

Volumetric Curvature Attributes for Mapping Faults, Fractures, Depositional and Diagenetic Features*

By

Satinder Chopra¹ and Kurt J. Marfurt²

Search and Discovery Article #40341 (2008)

Posted October 7, 2008

*Adapted from oral presentation at AAPG Annual Convention, San Antonio, TX, April 20-23, 2008

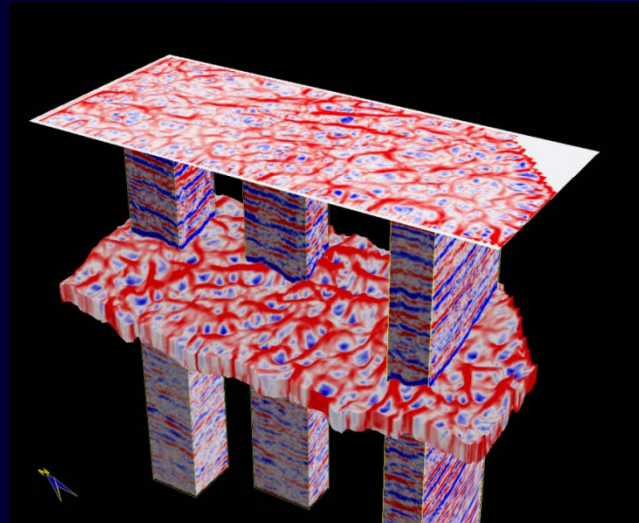
¹Arcis Corporation, Calgary, AB, Canada. (schopra@arcis.com)

²University of Oklahoma, Norman, OK.

Abstract

Curvature is a measure of the deviation of a surface from a plane. The more a surface is structurally flexed, folded, or faulted, the larger its curvature. Curvature is also sensitive to domes and sags associated with salt and shale diapirism, to differential compaction over heterogeneous sedimentary deposits, and to dissolution and collapse associated with diagenesis. Using well-established models of structural deformation coupled with well control, geoscientists can use curvature measures to predict paleostress and areas favorable to natural fractures. We demonstrate the application of curvature attributes for superior mapping of subsurface channels, levees, bars, contourites, and other stratigraphic features, particularly in older rocks that have undergone differential compaction. Until recently, curvature has been usually computed from picked horizon surfaces interpreted on 3D surface seismic data volumes. A significant advancement in the area of curvature attributes has been the volumetric estimation of curvature which alleviates the need for picking horizons in regions through which no continuous surface exists. The values of volumetric attributes are two-fold. First, the images have a higher signal-to-noise ratio than horizon-based attributes. Second, not every geologic feature that we wish to interpret may fall along a horizon that can be interpreted. The orientations of the fault/fracture lineaments interpreted on curvature displays can be combined in the form of rose diagrams, which in turn can be compared with similar diagrams obtained from image logs to gain confidence in calibration. While a direct prediction of open fractures may require a significant amount of calibration through the use of production, tracer, image logs, or microseismic measurements, volumetric attribute analysis serves as a powerful aid in defining the structural framework.

Volume curvature attributes for mapping faults, fractures and depositional features



Satinder Chopra*



**ARCIS CORPORATION,
CALGARY**

and

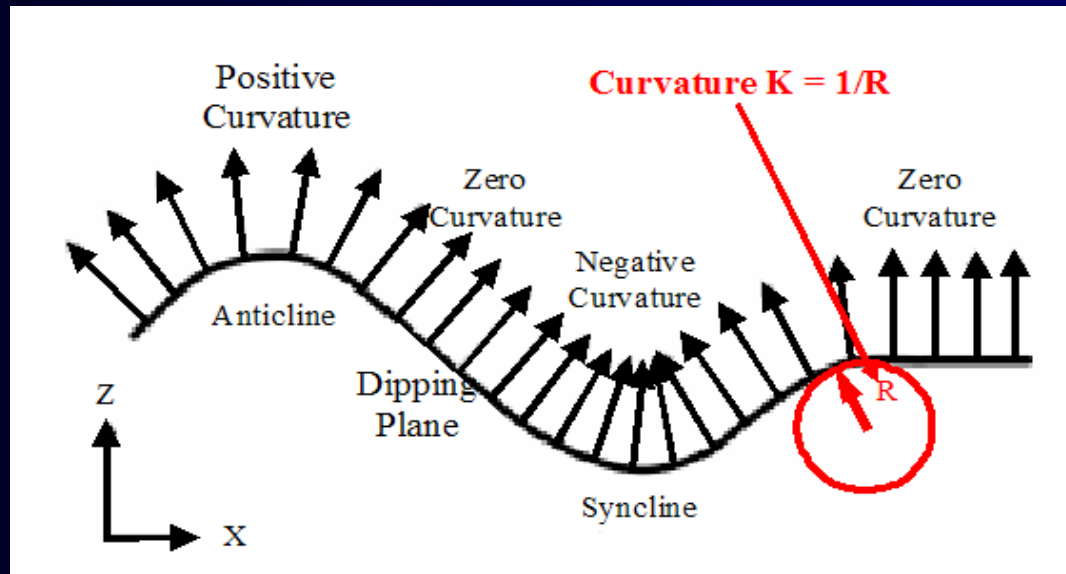
Kurt Marfurt



**UNIVERSITY OF OKLAHOMA,
NORMAN**

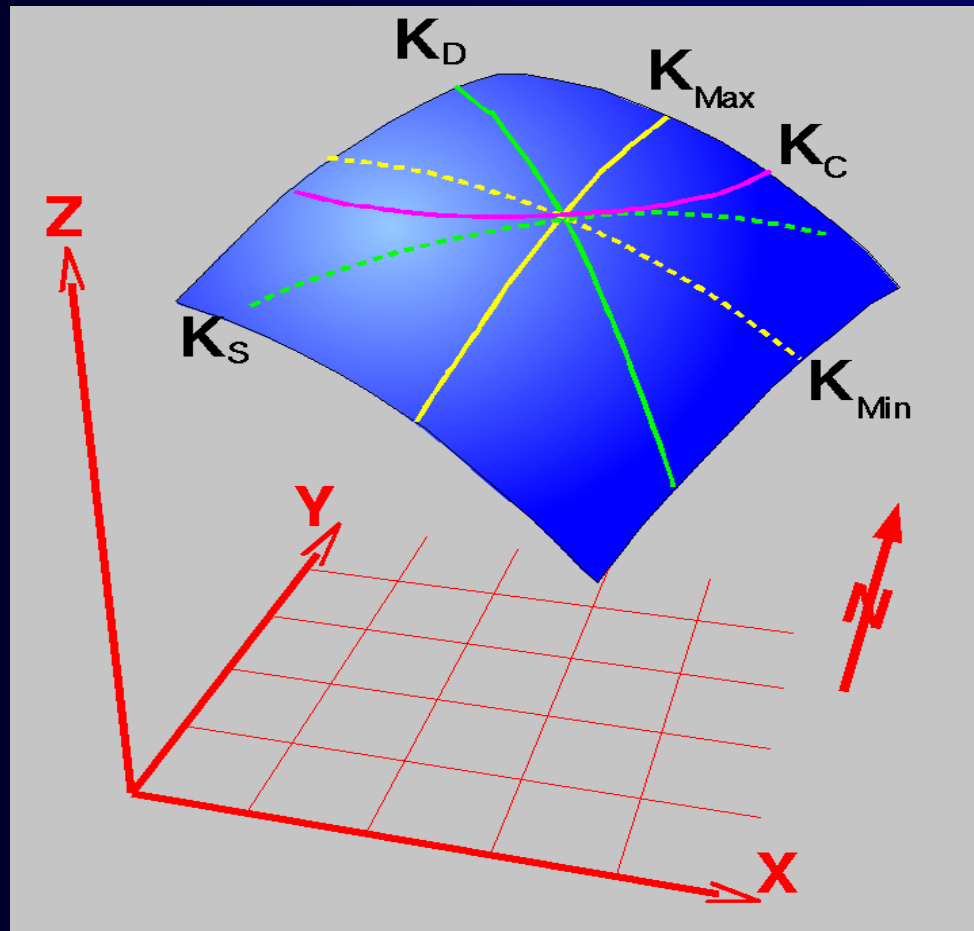
Curvature

Definition



(After Roberts, 2001)

Definition



(Roberts, 2001; Image courtesy: Bruce Hart)

Mathematically, the first step in determining the curvature from a grid of measurements is to fit a quadratic surface, $z(x,y)$, of the form

$$z(x,y)=ax^2+cxy+by^2+dx+ey+f .$$

Mean curvature

$$k_{mean}=[a(1+e^2)+b(1+d^2)-cde]/(1+d^2+e^2)^{3/2},$$

Gaussian Curvature

$$k_{Gauss}=(4ab-c^2)/(1+d^2+e^2)^2$$

Most-positive curvature

$$k_{pos} = (a+b)+[(a-b)^2 + c^2]^{1/2}$$

Most-negative curvature

$$k_{neg} = (a+b)-[(a-b)^2 + c^2]^{1/2}$$

(After Roberts, 2001)

Volume computation of curvature

- Fractional derivative approach on volumetric estimates of reflector dip.
- Yields multi-spectral estimates of curvature measures.

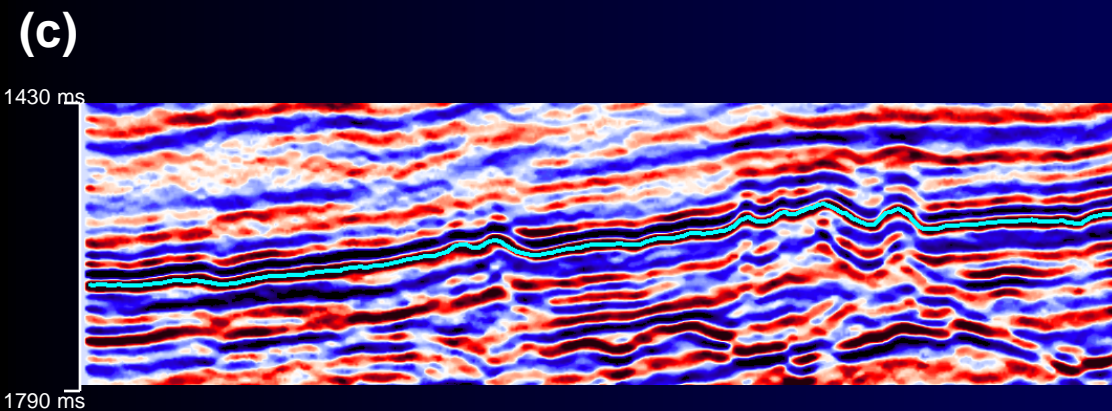
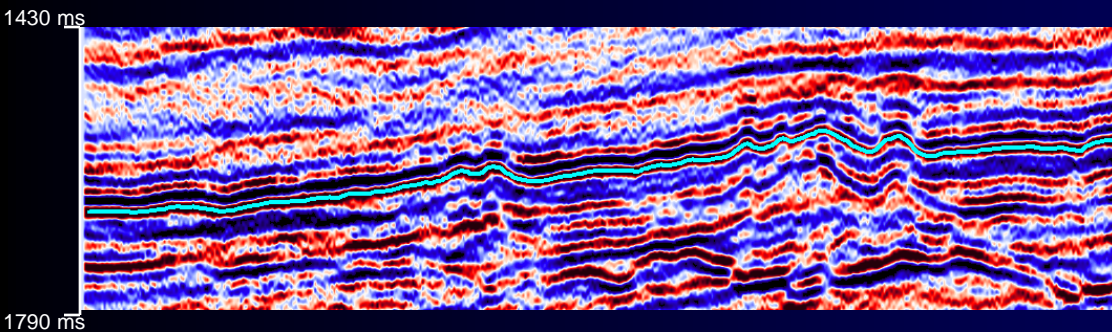
Fractional derivative approach:

For a function $u(x)$ and its first derivative $\frac{\partial u}{\partial x}$,
in the wavenumber domain, the first derivative is

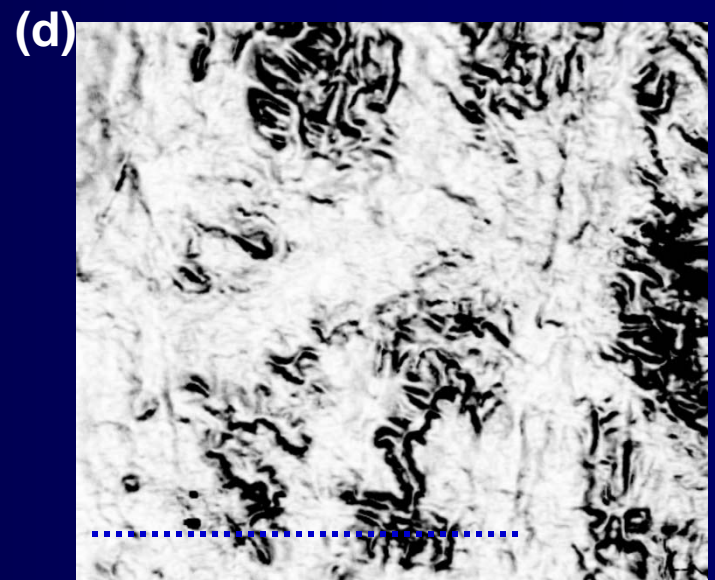
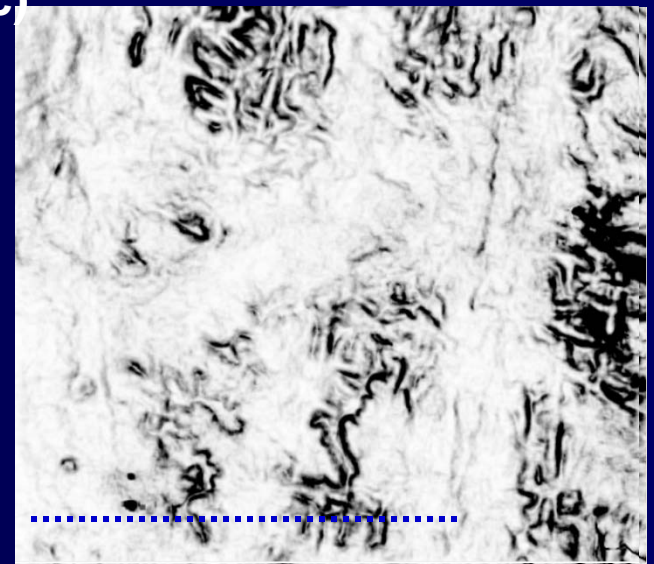
given as $F_{\alpha}\left(\frac{\partial u}{\partial x}\right) = (-ik_x)^{\alpha} F(u)$

where α is fractional real number;

(a) Median vs Structure-oriented filtering (c)



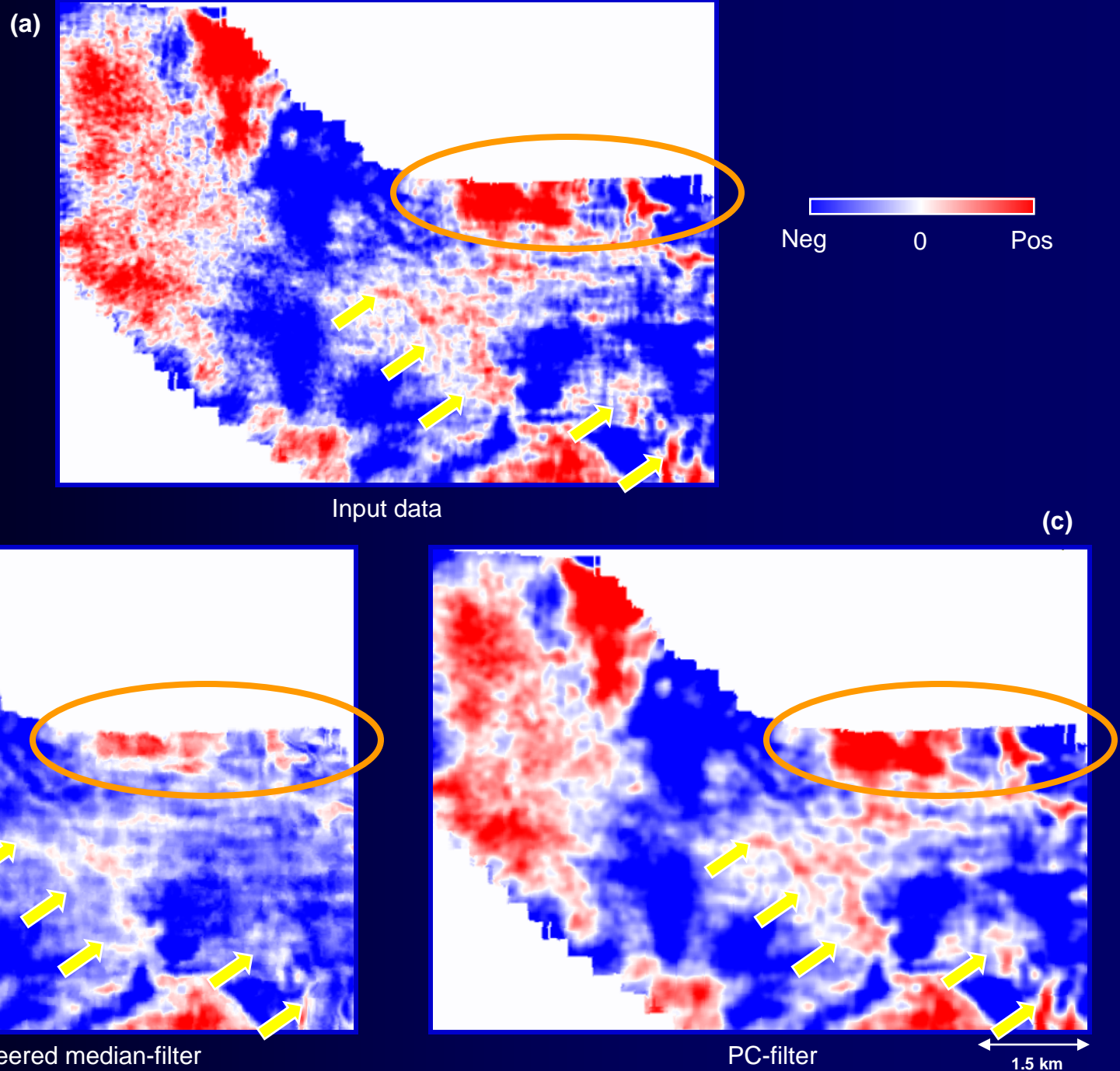
Inline sections through (a) the input seismic volume, and (b) the median filtered seismic volume



3 km

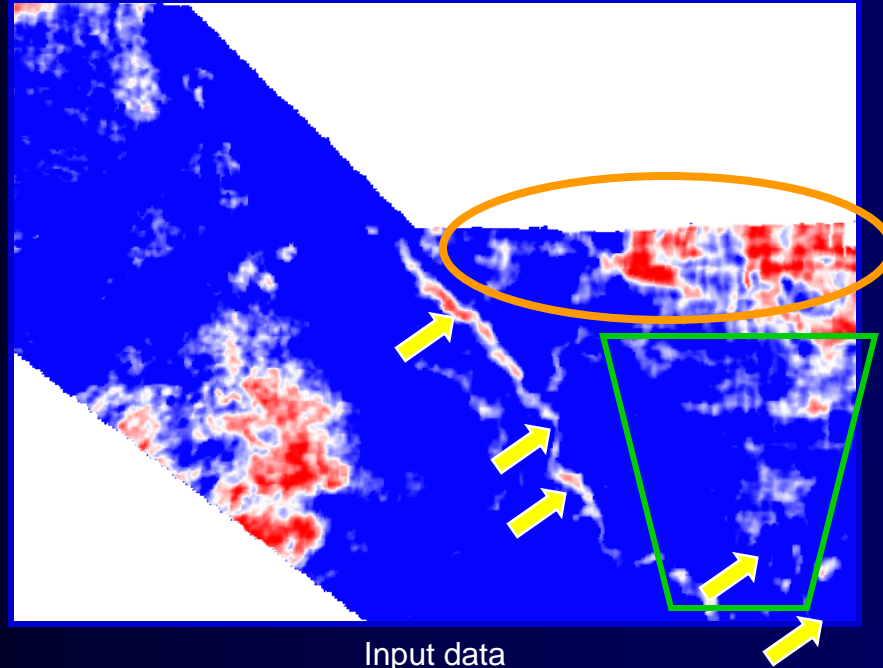
Strat slices through coherence volumes run on (c) the input seismic volume, and (d) the median filtered seismic volume, 76 ms below the horizon shown in (a) and (b)

Structure-oriented filtering vs median filtering

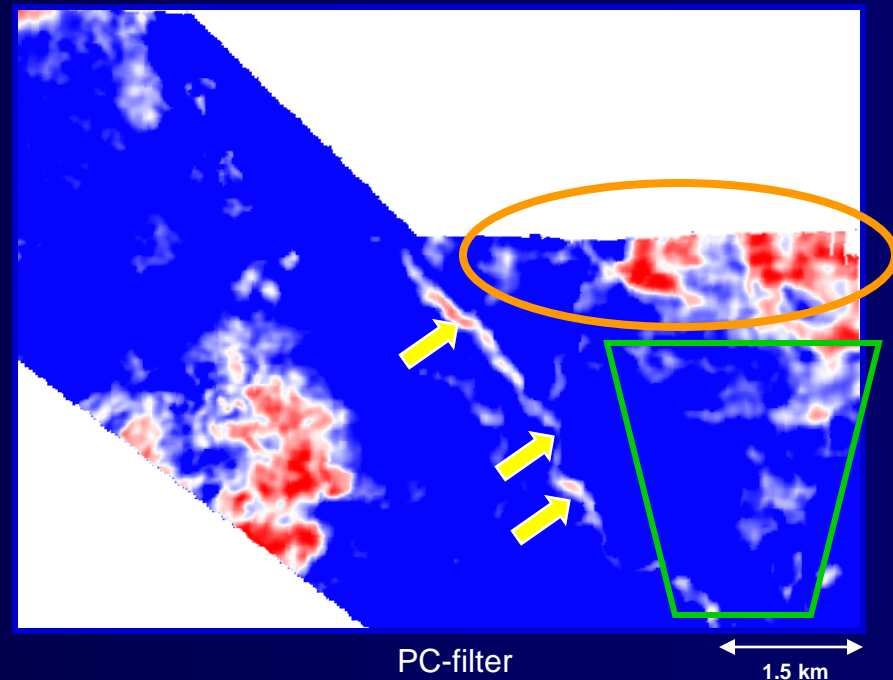
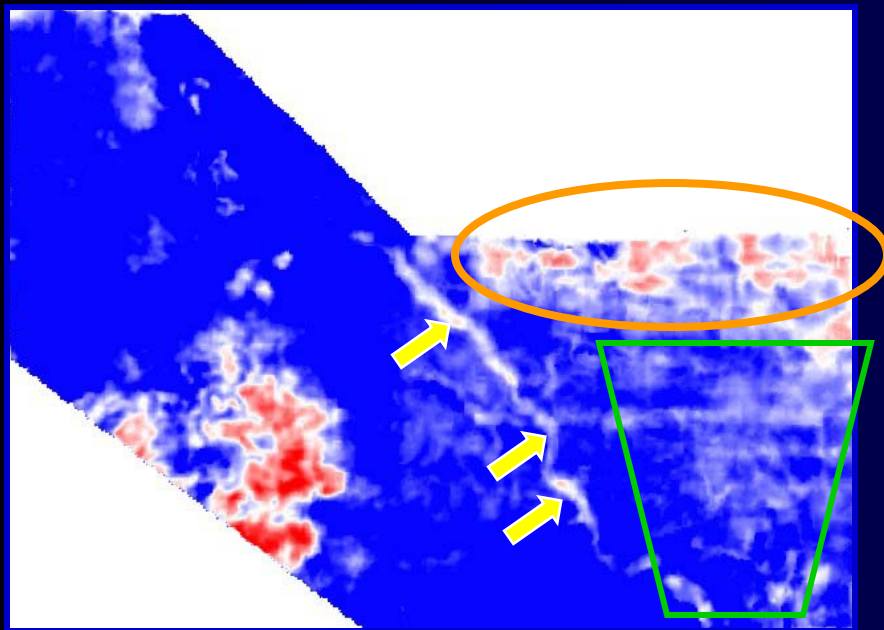


Comparison of seismic time slices at 1778 ms

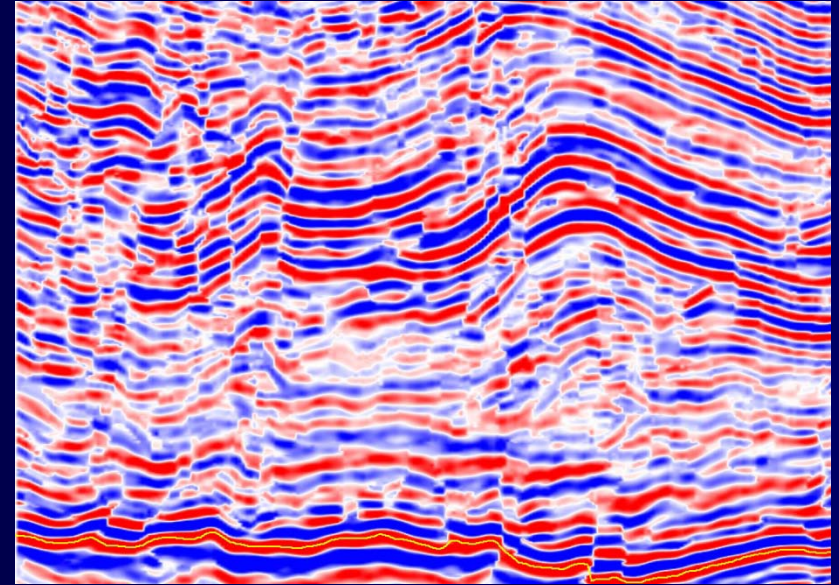
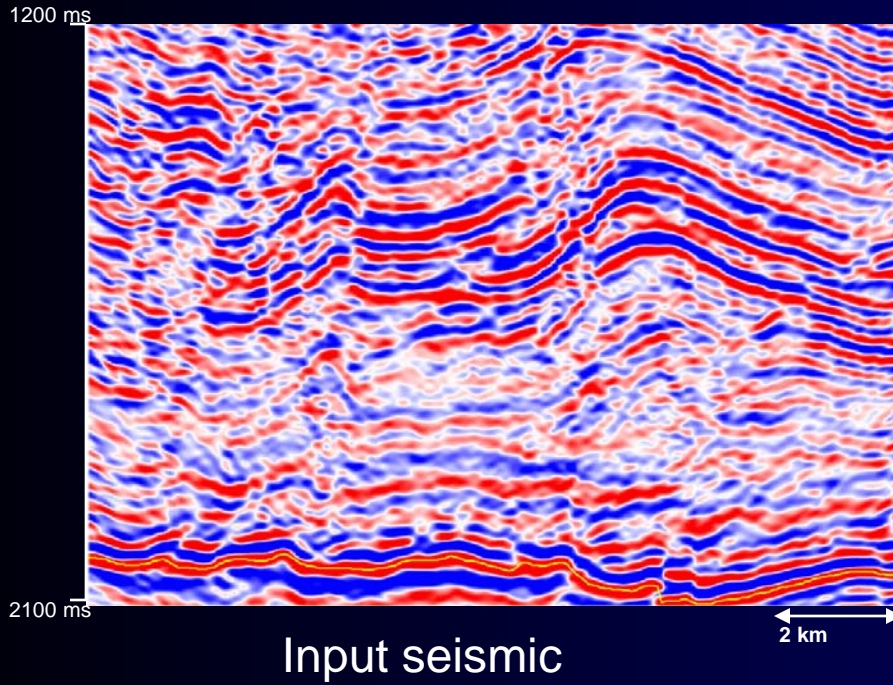
Structure-oriented filtering vs median filtering



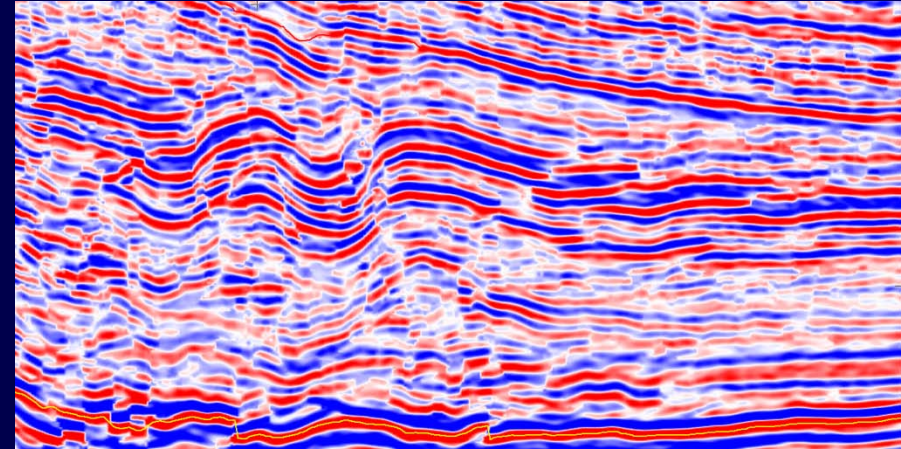
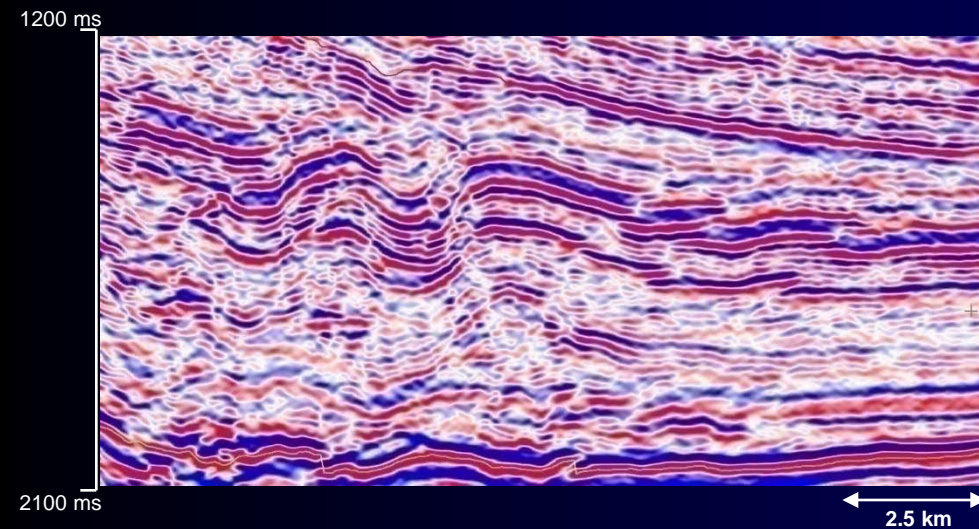
Comparison of horizon slices, 66 ms above a flattened marker



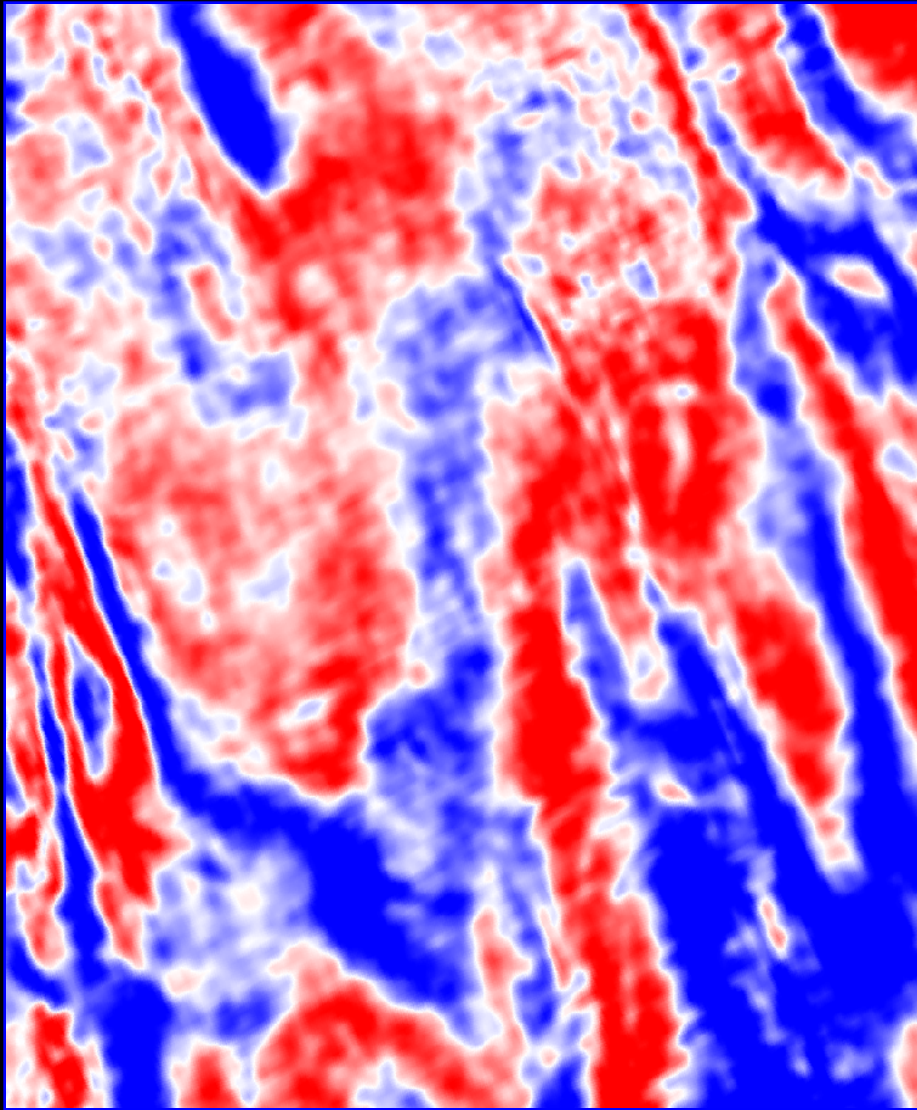
Conditioning of data before computation of curvature



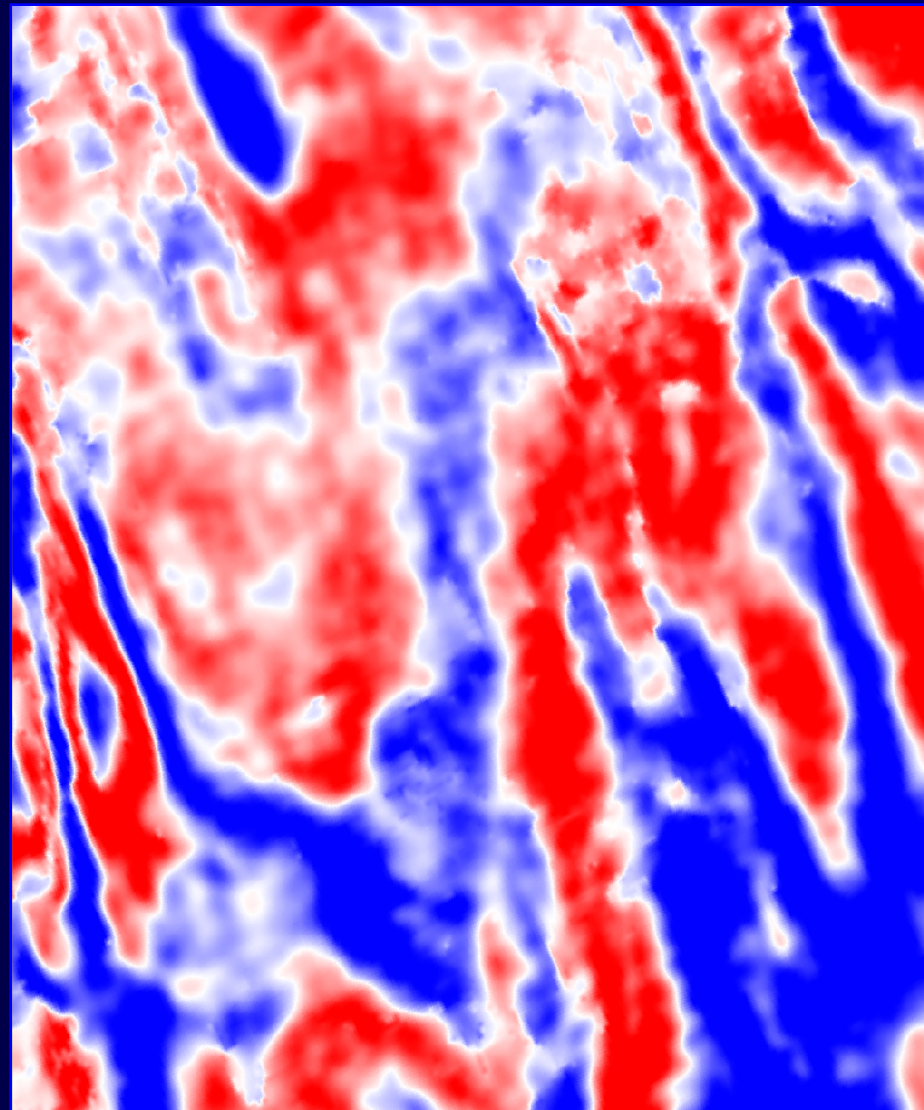
Input seismic after str-or-filtering



Structure-oriented filtering



A time slice at 968 ms from the 3D seismic volume



The same time slice after PC filtering

Common causes of acquisition footprint

Problems due to acquisition program

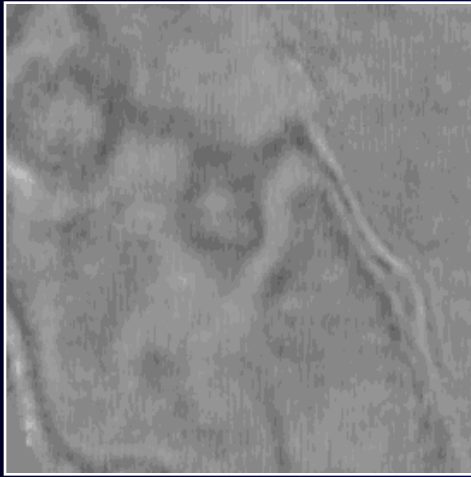
- Non-uniform offsets and azimuths in bins
- Non-uniform backscattered noise suppression
- Obstacles such as lakes, villages, or platforms
- Currents and tides

Problems due to processing

- Incorrect velocities
- Migration operator aliasing

Footprint removal

(a)



(b)

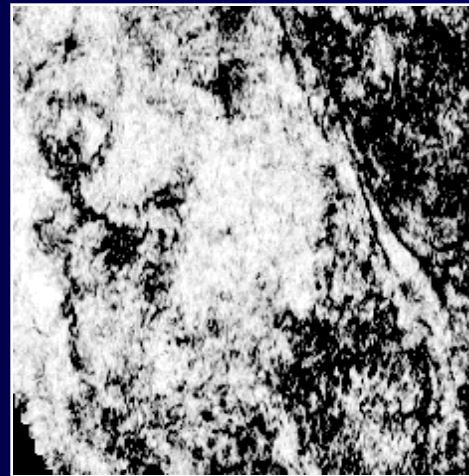


Low High

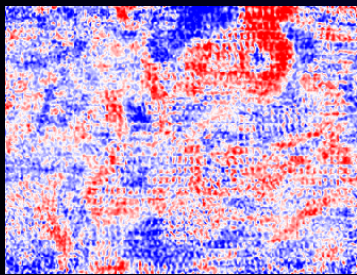
(c)



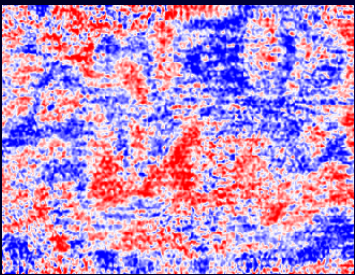
(d)



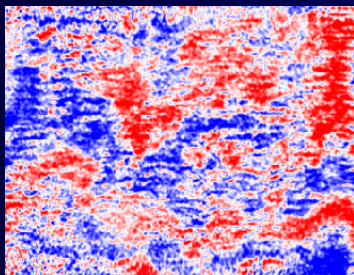
Time slices 472 ms



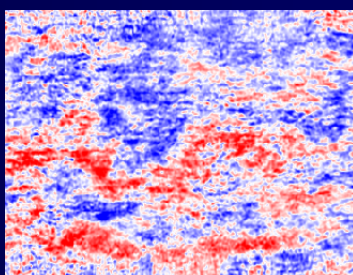
Time slices 588 ms



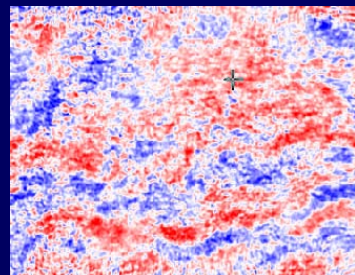
Time slices 694 ms



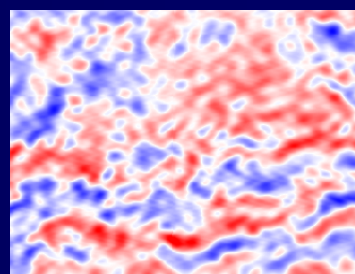
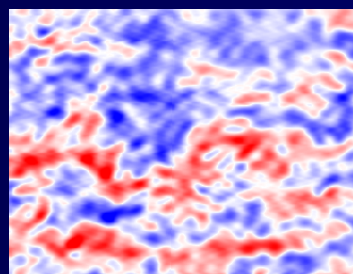
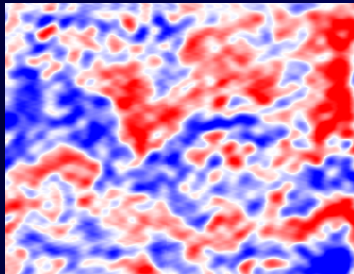
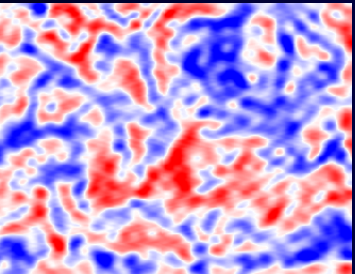
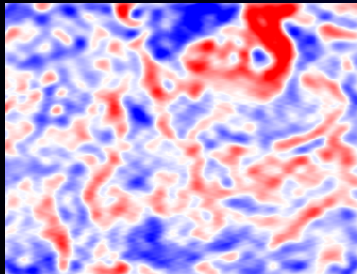
Time slices 918 ms



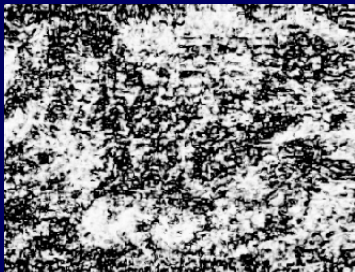
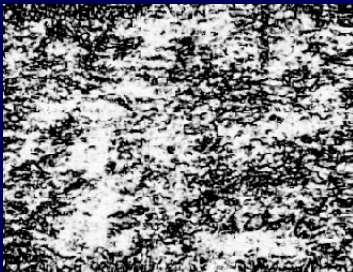
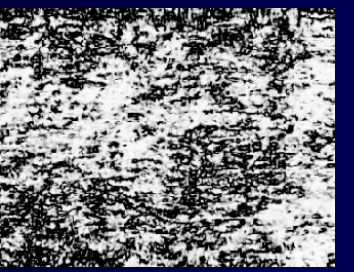
Time slices 1020 ms



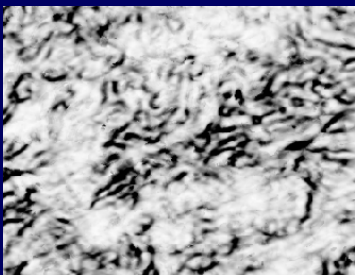
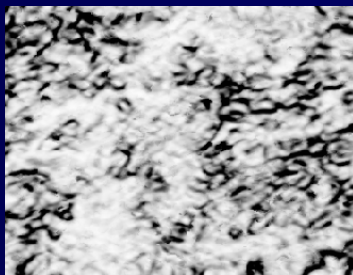
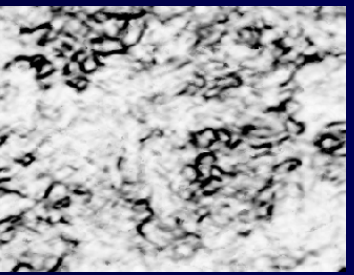
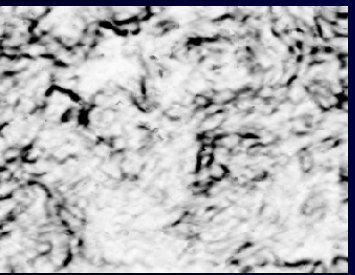
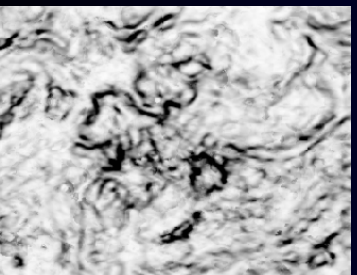
Input seismic data



Input seismic data after footprint removal

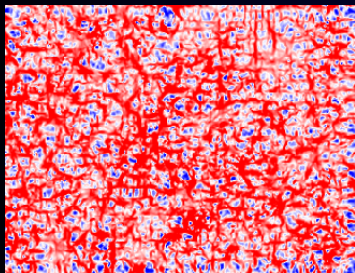


Coherence attribute computed on input seismic data

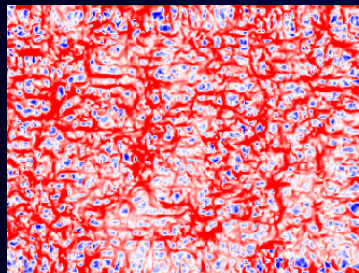


Coherence attribute computed on input seismic data after footprint removal

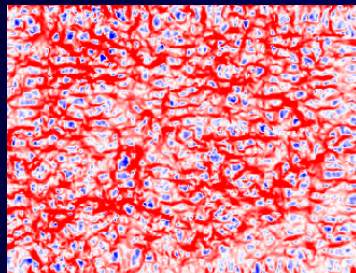
Time slices 472 ms



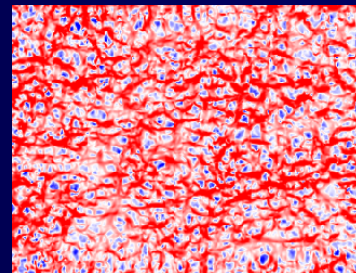
Time slices 588 ms



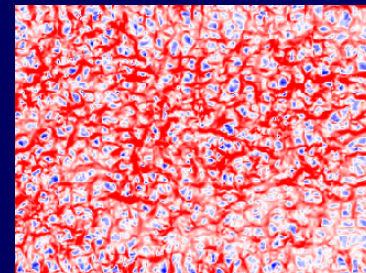
Time slices 694 ms



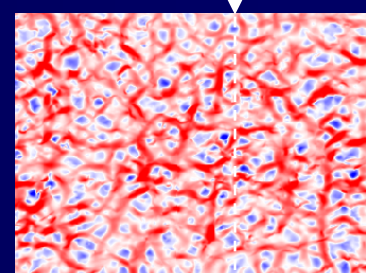
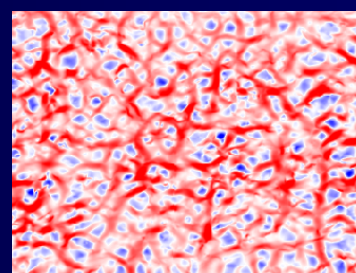
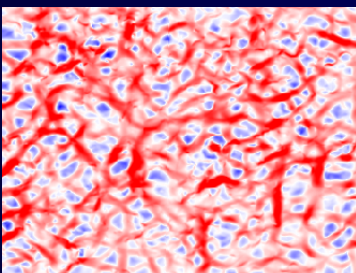
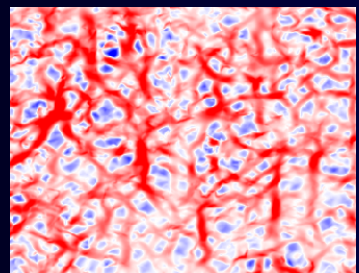
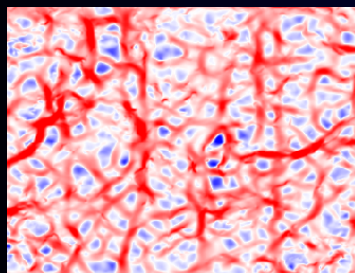
Time slices 918 ms



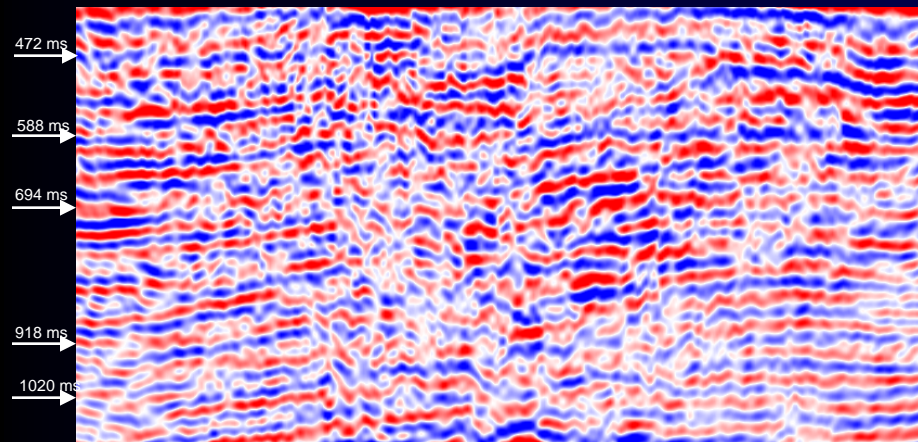
Time slices 1020 ms



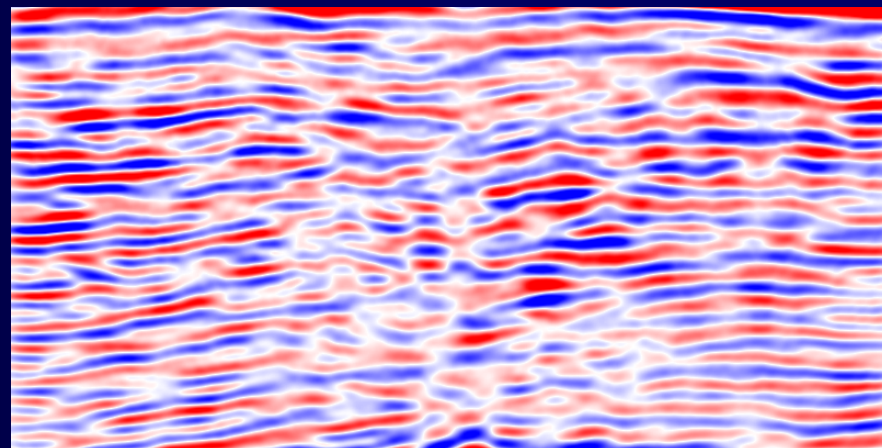
Most-positive curvature attribute computed on input seismic data



Most-positive curvature attribute computed on input seismic data after footprint removal



Input seismic data



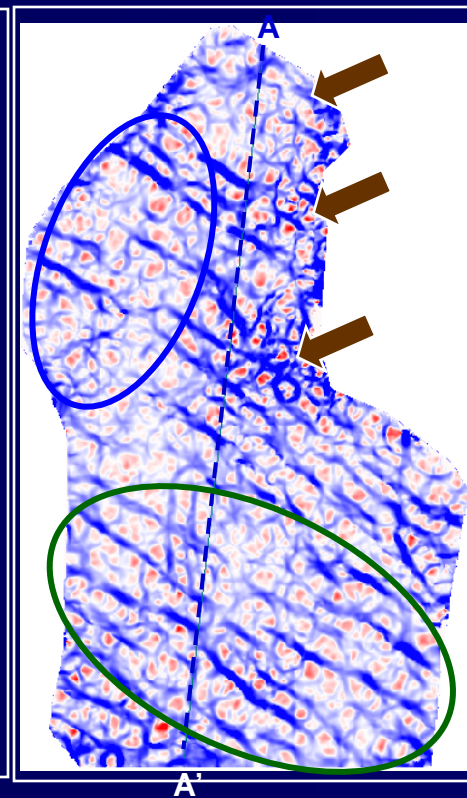
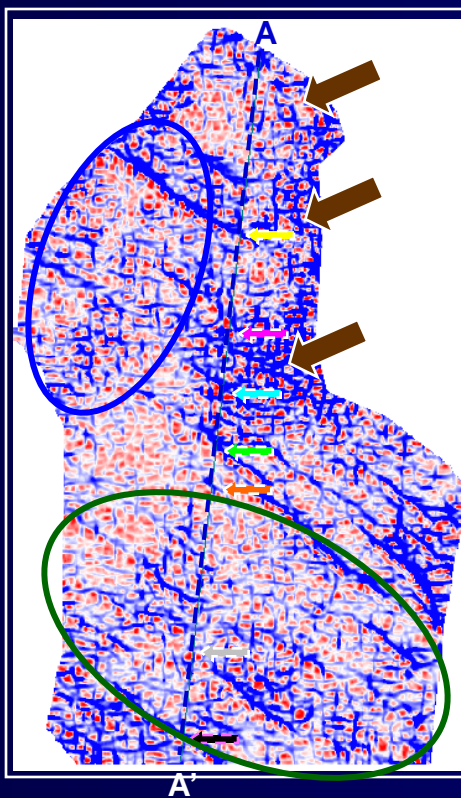
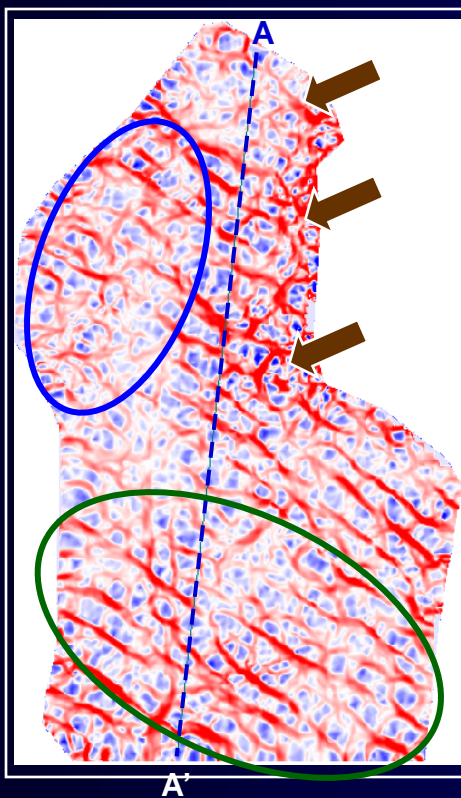
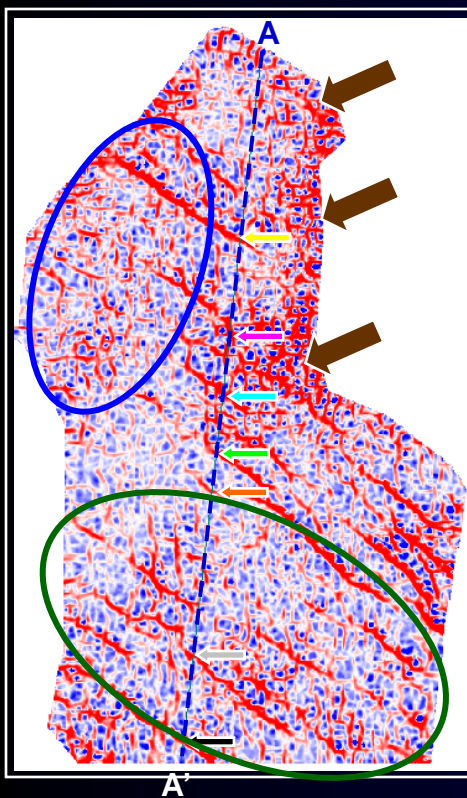
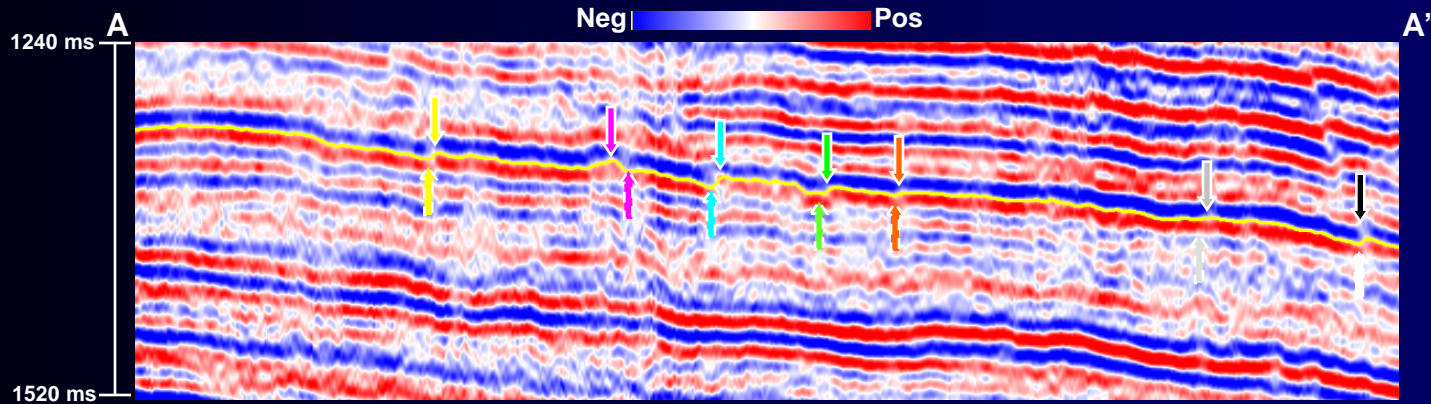
Input seismic data after footprint removal

Seismic Attributes

Volumetric computation of curvature

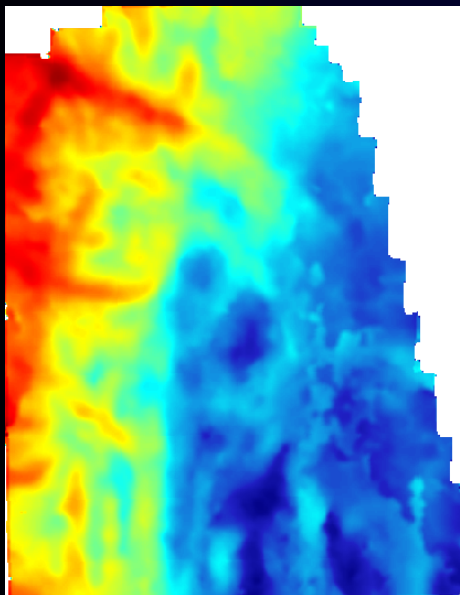
Horizon based curvature has been used successfully for prediction of faults and fractures (Lisle(1994), Hart et al (2002).

Volumetric curvature dispels the need to pick horizons (Al-Dossary and Marfurt (2006).

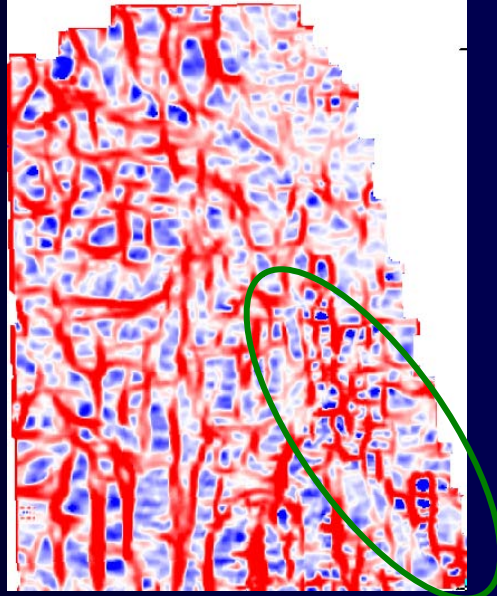


Neg 0 Pos Neg 0 Pos Neg 0 Pos Neg 0 Pos
 A segment of a seismic section along a random line (shown dotted in Figure 1(b)) showing a horizon (in yellow), (b) most-positive curvature computed on the horizon, (c) most-positive curvature extracted along the horizon from the most-positive curvature attribute volume, (d) most-negative curvature computed on the horizon, (e) most-negative curvature extracted along the horizon from the most-negative curvature attribute volume. Notice the artifacts seen on the horizon computed curvature displays, which are not seen on the attributes extracted along the horizon from the curvature attribute volumes.

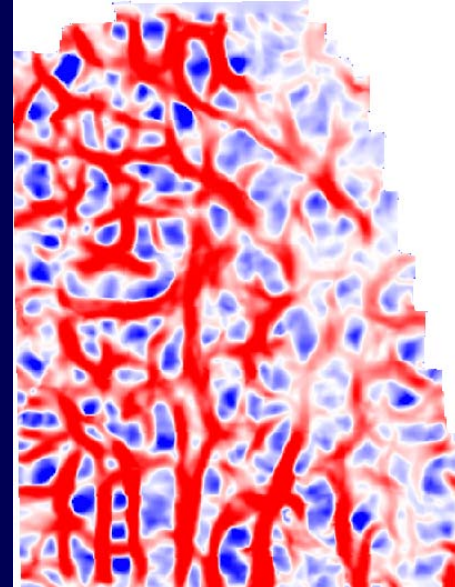
1 km



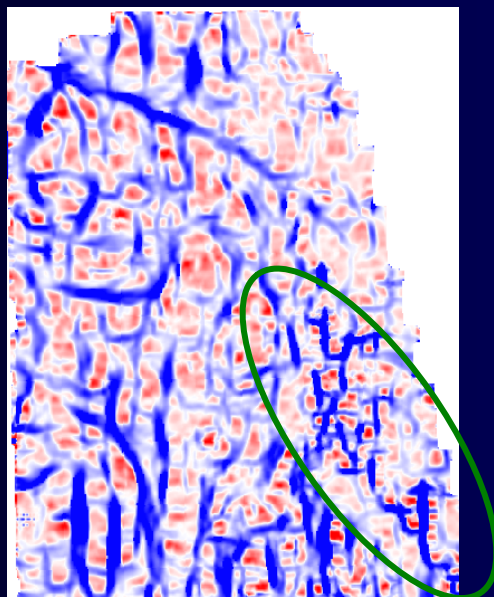
Time surface



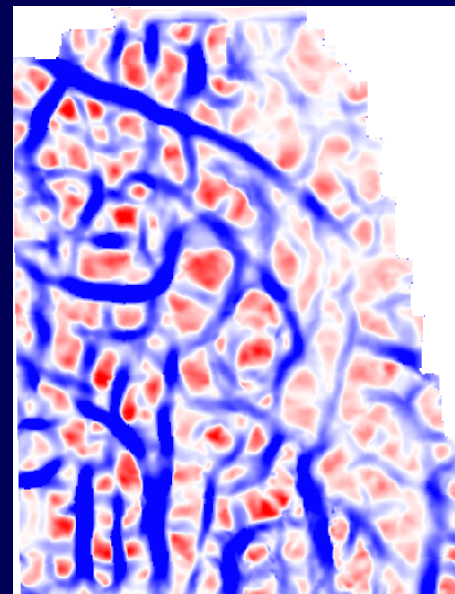
Most-positive curvature computed from the time horizon



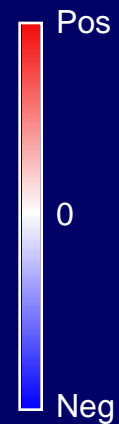
Volumetric most-positive curvature extracted along the time horizon



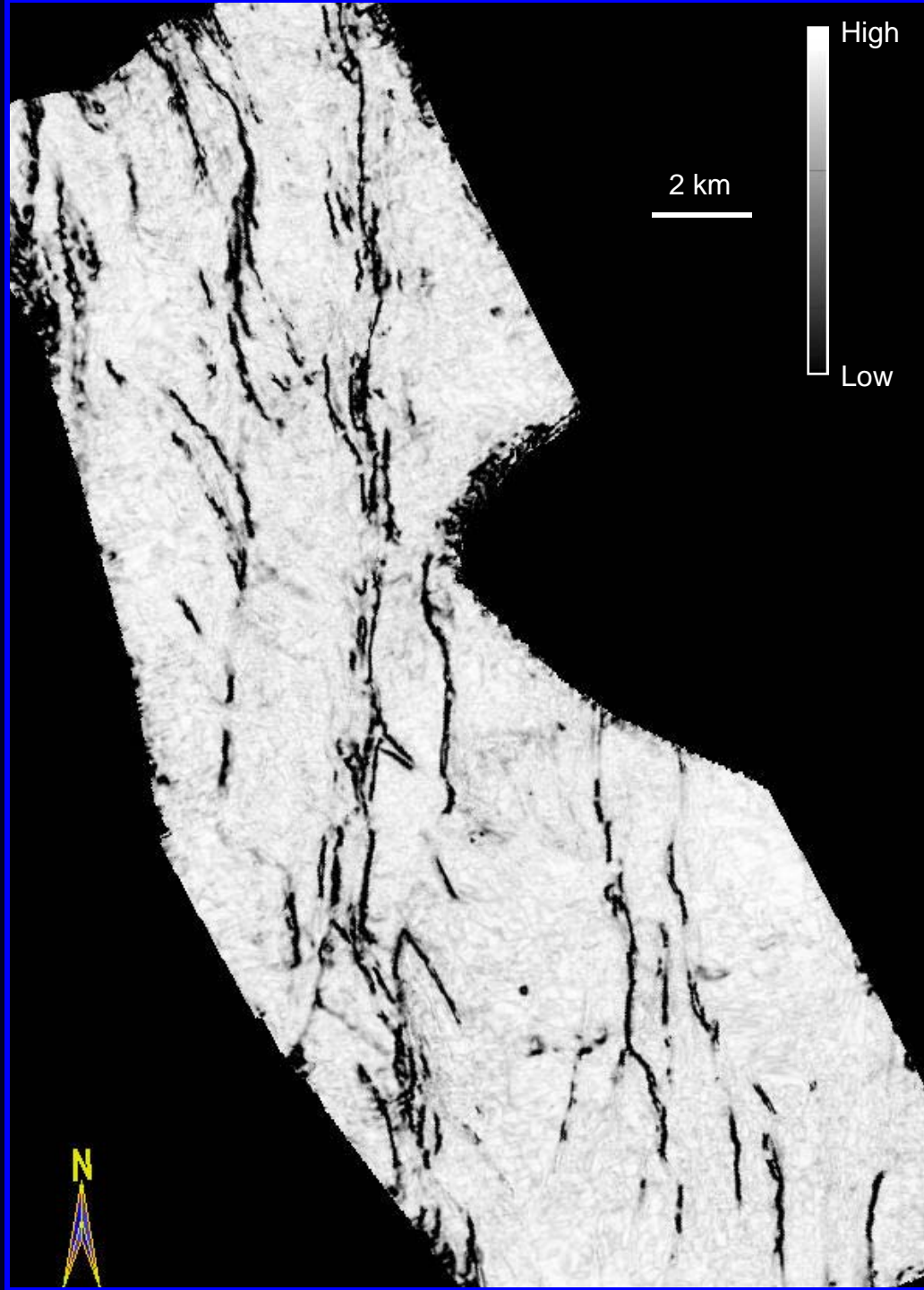
Most-negative curvature computed from the time horizon



Volumetric most-negative curvature extracted along the time horizon

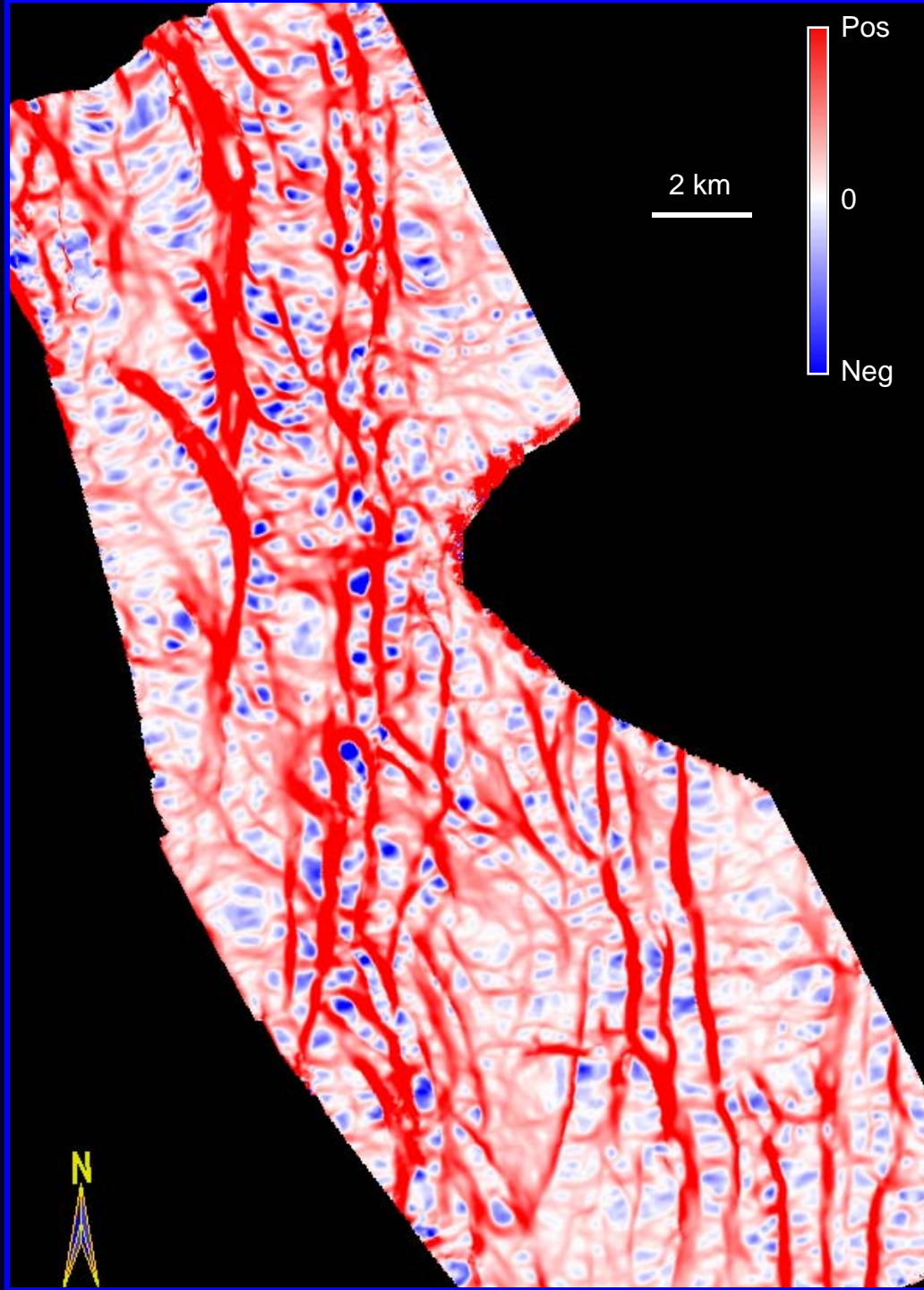


Data courtesy: Arcis Corporation, Calgary



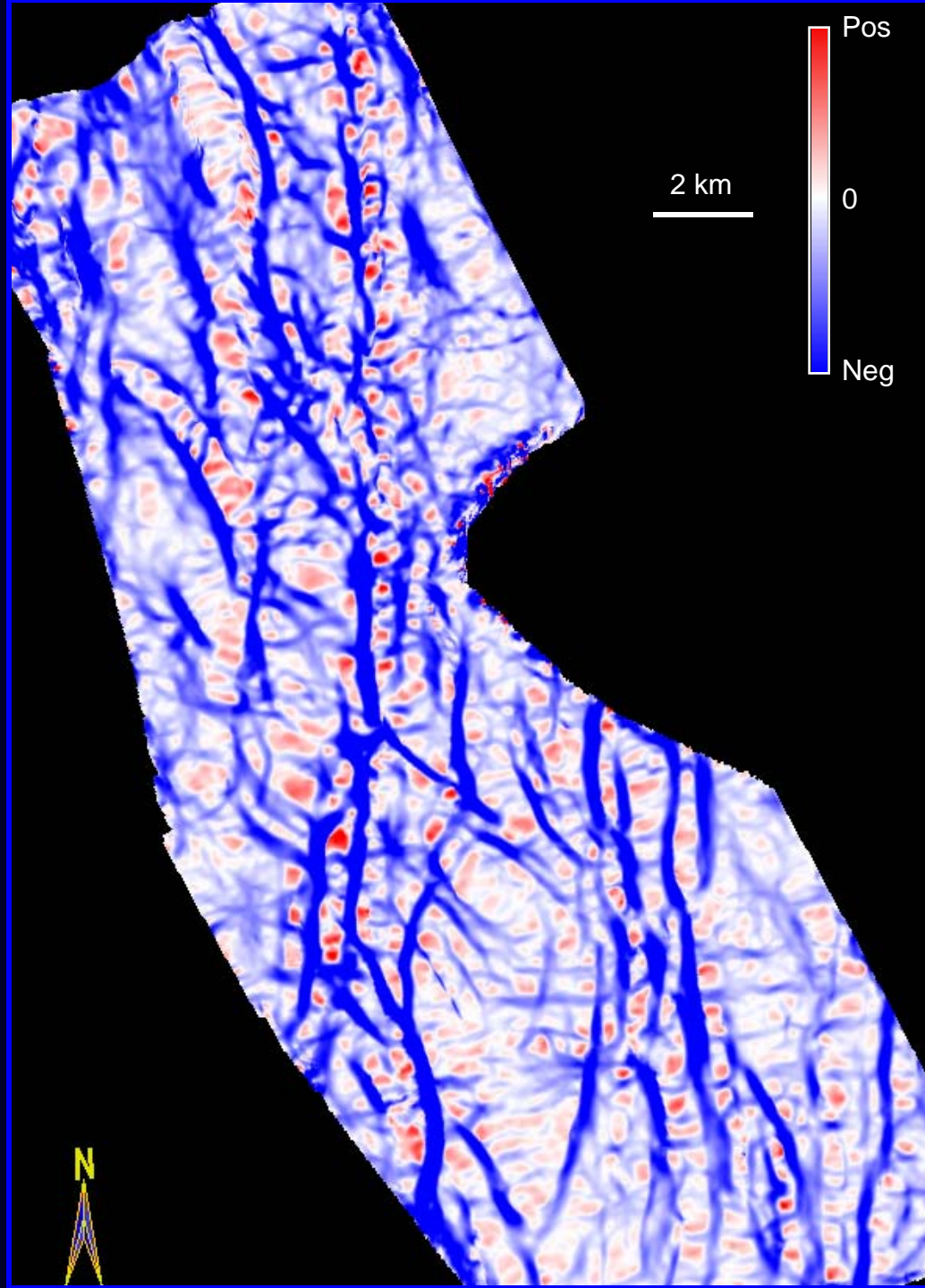
Horizon slice through the
coherence volume

*Data courtesy: Arcis
Corporation, Calgary*



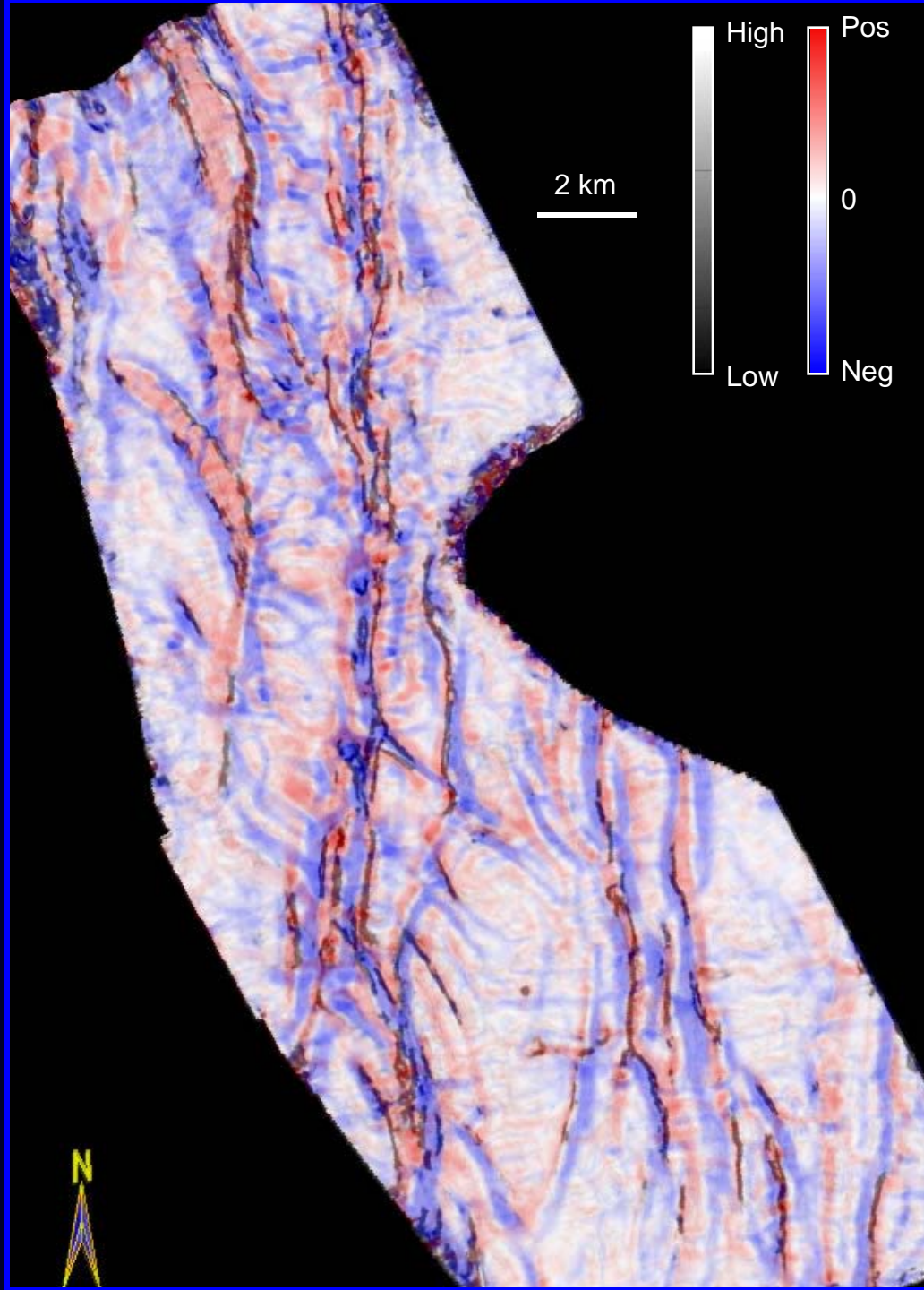
Horizon slice through the
most-positive curvature
volume

*Data courtesy: Arcis
Corporation, Calgary*



Horizon slice through the
most-negative curvature
volume

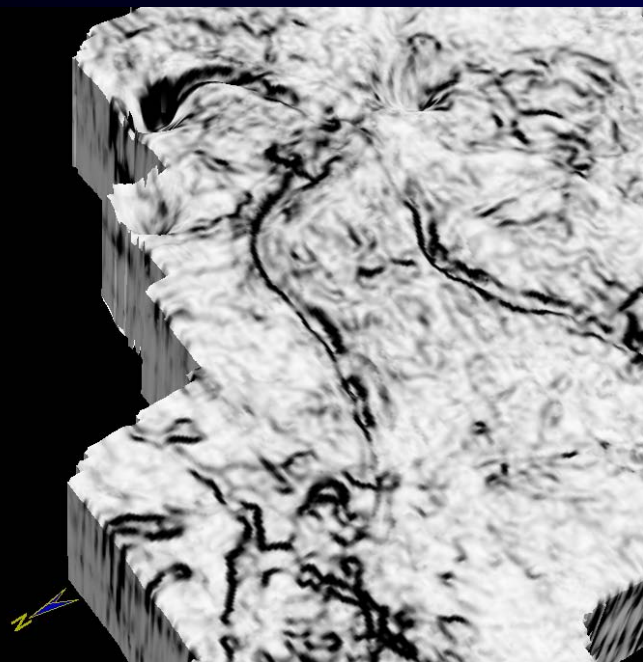
*Data courtesy: Arcis
Corporation, Calgary*



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

*Data courtesy: Arcis
Corporation, Calgary*

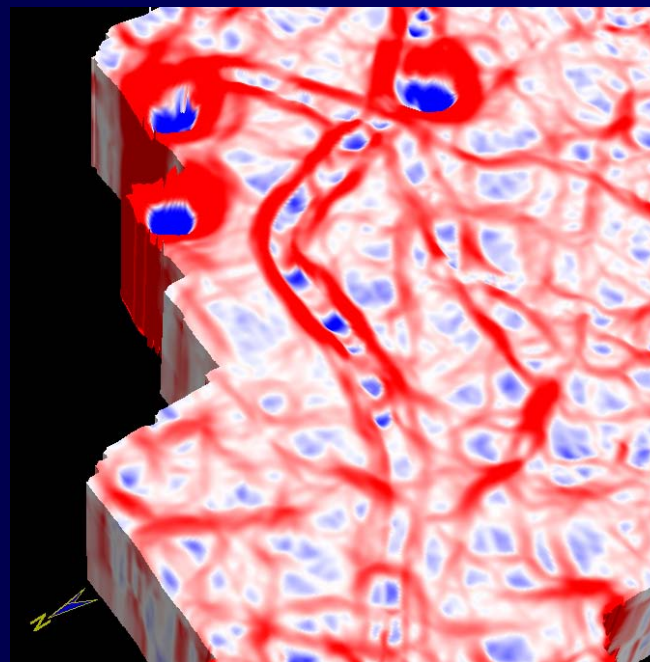
(a)



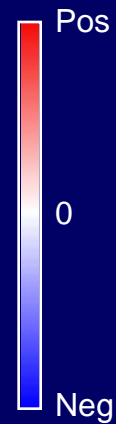
Strat_slice through the coherence volume



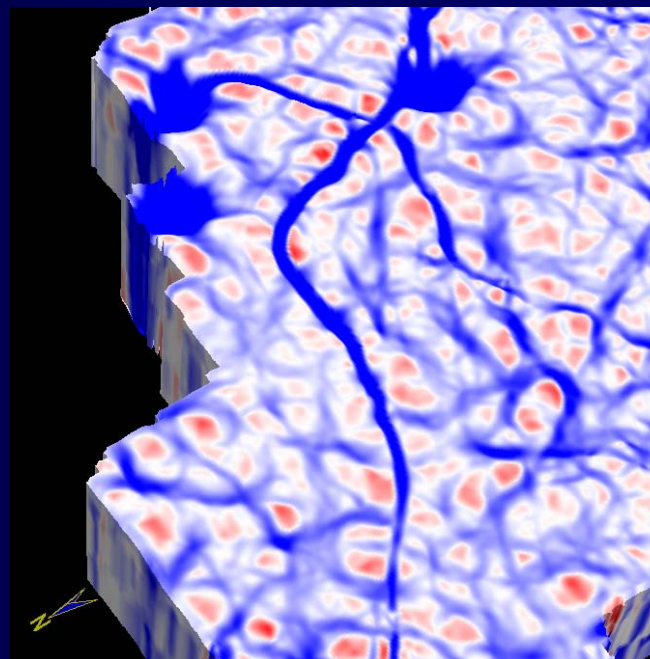
(b)



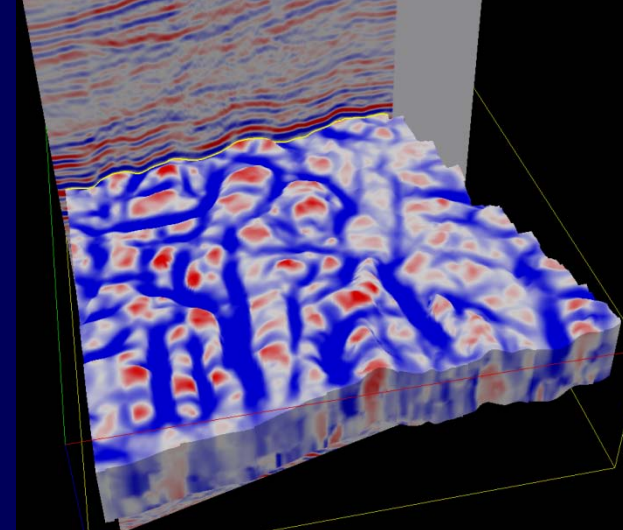
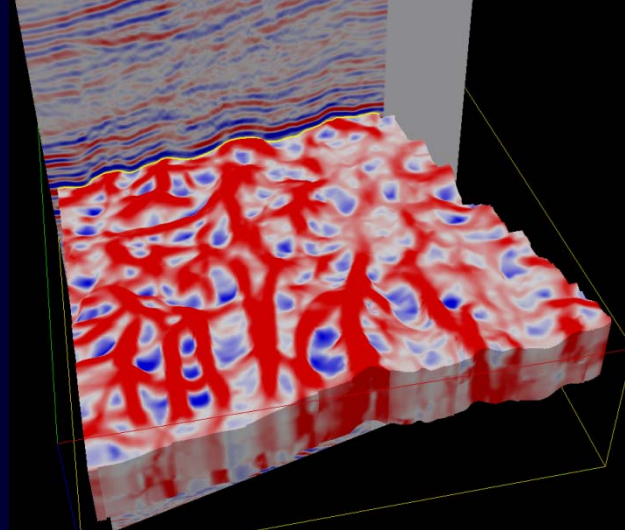
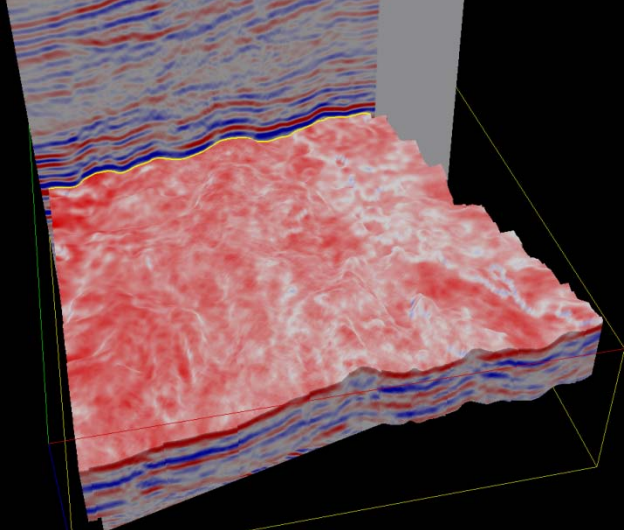
Strat slice through the most-positive curvature volume



(c)



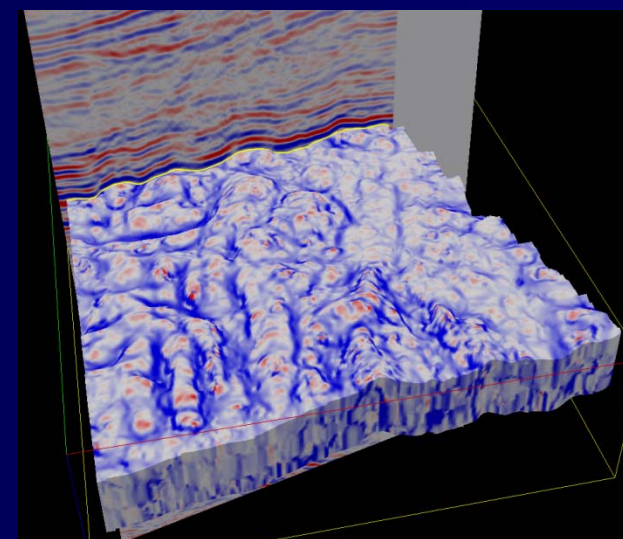
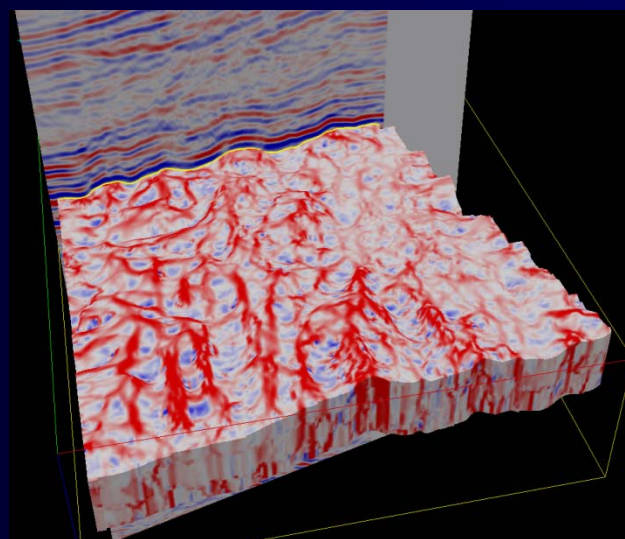
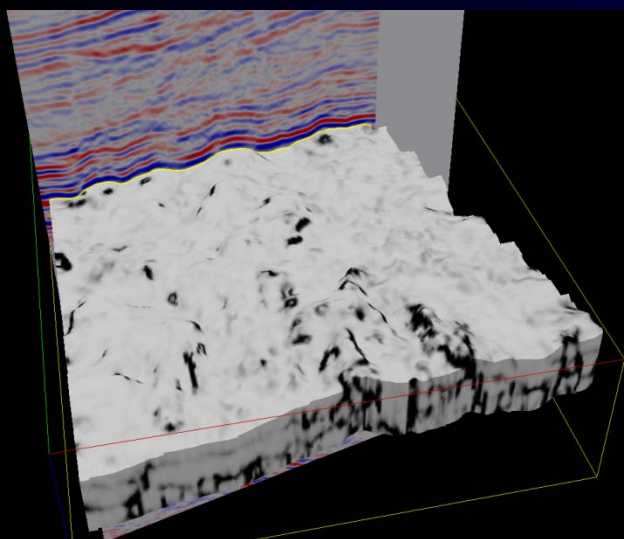
Strat slice through the most-negative curvature volume



(a) Seismic amplitude

(c) Most-positive curvature (long-wavelength)

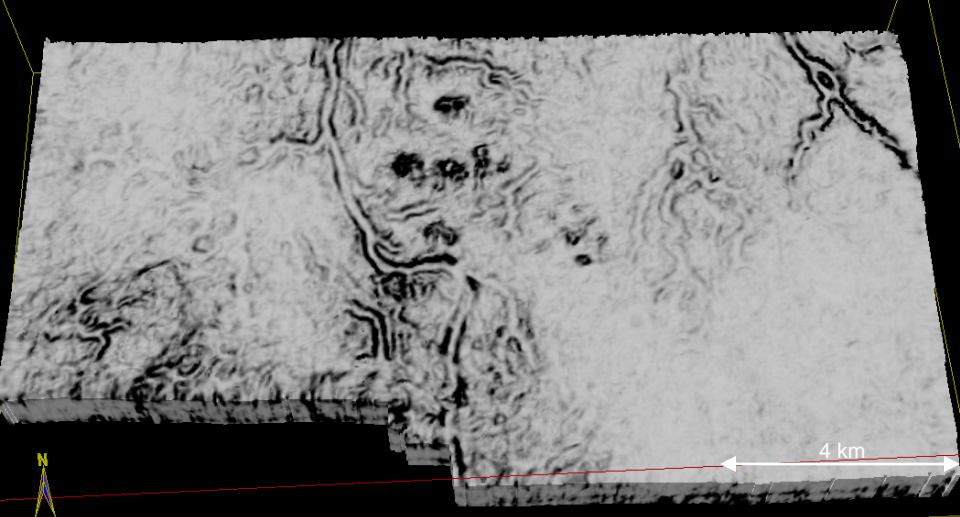
(d) Most-negative curvature (long-wavelength)



(b) Coherence

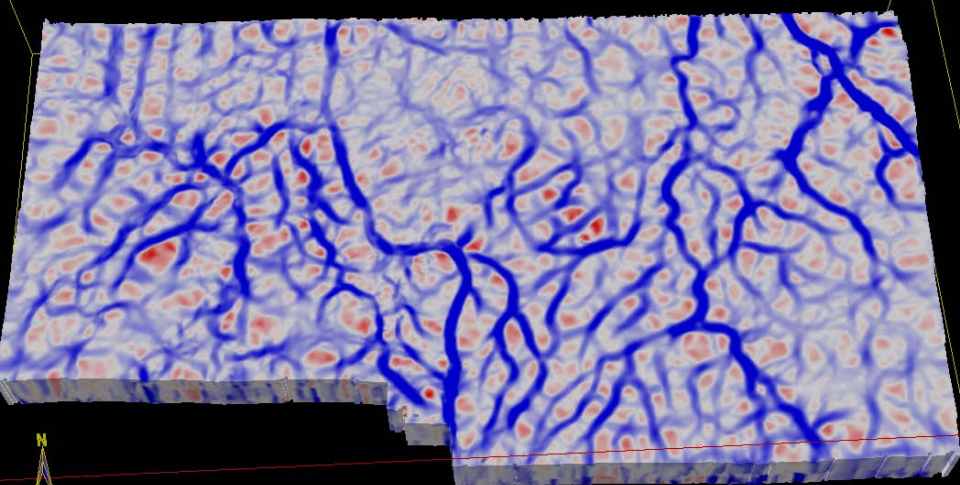
(e) Most-positive curvature (short-wavelength)

(f) Most-negative curvature (short-wavelength)



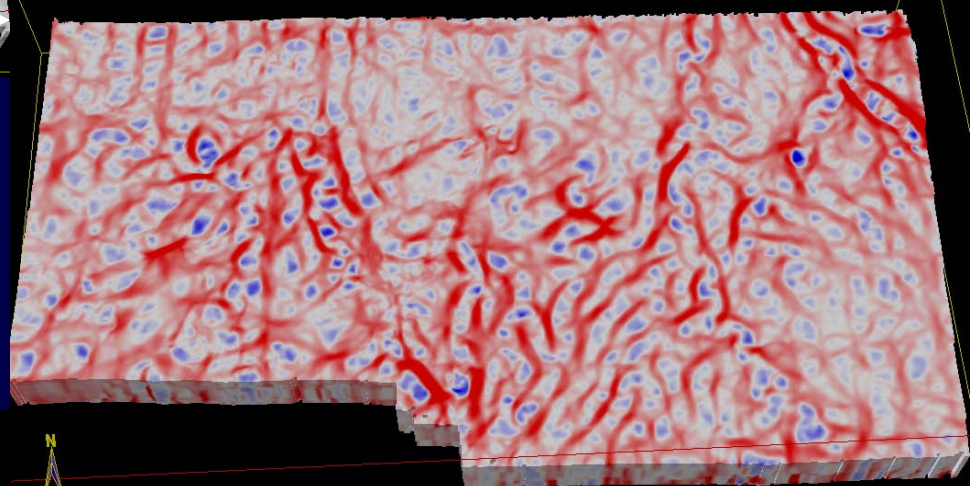
Low  High

Most-positive curvature



Neg  Pos

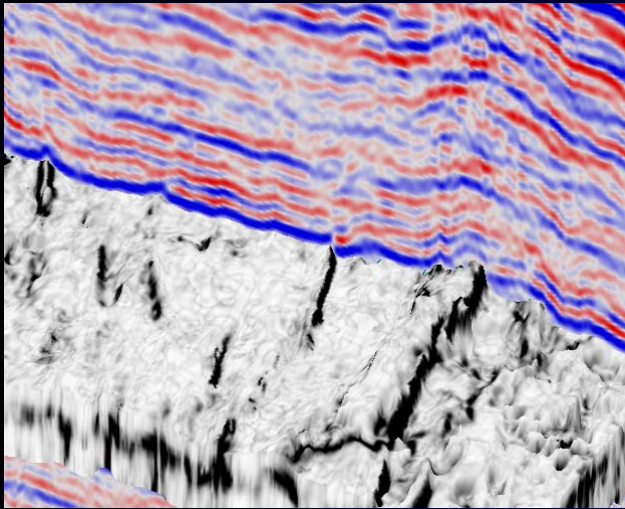
Coherence



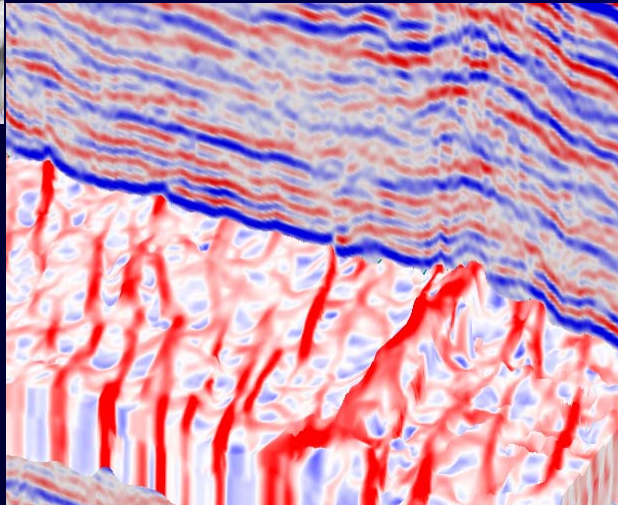
Neg  Pos

Most-negative curvature

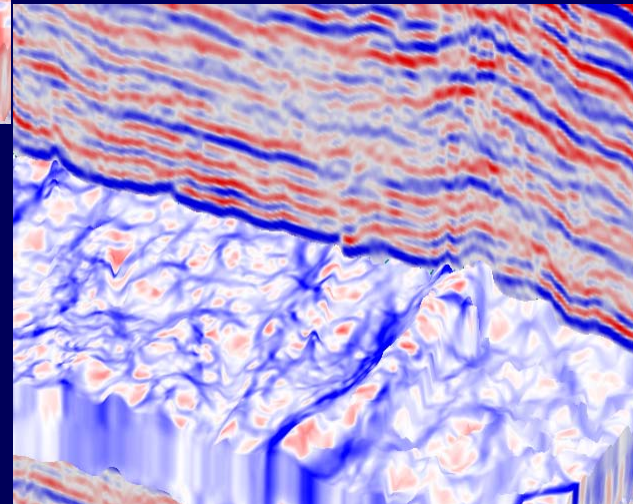
Chair displays



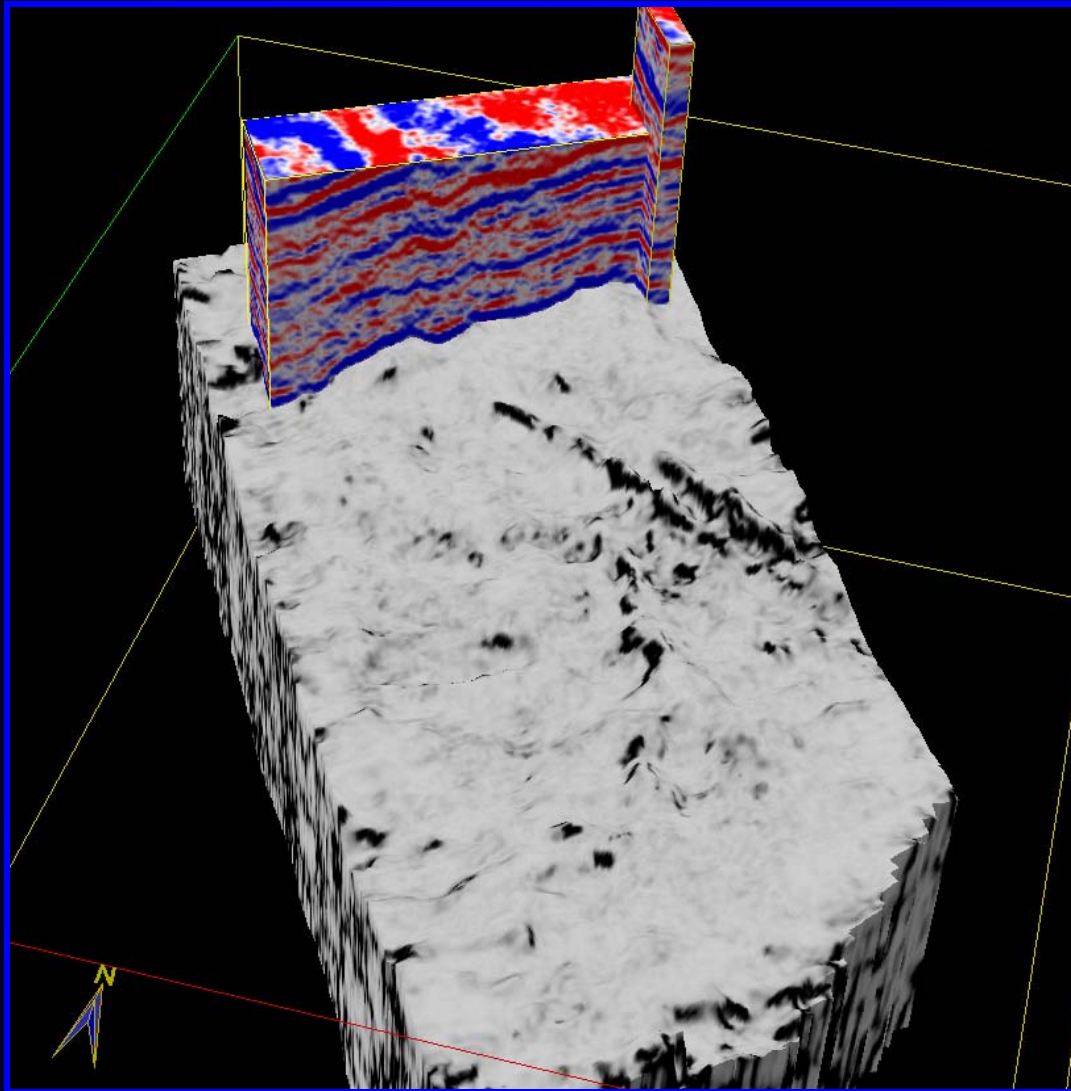
Coherence



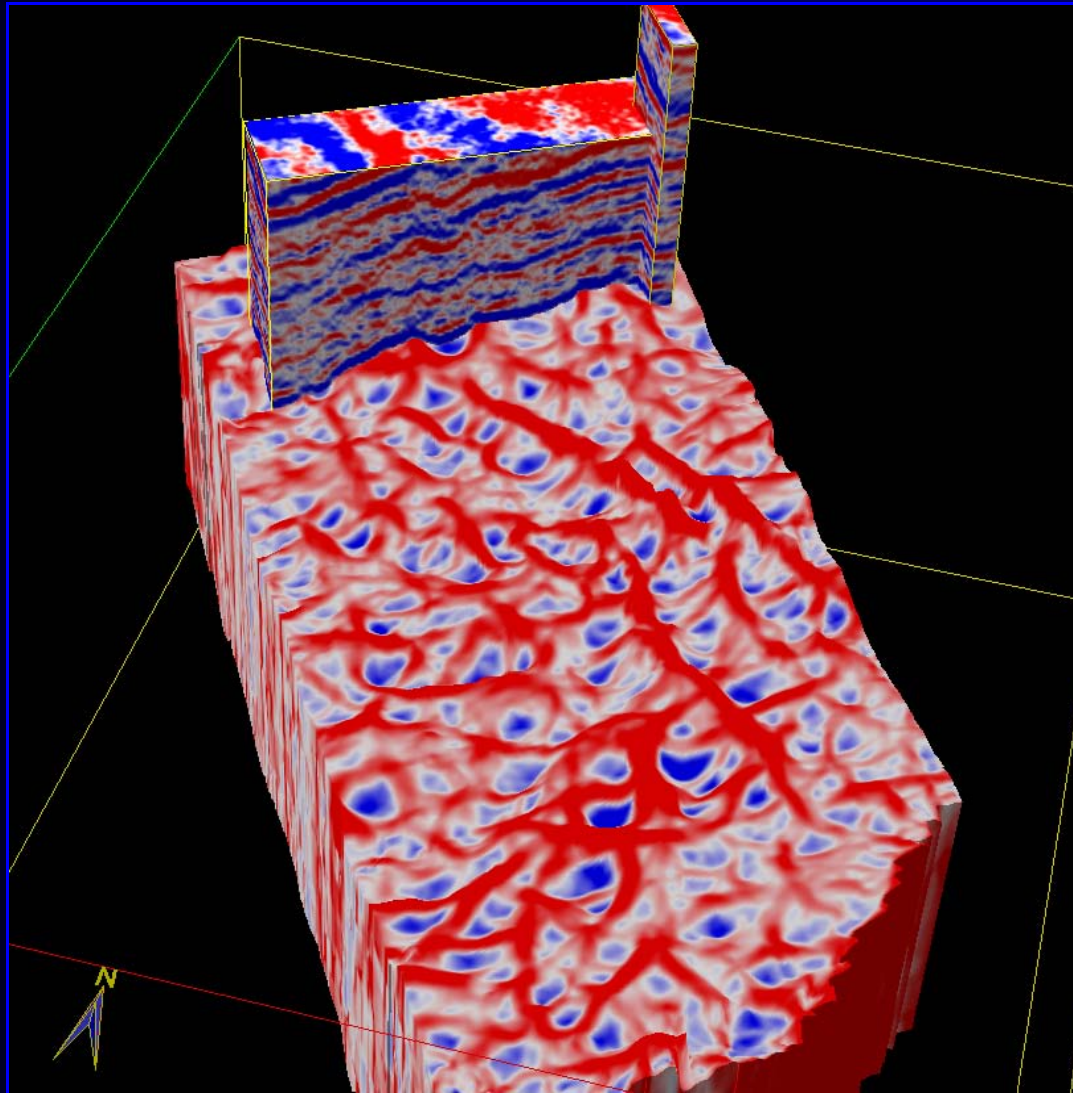
Most-positive curvature



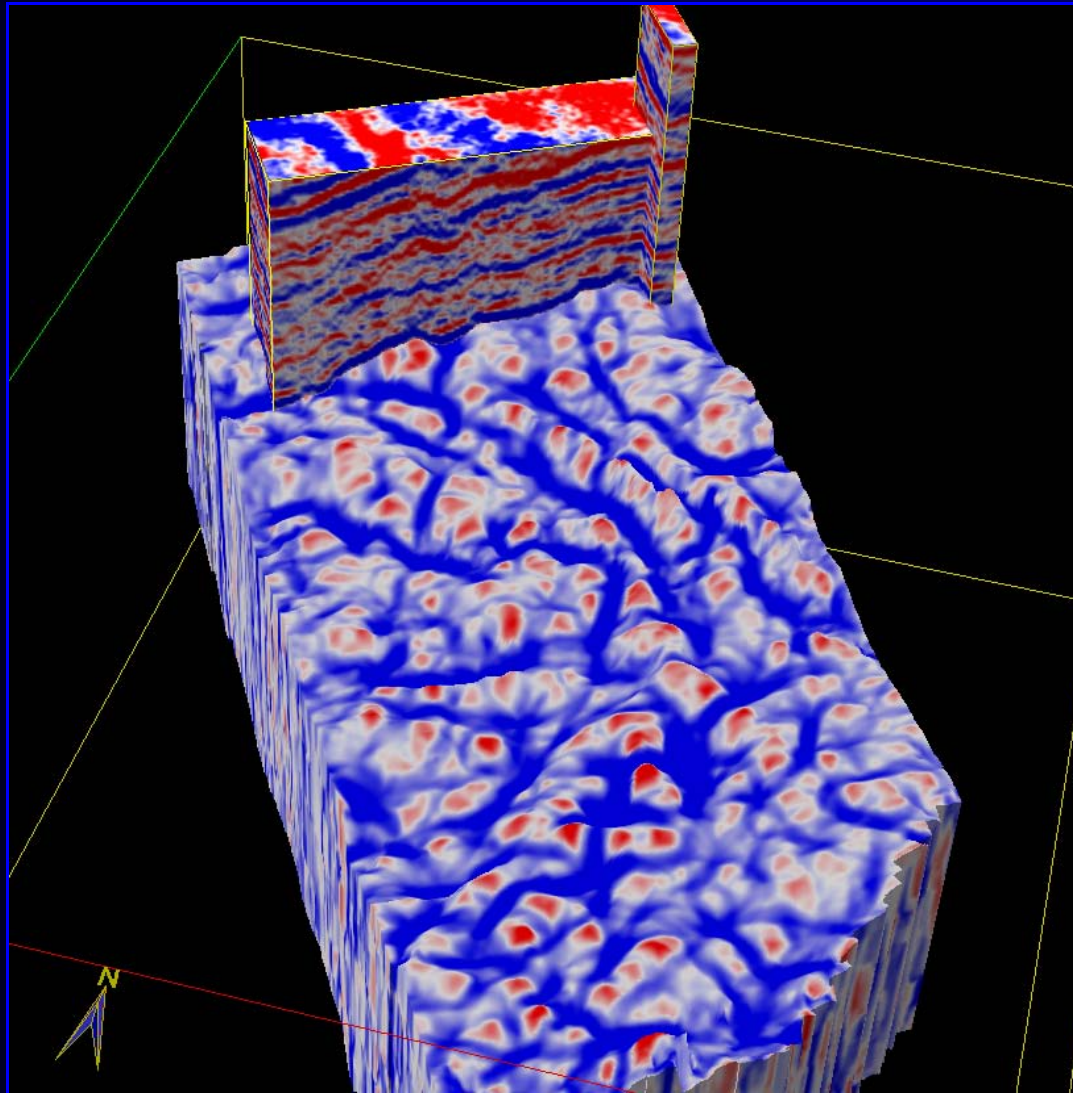
Most-negative curvature



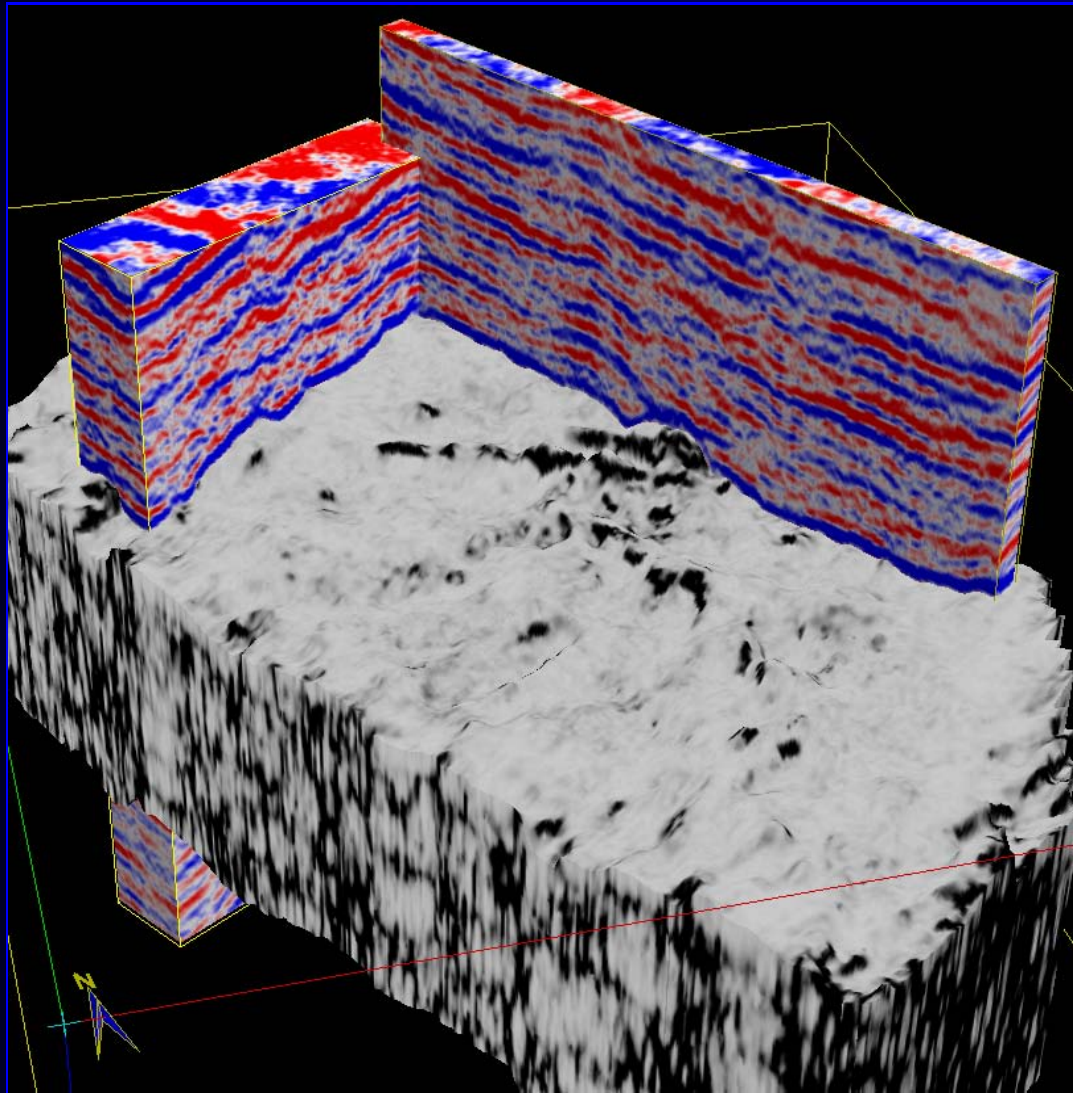
A seismic sub-cube intersecting the coherence strat-cube



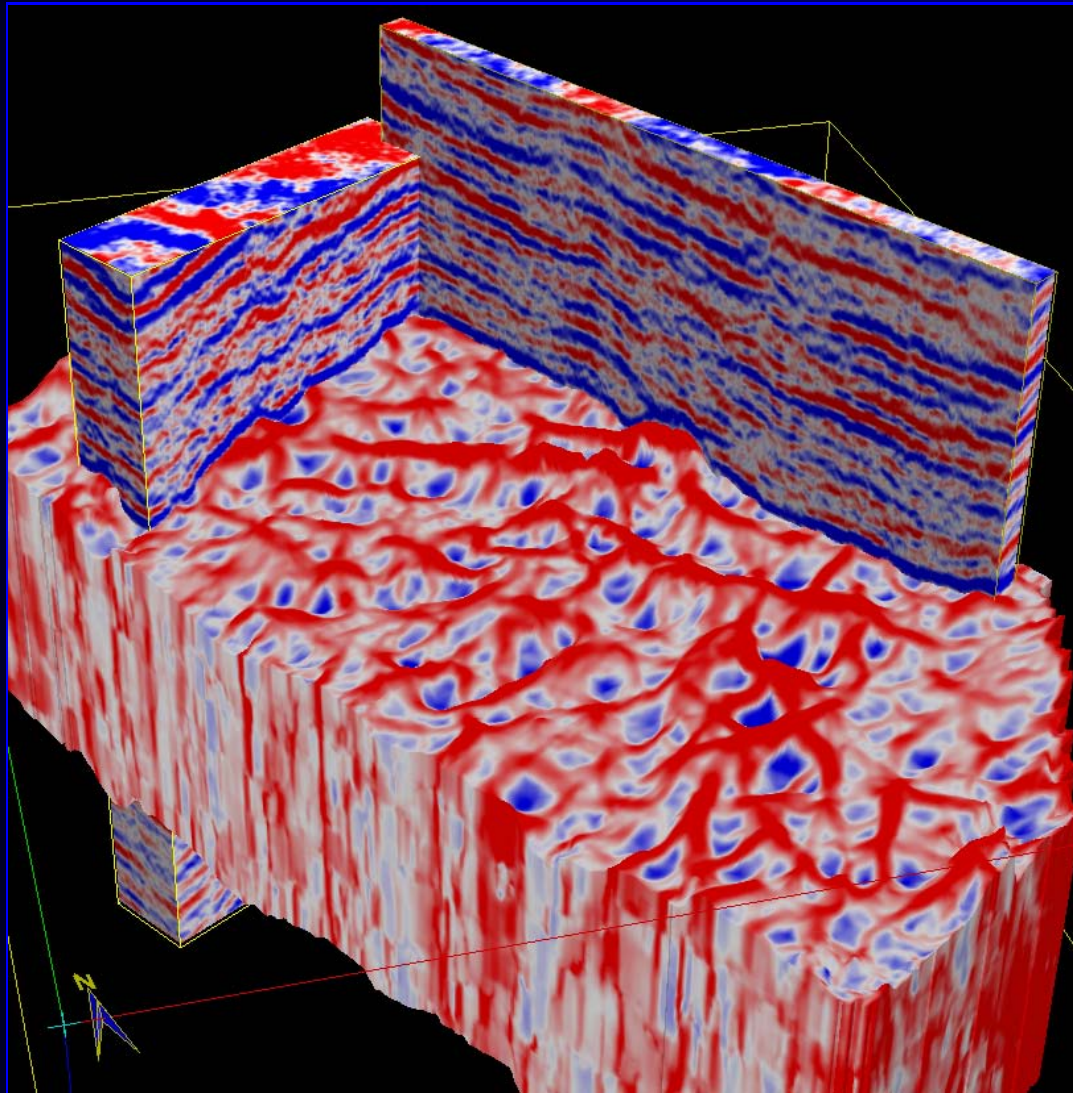
A seismic sub-cube intersecting the most-positive curvature strat-cube



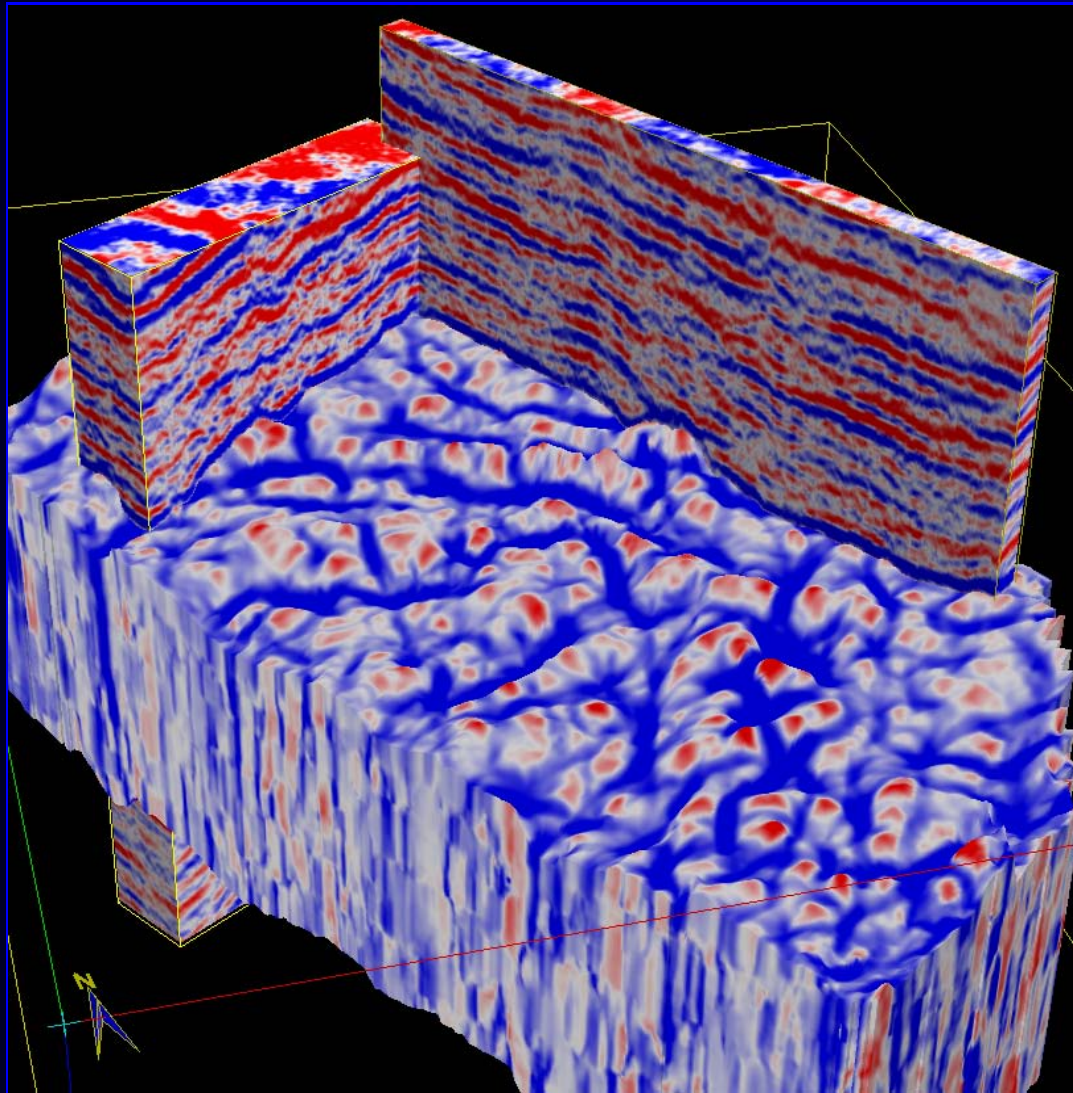
A seismic sub-cube intersecting the most-negative curvature strat-cube



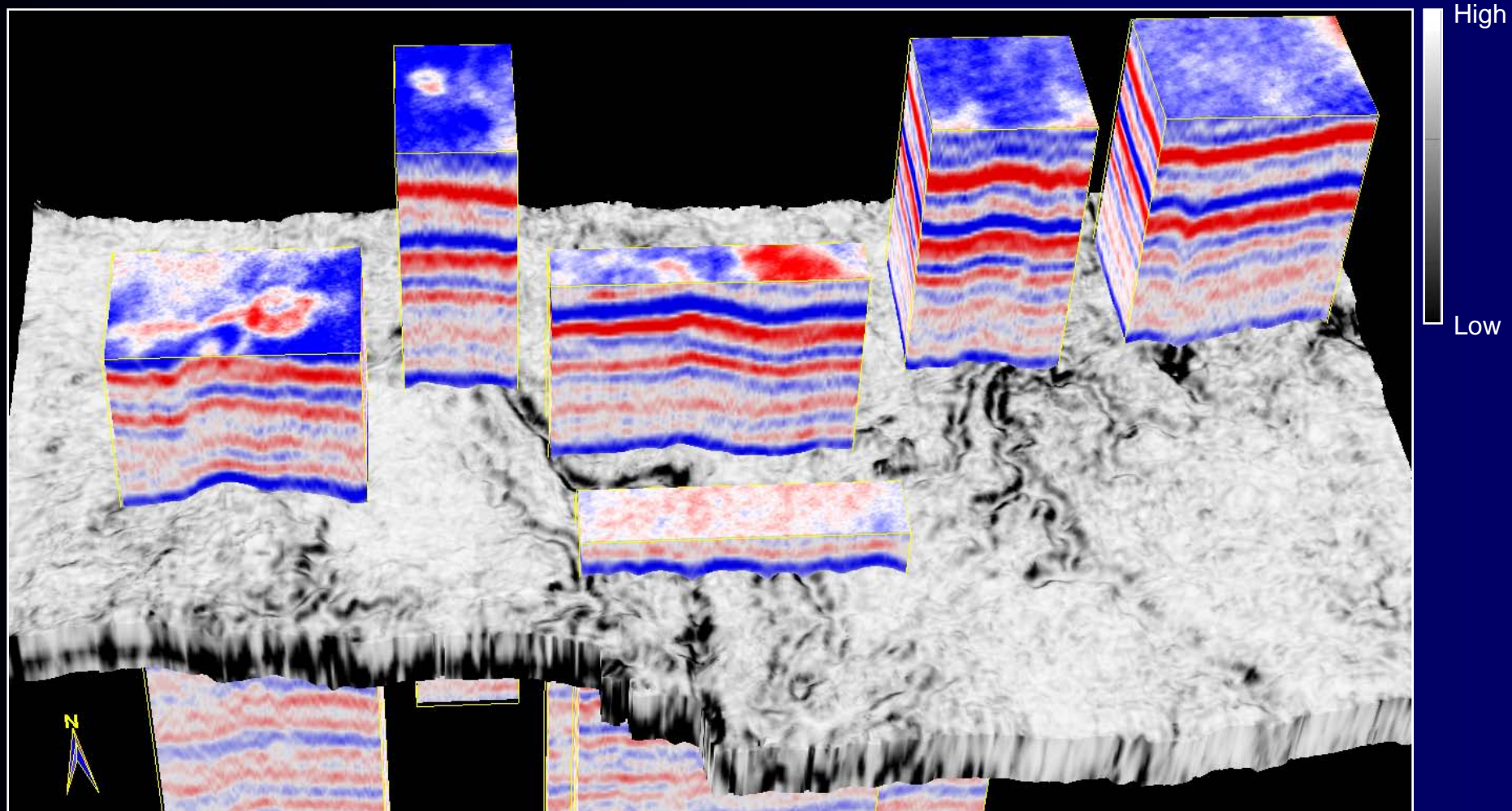
A seismic sub-cube intersecting the coherence strat-cube



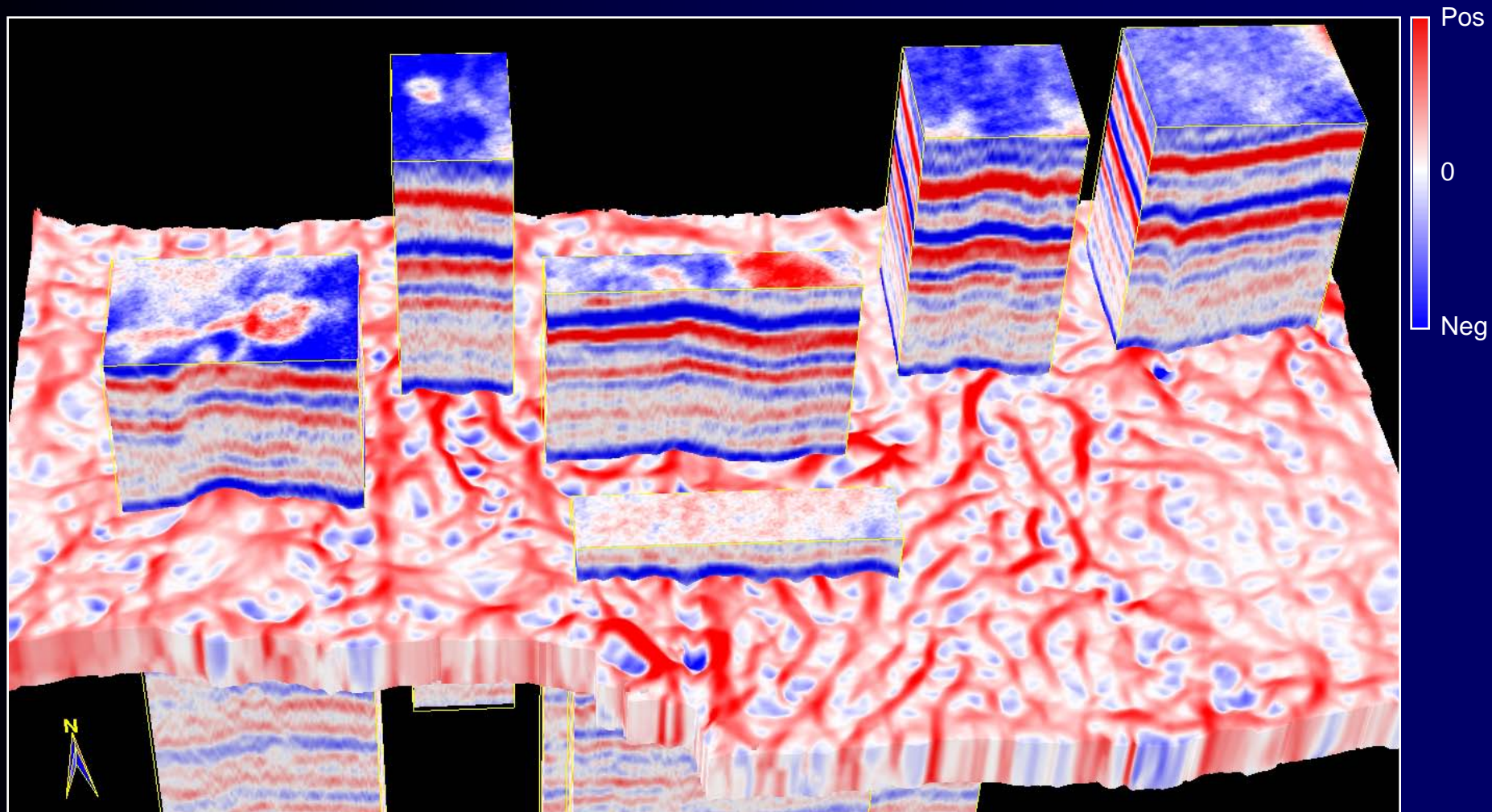
A seismic sub-cube intersecting the most-positive curvature strat-cube



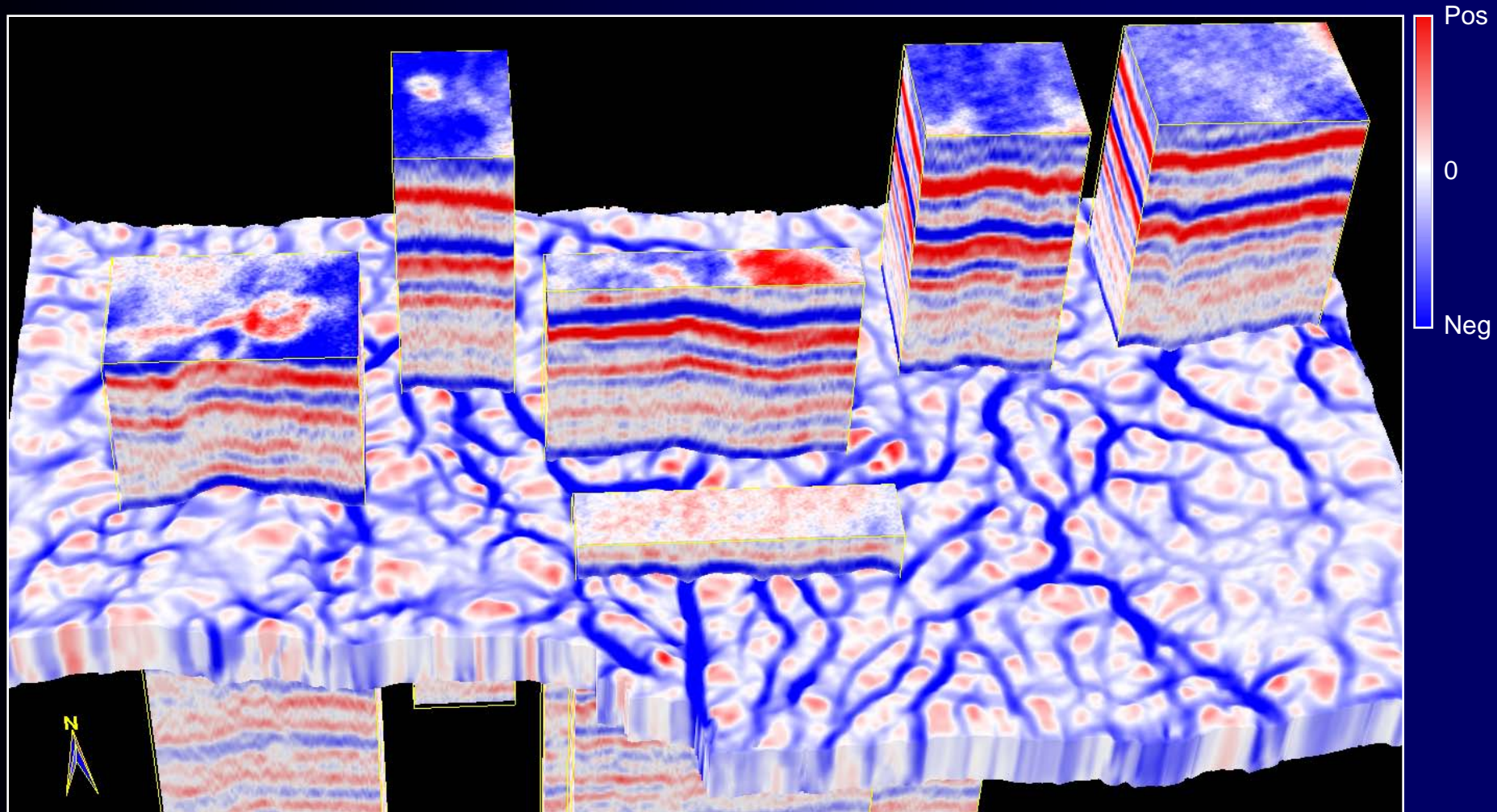
A seismic sub-cube intersecting the most-negative curvature strat-cube



Data courtesy: Arcis Corporation, Calgary

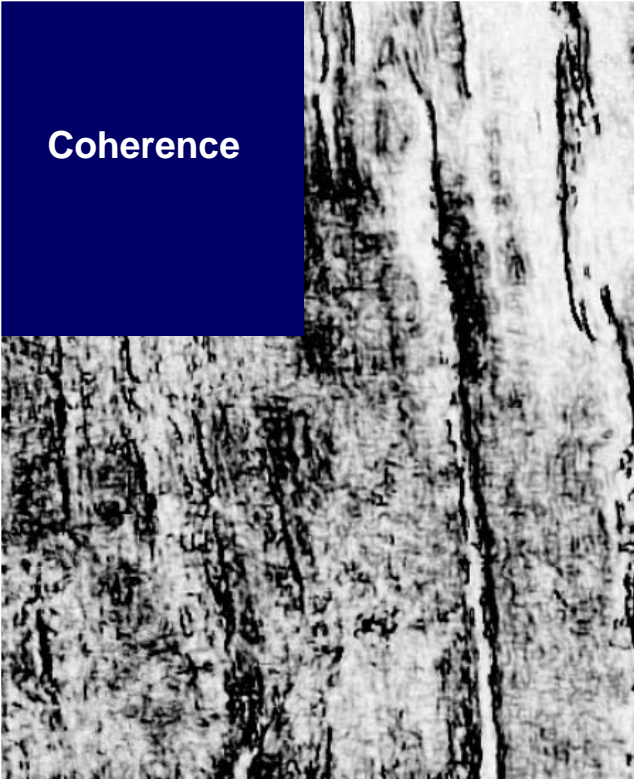


Data courtesy: Arcis Corporation, Calgary

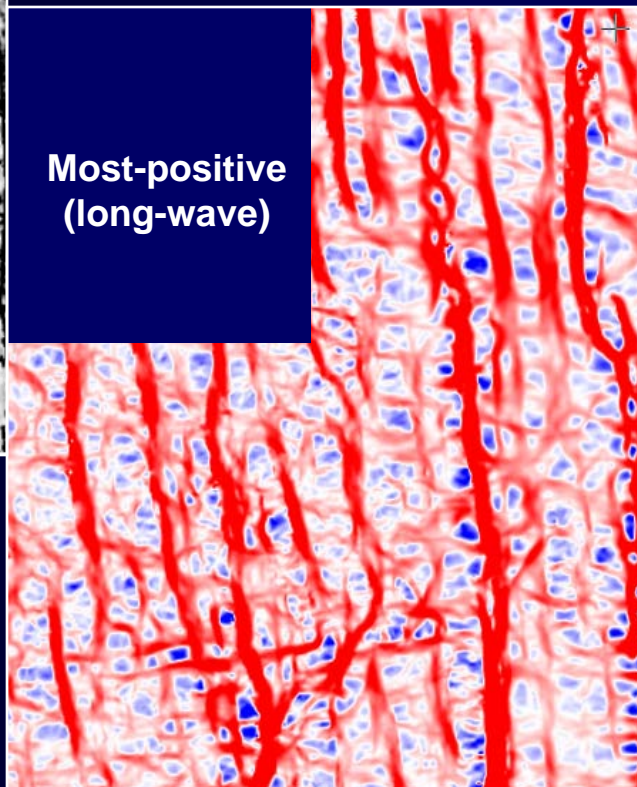


Data courtesy: Arcis Corporation, Calgary

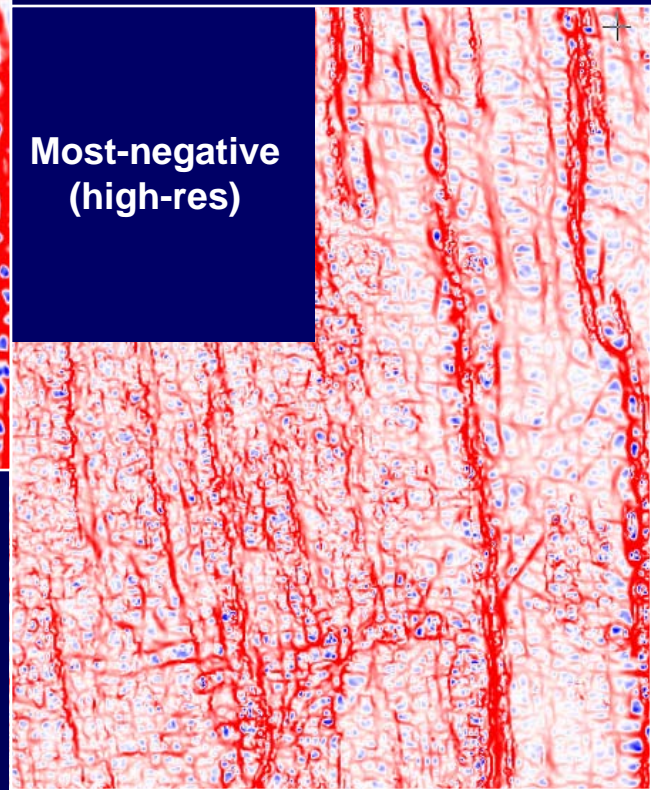
Coherence



**Most-positive
(long-wave)**

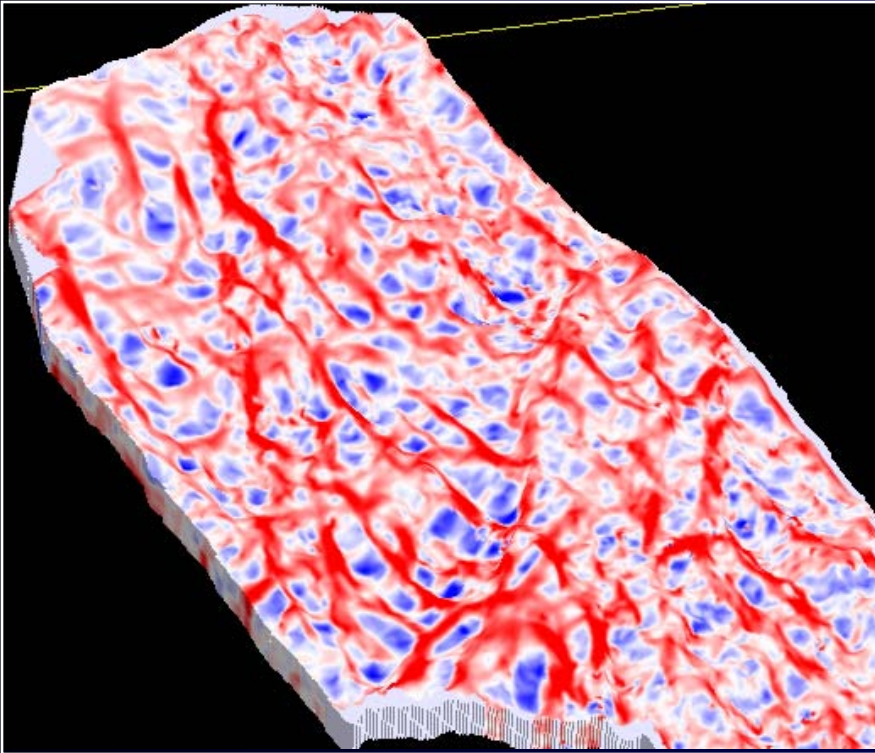


**Most-negative
(high-res)**

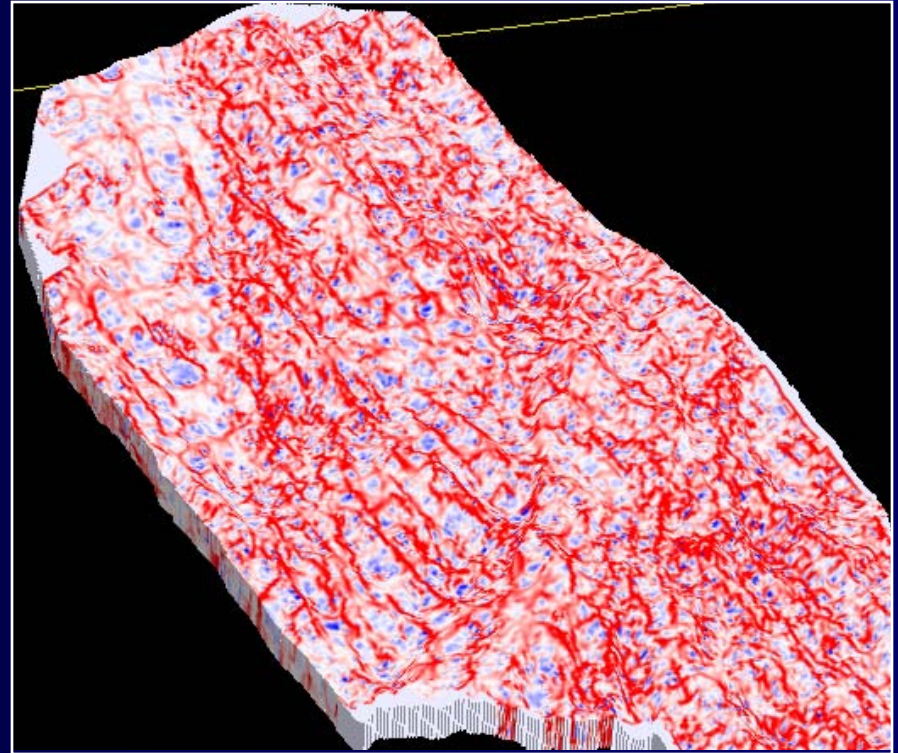


Time slice 1160 ms

Strat-slices

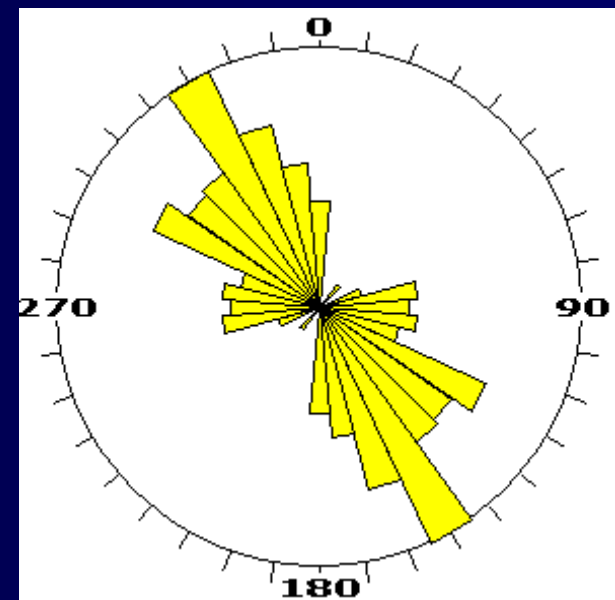
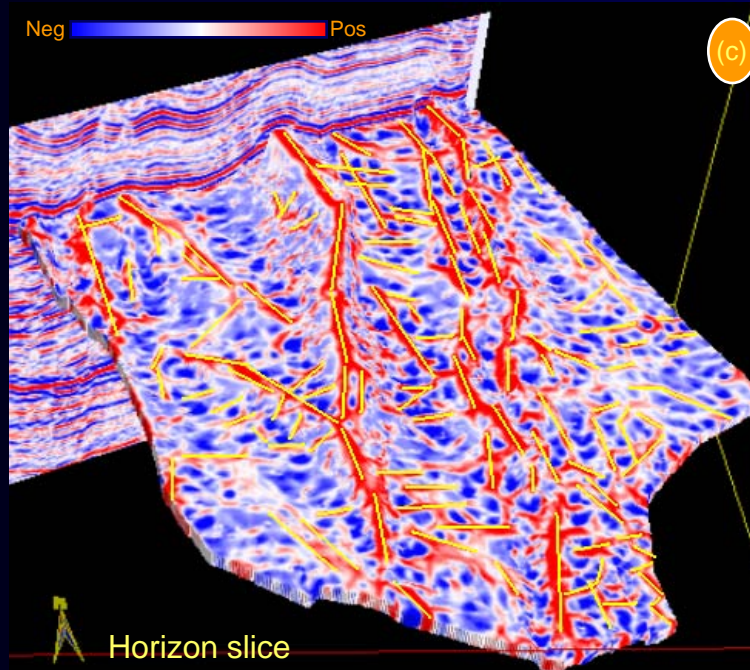
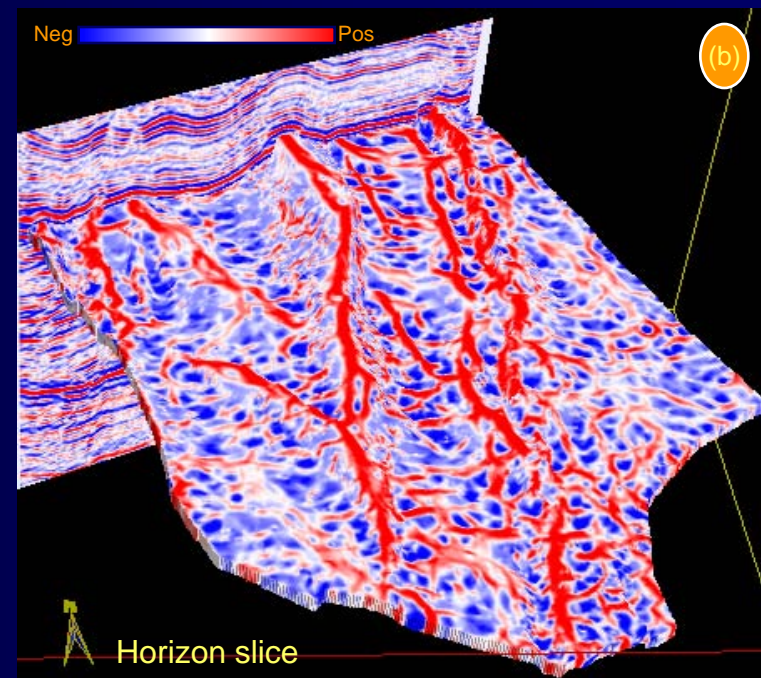
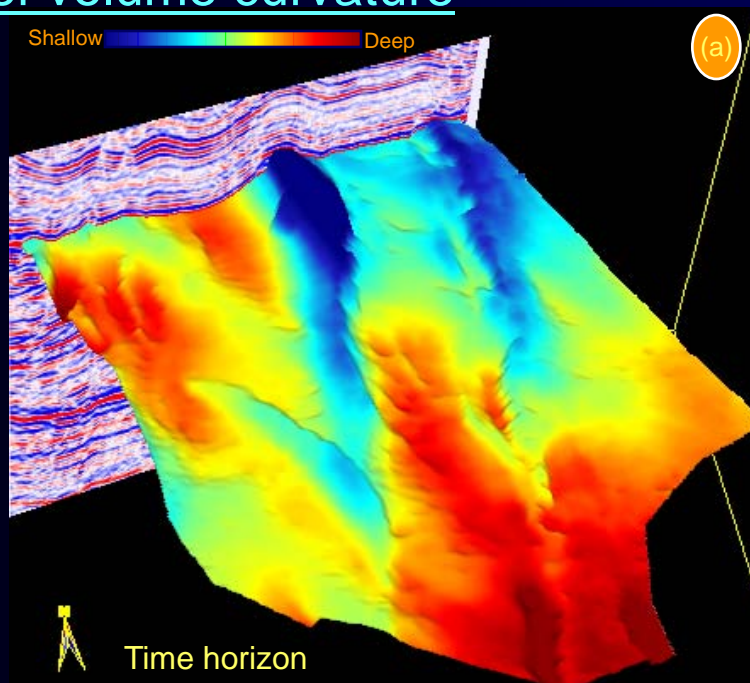


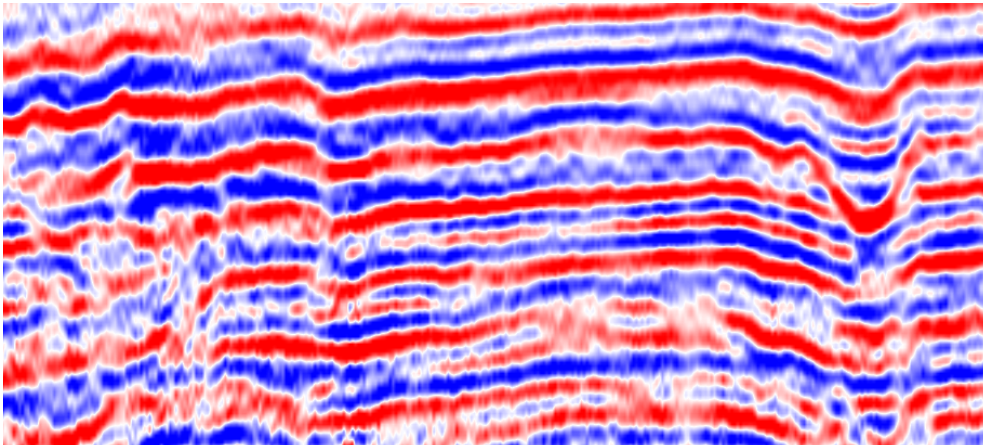
Most-positive curvature
(Long wavelength)



Most-positive curvature
(High resolution)

Calibration of volume curvature



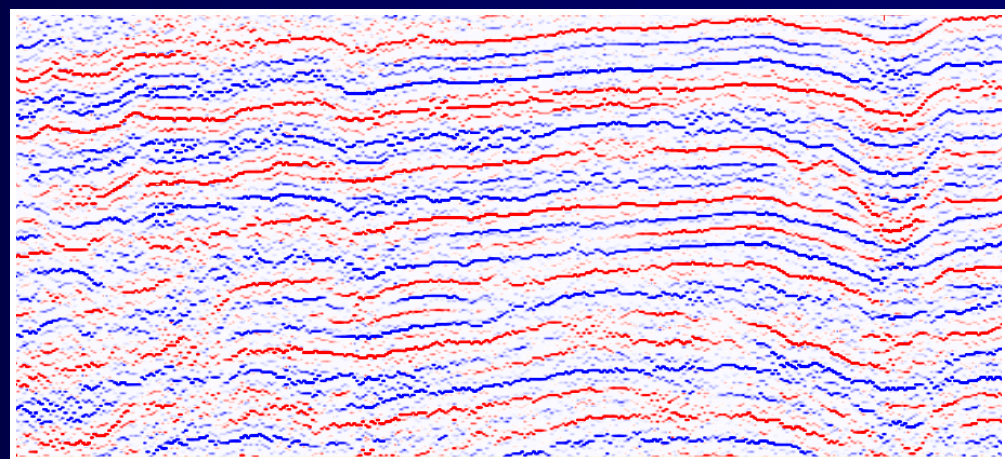


250 ms

(b)

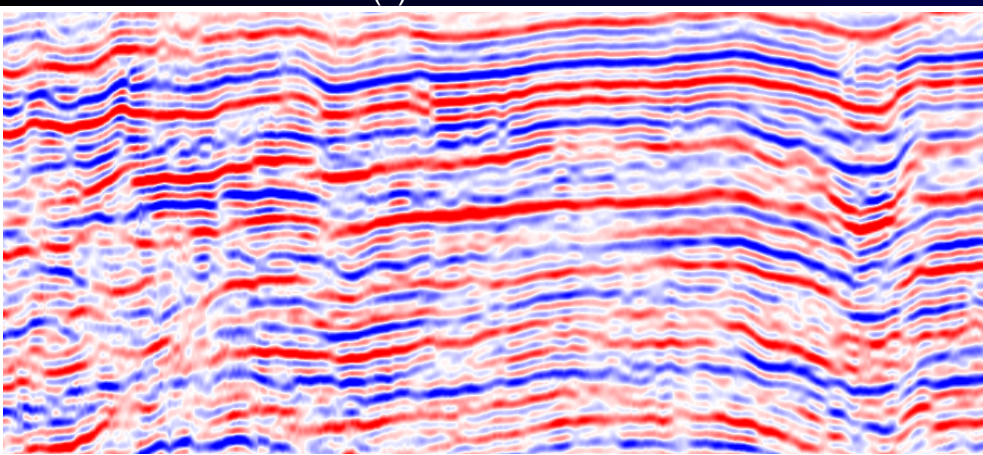
Seismic

(a)



(c)

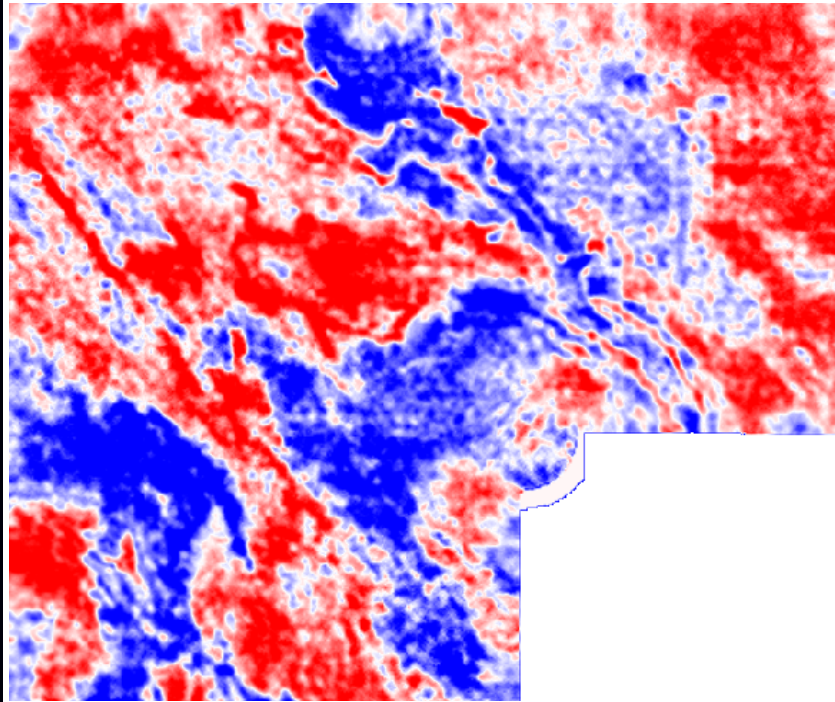
Thin-bed reflectivity



Reflectivity with a bandpass wavelet (high end 120 Hz)

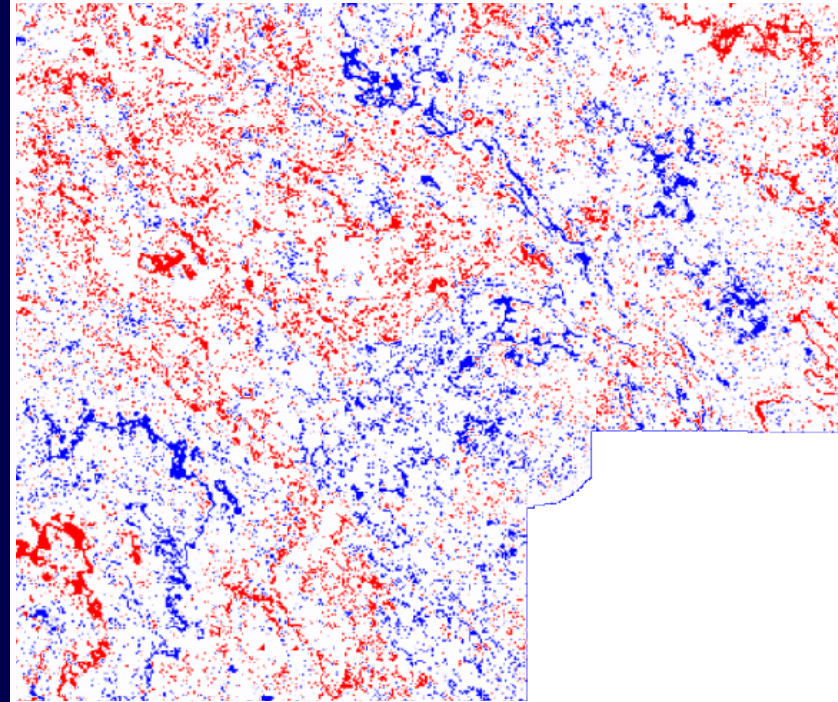
Data courtesy: Arcis Corporation, Calgary

(a)



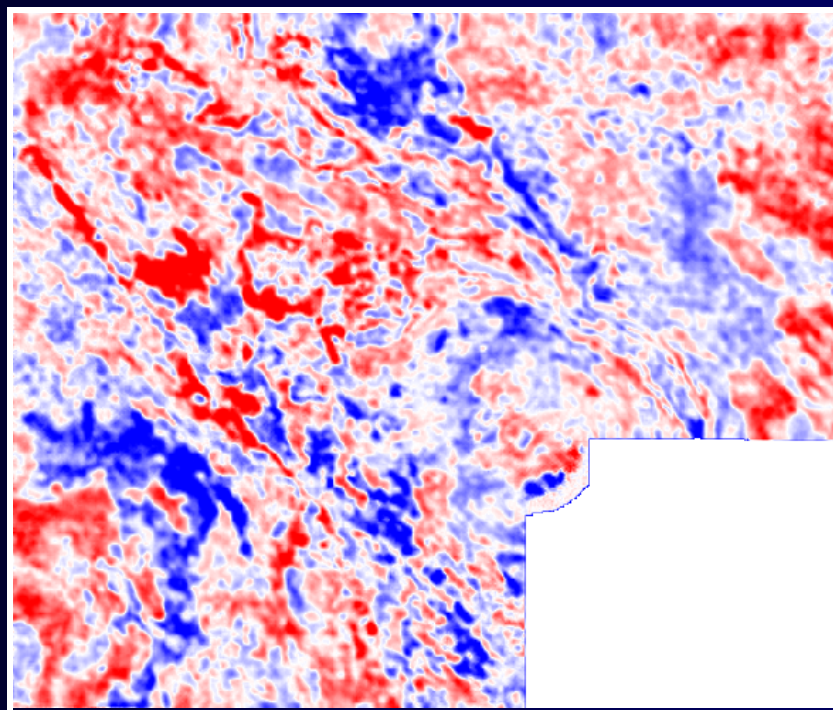
Seismic

(b)



Thin-bed
reflectivity

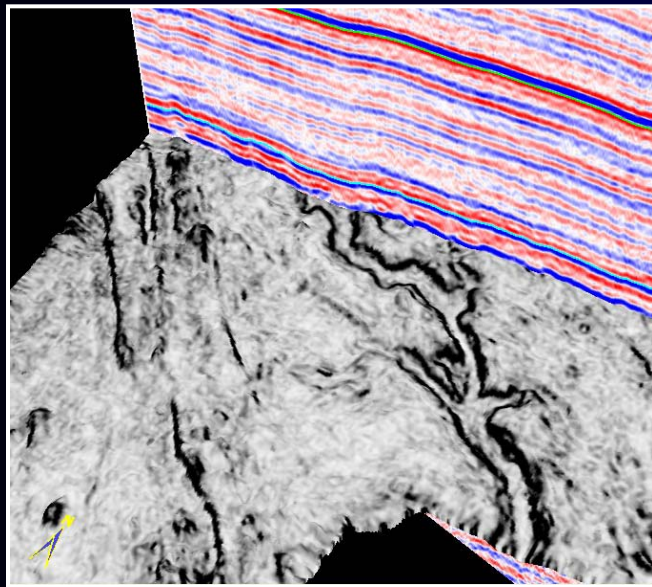
(c)



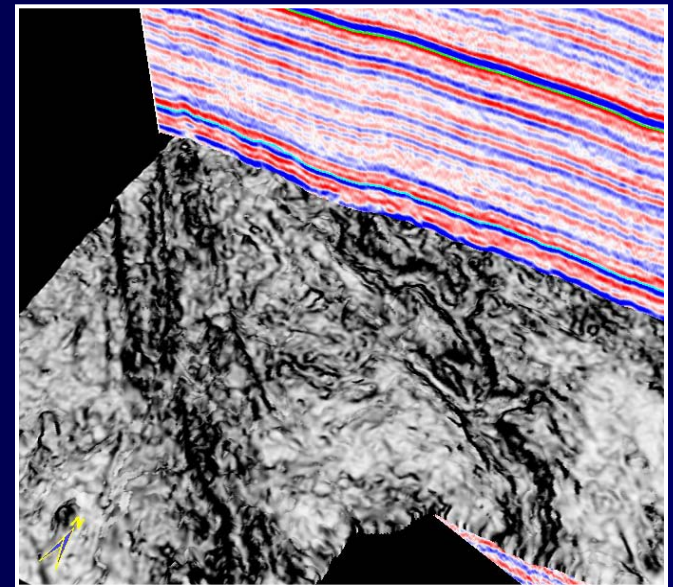
Reflectivity with a bandpass
wavelet (high end 120 Hz)

Time slices at 1500 ms

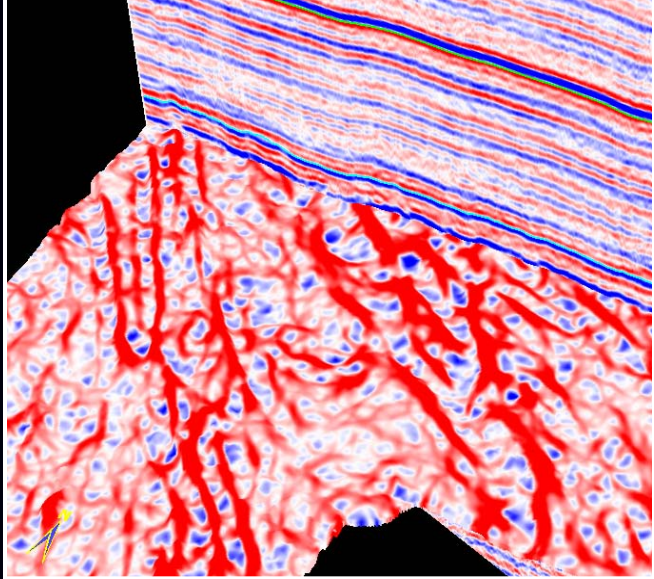
*Data courtesy: Arcis
Corporation, Calgary*



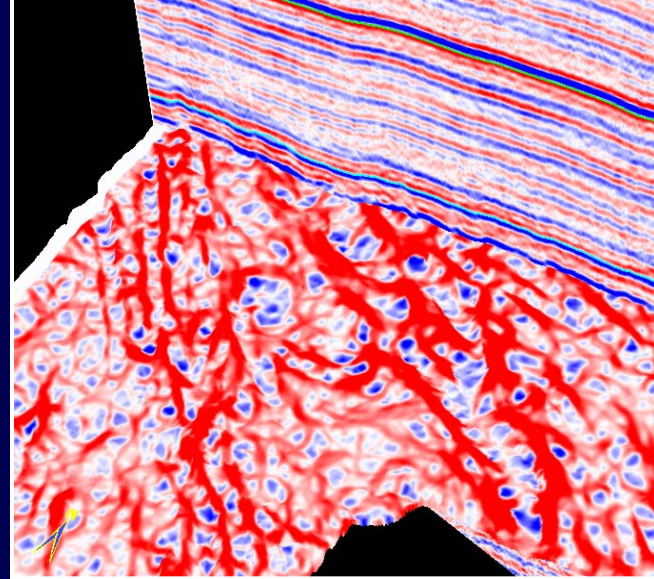
Coherence on the input volume



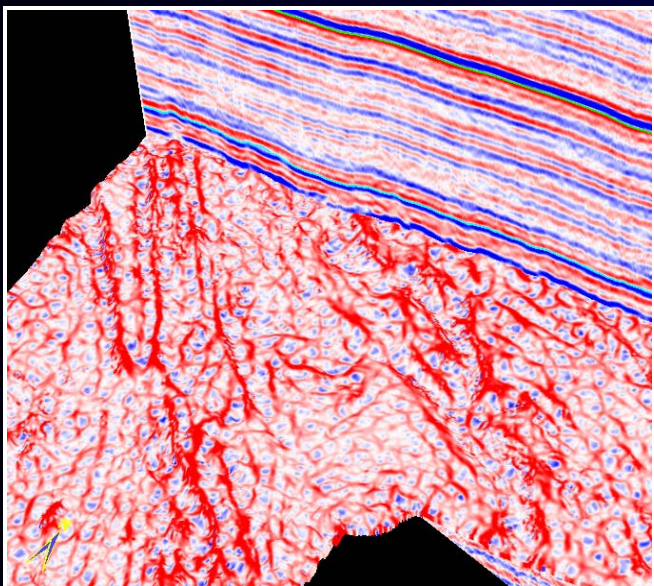
Coherence on the frequency-enhanced volume



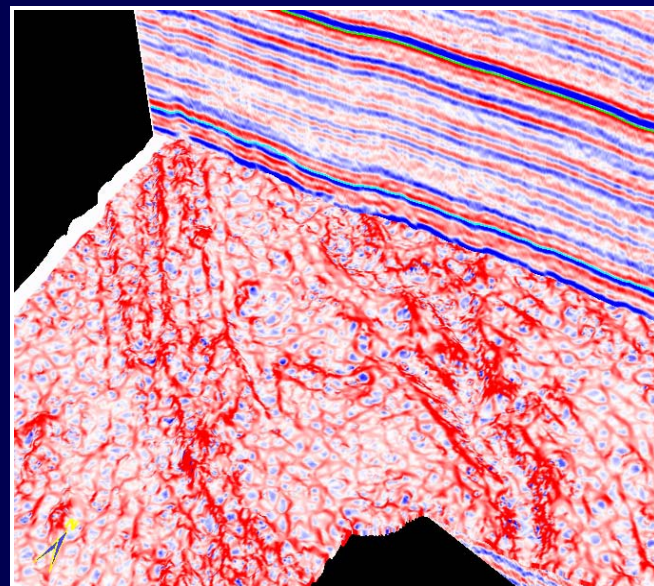
Most-positive curvature on the input volume



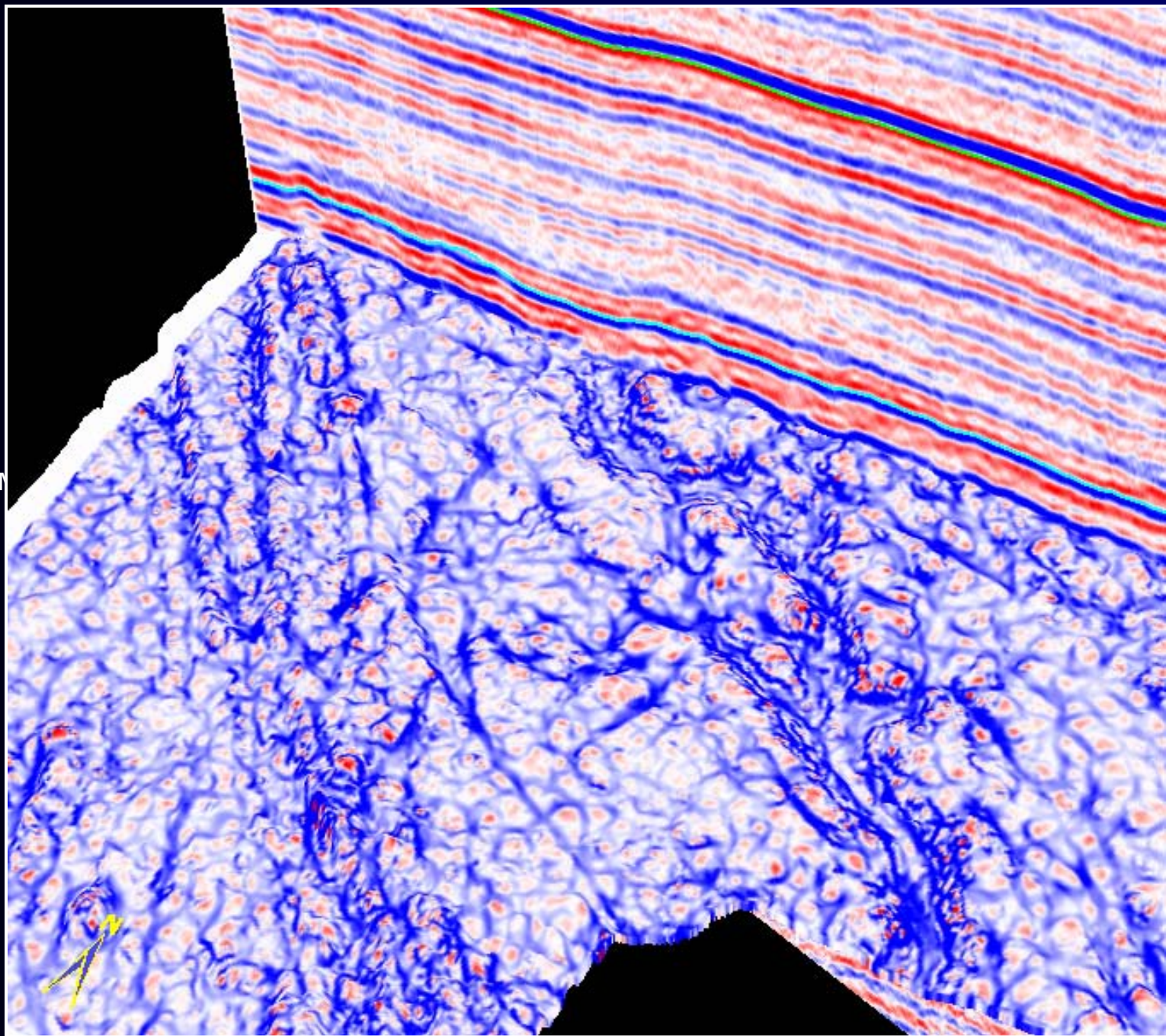
Most-positive curvature on the input volume with thin-bed reflectivity run on it and then convolved with a wavelet of high-end bandpass of 120 Hz



Most-positive curvature (short-wavelength) on the input volume



Most-positive curvature (short-wavelength) on the input volume with thin-bed reflectivity run on it and then convolved with a wavelet of high-end bandpass of 120 Hz



put volume
ed with a

Conclusions

1. Conditioning of data is beneficial for attribute computation. Noise can be suppressed by iteratively running spatial filtering on horizon surfaces or structure-oriented filtering (principal component).
2. Most-positive and most negative curvature offers better interpretation of subtle fault detail than other attributes.
3. Curvature attributes are a useful set of attributes that provide images of structure and stratigraphy. They complement those seen by the well-accepted coherence algorithms.
4. The orientations of the fault/fracture lineaments interpreted on curvature displays can be combined in the form of rose diagrams, which in turn can be compared with similar diagrams obtained from image logs to gain confidence in calibration.

References

Al-Dossary, S., and K.J. Marfurt, 2006, 3-D volumetric multispectral estimates of reflector curvature and rotation: *Geophysics*, v. 71/5, p. P-41-P51.

Hart, B.S., and R. Pearson, 2002, 3-D seismic horizon-based approaches to fracture-swarm sweet spot definition in tight-gas reservoirs: *The Leading Edge*, v. 21/1, p. 28-35. doi: 10.1190/1.1445844.

Lisle, R.J., 1994, Detection of zones of abnormal strains in structures using Gaussian curvature analysis: *AAPG Bulletin*, v. 78/12, p. 1811-1819.

Roberts, A., 2001, Curvature attributes and their application to 3-D interpreted horizons: *First Break*, v. 19/2, p. 85-100.

THANK YOU