Structural Curvature versus Amplitude Curvature*

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Abstract

Seismic curvature attributes can enhance subtle information that may be difficult to see using attributes such as dip-magnitude and dip-azimuth. Recently, curvature attributes and associated interpretation workflows have been developed by a broad range of interpreters such that curvature computations have found their way into most commercial interpretation software packages. Initially introduced as 2D computations on picked seismic surfaces, curvature computations from volumetric estimates of inline and crossline dip components followed soon after. Volumetric curvature is generated by taking derivatives of volumetric estimates of reflector dip and azimuth that best represents the best single dip for each single sample in the volume. We refer to these calculations as structural curvature, as the calculations are carried out on reflector depth or time.

We can also compute curvature attributes using seismic amplitude and refer to such a computation as amplitude curvature. Horizon-based amplitude curvature is in the hands of most interpreters. First, we generate a horizon slice through a seismic amplitude, RMS amplitude, or impedance volume. Next, we compute the inline and crossline derivatives of this map. Computing derivatives of these gradients (or second derivatives of amplitude) gives us amplitude curvature. Such maps can often delineate the edges of bright spots, channels, and other stratigraphic features at any desired direction.

Volumetric estimates of reflector amplitude gradients are computed in small windows along previous estimates of structural inline and crossline dip. To minimize the negative impact of noise on such computations, we favor computing derivatives of the coherent component of the data using a covariance matrix and principal component analysis such as commonly used in structure-oriented filtering. For data processed with an amplitude-preserving sequence, amplitude variations are diagnostic of geologic information such as changes in porosity, thickness and /or lithology. We have found that the computation of curvature

on amplitude gradients furnishes higher level of lineament information that appears to be promising. The application of amplitude curvature to impedance images is particularly interesting where low-impedance, diagenetically-altered cracks can be nicely highlighted.

As with structural curvature, one can generate rose diagrams of the lineaments that can be compared with similar roses obtained from image logs.

References

Al-Dossary, S., and K.J. Marfurt, 2006, 3D volumetric multispectral estimates of reflector curvature and rotation: Geophysics, v. 71/5, p. P41-P51.

Chopra, S., 2001, Coherence technology evolves: Hart's E&P, v. 74/9, p. 49-50, 52.

Chopra, S., and K.J. Marfurt, 2007, Curvature attribute applications to 3D surface seismic data: The Leading Edge, v. 26/4, p. 404-414.

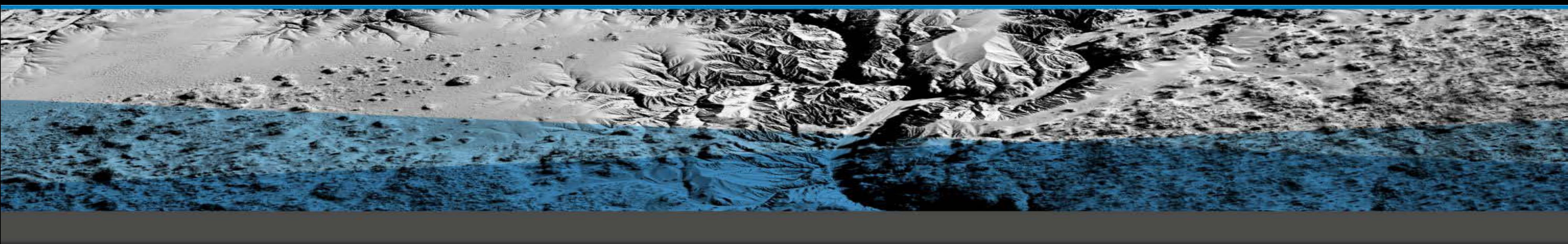
Marfurt, K.J., 2006, Robust estimates of 3D reflector dip and azimuth: Geophysics, v. 71/4, p. P29-P40.

Marfurt, K.J., and R.L. Kirlin, 2000, 3D broad-band estimates of reflector dip and amplitude: Geophysics, v. 65/1, p. 304-320.

Oliveros, R.B., and B.J. Radovich, 1997, Image-processing display techniques applied to seismic instantaneous attributes over the Gorgon gas field, North West Shelf, Australia: SEG Annual Meeting Expanded Technical Program Abstracts with Biographies, Society of Exploration Geophysicists, v. 16, p. 2064-2067.

Roberts, A., 2001, Curvature attributes and their application to 3D interpreted horizons: First Break, v. 19.2, p. 85-100.

Structural Curvature versus Amplitude Curvature



Satinder Chopra

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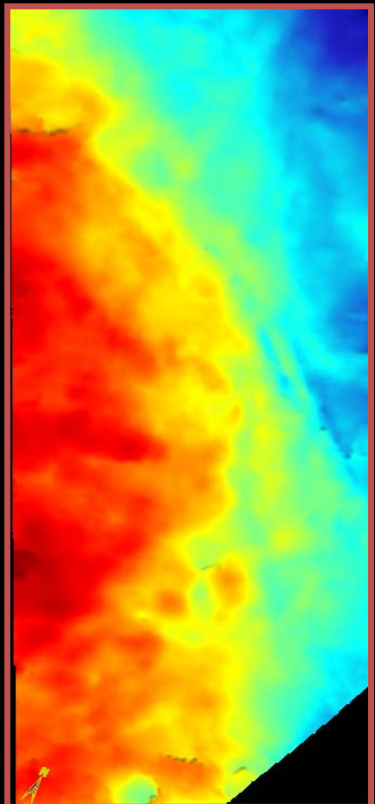
ConocoPhillips SCHOOL OF GEOLOGY & GEOPHYSICS The University of Oklahoma

Talk delivered at AAPG Convention, Long Beach on 23rd April, 2012

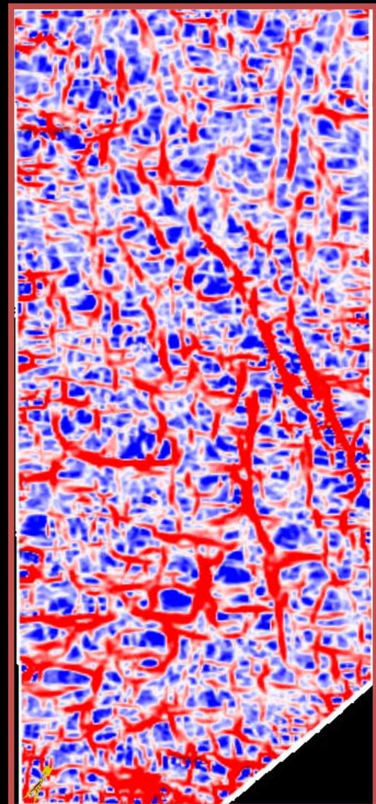
Structural curvature versus Amplitude curvature

1. Seismic curvature attributes introduced by Roberts (2001).
2. Curvature is a 2D second-order derivative of time or depth structure, or a 2D first order derivative of inline and crossline dip components.
3. Al-Dossary and Marfurt (2006) introduced volume computation of curvature and so curvature computation can now be carried out on both time surfaces and 3D seismic volumes.

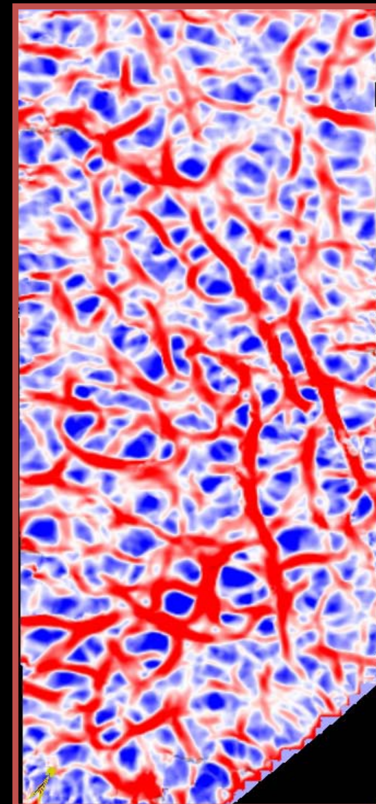
Structural curvature versus Amplitude curvature



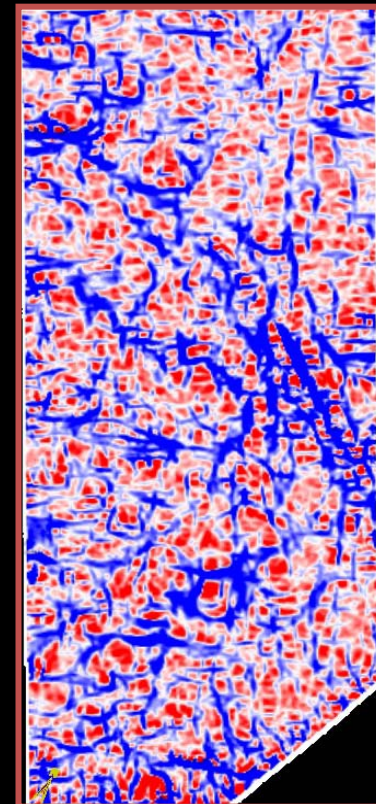
Time surface



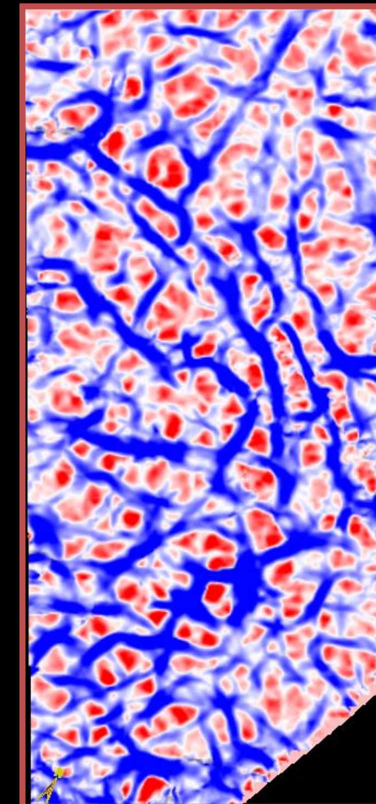
Most-positive curvature computed on the time horizon



Most-positive curvature extracted along the time horizon from the most-positive curvature attribute volume



Most-negative curvature computed on the time horizon

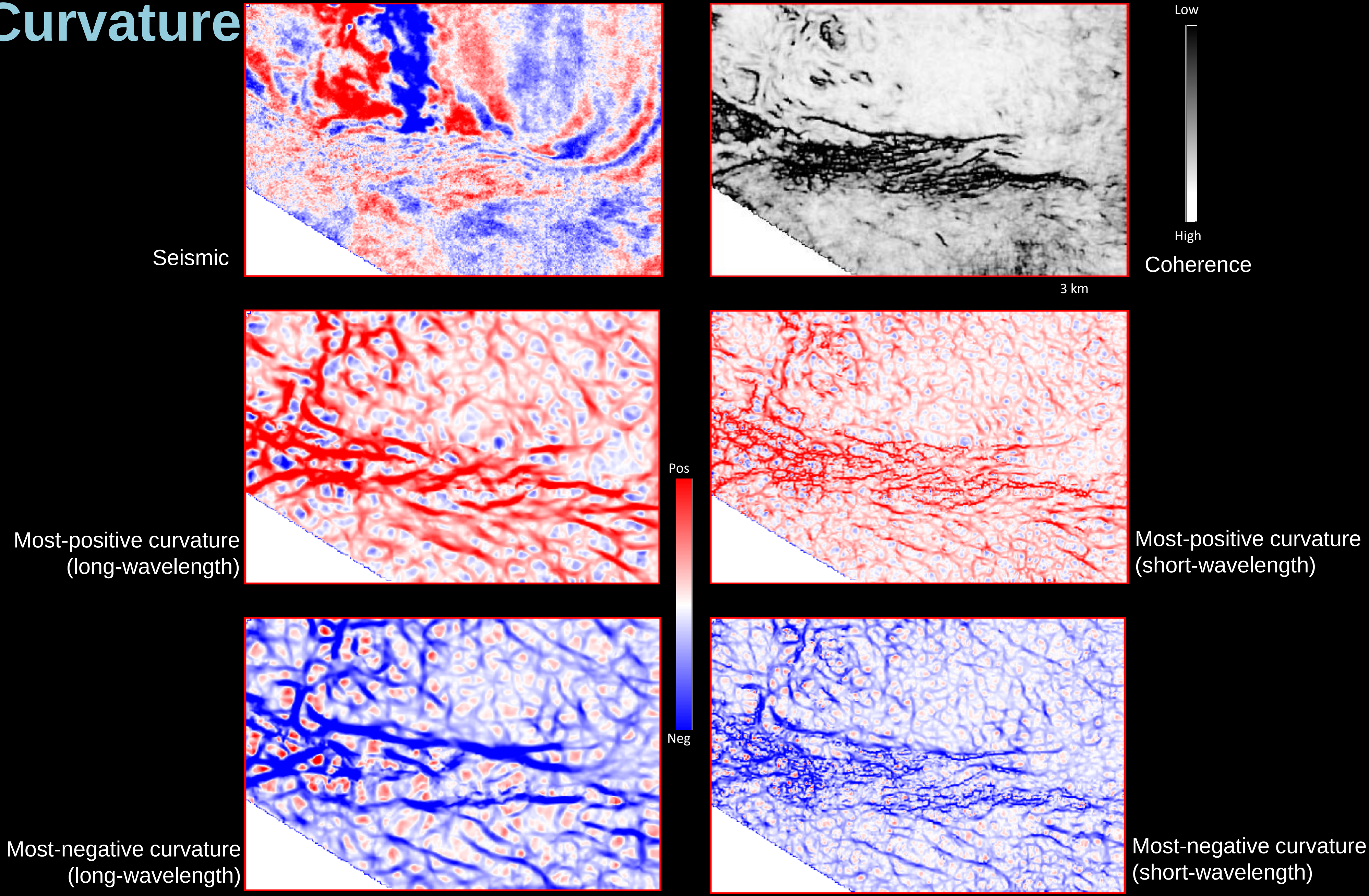


Most-negative curvature extracted along the time horizon from the most-positive curvature attribute volume

Surface-based versus volume-based curvature

Such calculations may be referred to as **structural curvature**

Curvature



Notice the clear set of faults/fractures generated from coherence and curvature attributes.

Structural curvature versus Amplitude curvature

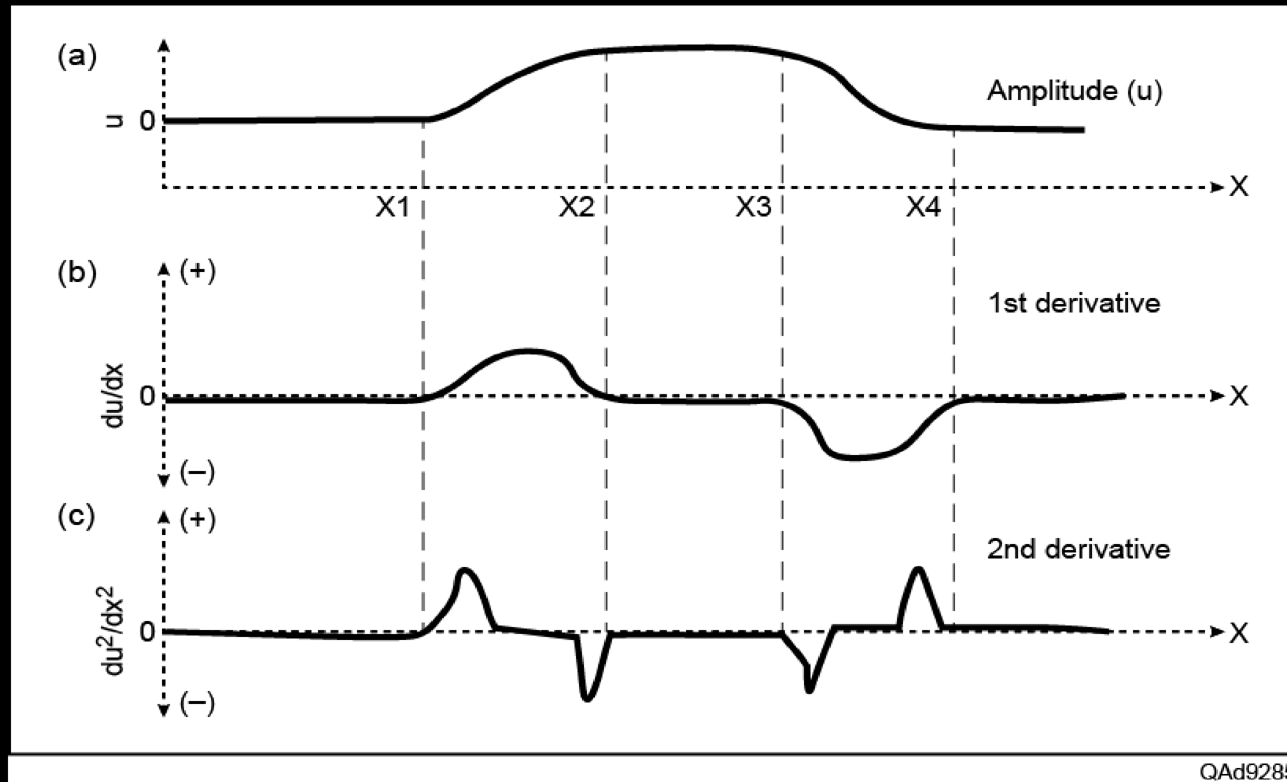
1. Thus structural curvature refers to the lateral second derivatives of reflector time or depth.

2. It is also possible to compute second-order derivatives of amplitude.

$$e_{mean} = \frac{1}{2}\nabla^2 a = \frac{1}{2}\left[\frac{\partial^2 a}{\partial x^2} + \frac{\partial^2 a}{\partial y^2}\right]$$

where ∂a/∂x and ∂a/∂y are the components of amplitude in the inline and crossline directions.

Structural curvature versus Amplitude curvature



Amplitude anomaly exhibiting its lateral change in the x-direction. Notice the extrema seen in (c) demarcating the limits of the anomaly

Structural curvature versus Amplitude curvature

1. Computation of second-order derivatives of amplitude should not come as a surprise.

2. Historically, Oliveros and Radovich (1997) discussed about their “DiscV” and “DiscH” curvature attributes based on second derivatives of the log(inst. amplitude).

3. Of course this is not the same as computing derivatives of amplitude along dip, but it is a step in that direction.

4. Their purpose was the same, to highlight discontinuities.

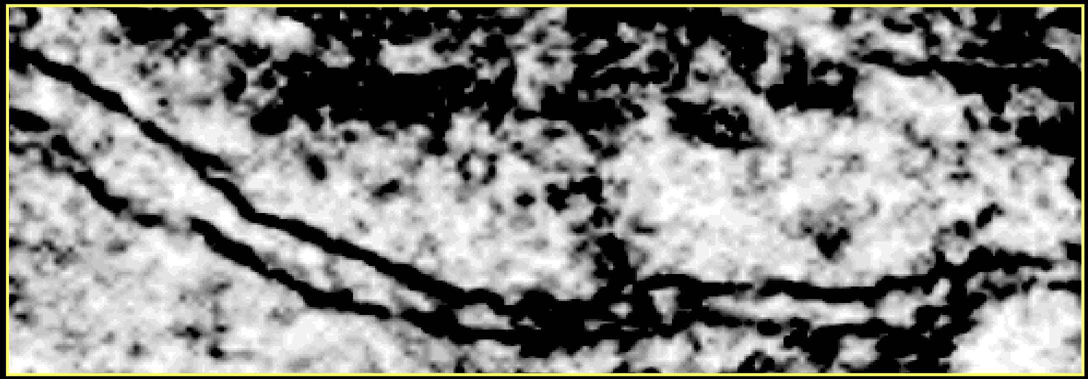
Structural curvature versus *Amplitude* curvature

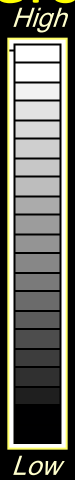
Time slice (3.1s) from instantaneous amplitude

Time slice (3.1s) from attribute based on second derivative of log of instantaneous amplitude

(Oliveros and Radovich, 1997)

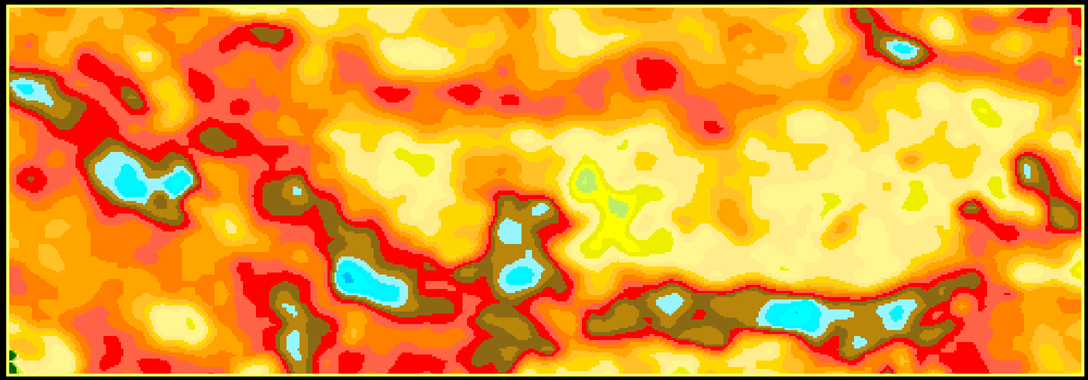
Coherence on impedance inversion

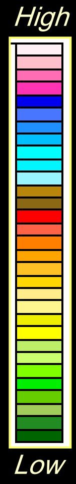




1044 ms

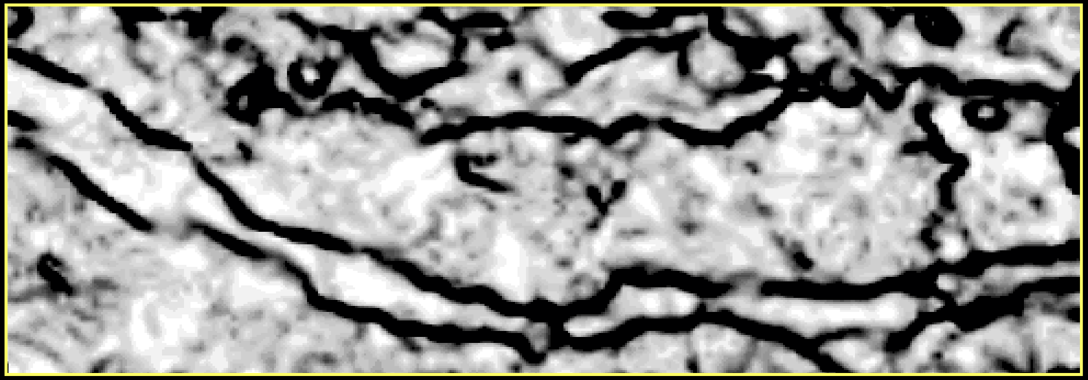
Coherence on zero offset seismic

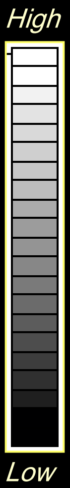




1044 ms

Derived P impedance





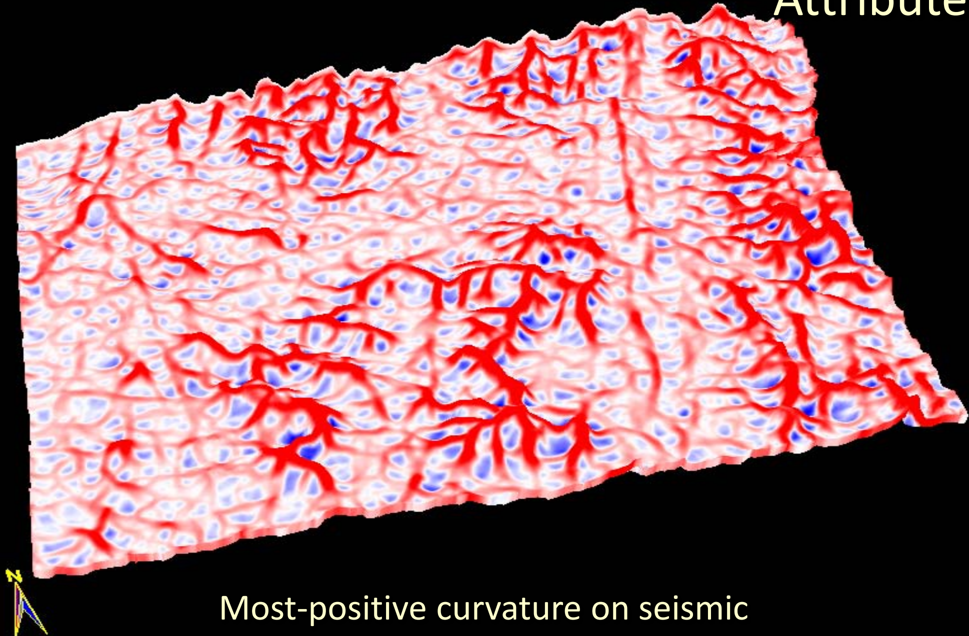
1044 ms

Coherence on P impedance

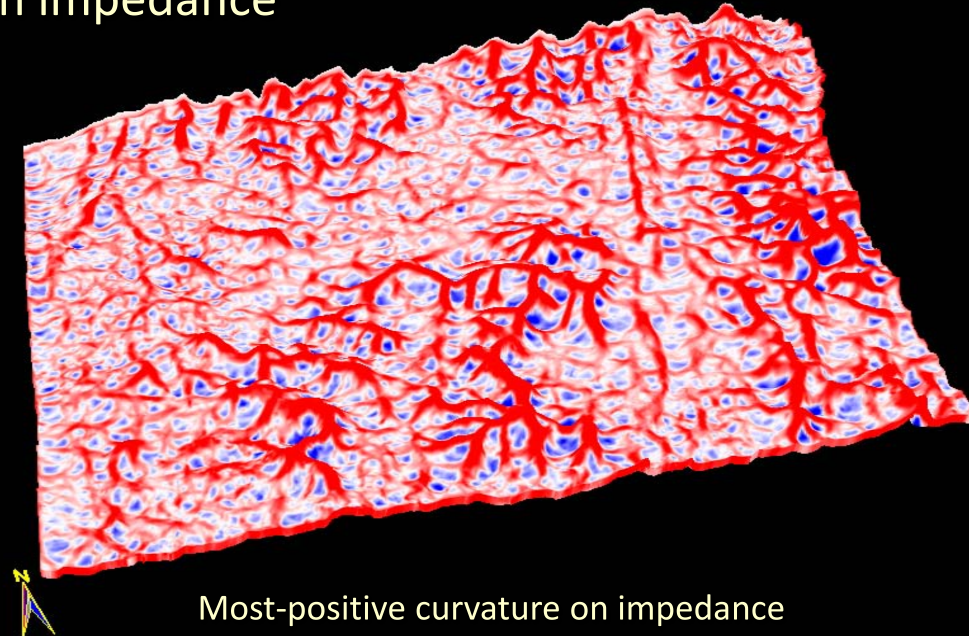
Time slices from different data volumes

Chopra 2001

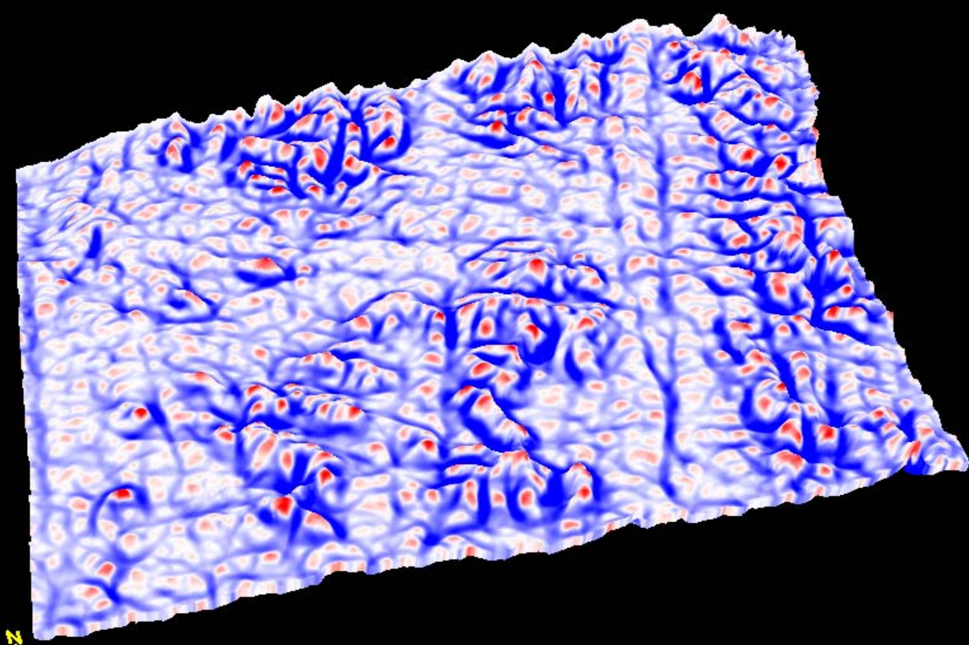
Attributes on impedance



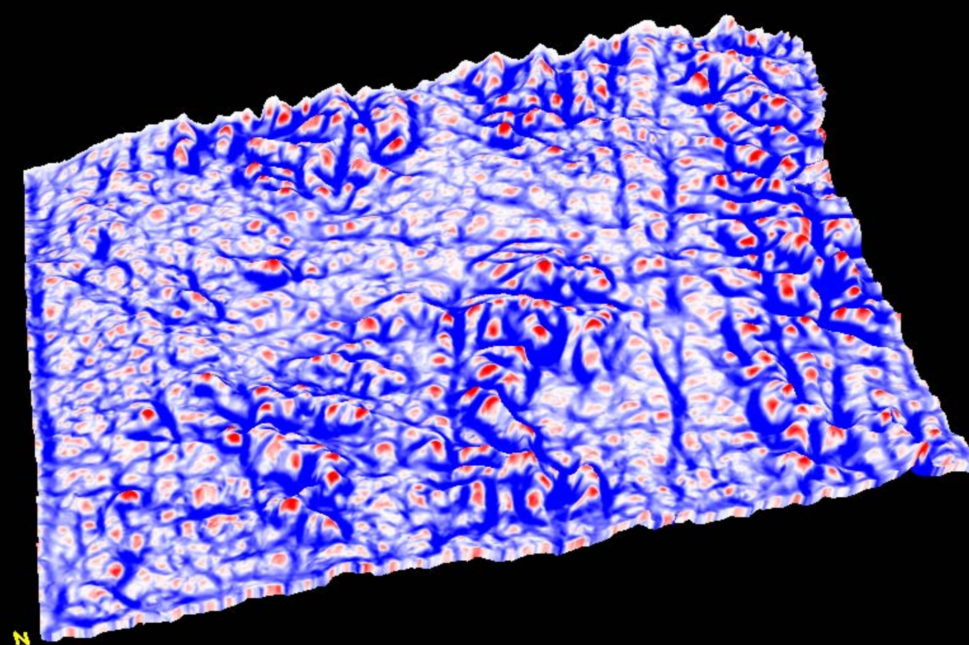
Most-positive curvature on seismic



Most-positive curvature on impedance



Most-negative curvature on seismic



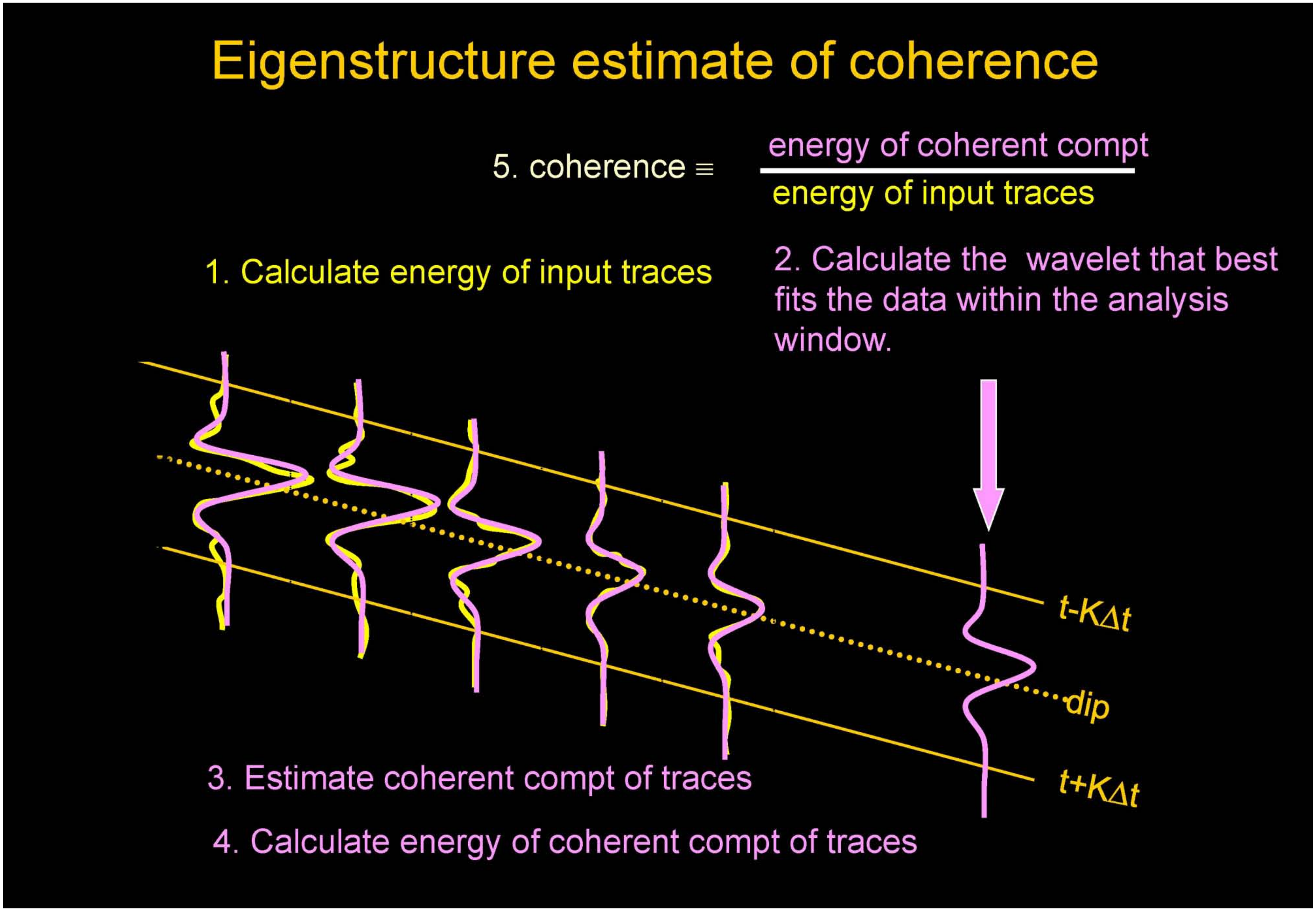
Most-negative curvature on impedance

Structural curvature versus Amplitude curvature

Marfurt and Kirlin (2000) and Marfurt (2006) demonstrated the estimation of reflector amplitude gradients within an analysis window.

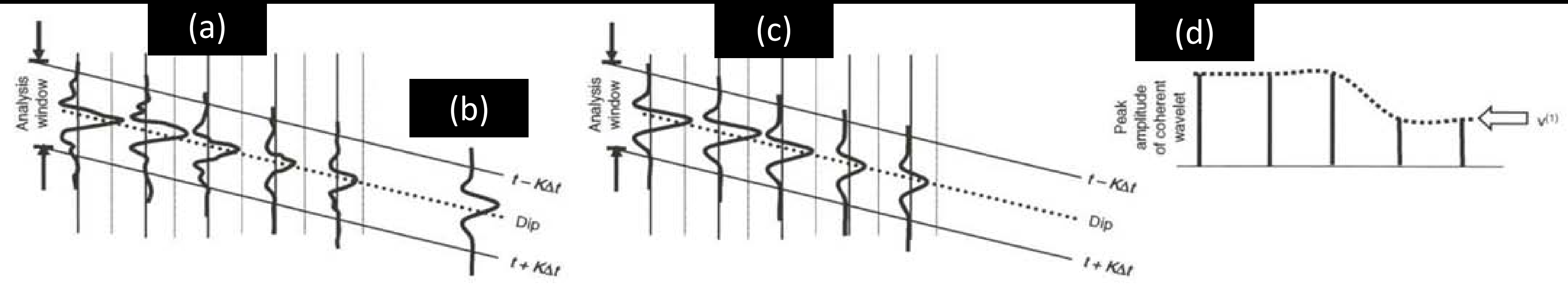
$$g_x = \lambda_1 \sum_{k=-K}^{+K} \frac{\partial v_1(x,y)}{\partial x}$$ and $$g_y = \lambda_1 \sum_{k=-K}^{+K} \frac{\partial v_1(x,y)}{\partial y}$$

where v_1 is the principal component and λ_1 is its corresponding eigenvalue, which represents the energy of this data component.



Presenter’s Notes: A schematic diagram showing the steps used in eigenstructure estimation of coherence. (a) First, we calculate the energy of the input traces within an analysis window, (b) next, we calculate the seismic waveform that best approximates the waveform of each input trace, and (c) finally, we replace each trace by a scaled version of (b) that best fits the input trace. The eigenstructure coherence is the ratio of the energy of (c) to the energy of (a). If each windowed trace in (a) has the exact same waveform (but perhaps a different amplitude), the coherence = 1.0; otherwise, it is less than 1.0.

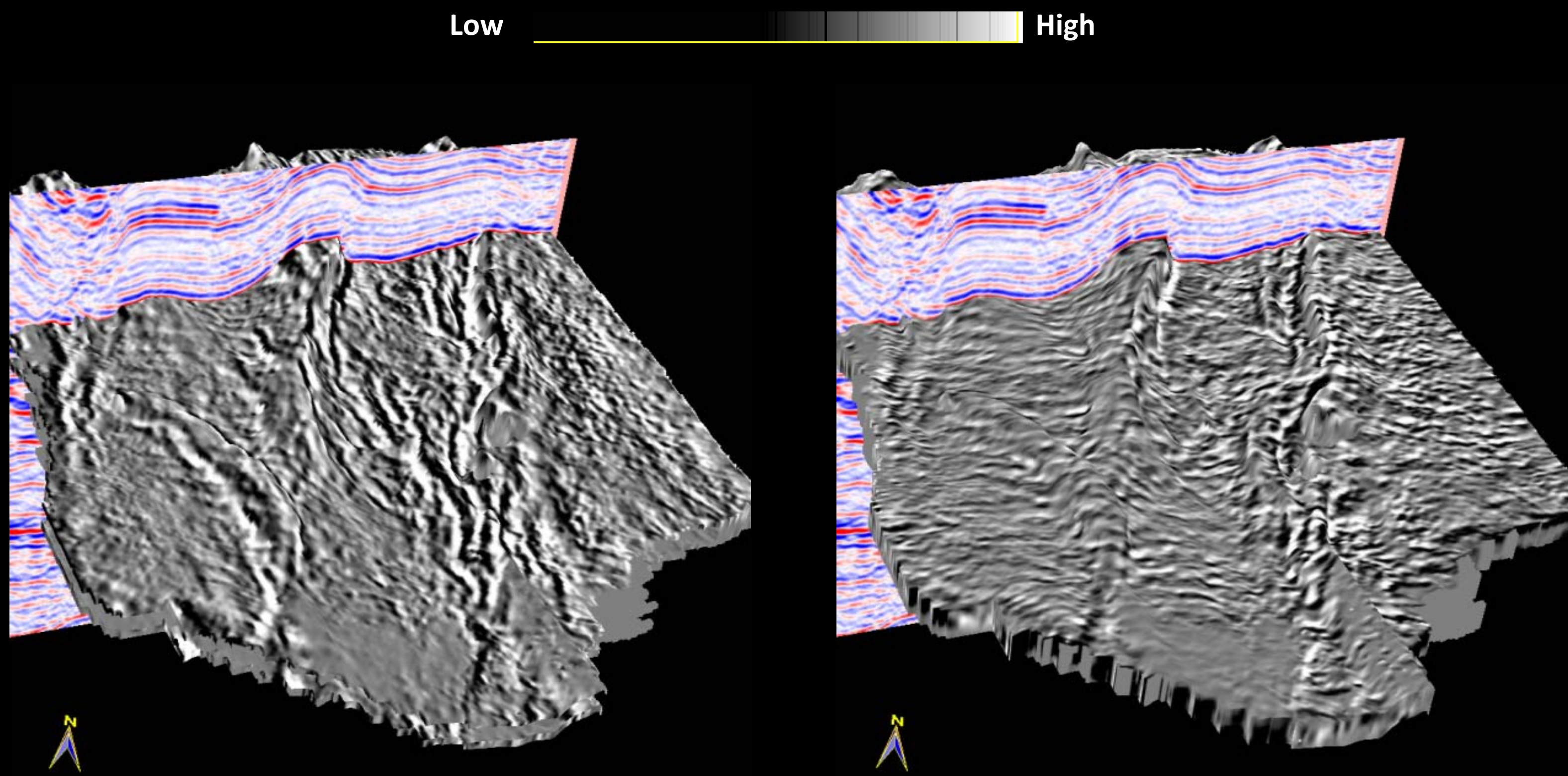
Energy gradient



1. The amplitudes of the five wavelets in (c) above define the components of the five element long principal component eigenvector, v^1.

2. To calculate the energy-weighted coherent amplitude gradients, we take the derivative of the curve shown by the dotted line in (d) and weight it by the sum of the coherent energy within the analysis window shown in (c).

Structural curvature versus Amplitude curvature

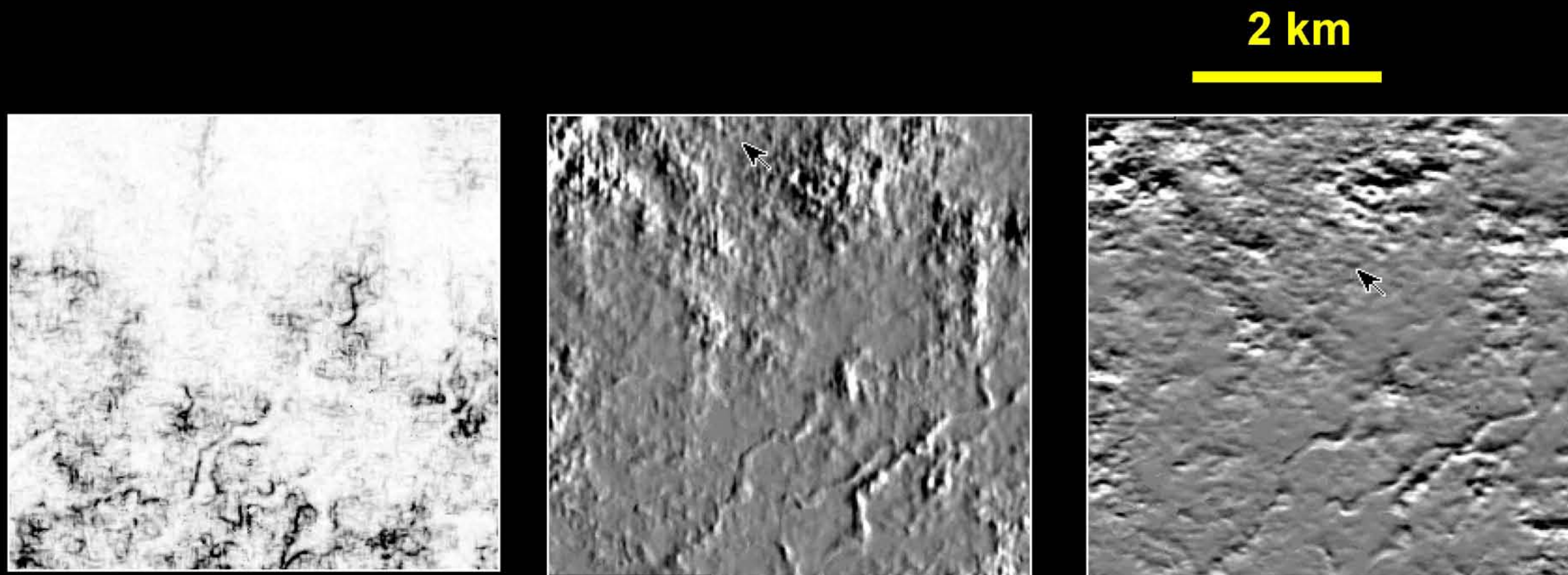


Inline energy gradient

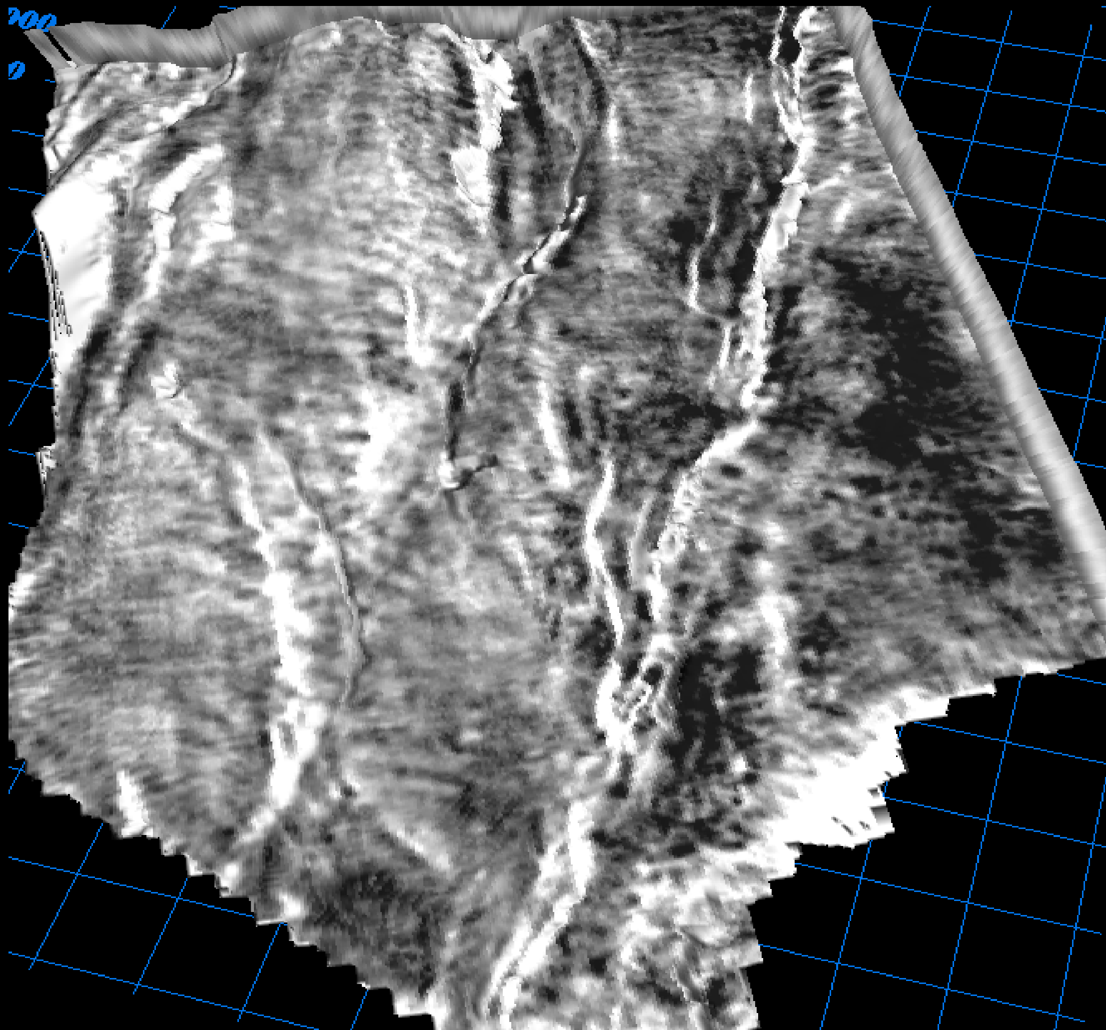
Crossline energy gradient

3D chair view showing the seismic inlines correlated with the inline energy gradient (left) and the crossline energy gradient (right) strat-cubes.

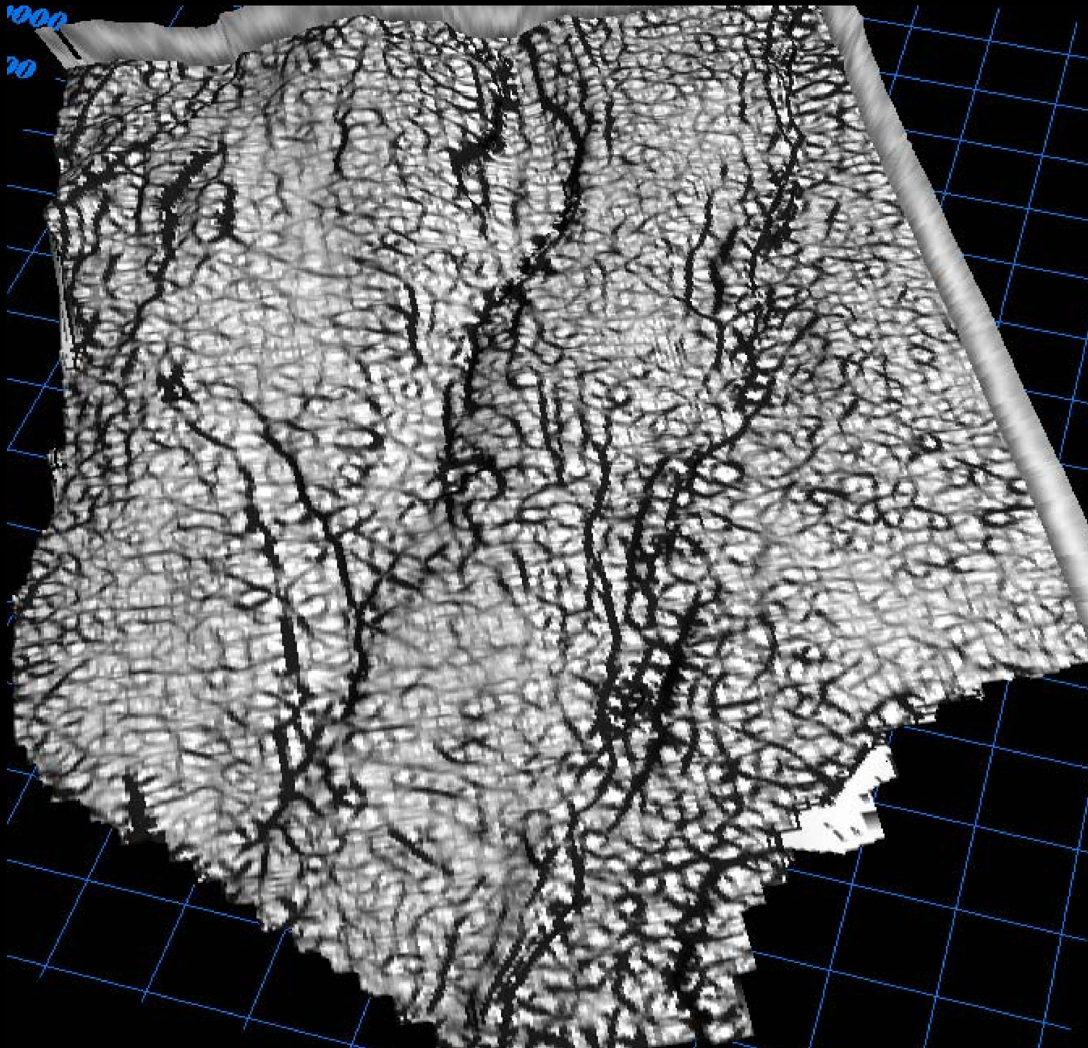
Midcontinent, USA
Time slices



Presenter’s Notes: Time slices at *t* = 0.832 s, through the (a) east-west and (b) north-south components of energy-weighted coherent-amplitude gradients, and (c) a coherence time slice, all through a survey at approximately Pennsylvanian level from the Midcontinent, USA. Although the channels can be seen on the coherence time slice, they can be traced farther using the amplitude-gradient images.

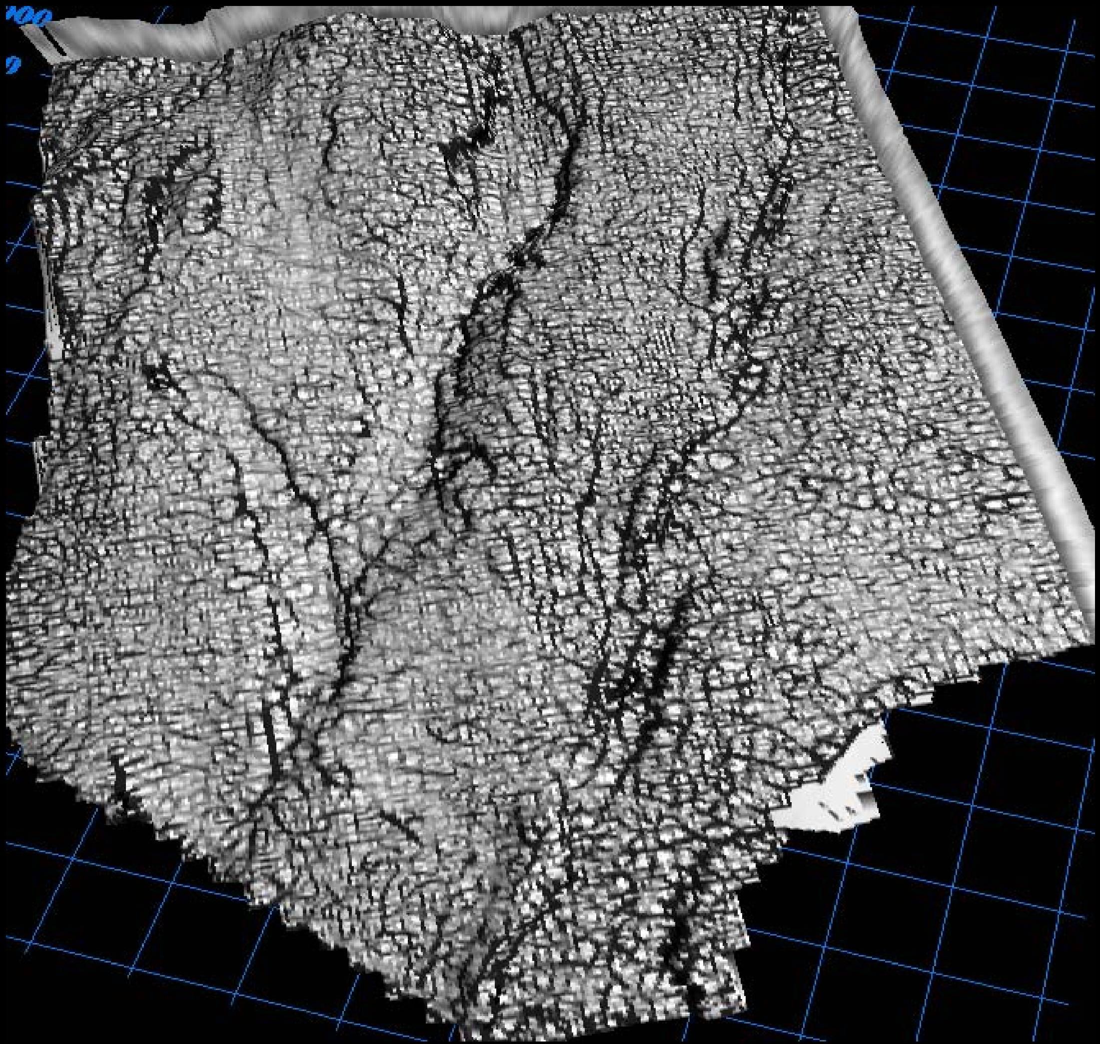


Horizon slice from the seismic amplitude volume



Most-positive curvature of the amplitude

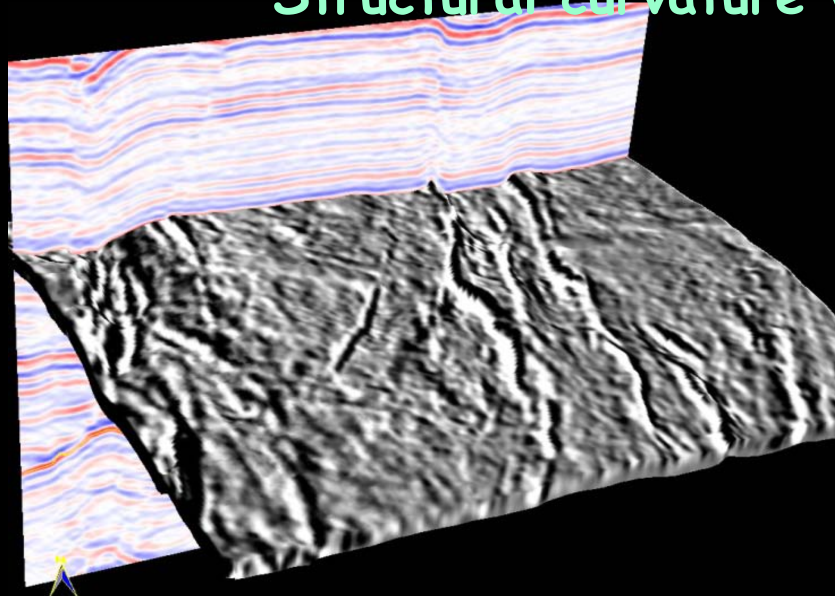
(long wavelength)



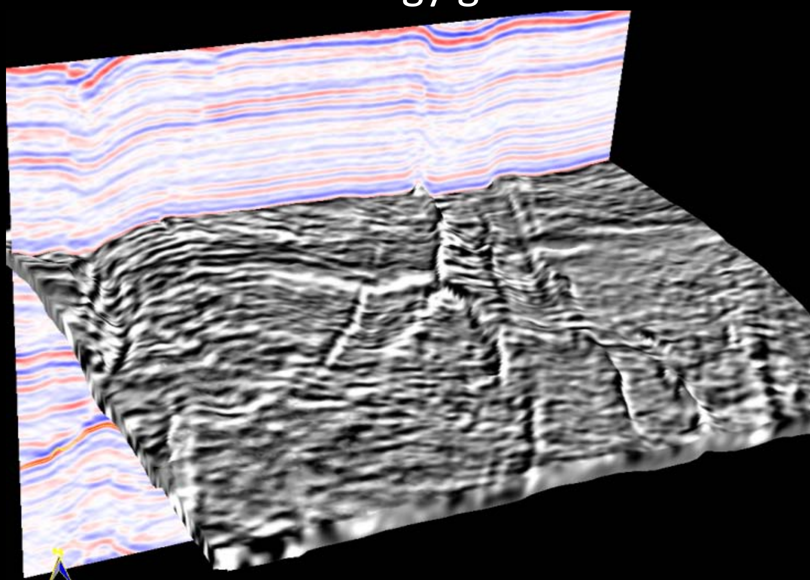
Most-positive curvature of the amplitude

(short wavelength)

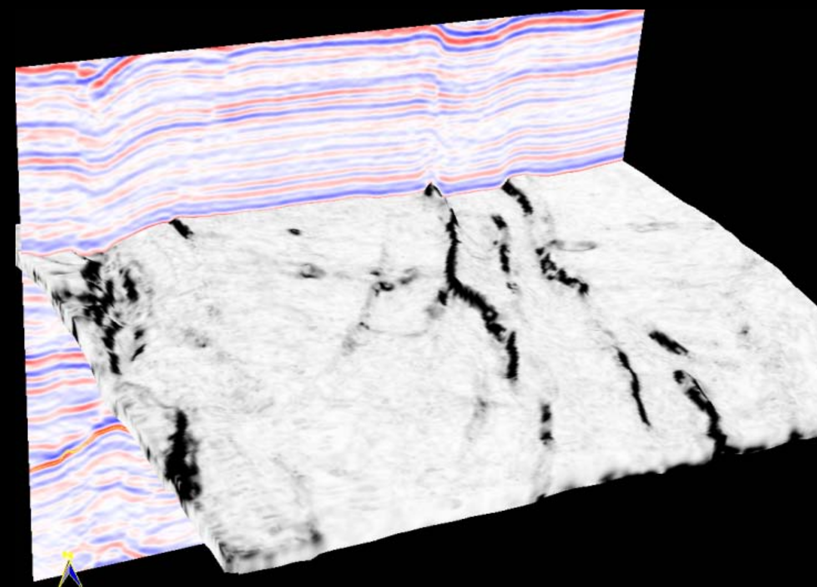
Structural curvature versus Amplitude curvature



Inline energy gradient



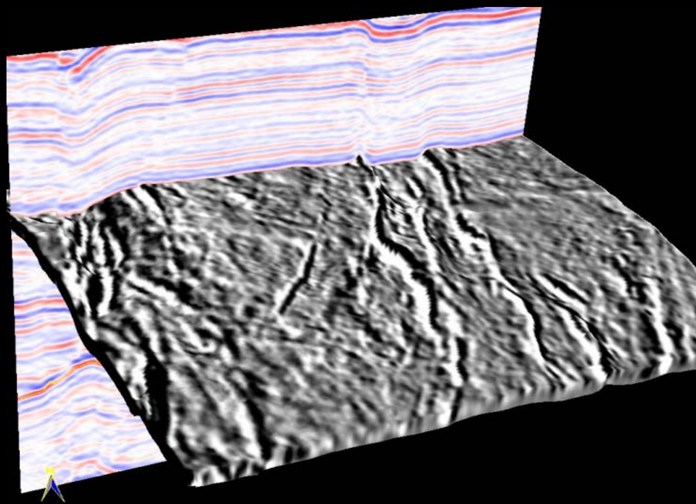
Crossline energy gradient



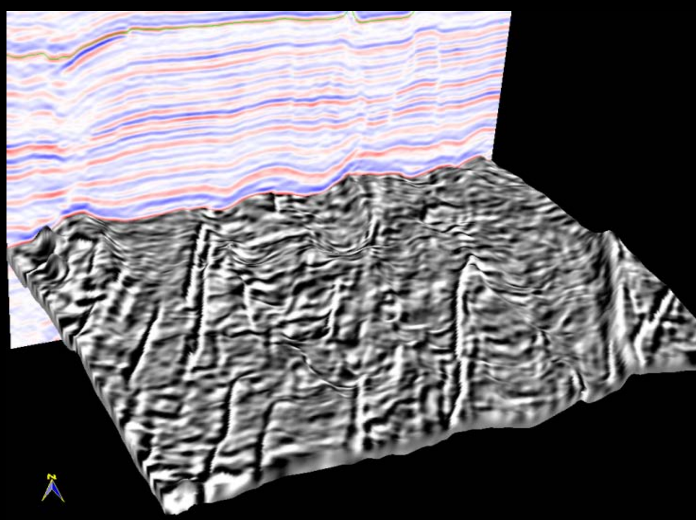
Coherence (Energy-Ratio)

Horizon slices close to 1400 ms

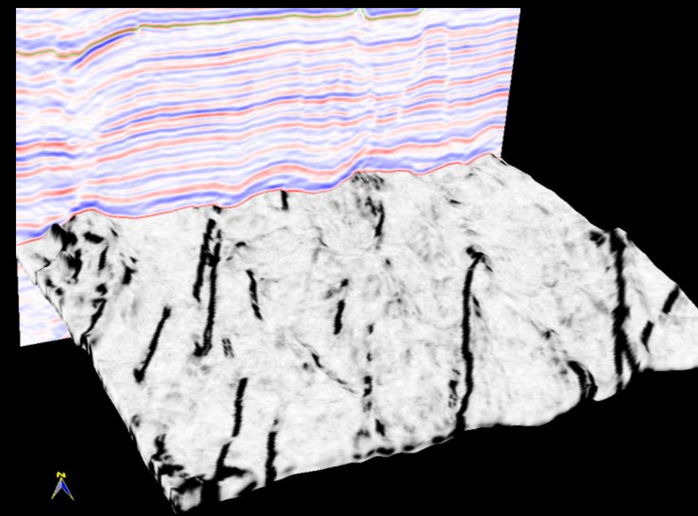
Structural curvature versus Amplitude curvature



Inline energy gradient



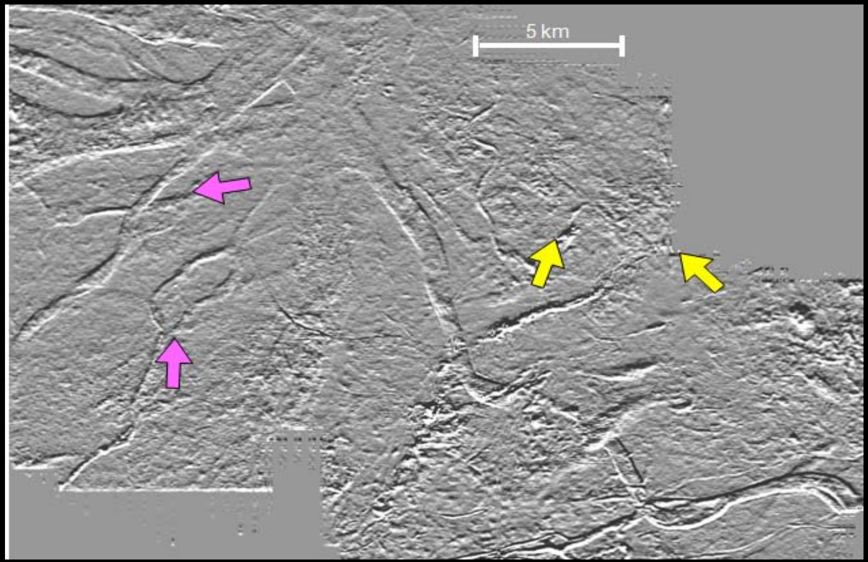
Crossline energy gradient



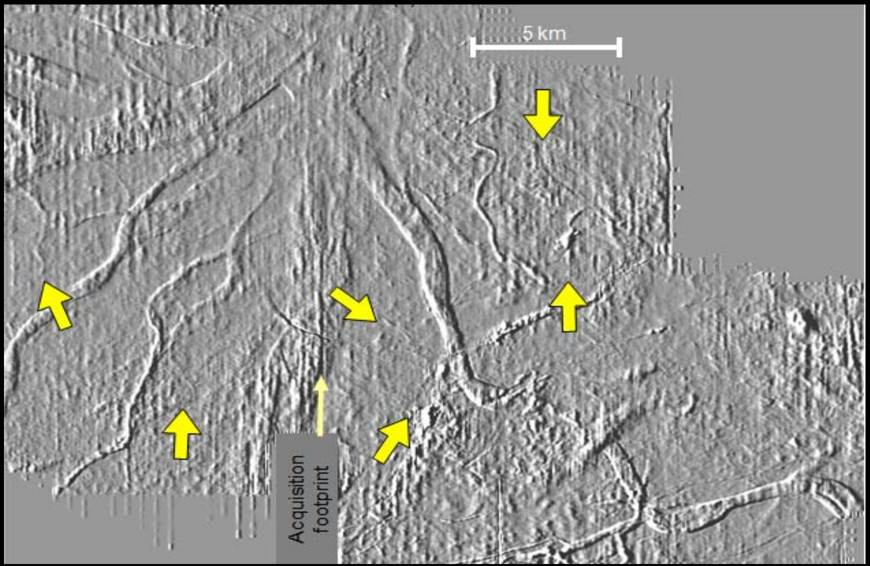
Coherence (Energy-Ratio)

Horizon slices close to 1800 ms

South Marsh Island, Gulf of Mexico

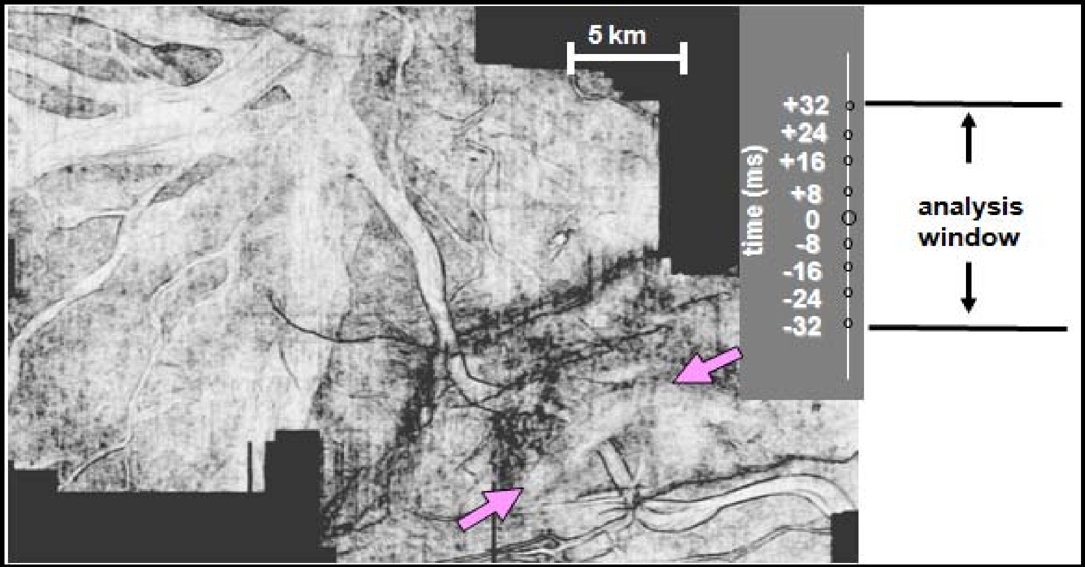


Inline (NS) energy-weighted coherent amplitude gradient



Crossline (EW) energy-weighted coherent amplitude gradient

Coherence

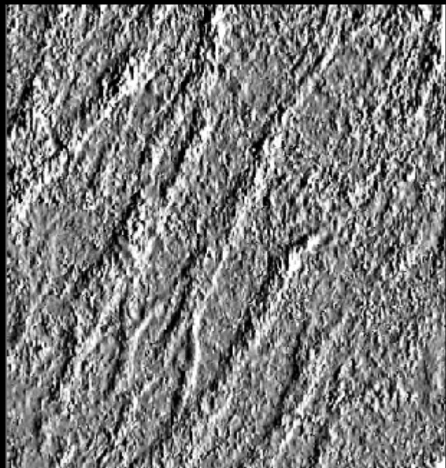


Horizon slices

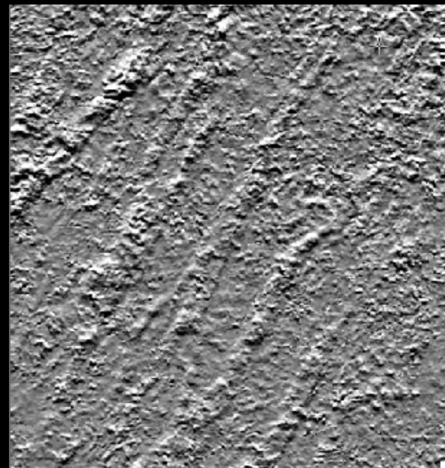
(Chopra and Marfurt, 2007)

Structural curvature versus Amplitude curvature

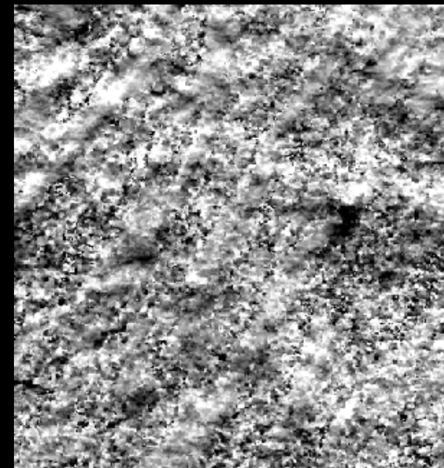
1 km



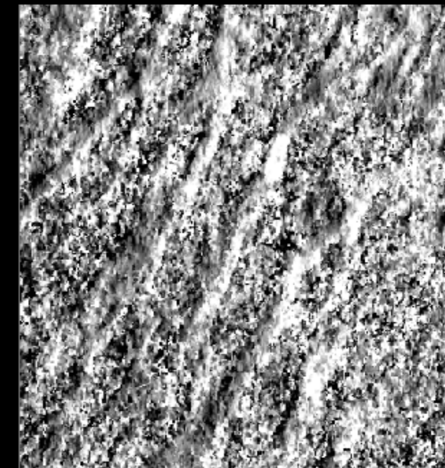
Inline (NS) energy gradient



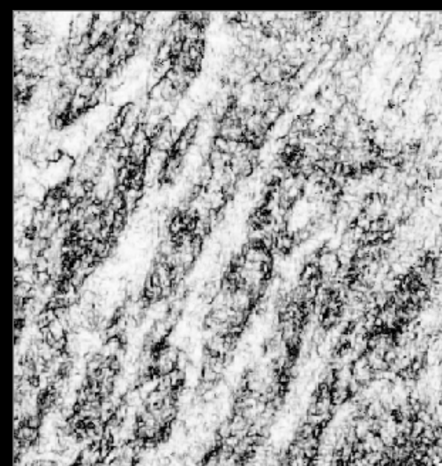
Crossline (EW) energy gradient



Inline (NS) dip



Crossline (EW) dip

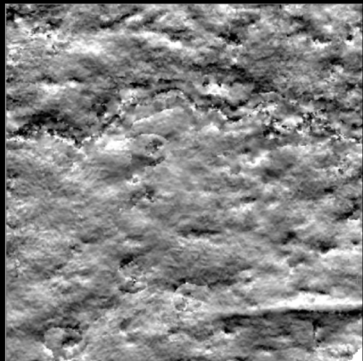


Coherence

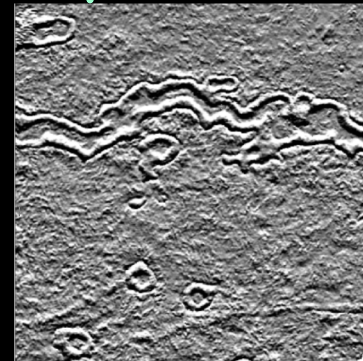
Stratal slices close to 900 ms from different attribute volumes

Data courtesy: Fairborne Energy Ltd., Calgary

Structural curvature versus Amplitude curvature


Inline (NS) dip

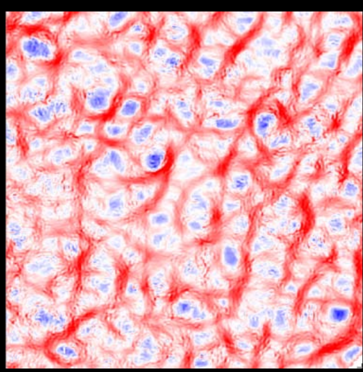

Crossline (EW) dip

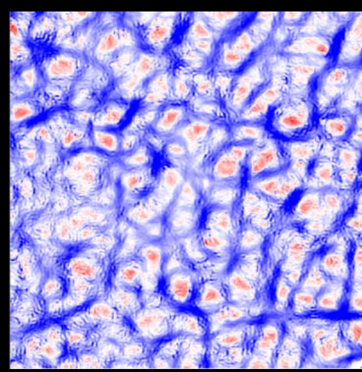

Inline (NS) energy gradient

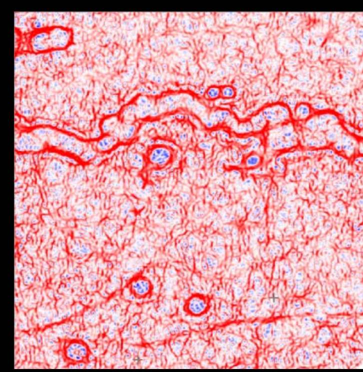

Crossline (EW) energy gradient

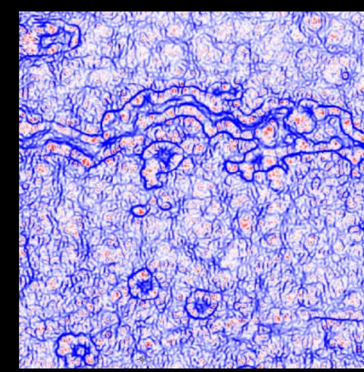

Coherence

1 km


Principal structural positive curvature (LW)

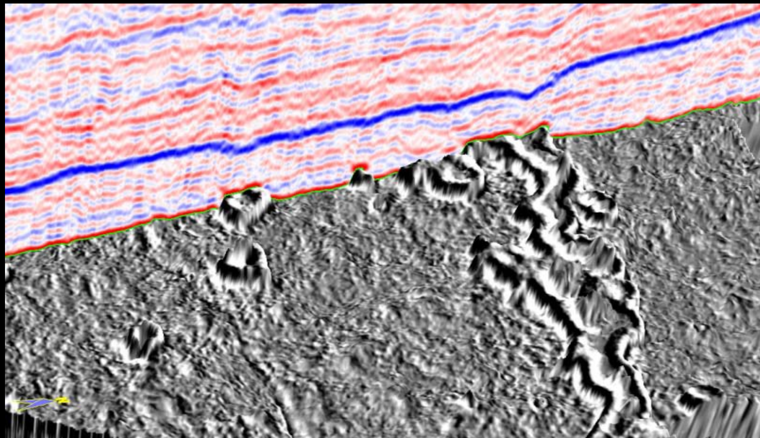

Principal structural negative curvature (LW)


Principal amplitude positive curvature (LW)

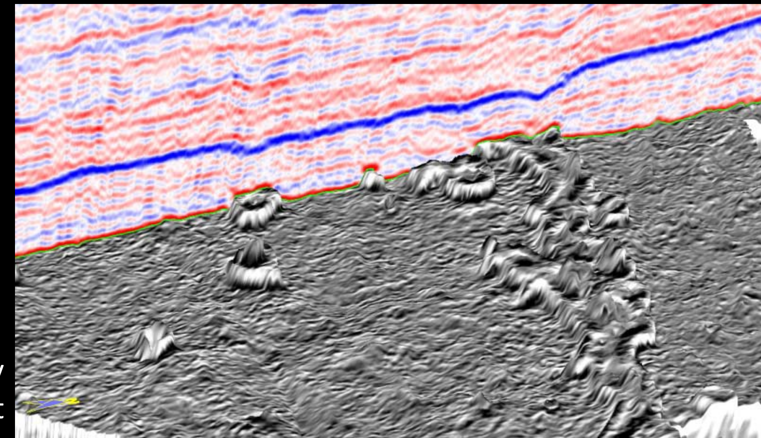

Principal amplitude negative curvature (LW)

Data courtesy: Fairborne Energy Ltd., Calgary

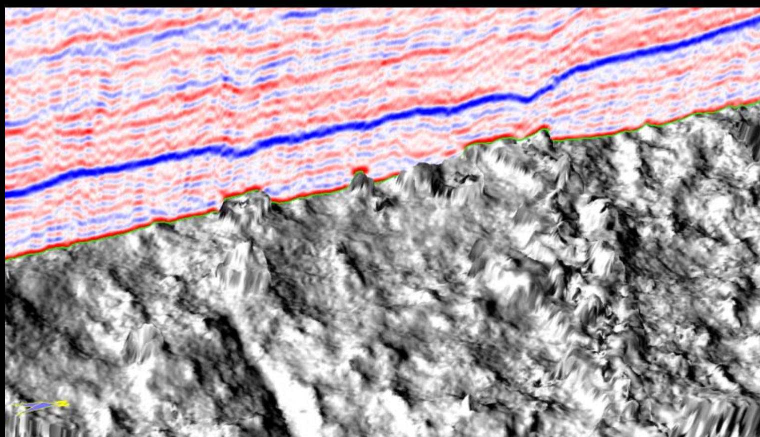
Structural curvature versus Amplitude curvature



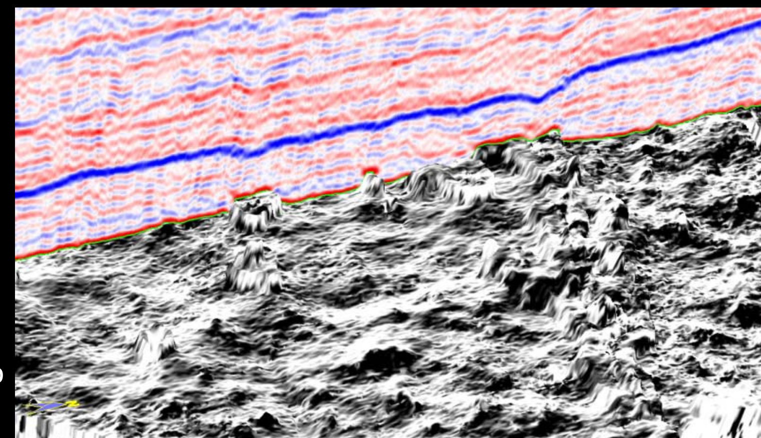
Inline (NS) energy gradient



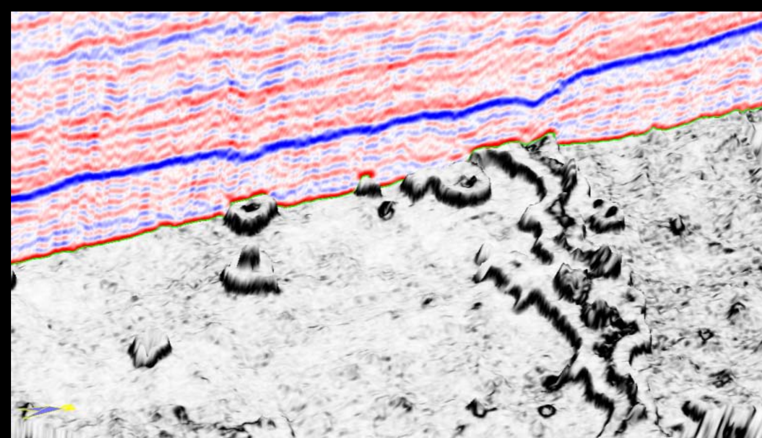
Crossline (EW) energy gradient



Inline (NS) dip



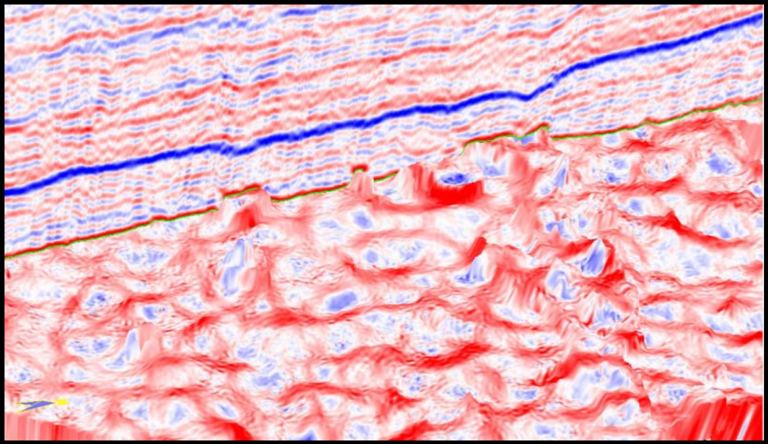
Crossline (EW) dip



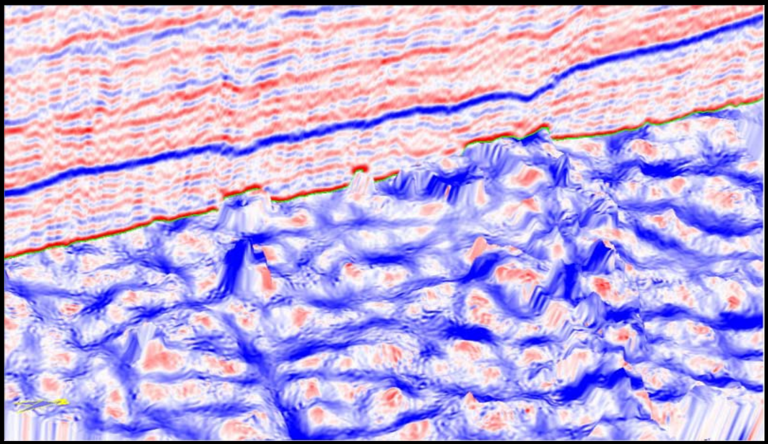
Coherence

Data courtesy: Fairborne Energy Ltd., Calgary

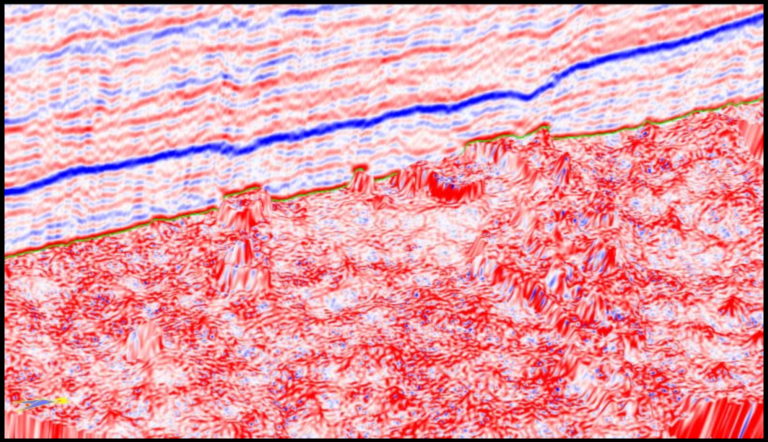
Structural curvature versus Amplitude curvature



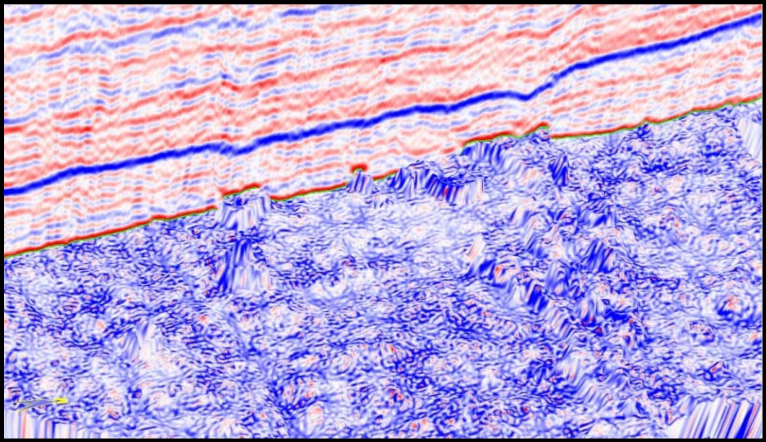
Principal structural positive curvature (LW)



Principal structural negative curvature (LW)



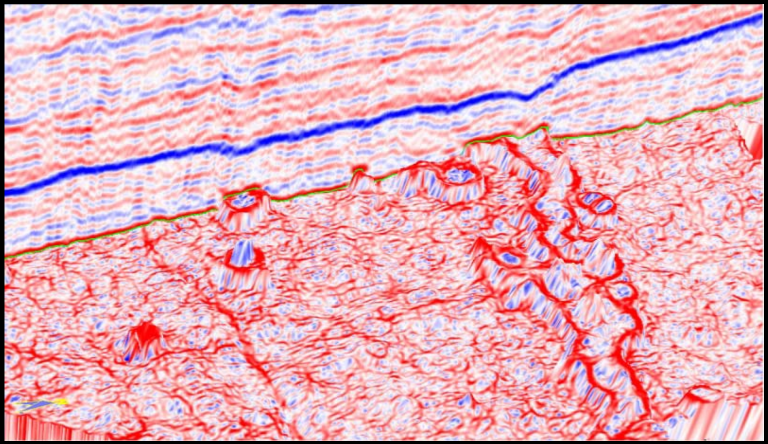
Principal structural positive curvature (SW)



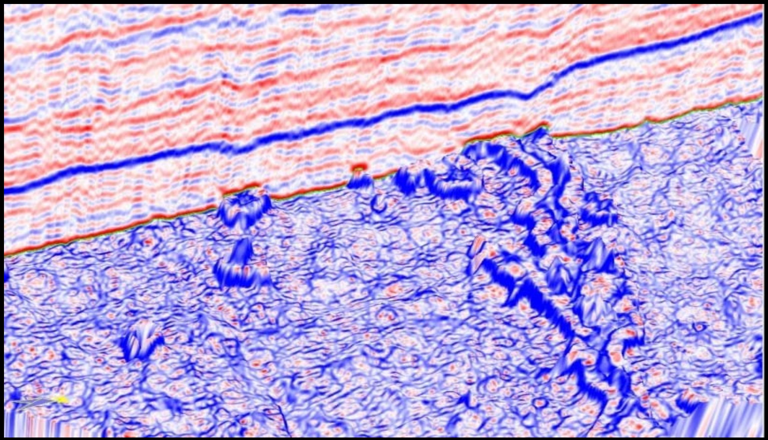
Principal structural negative curvature (SW)

Data courtesy: Fairborne Energy Ltd., Calgary

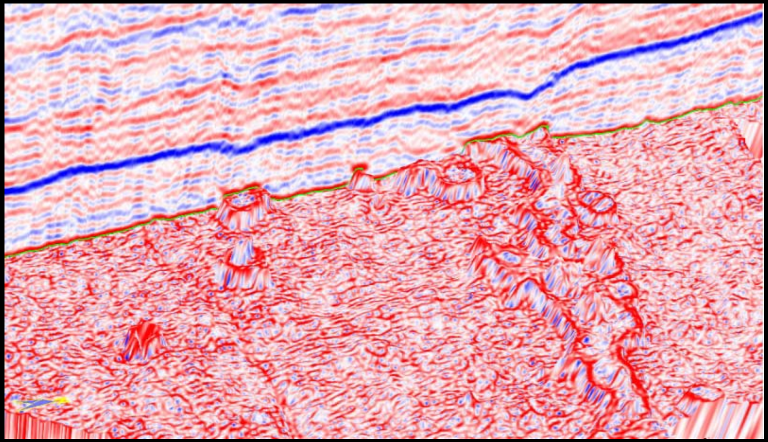
Structural curvature versus Amplitude curvature



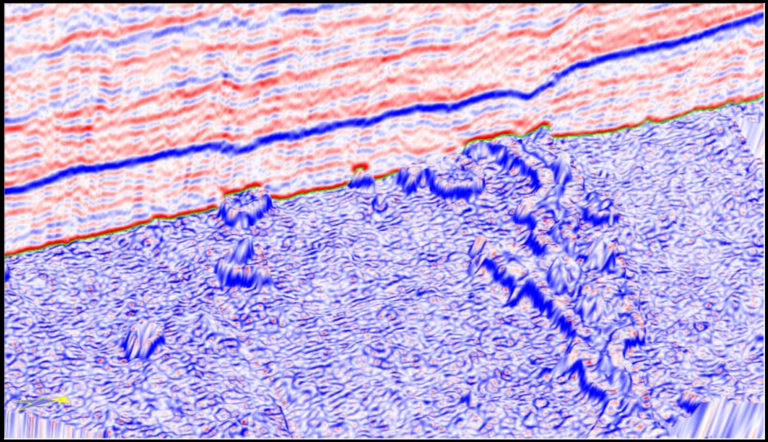
Principal amplitude positive curvature (LW)



Principal amplitude negative curvature (LW)

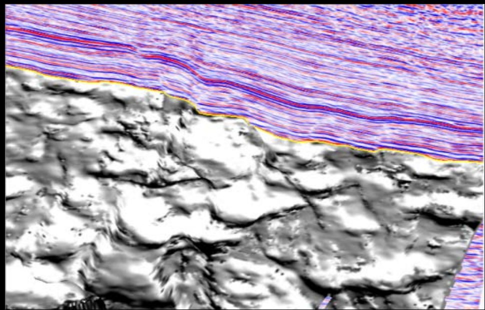


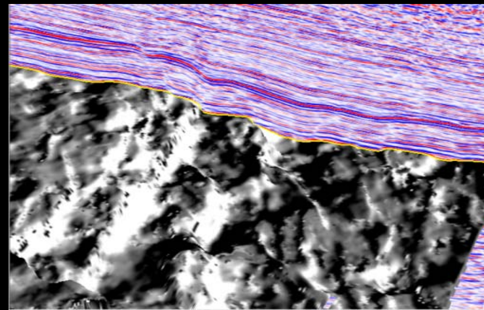
Principal amplitude positive curvature (SW)

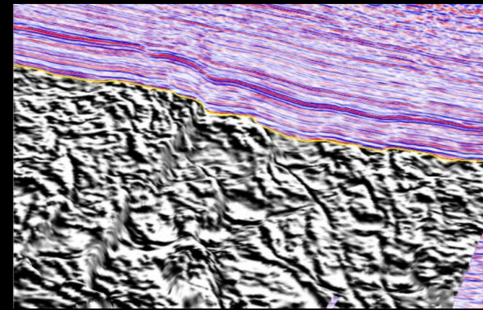


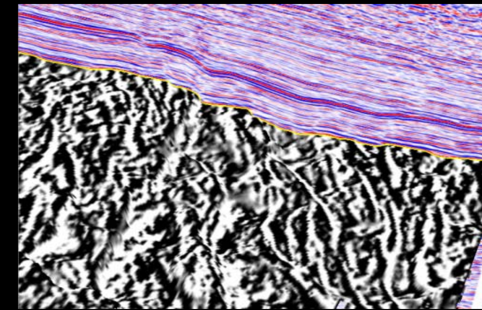
Principal amplitude negative curvature (SW)

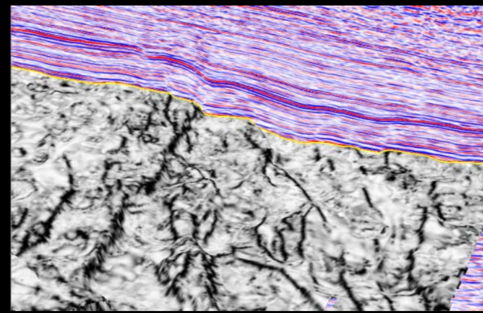
Data courtesy: Fairborne Energy Ltd., Calgary


Inline (NS) dip

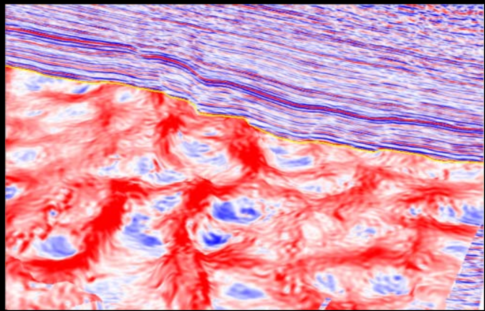

Crossline (EW) dip

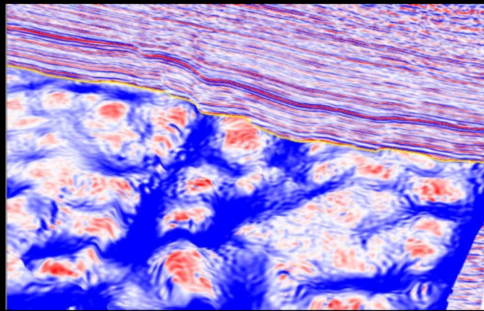

Inline (NS) energy gradient

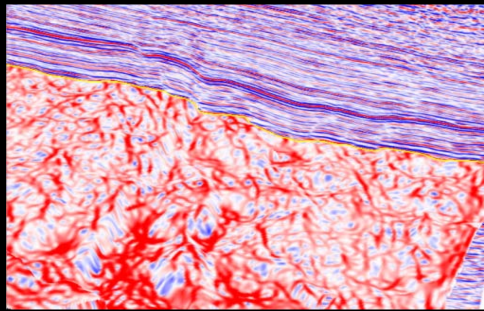

Crossline (EW) energy gradient

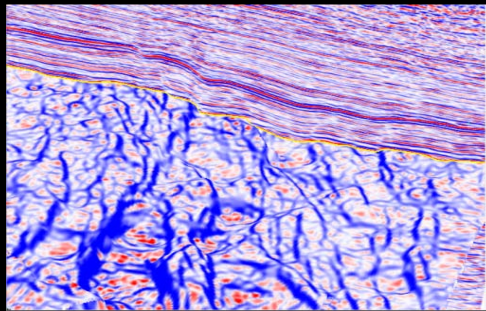

Coherence

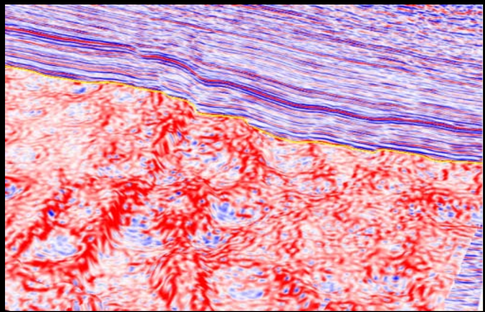
Data courtesy: EOG Resources

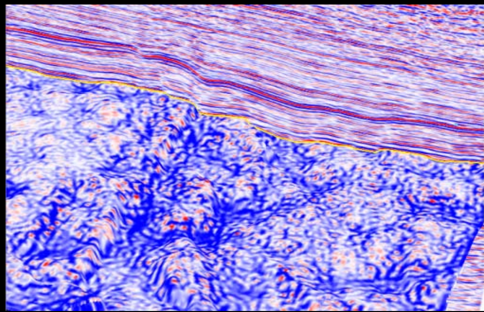

Structural positive curvature (LW)

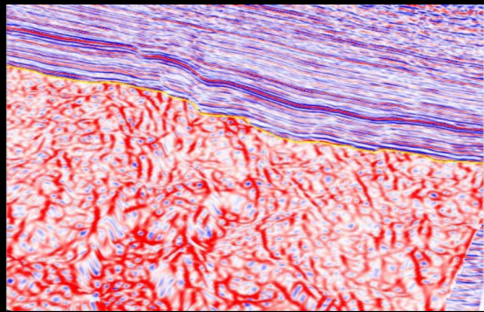

Structural negative curvature (LW)

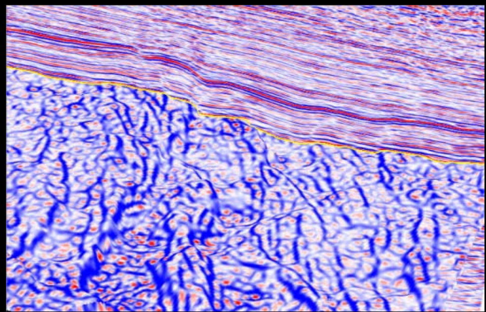

Amplitude positive curvature (LW)

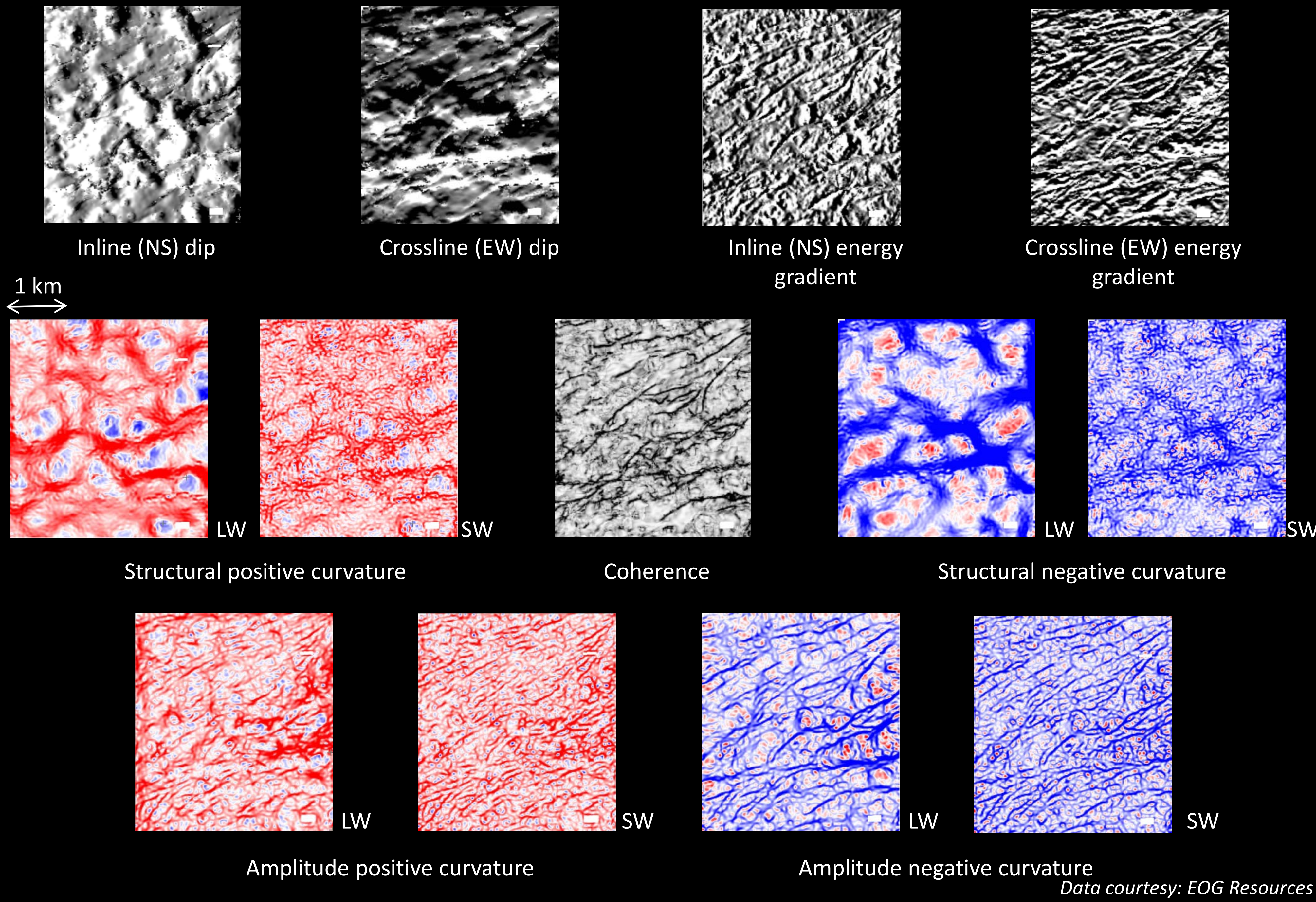

Amplitude negative curvature (LW)


Structural positive curvature (SW)


Structural negative curvature (SW)


Amplitude positive curvature (SW)

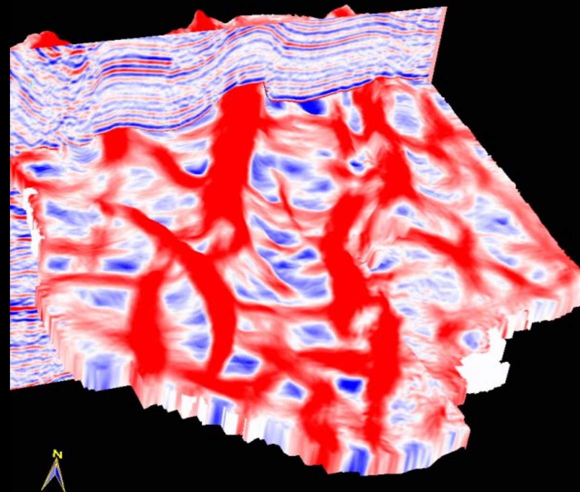

Amplitude negative curvature (SW)


Inline (NS) dip
Crossline (EW) dip
Inline (NS) energy gradient
Crossline (EW) energy gradient
1 km
LW
SW
Structural positive curvature
Coherence
LW
SW
Structural negative curvature
LW
SW
Amplitude positive curvature
LW
SW
Amplitude negative curvature
Data courtesy: EOG Resources

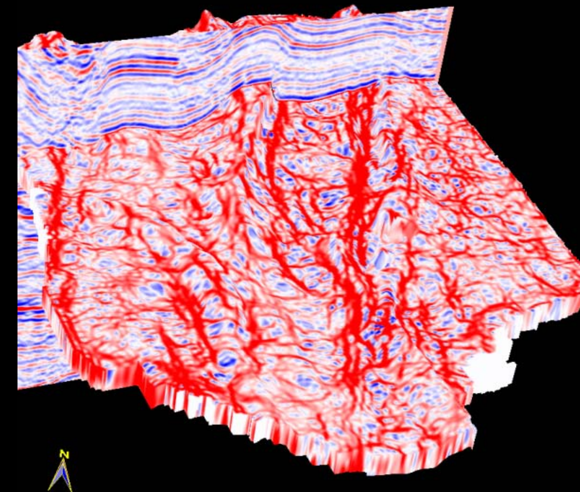
Structural curvature versus Amplitude curvature

STRUCTURAL

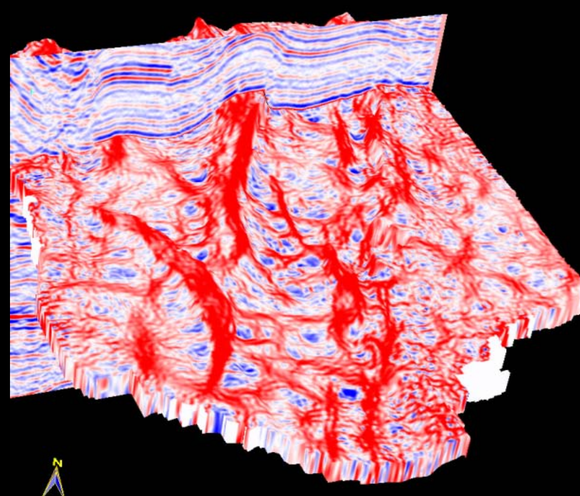
AMPLITUDE



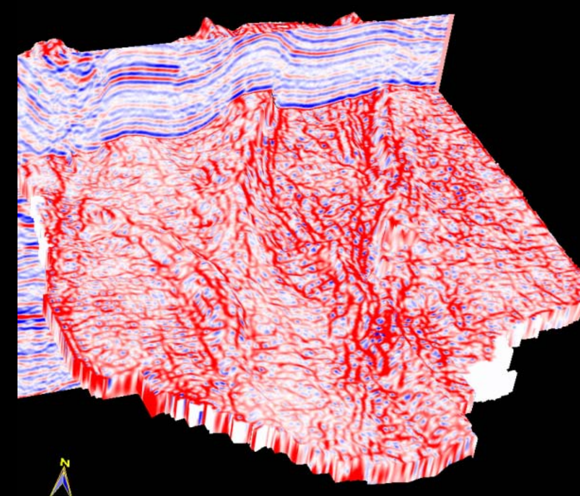
Most-positive curvature (long-wavelength)



Most- positive curvature (long-wavelength)



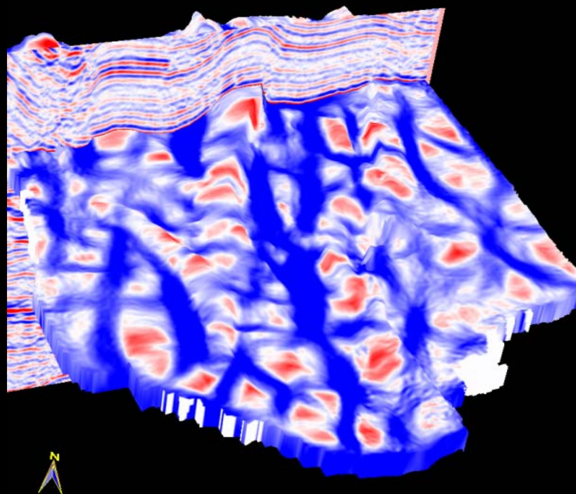
Most-positive curvature (short-wavelength)



Most-positive curvature (short-wavelength)

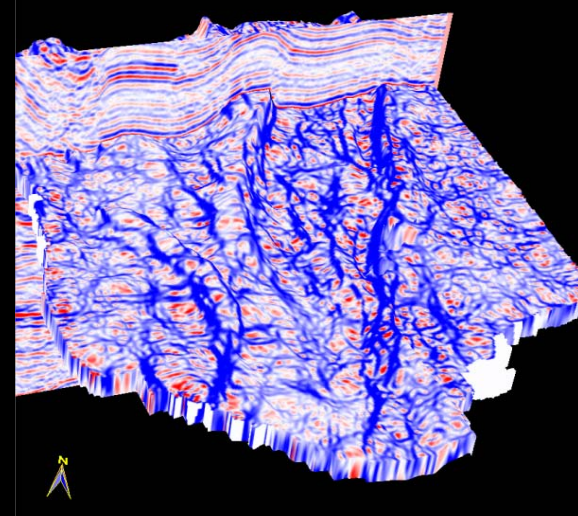
Structural curvature versus Amplitude curvature

STRUCTURAL

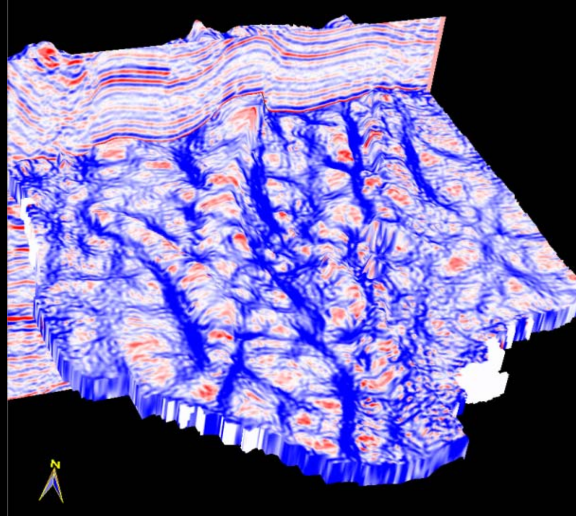


Most-negative curvature (long-wavelength)

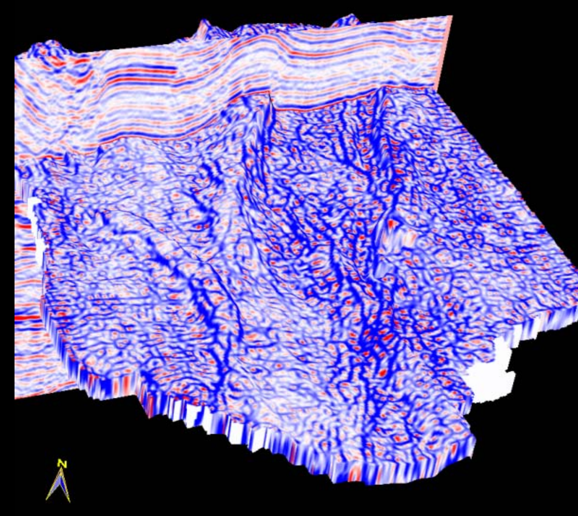
AMPLITUDE



Most- negative curvature (long-wavelength)



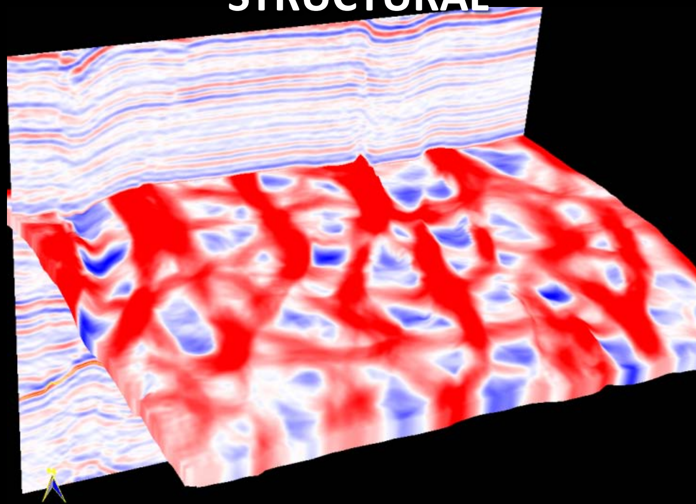
Most-negative curvature (short-wavelength)



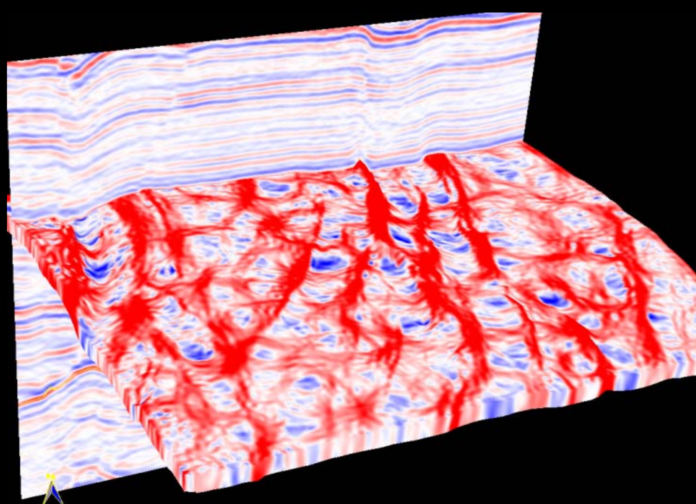
Most-negative curvature (short-wavelength)

Structural curvature versus Amplitude curvature

STRUCTURAL

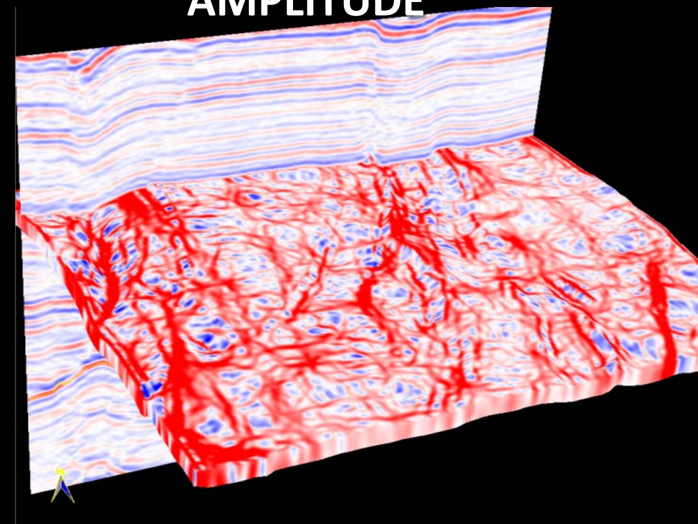


Most-positive curvature (long-wavelength)

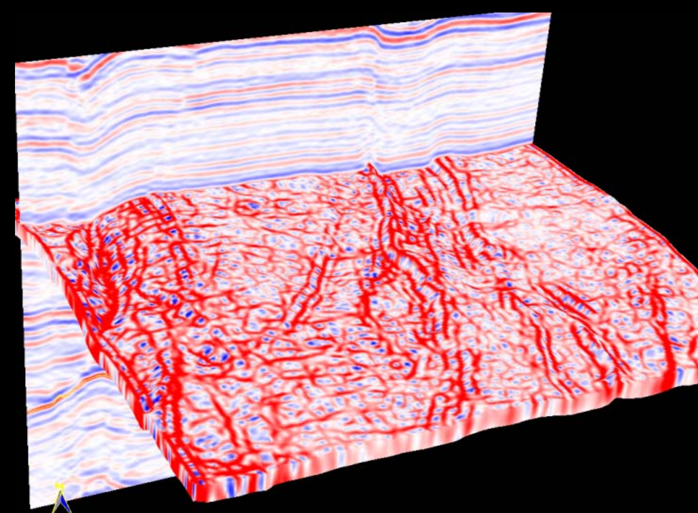


Most-positive curvature (short-wavelength)

AMPLITUDE



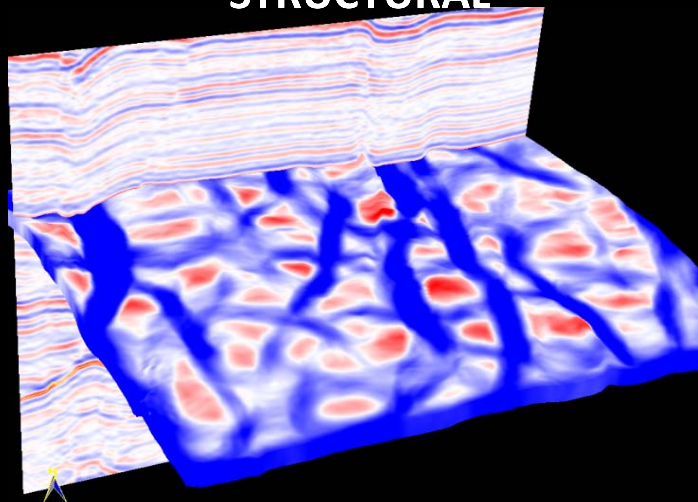
Most- positive curvature (long-wavelength)



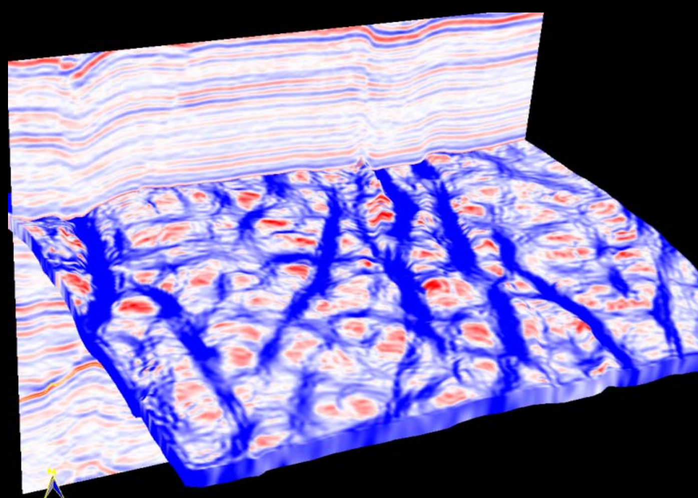
Most-positive curvature (short-wavelength)

Structural curvature versus Amplitude curvature

STRUCTURAL

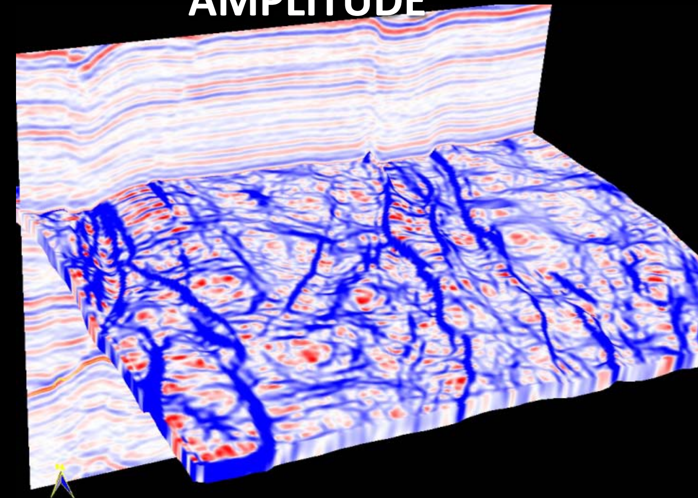


Most-negative curvature (long-wavelength)

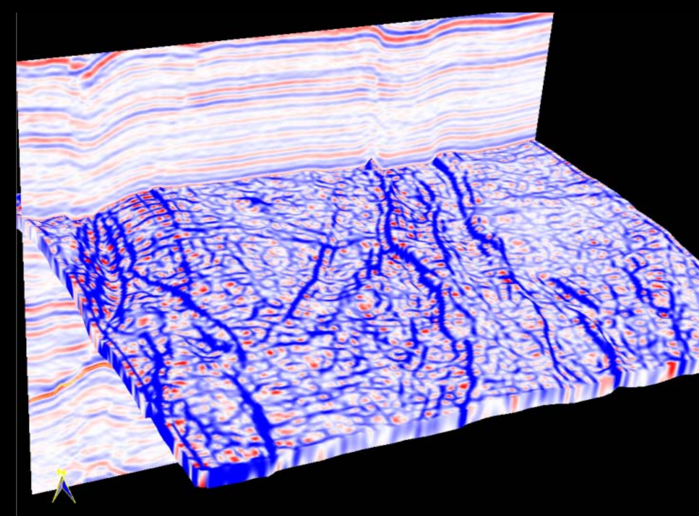


Most-negative curvature (short-wavelength)

AMPLITUDE



Most- negative curvature (long-wavelength)



Most-negative curvature (short-wavelength)

Conclusions

1. Computation of curvature on amplitude gradients furnishes higher level of lineament information that appears to be promising.

2. For data processed with an amplitude preserving sequence, amplitude variations are diagnostic of geologic information.

3. We hope to extend this work to the generation of rose diagrams for the lineaments observed on amplitude curvature and make comparisons with similar roses obtained from image logs.

Acknowledgements

1. Fairborne Energy Ltd.
2. Arcis Seismic Solutions
3. Geomodeling Technology Corporation

THANK YOU for your attention…