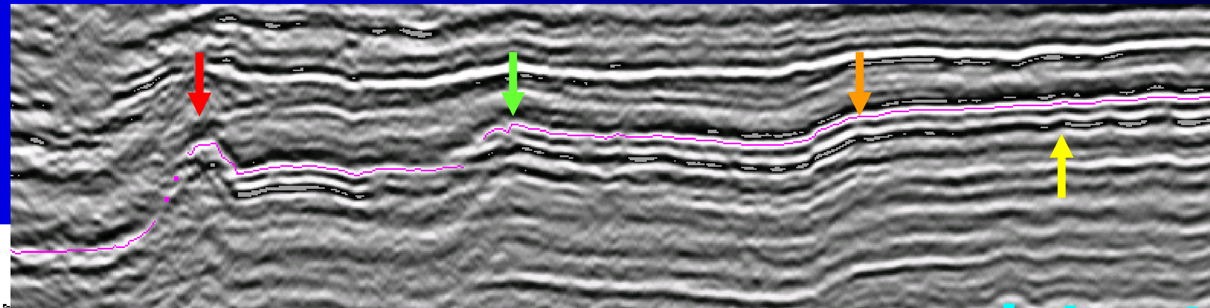


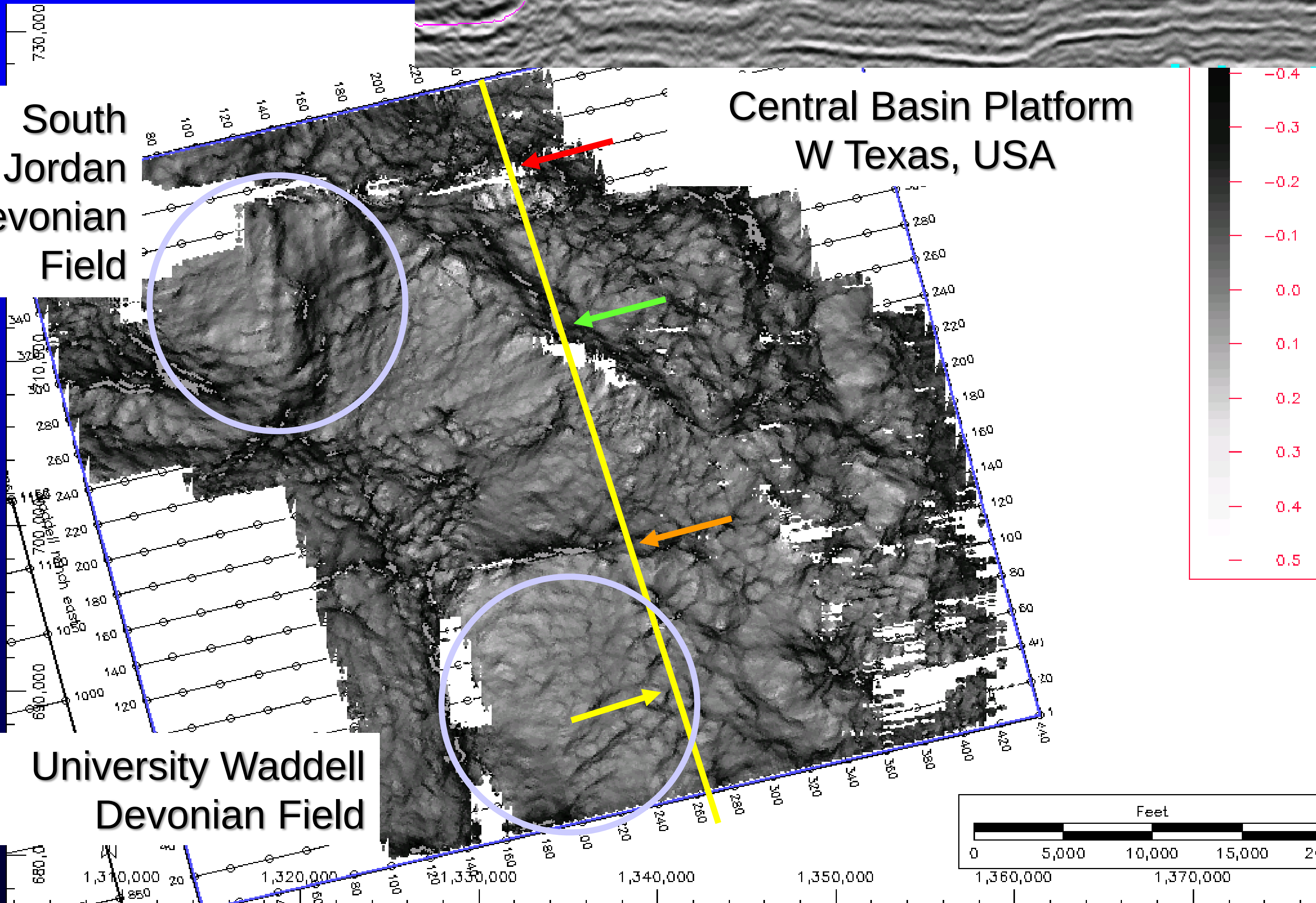
(Melville et al., 2004)

Expression of folds and flexures on seismic attributes

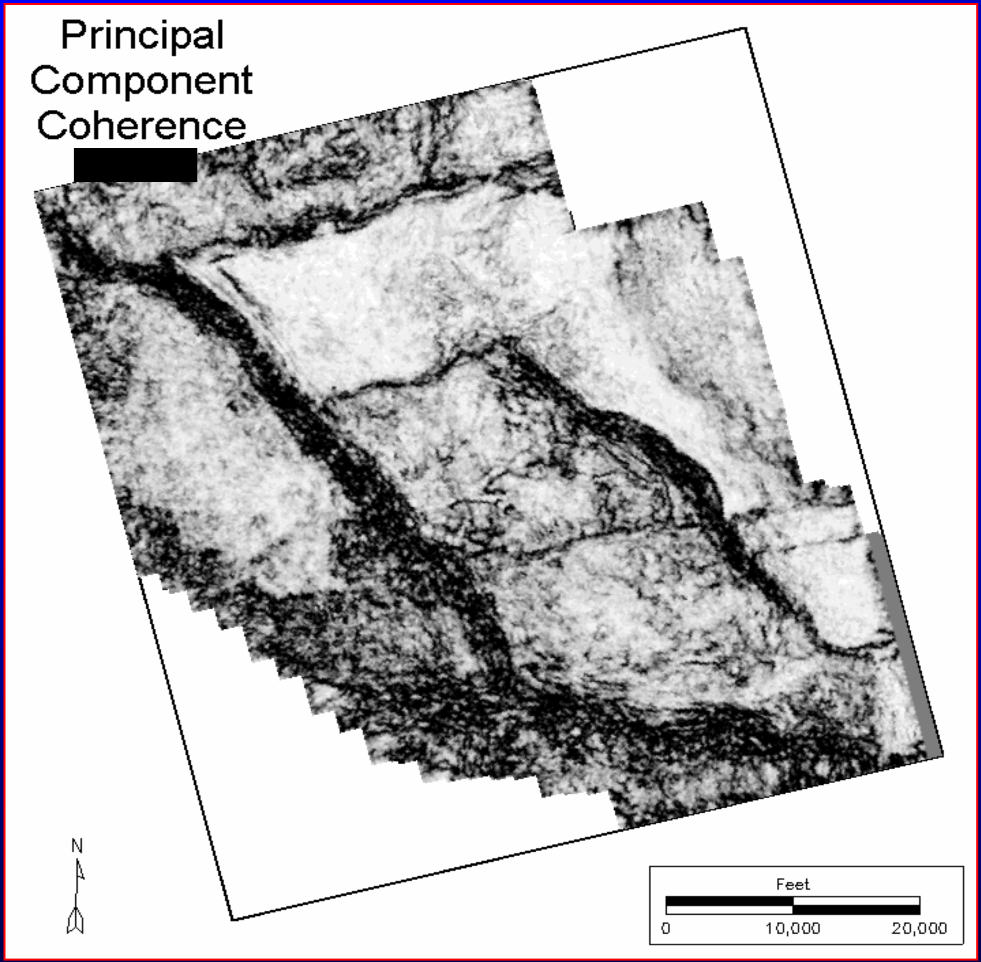
Devonian Thirtyone Limestone/Dolomite Formation
Central Basin Platform, W Texas, USA

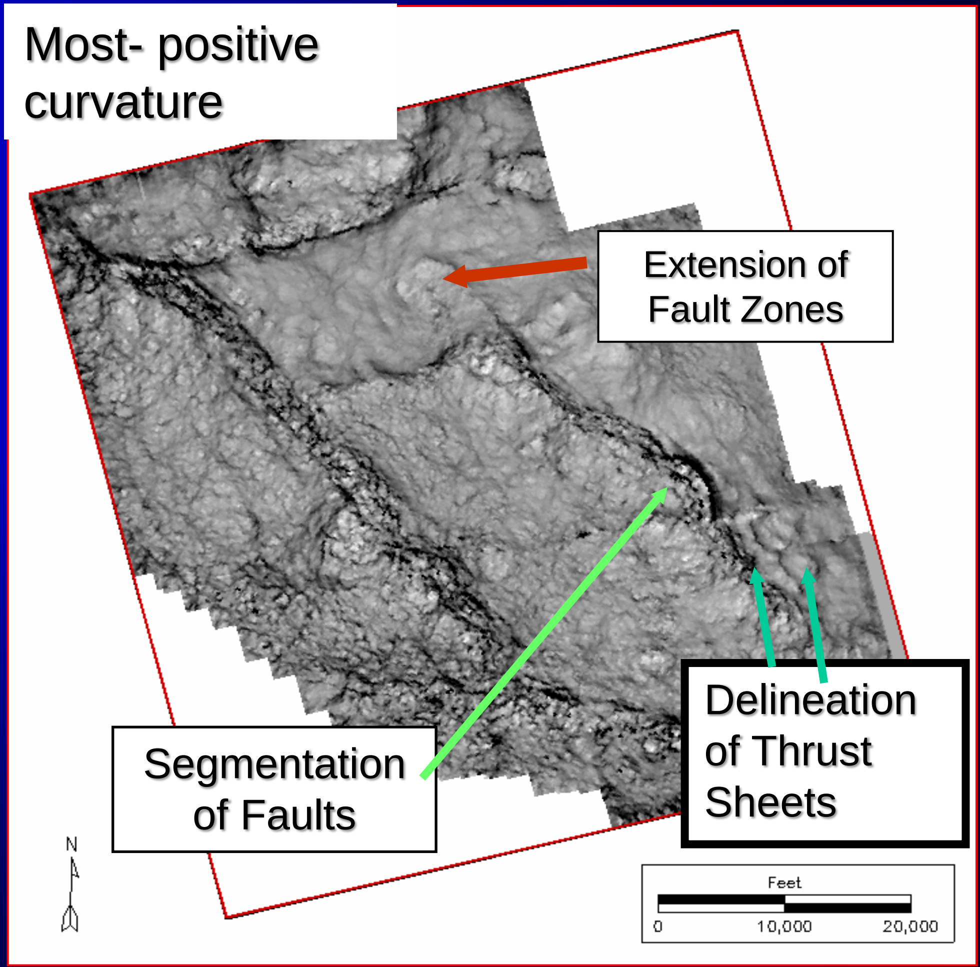
Devonian Horizon slice through most-positive curvature





Coherence sees discontinuities, curvature sees flexures and folds



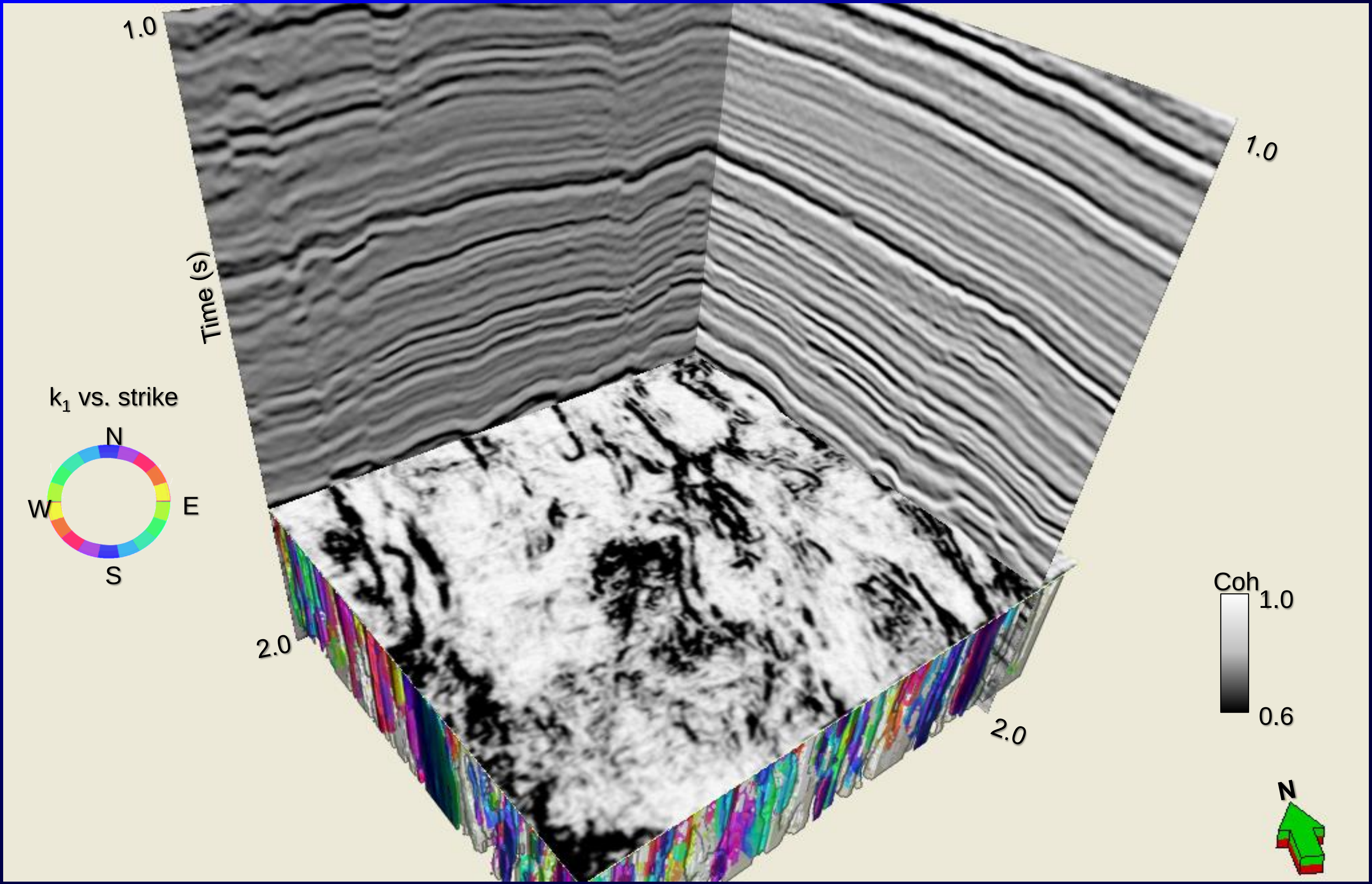


Benefits: (1) Better placement of wells; (2) Targeting bypassed pay

Rotation of fault blocks and lateral variation of accommodation space

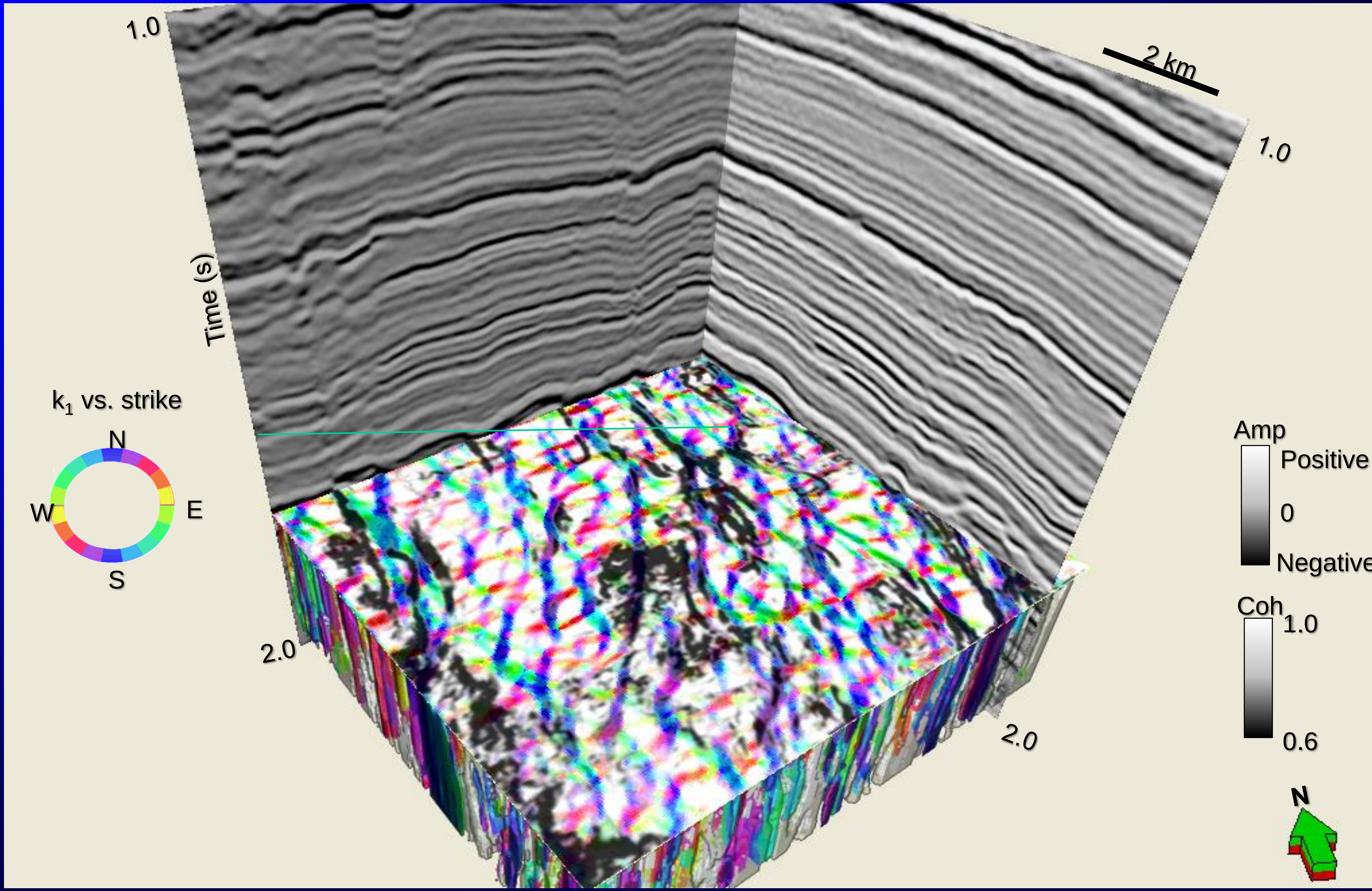
Alberta, Canada

Coherence
t = 1.710 s



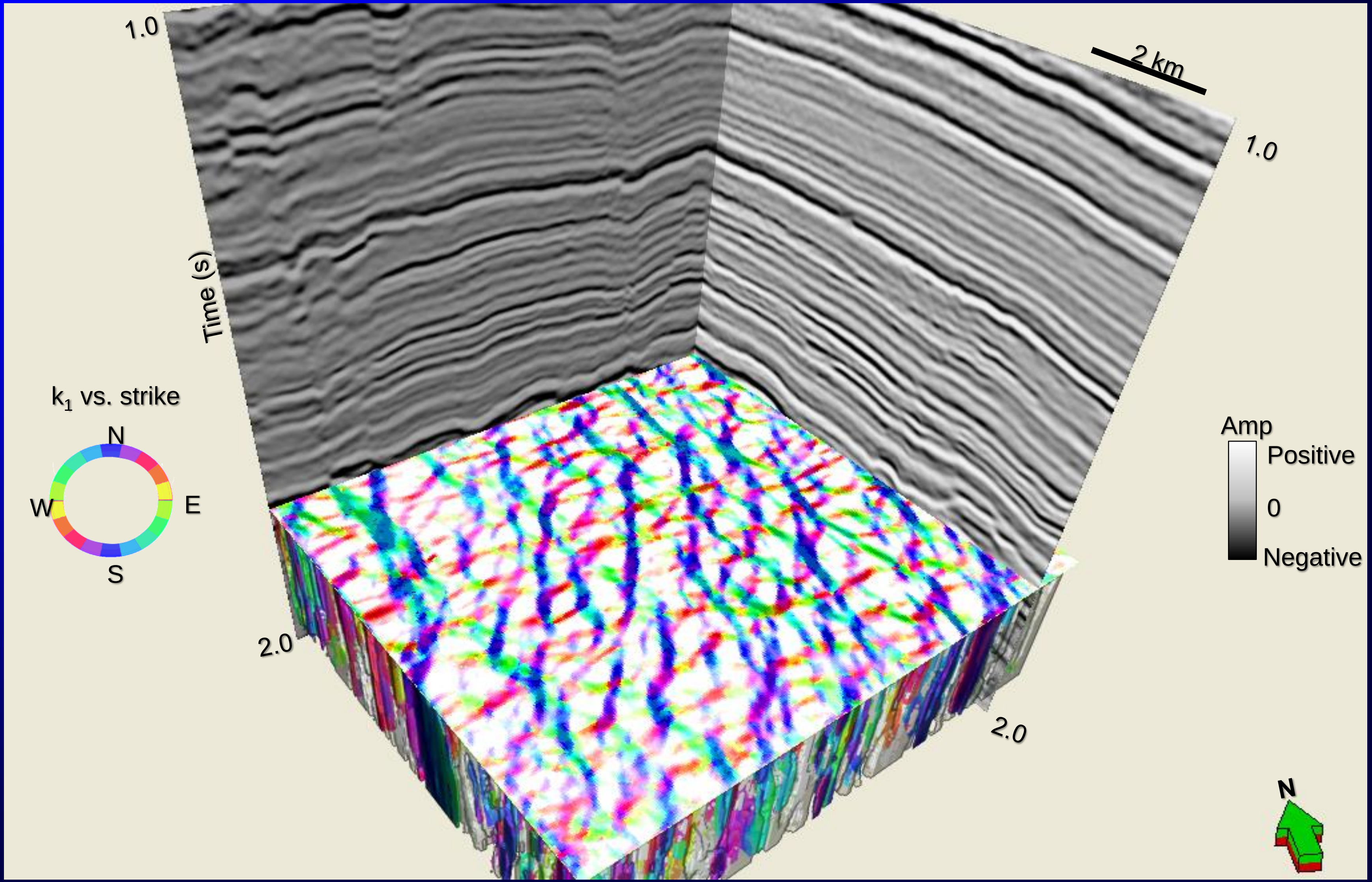
(Chopra and Marfurt, 2011)

Most-positive principal curvature, k_1, vs. its strike ψ_1 *co-rendered with coherence* t = 1.710 s



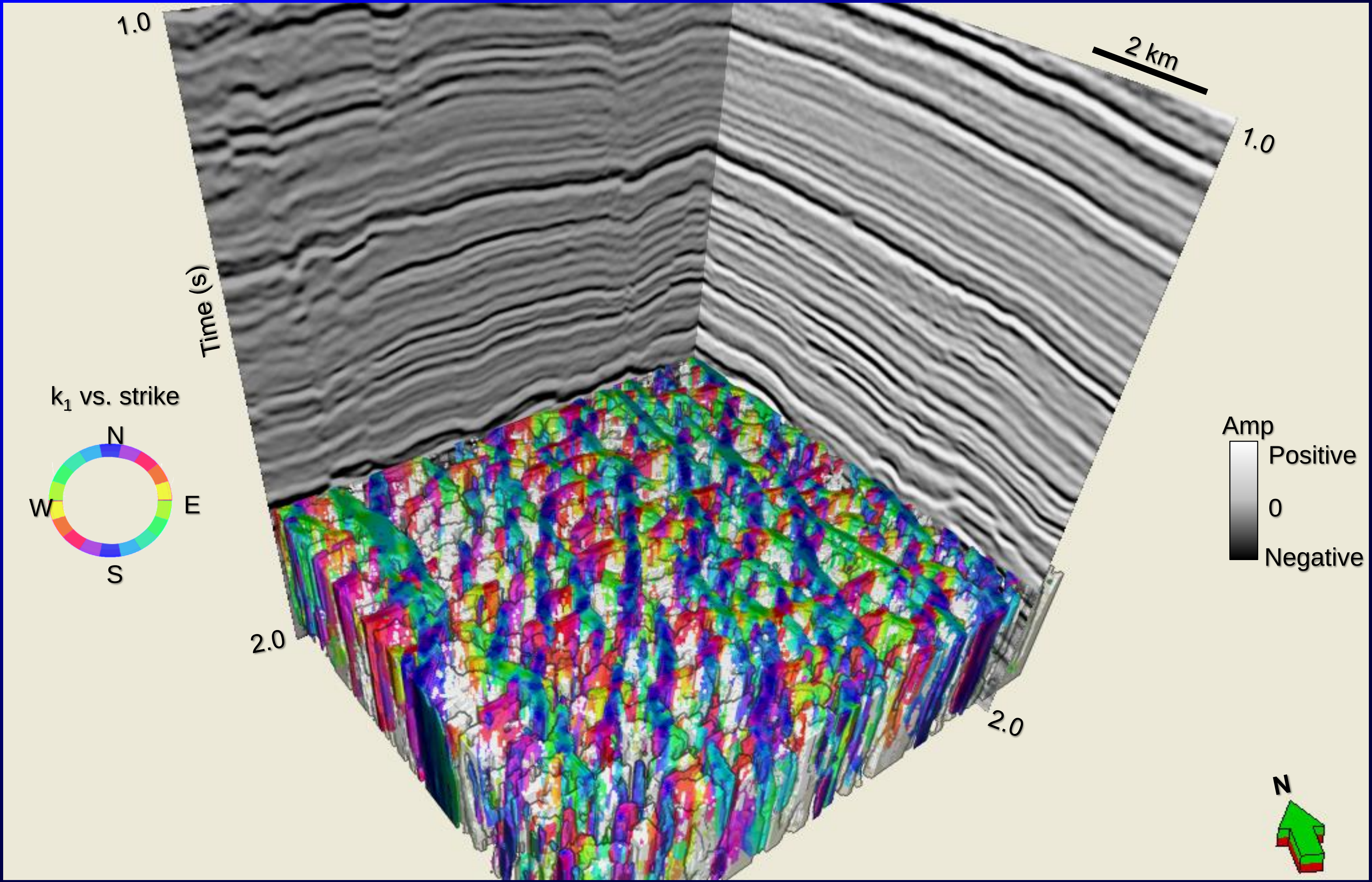
(Chopra and Marfurt, 2011)

Most-positive principal curvature, k_1 , vs. its strike ψ_1
t = 1.710 s



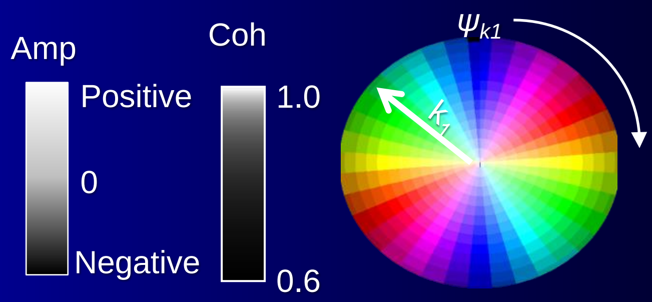
(Chopra and Marfurt, 2011)

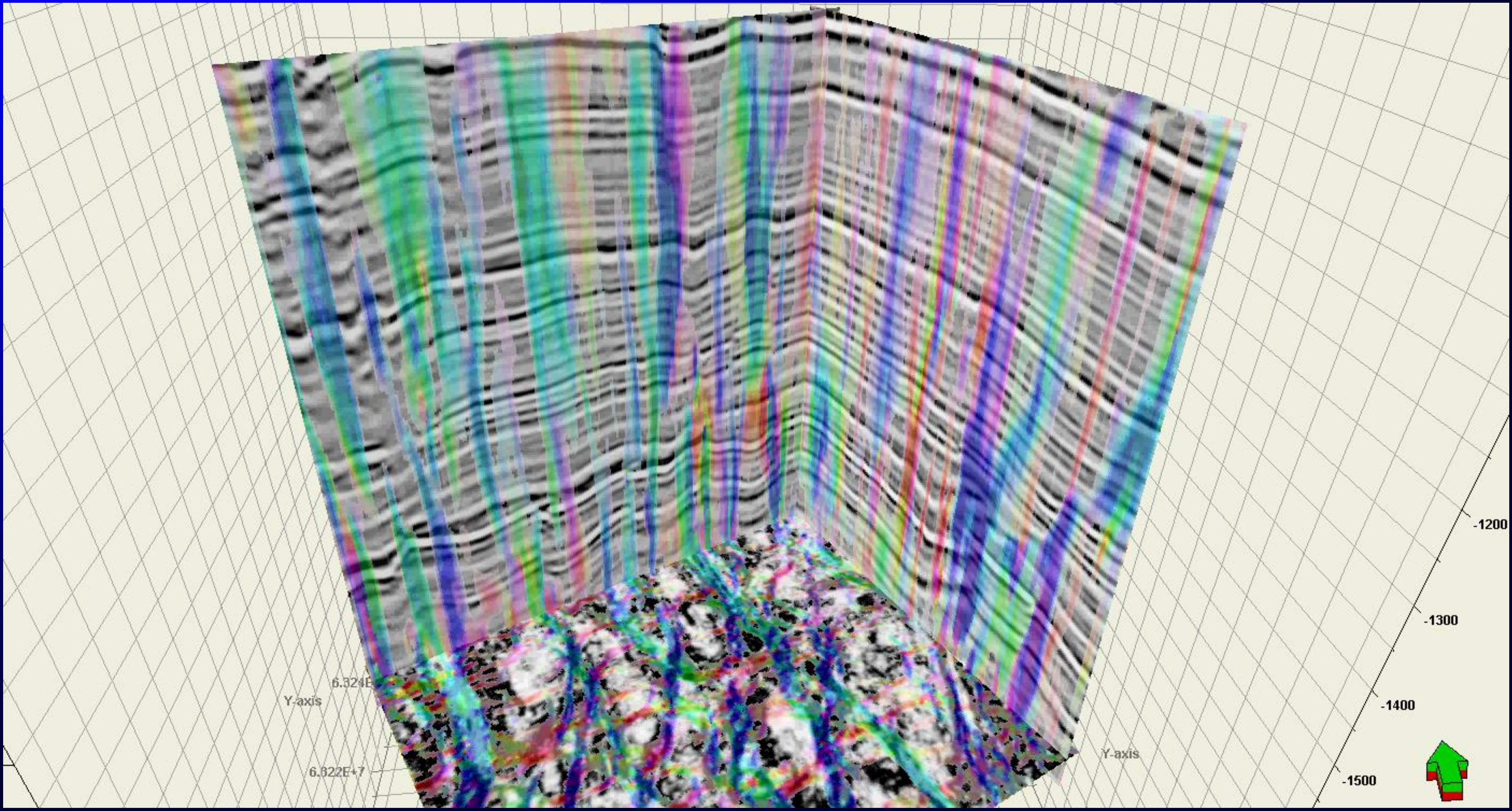
Most-positive principal curvature, k_1 , vs. its strike ψ_1



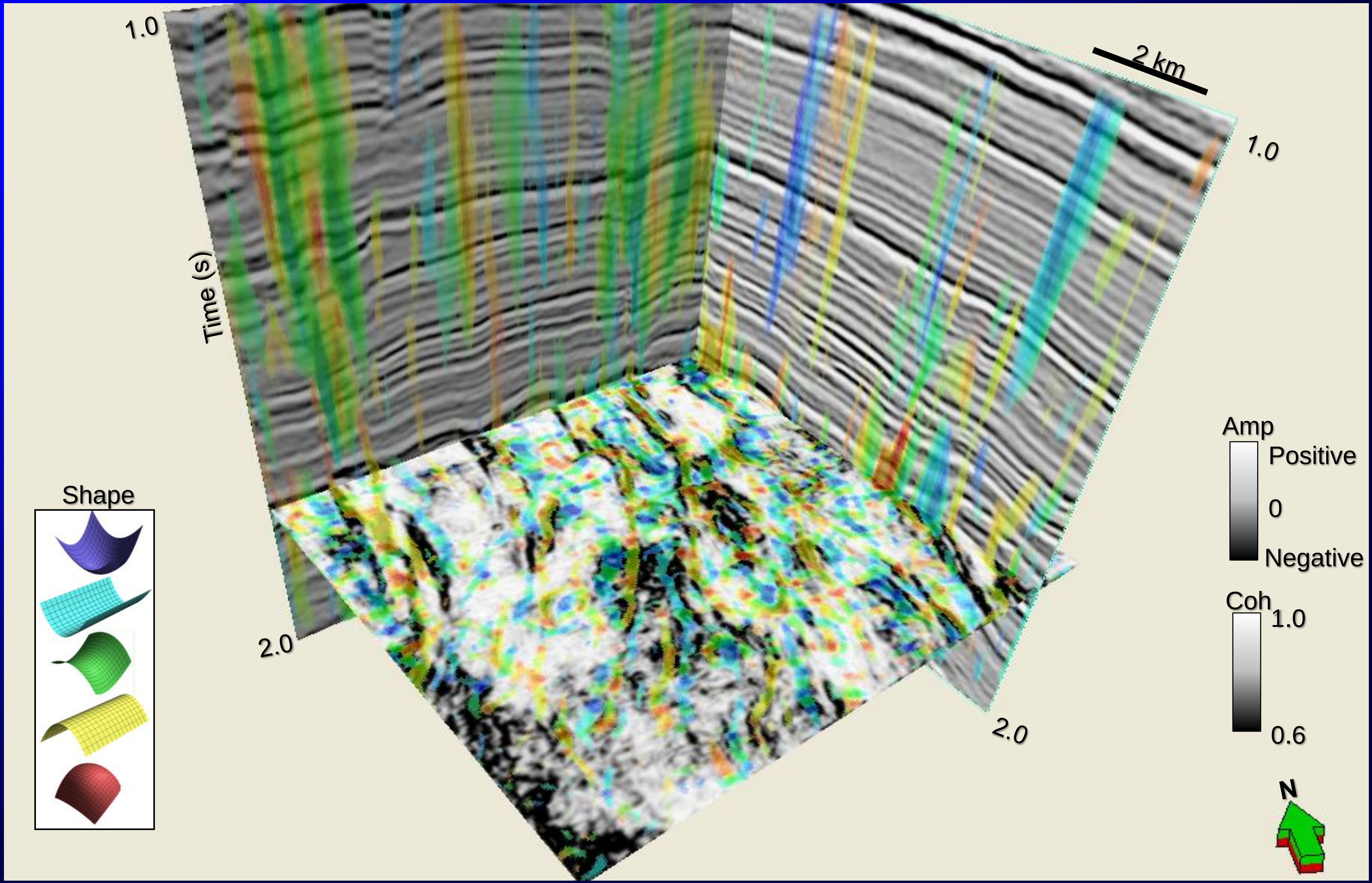
(Chopra and Marfurt, 2011)

Strike of most-positive principal curvature, ψ_{k1}, modulated by its strength, k_1 (Alberta, Canada)



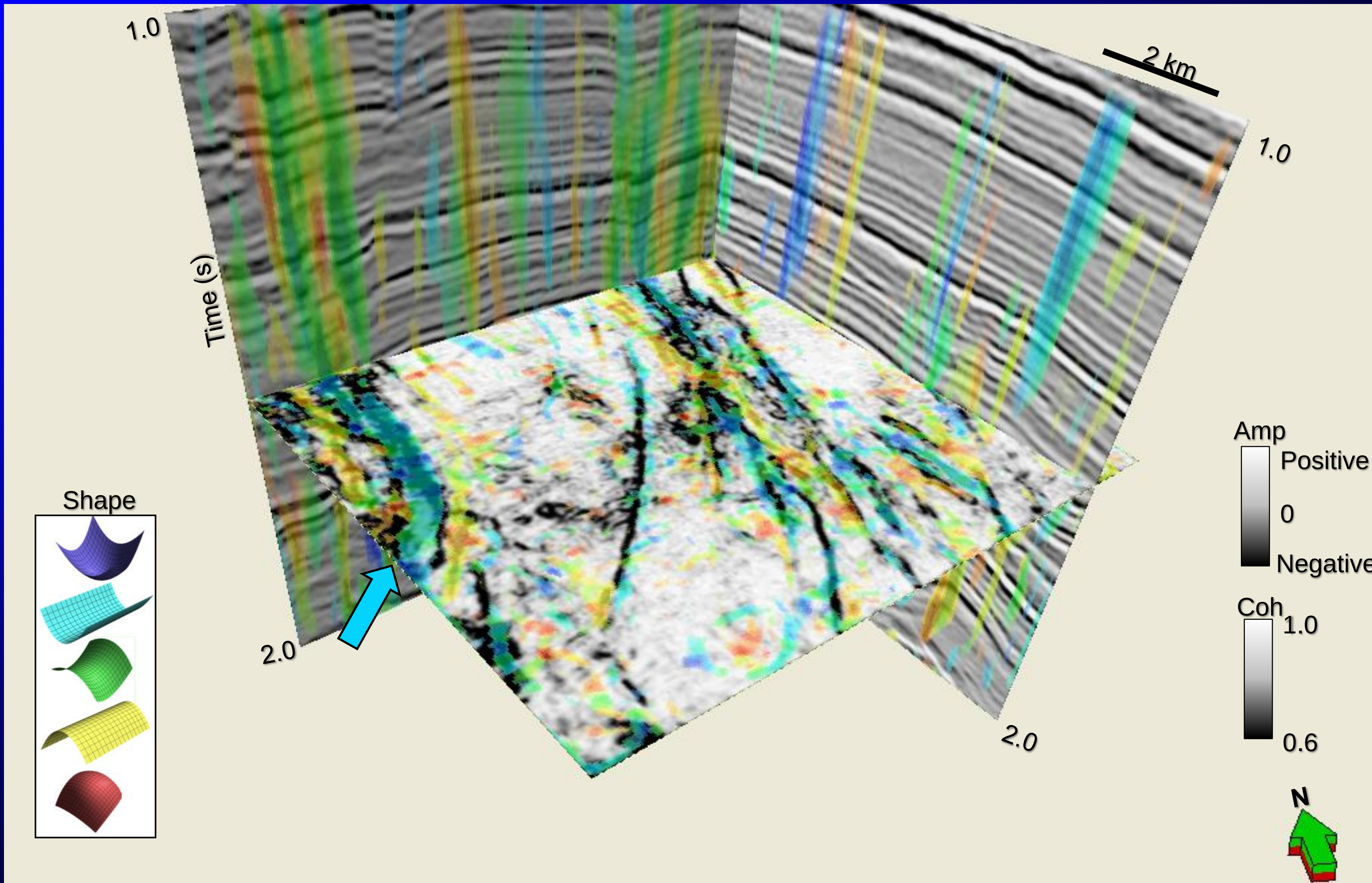


Shapes co-rendered with coherence
t = 1.710 s



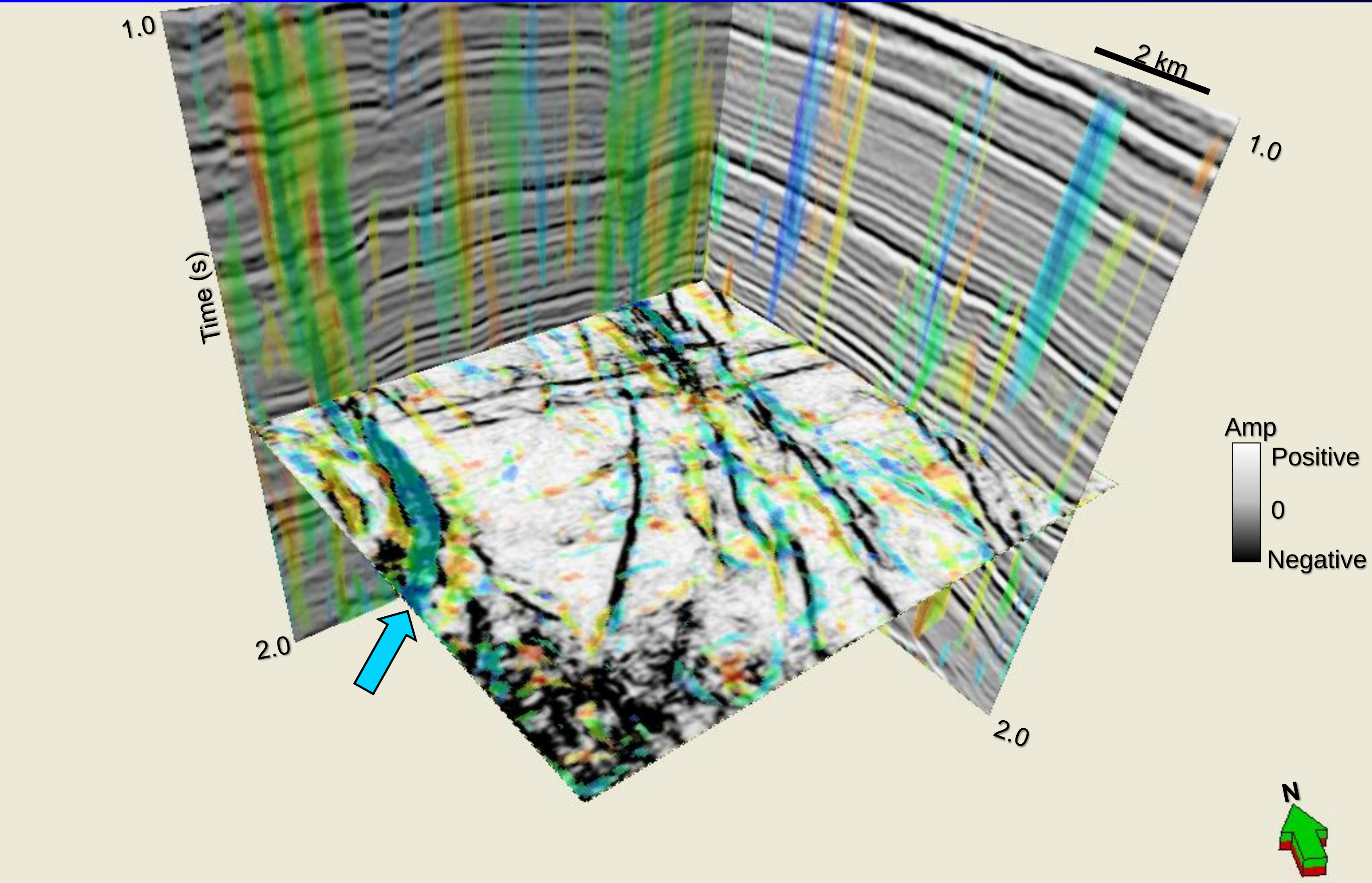
(Chopra and Marfurt, 2011)

Shapes co-rendered with coherence
t = 1.550 s



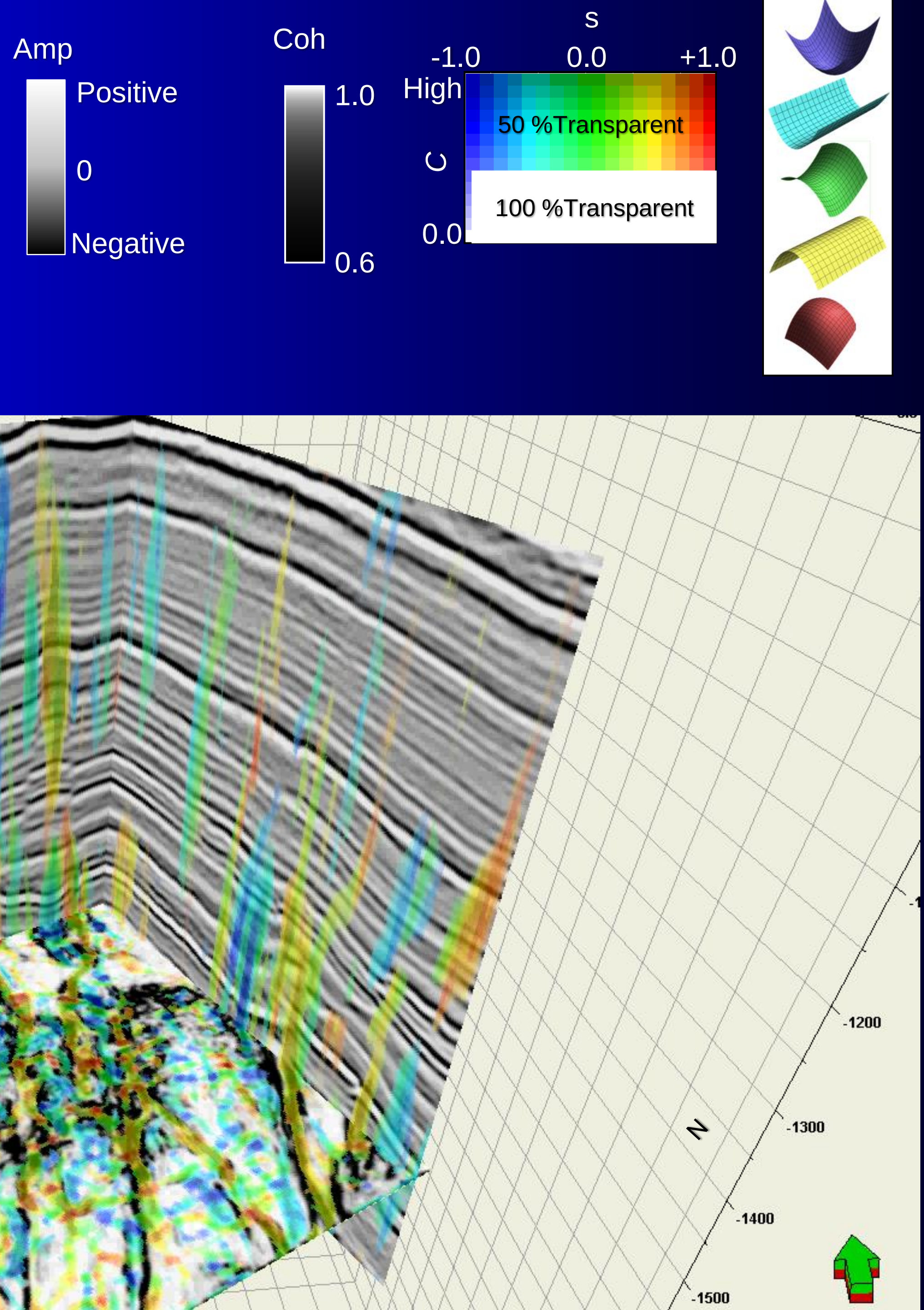
(Chopra and Marfurt, 2011)

Shapes co-rendered with coherence
t = 1.550 s

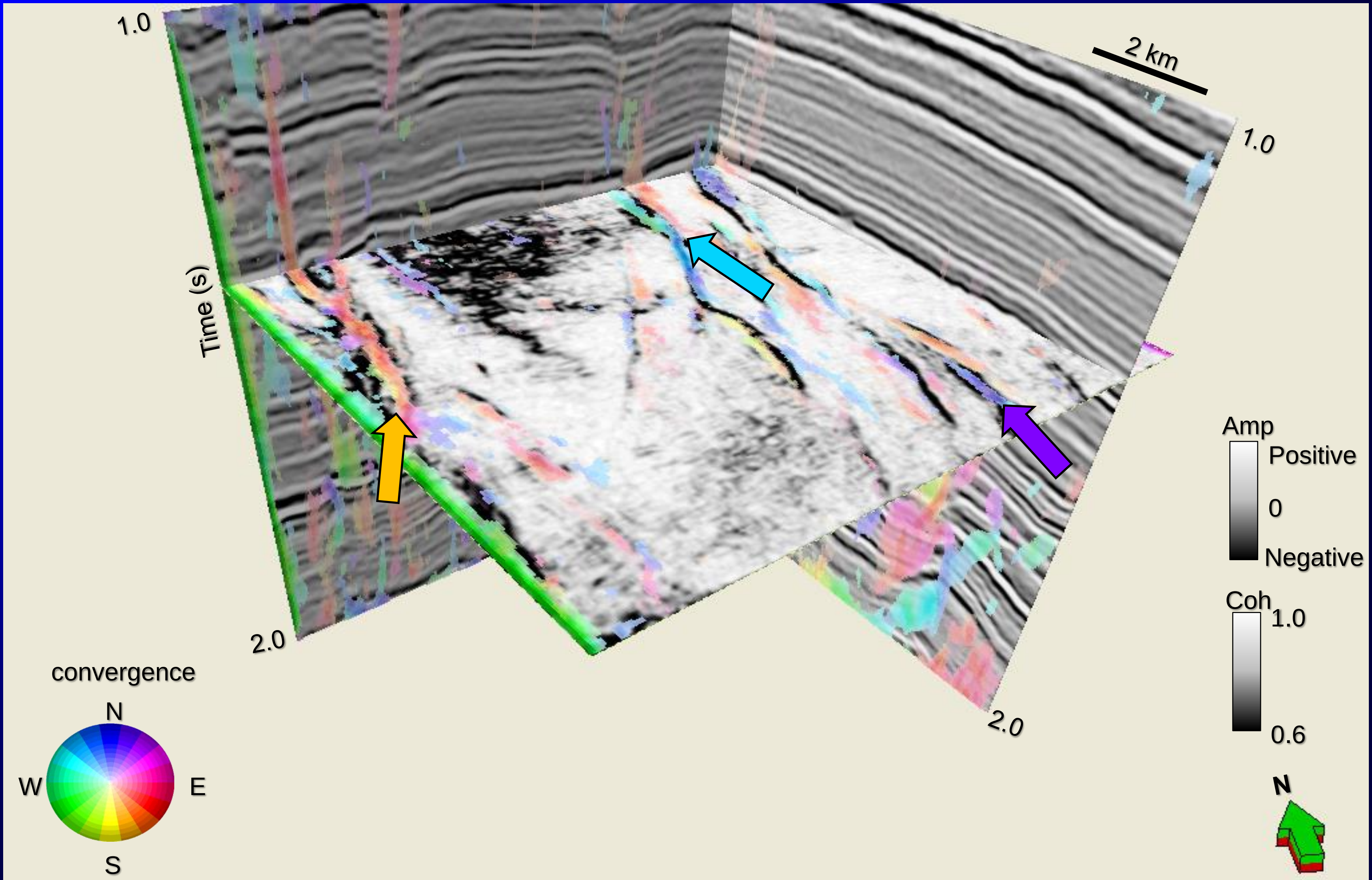


(Chopra and Marfurt, 2011)

Shape index, *s*, modulated by curvedness, *C* (Alberta, Canada)

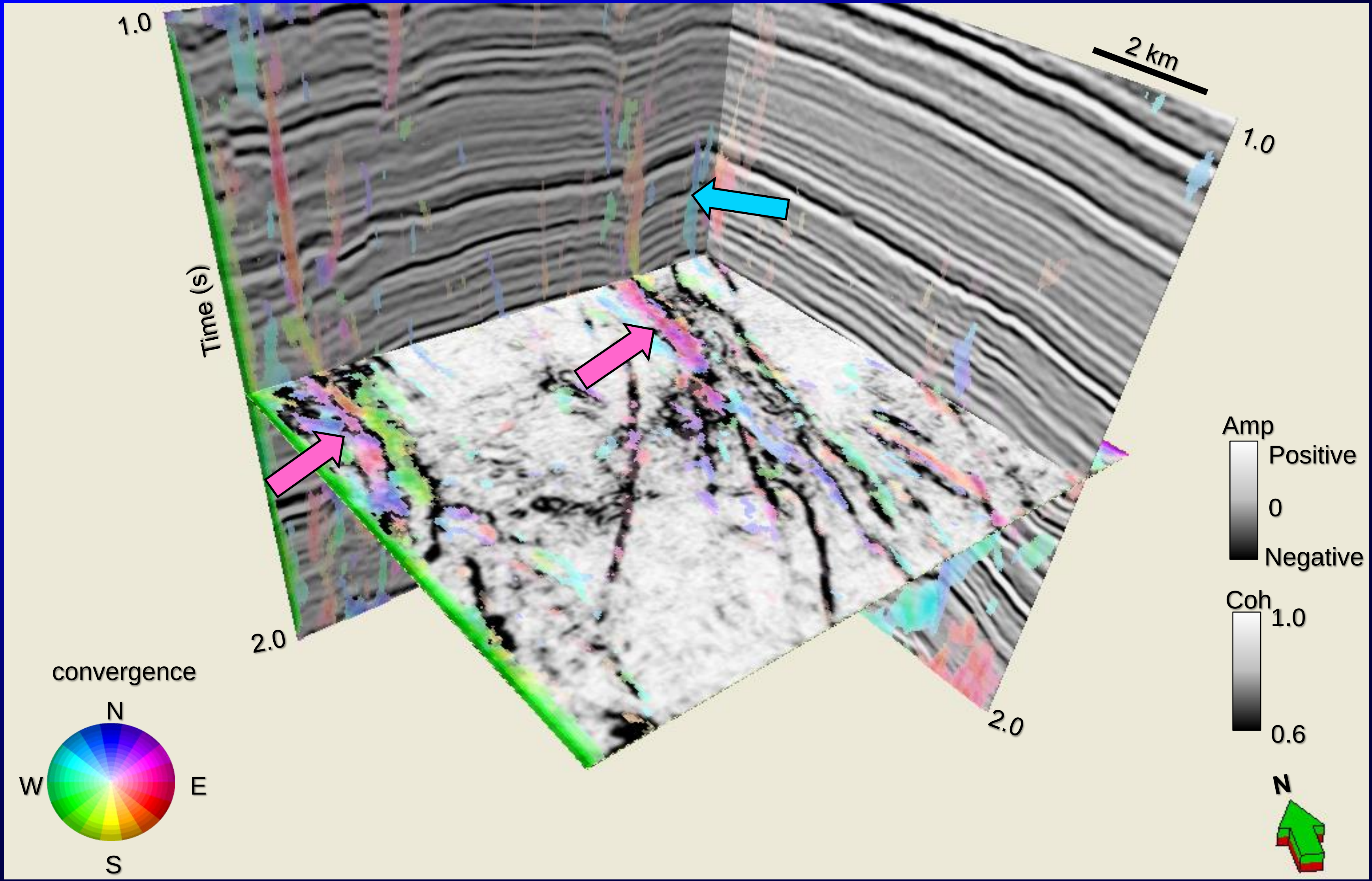


Reflector convergence co-rendered with coherence
t = 1.330 s



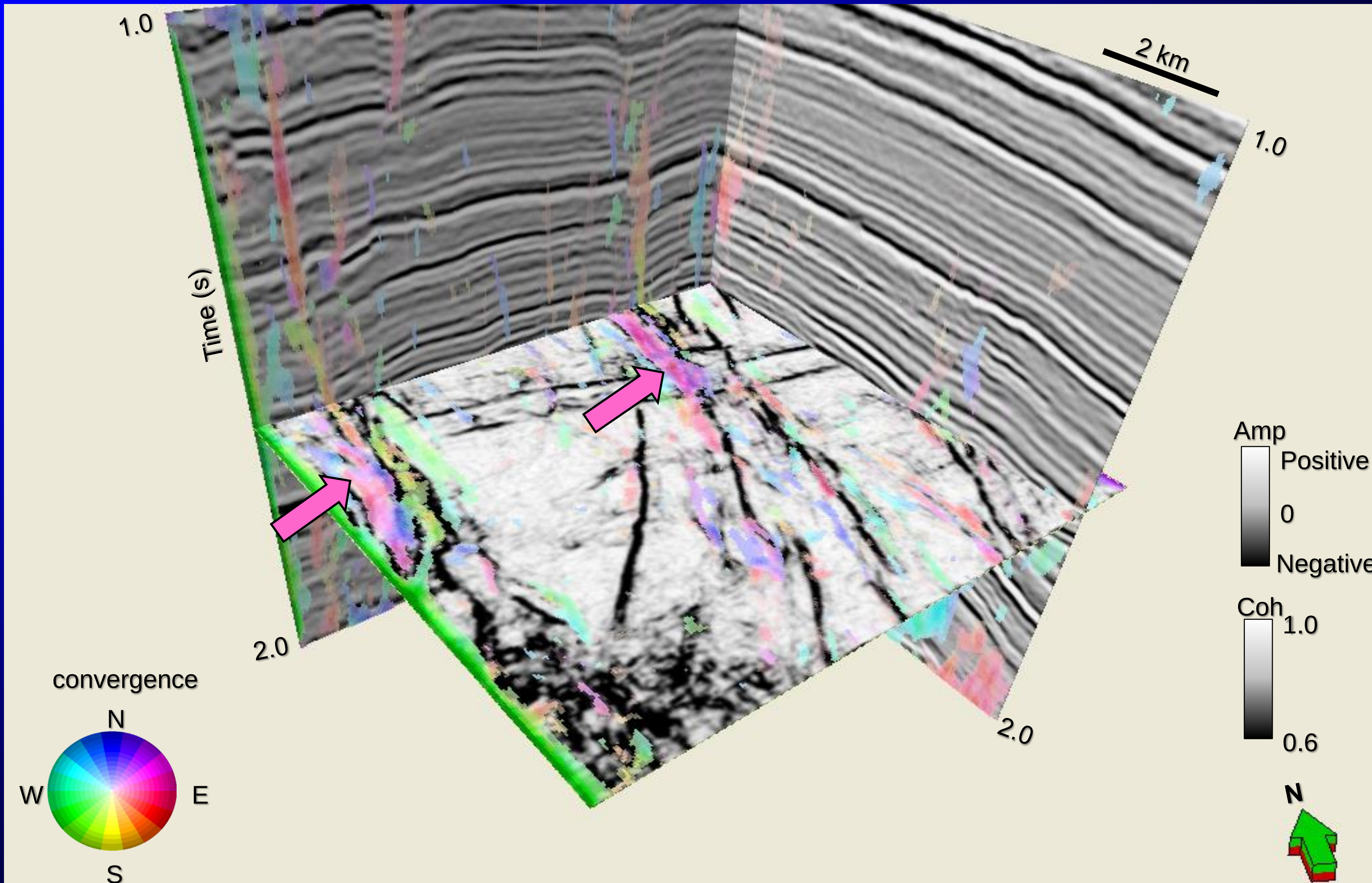
(Chopra and Marfurt, 2011)

Reflector convergence co-rendered with coherence
t = 1.500 s



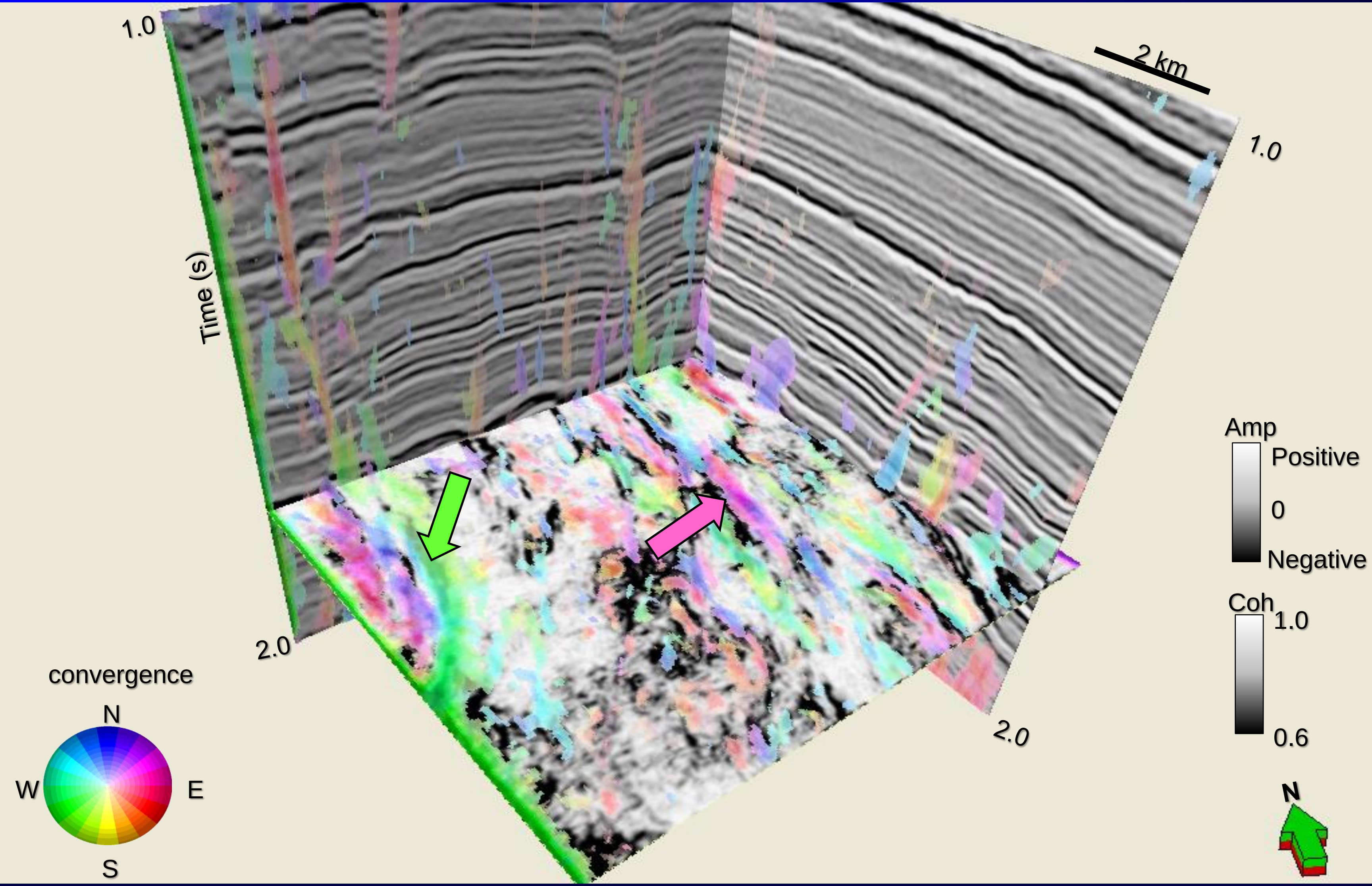
(Chopra and Marfurt, 2011)

Reflector convergence co-rendered with coherence
t = 1.550 s



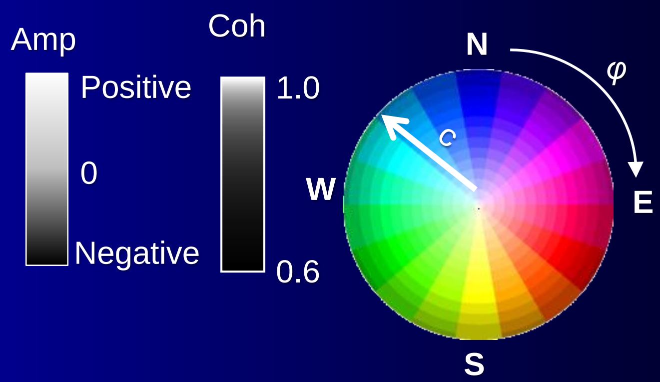
(Chopra and Marfurt, 2011)

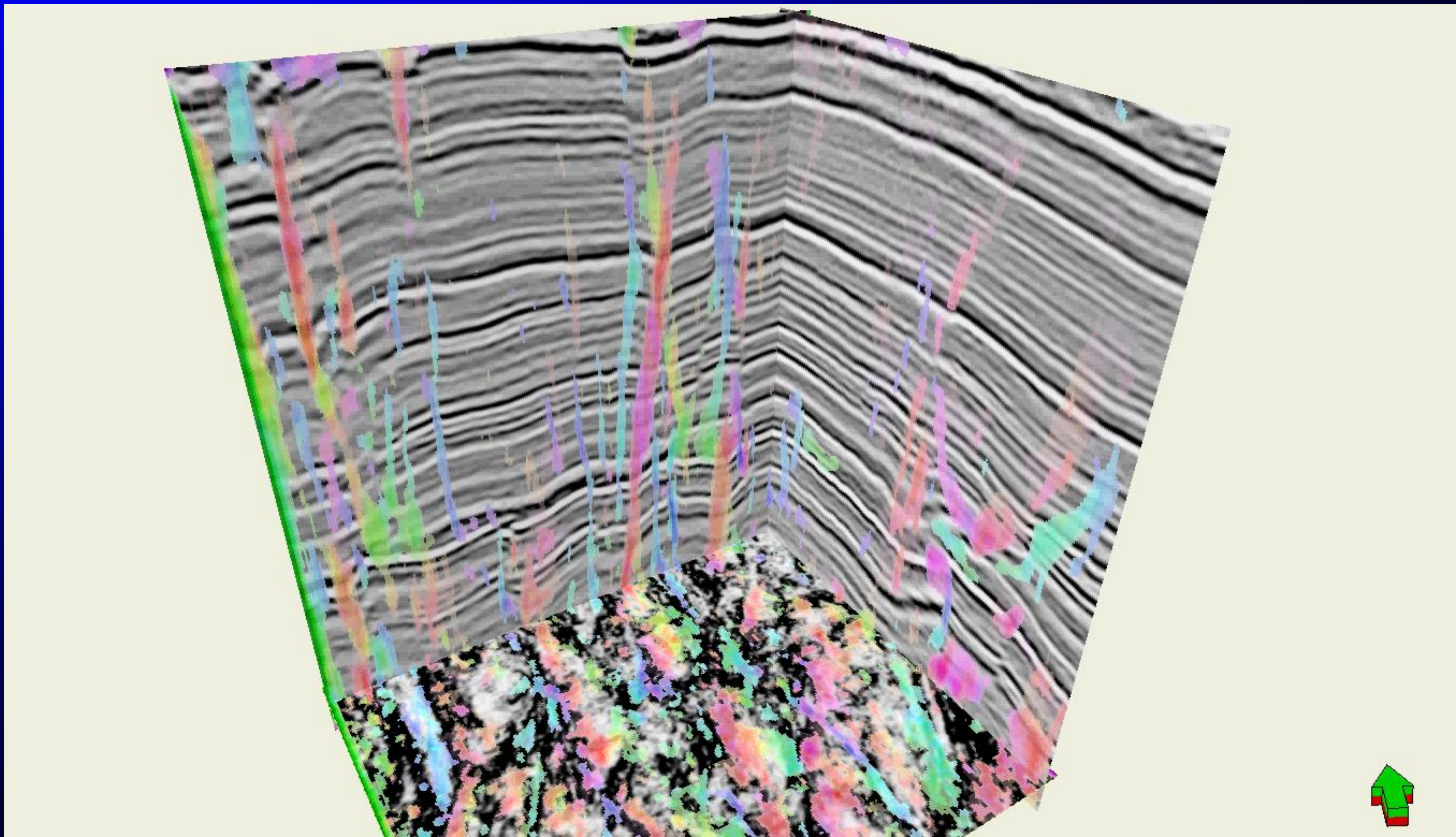
Reflector convergence co-rendered with coherence
t = 1.710 s



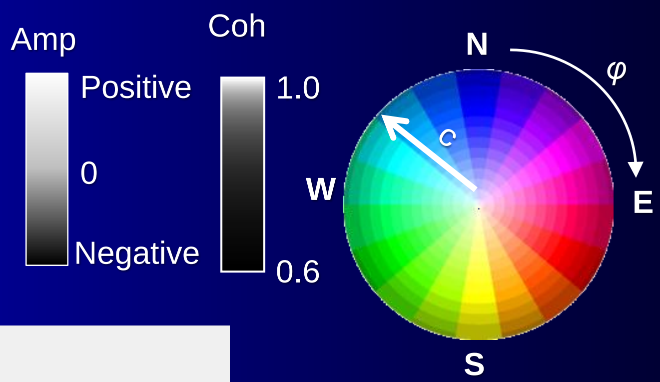
(Chopra and Marfurt, 2011)

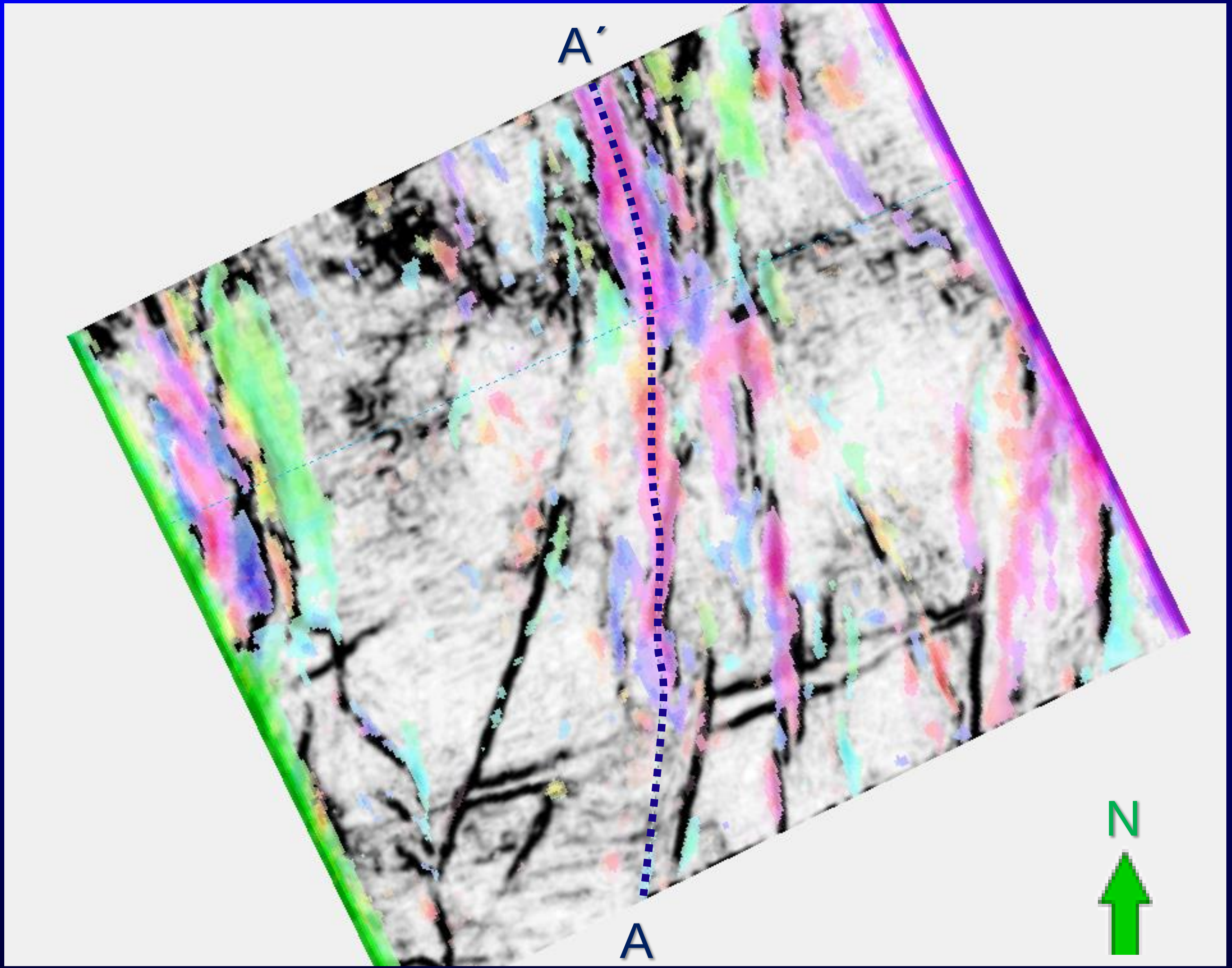
Reflector vector convergence
Azimuth of convergence, *φ*, modulated by its strength, *c*. (Alberta, Canada)





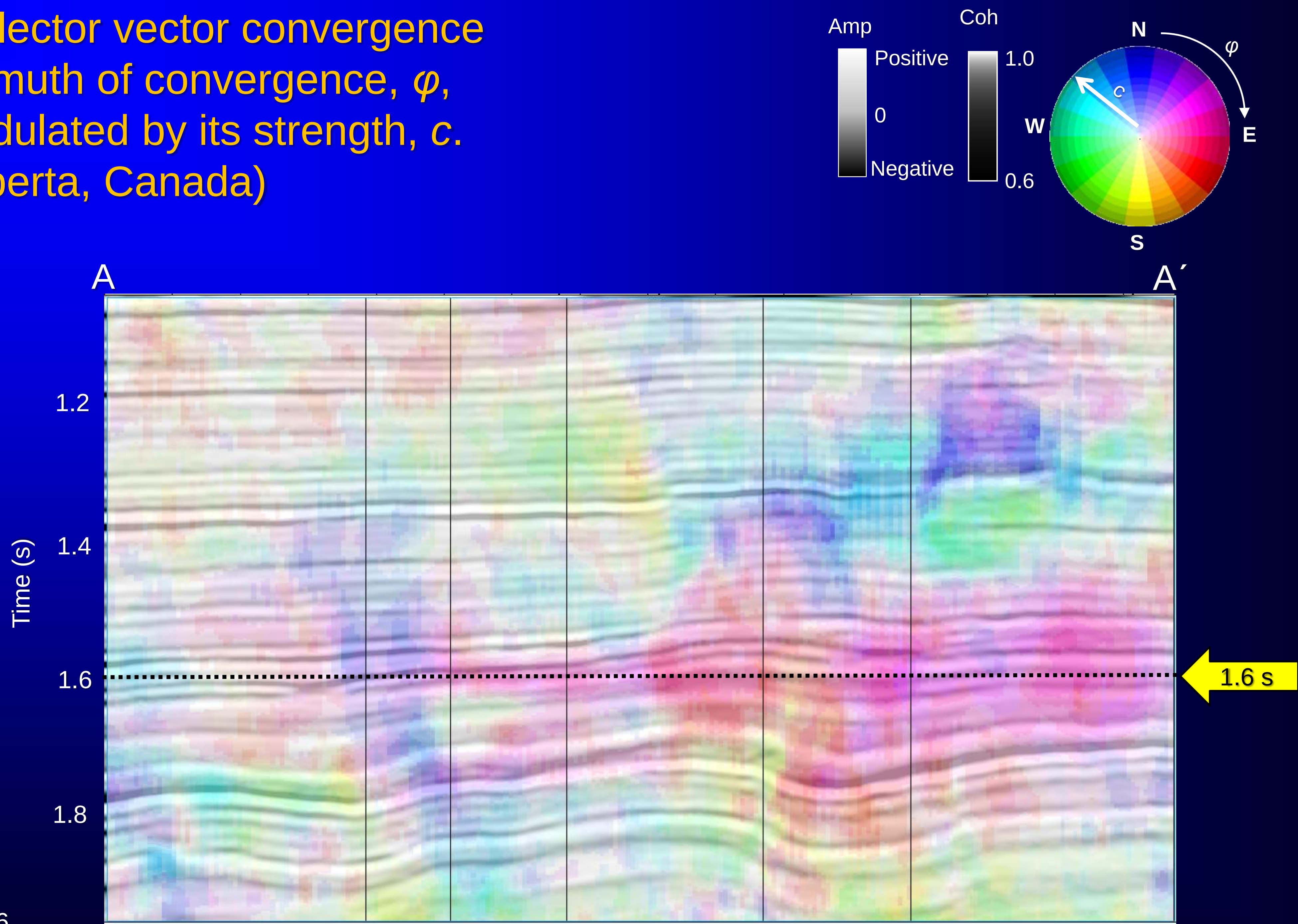
Reflector vector convergence
Azimuth of convergence, φ, modulated by its strength, c. (Alberta, Canada)





Time slice at t=1.6 s

Reflector vector convergence
Azimuth of convergence, *φ*, modulated by its strength, *c*. (Alberta, Canada)



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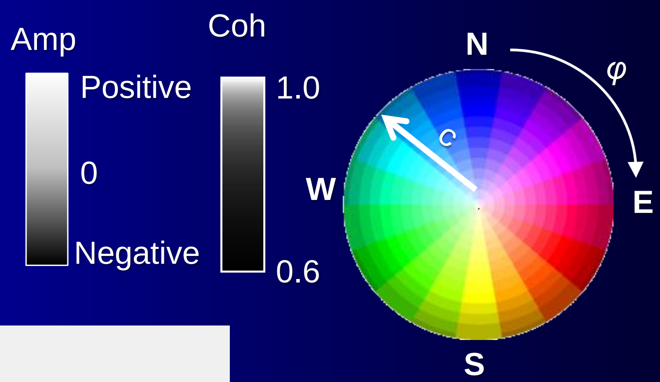
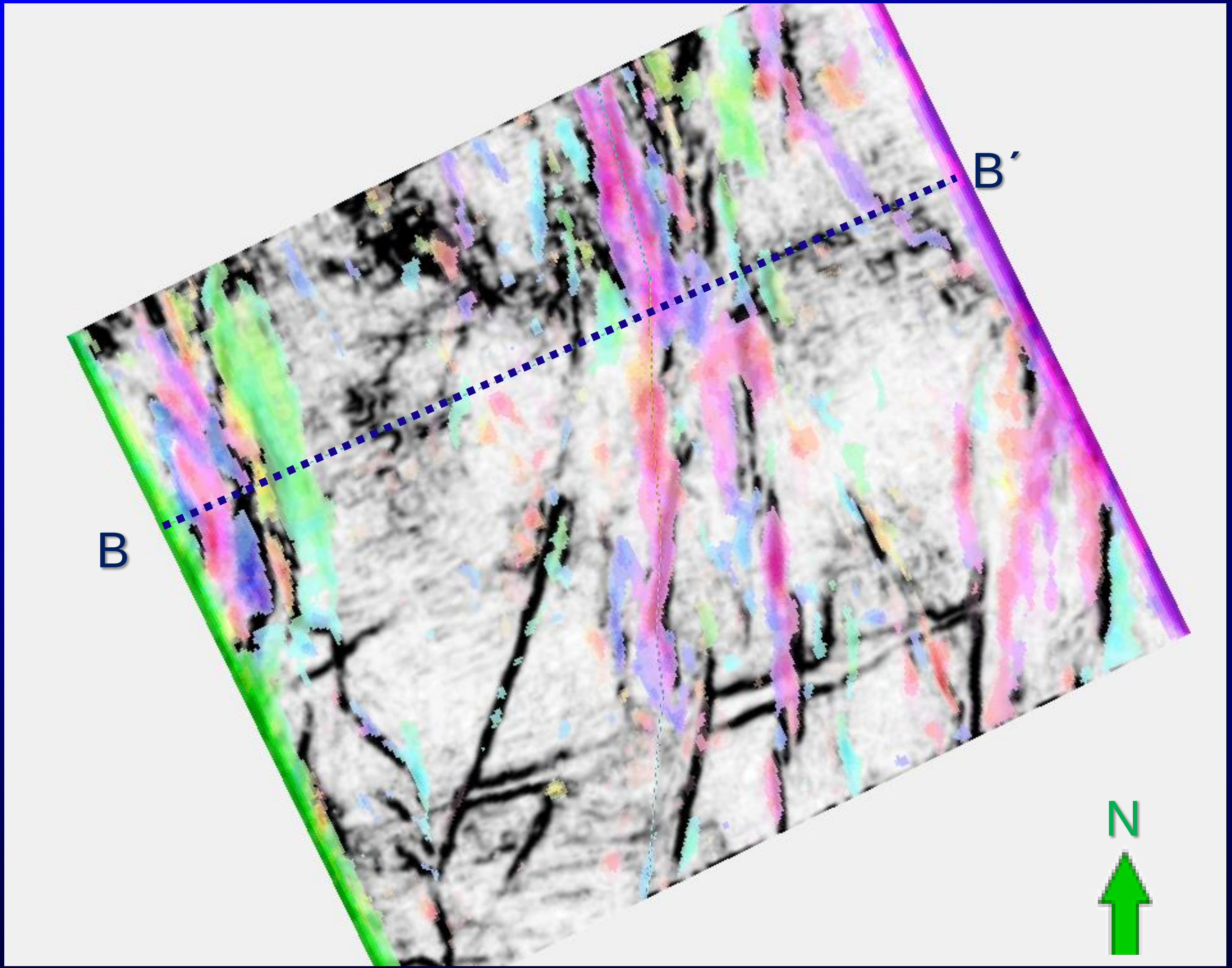
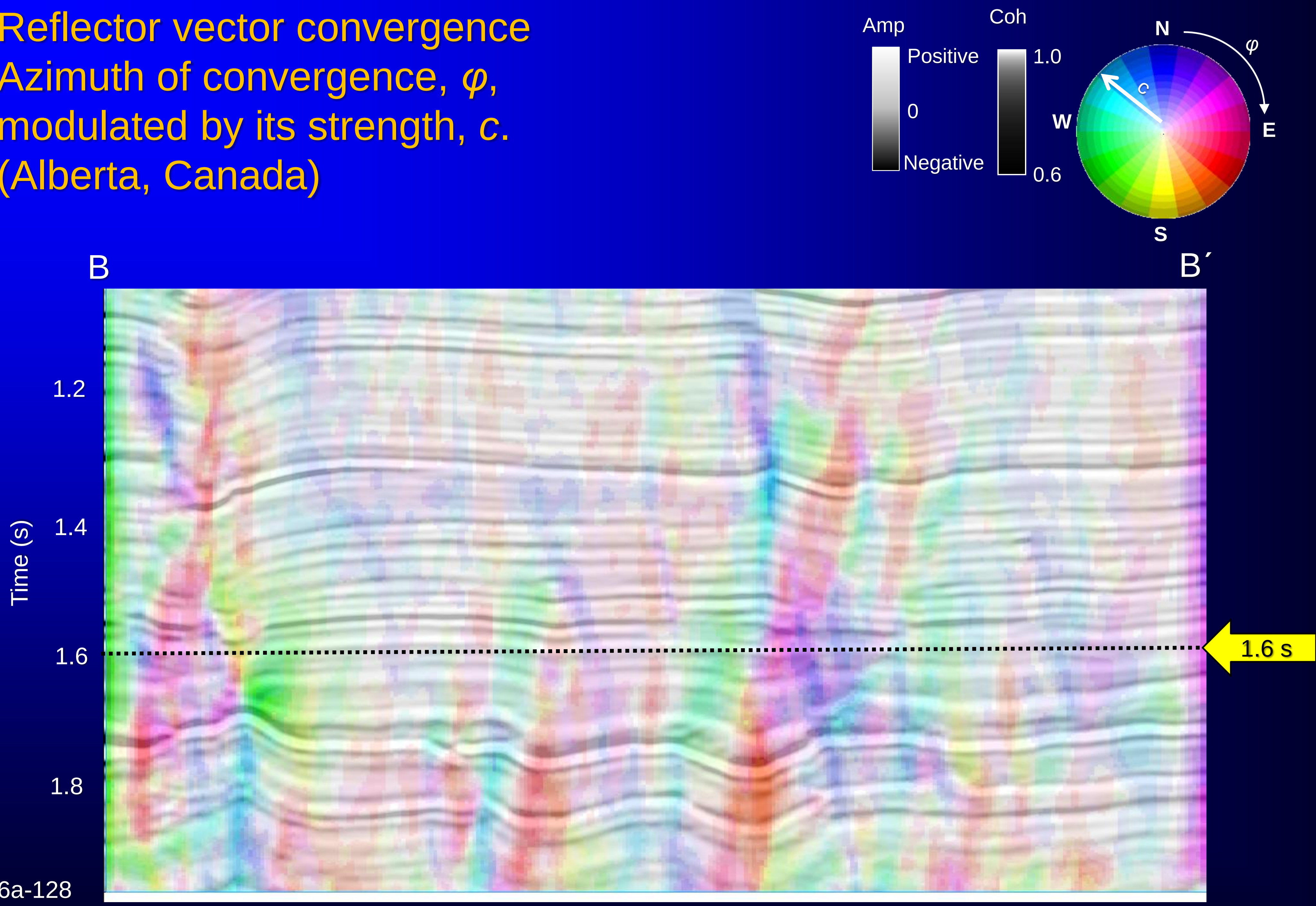
Reflector vector convergence
Azimuth of convergence, φ, modulated by its strength, c. (Alberta, Canada)



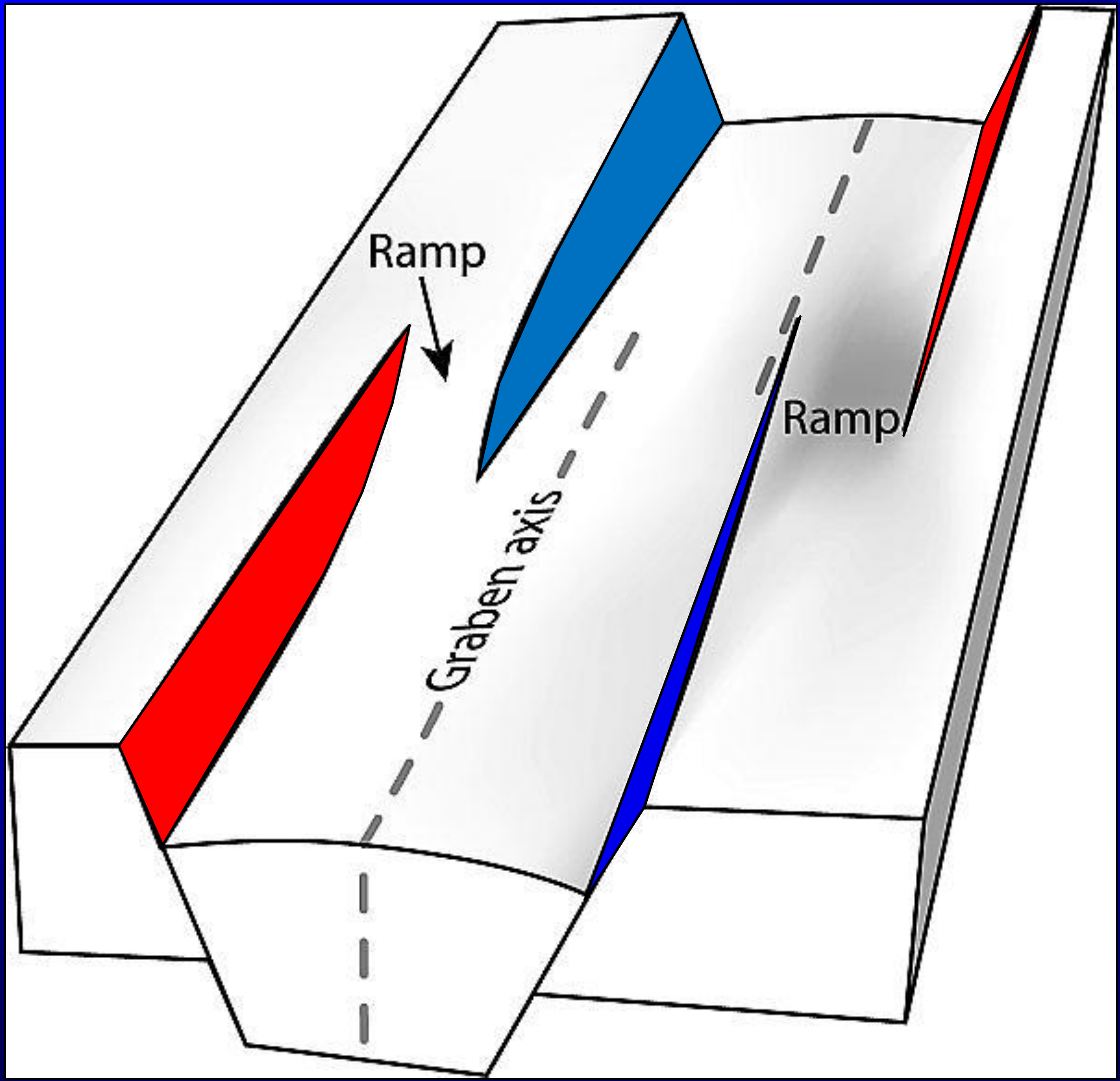


Time slice at t=1.6 s

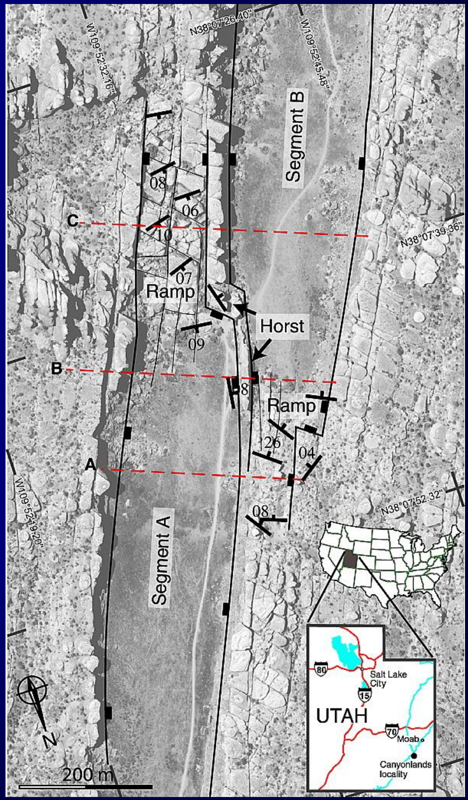
Reflector vector convergence
Azimuth of convergence, φ, modulated by its strength, c. (Alberta, Canada)



6a-128

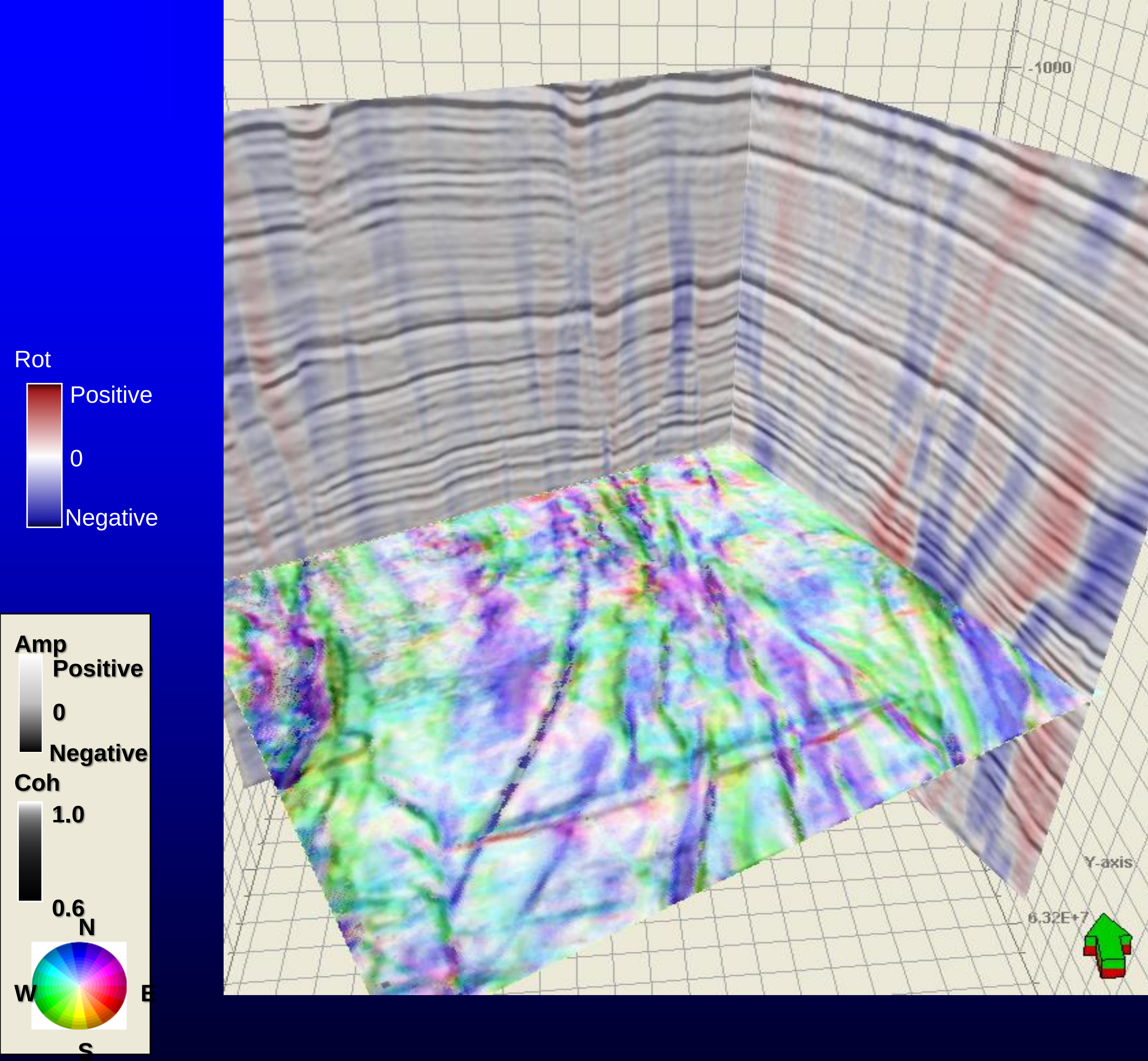


Fault linkage and graben stepovers (Devil's Lane, Utah)



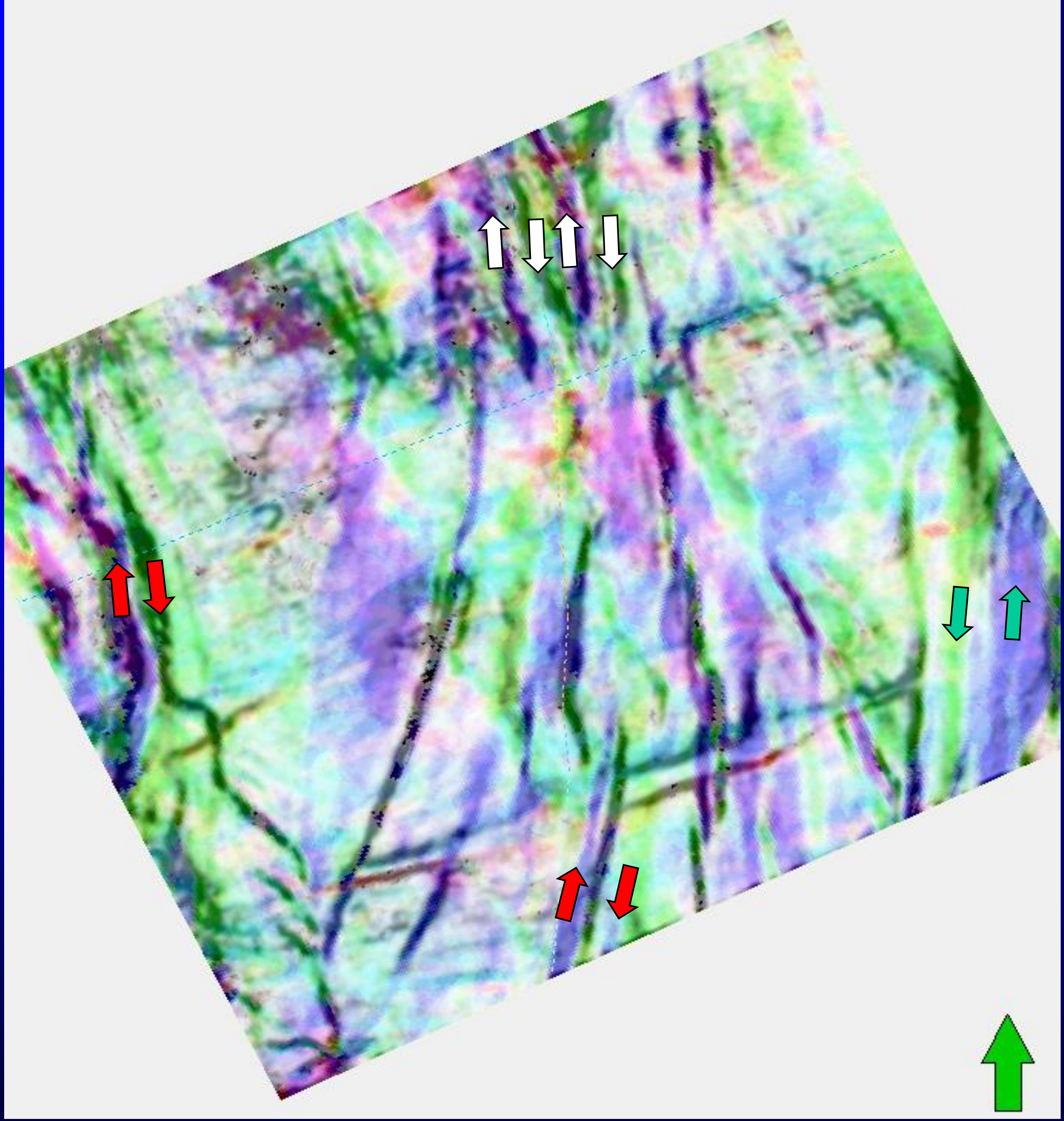
(Fossen et al., 2010)

Vector dip co-rendered with coherence

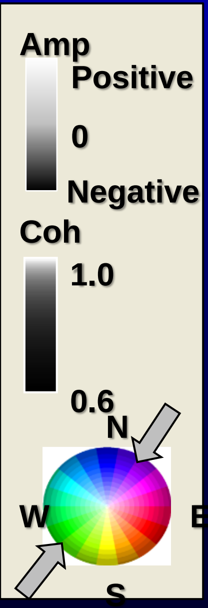


t=1.610 s

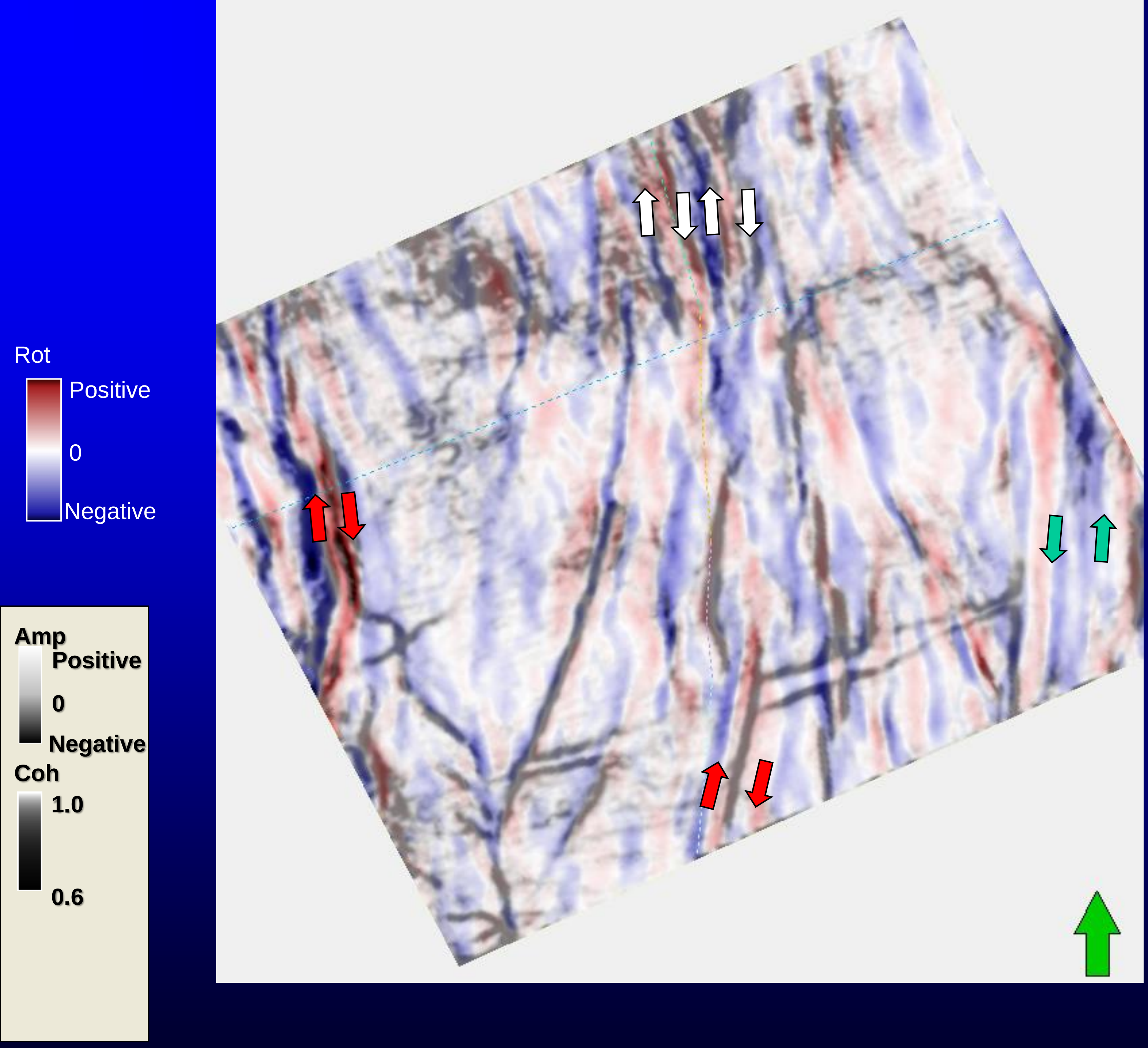
Reflector rotation about the average normal co-rendered with coherence



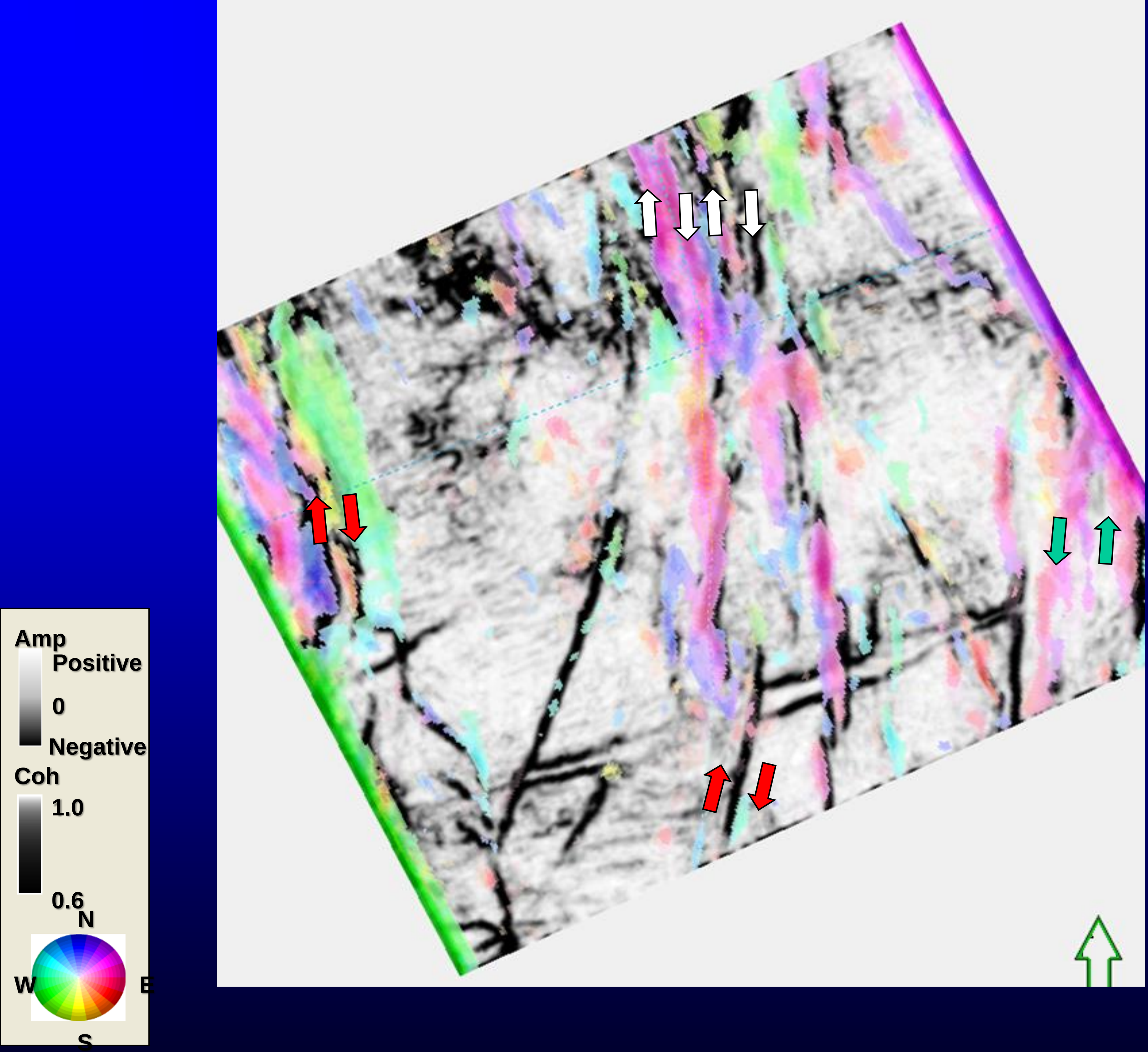
t=1.610 s



Reflector rotation about the average normal co-rendered with coherence



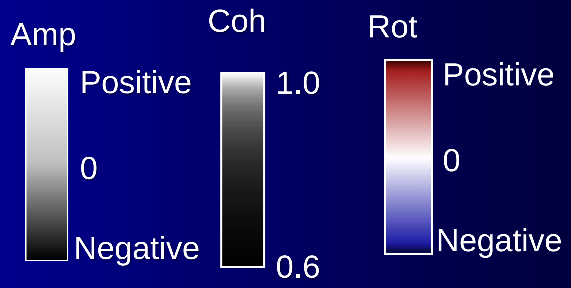
t=1.610 s

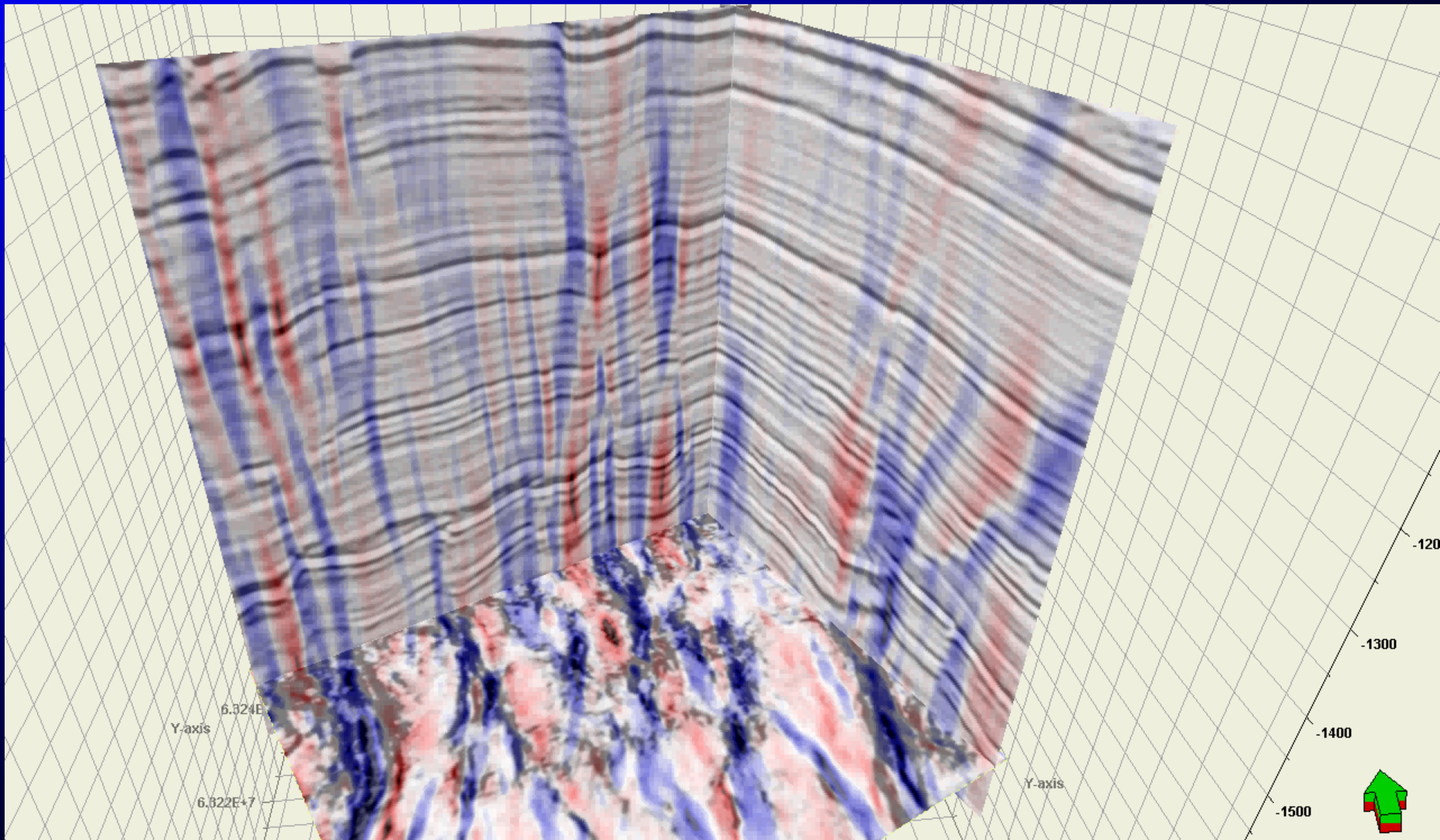


Reflector convergence co-rendered with coherence

t=1.610 s

Reflector rotation about the average normal





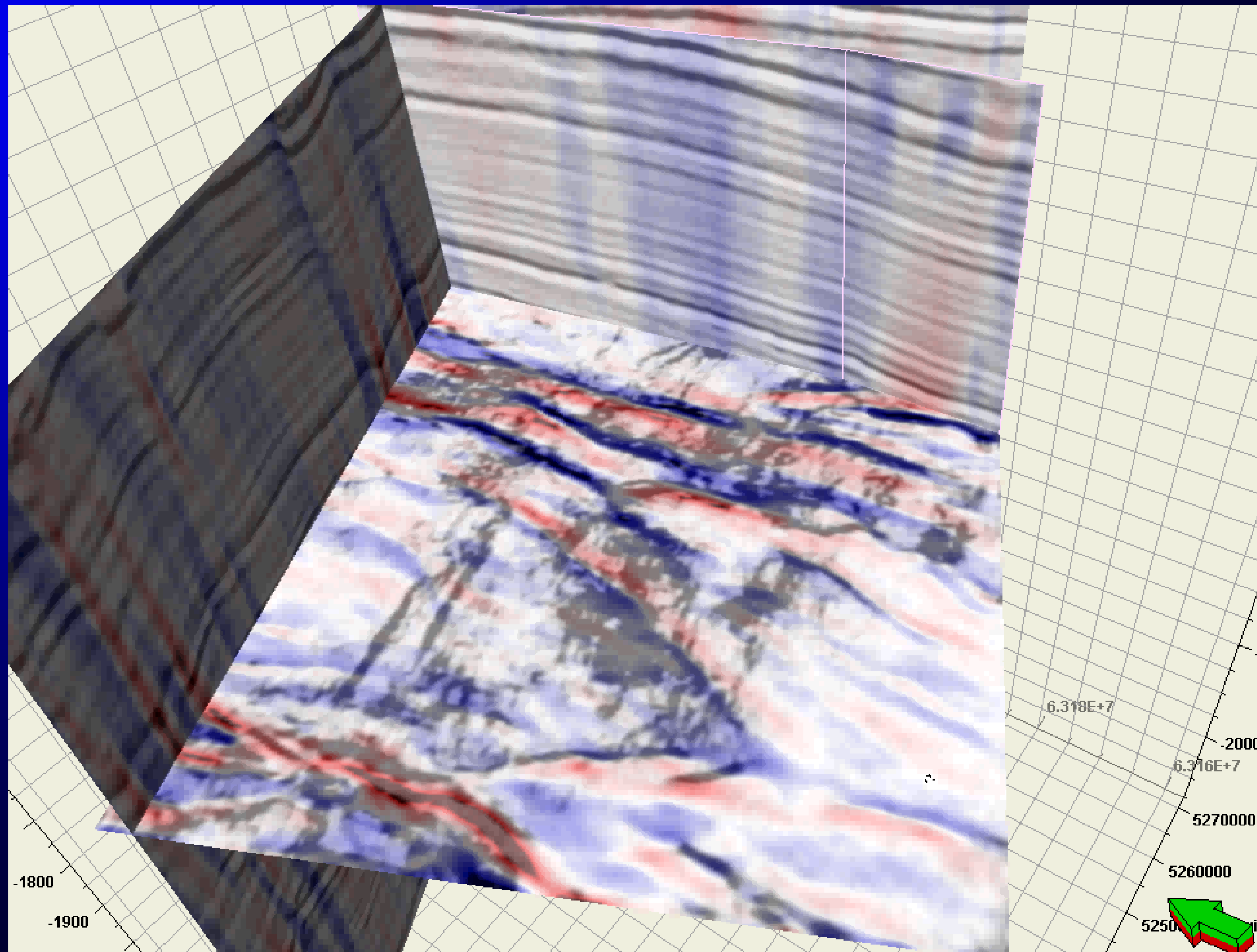
(Chopra and Marfurt, 2012)

Reflector rotation about the average normal

Amp
Positive
0
Negative

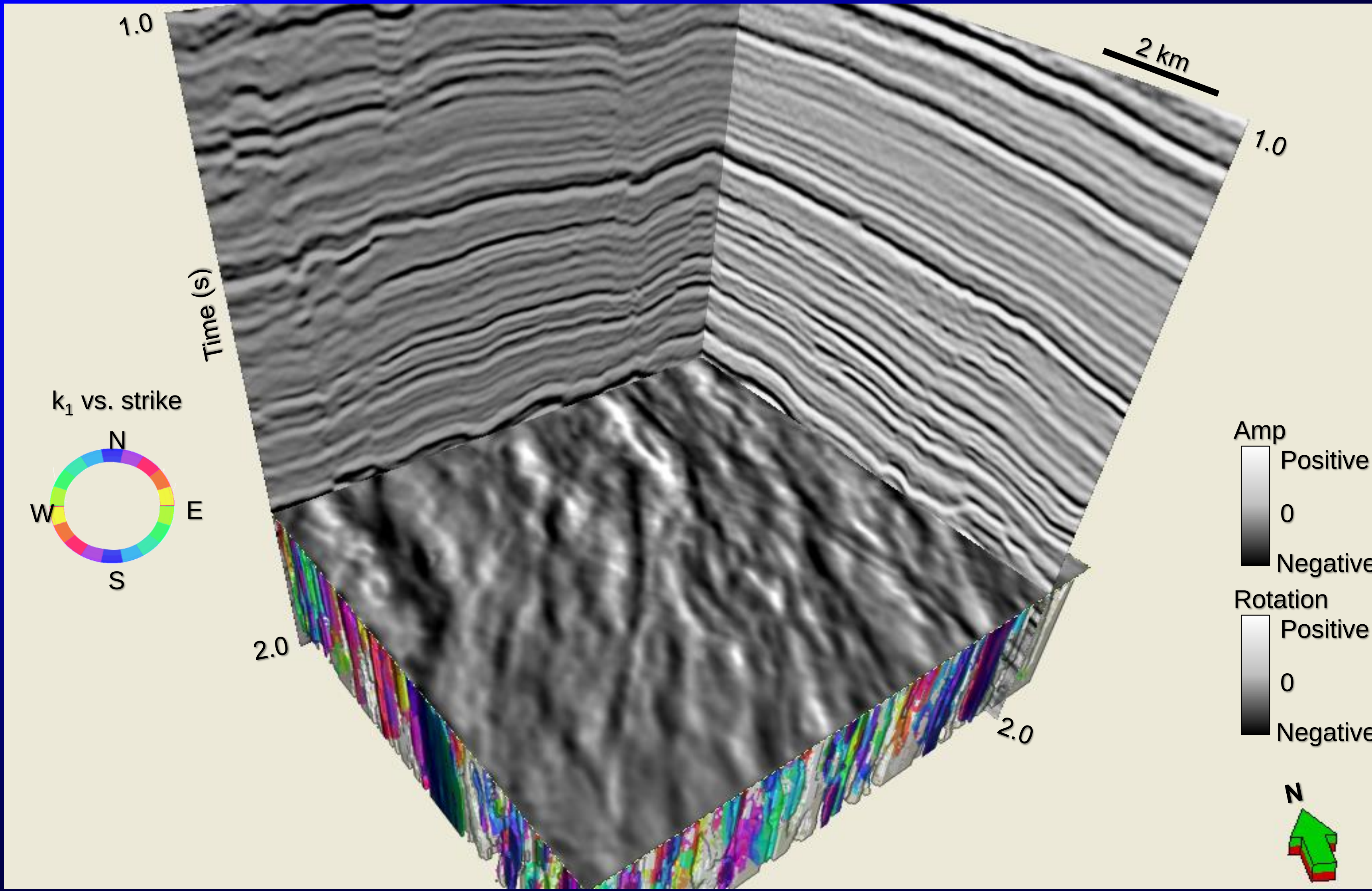
Coh
1.0
0.6

Rot
Positive
0
Negative



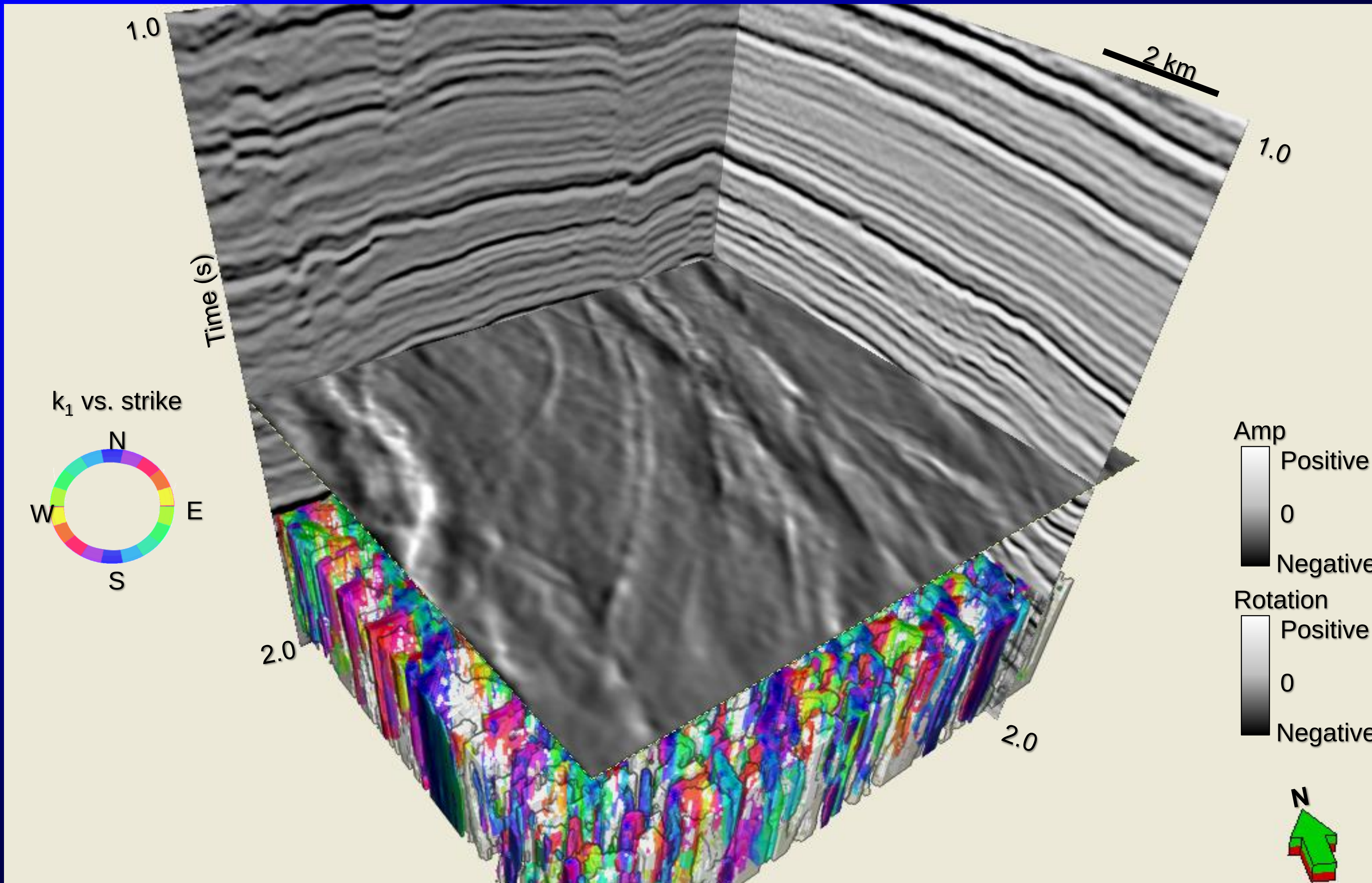
(Chopra and Marfurt, 2012)

Reflector rotation
t = 1.710 s



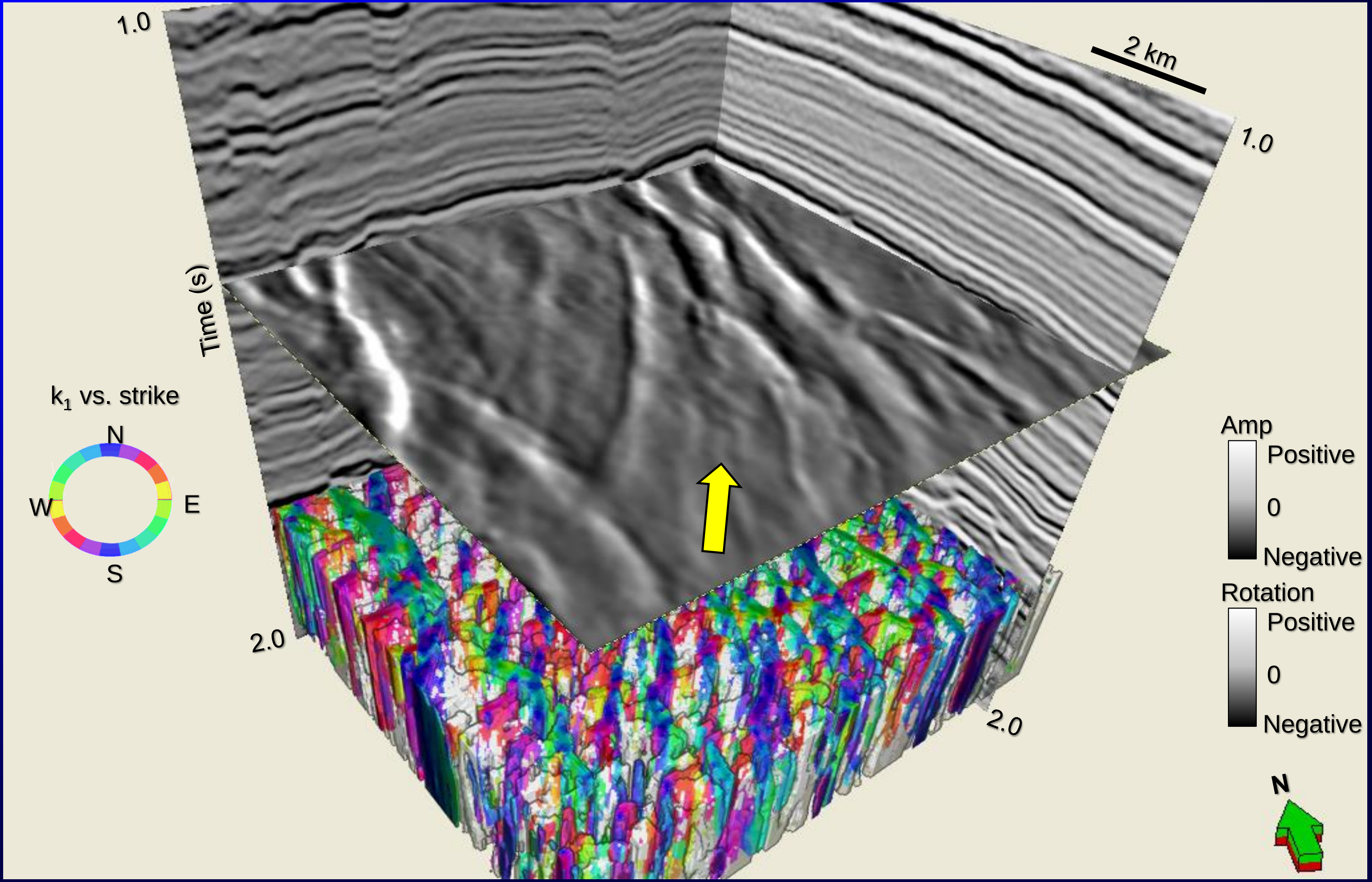
(Chopra and Marfurt, 2011)

Reflector rotation
t = 1.500 s



(Chopra and Marfurt, 2011)

Reflector rotation
t = 1.330 s

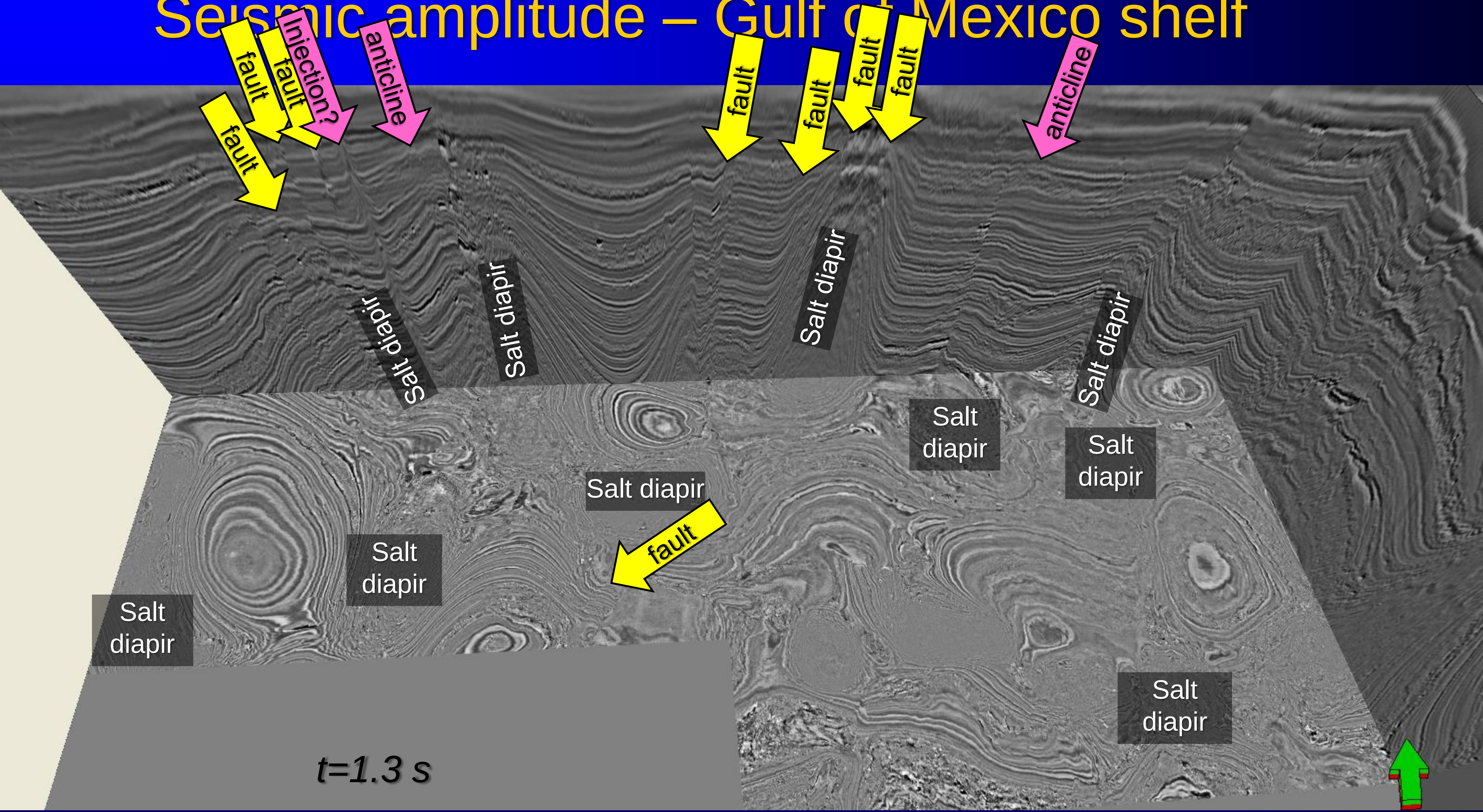


(Chopra and Marfurt, 2011)

Attribute expression of salt tectonics

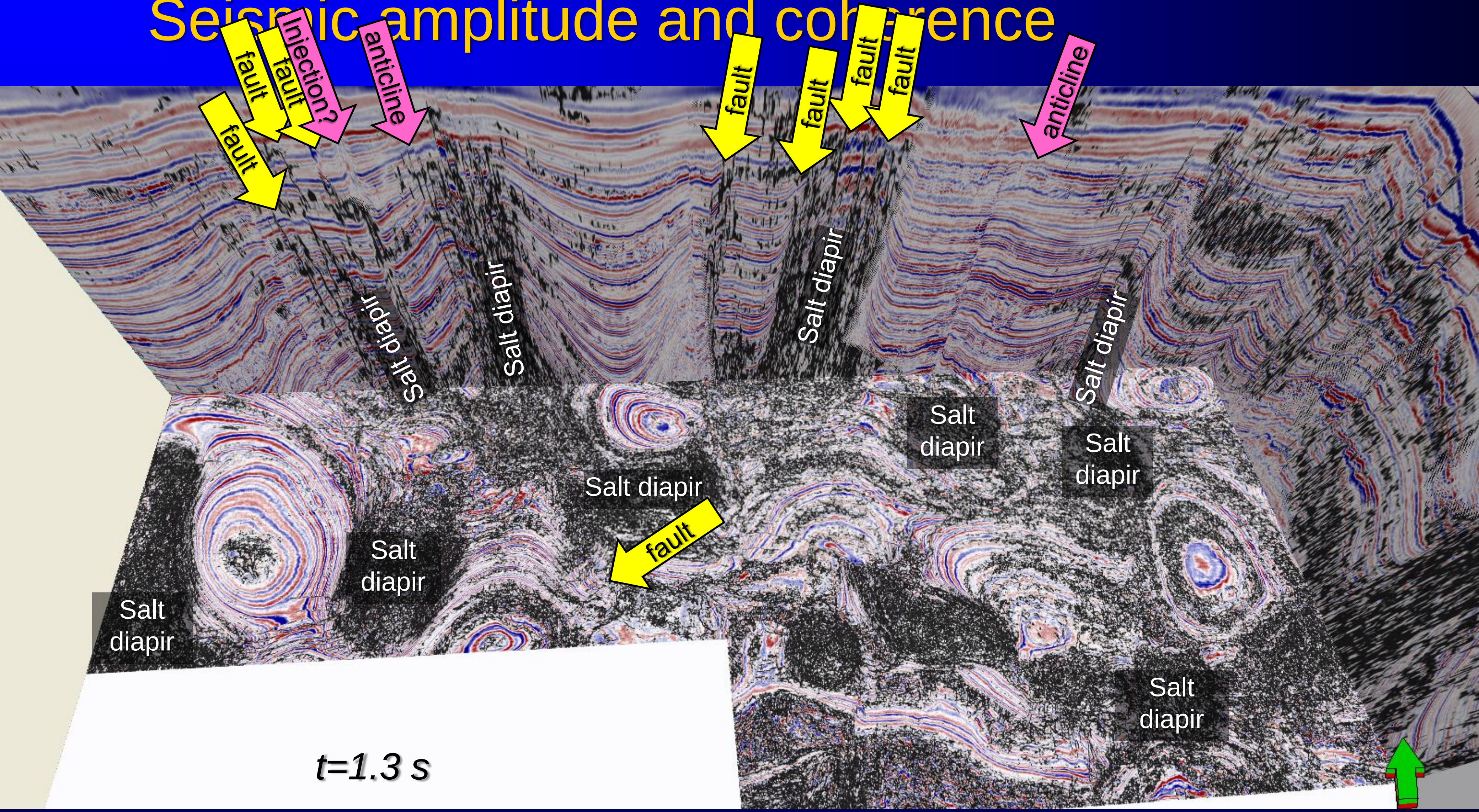
Tertiary section, Gulf of Mexico Shelf, U.S.A.

Seismic amplitude – Gulf of Mexico shelf



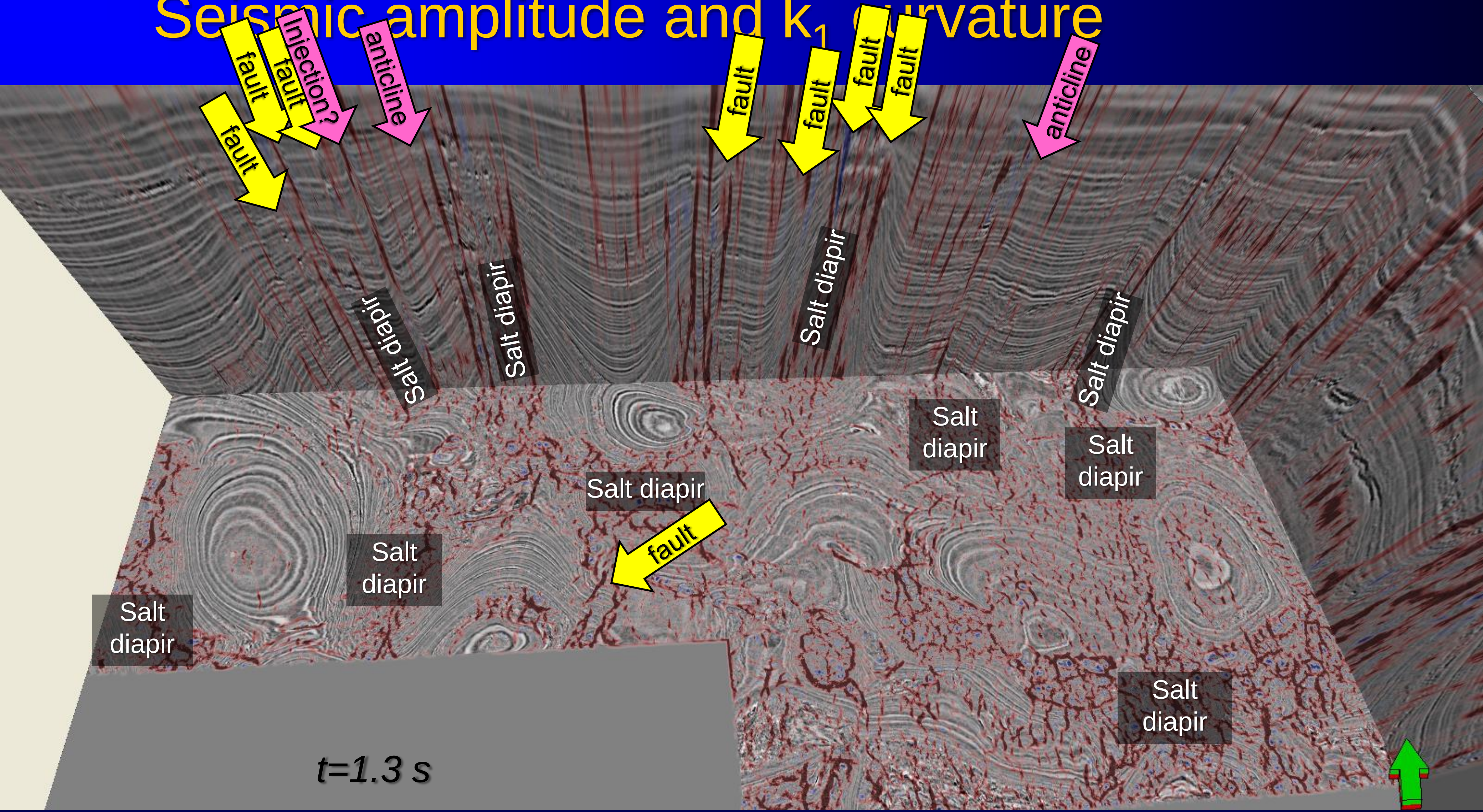
(Data courtesy of PGS)

Seismic amplitude and coherence



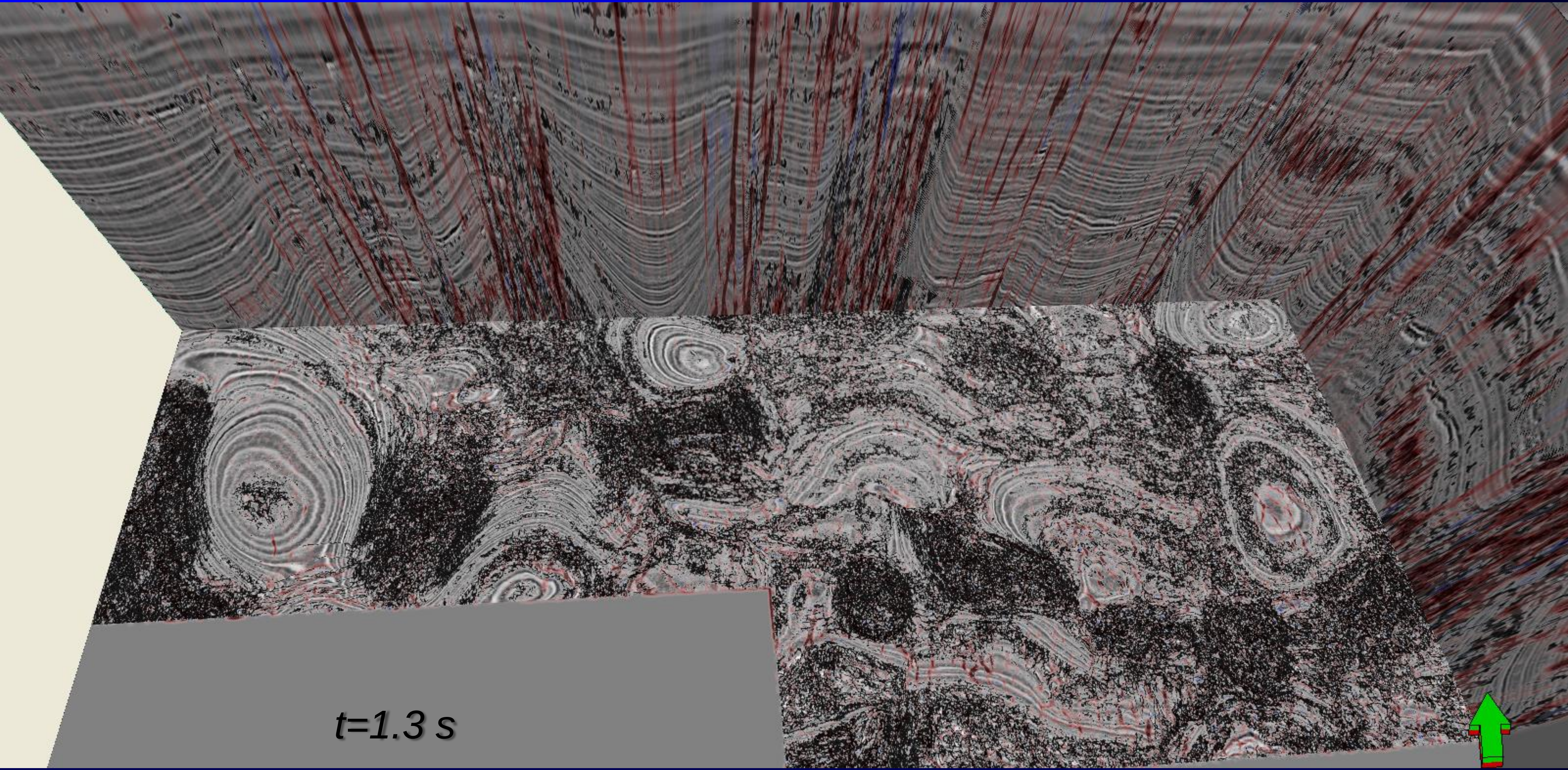
(Data courtesy of PGS)

Seismic amplitude and k_1 curvature



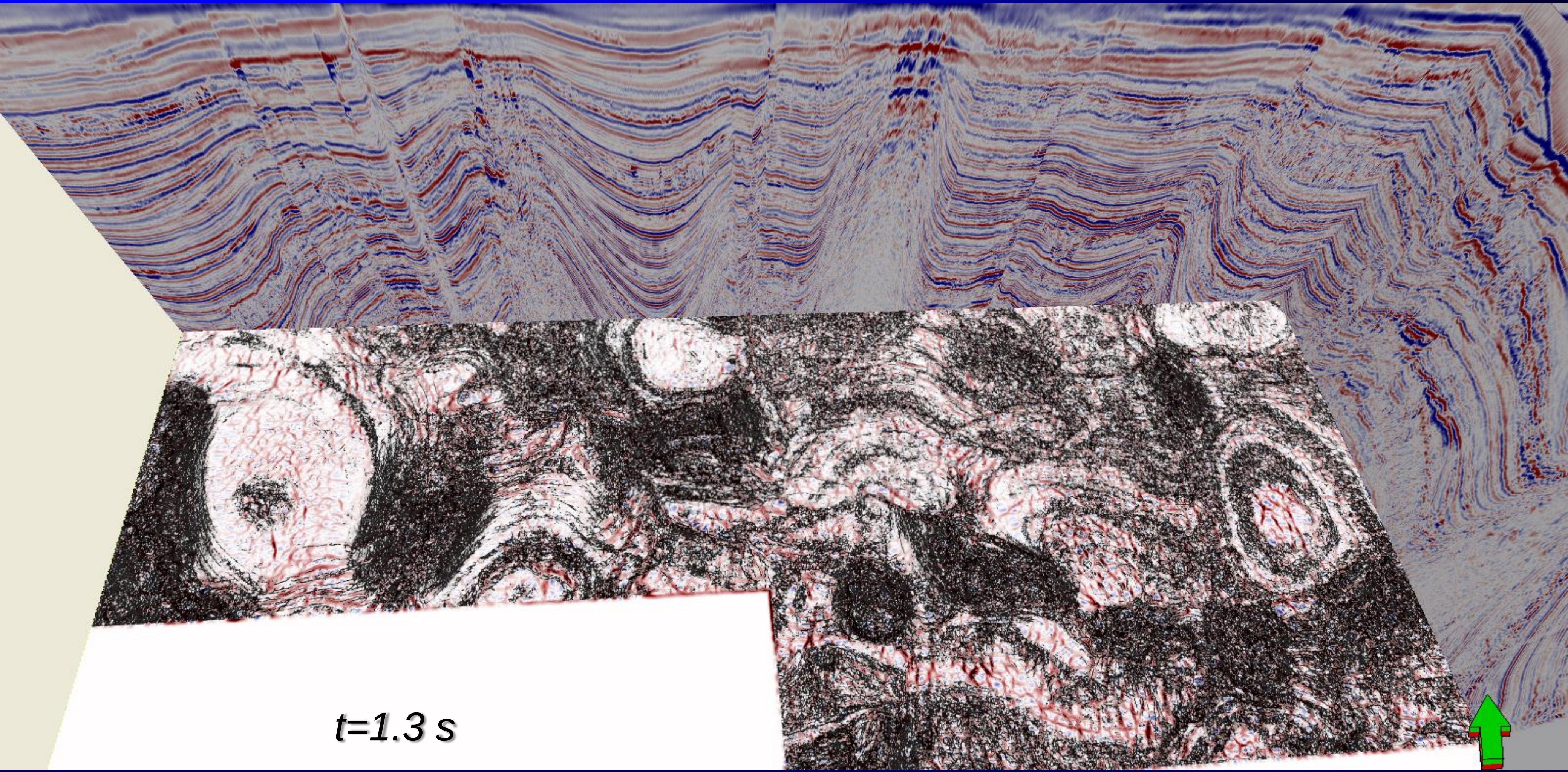
(Data courtesy of PGS)

Seismic amplitude, coherence, and k_1 curvature



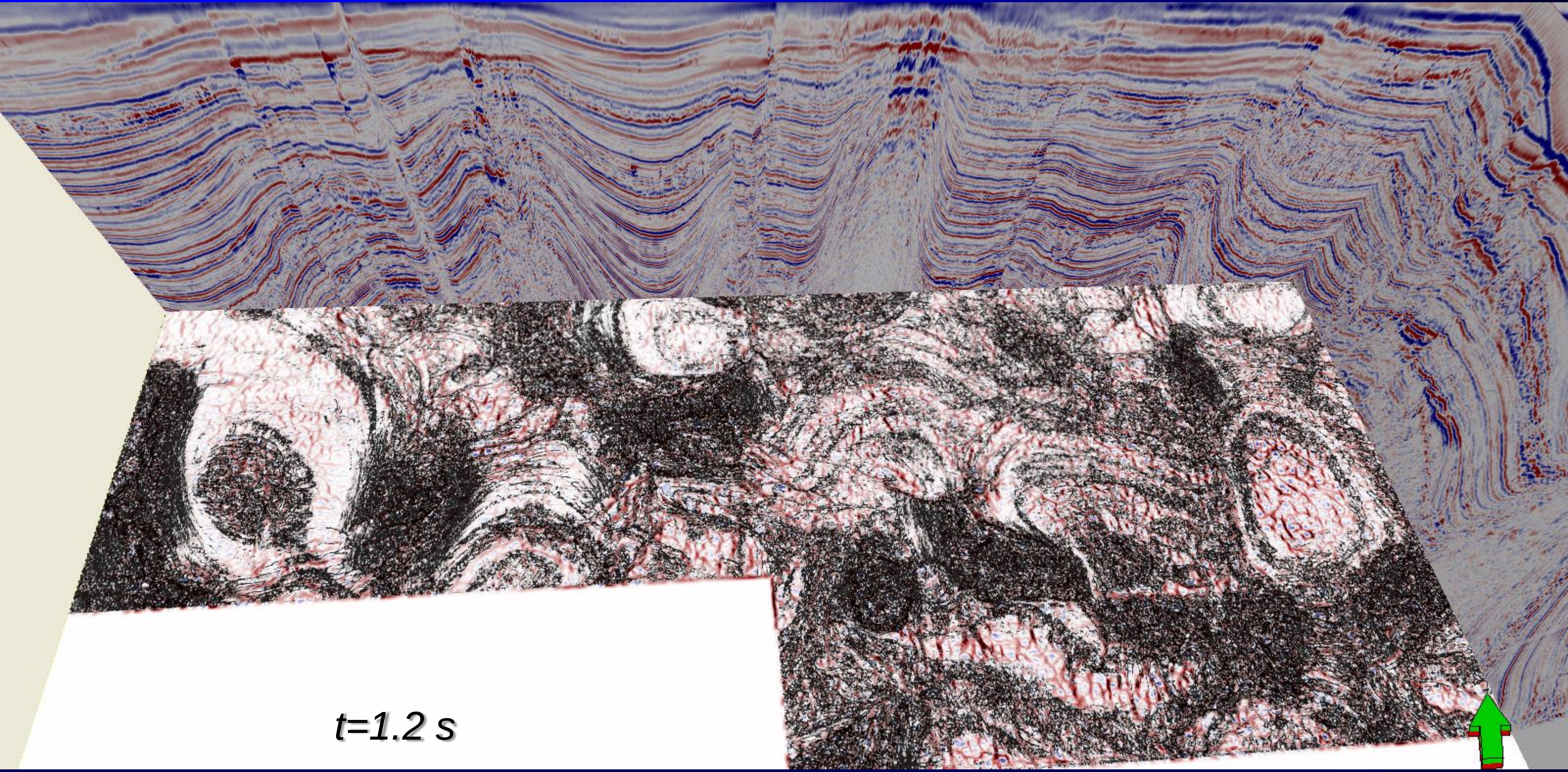
(Data courtesy of PGS)

Seismic amplitude, coherence, and k_1 curvature



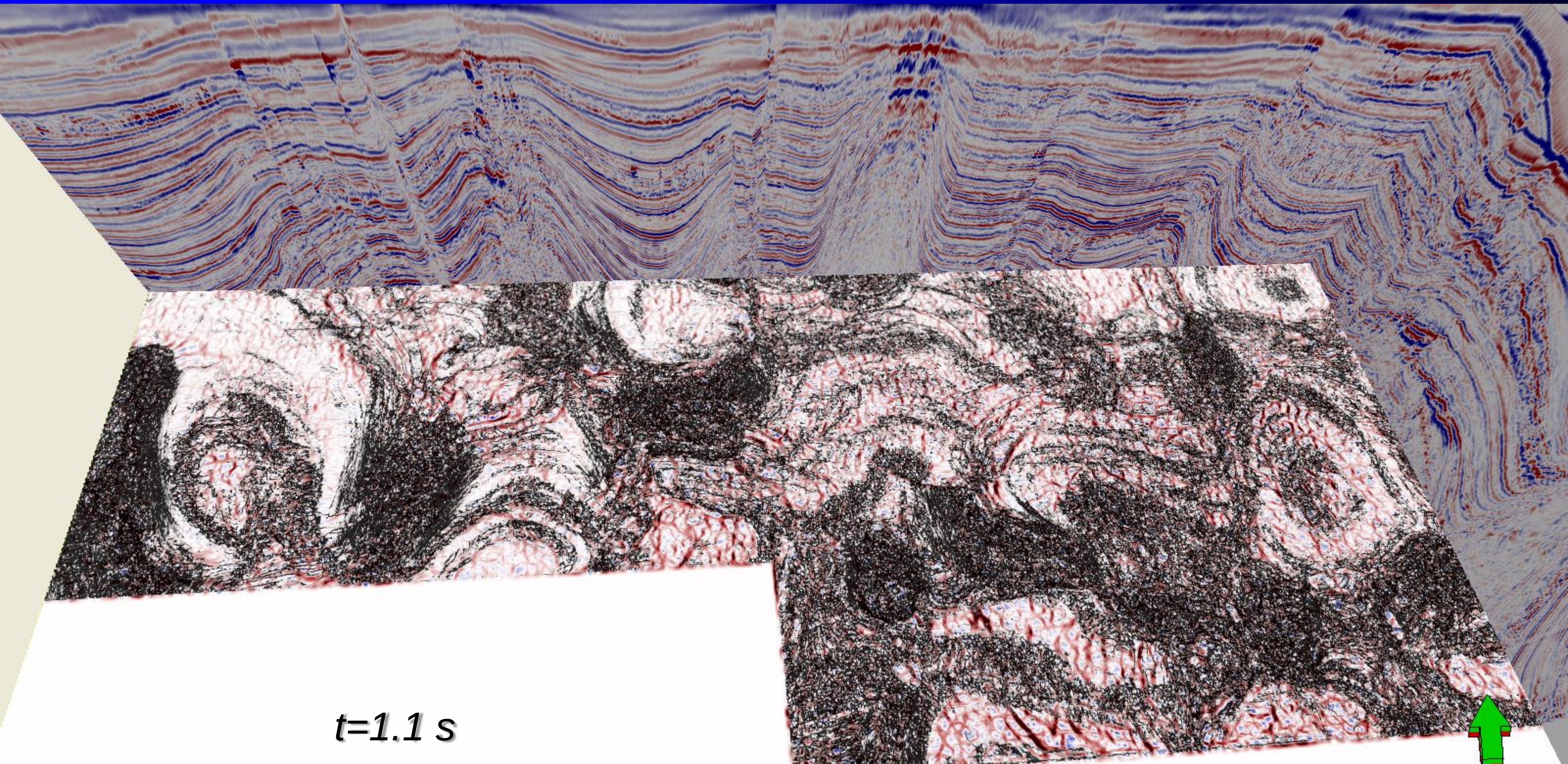
(Data courtesy of PGS)

Seismic amplitude, coherence, and k_1 curvature



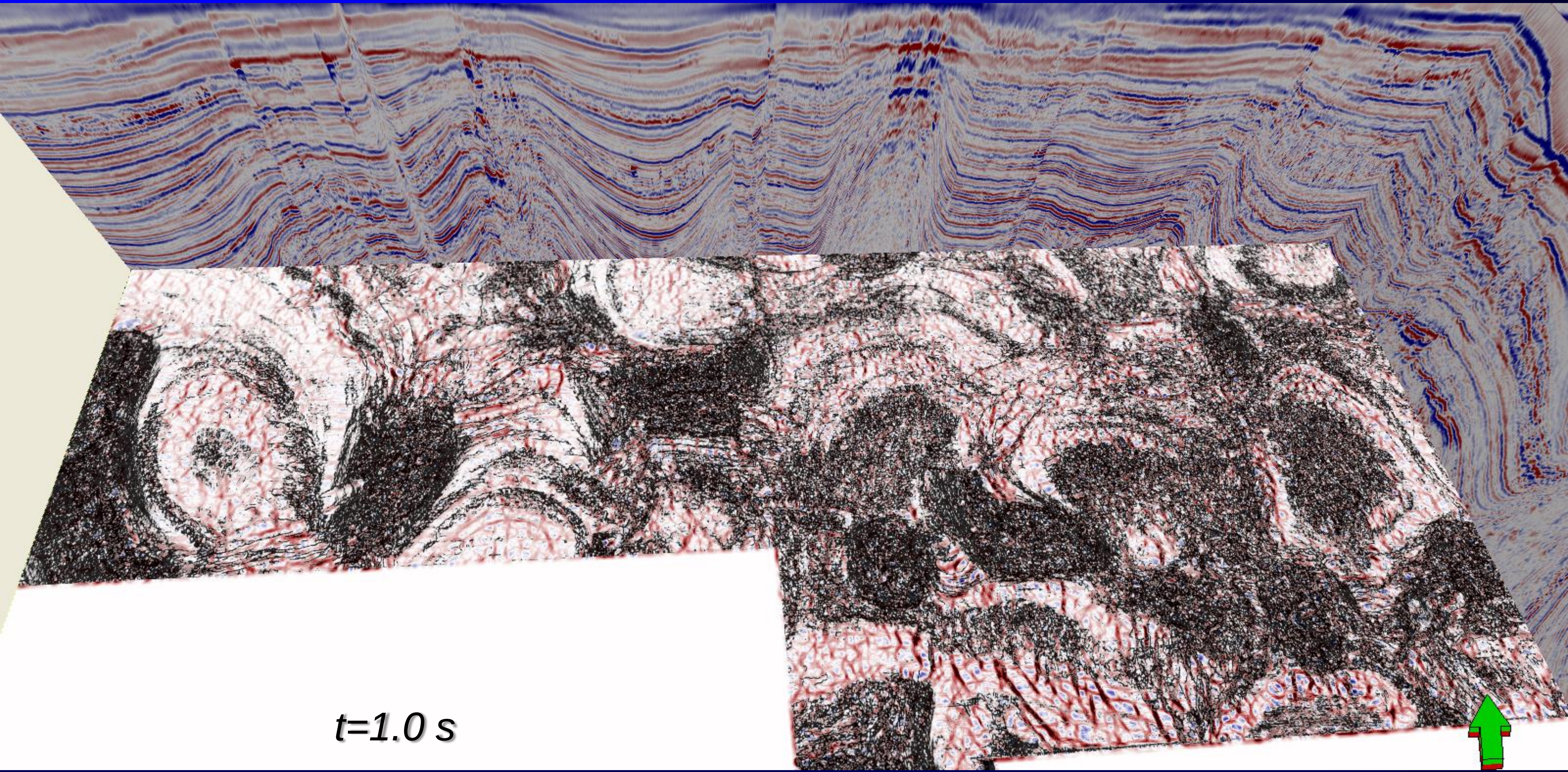
(Data courtesy of PGS)

Seismic amplitude, coherence, and k_1 curvature



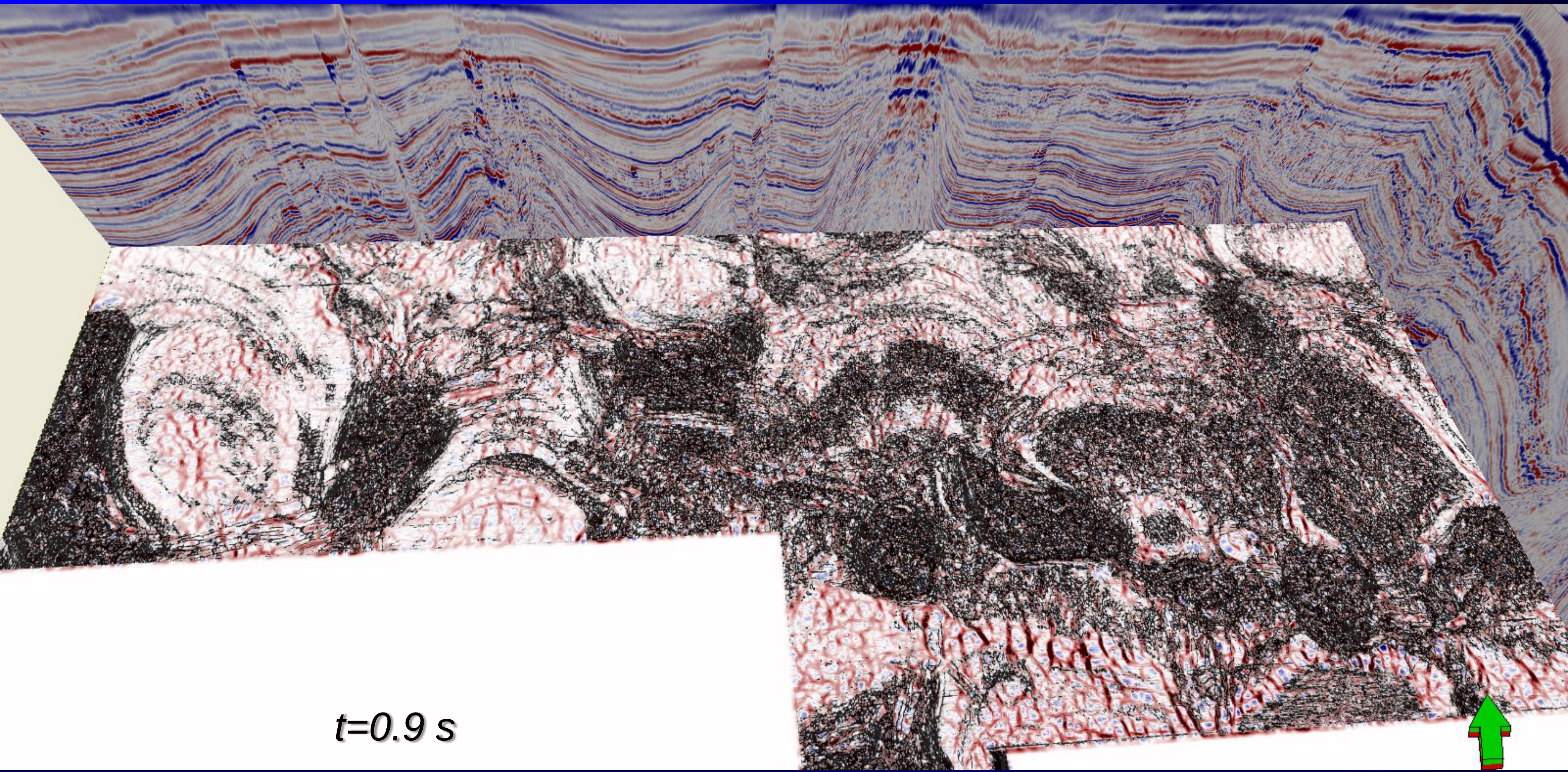
(Data courtesy of PGS)

Seismic amplitude, coherence, and k_1 curvature



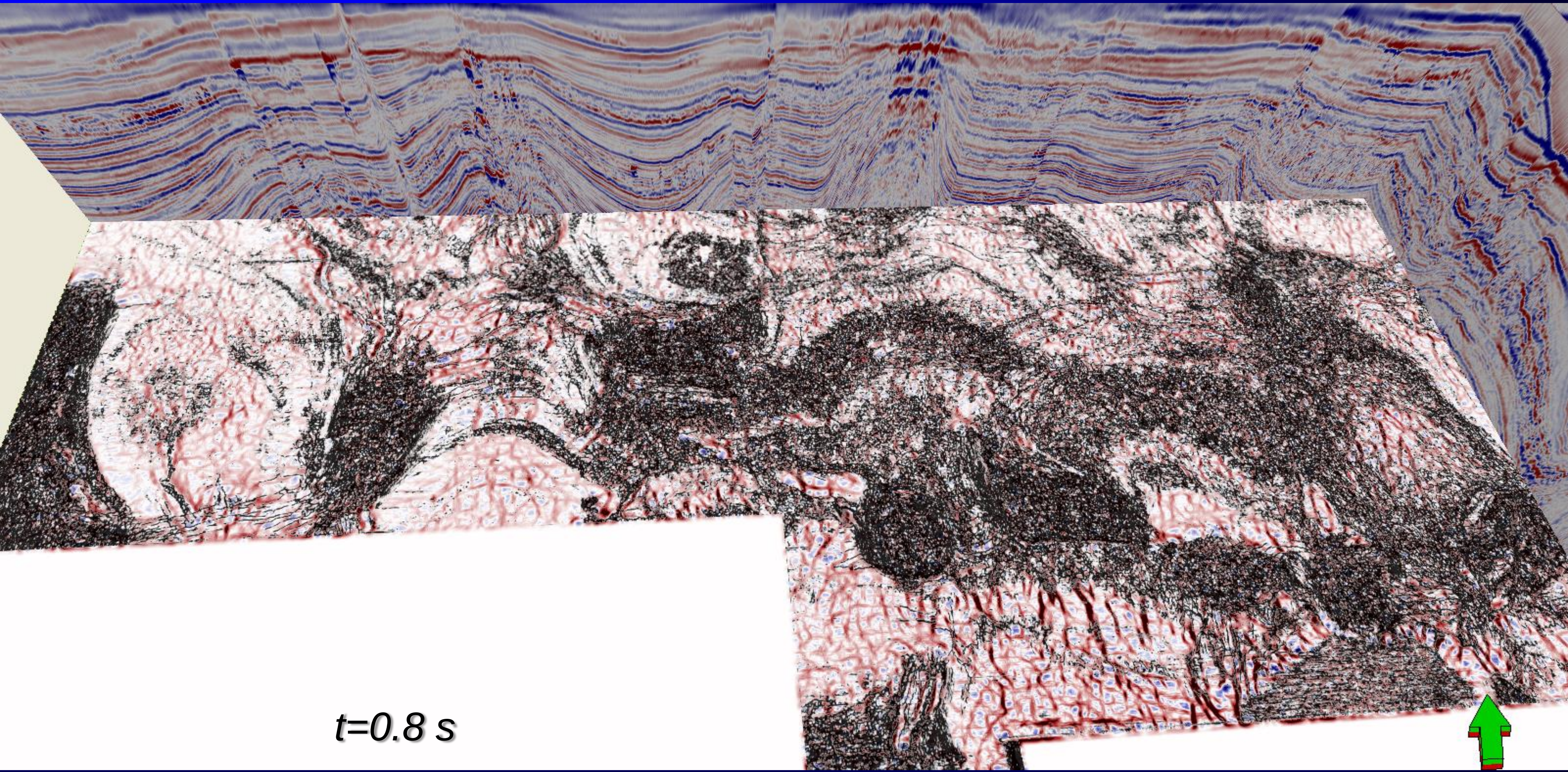
(Data courtesy of PGS)

Seismic amplitude, coherence, and k_1 curvature



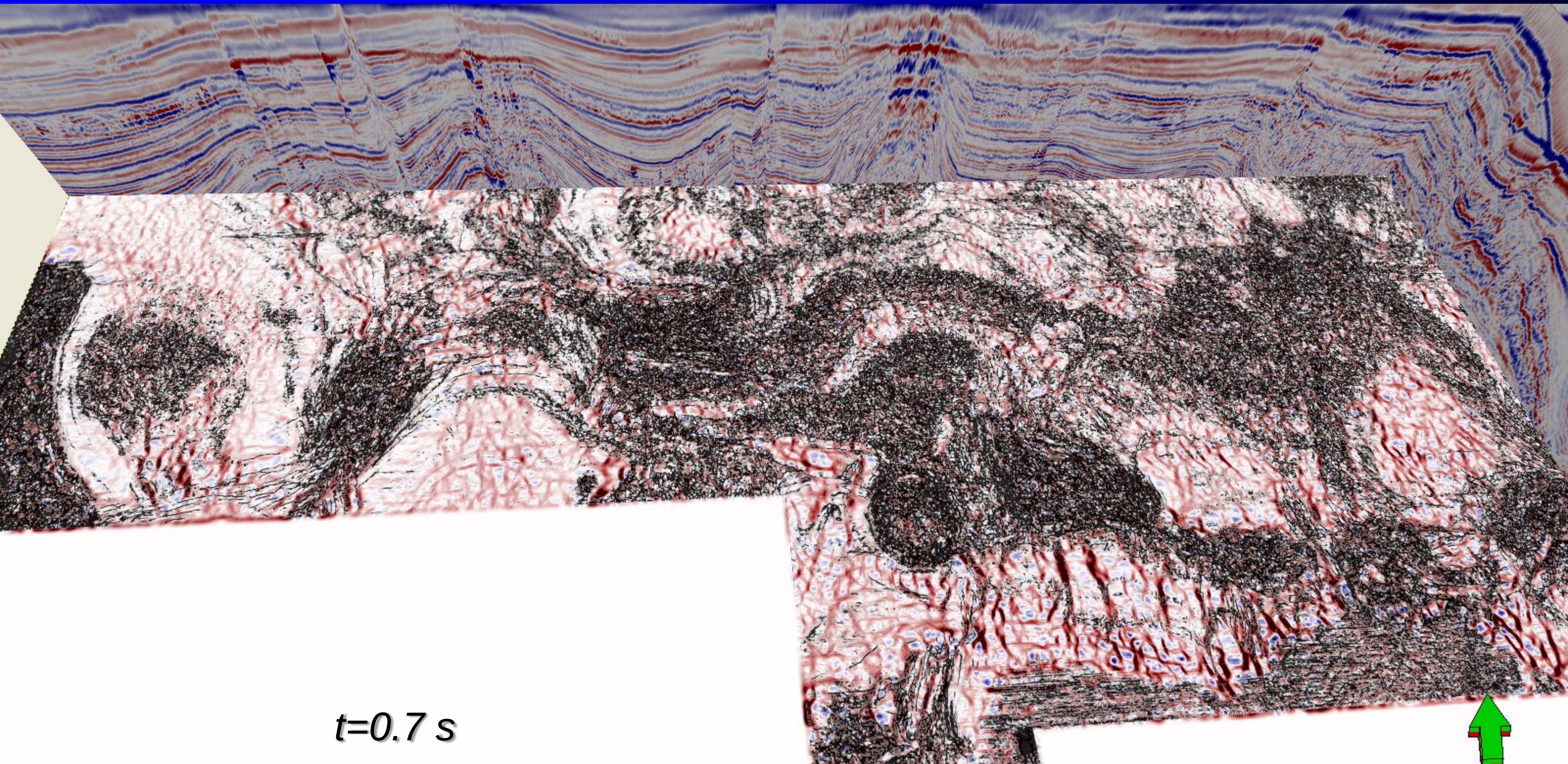
(Data courtesy of PGS)

Seismic amplitude, coherence, and k_1 curvature



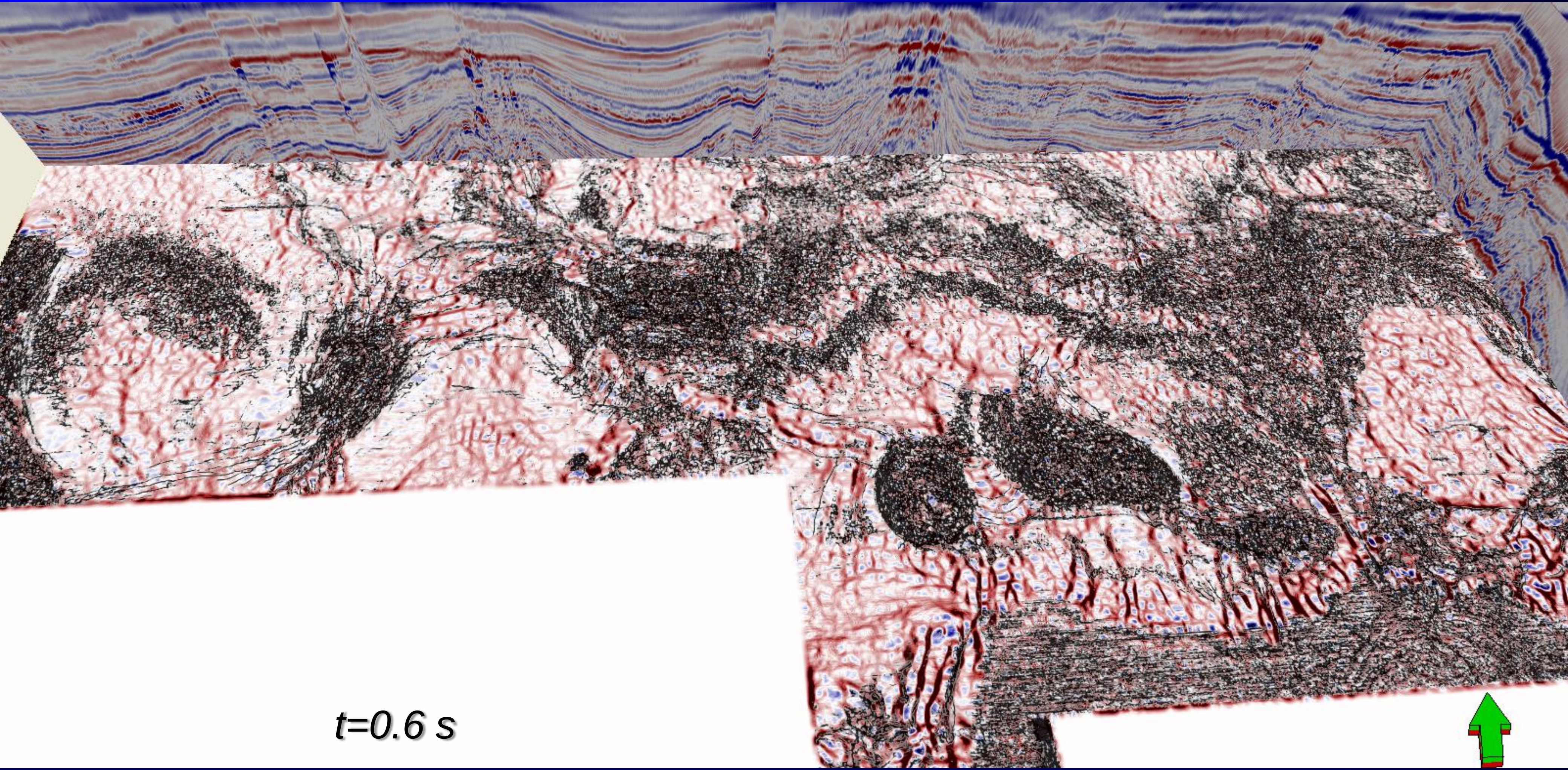
(Data courtesy of PGS)

Seismic amplitude, coherence, and k_1 curvature



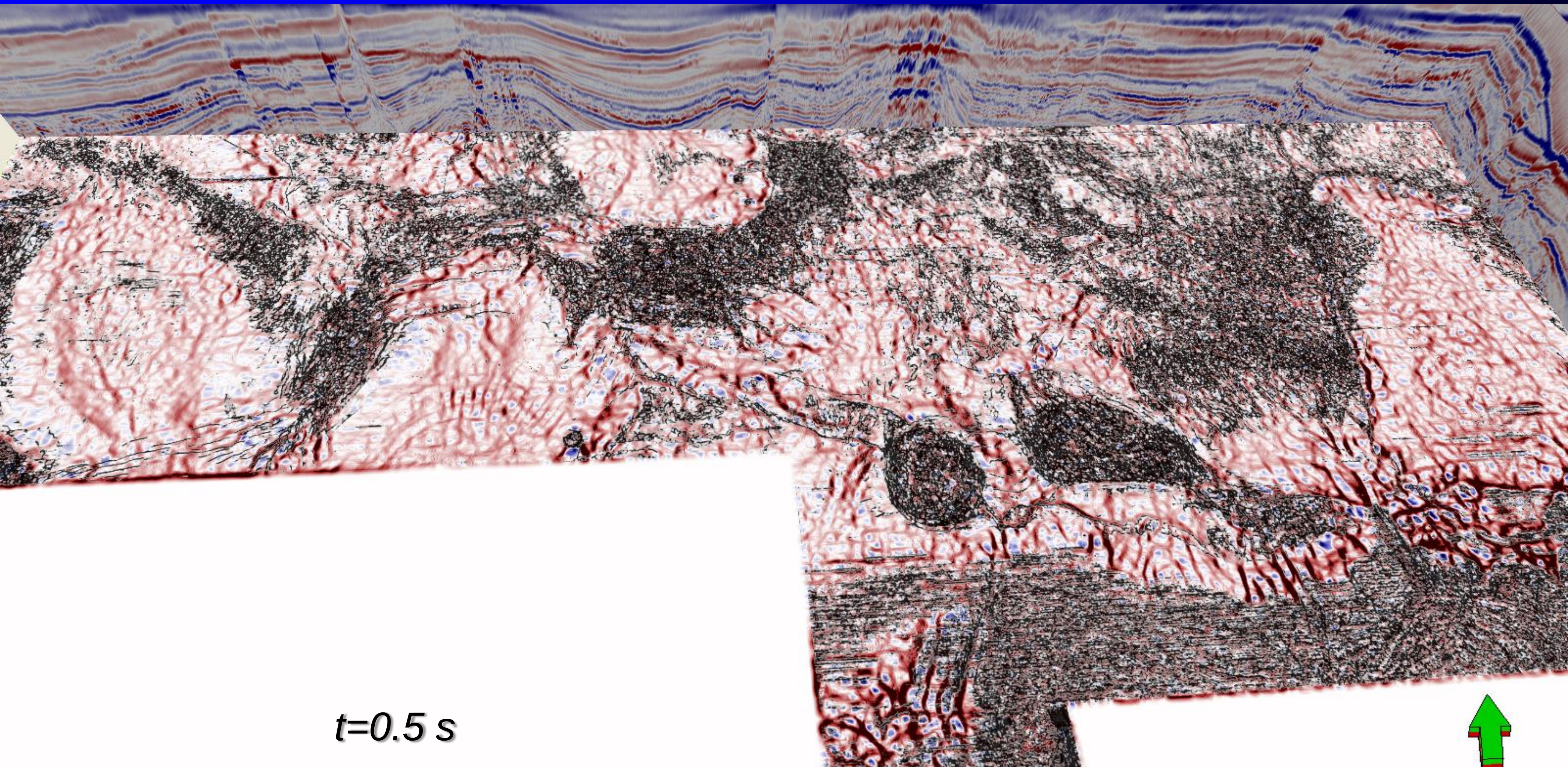
(Data courtesy of PGS)

Seismic amplitude, coherence, and k_1 curvature



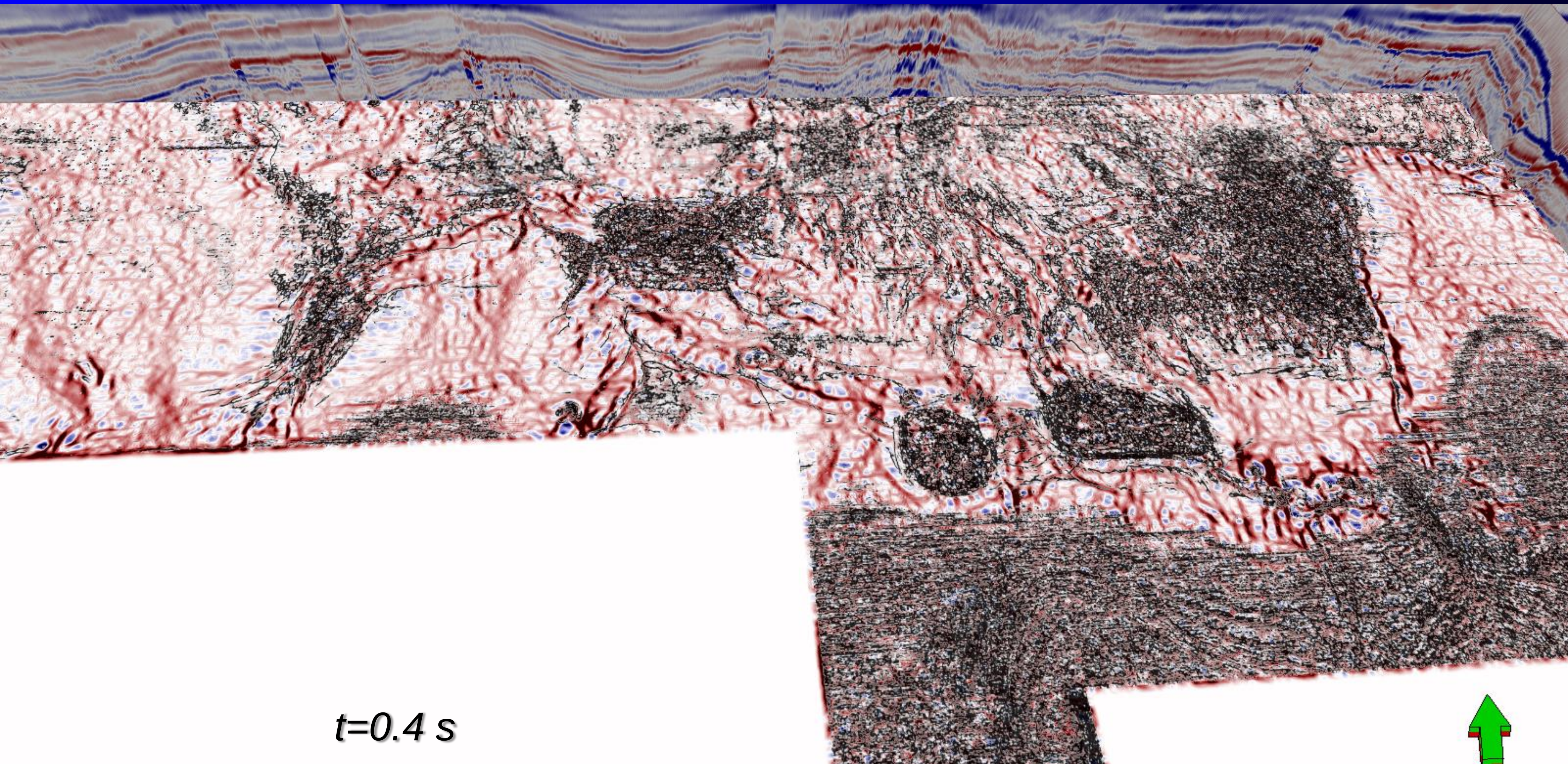
(Data courtesy of PGS)

Seismic amplitude, coherence, and k_1 curvature



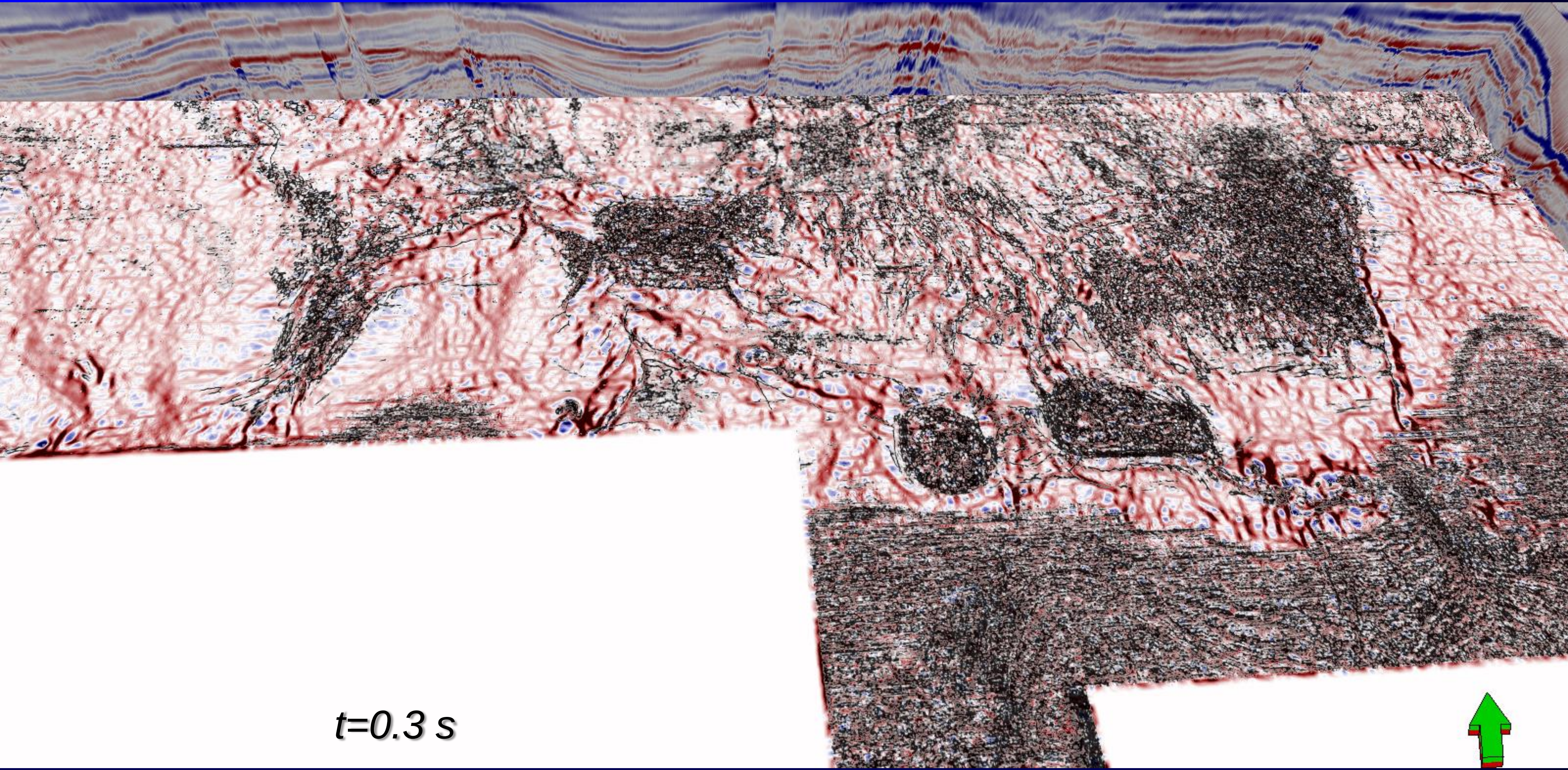
(Data courtesy of PGS)

Seismic amplitude, coherence, and k_1 curvature



(Data courtesy of PGS)

Seismic amplitude, coherence, and k_1 curvature

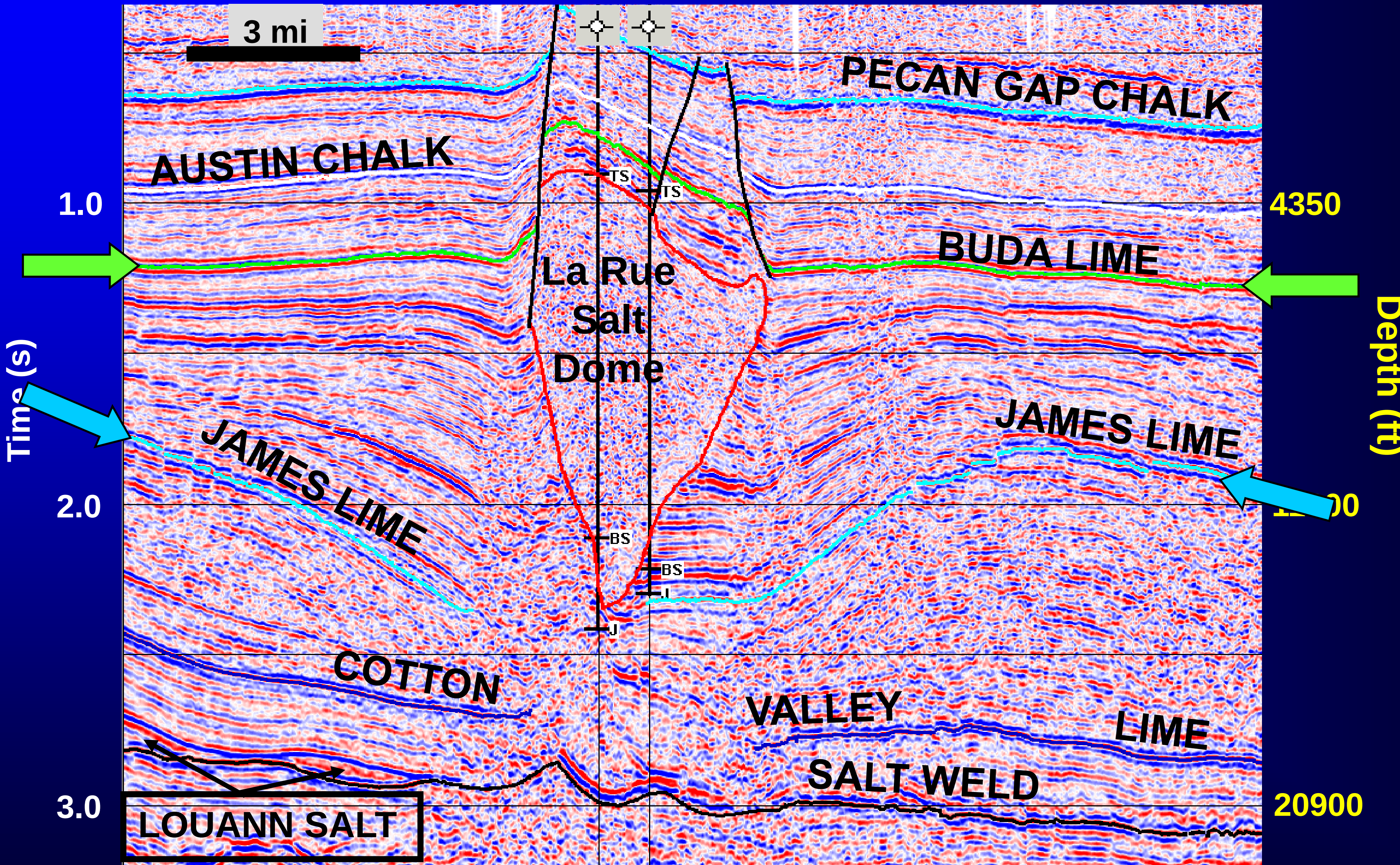


(Data courtesy of PGS)

Impact of Salt Withdrawal on Carbonate Deformation

Cotton Valley Limestone
E Texas and NW Louisiana, USA

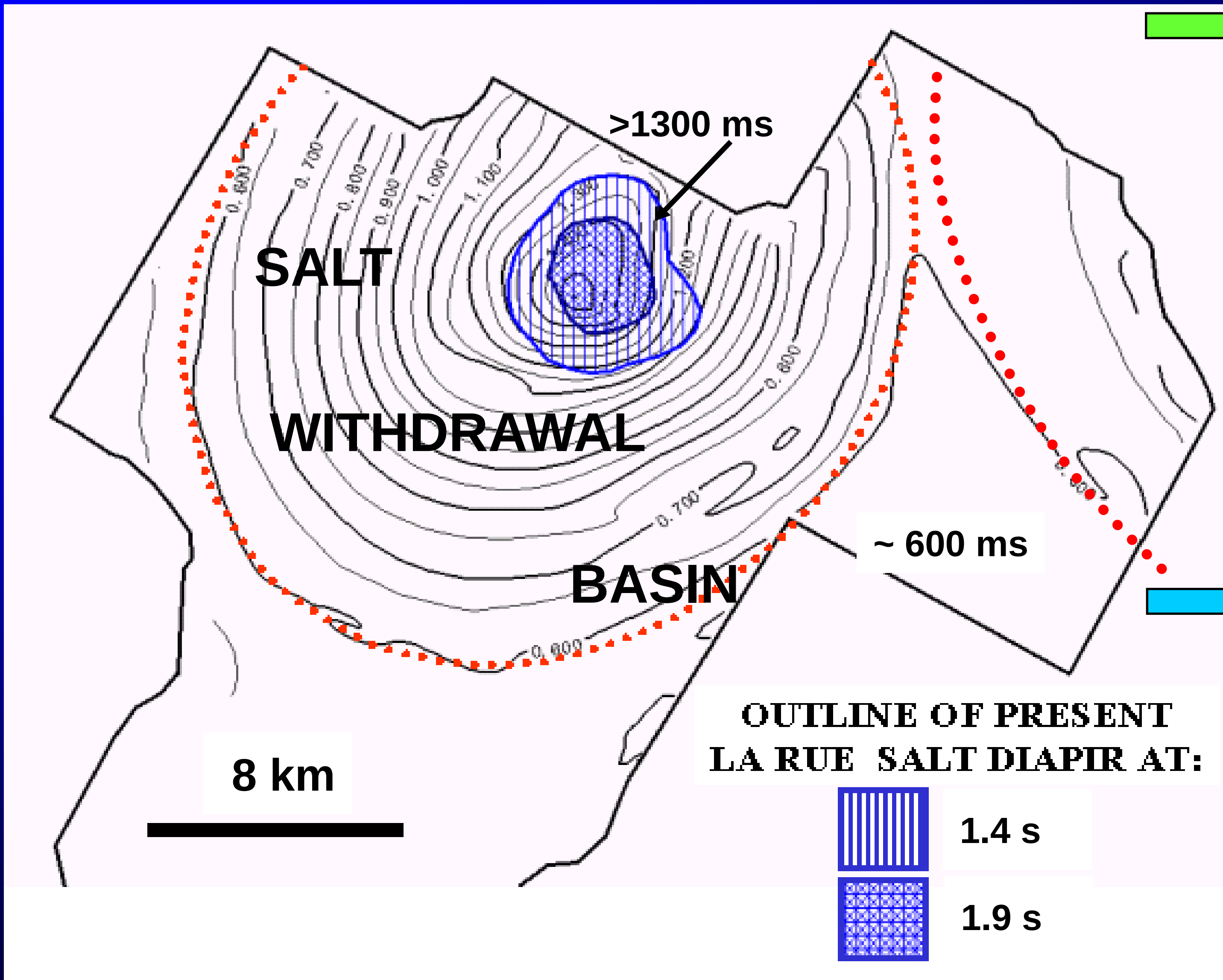
Vertical seismic section through the La Rue salt dome, East Texas, USA

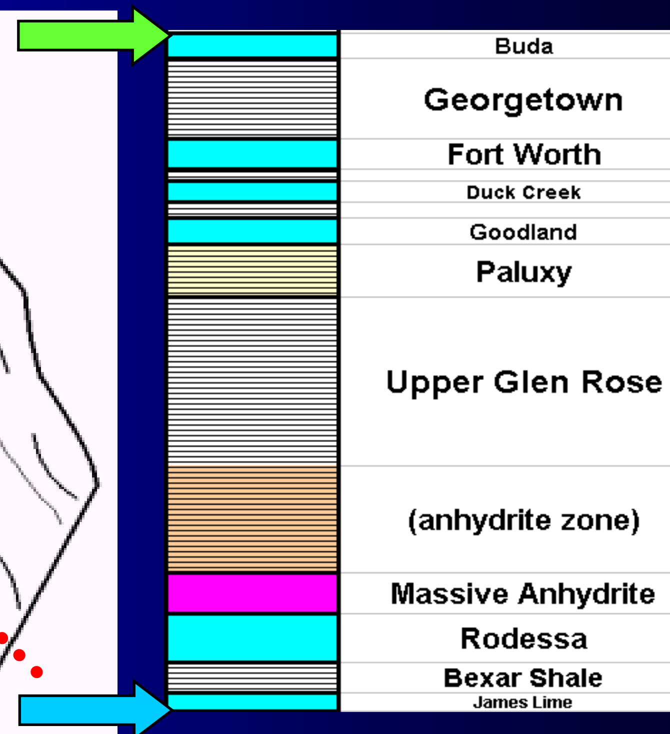


6a-156

(Maione, 2001)

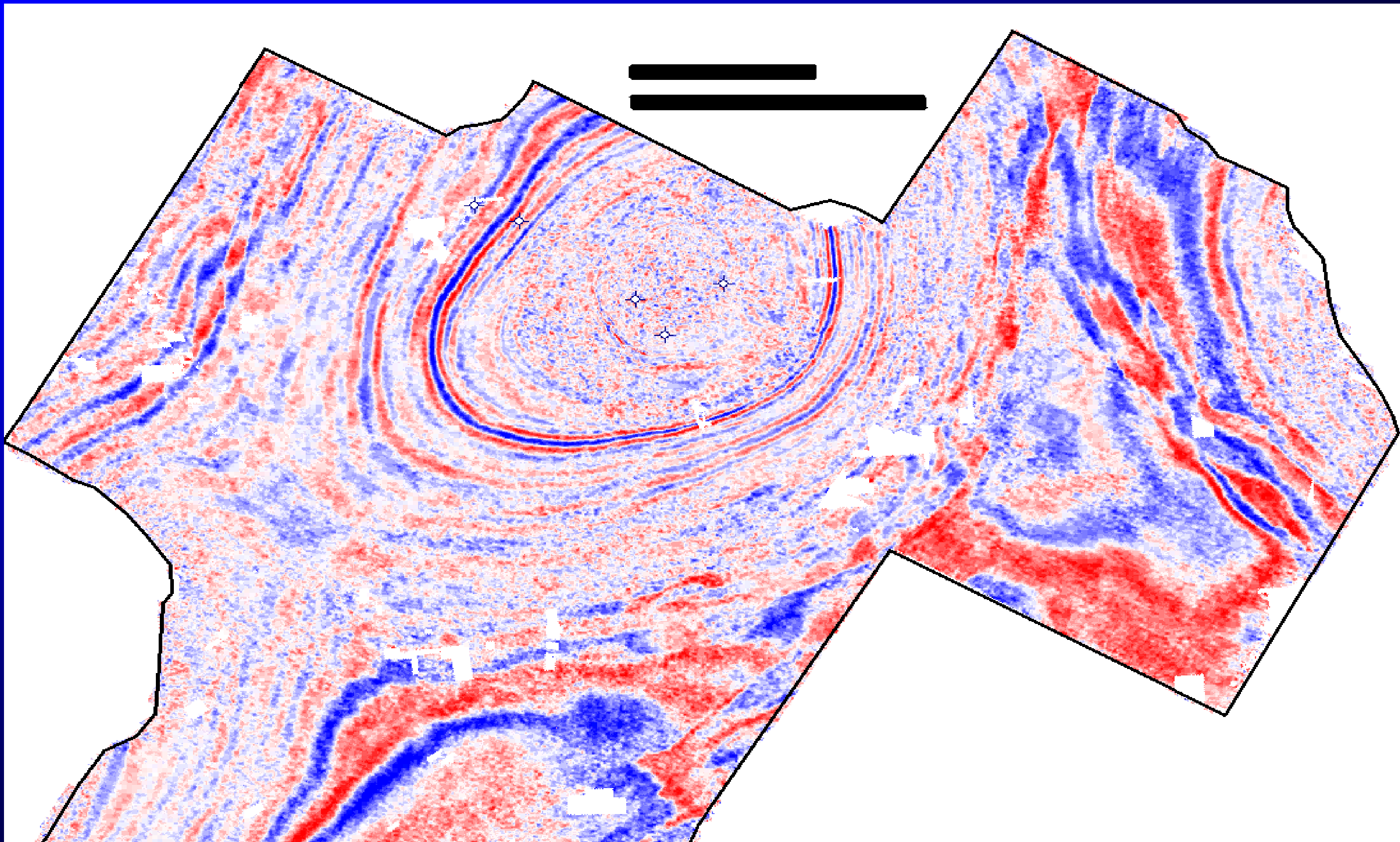
Isochron contour map of the interval between the James and Buda Limestones





(Maione, 2001)

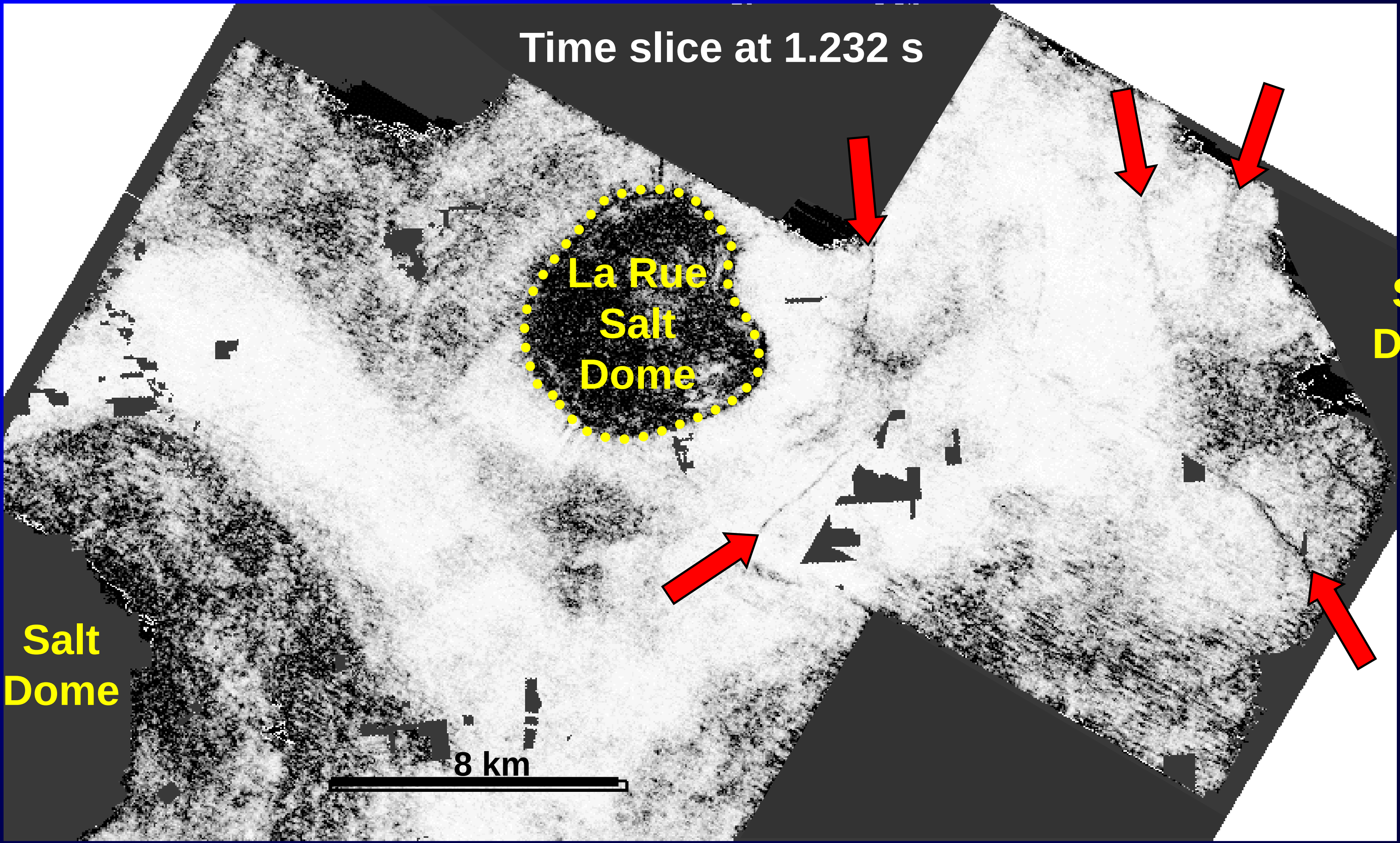
Time slice through La Rue Salt Dome, East Texas, USA



Ring faults difficult to see on seismic data, easier to see on coherence

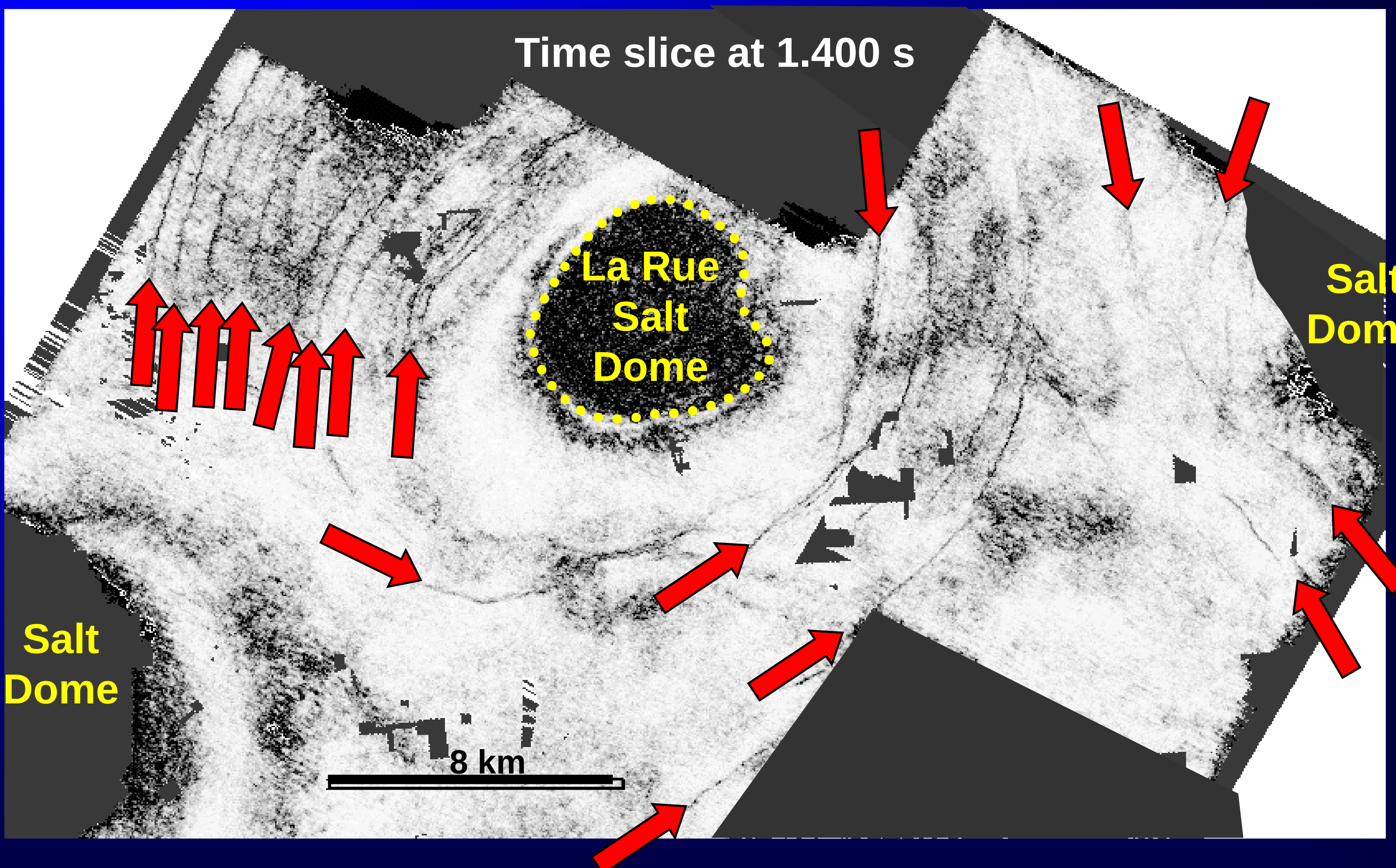
(Maione, 2001)

Time slice through coherence volume



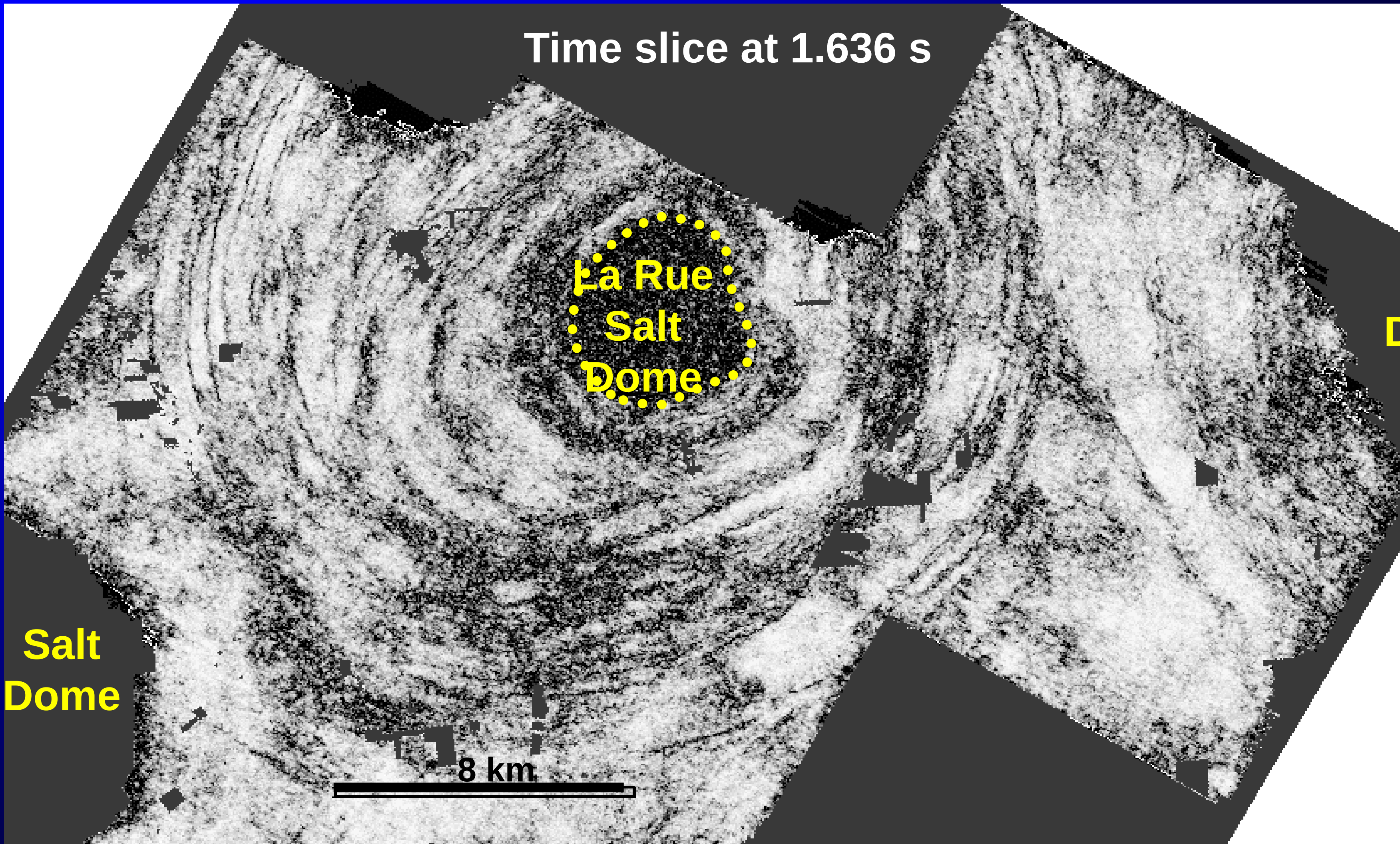
(Maione, 2001)

Time slice through coherence volume



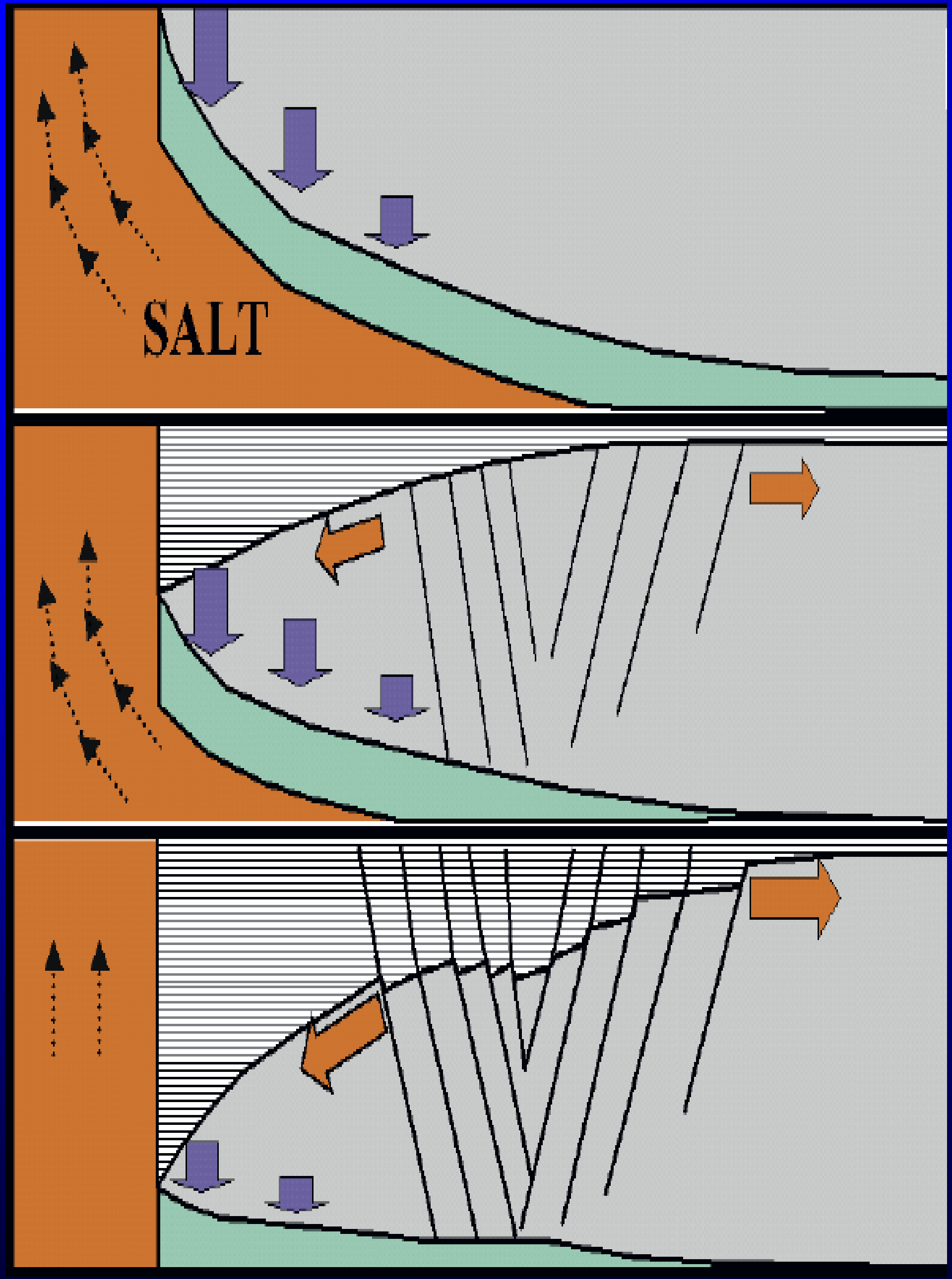
(Maione, 2001)

Time slice through coherence volume



(Maione, 2001)

Geologic model



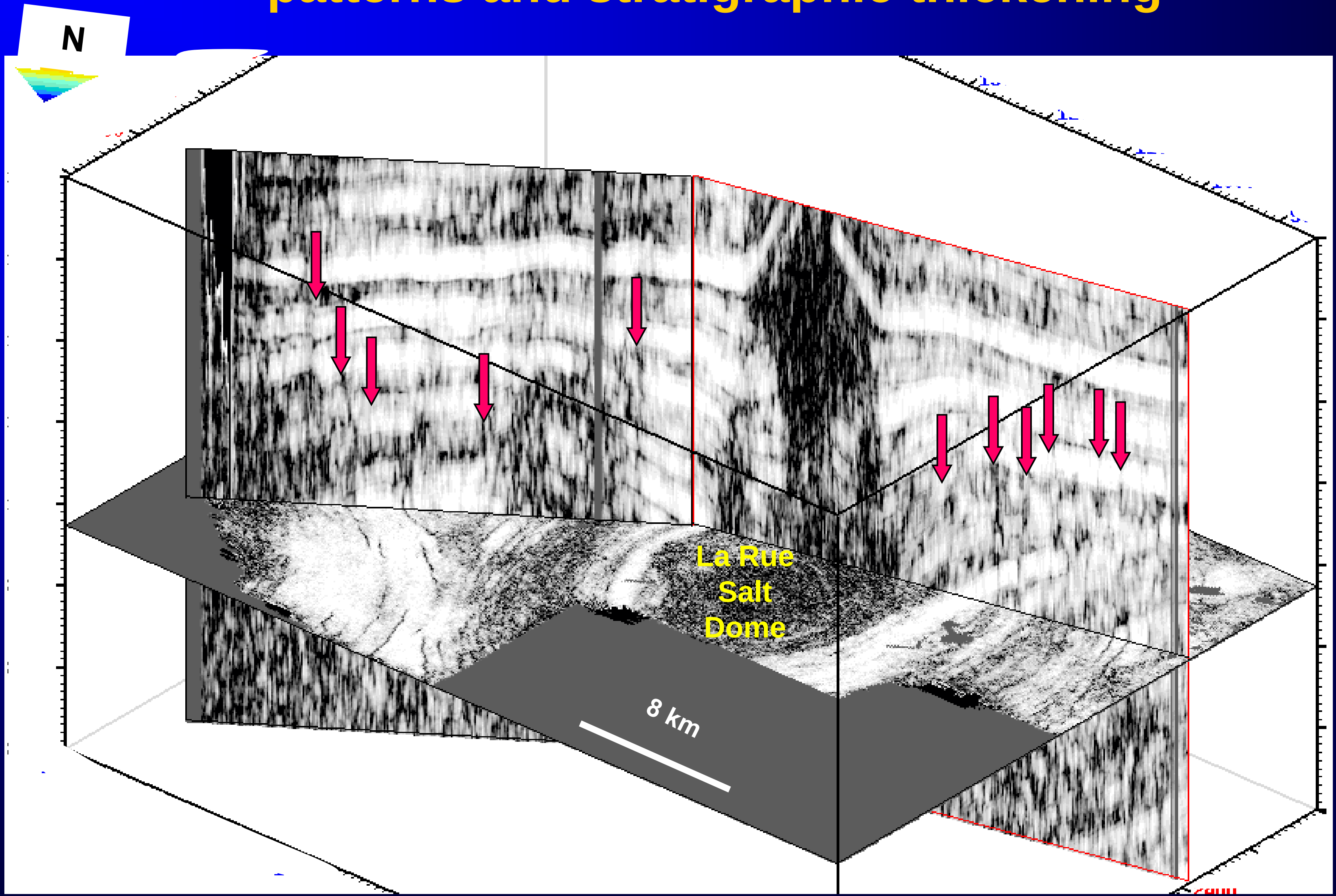
Lateral migration of deep salt is initiated following the formation of a diapir (left). Evacuation of deep salt initiates subsidence of the overlying formations.

Withdrawal basin (pattern) begins to form as subsidence occurs over the vacating salt. Varying rates of subsidence creates extensional strain in the upper part of the descending hanging wall (horizontal arrows).

Extensional faults develop in the hanging wall within the zone of maximum strain. Note the formation of a central graben, and the presence of fault traps between the diapir and the graben.

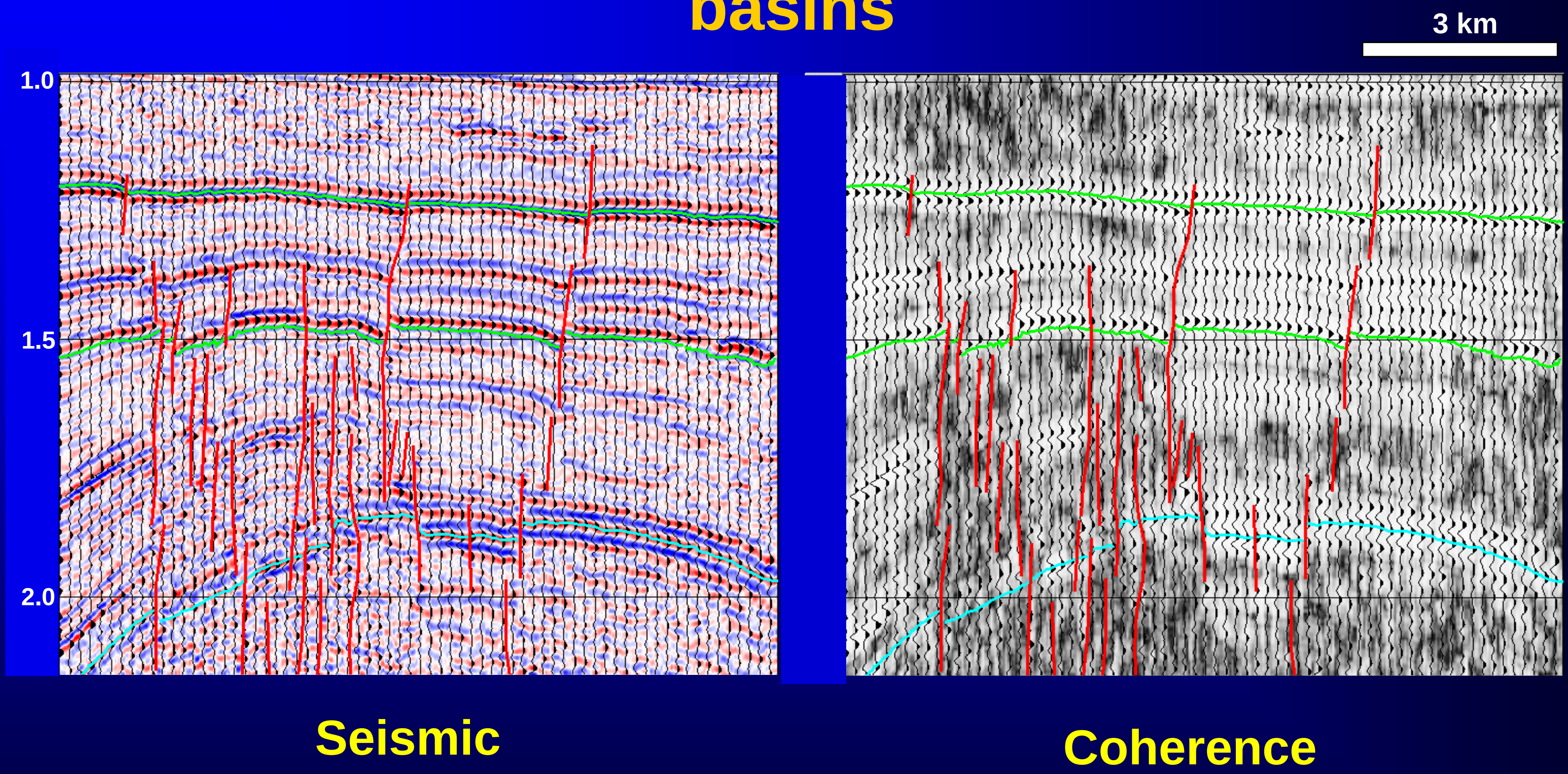
(Maione, 2001)

Coherence volume, looking South, showing concentric ring fault patterns and stratigraphic thickening



(Maione, 2001)

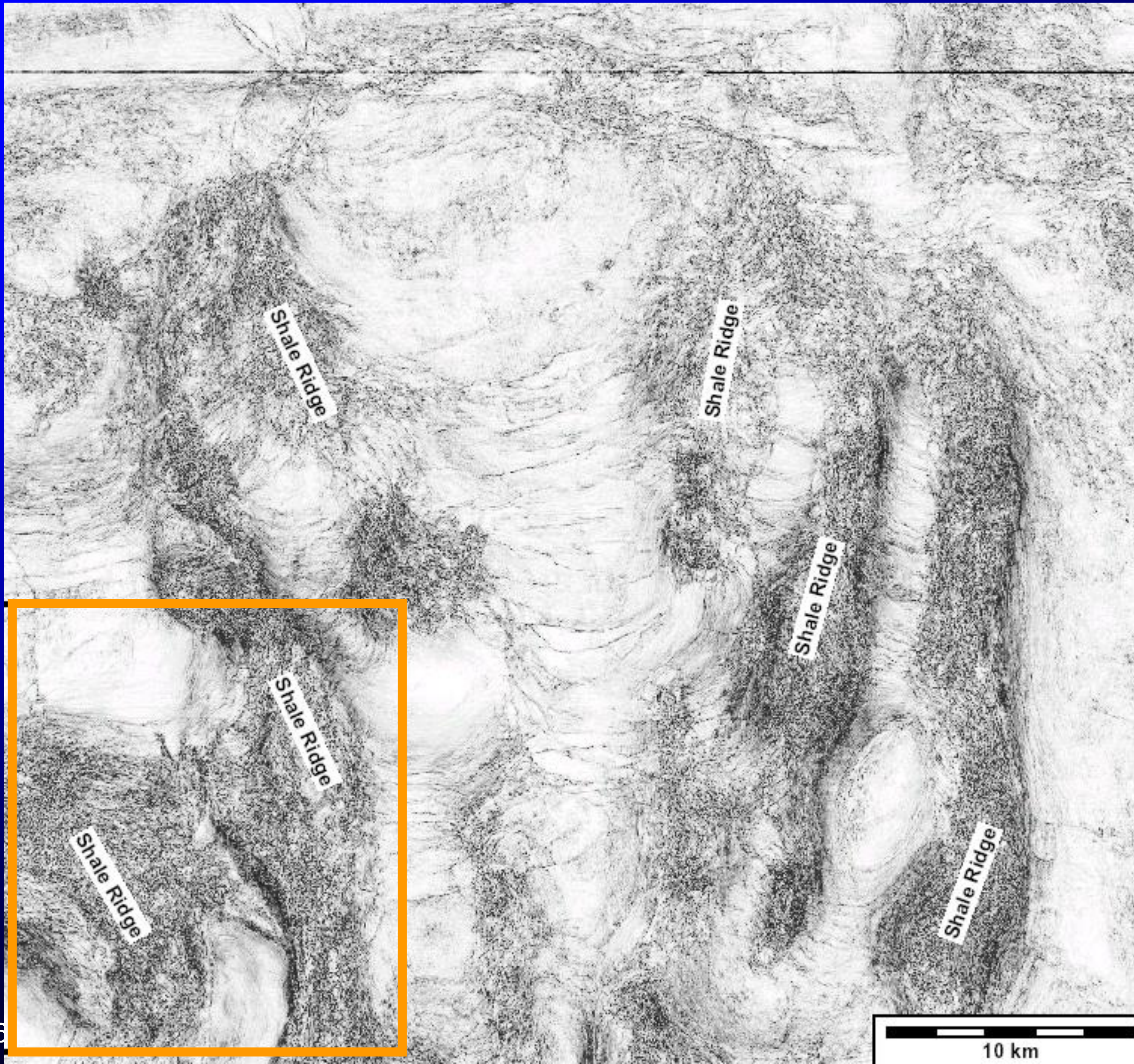
Vertical section between two salt withdrawal basins



(Maione, 2001)

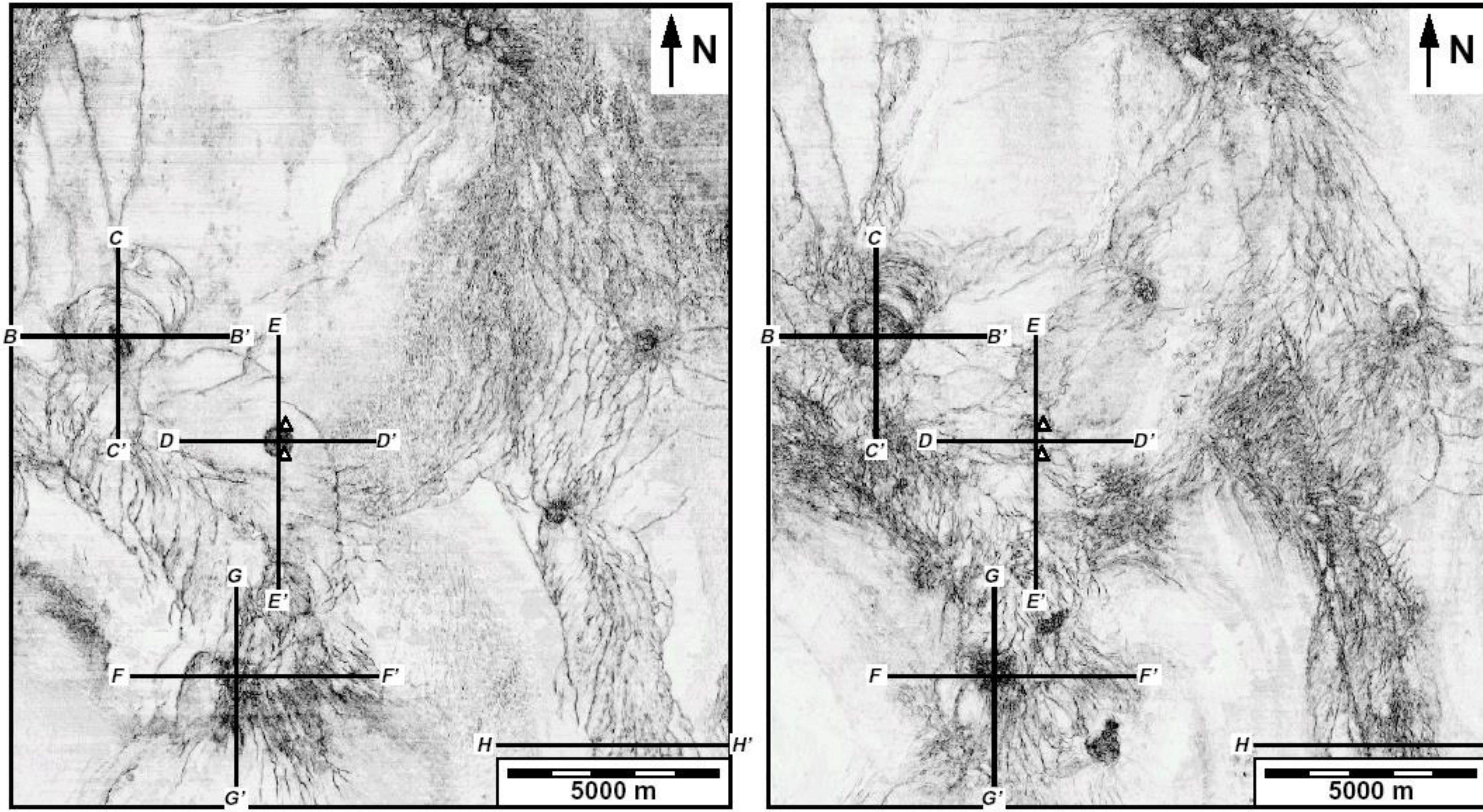
Shale Diapirism

Offshore Nigeria



Coherence slice at 1725 ms (Nigerian continental slope).

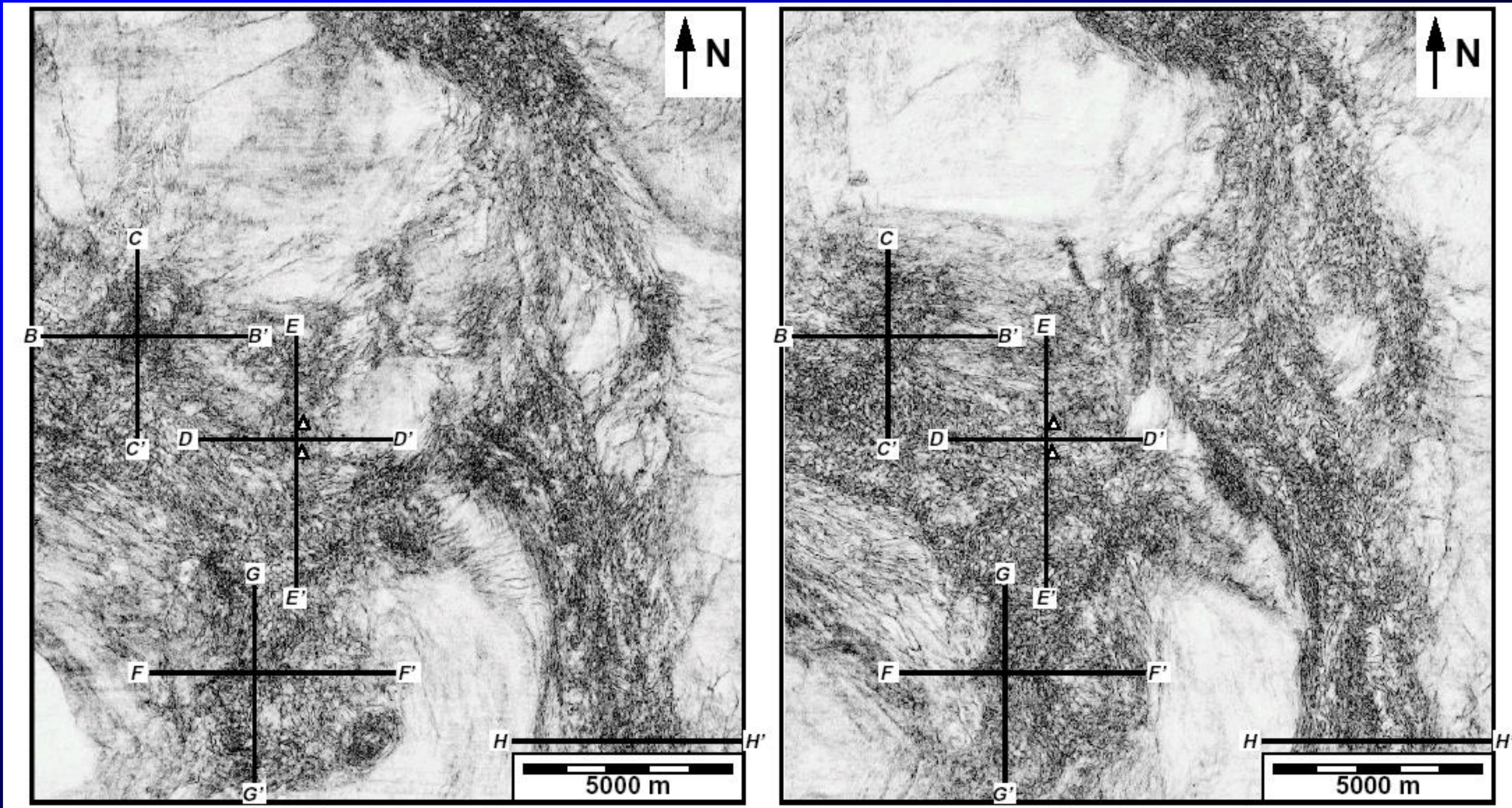
(Haskell et al., 1999)



A) *225 ms below sea floor*

B) *725 ms below sea floor*

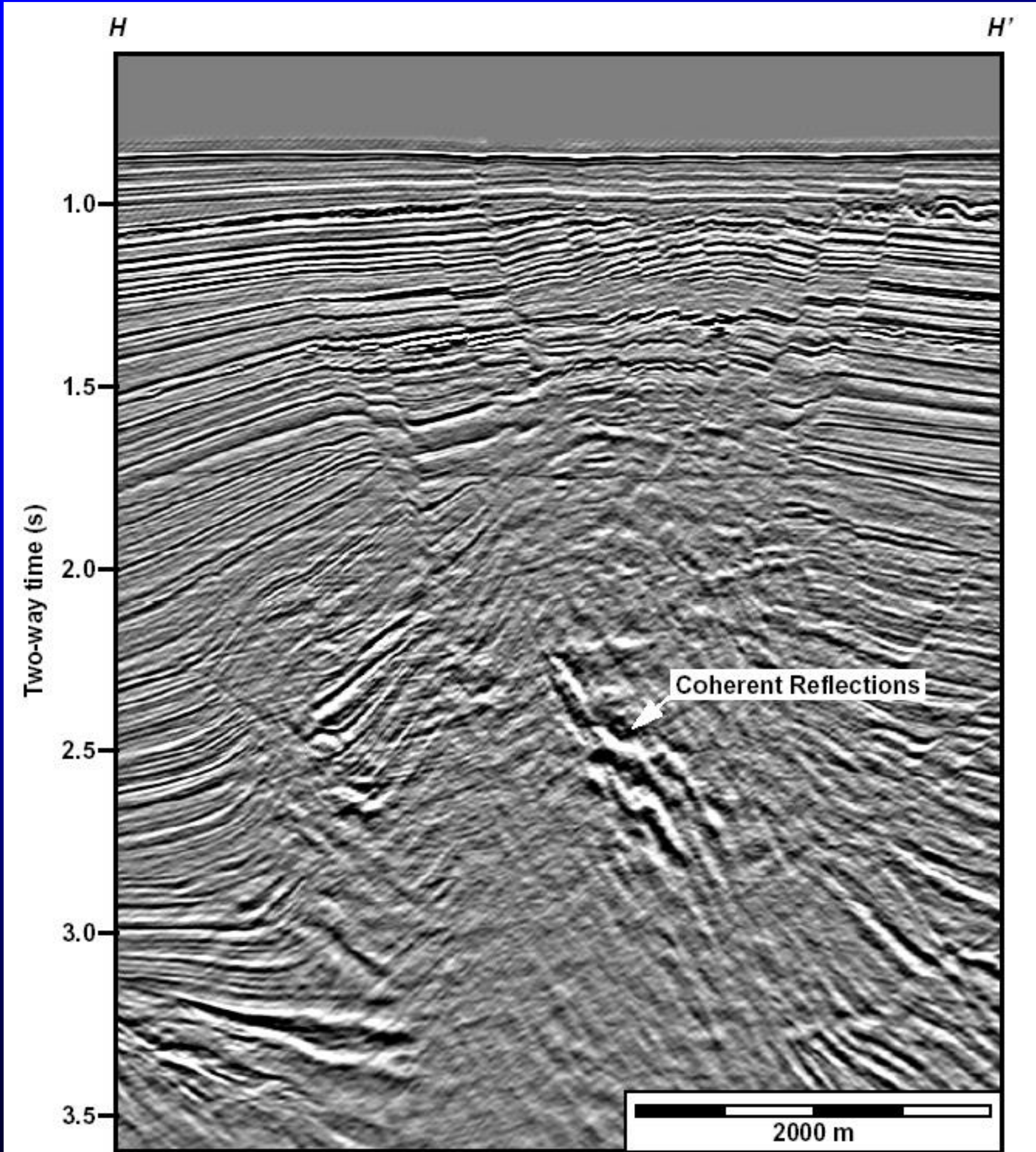
(Haskell et al., 1999)



C) *1225 ms below sea floor*

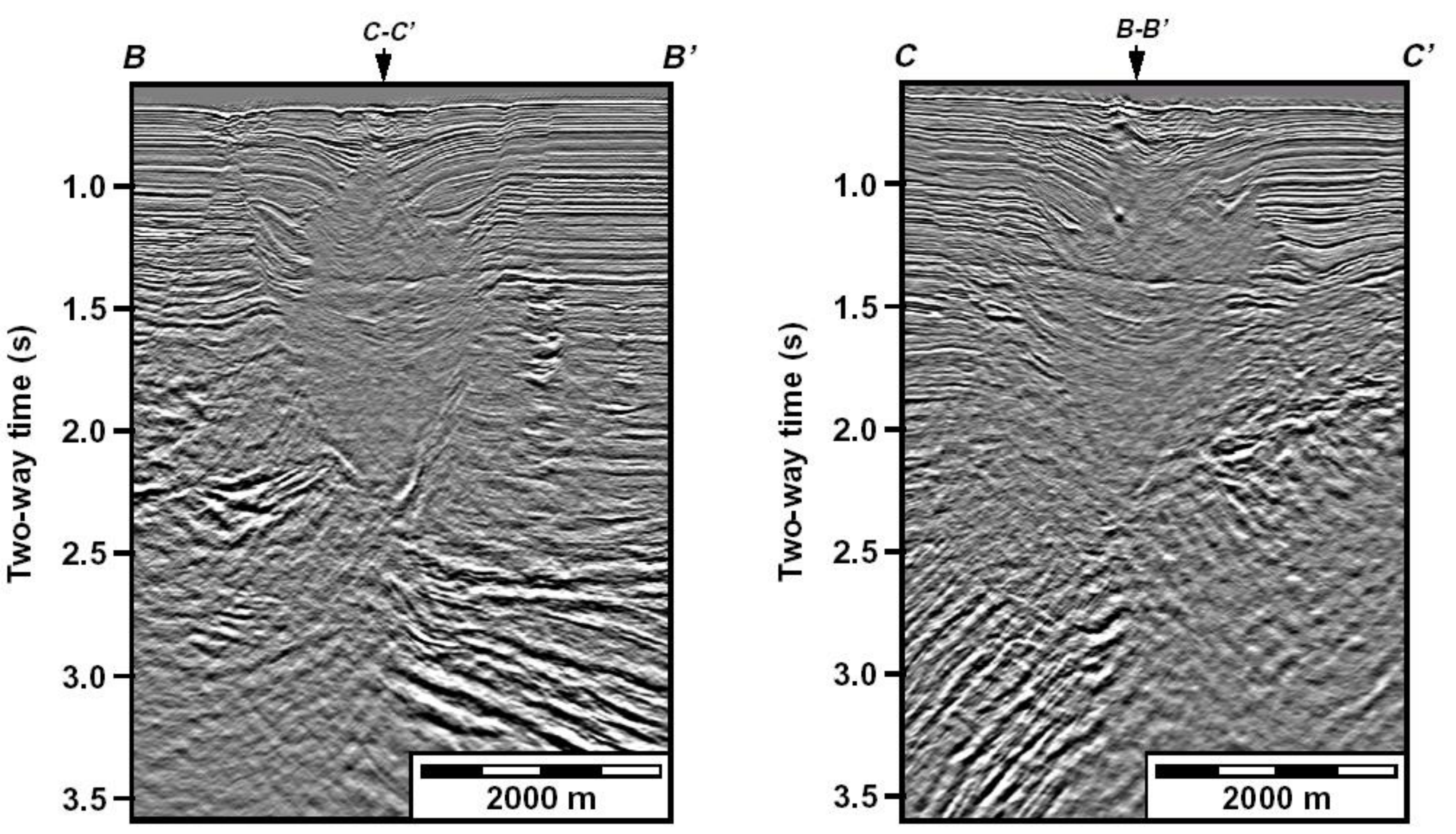
D) *1725 ms below sea floor*

(Haskell et al., 1999)



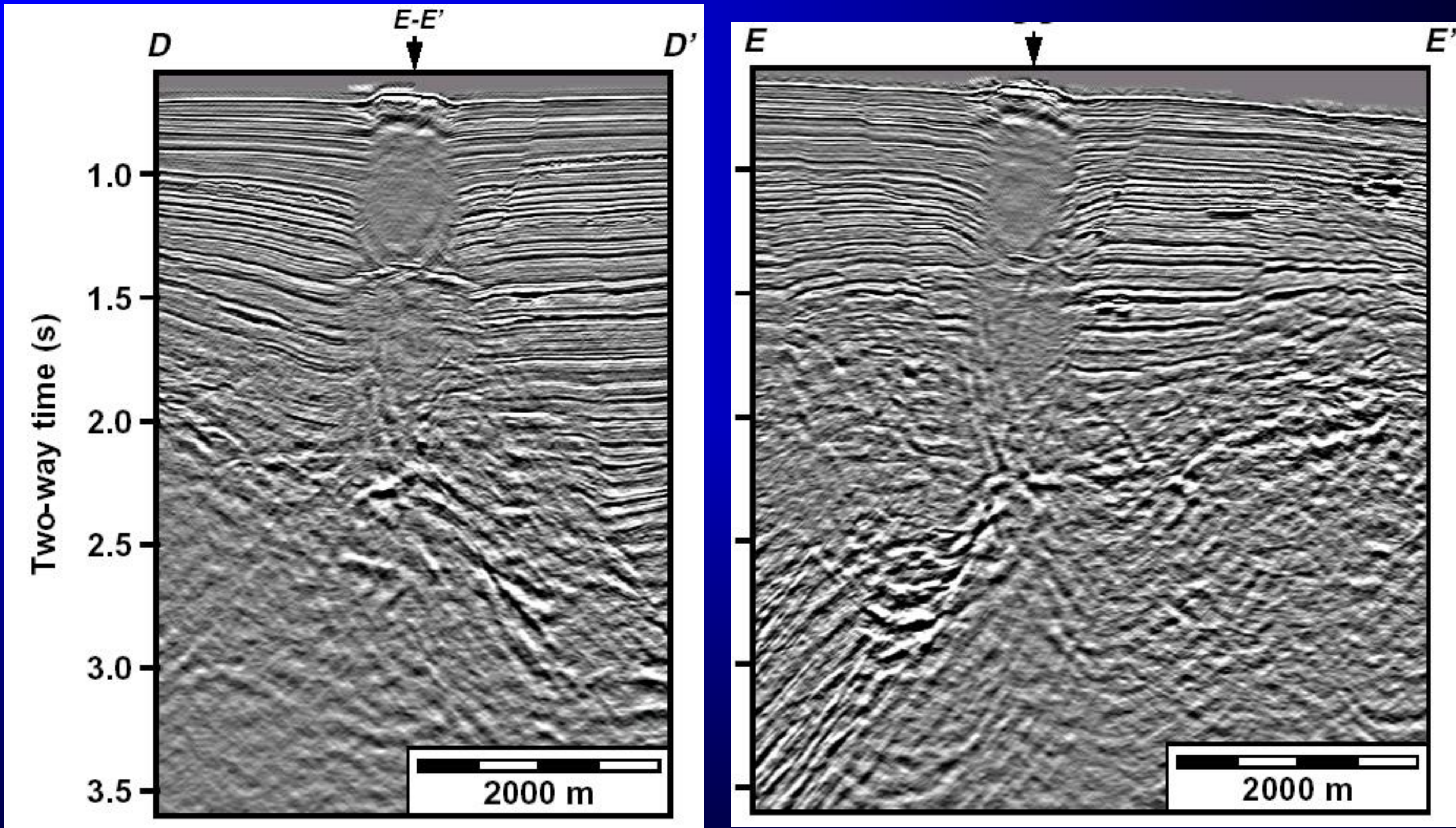
Vertical seismic section showing coherent reflections within a shale ridge.

(Haskell et al., 1999)



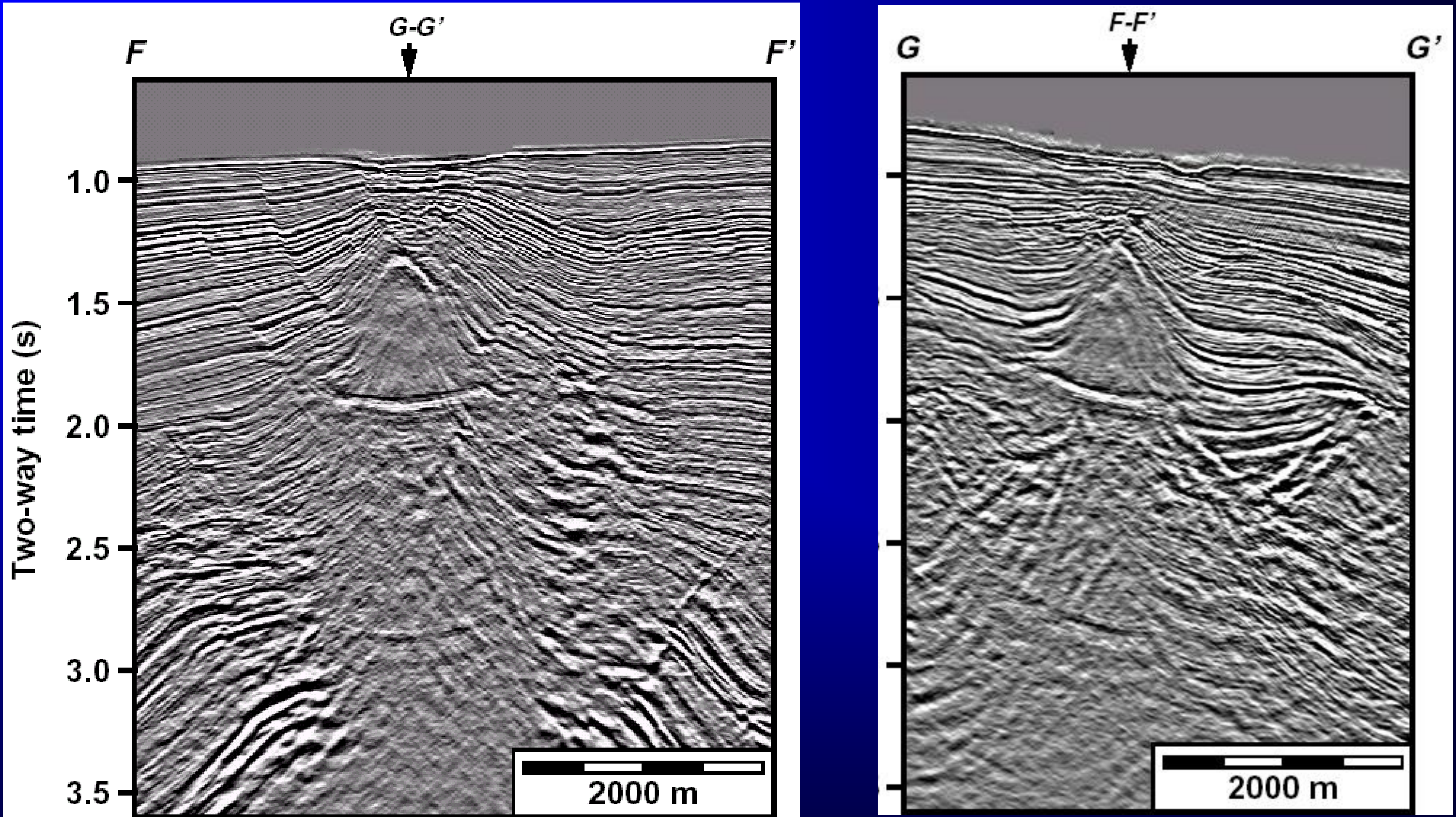
Vertical seismic sections through the shale diapirs

(Haskell et al., 1999)



Vertical seismic sections through the shale diapirs

(Haskell et al., 1999)

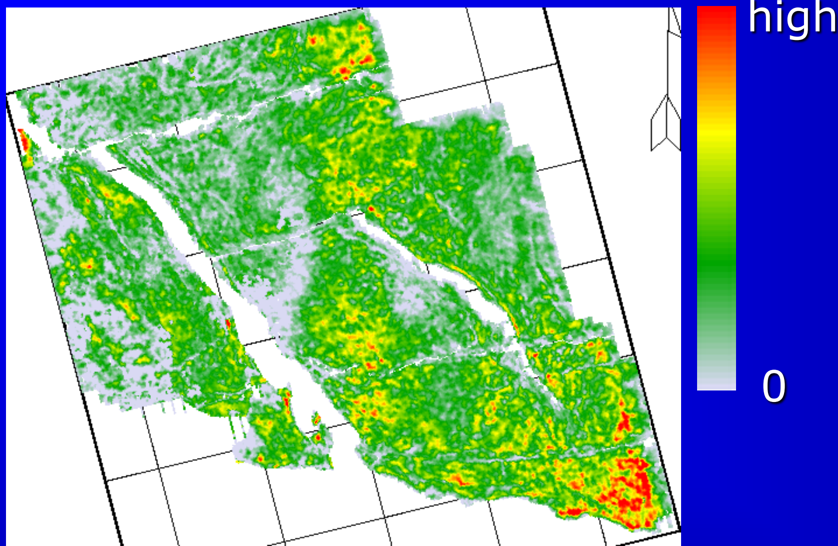


Vertical seismic sections through the shale diapirs

(Haskell et al., 1999)

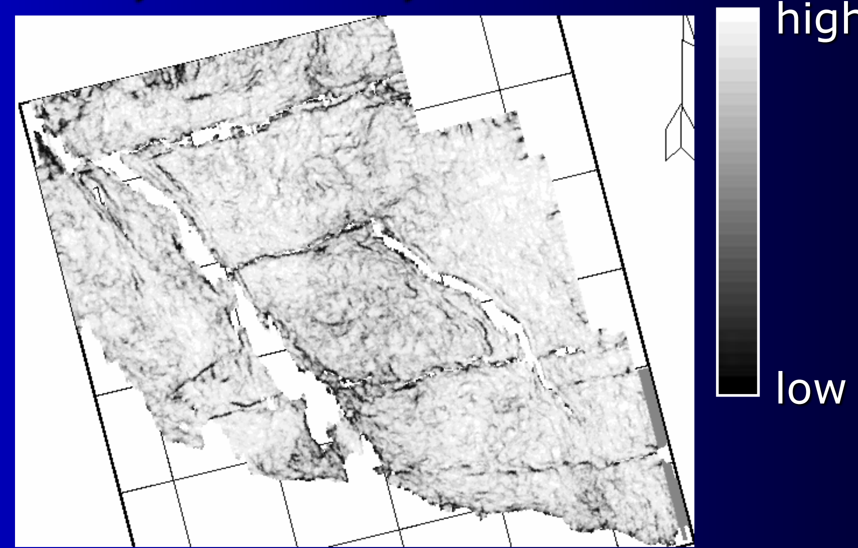
Mapping Folds and Flexures

Central Basin Platform, Texas, USA

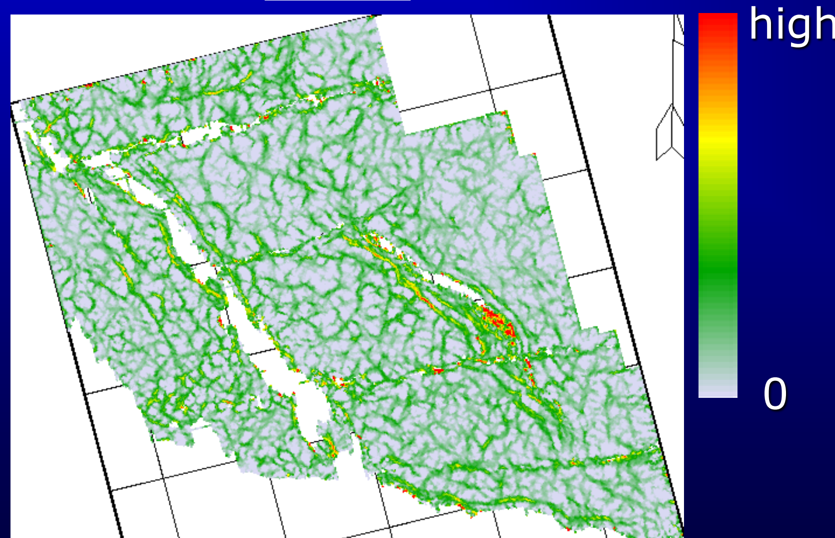


Seismic amplitude

5 km



Coherence

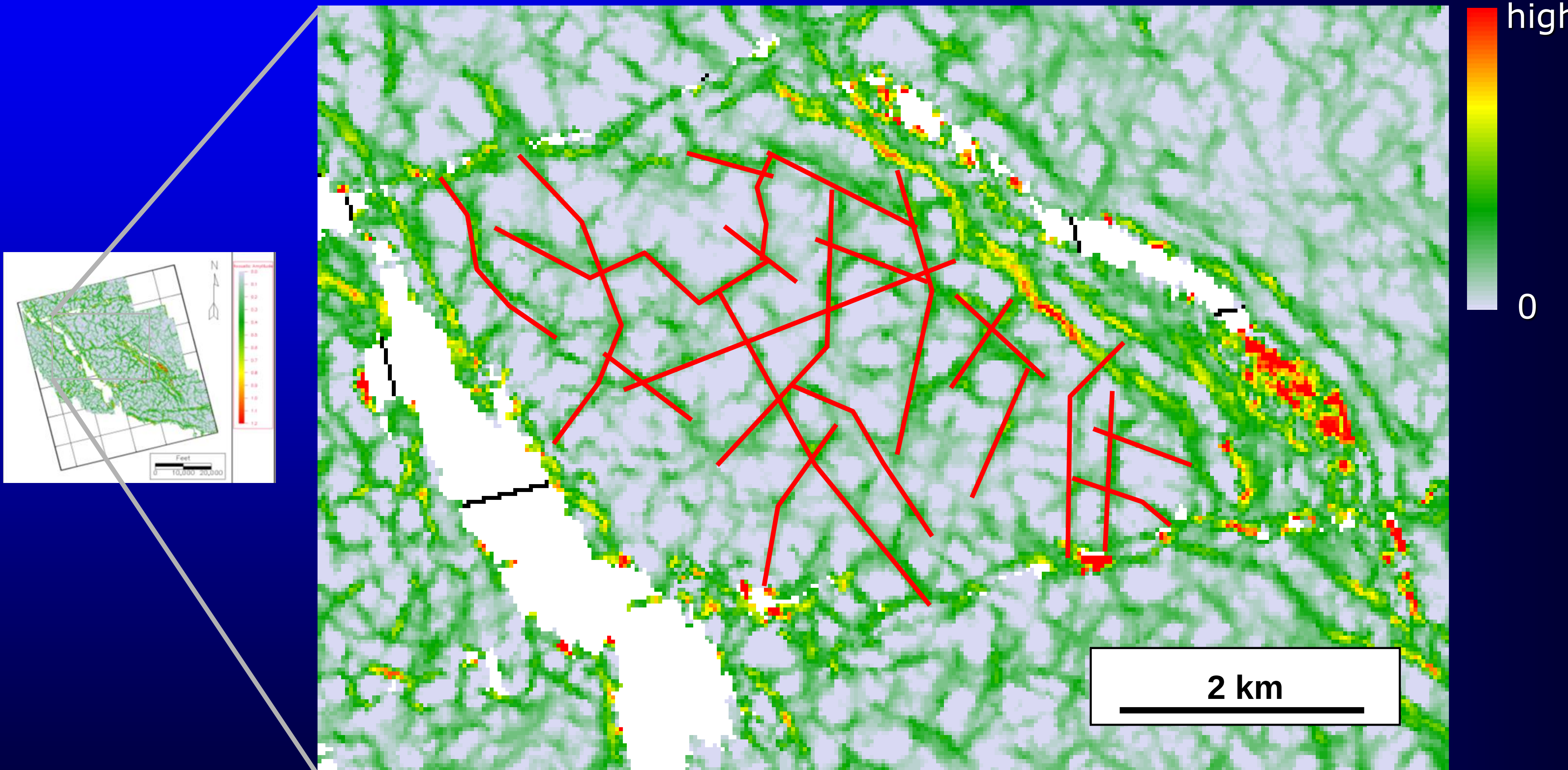


Most positive curvature

Horizon slices along Devonian

(Blumentritt et al., 2006)

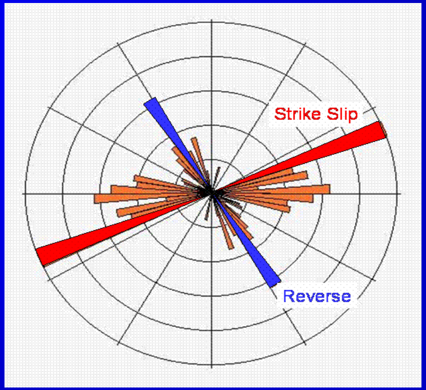
Pick lineaments seen on curvature



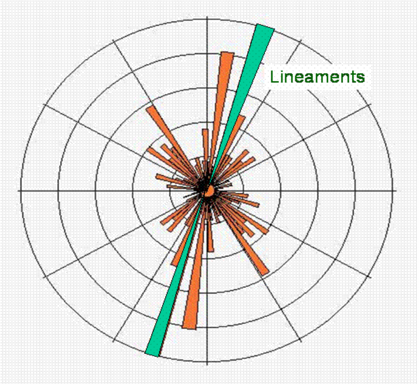
(Blumentritt et al., 2006)

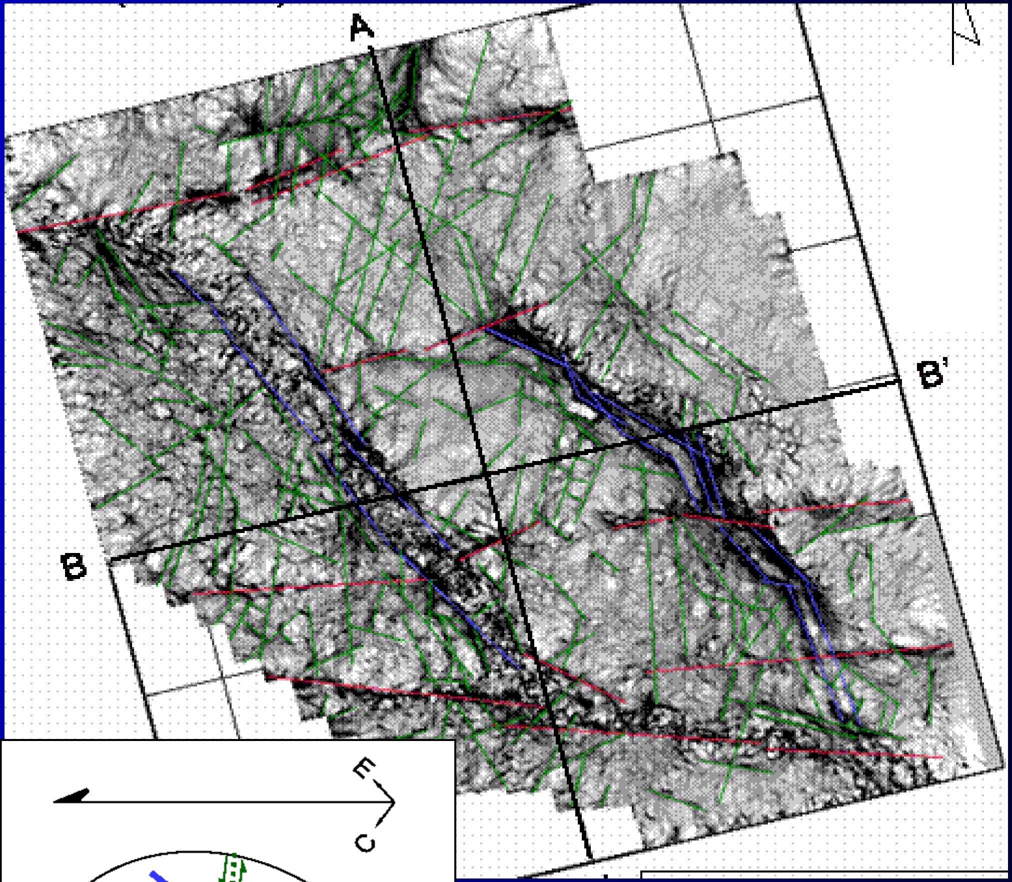
Interpretation of Lineaments

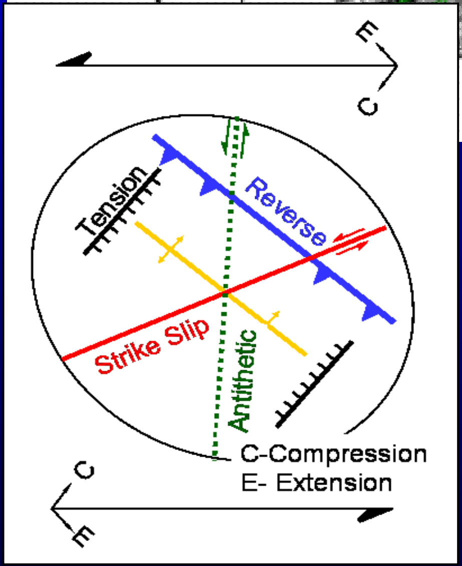
Red and Blue lines: Readily observable faults



Green lines: Subtle geologic features



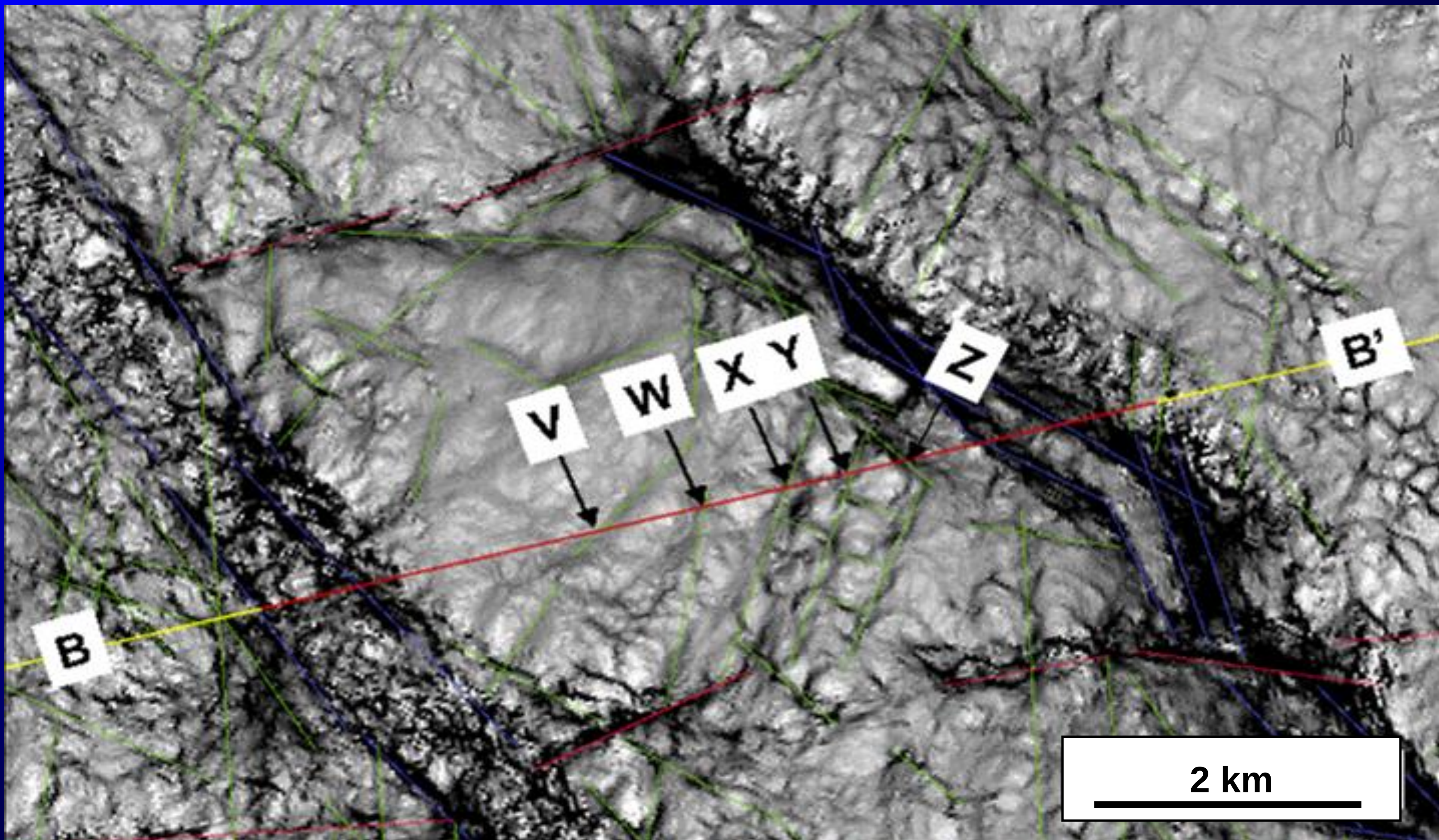




Deformation model

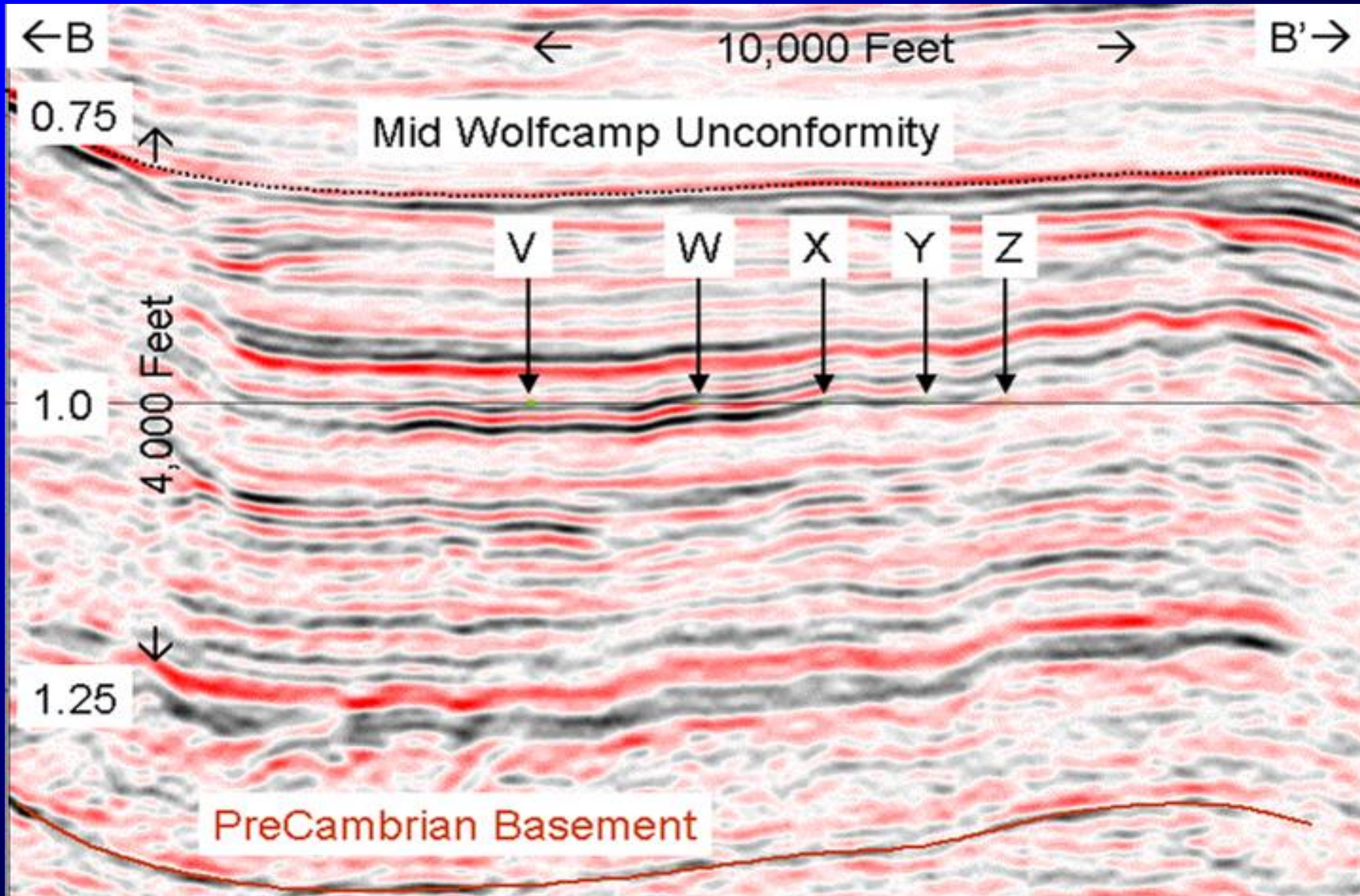
(Blumentritt et al., 2006)

What is the geologic explanation of these lineaments?



(Blumentritt et al., 2006)

Buckling in Competent Rocks?



(Blumentritt et al., 2006)

Structural Deformation

In Summary:

• Geometric attributes allow us to quickly define and name a coarse fault network.

• Geometric attributes are relatively insensitive to the seismic source wavelet, such that they are useful in visualizing geologic features that span surveys subjected to different acquisition and processing.

• Curvature illuminates not only folds and flexures, but also intensely fractured zones about faults that appear on seismic data as flexures.

• Co-rendering curvature and coherence provides a means of visualizing deformation on simple time slices.