Lecture 4: Color display and 3D visualization

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Learner Objectives

After this section you should be able to:

- Identify good and bad color display practices,
- Manipulate HLS and RGB color models,
- Effectively use transparency,
- Display multiple attributes in a single image, and
- Apply color schemes that allow you to effectively communicate these features to others.

Outline

1. **Review physiology of human visual perception**

2. **Examine differences between RGB, CMYK, HLS, and CIE-LAB color models**

3. **Review the following color display models:**
   - **Single gradational color bars**
   - **Dual gradational color bars**
   - **Blended images**
   - **Opacity/transparency mapping**
   - **Composite images**
   - **2-D color tables**
   - **3-D color tables**
   - **Shaded relief images**

4. **Identify good and bad color display practices**

Components of geovolume visualization and interpretation

1. **Recognition : determining distinguishing characteristics of an event to be mapped,**
2. **Signal Analysis: enhancing the distinguishing characteristics,**
3. **Color: selection of the optimum color scheme**
4. **Motion: animate between different depths, slices, or even attributes**
5. **Isolation via voxel processing: separation of events of interest from other data**
6. **Distance: accurate 3-D binocular projections**

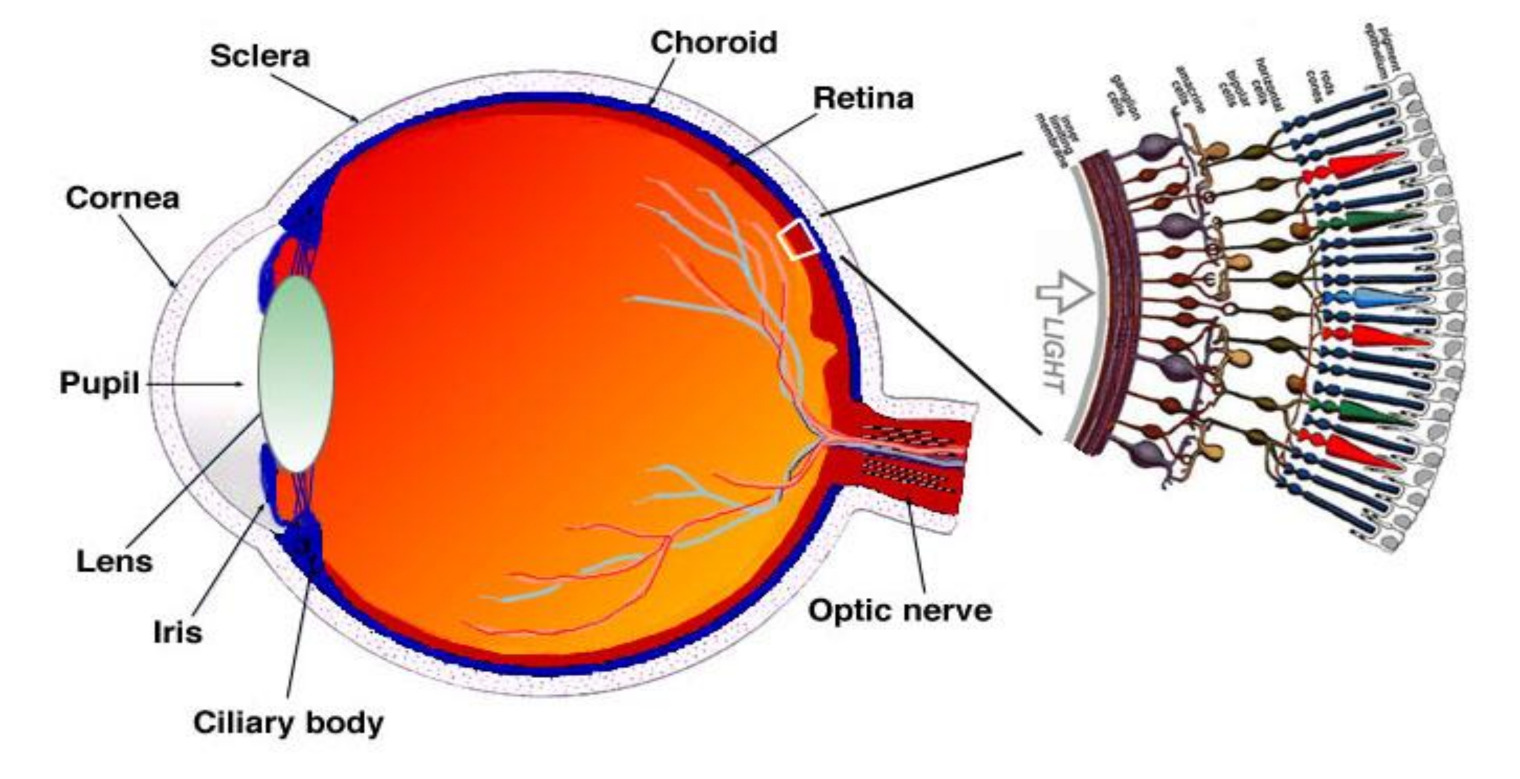
(Sheffield et al., 2000)

Color vision

Cone and Rod receptors

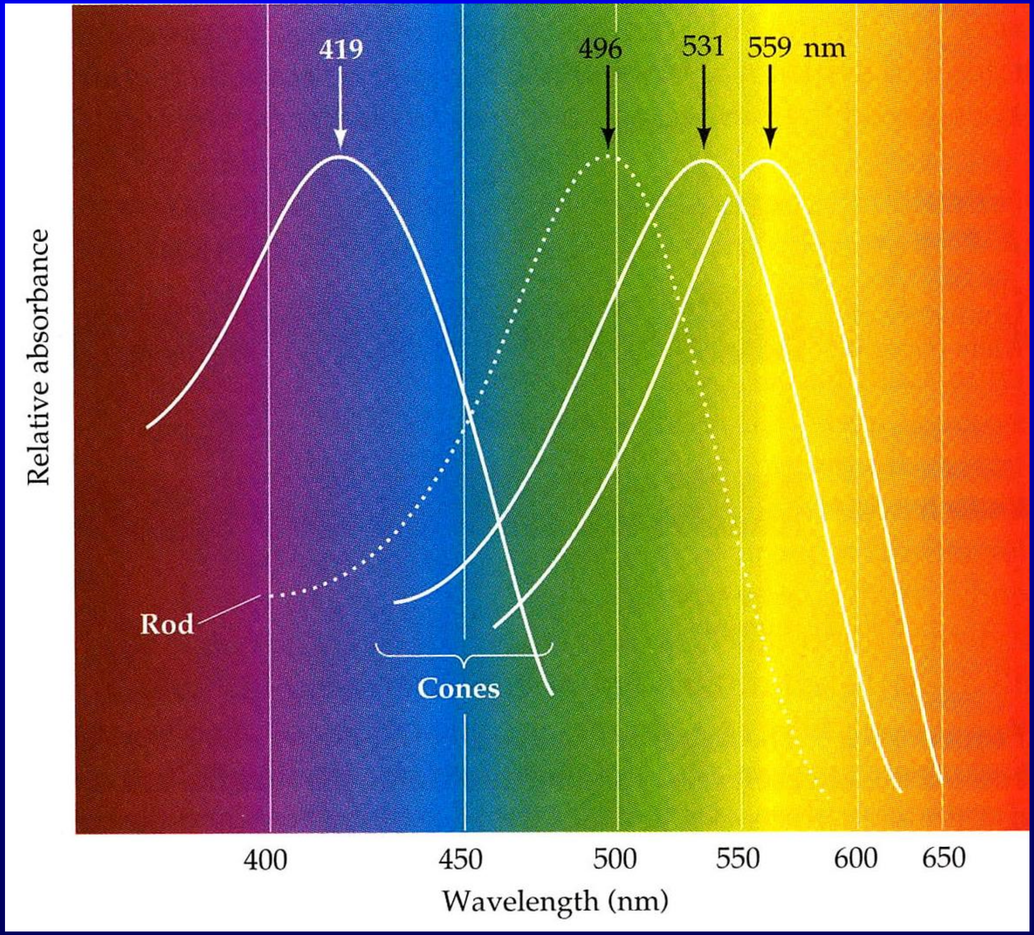
Cone: 3 types, each being sensitive to a different range of wavelengths

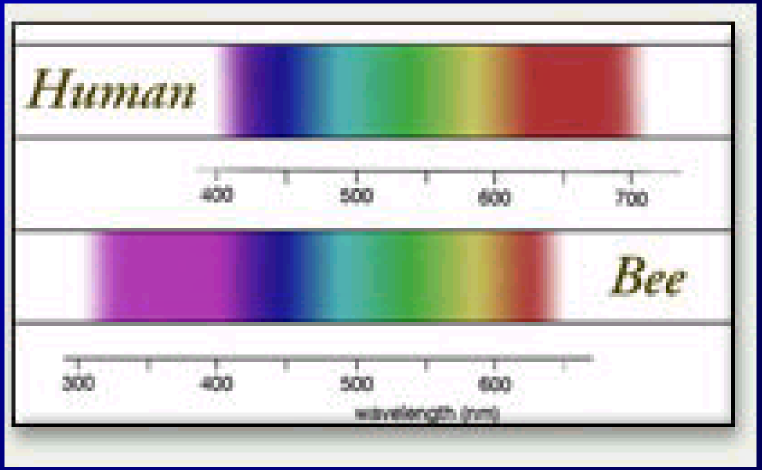
Rod: for night vision, sensitive to a broad range of light intensities



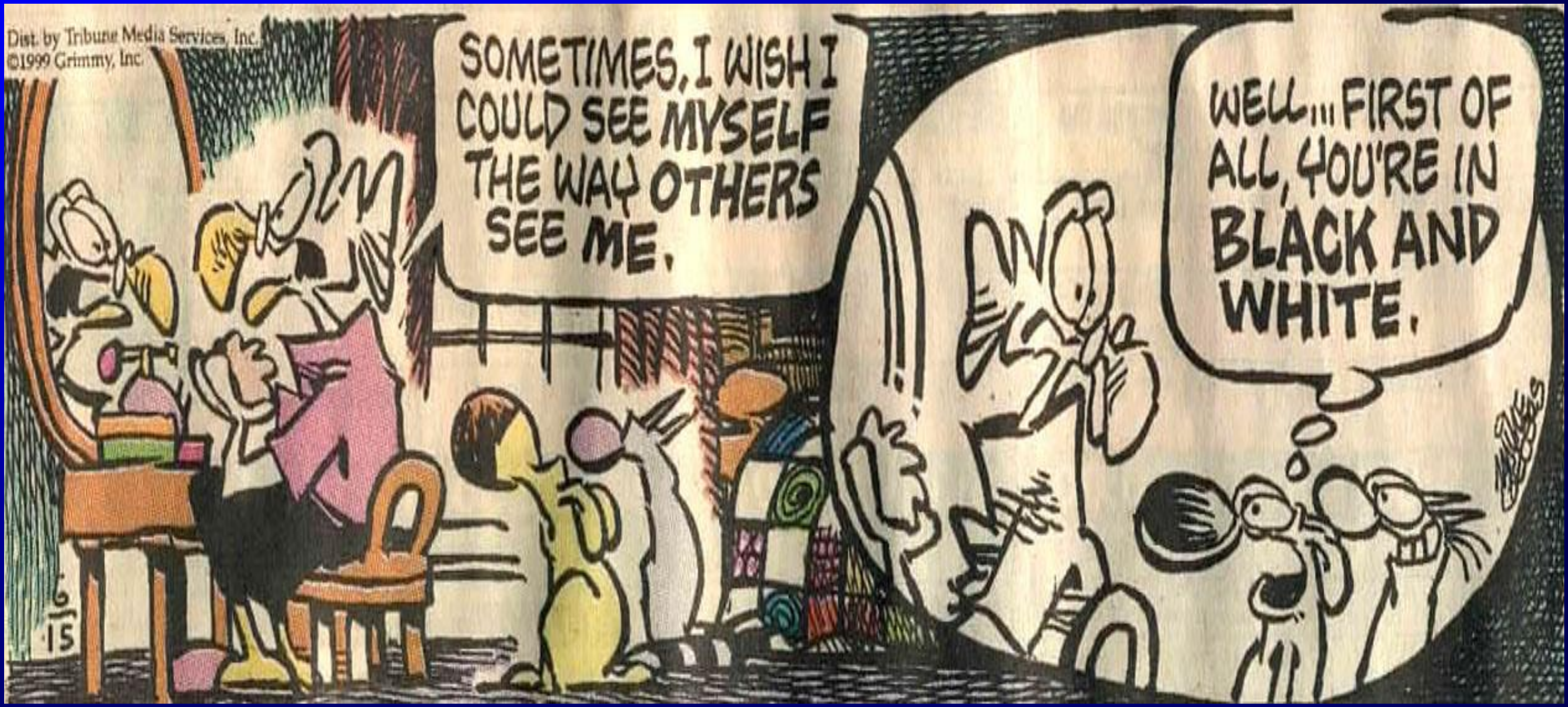
Visible spectrum

Cone response is interpreted by the brain as colors



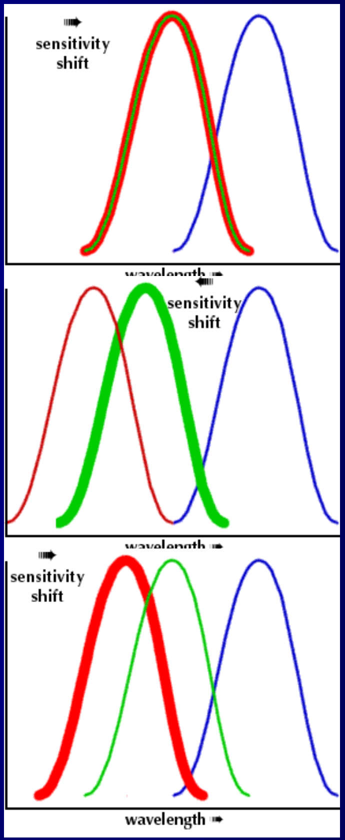


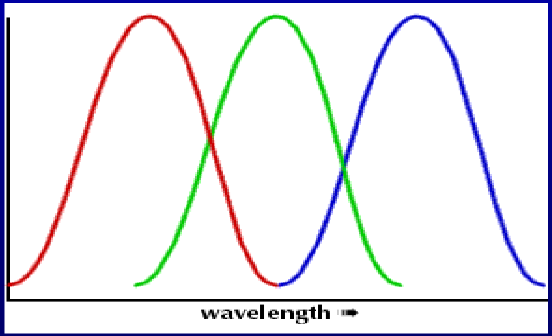
The range of vision for the bee and butterfly extends into the ultraviolet. What kind of colors do they see?

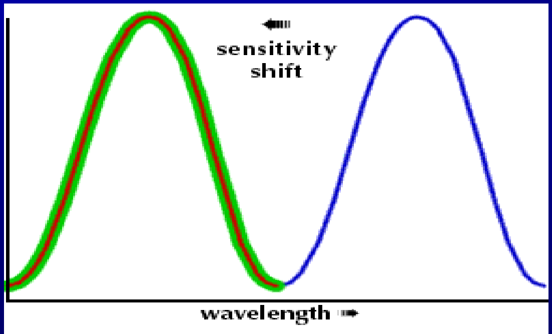

Dist. by Tribune Media Services, Inc.
©1999 Grimmy, Inc.
SOMETIMES, I WISH I COULD SEE MYSELF THE WAY OTHERS SEE ME.
WELL... FIRST OF ALL, YOU'RE IN BLACK AND WHITE.
6-15

Color deficiency

All color blindness
8.0% male
0.5% female





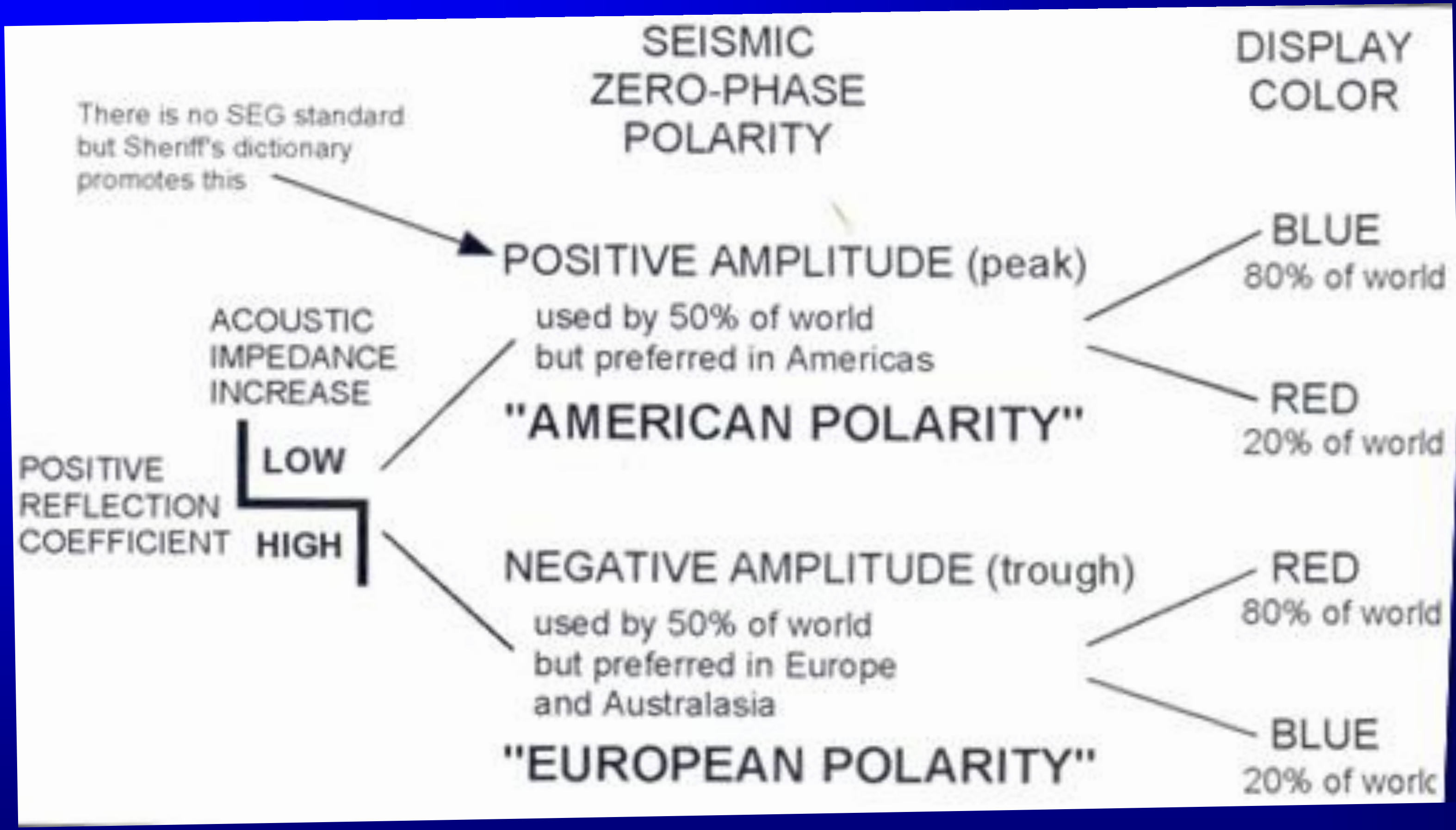


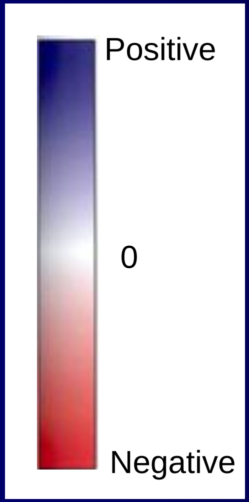
normal perception

red-green deficiency ~5% male

http://www.firelily.com/opinions/color.html

Polarity conventions

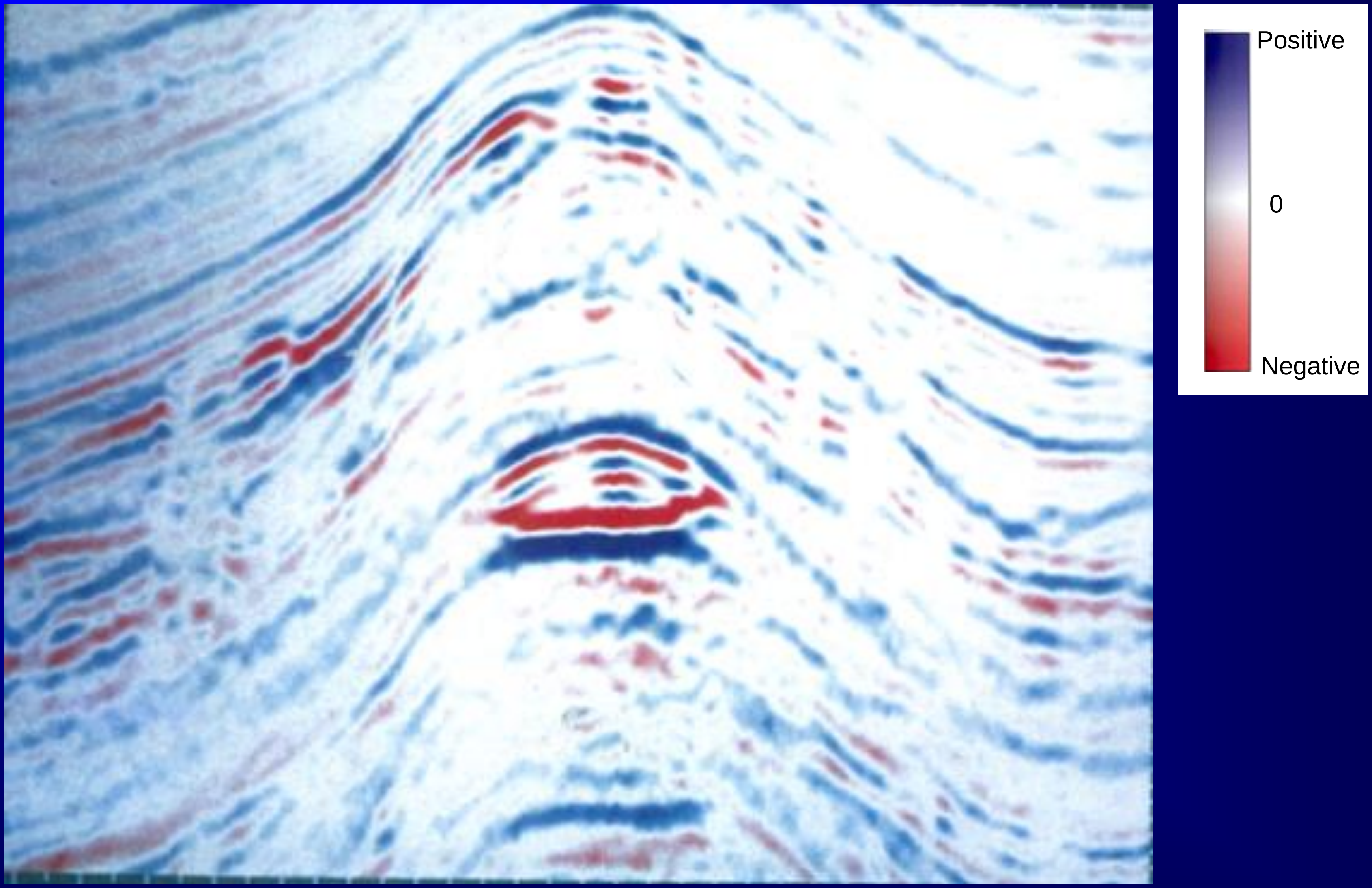




1. Use blue for positive, red for negative
2. Always display your color bar, labeled with 'Positive', '0', and 'Negative'
3. Identify which polarity convention you are using

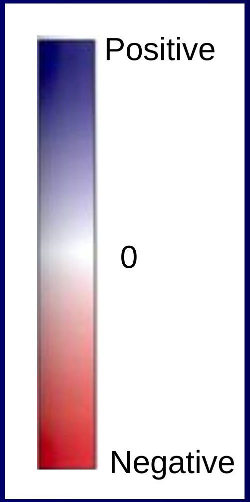
(Brown, 2007)

Flat spot showing polarity of 90 degrees



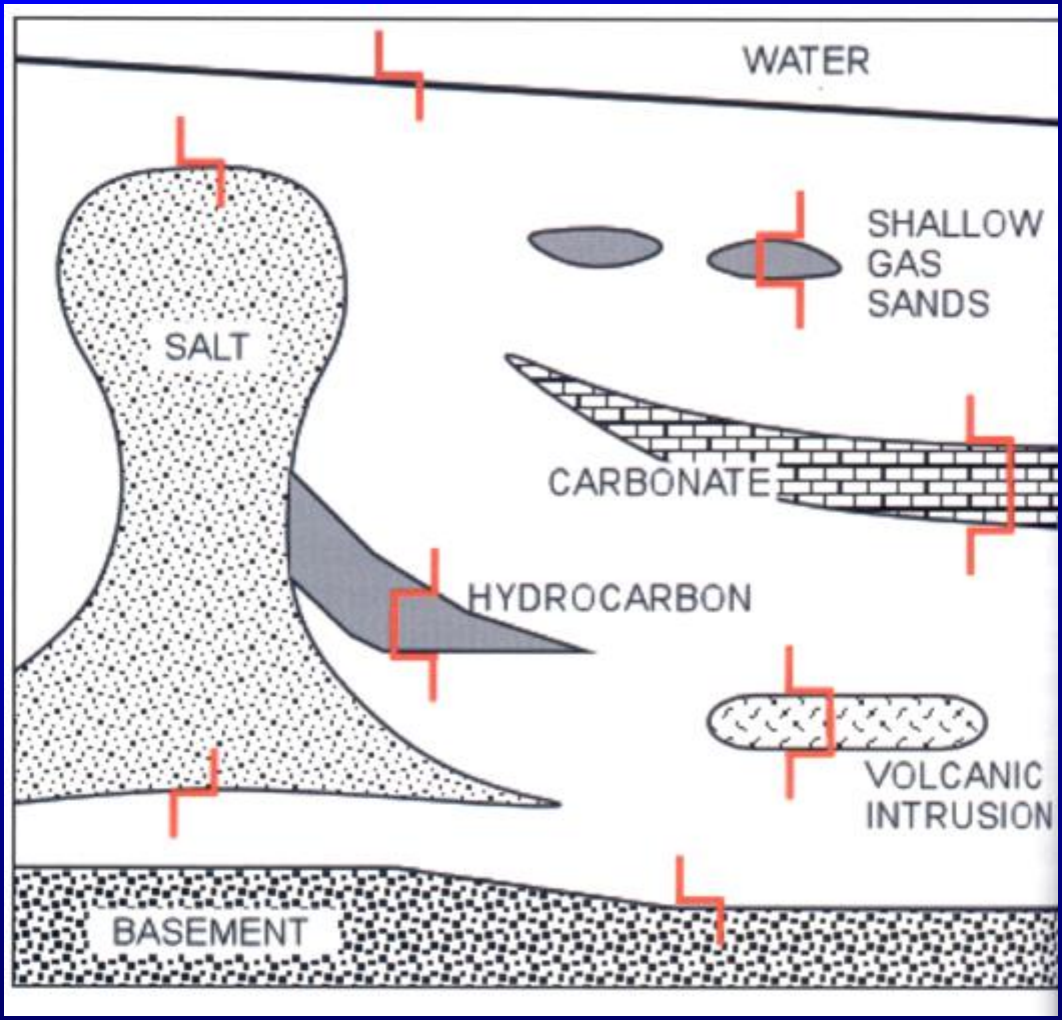
(Brown, 2007)

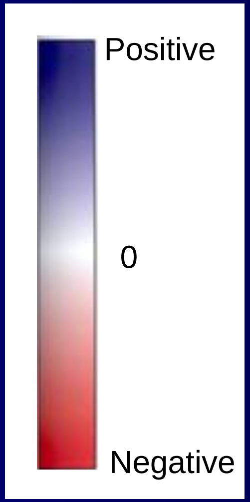
Shallow gas showing polarity of 90 degrees



(Brown, 2007)

Assessing polarity in the absence of well control



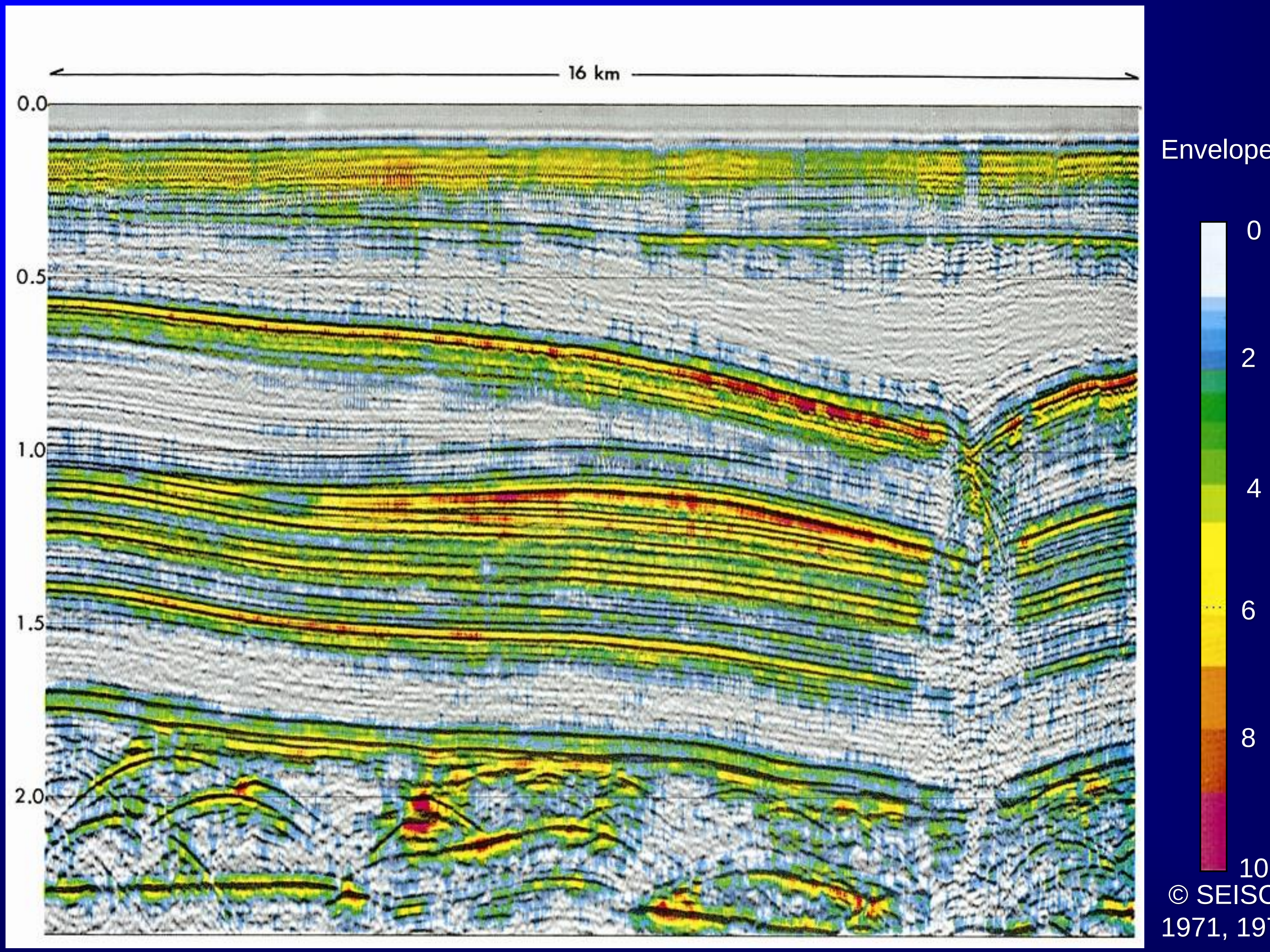


(Brown, 2007)

Multiattribute Display Tools

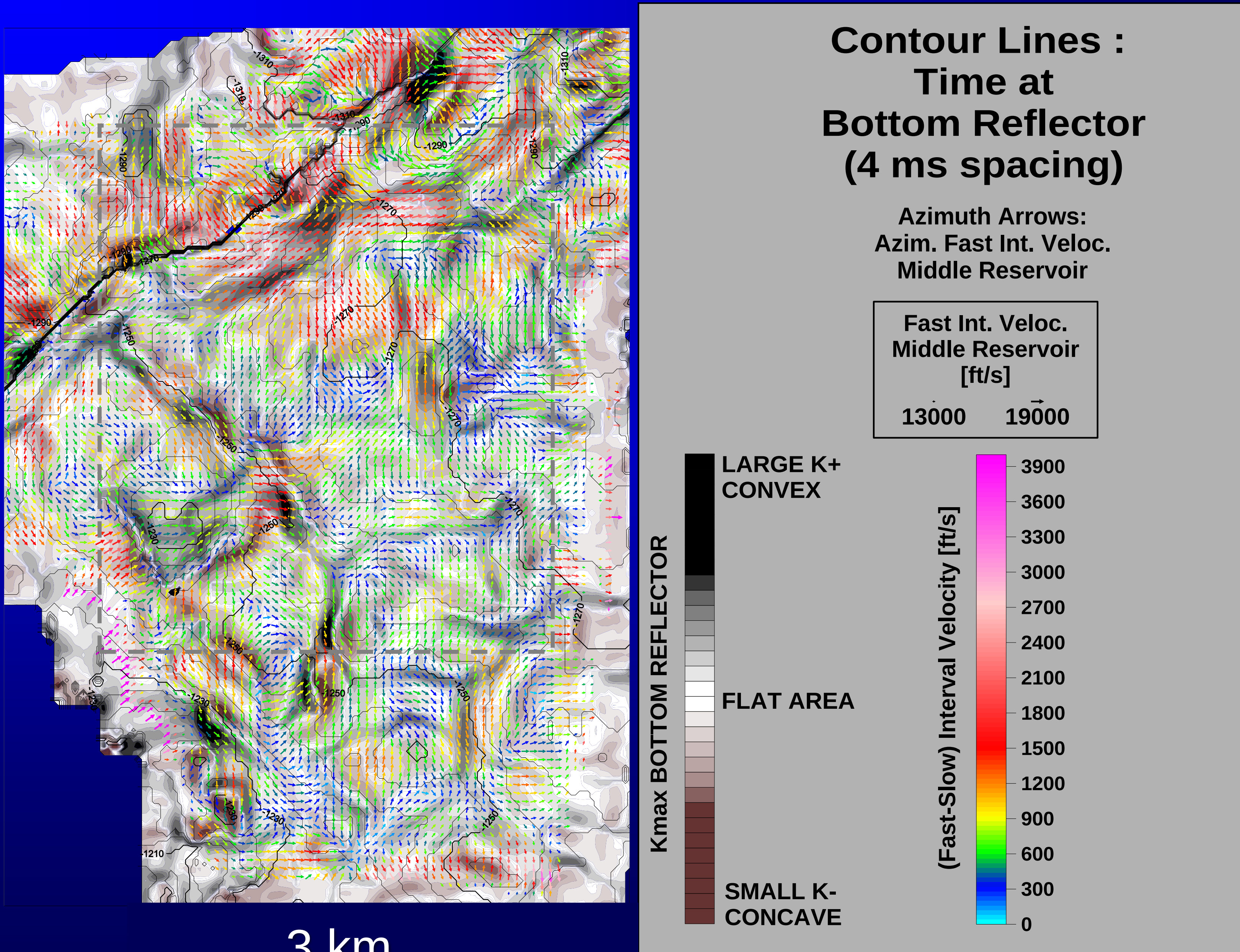
- Overplotting
- Shaded relief maps
- Bump maps
- Color blending/transparency/opacity
- RGB blended images
- HLS color modulated images

Multiattribute display using overlays



(Anstey, 2005)

Multiattribute display of vector data using color icons



3 km

(Simon, 2005)

Multiattribute Display Tools

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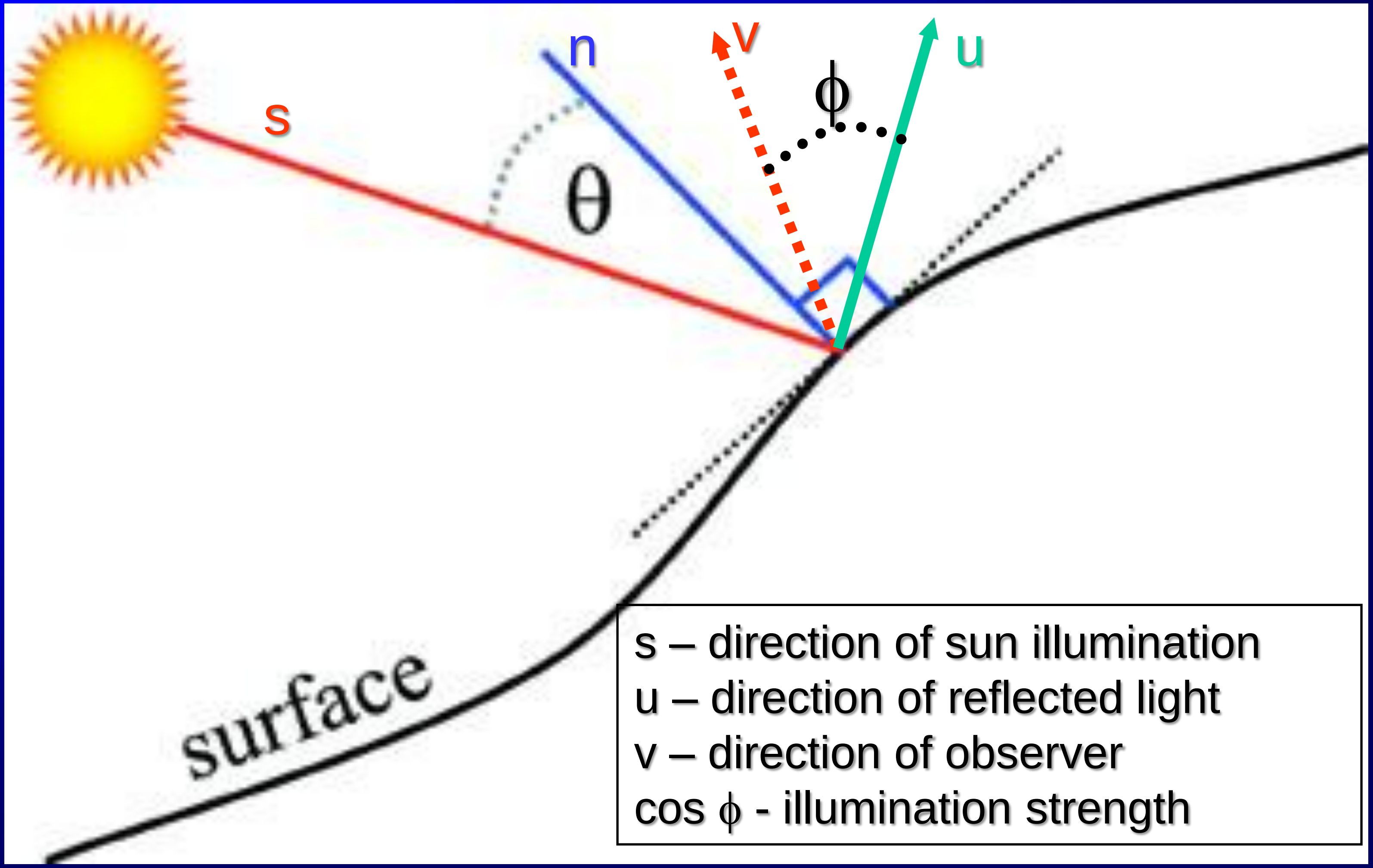
- HLS color modulated images

Shaded relief – specular illumination



(Barnes, 2002)

Diffuse reflection

$$I_d = \hat{\mathbf{s}} \cdot \hat{\mathbf{n}} = \cos(\theta)$$

sun vector

normal to surface

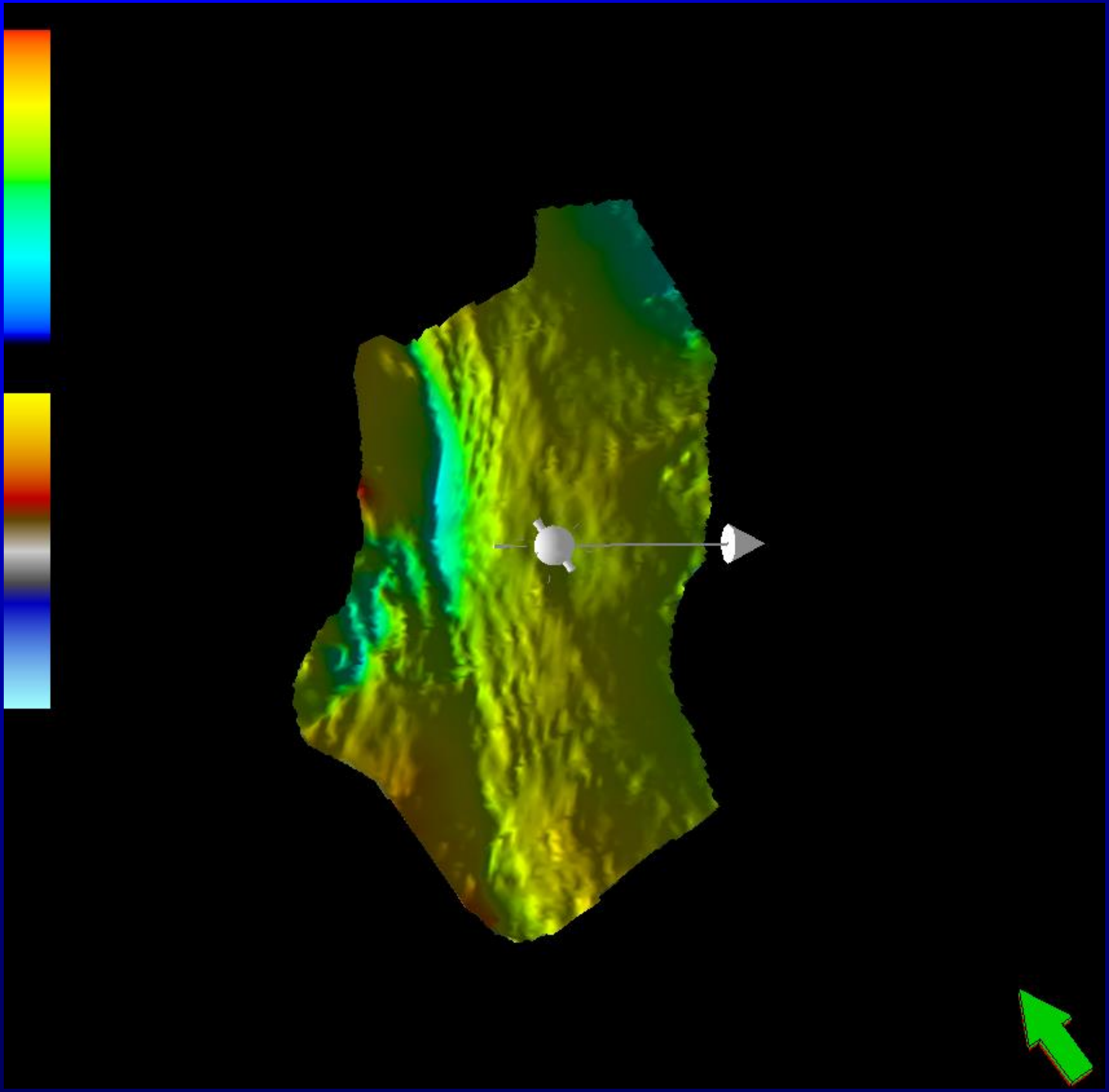
Specular reflection

$$I_s = \left\| \hat{\mathbf{u}} \cdot \hat{\mathbf{v}} \right\|^b = \left\| \cos(\phi) \right\|^b$$

vector to observer

reflection vector

Shaded relief map (using modern commercial software)



(Data courtesy of Anadarko)

Multiattribute Display Tools

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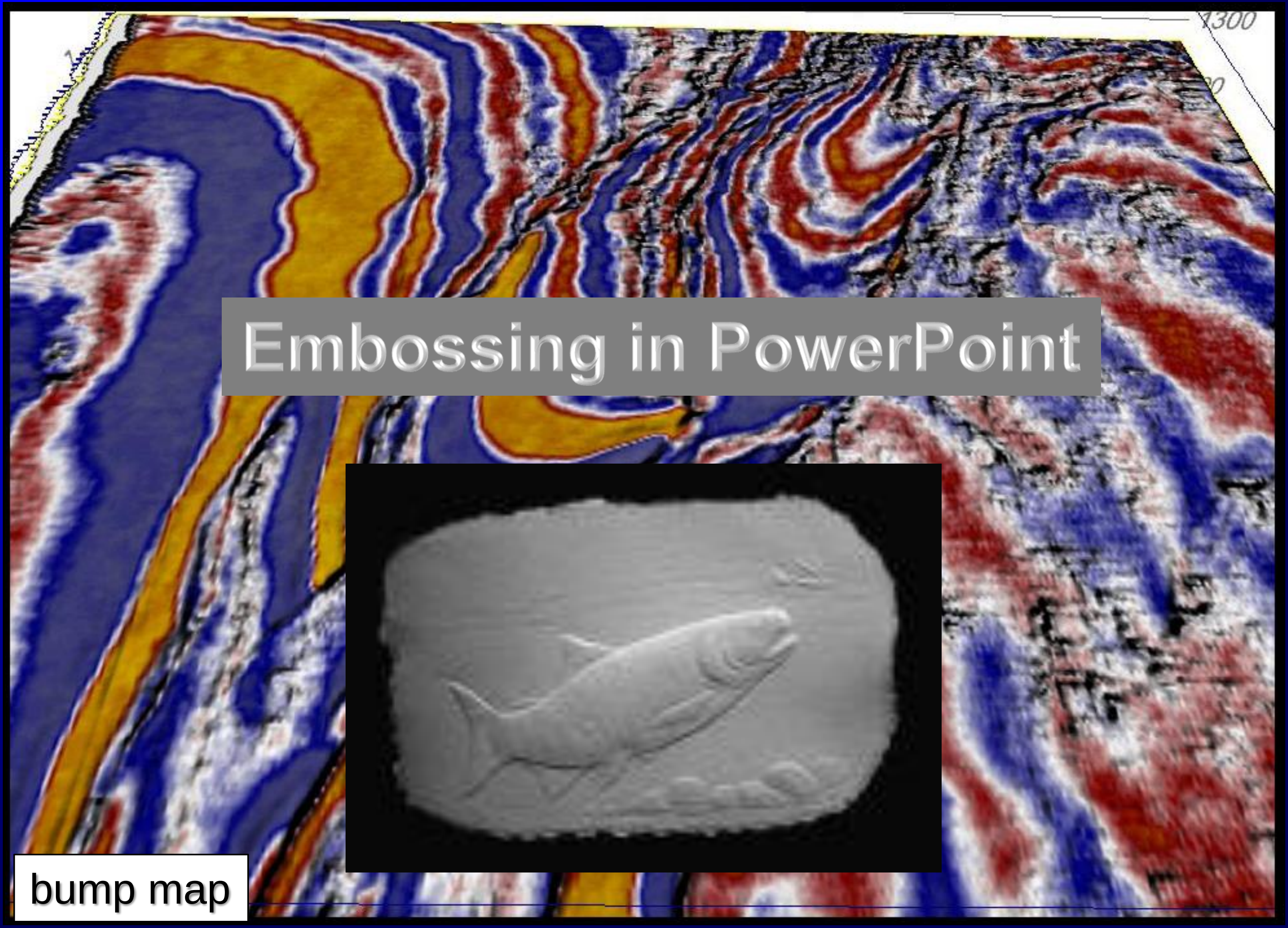
Horizon 'Bump Maps'



(Lynch et al., 2005)

Multiattribute Display Tools

- Overplotting
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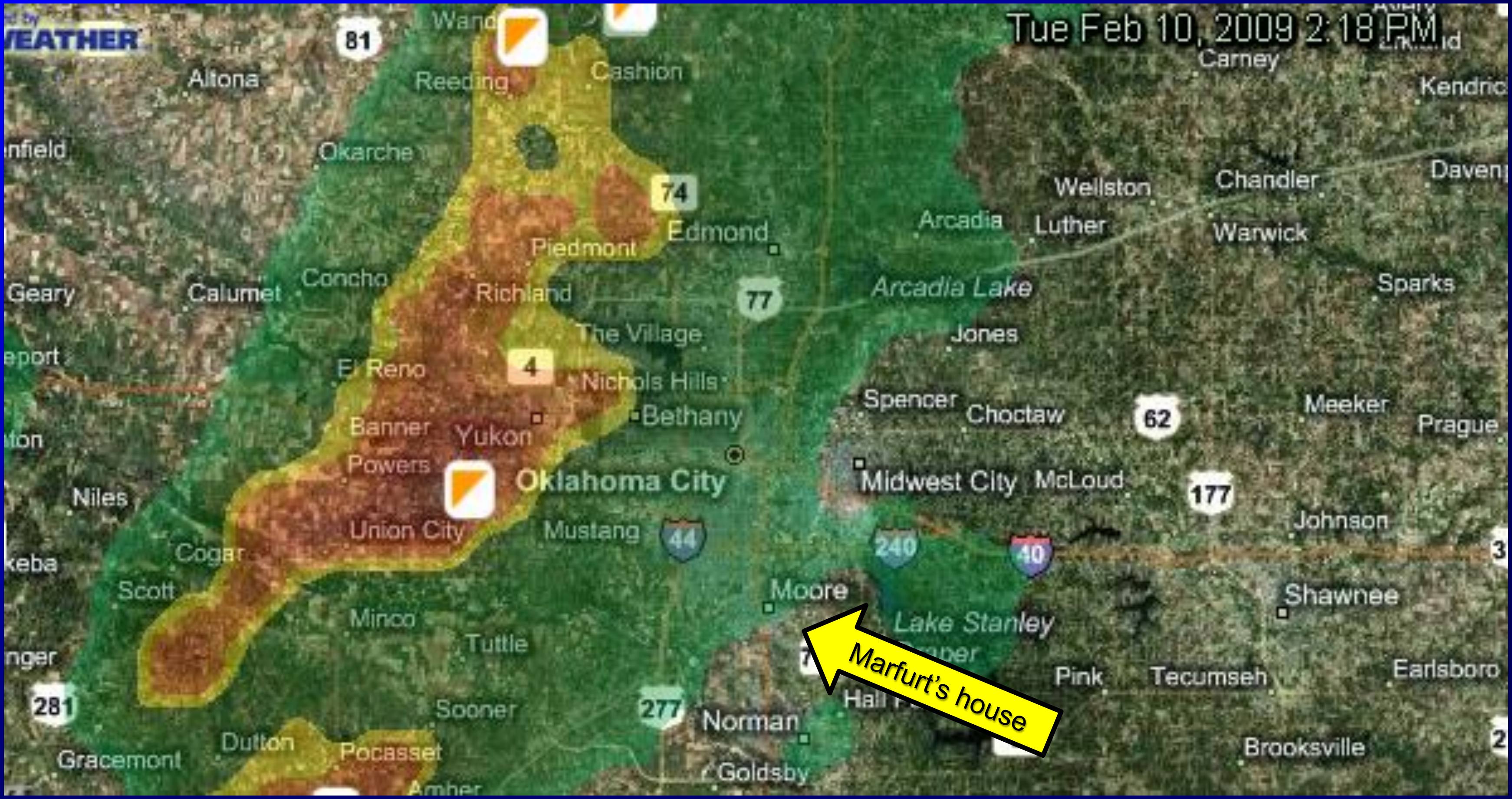
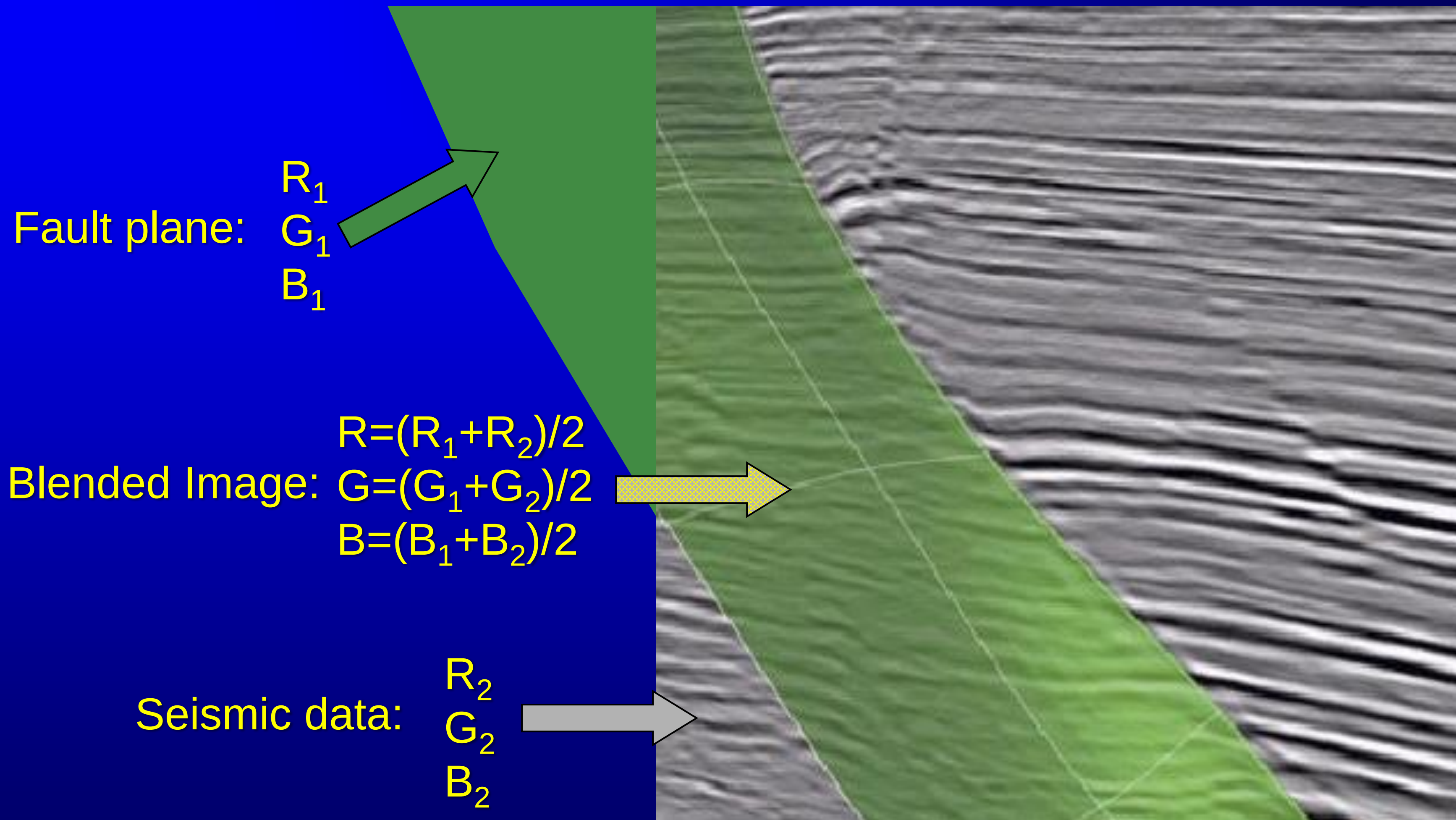
- HLS color modulated images

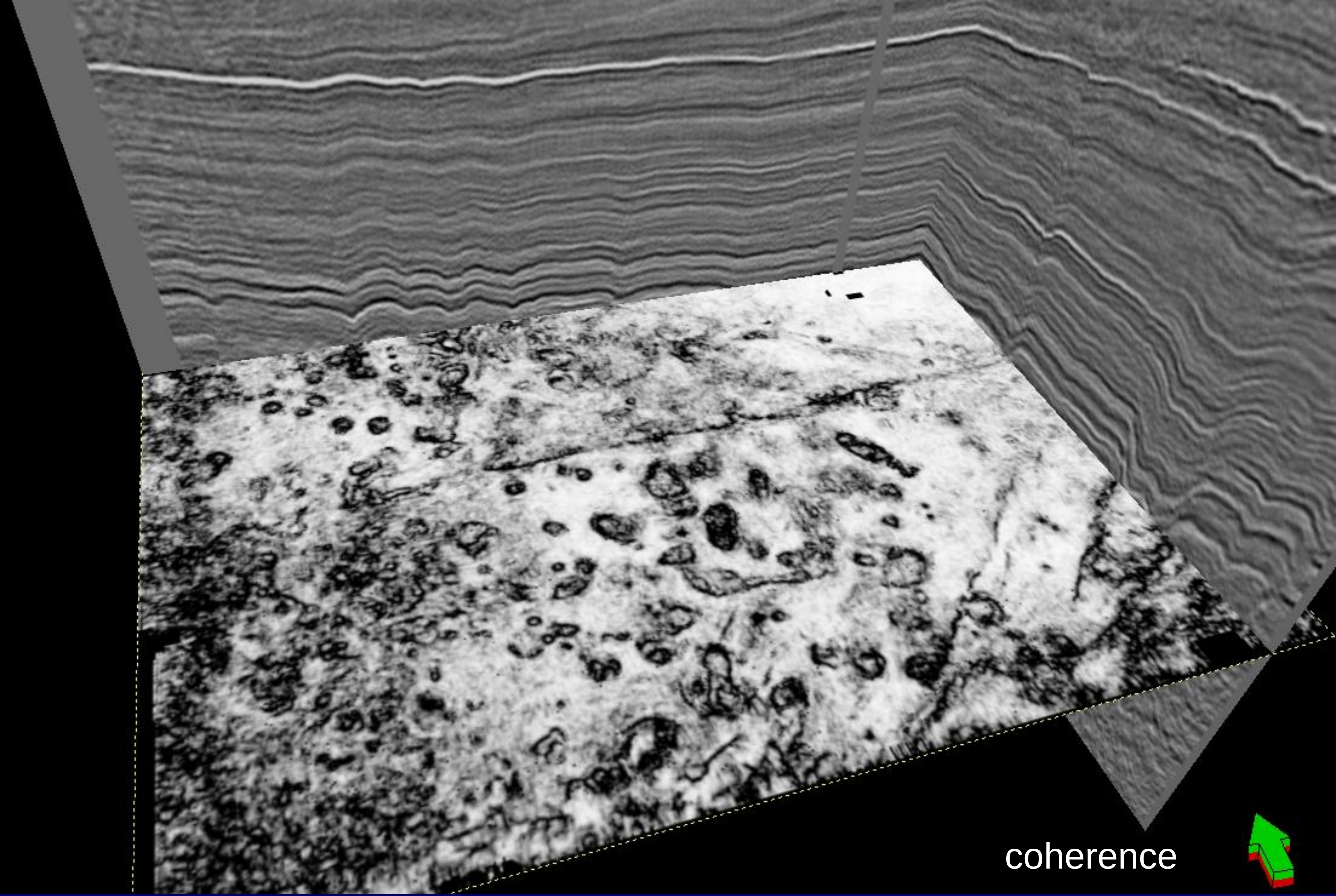
Everyday applications of opacity



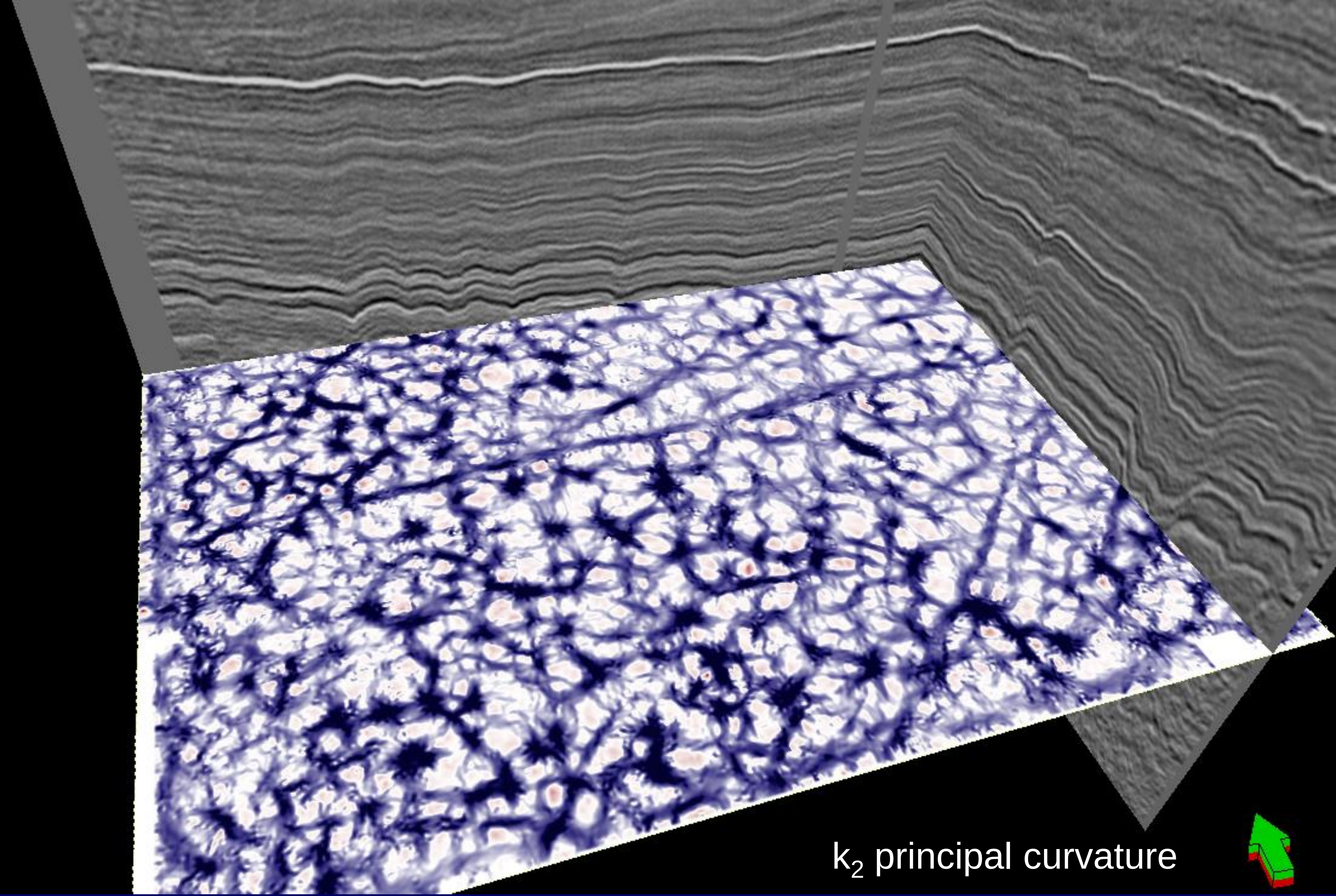
Multiattribute display using blending/transparency/opacity



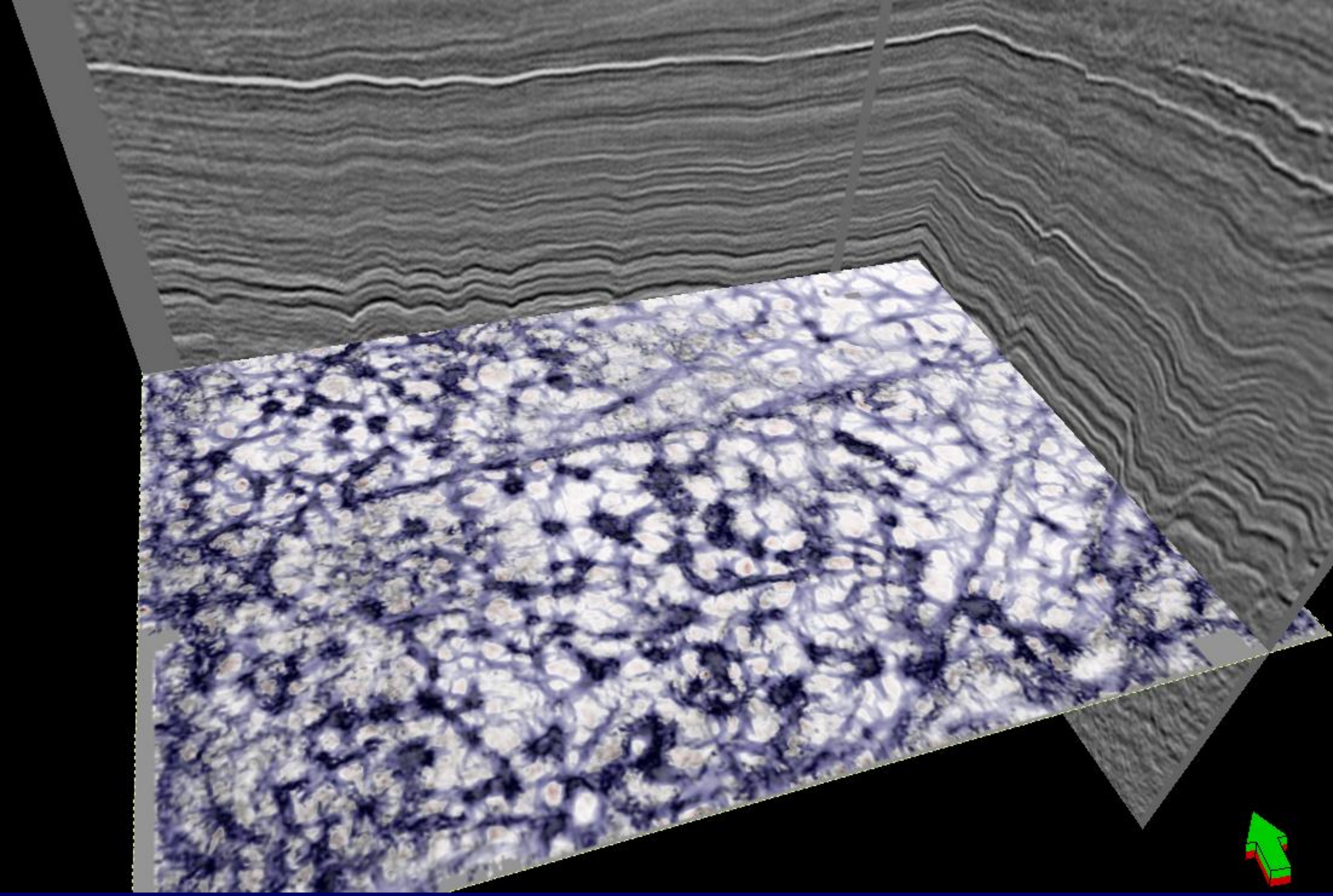
(after Meyer et al., 2001)



Animating coherence and k_2 principal curvature

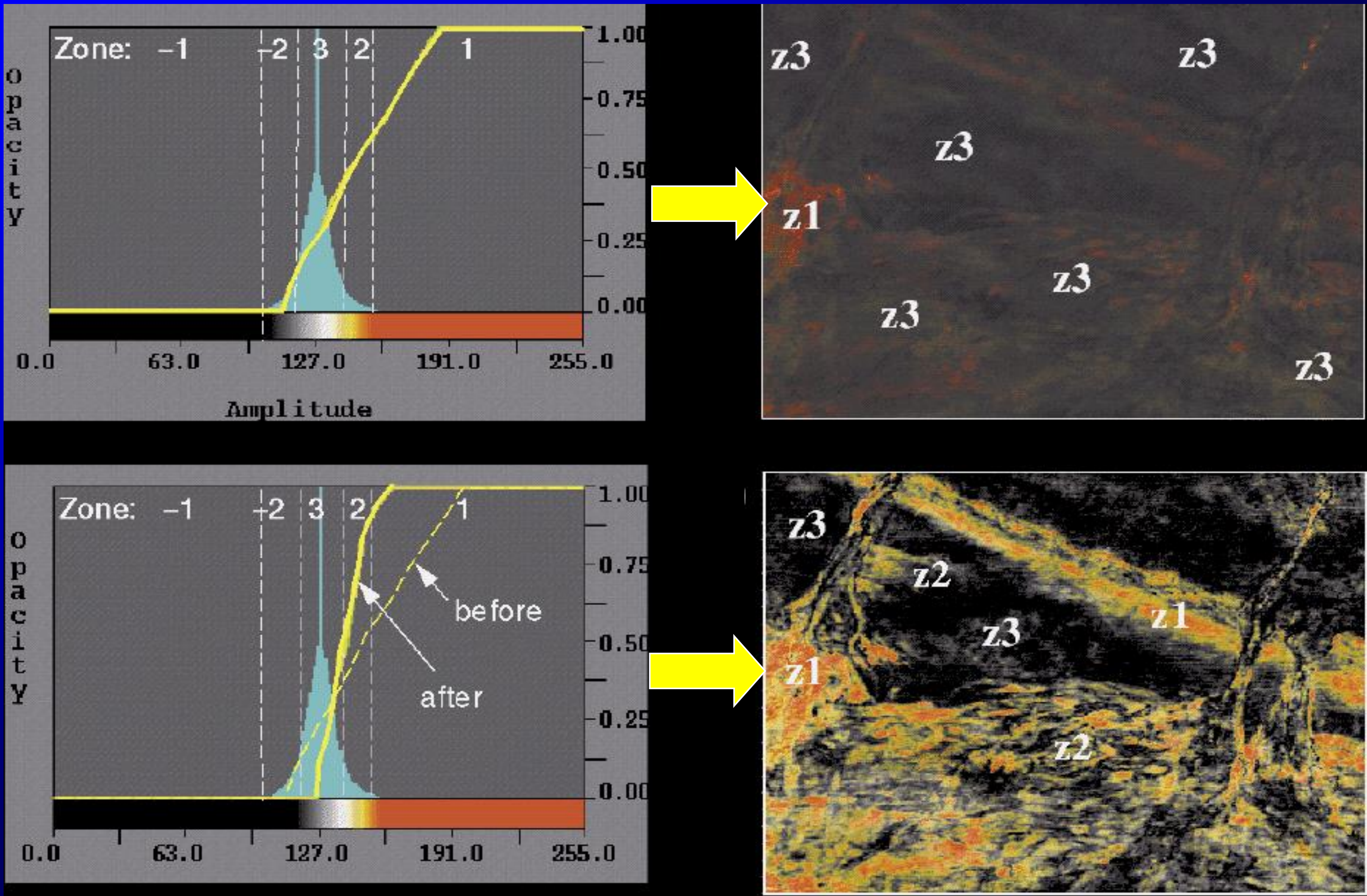


Animating coherence and k_2 principal curvature



Co-rendering coherence and k_2 principal curvature (50% opacity)

Alpha-blending of 20 horizon slices



(Kidd, 1999)

Color Depth (the number of colors)

16,777,216 colors
R=256,G=256,B=256

(24-bit color)

4096 colors
R=16,G=16,B=16

216 colors
R=6,G=6,B=6

Only a few interpretation packages provide 24-bit color.
Most are still limited to 8-bit color (256 colors)

(Dao and Marfurt, 2011)

Multiattribute Display Tools

- Overplotting
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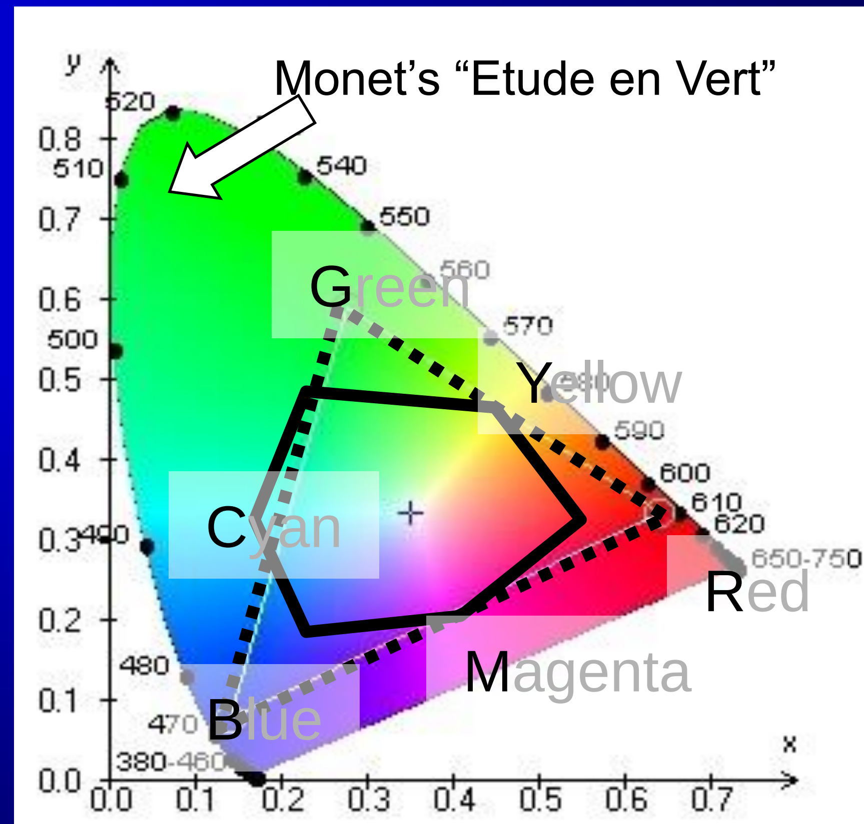
- Bump maps
- Color blending/transparency/opacity
- RGB blended images
- HLS color modulated images

nd CMY color models

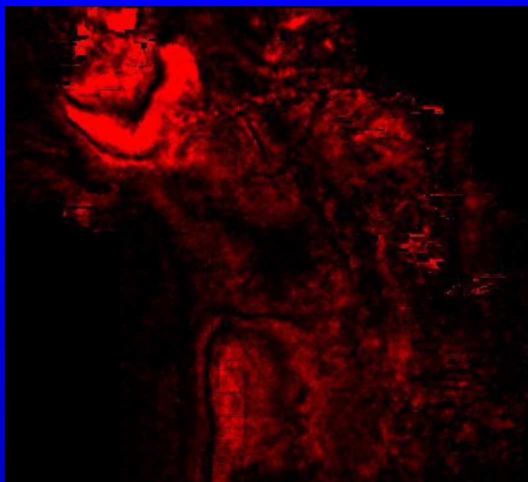
- F[...]eens
- CMYK used for hard copies



Commission International d'Eclairage (CIE) color map of human visual perception

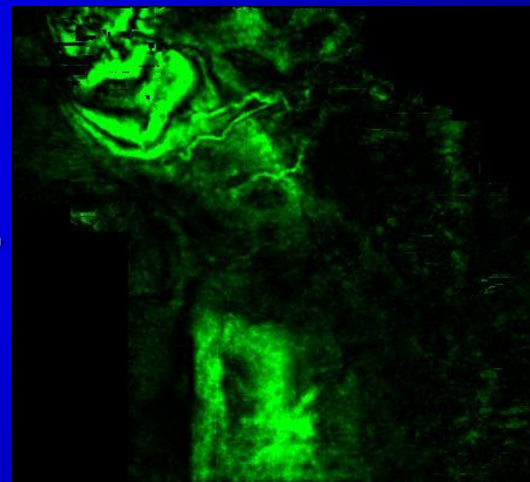
http://www.hf.faa.gov

RGB color stack



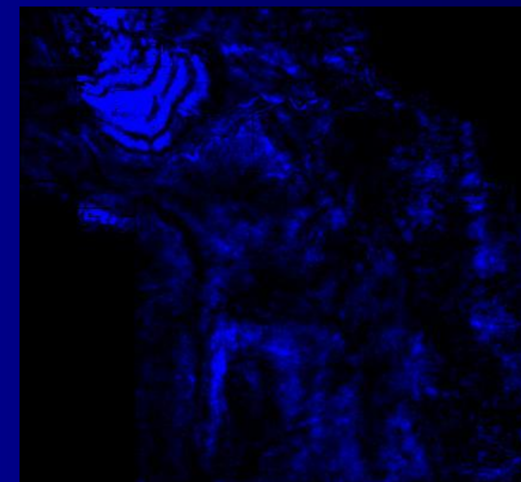
Red =16 Hz

+



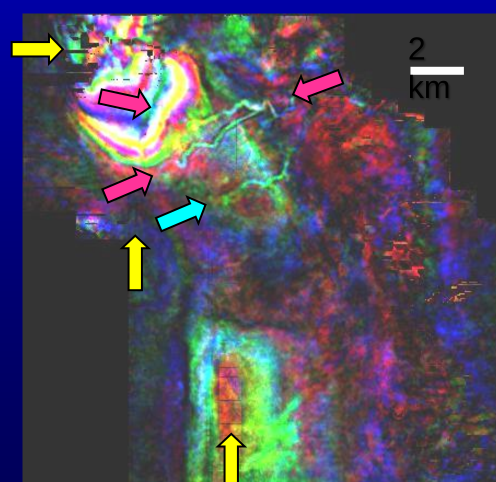
Green=32 Hz

+



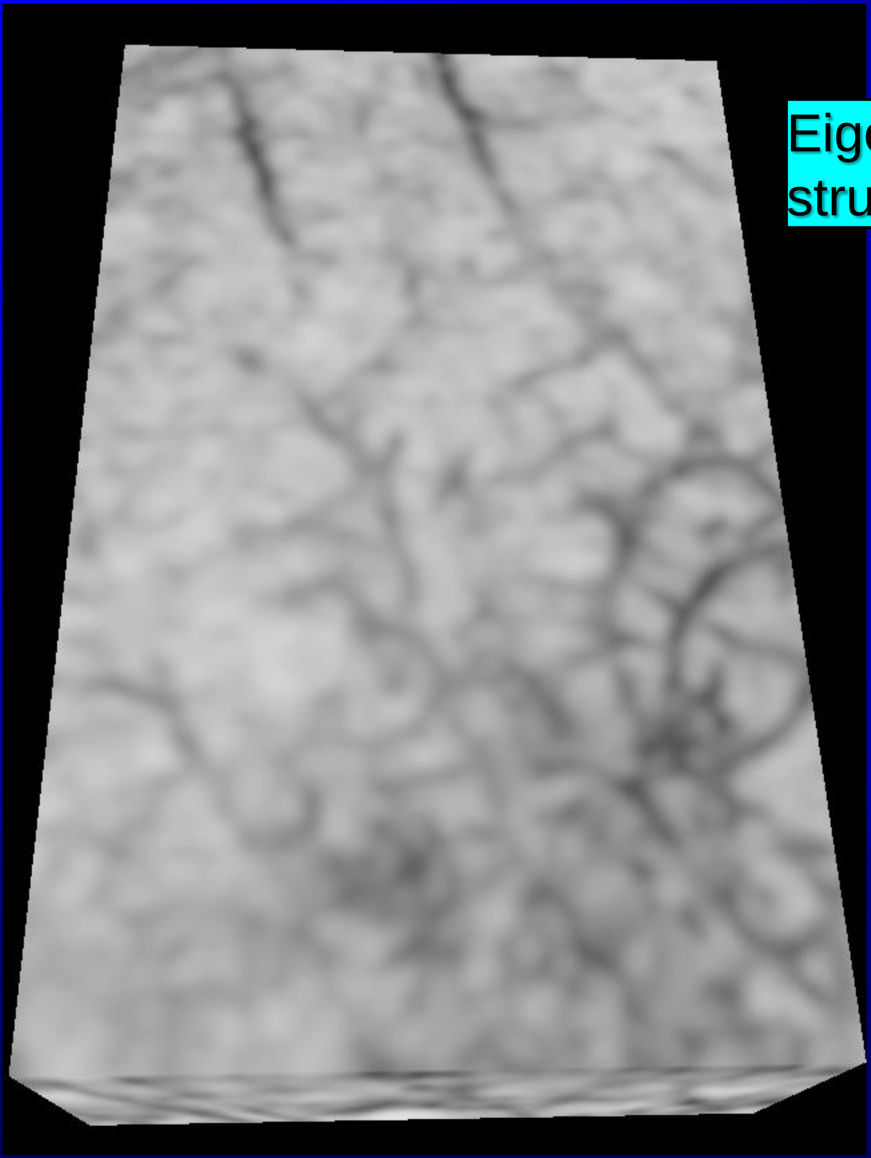
Blue=48

=



(Guo and Marfurt, 2007)

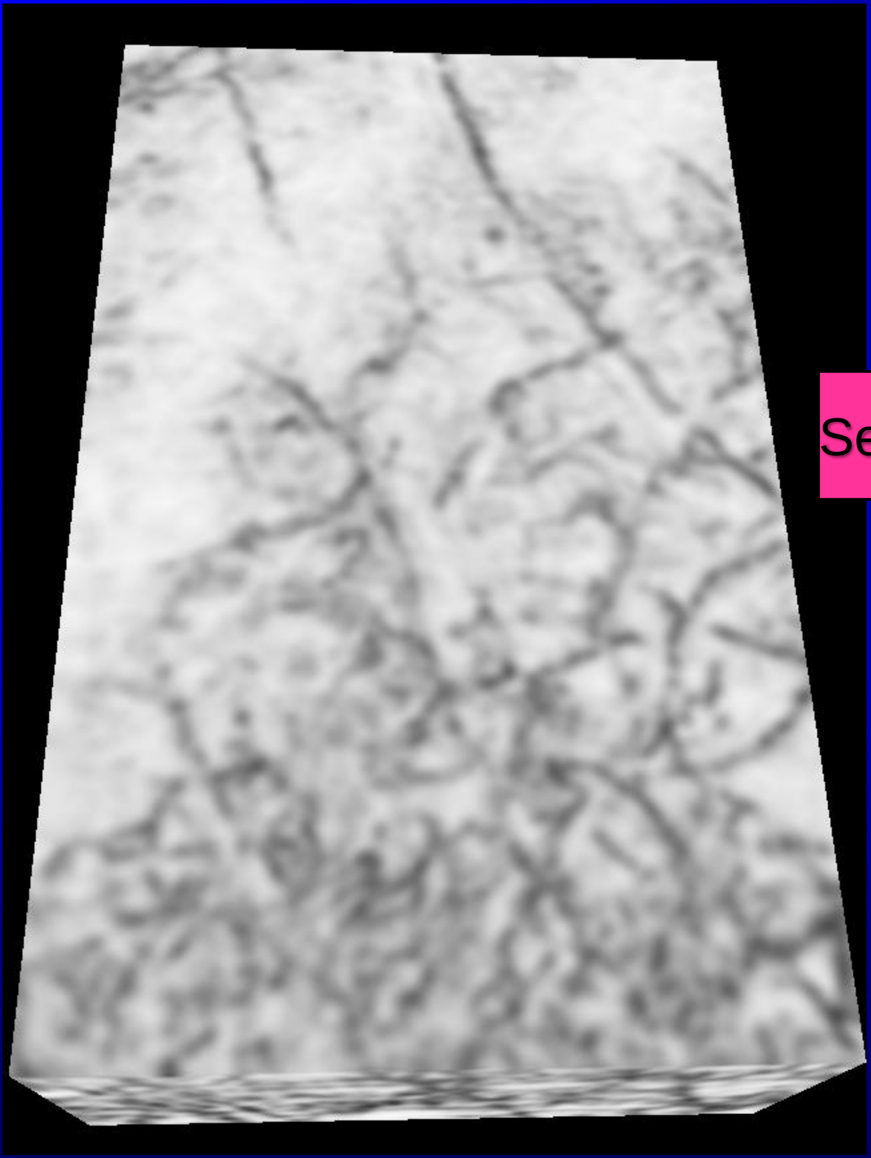
CMY color stack



Eigenvalues of gradient structure tensor

(Courtesy ffA)

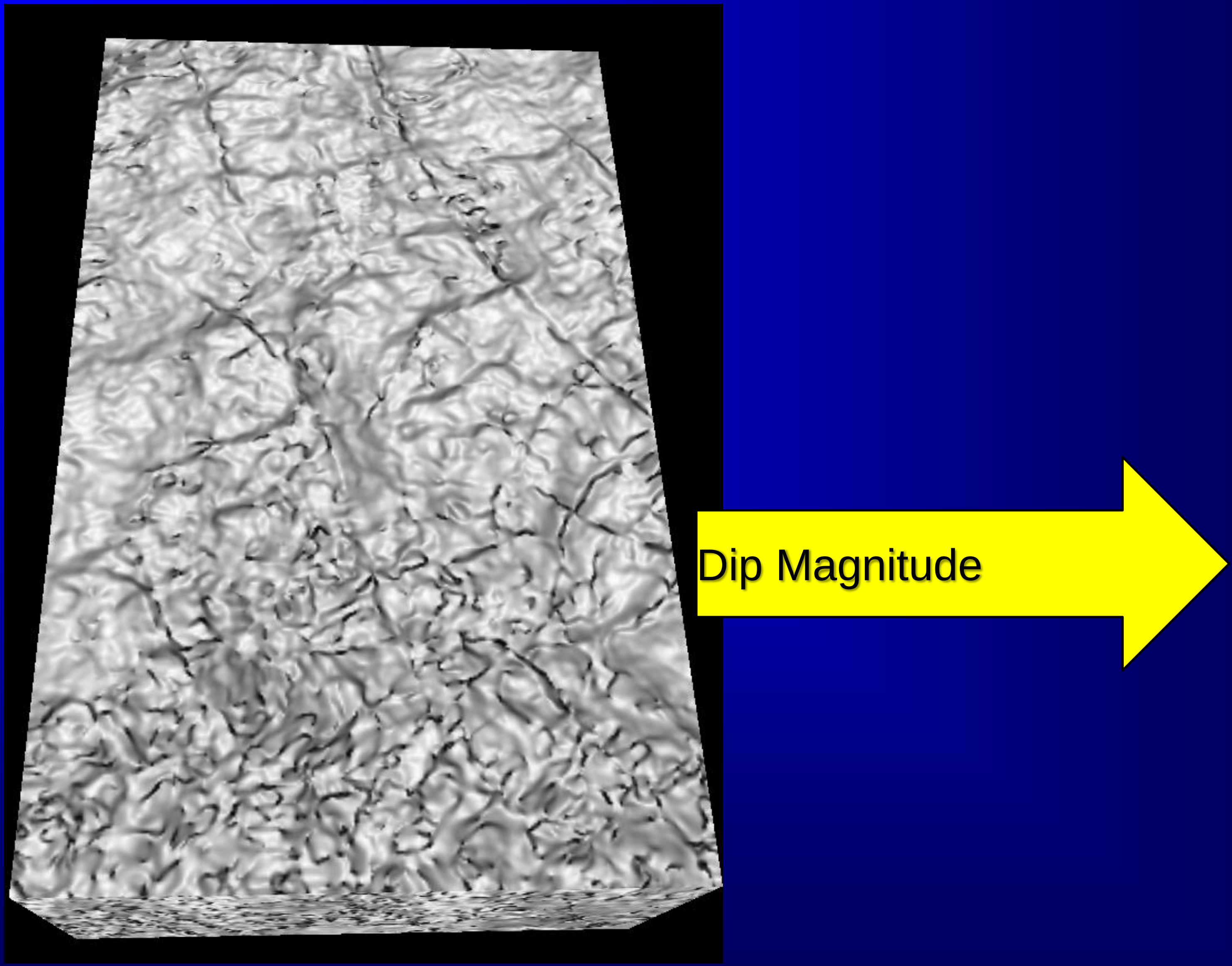
CMY color stack



Semblance

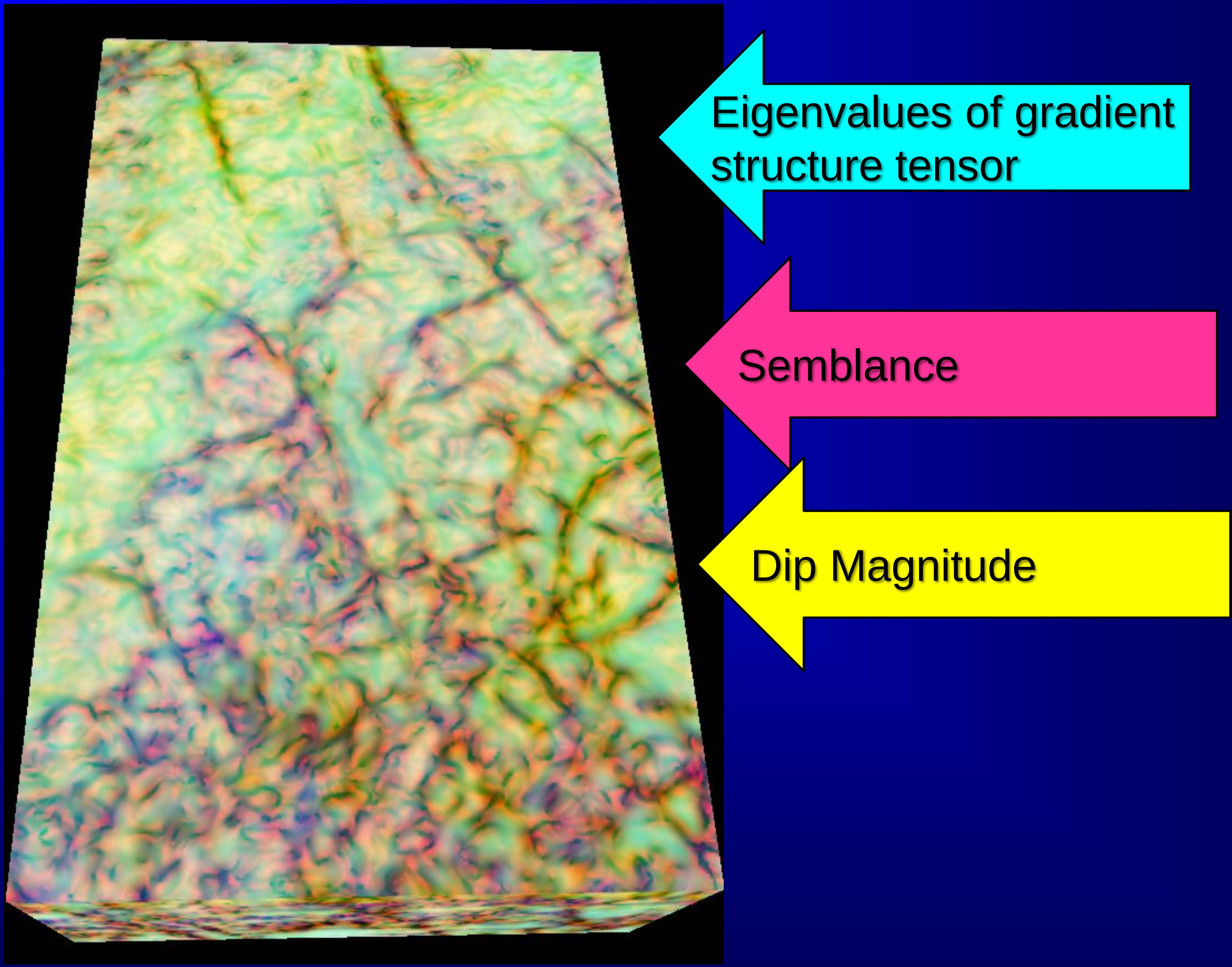
(Courtesy ffA)

CMY color stack



(Courtesy ffA

CMY color stack



(Courtesy ffA)

Multiattribute Display Tools

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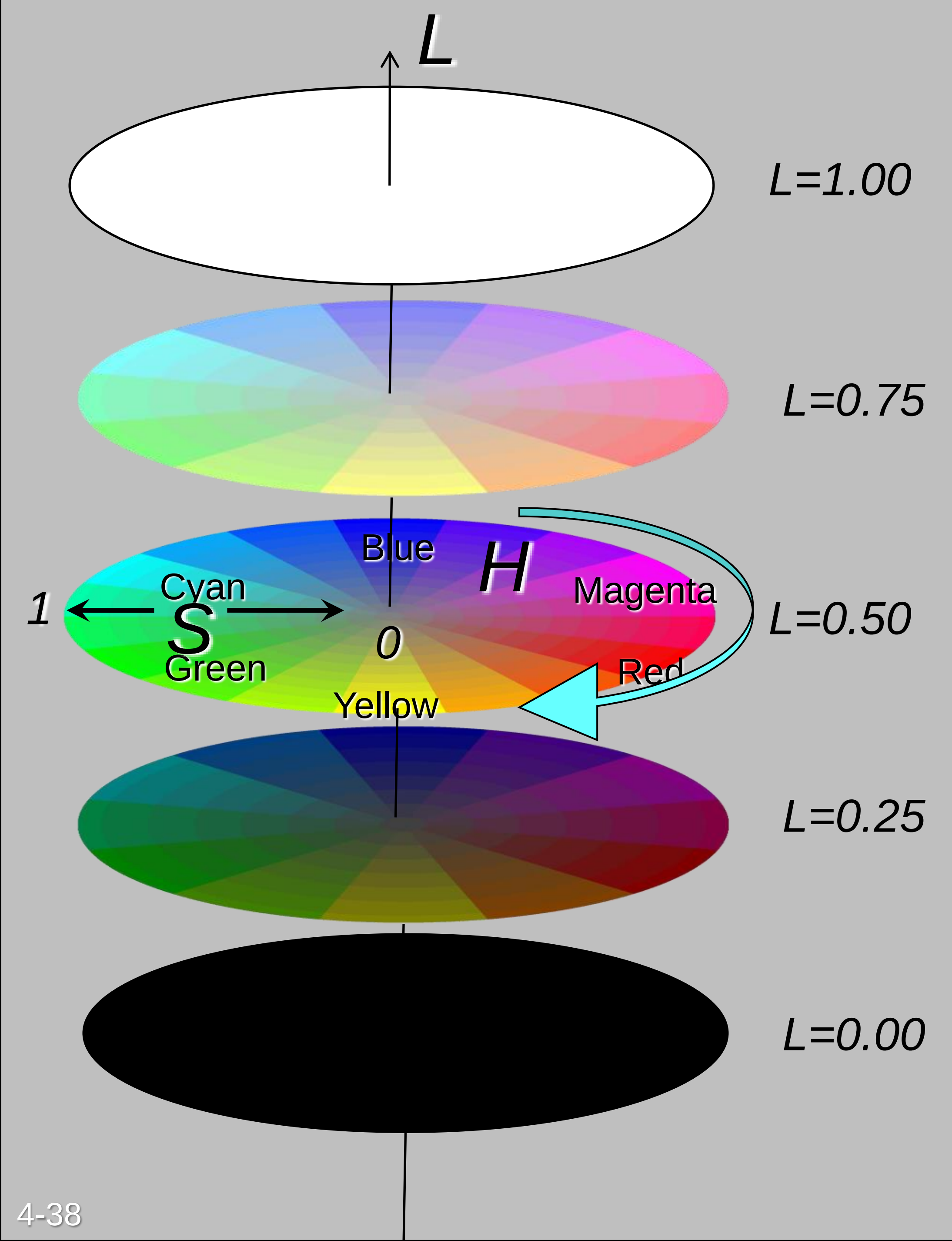
- RGB blended images
- HLS color modulated images

The HLS color model



Hue: the wavelength contrast aspect of color

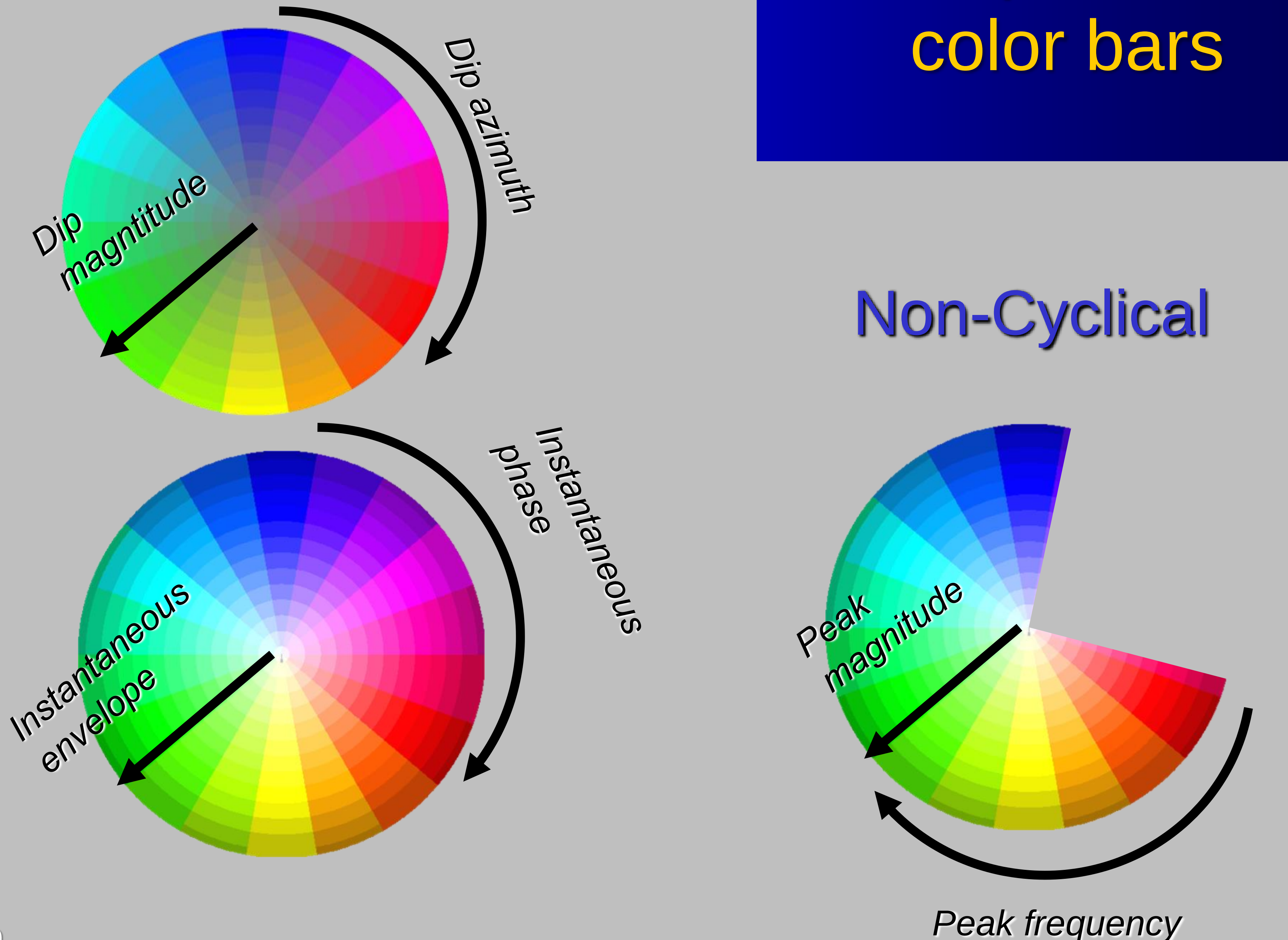
Lightness: the level of illumination

Saturation: the degree to which the hue differs from a neutral gray

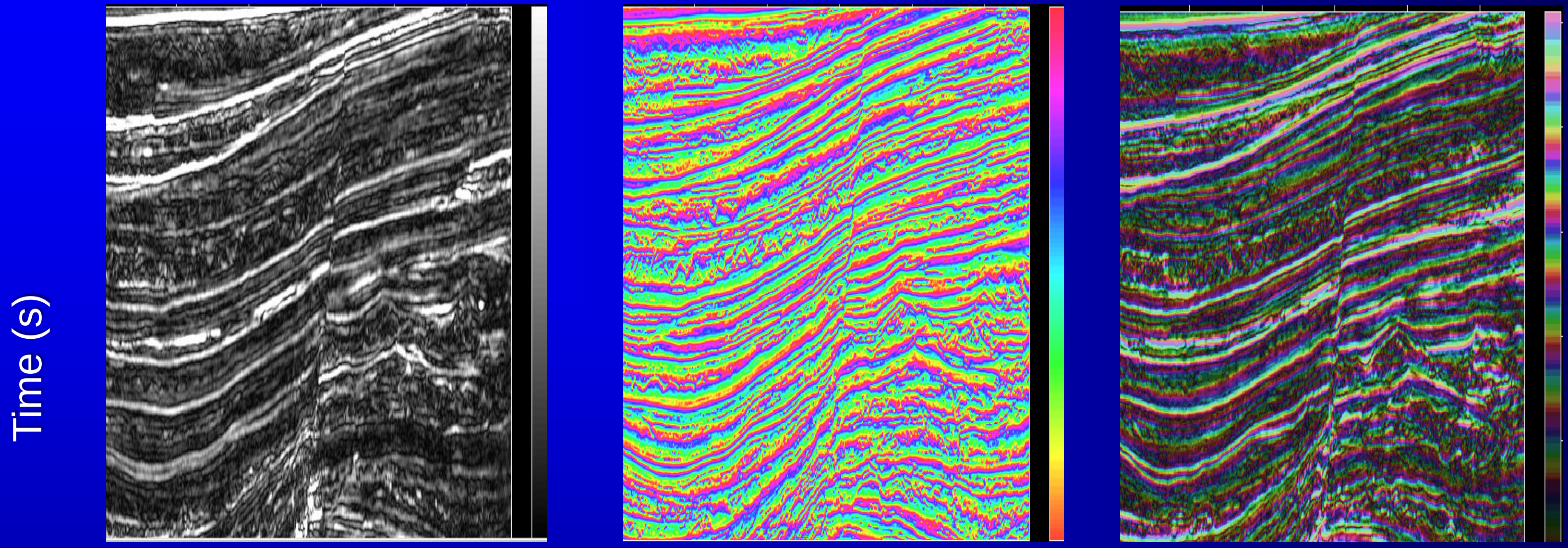
Examples of 2D color bars

Cyclical

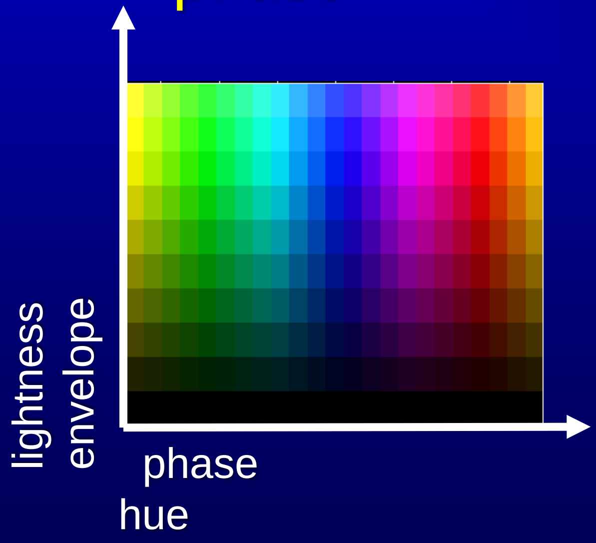
Non-Cyclical



Multiattribute display using 2D color tables

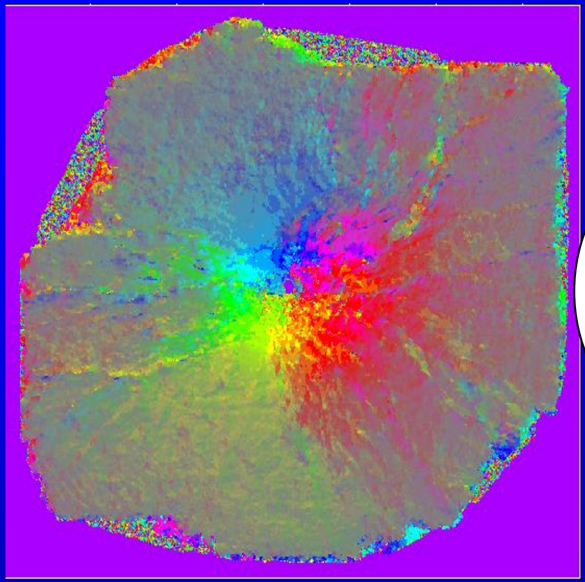


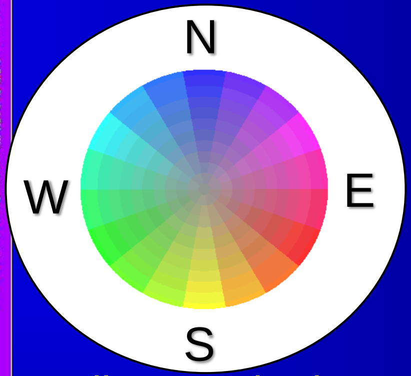
envelope phase composite



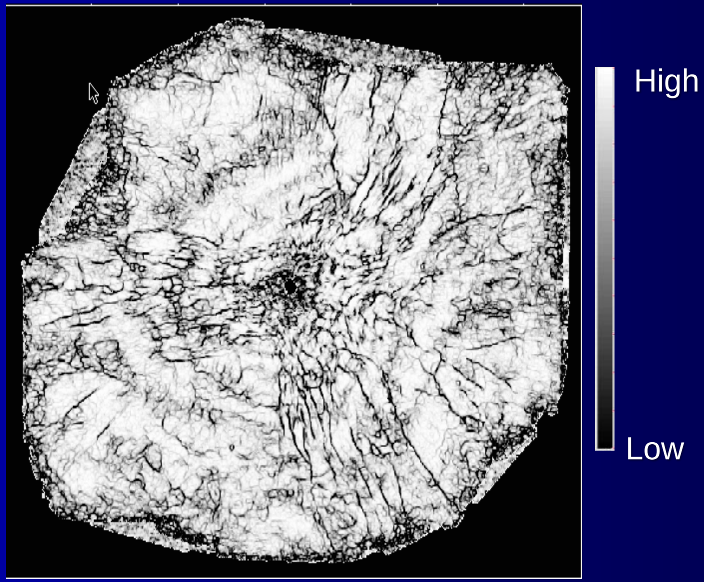
(after Knobloch, 1982)

Multiattribute display using 3D color tables



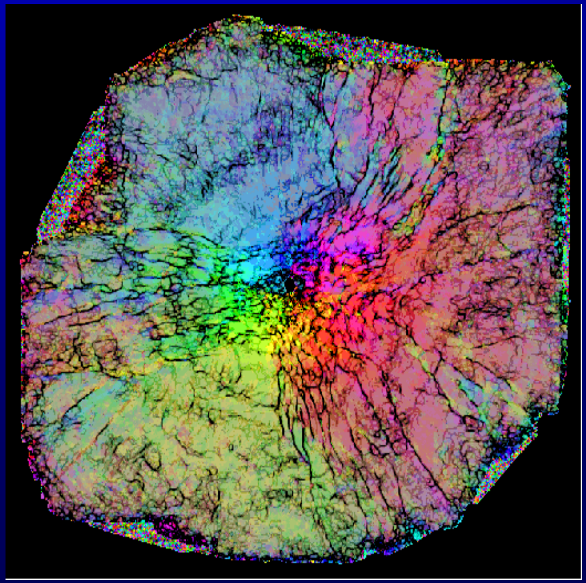


S=dip magnitude,
H=dip azimuth



L=coherence

t=1.0 s



S=dip magnitude, H=dip azimuth, L=coherence

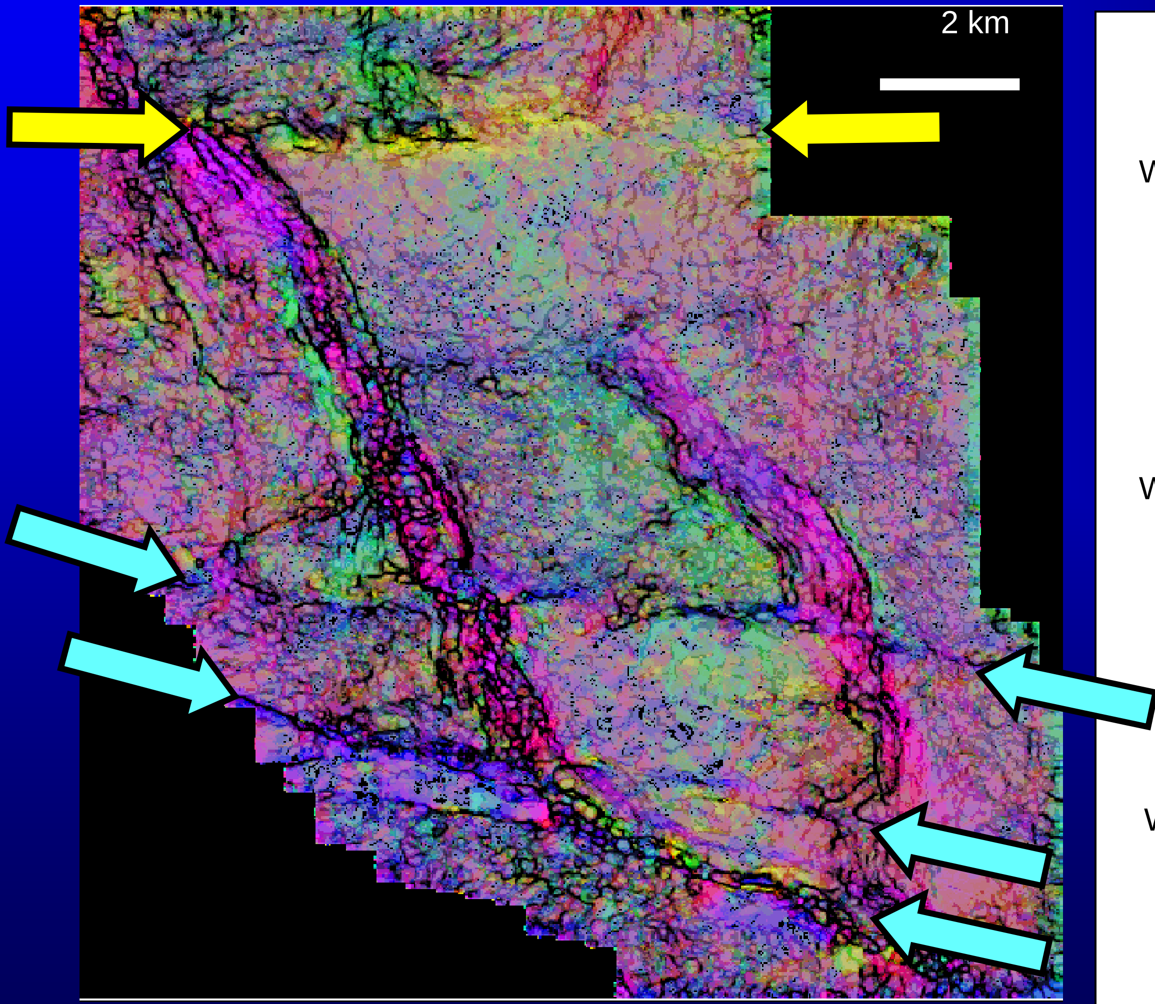
(Lin et al., 2003)

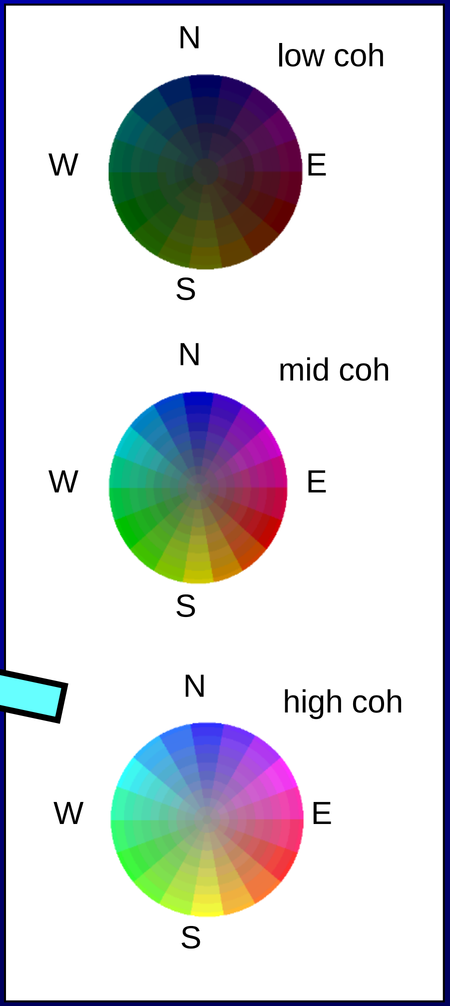
Multiattribute display using 3D color tables

azimuth -> H

dip magnitude -> S

coherence -> L

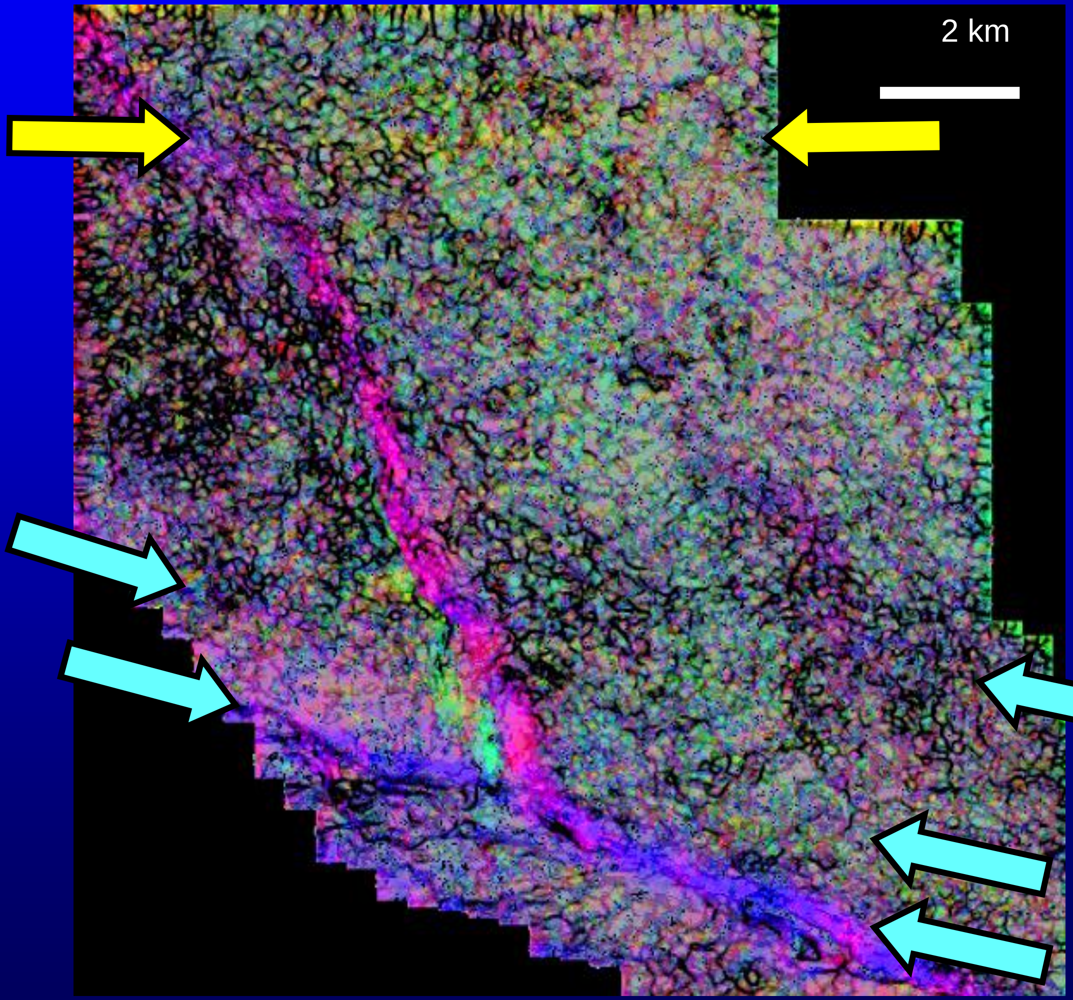


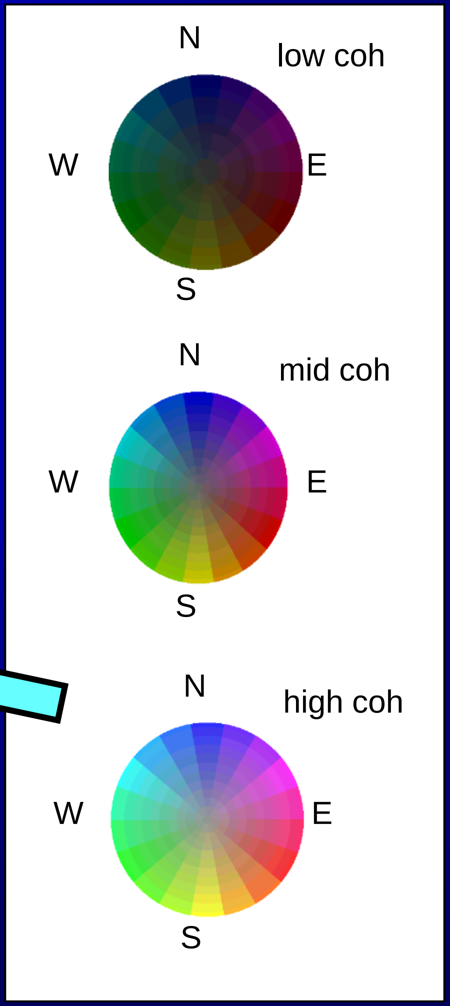


(Data courtesy of OXY)

3D color tables

azimuth -> H
dip magnitude -> S
coherence -> L





(Data courtesy of OXY)

Common display pitfalls

- displaying continuous data with colors that are not adjacent in RGB or HLS space

- using a dual gradational color bar to display single polarity data

- not using a neutral color to display zero values

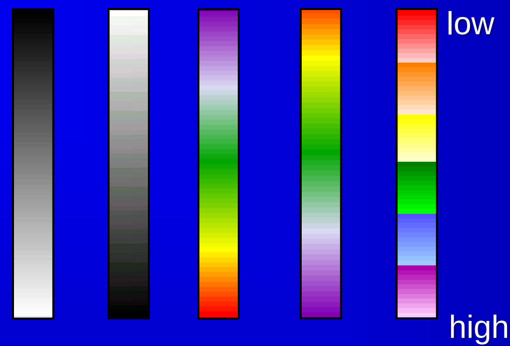
- using a single gradational color bar to display cyclical data

- defining display limits assuming a normal distribution histogram

- interpolating discontinuous color bars

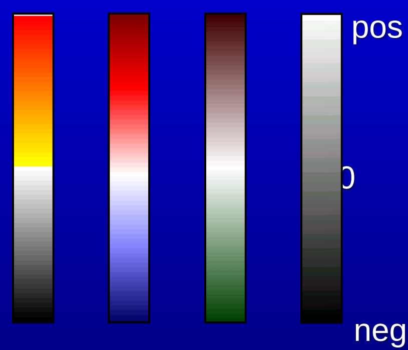
1D Color bars for effective attribute display

Color bars for single polarity attributes



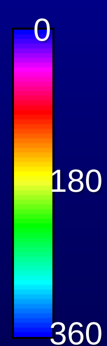
Amplitude extractions, frequency, time/structure, dip magnitude, envelope, coherence, …

Color bars for dual polarity attributes

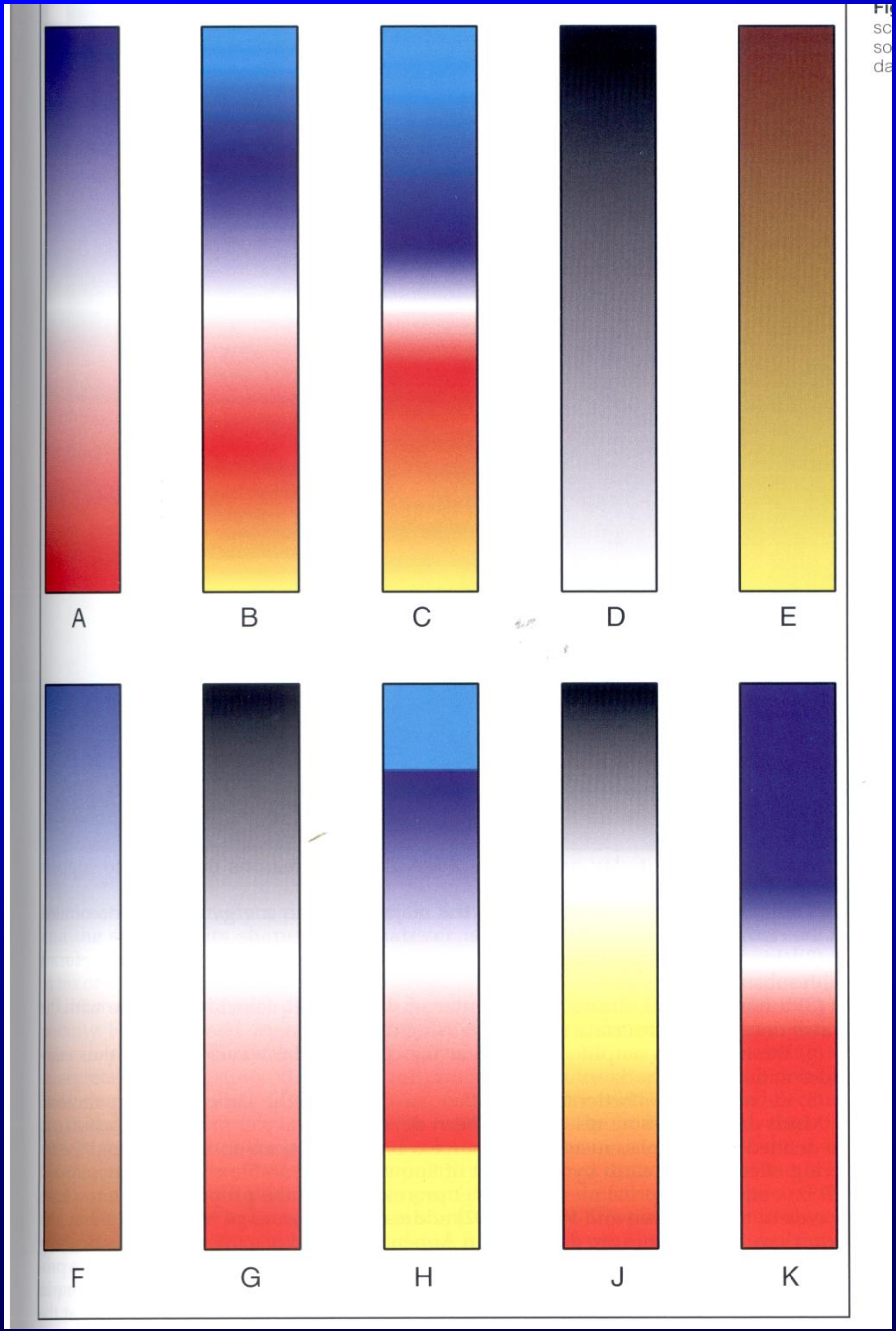


Seismic data, curvature, …

Color bars for cyclical attributes



Phase, azimuth, strike,…

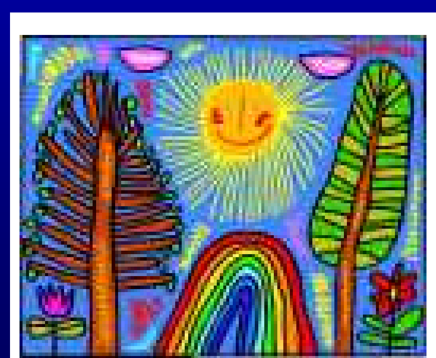


Good and bad amplitude color bars

(Brown, 2007)

Color perception is a learned response

convention ?



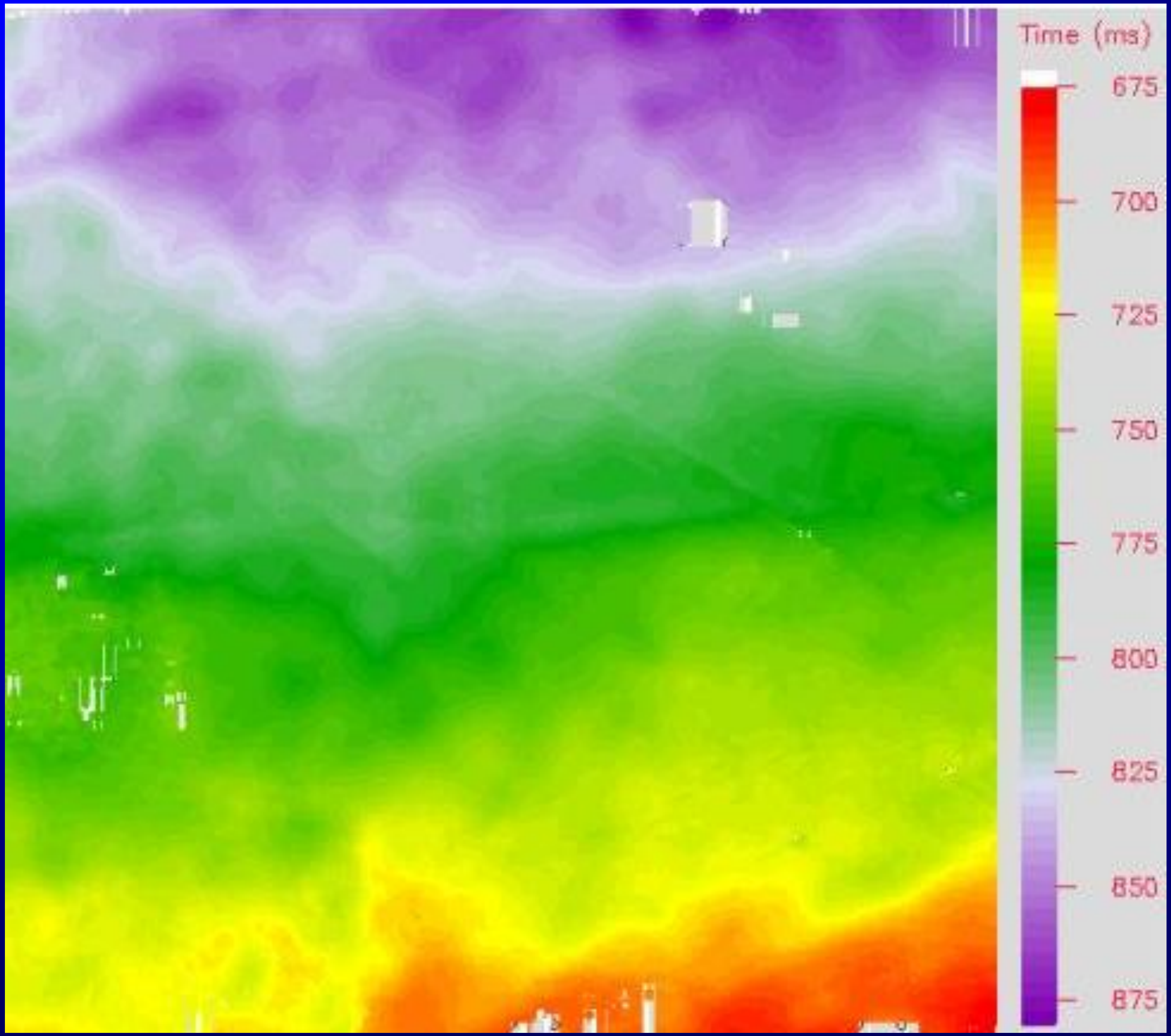
Order of rainbow?

culture ?

上市行情
4319.99 ▼30.60
上櫃行情
88.63 ▼0.70

MARKETS: 4:30pm ET, 3/10				
DJIA	⬇	-171.90	7568.10	-2.27%
NAS	⬇	-26.92	1278.37	-2.11%
S&P	⬇	-14.62	807.48	-1.81%

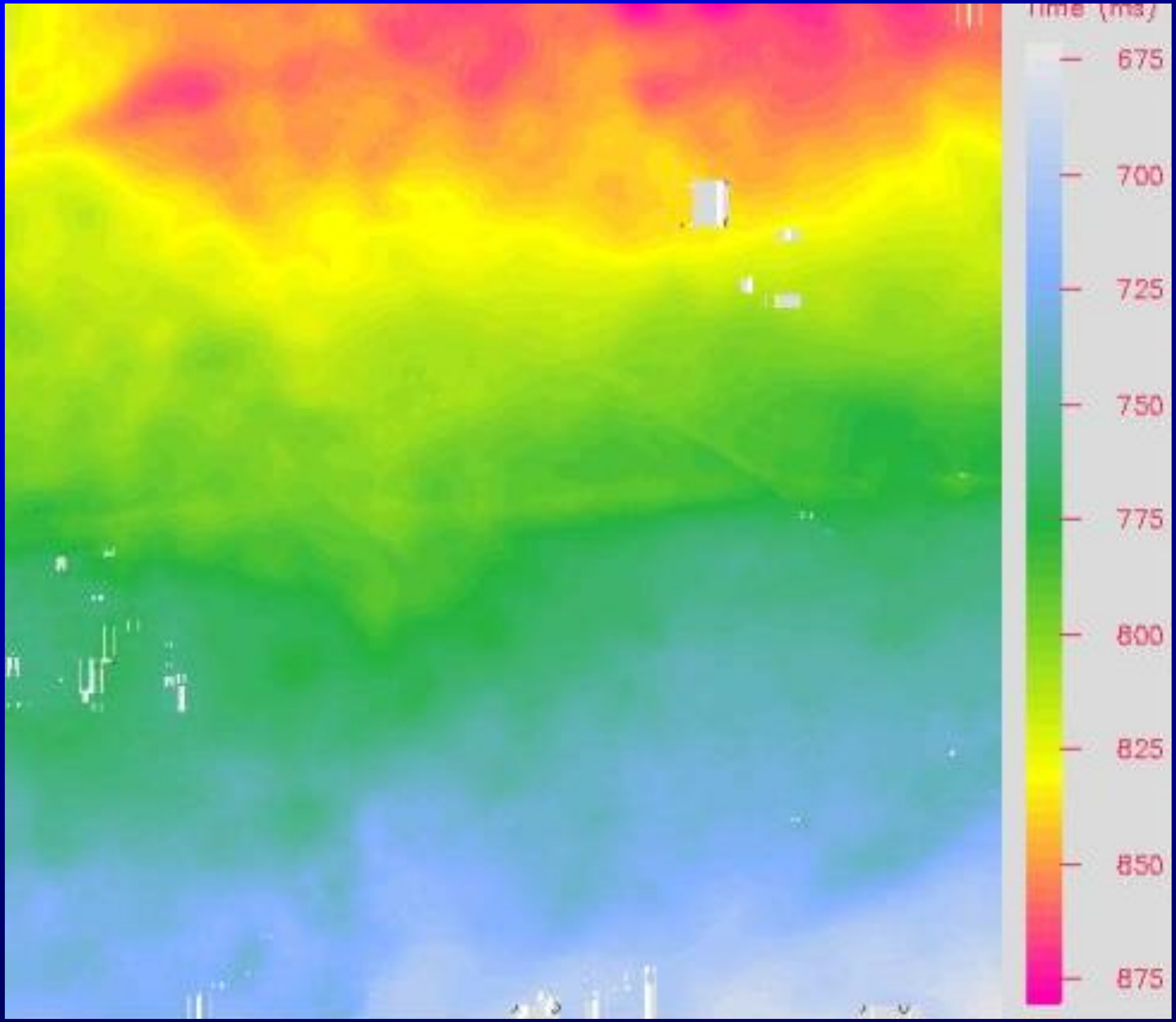
Examples of good and bad color maps



Time structure map plotted against rainbow colors

Good: Shallow structures where oil and gas may be found are 'hotter'

Examples of good and bad color maps



Time structure map plotted against rainbow colors

Bad: Deeper structures are hotter (like temperature) – this is how geophysicists plot velocity. Eye is drawn to synclinal features.

Common display pitfalls

• displaying continuous data with colors that are not adjacent in RGB or HLS space

• using a dual gradational color bar to display single polarity data

• not using a neutral color to display zero values

• using a single gradational color bar to display cyclical data

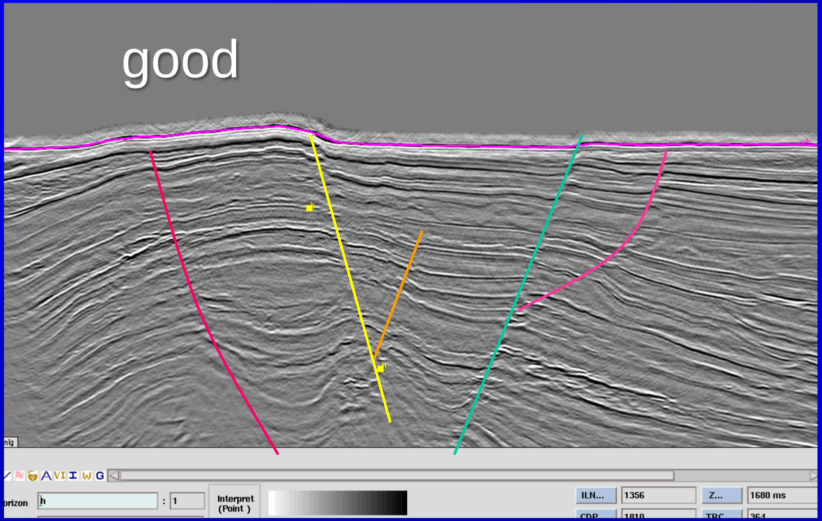
• defining display limits assuming a normal distribution histogram

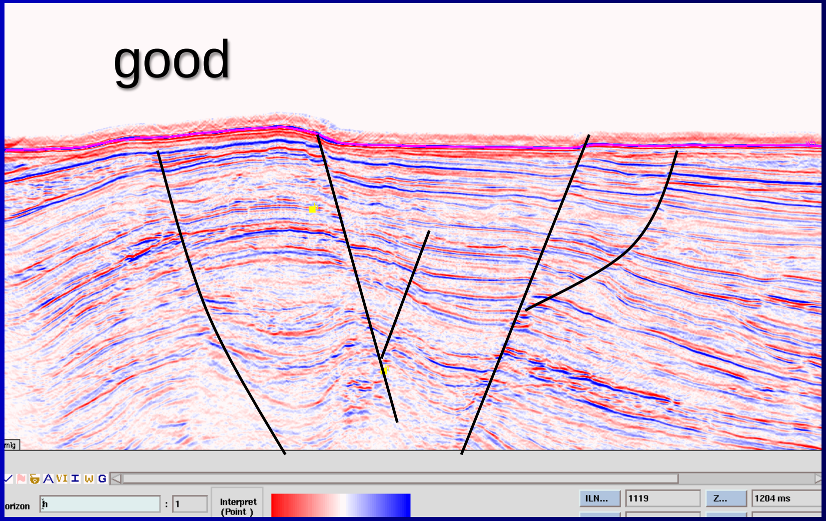
• interpolating discontinuous color bars

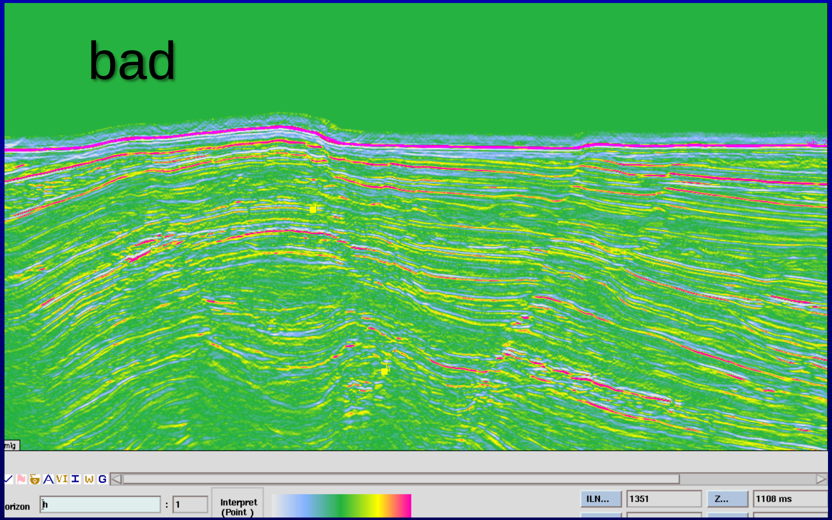
Examples of good and bad color maps

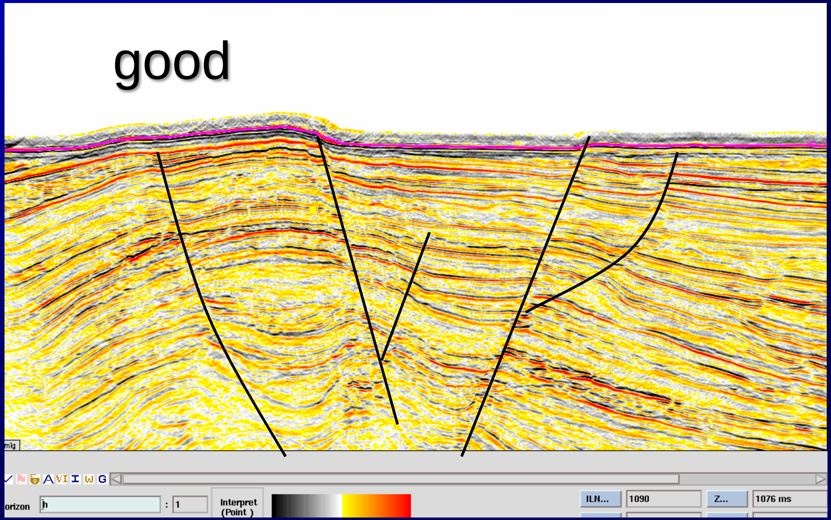
Single gradational

Double gradational



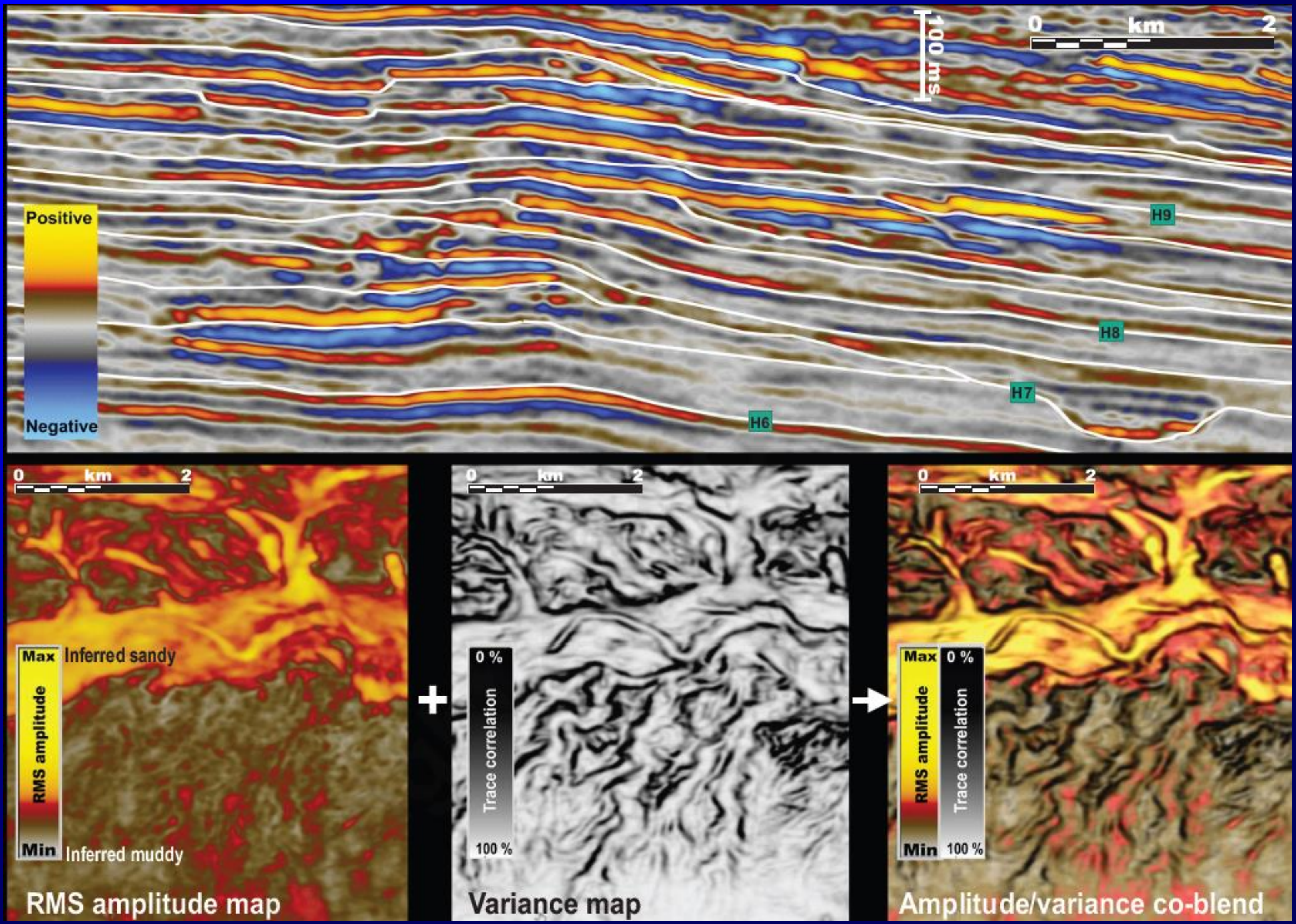






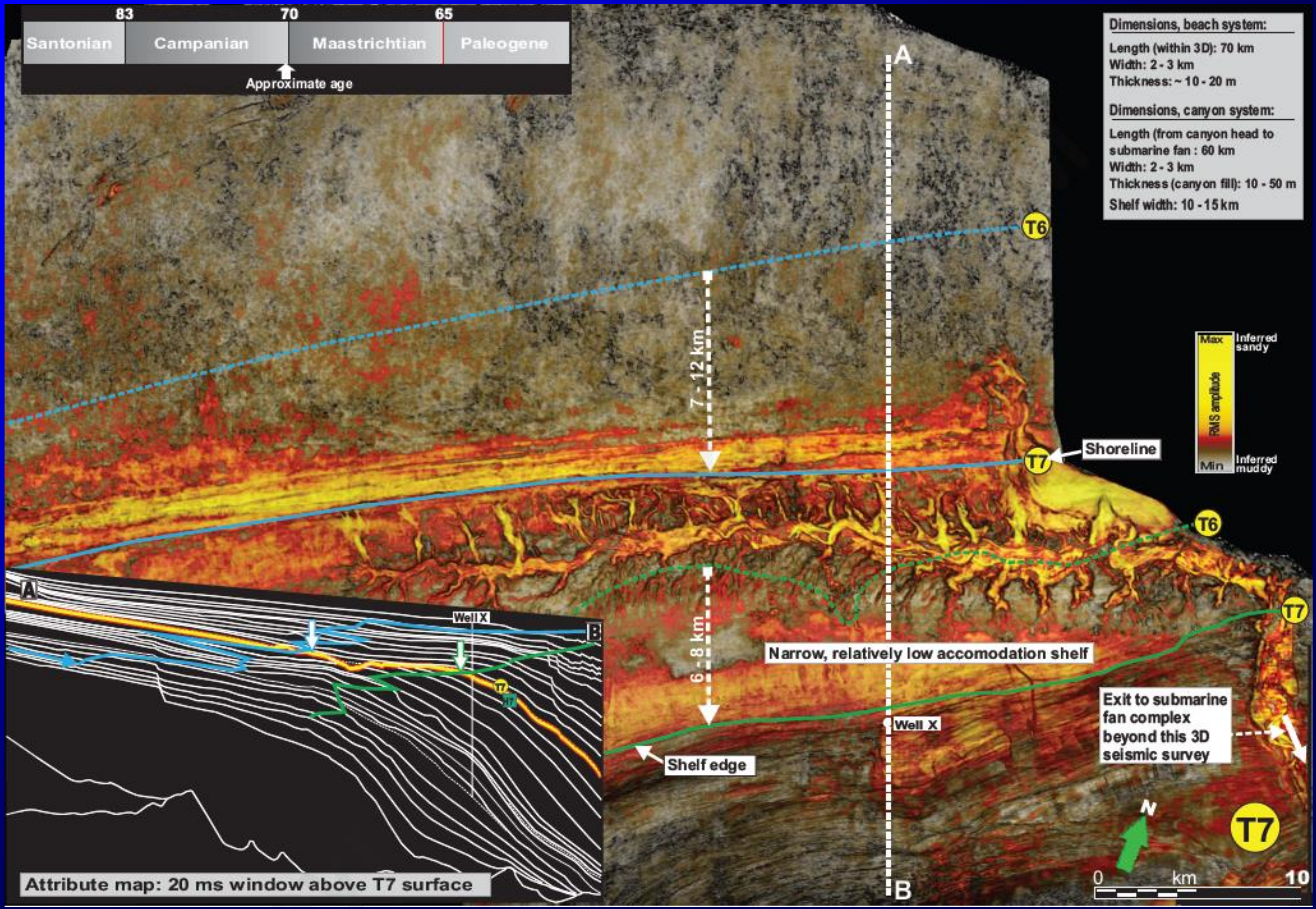
Always use a background color for zero!

An effective blending scheme



(Hadler-Jacobsen et al., 2010)

An effective blending scheme

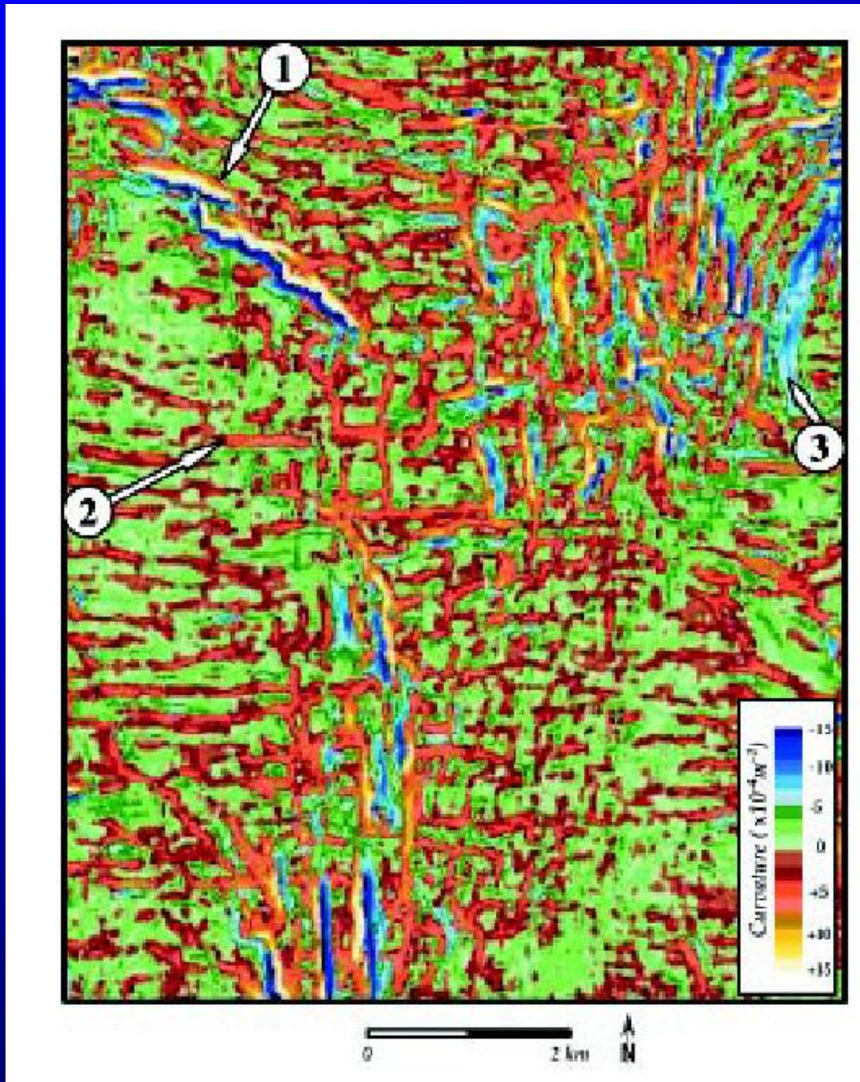


(Hadler-Jacobsen et al., 2010)

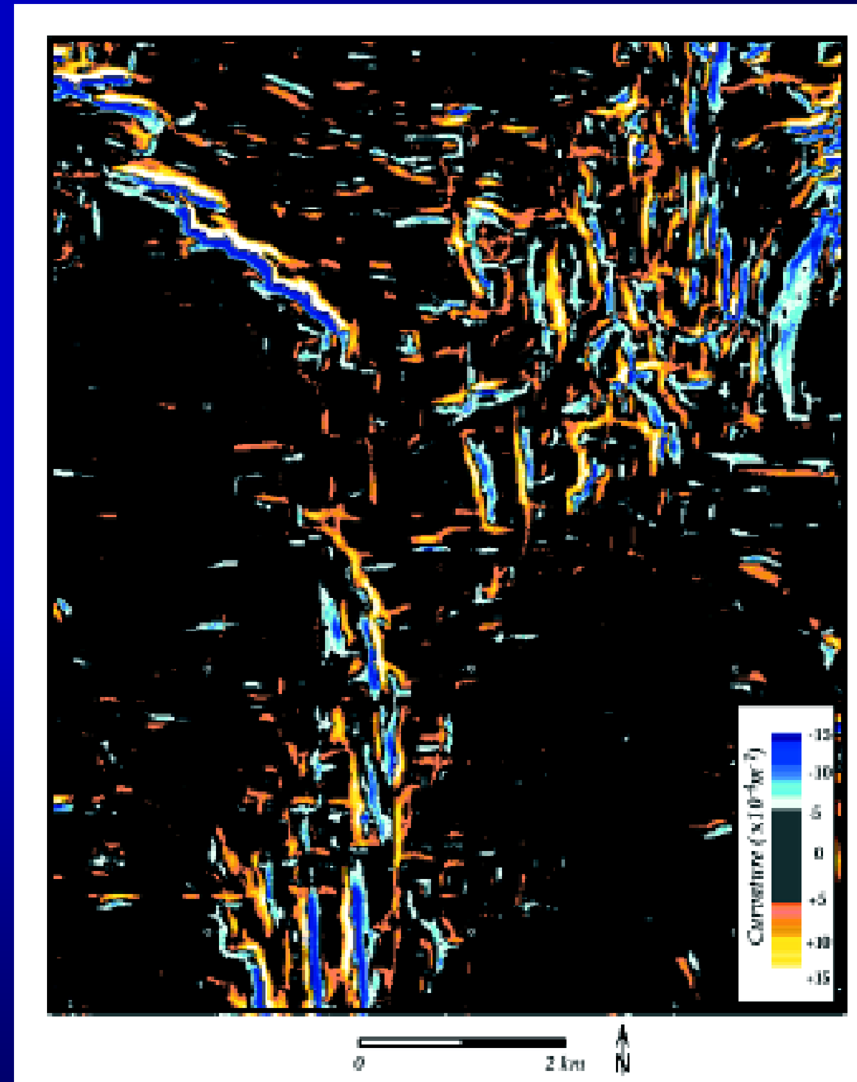
Common display pitfalls

- displaying continuous data with colors that are not adjacent in RGB or HLS space
- using a dual gradational color bar to display single polarity data
- not using a neutral color to display zero values
- using a single gradational color bar to display cyclical data
- defining display limits assuming a normal distribution histogram
- interpolating discontinuous color bars

Examples of good and bad color maps



Maximum curvature, k_{max}



Maximum curvature, k_{max} (with values near zero set to background!)

(Roberts, 2001)

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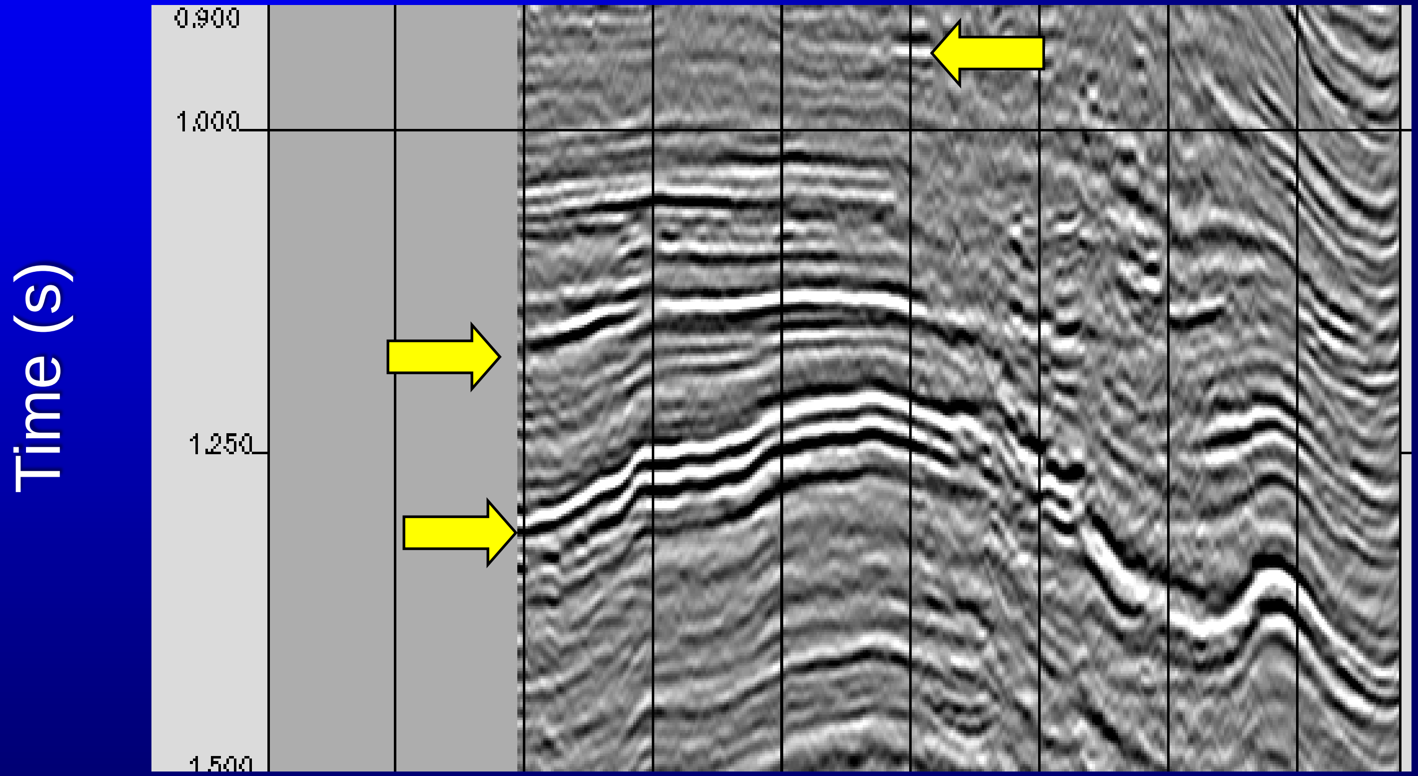
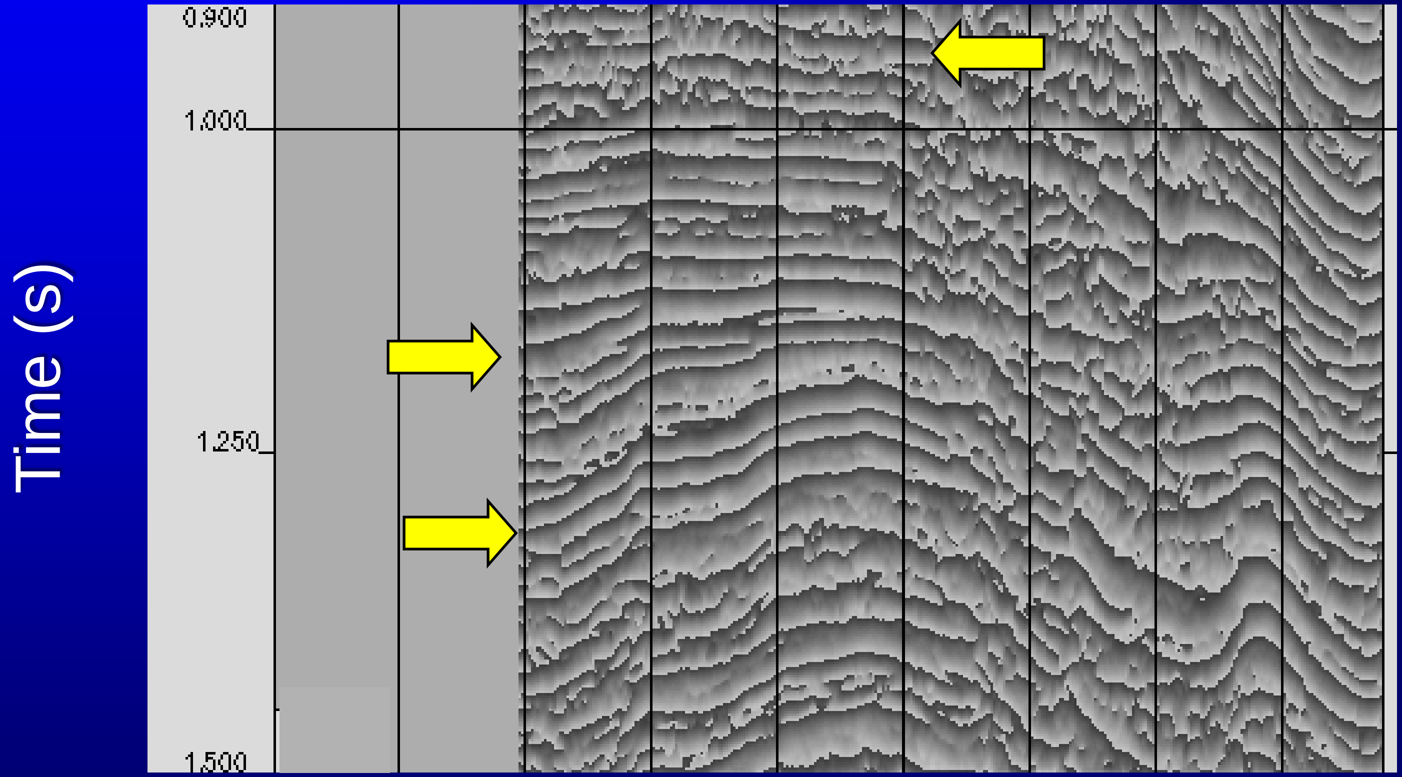
Attribute Display in Interpretation Workstations



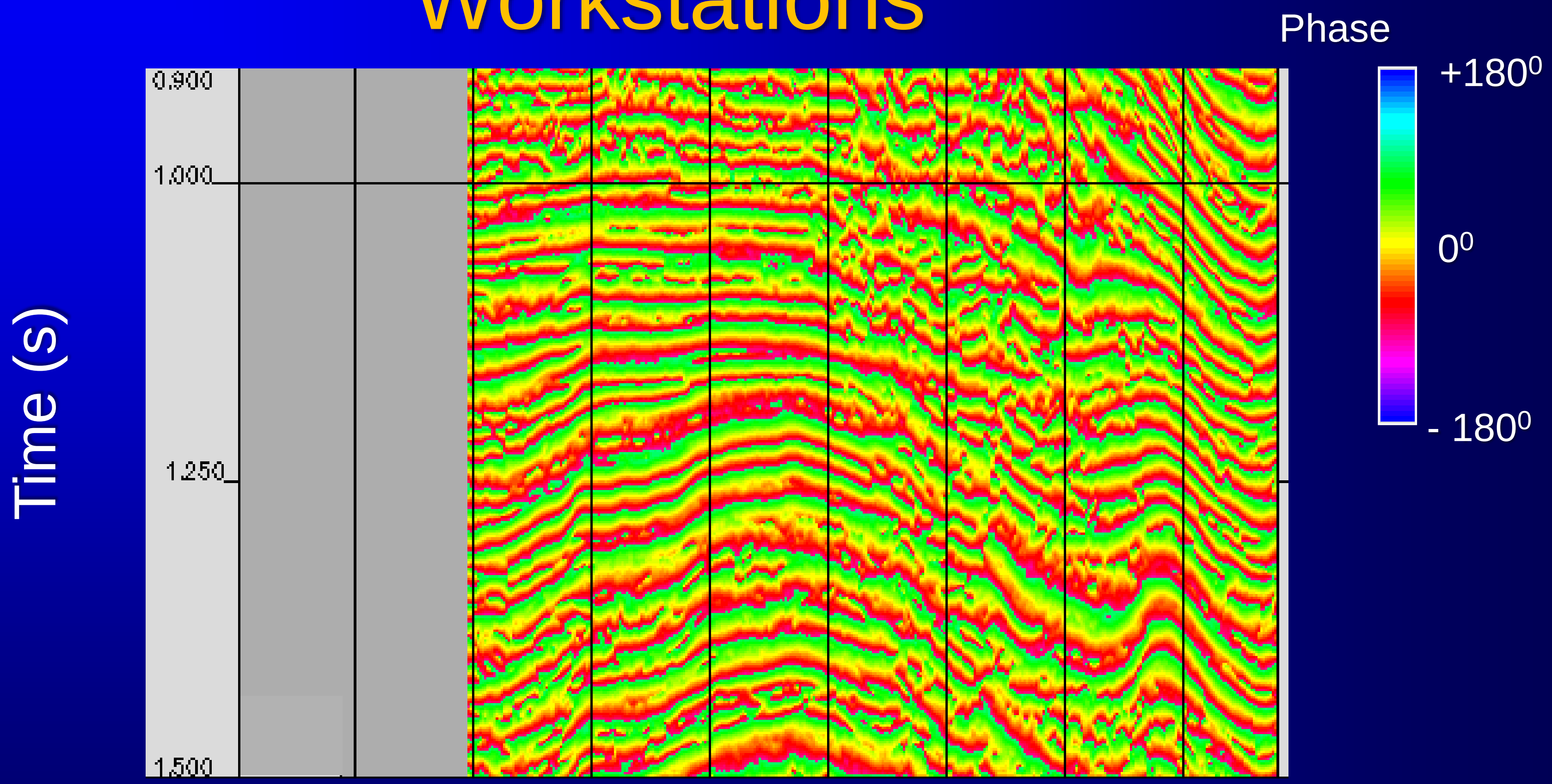
Vertical slice through seismic amplitude
Central Basin Platform, TX

Attribute Display in Interpretation Workstations



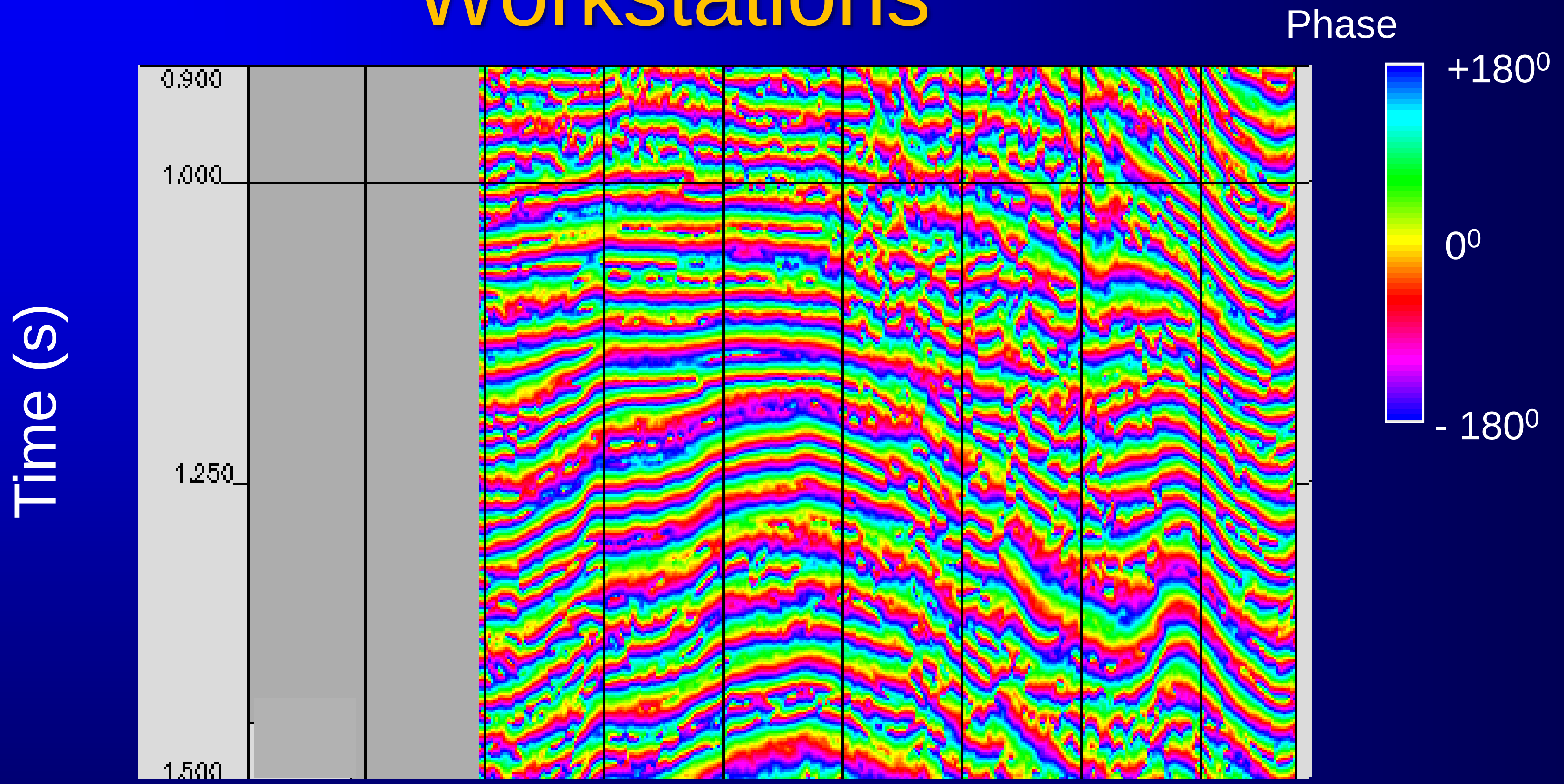
Vertical slice through instantaneous phase – single gradational gray scale color bar

Attribute Display in Interpretation Workstations



Vertical slice through instantaneous phase – Cyclical color bar using (default) RMS scaling

Attribute Display in Interpretation Workstations



Vertical slice through instantaneous phase – Cyclical color bar using user-defined scaling

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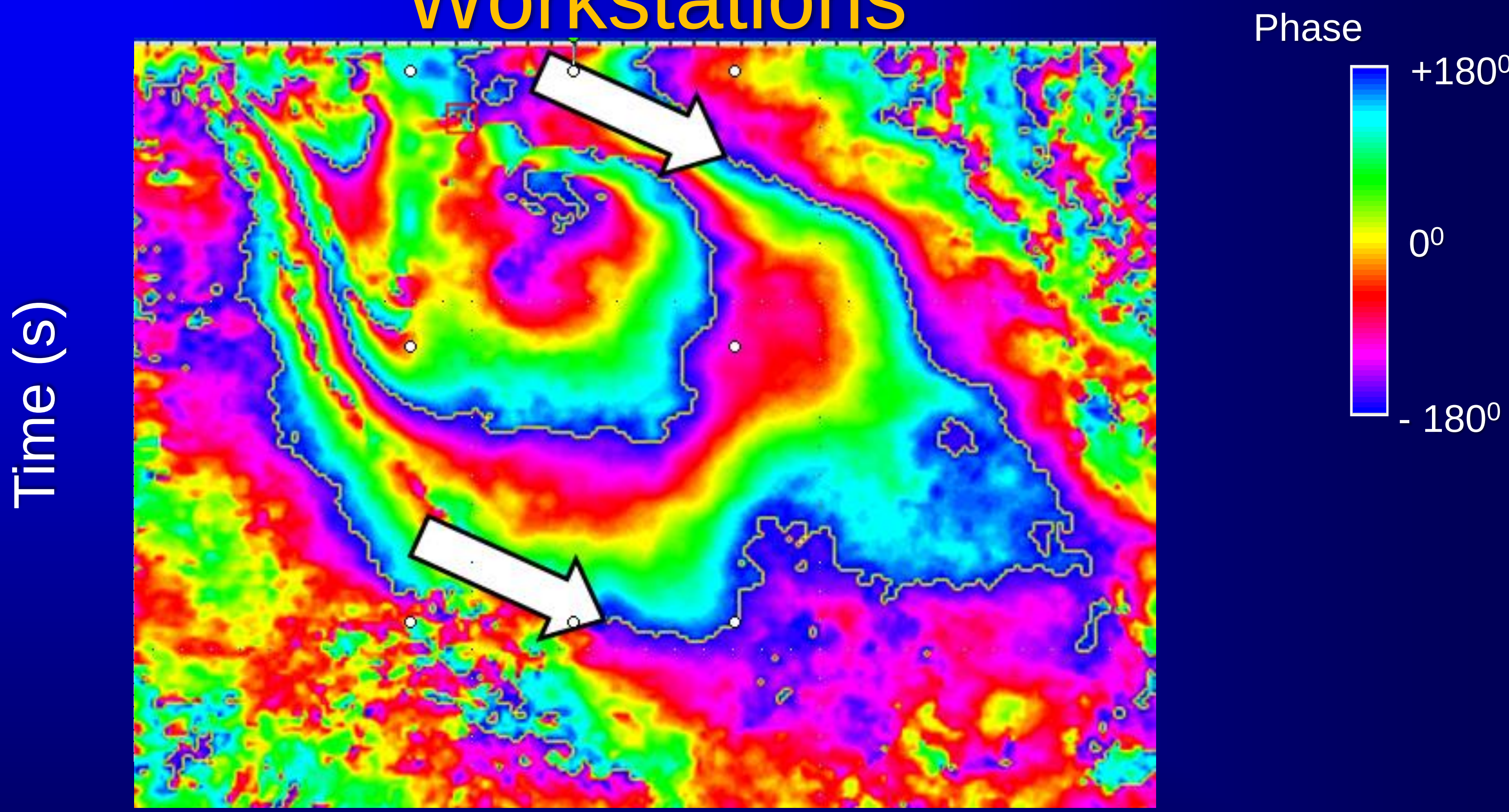
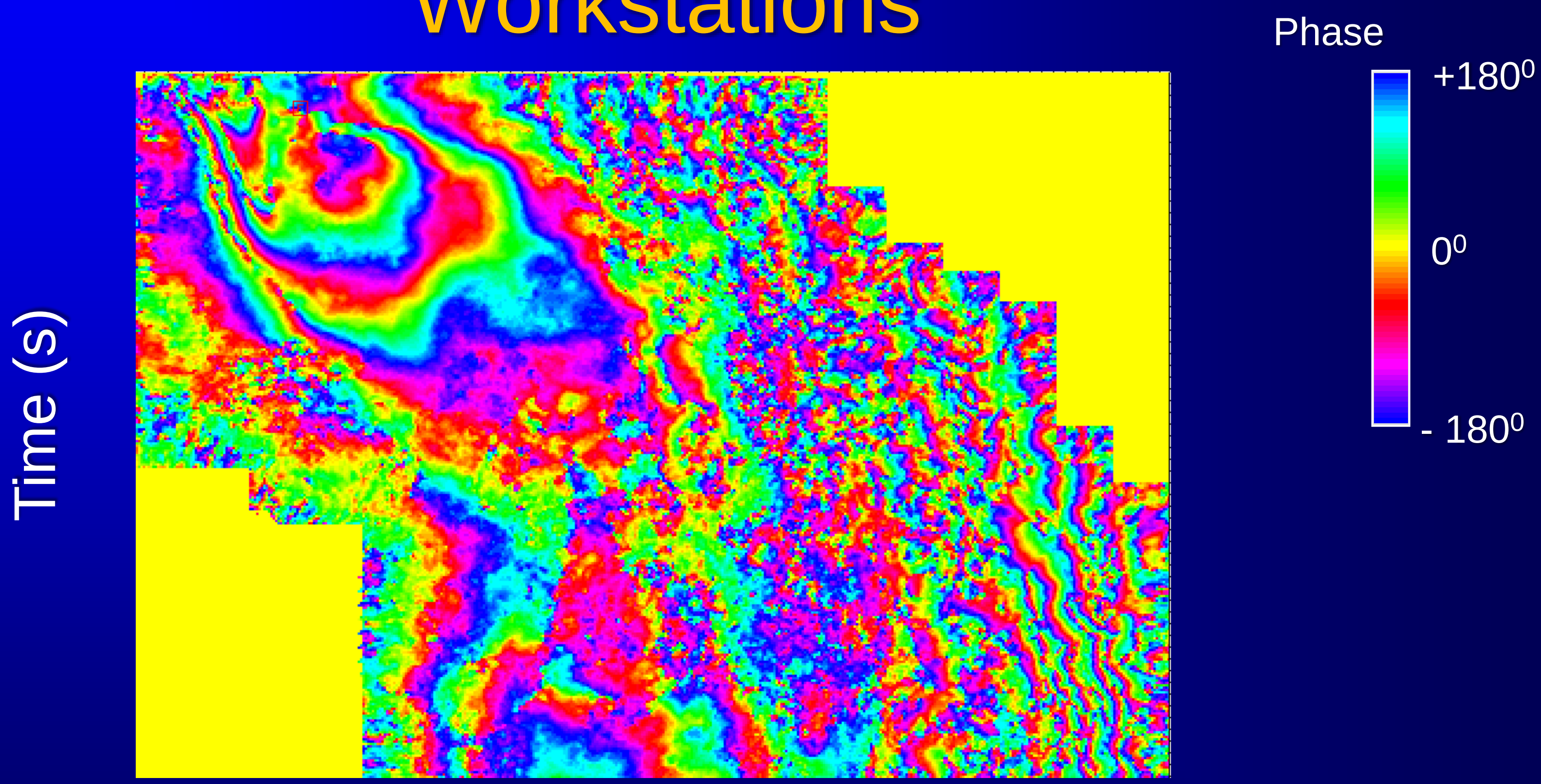
Attribute Display in Interpretation Workstations



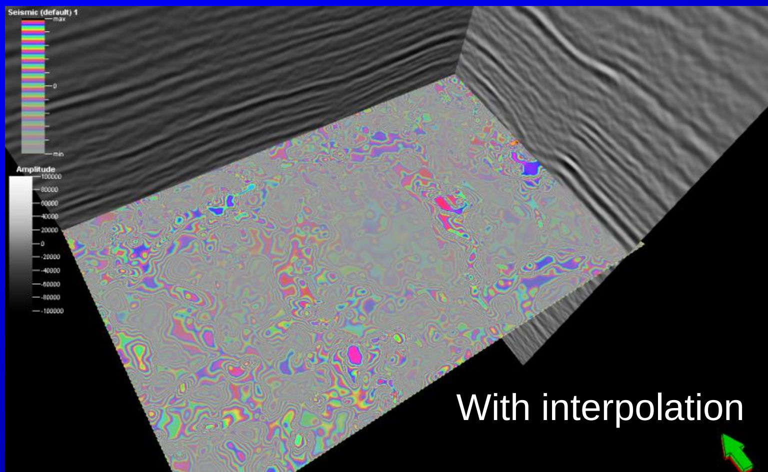
Time slice through instantaneous phase – Cyclical color bar using user-defined scaling. Interpolated traces.

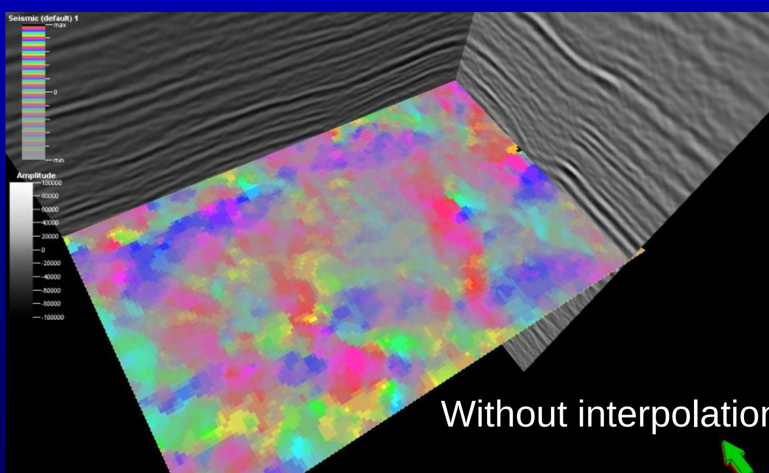
Attribute Display in Interpretation Workstations

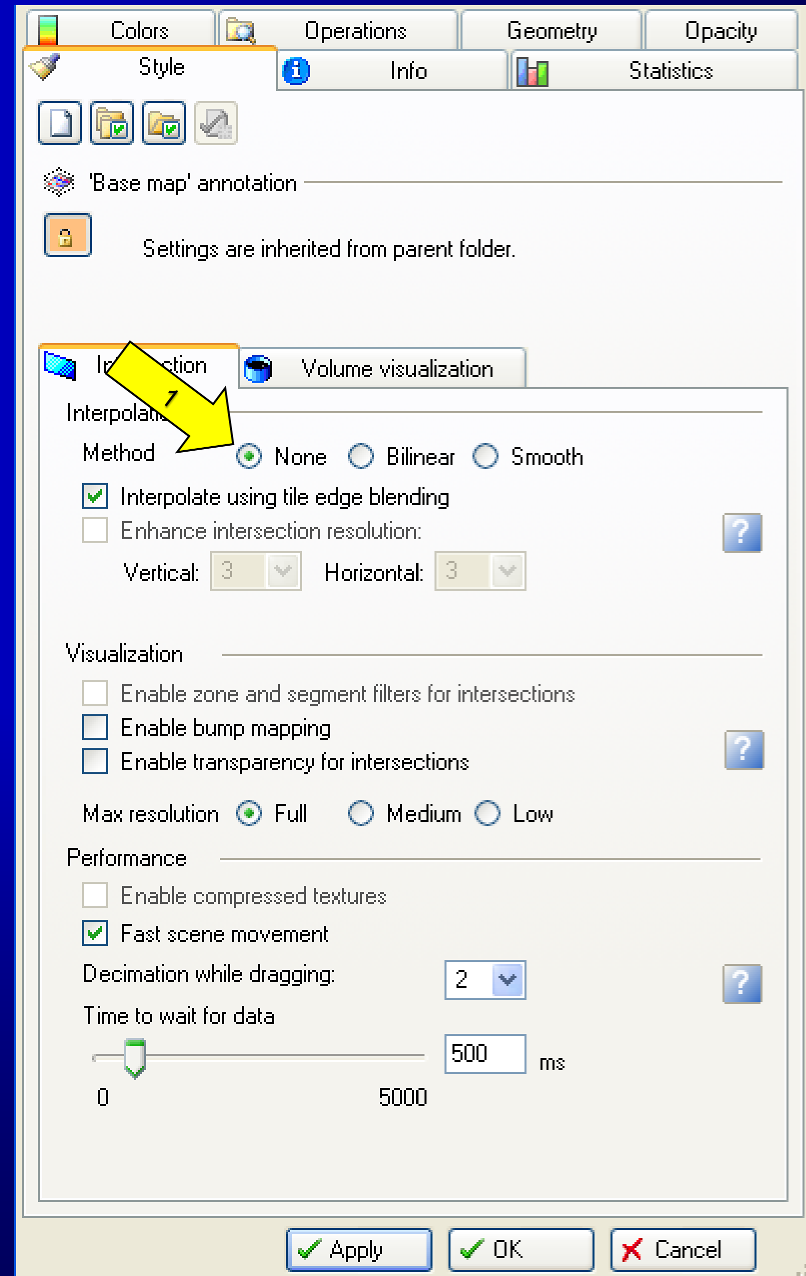


Time slice through instantaneous phase – Cyclical color bar using user-defined scaling. Replicated traces.

2D color bars



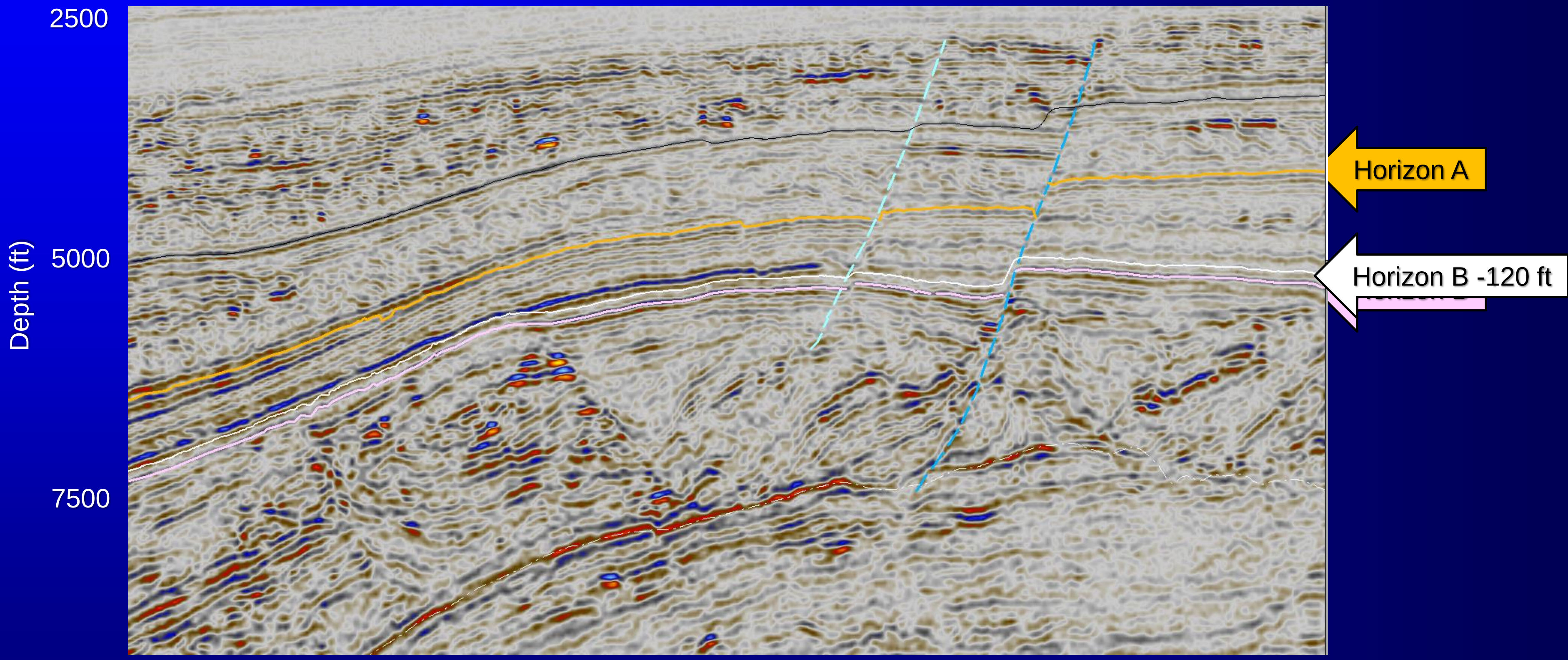




Types of Attribute Displays

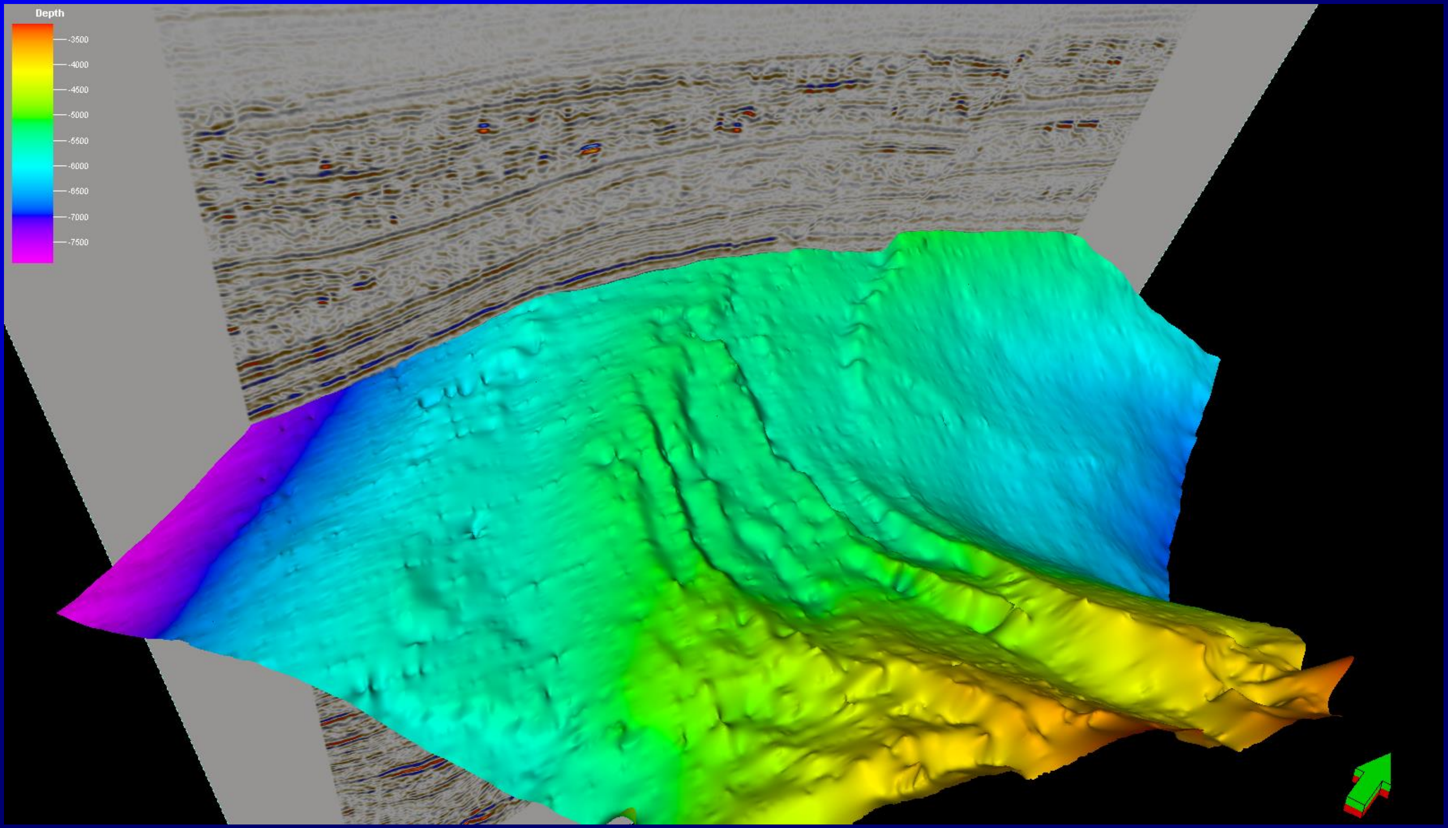
- Vertical and horizontal (time) slices through attribute volumes
- Attributes computed *from* a picked horizon
  - Time-structure maps
  - Dip-magnitude and dip-azimuth maps
  - Horizon-based curvature
- Attributes extracted *along* a picked horizon (horizon slices)
- Attributes extracted parallel to a picked horizon (phantom horizon slices)
- Attributes extracted proportionally between two picked horizons (stratal slices)
- Attributes computed between two picked horizons (formation attributes)
- Geobodies

Two picked horizons



(Sarkar et al. 2009)

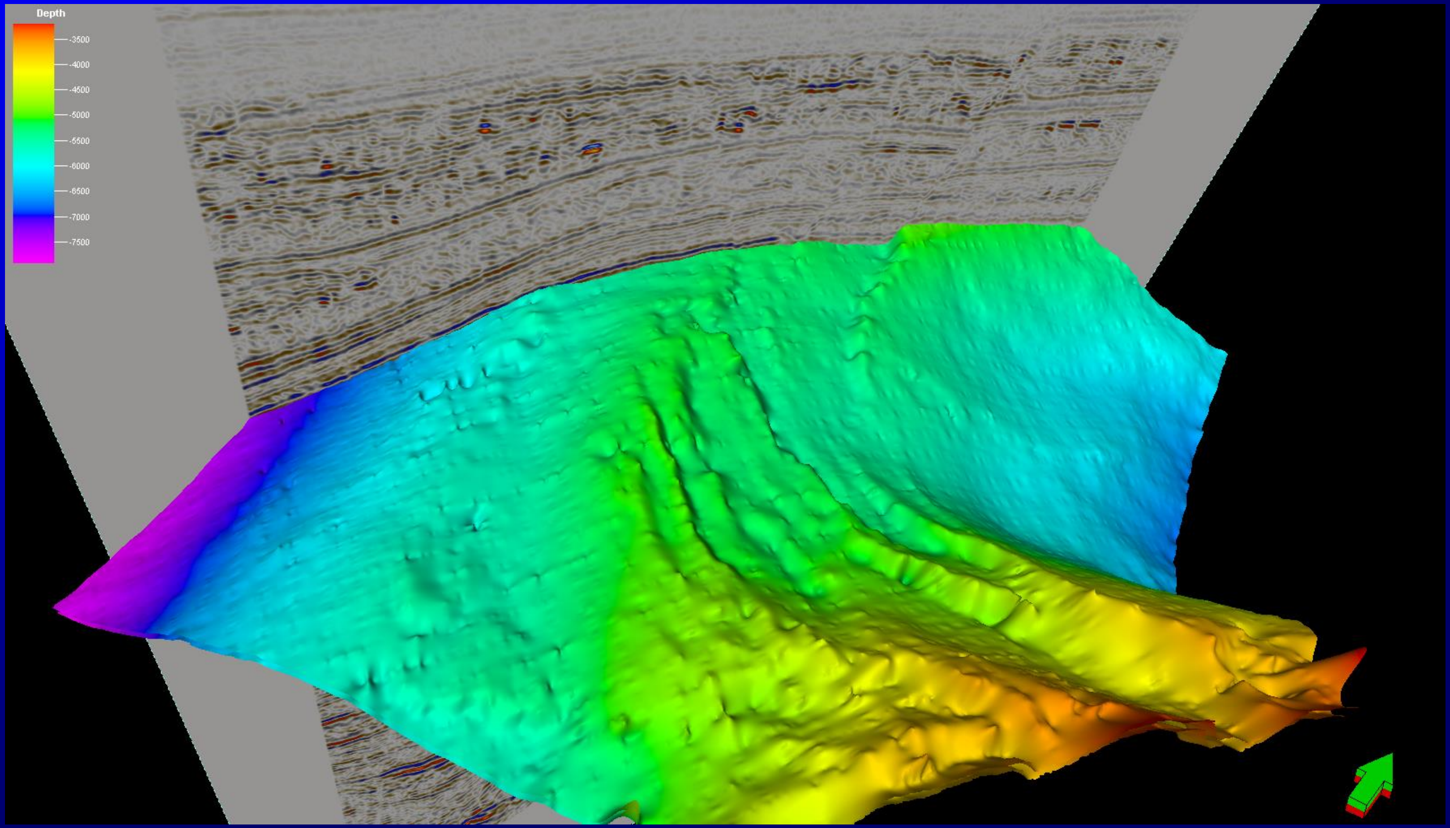
Time-structure map of horizon B



(Sarkar et al. 2009)

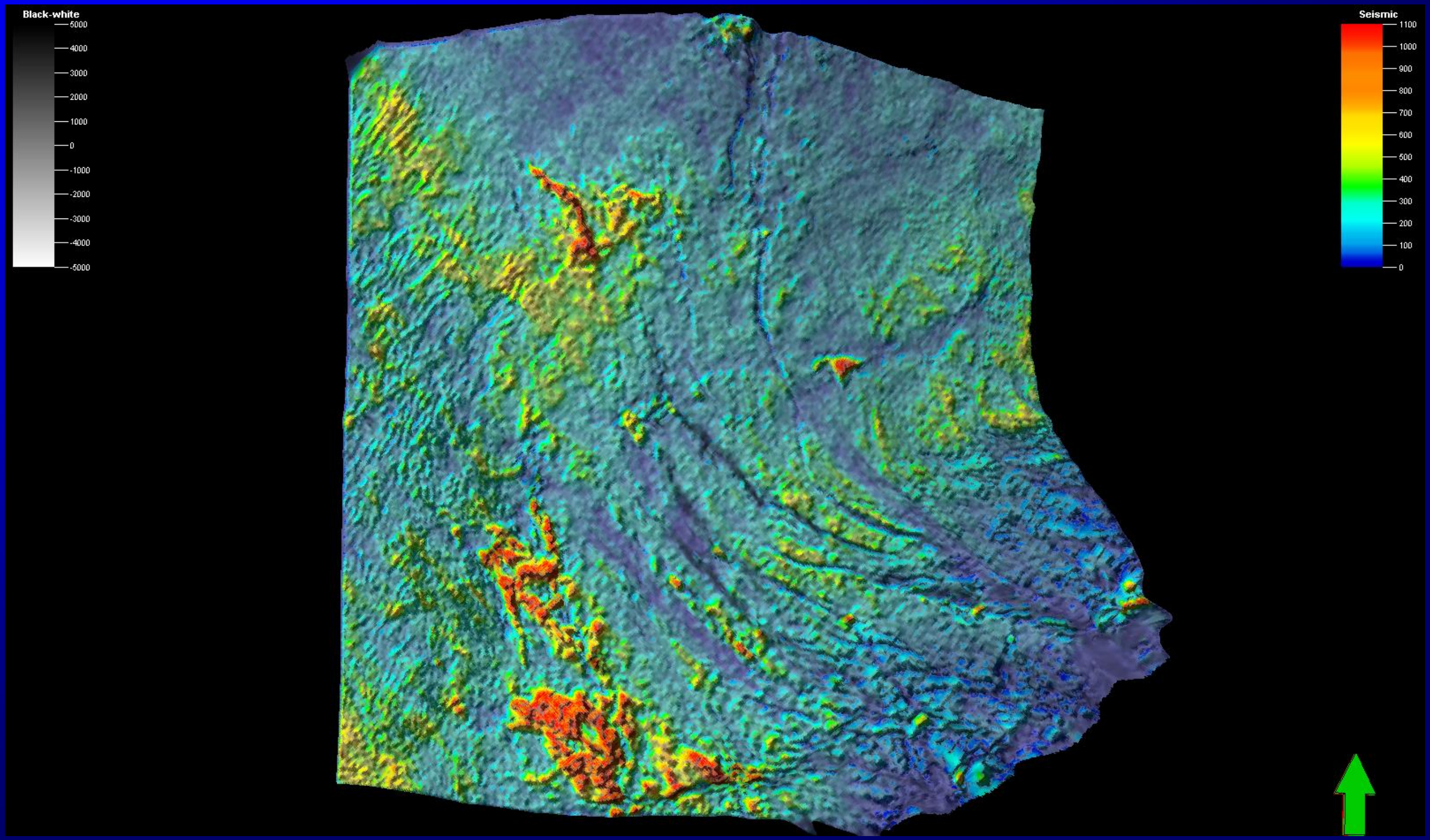
Time-structure map of horizon B - 120 ft

(a phantom horizon)



(Sarkar et al. 2009)

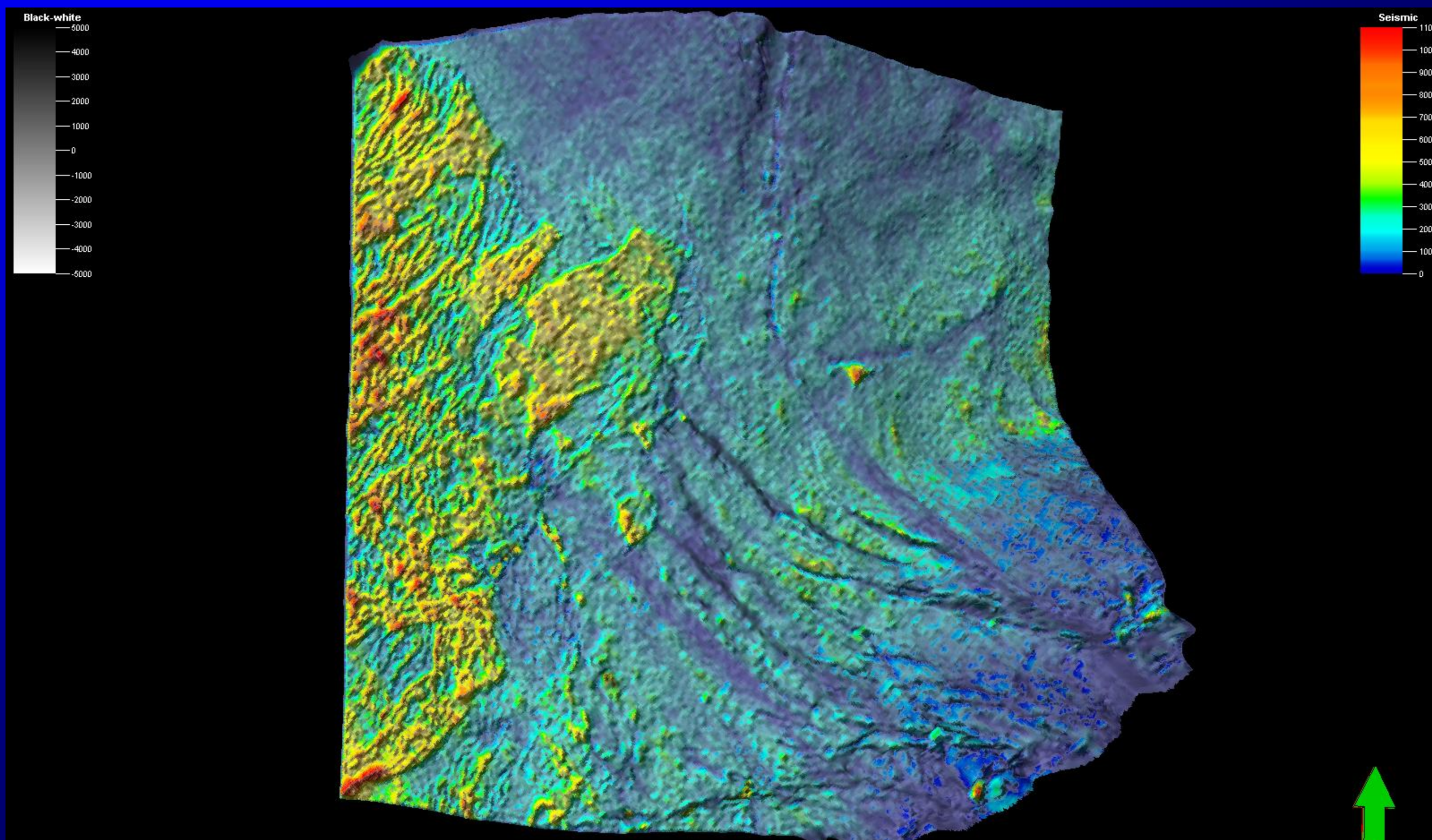
Horizon slice through attributes
(along horizon B)



(Sarkar et al. 2009)

Phantom horizon slice through attributes

(120 ft above horizon B)



(Sarkar et al. 2009)

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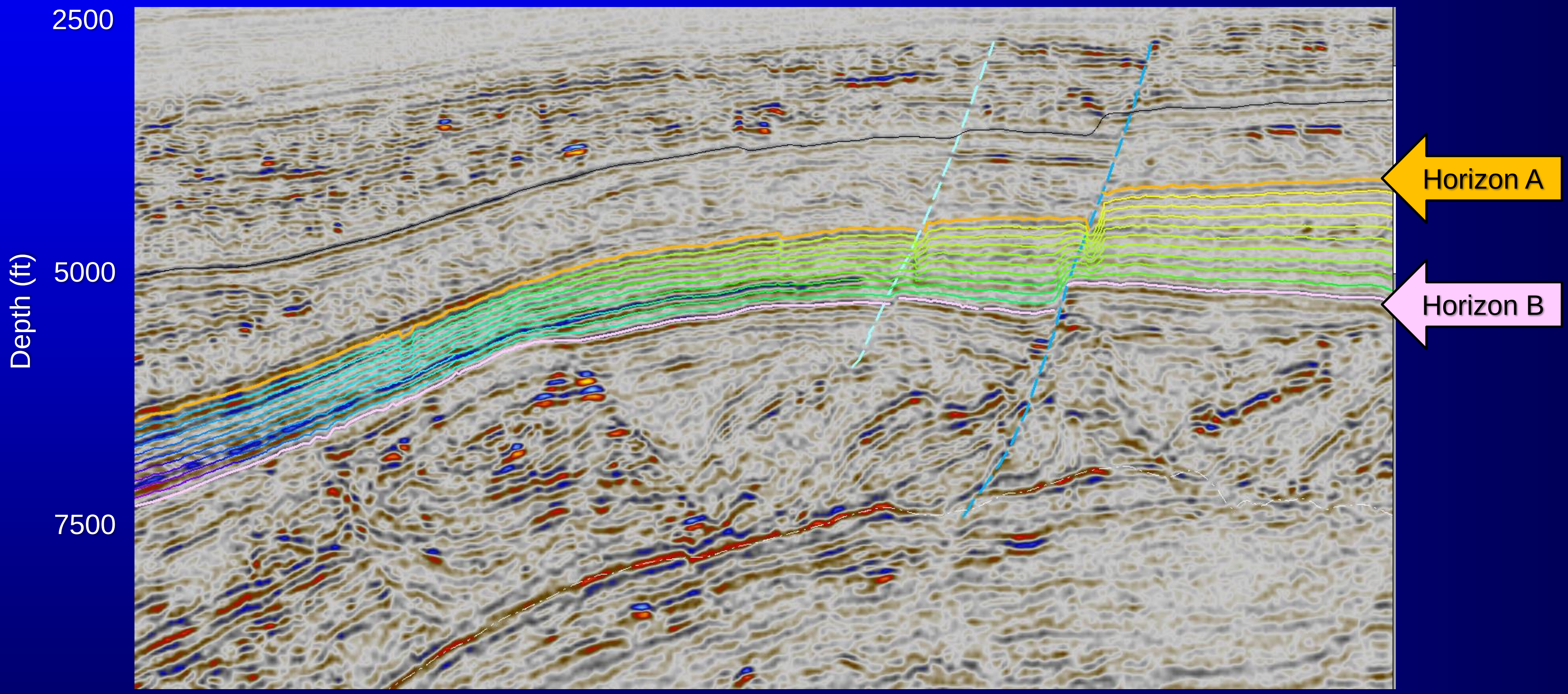
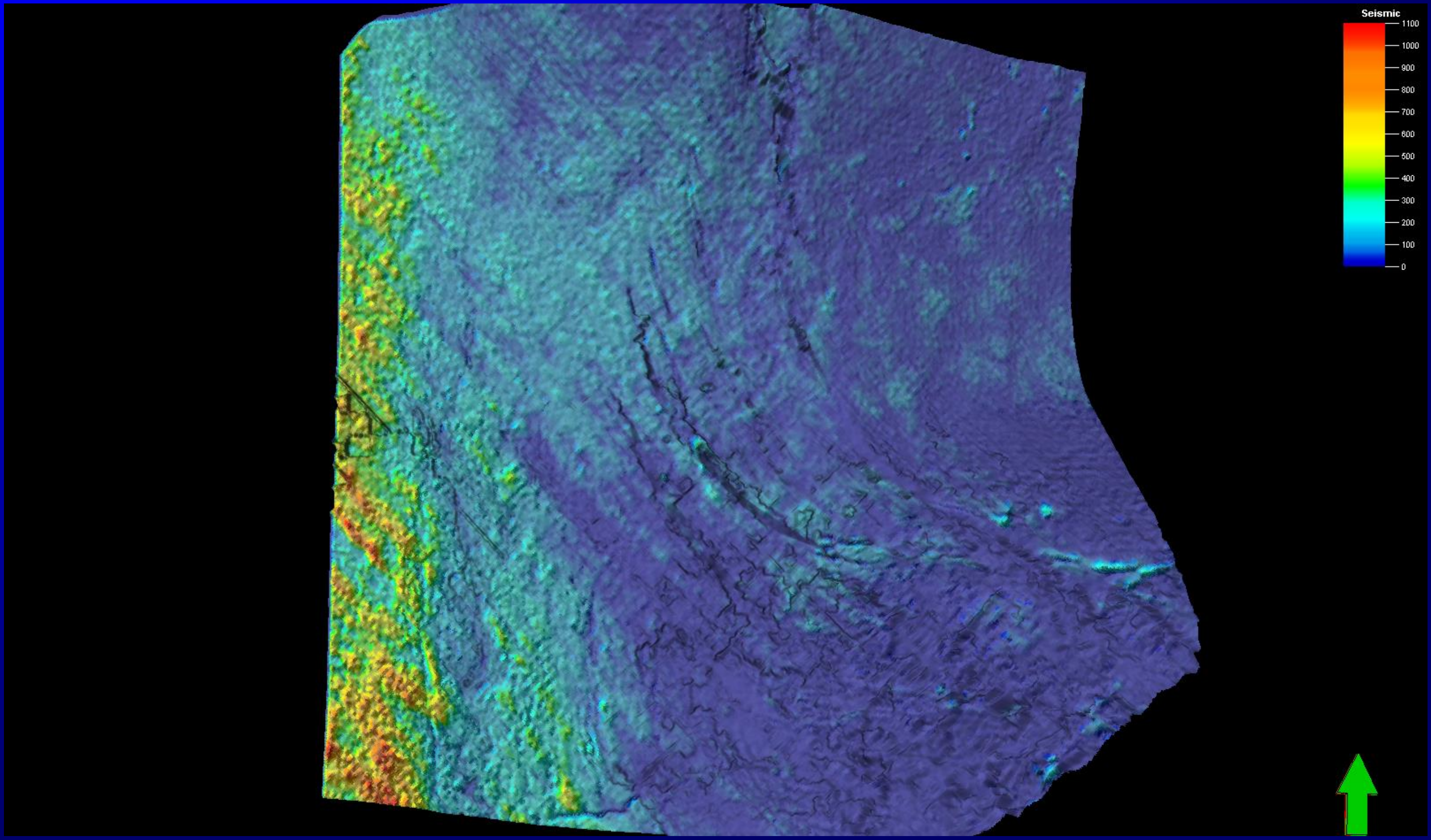
9 stratal (proportional) slices between horizons A and B



(Sarkar et al. 2009)

Stratal slice through attributes

(nine proportional slices between horizons A and B)



(Sarkar et al. 2009)

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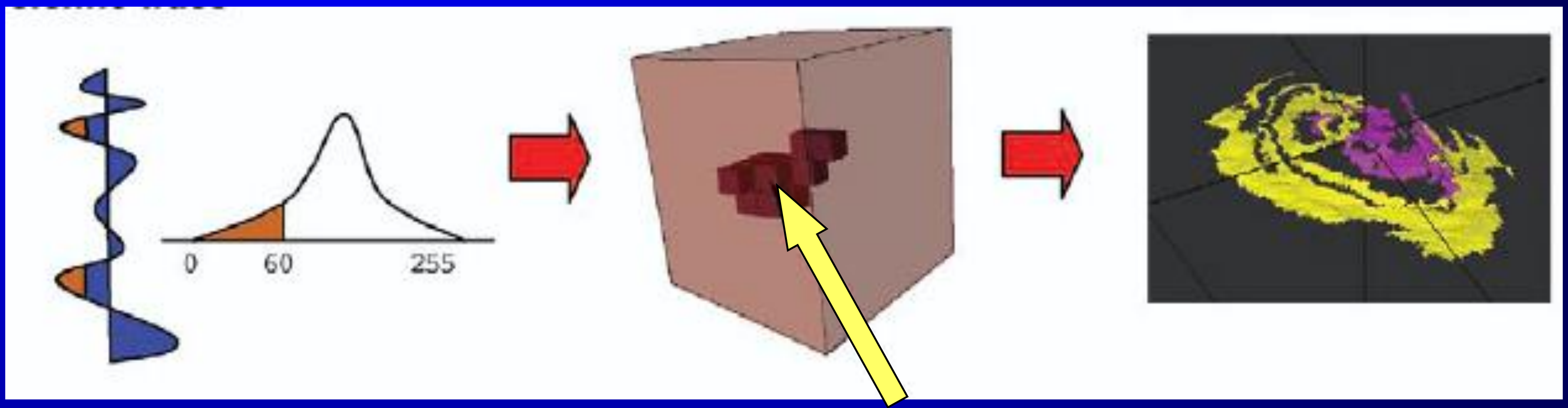
Voxel Detection and Geobodies

(Connected Component Labeling)



Seismic trace

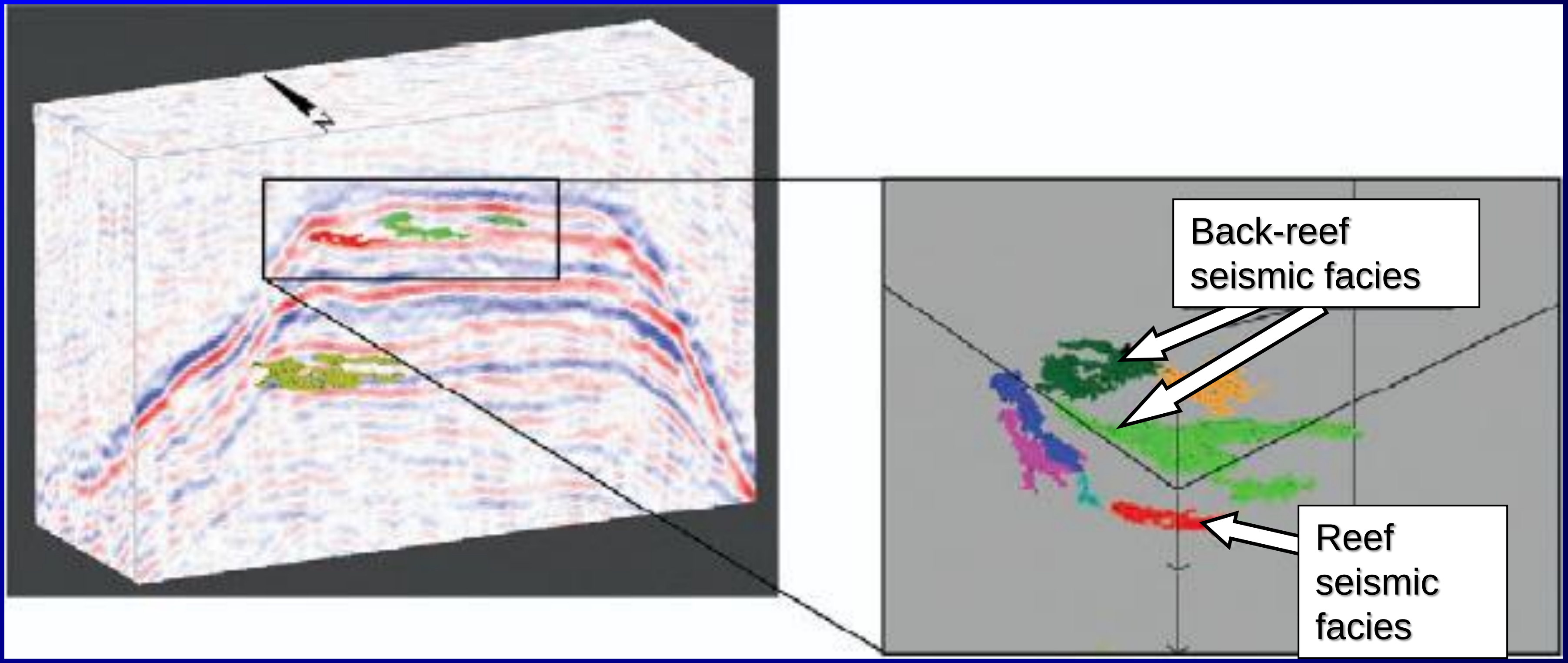
Amplitude histogram

Detected voxels
(0 < amp < 60)

Extracted bodies

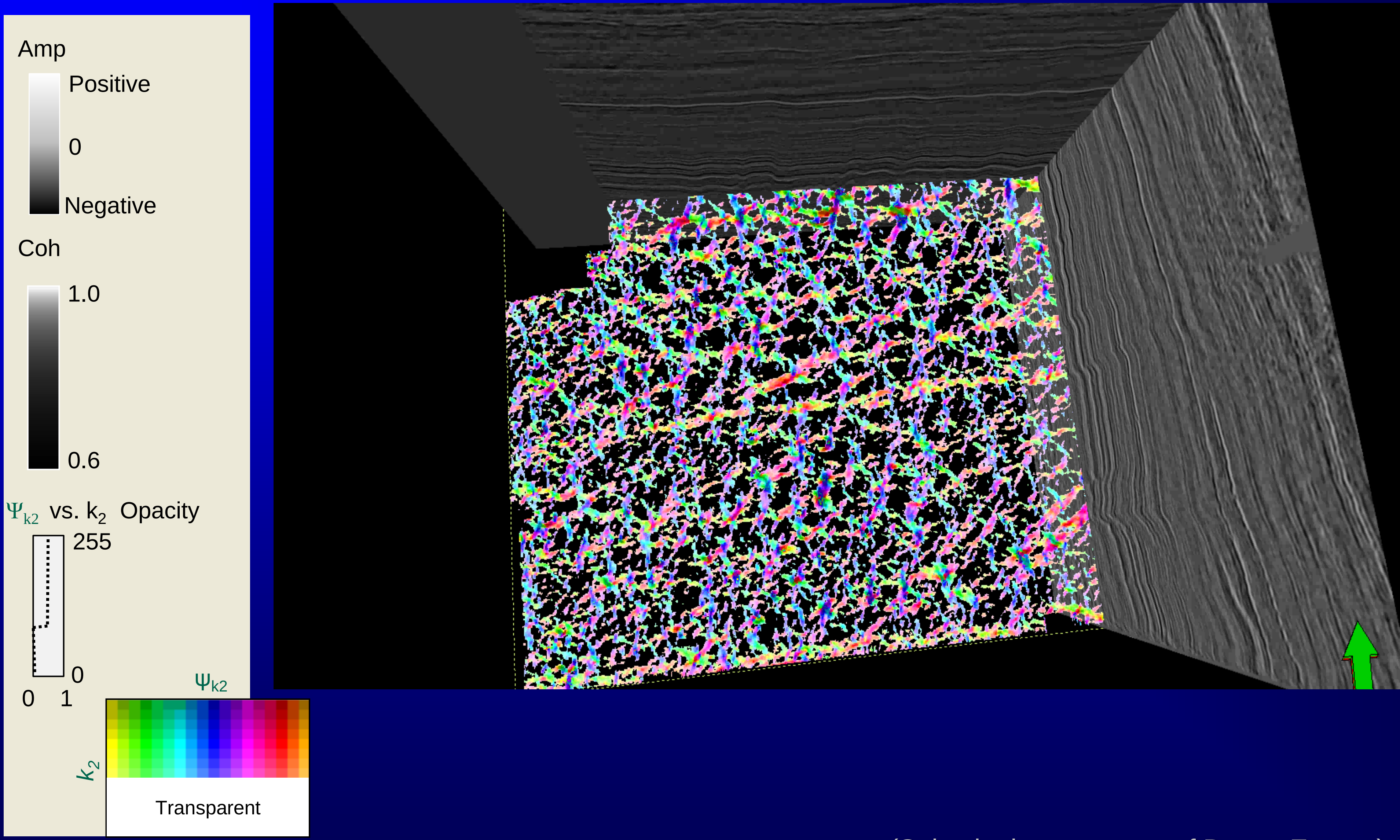
(Masaferro et al., 2003)

Voxel Detection and Geobodies



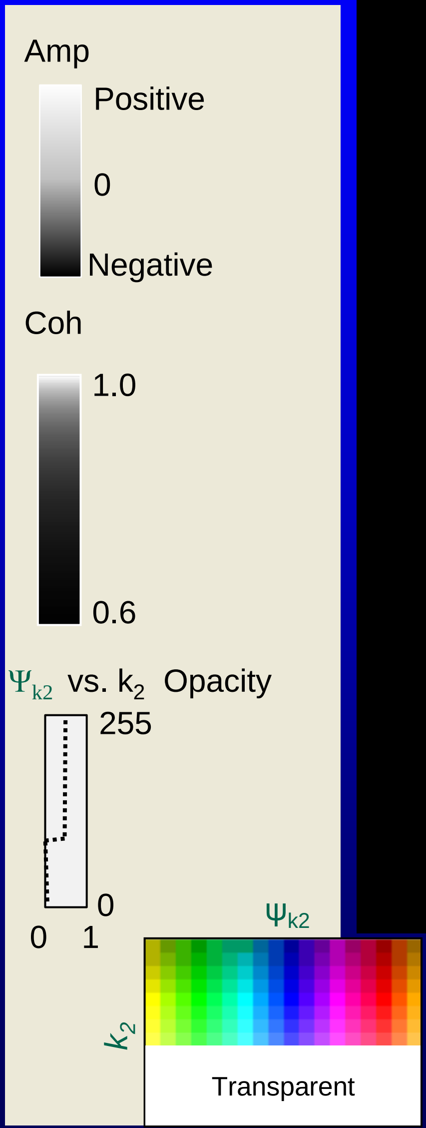
(Masaferro et al., 2003)

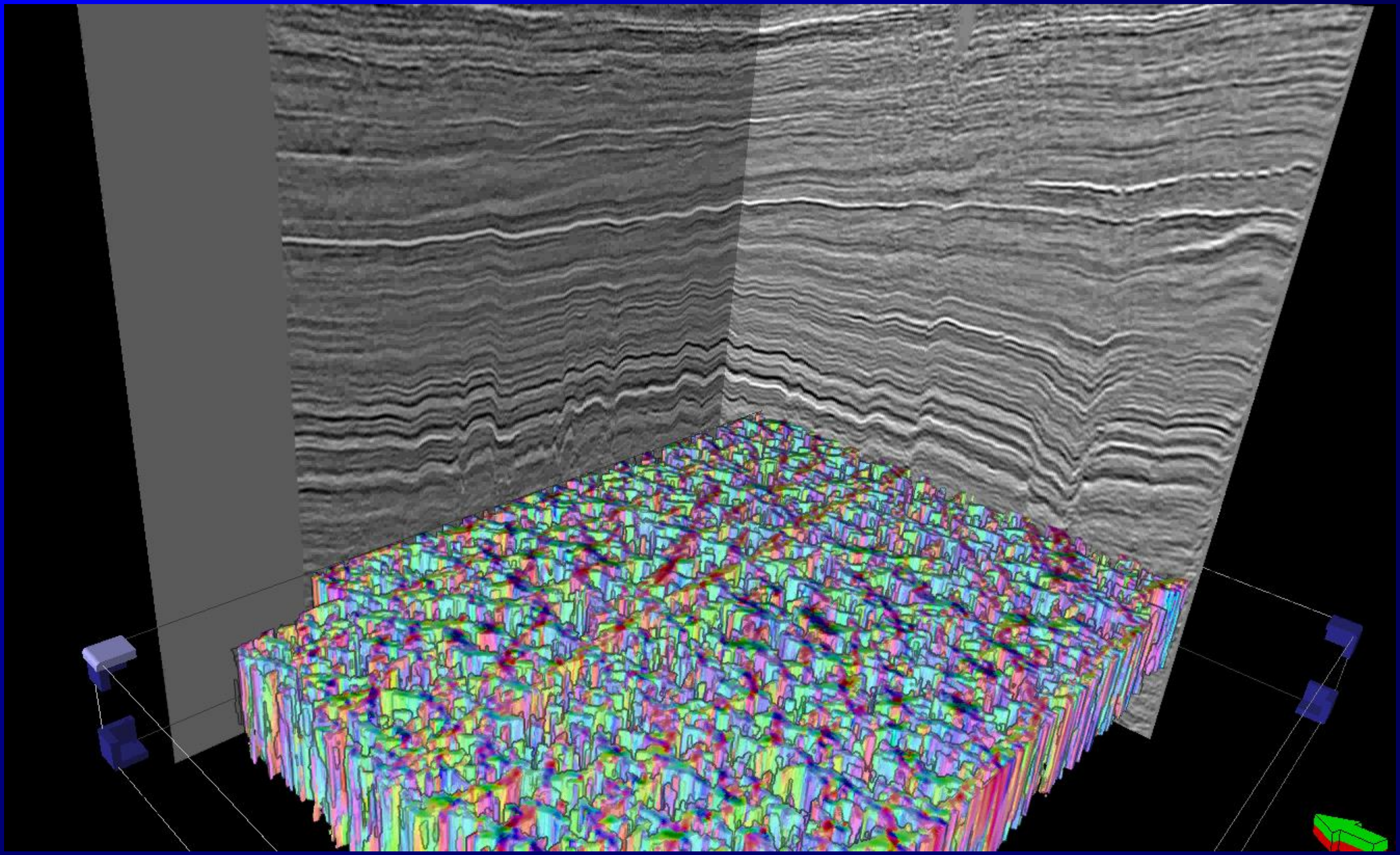
Time slices through strike modulated by most-negative principal curvature



(Seismic data courtesy of Devon Energy)

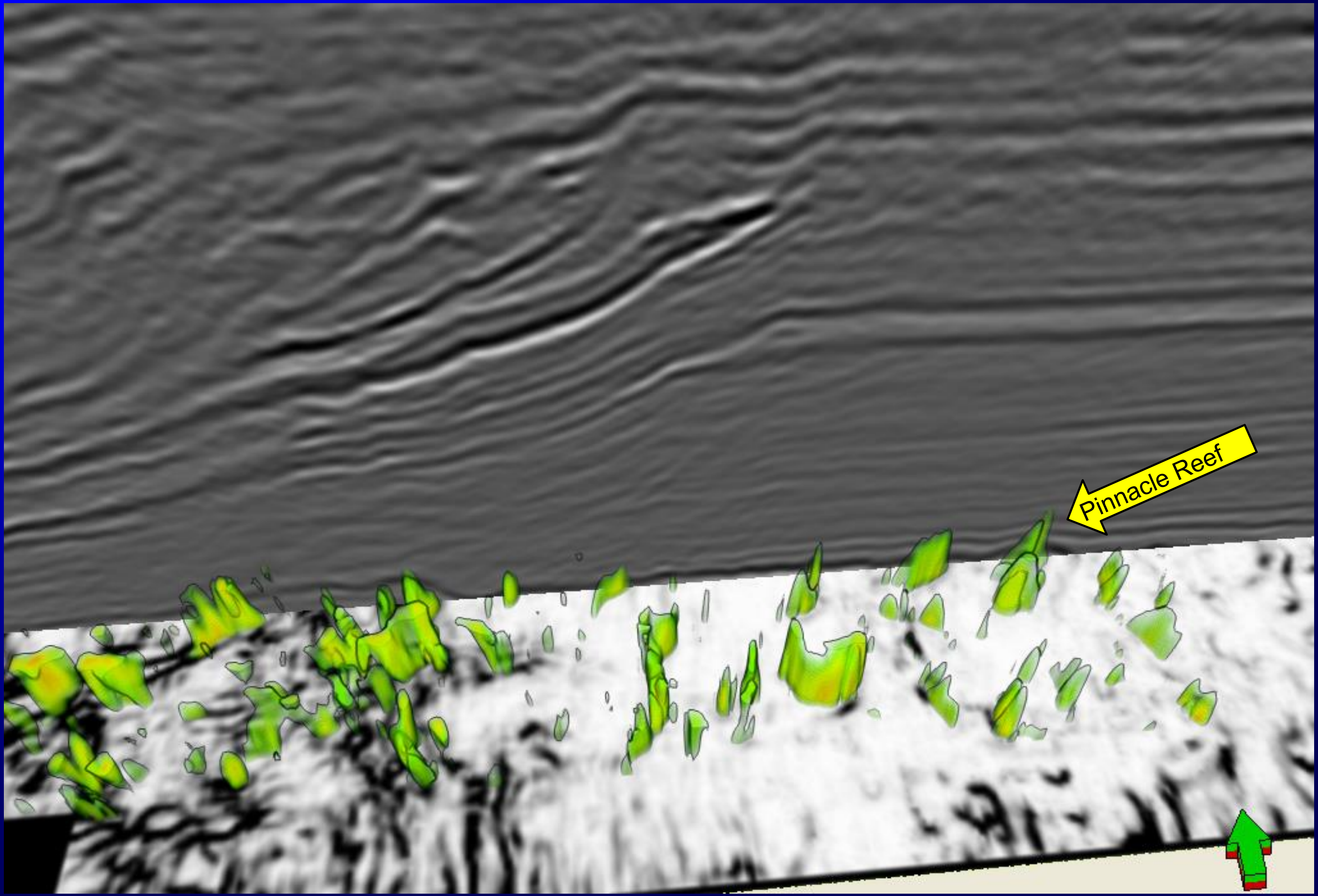
"Box probe" through strike modulated by most-negative principal curvature





(Seismic data courtesy of Devon Energy)

Boxprobe rendering of ridge and dome shapes with a coherence time slice



(Seismic data courtesy of Parallel Petroleum LLC)

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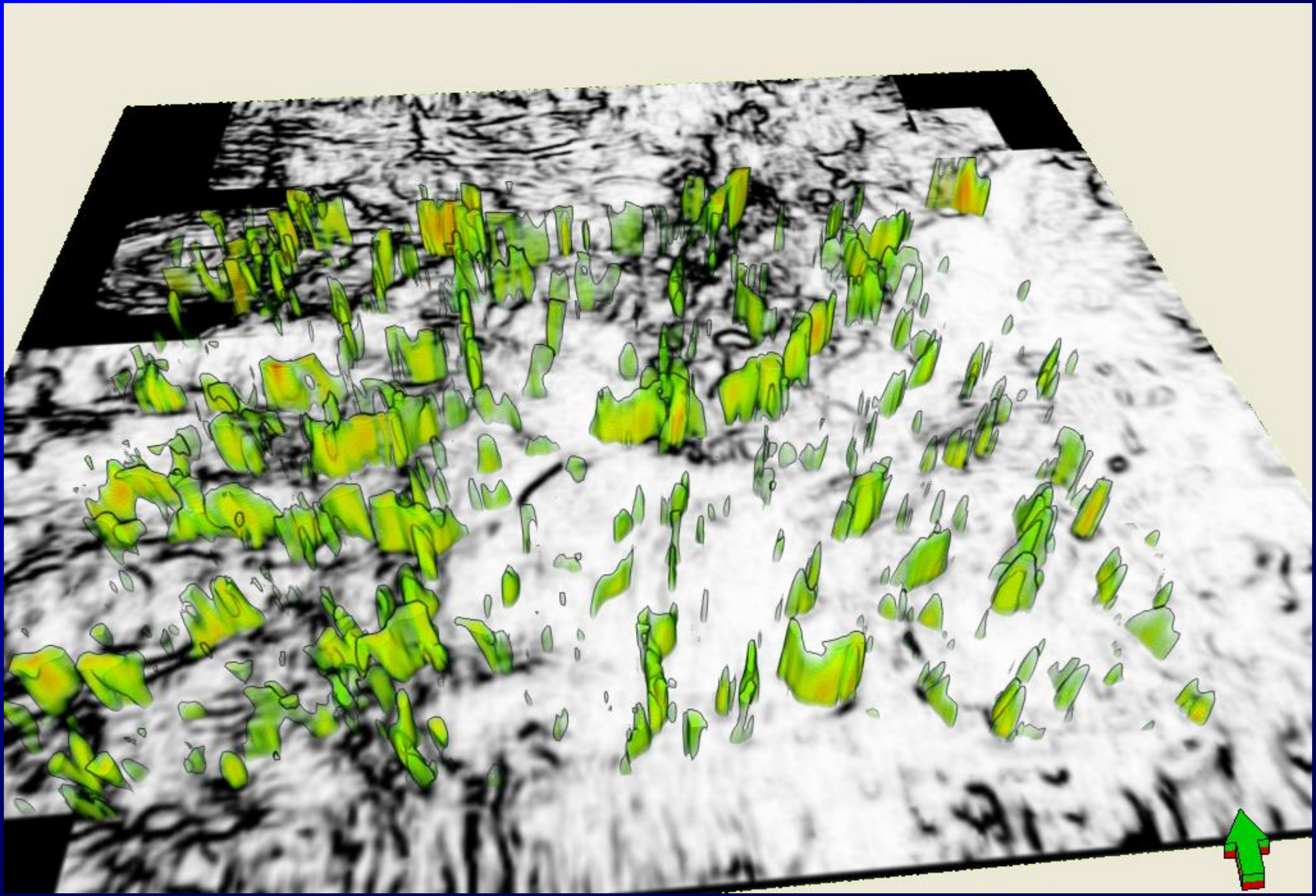

(Seismic data courtesy of Parallel Petroleum LLC)

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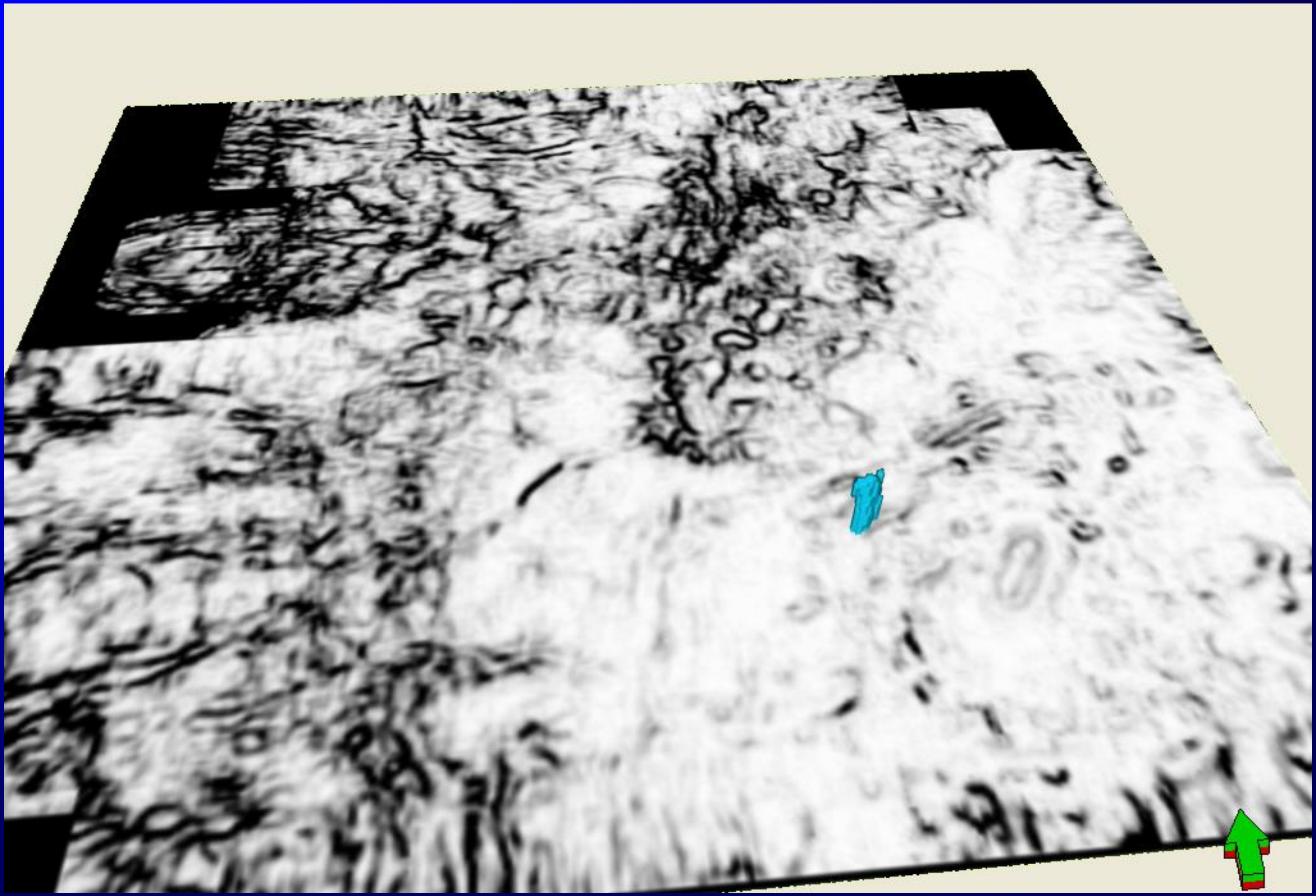
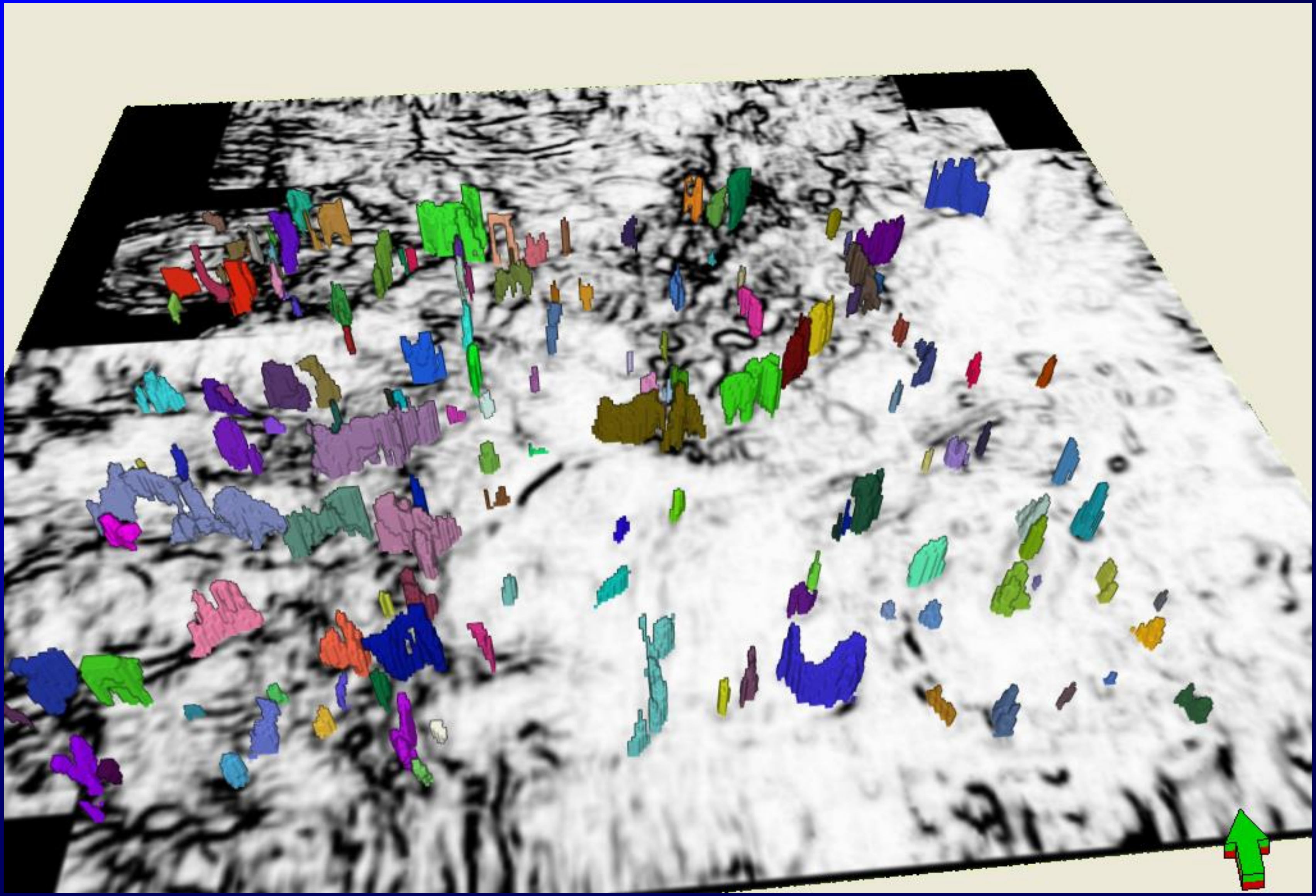
- Geobodies

Picking a geobody



(Seismic data courtesy of Parallel Petroleum LLC)

Picking multiple geobodies



(Seismic data courtesy of Parallel Petroleum LLC)

Single Attribute Display

In Summary:

- The best color scales are those that have analogues to everyday human perception and/or experience (e.g. hot/cold colors, shaded relief maps, …)

- Hue is a natural choice for attributes that are cyclic (e.g. phase, azimuth, strike, …)

- Lineaments or discontinuities show up best in monochrome (gray scale, sepia,…)

- Choice of discontinuous color scales prevent the data from speaking for themselves. Rather use single or double gradational scales (Brown, 1999)

- Use a neutral background color for data having low information content! (e.g. white or black for zero curvature) (Kidd, 1999).

Multiattribute Display

- The RGB model works best for attributes that are of the same type and have similar amplitude ranges

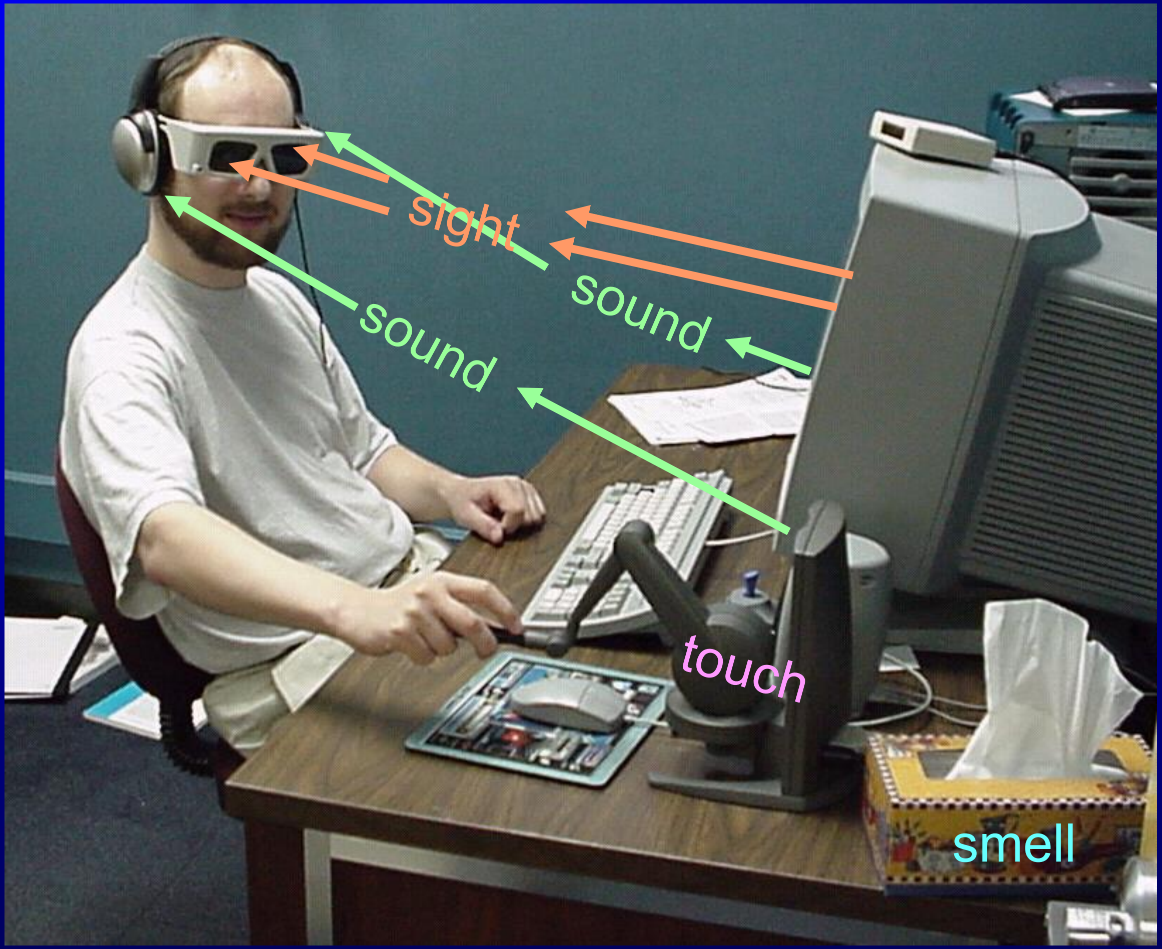
- Blending works best when one of the attributes is plotted against the black-white lightness axis, rendering easy-to-interpret pastel images

- Blending is easy to implement on surfaces, more challenging to implement on volumes

- The HLS color model allows us to construct 2D and 3D color tables that allow the interpreter to modulate attributes by a measure of ‘confidence’
    - meaningful azimuths require finite dip magnitude
    - meaningful frequencies require finite spectral amplitude

- Crossplotting, boxprobes, and mulitattribute geobody definition bridges the gap between multiattribute visualization and clustering

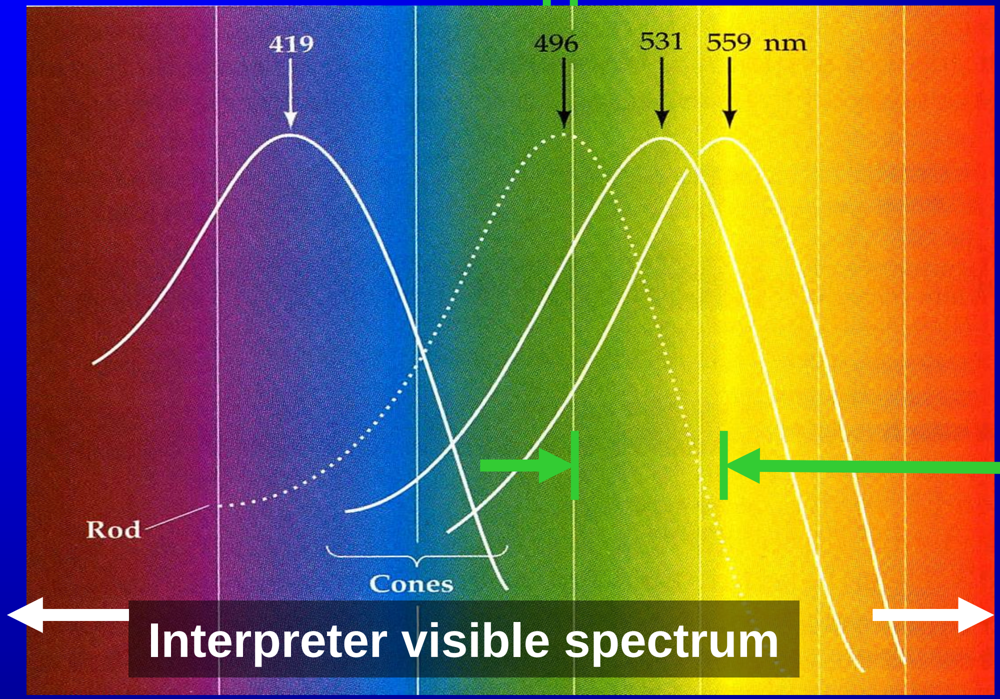
Full sense interpretation



(Harding et al., 2000)

Traditional US Oil Executive visible spectrum

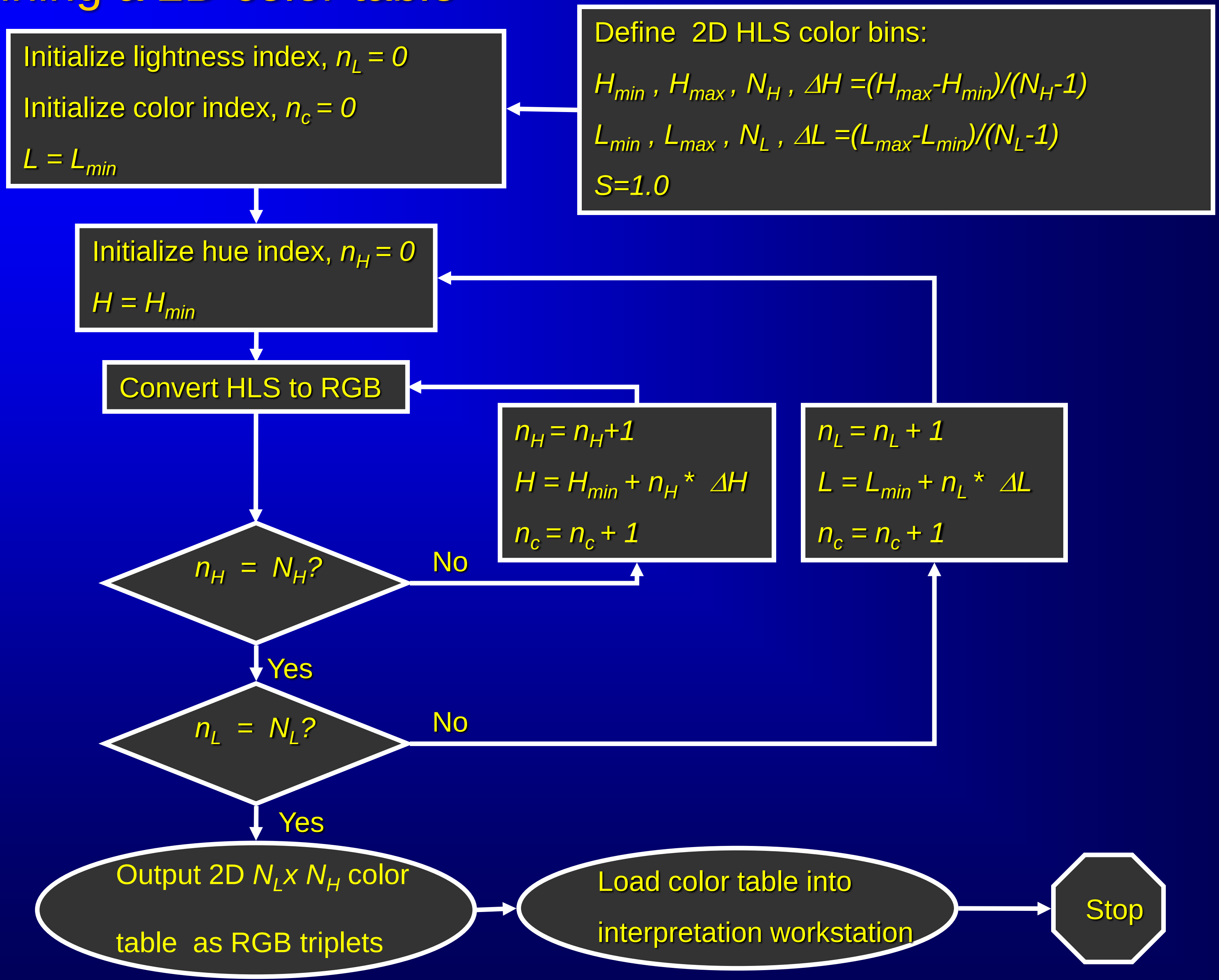
amplitude



Modern US Oil Executive
visible spectrum

wavelength (nm)

Defining a 2D color table



Mapping attributes against a 2D color table