3D Seismic interpretation

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Complex trace attributes

Learner Objectives

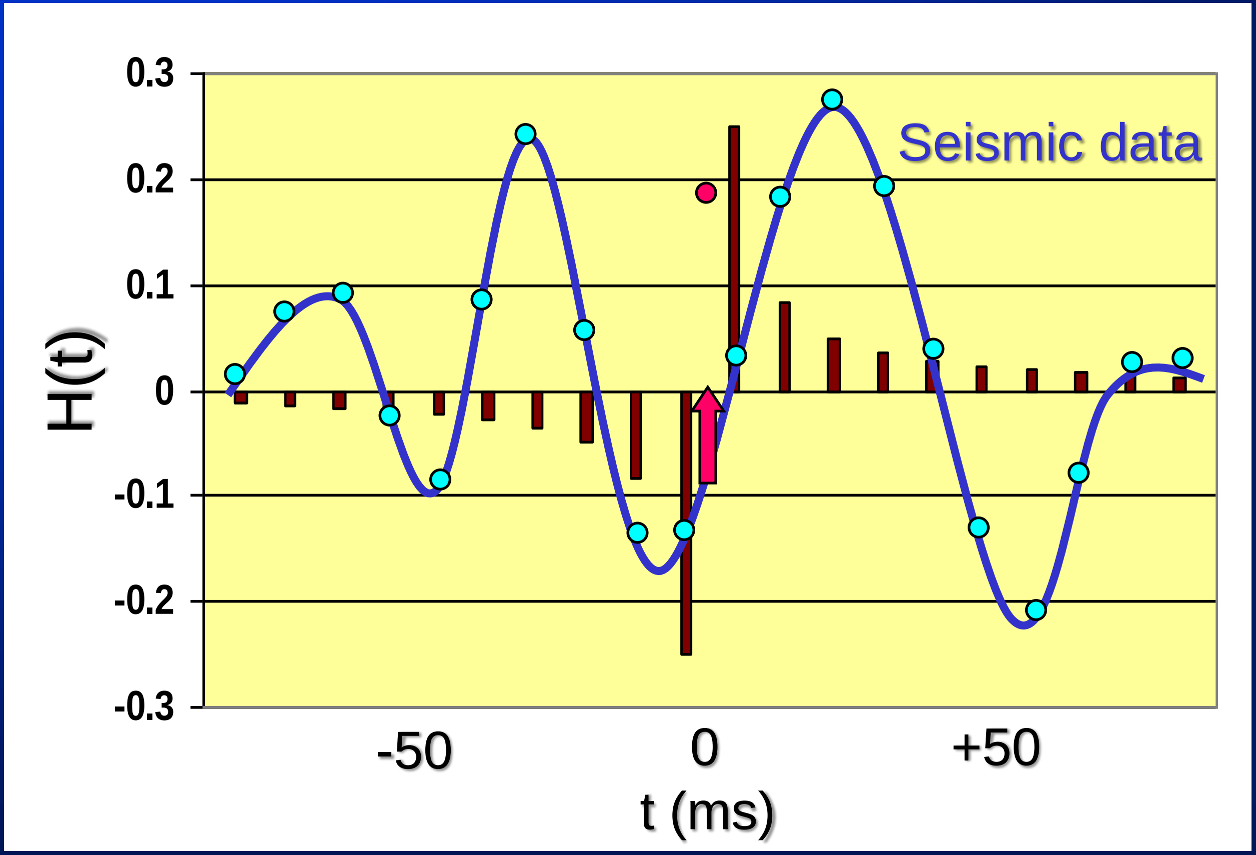
After this section you will be able to:

- visualize the Hilbert transform of the data by looking at the original seismic trace
- use complex trace attributes as building blocks for interpretation
- Evaluate the application of phase unwrapping as a tool for sequence stratigraphic analysis

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

The Hilbert transform

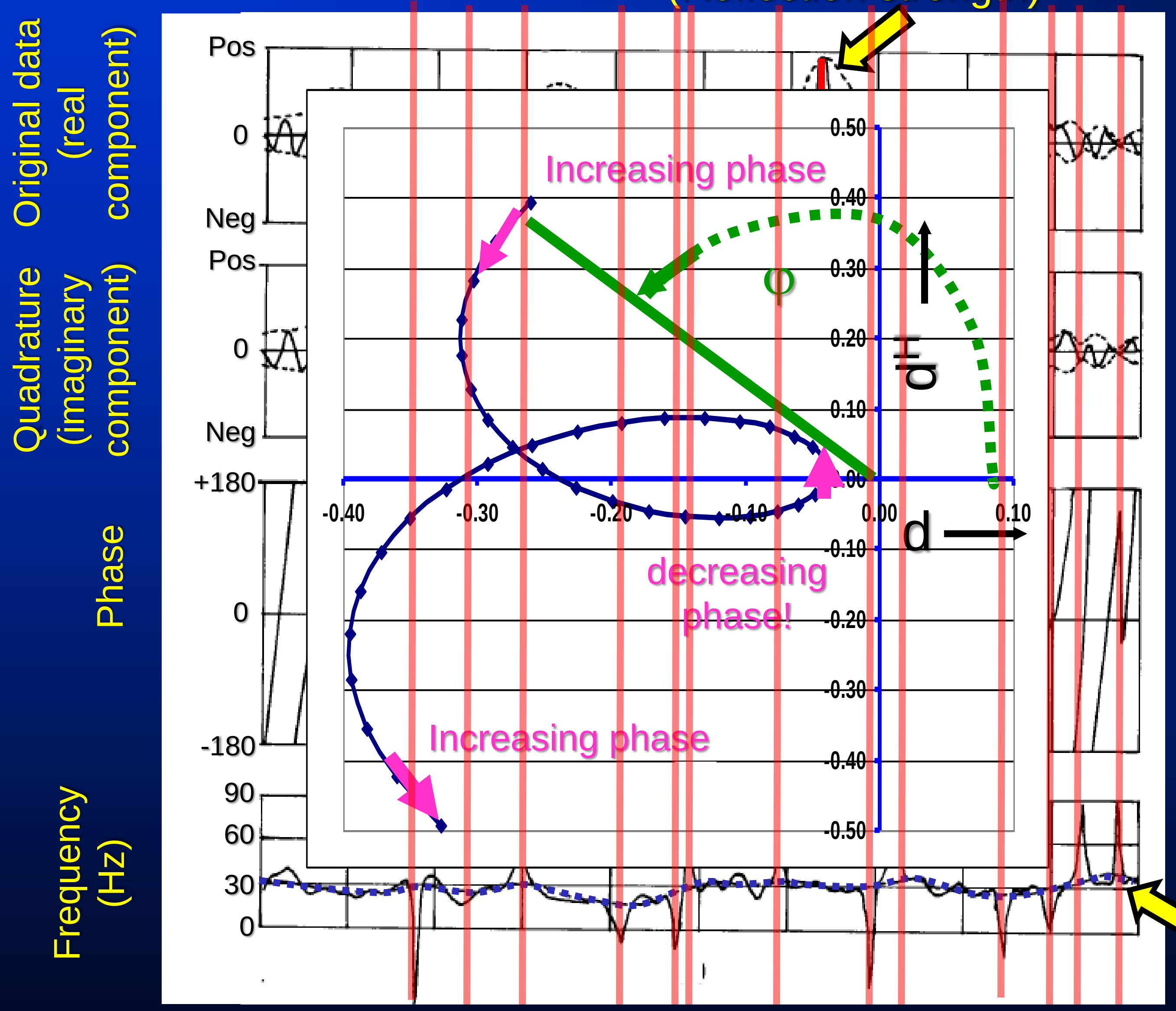


This is NOT instantaneous!

In the time domain: $d^{H}(t) = H(t)*d(t)$

In the frequency domain: $d^{H}(t) = F^{-1}\{ i\, F[d(t)]\}$

The analytic trace



$e(t) = \{[d(t)]^2 + [d^H(t)]^2\}^{1/2}$

$d(t)$

$d^H(t)$

$\phi(t) = \mathrm{ATAN2}[d^H(t), d(t)]$

$$\overline{f}_n \equiv \frac{\sum_{k=-K}^{K} e_{n+k} f_{n+k}}{\sum_{k=-K}^{K} e_{n+k}}$$

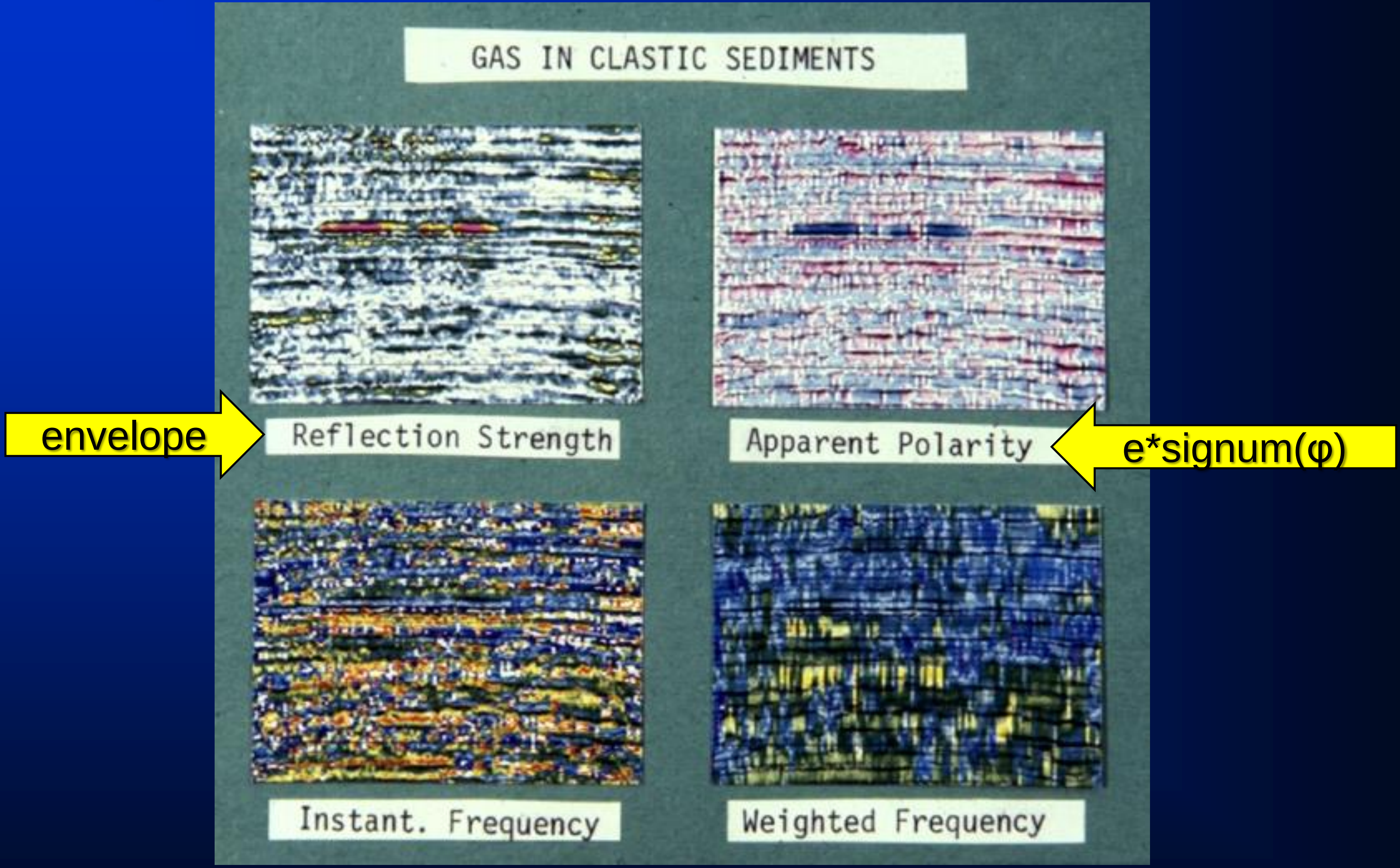
Weighted-average frequency

(Taner et al., 1979)

在数学与信号处理的领域中，一个实数值函数$s(t)$的**希尔伯特转换**(Hilbert transform)——在此标示为$\mathcal{H}$——是将信号$s(t)$与$1/(\pi t)$做卷积，以得到$\widehat{s}(t)$。因此，希尔伯特转换结果$\widehat{s}(t)$可以被解读为输入是$s(t)$的线性非时变系统(linear time invariant system)的输出，而此一系统的脉冲响应为$1/(\pi t)$。这是一项有用的数学，用在描述一个以实数值载波做调制的信号之复数包络(complex envelope)，出现在通讯理论（应用方面的详述请见下文。）

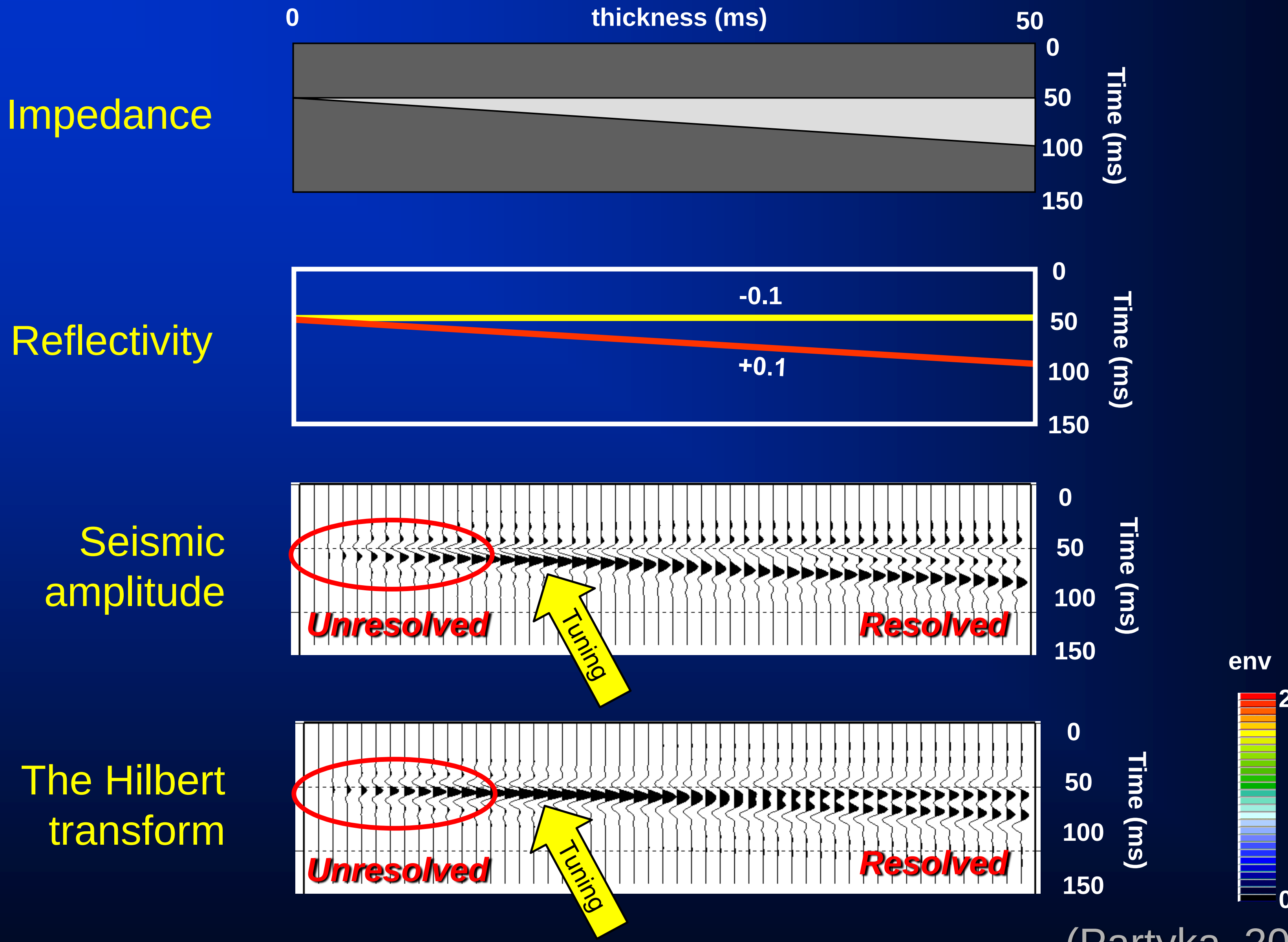
希尔伯特转换是以著名数学家大卫·希尔伯特(David Hilbert)来命名。

Early applications of complex trace attributes



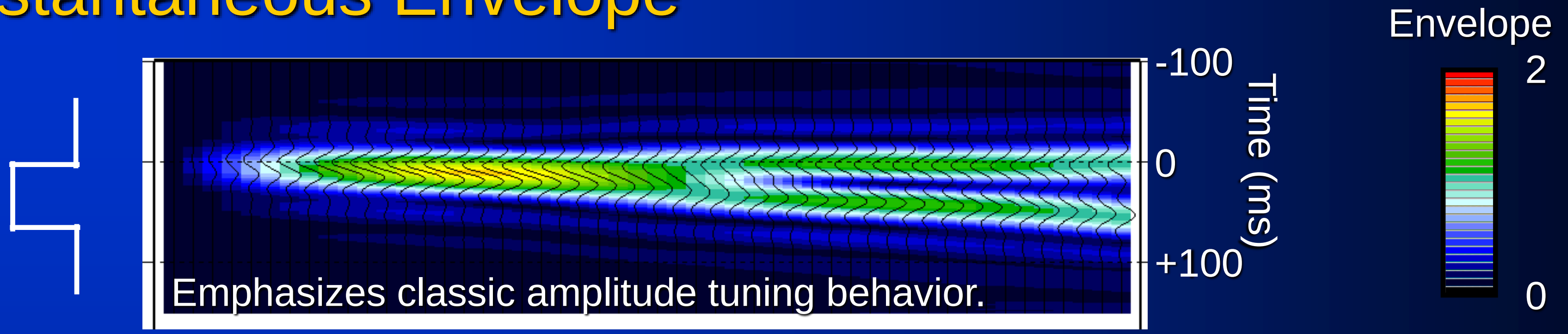
(Courtesy Tury Taner, Rock Solid Images)

Thin bed tuning and the wedge model



(Partyka, 2001)

Instantaneous Envelope

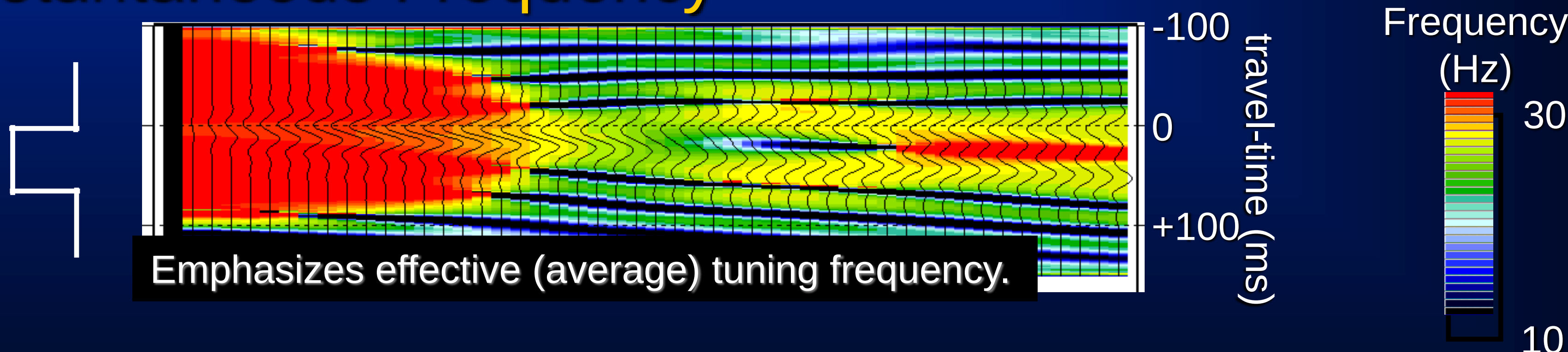


Emphasizes classic amplitude tuning behavior.

Instantaneous Phase

Emphasizes reflection continuity/discontinuity.

Instantaneous Frequency

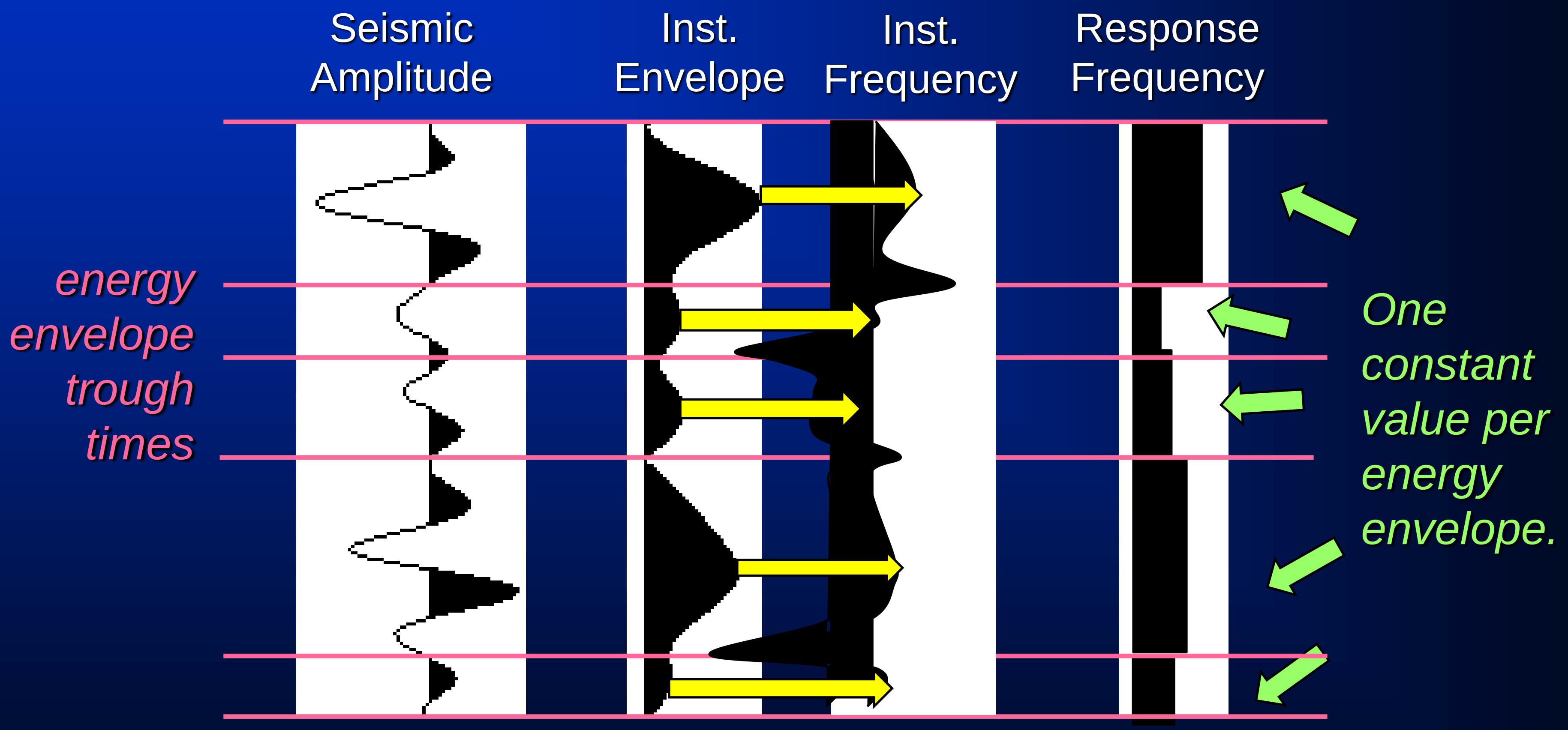


Emphasizes effective (average) tuning frequency.

(Partyka, 2000)

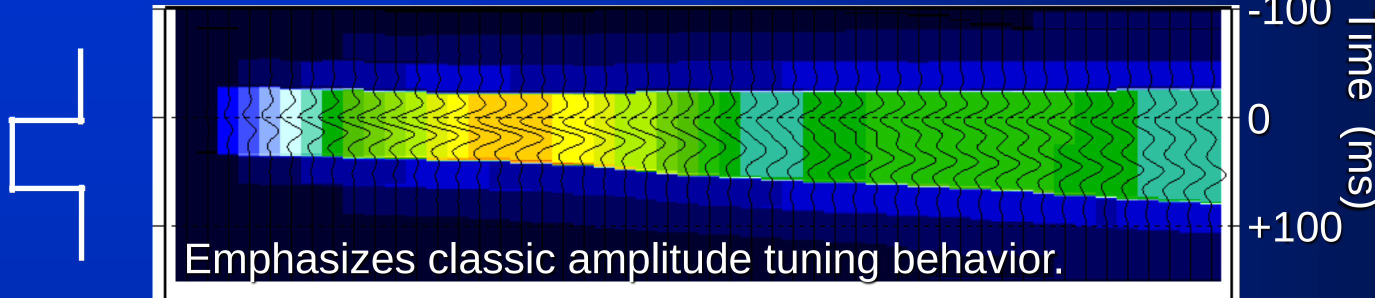
Response (or Wavelet) Attributes

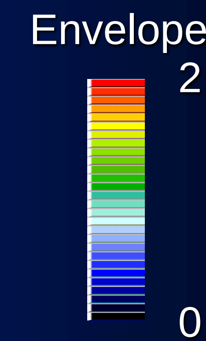
Characterize reflection zones contained within energy envelope lobes.



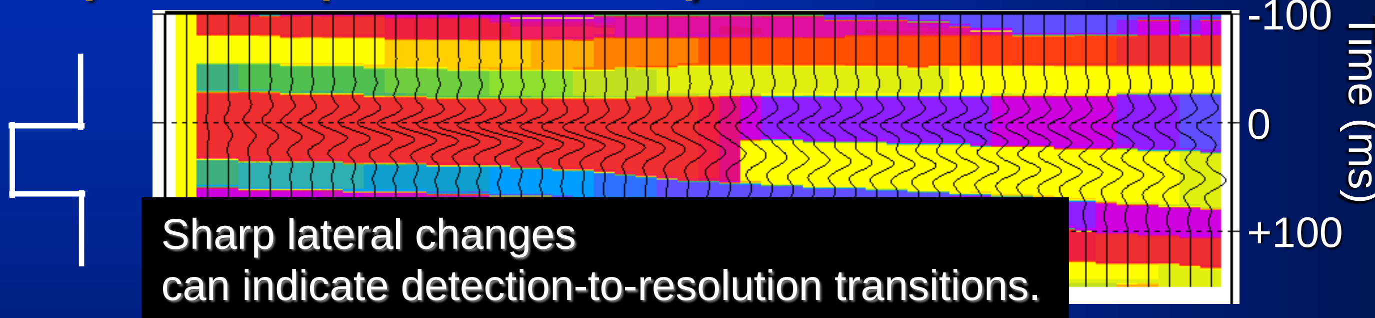
(Partyka, 2000)

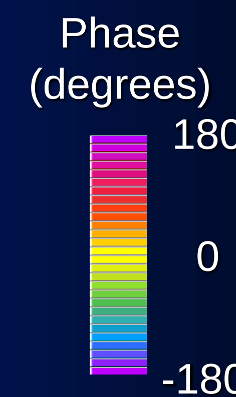
Response (or Wavelet) Envelope



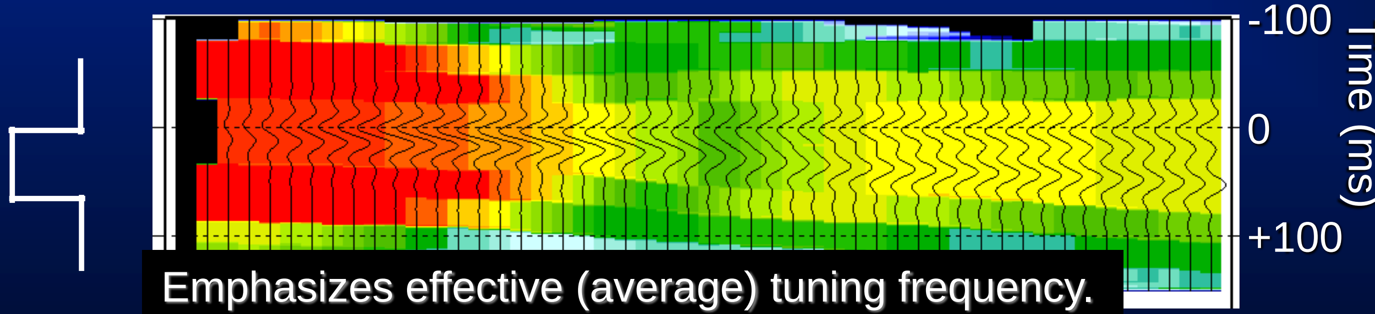


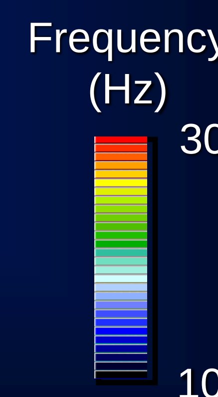
Response (or Wavelet) Phase





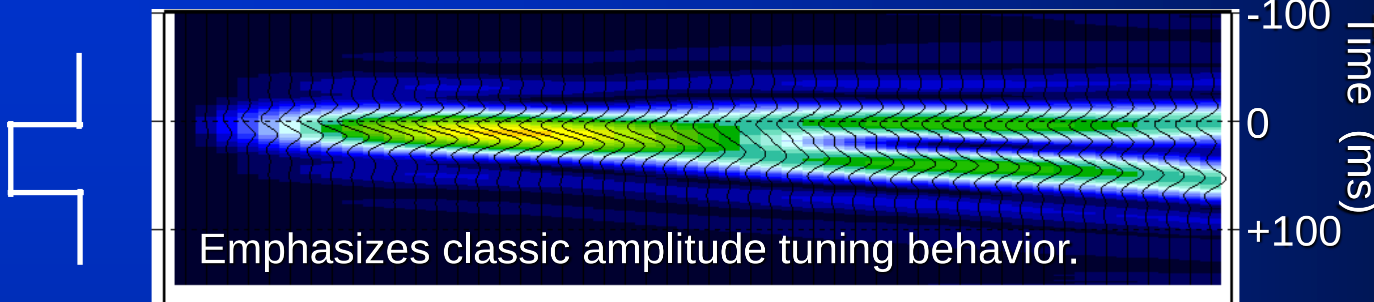
Response (or Wavelet) Frequency



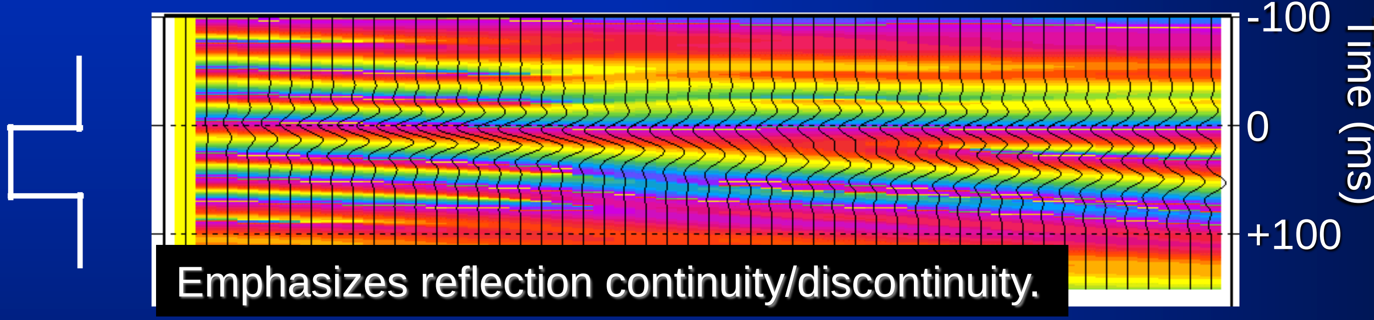


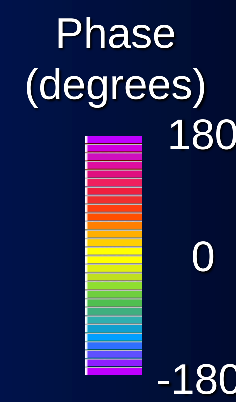
(Partyka, 2000)

Instantaneous Envelope

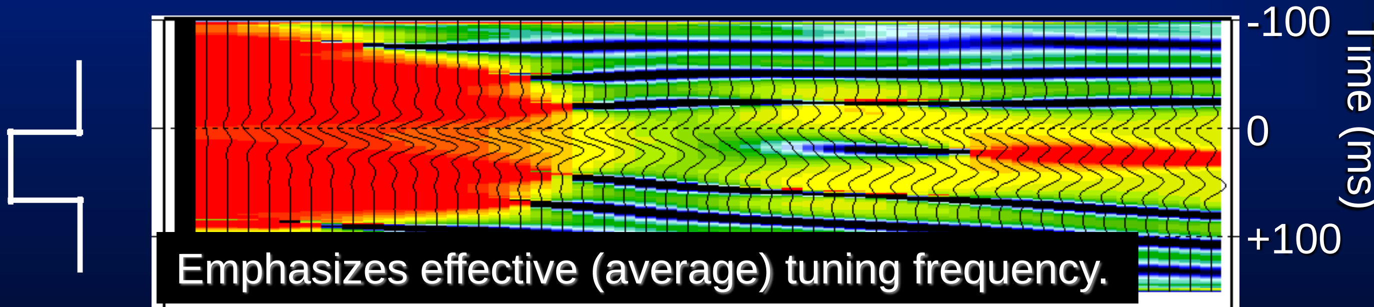


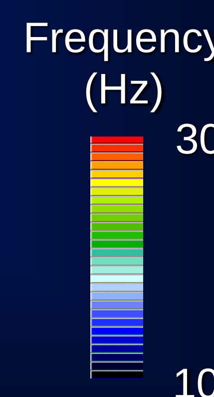
Instantaneous Phase





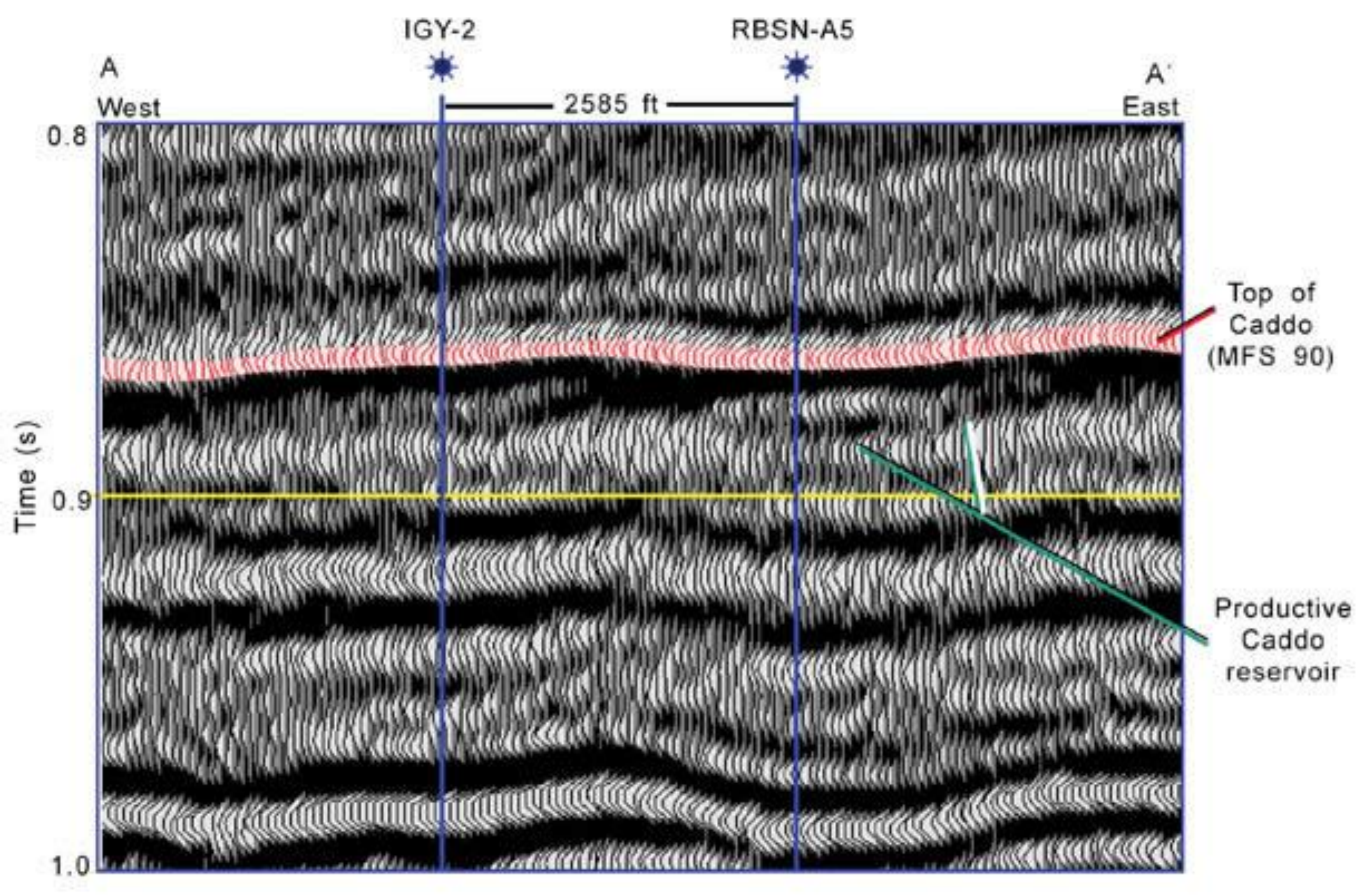
Instantaneous Frequency





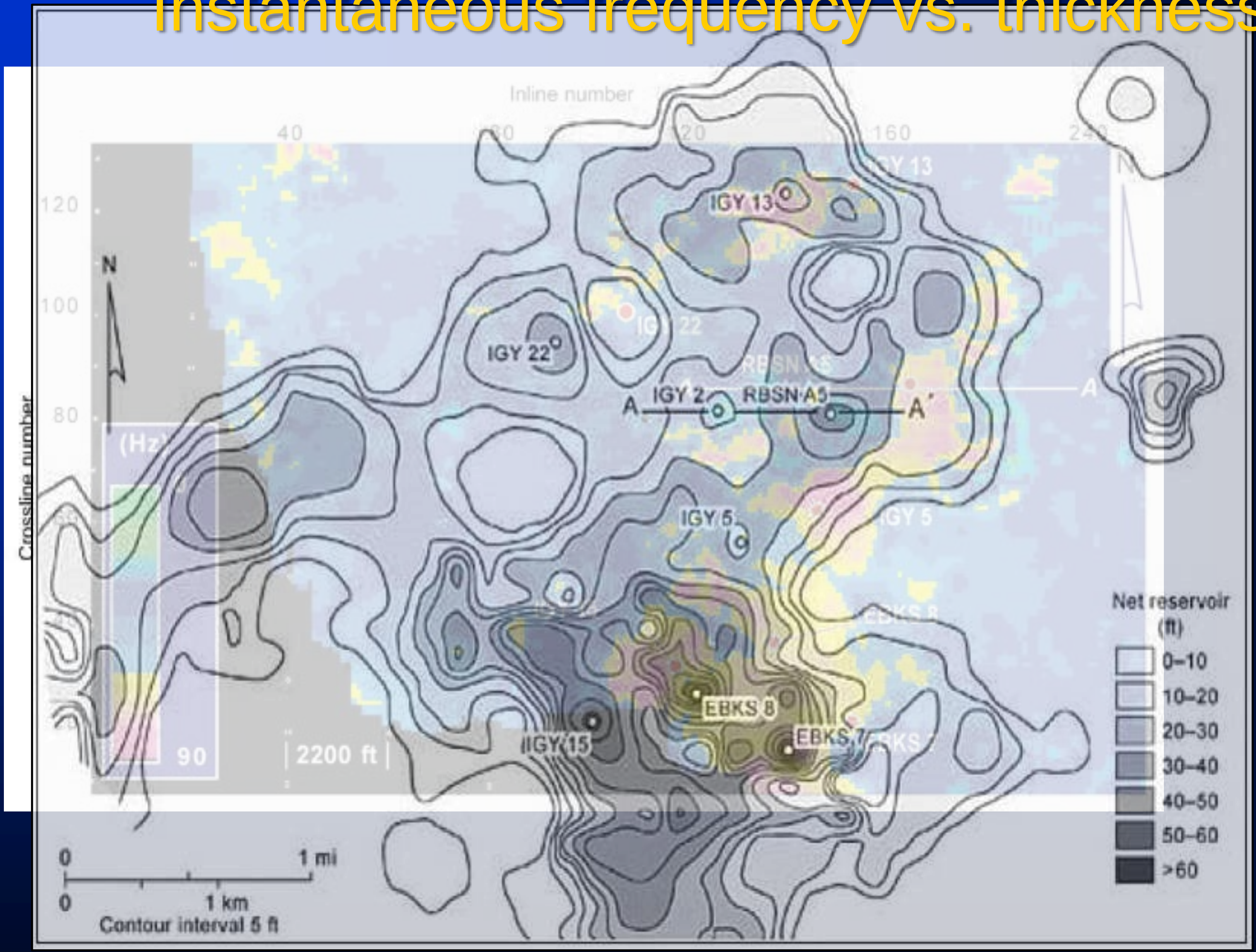
(Partyka, 2000)

Vertical slice through amplitude



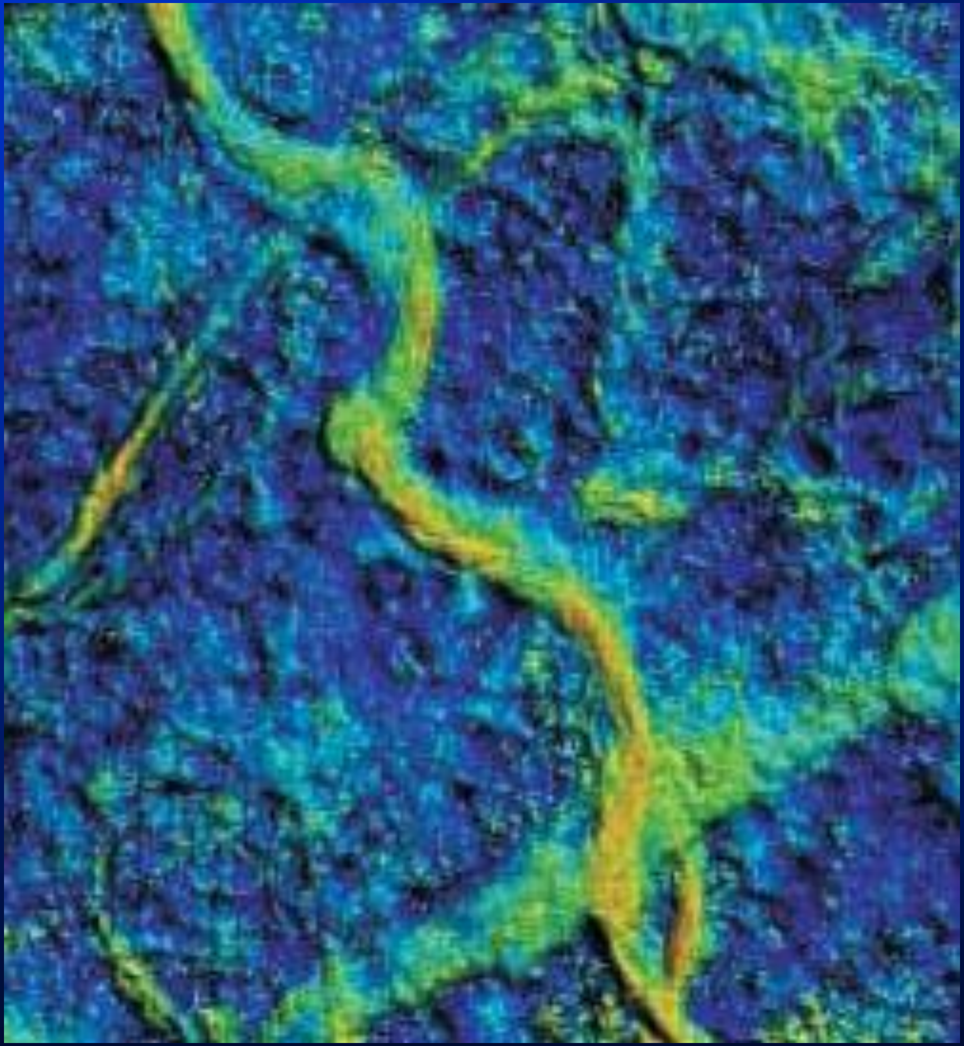
(Hardage, 2008)

Instantaneous frequency vs. thickness



(Hardage, 2008)

Combinations of instantaneous attributes

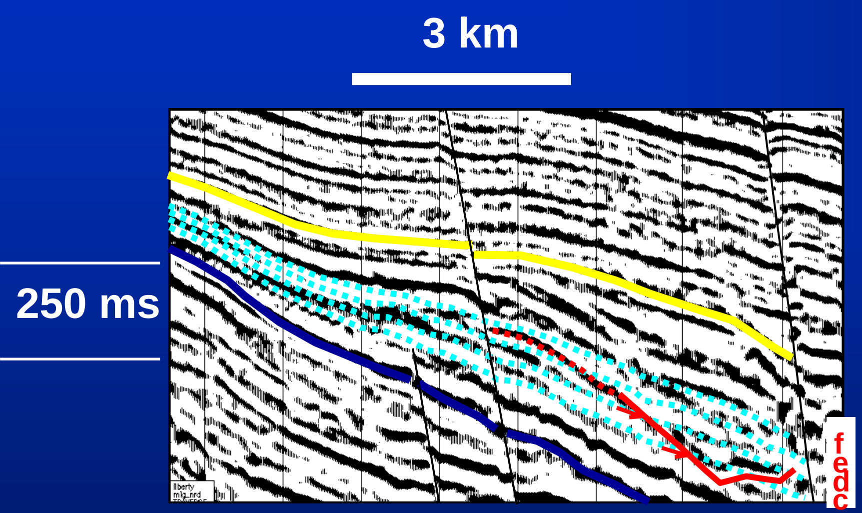


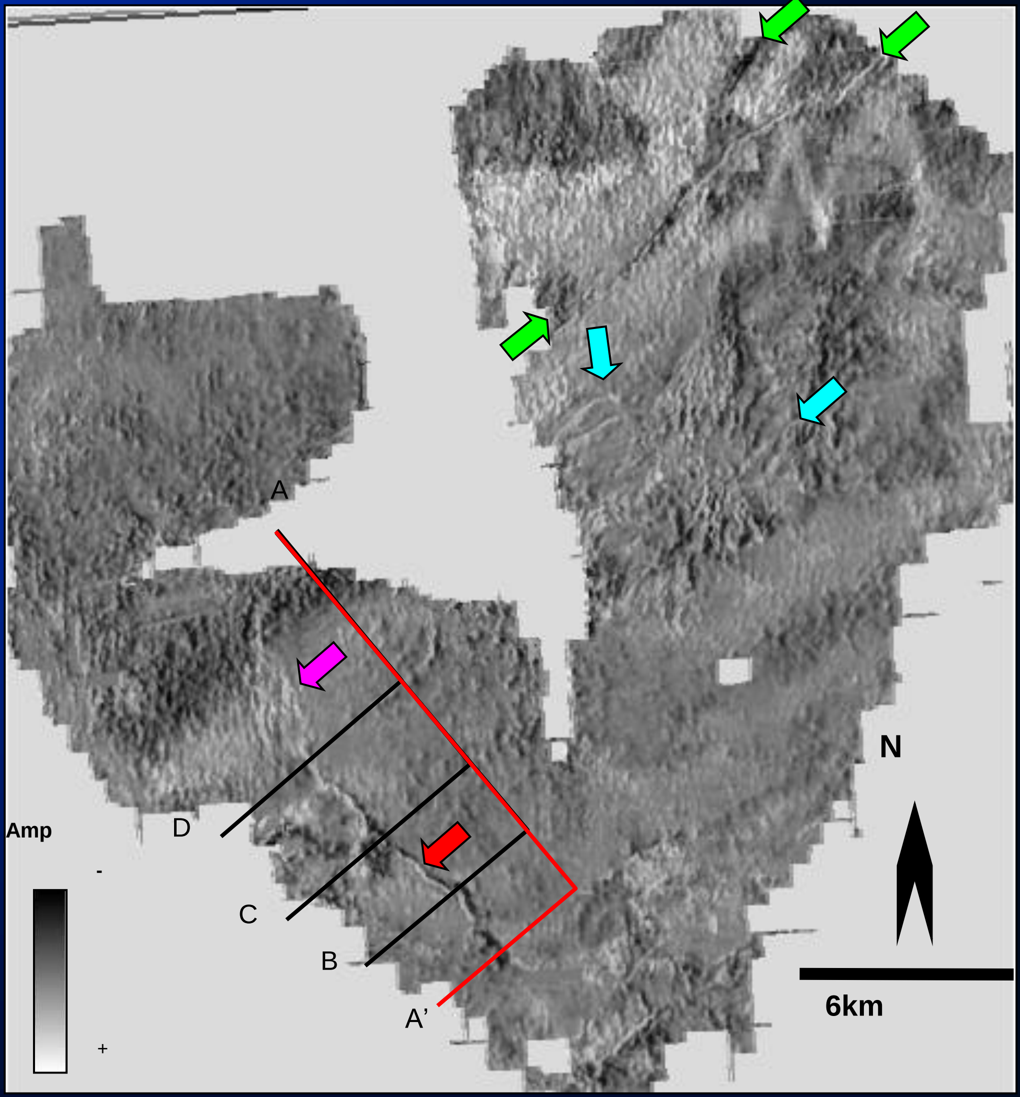
Sweetness co-rendered with coherence

sweetness=envelope/SQRT(f_{inst})

(Hart, 2008)

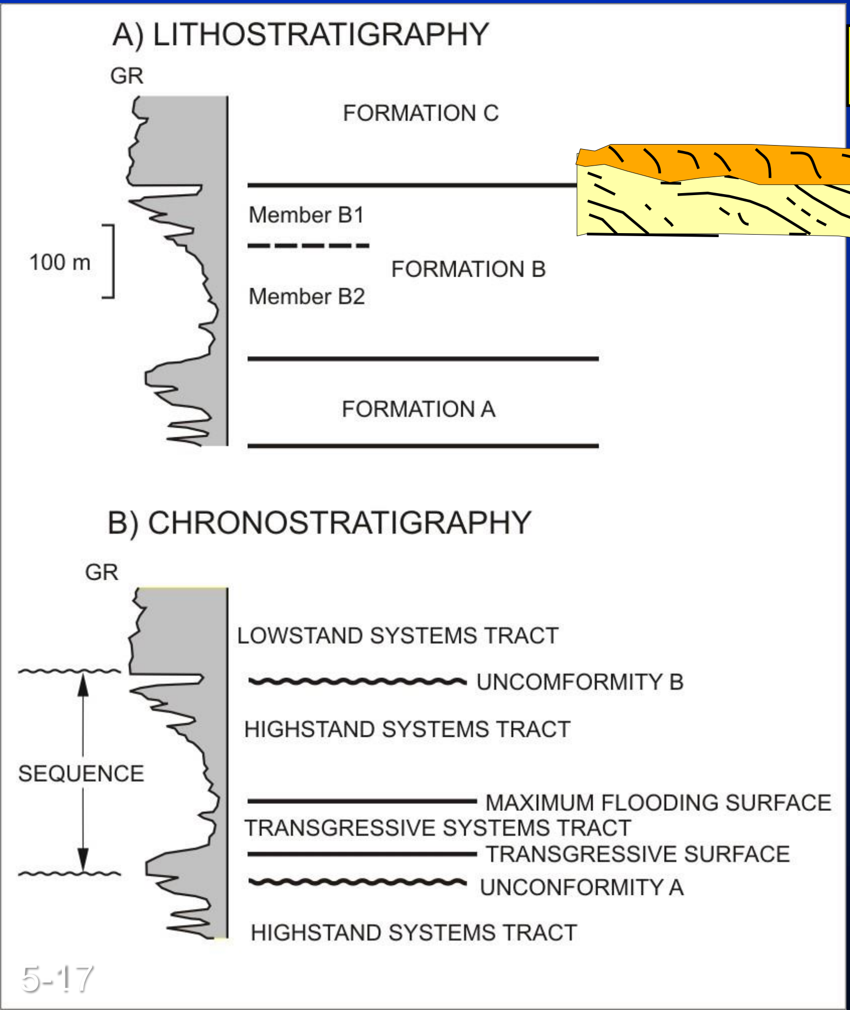
Stratal slice through an amplitude gradient volume

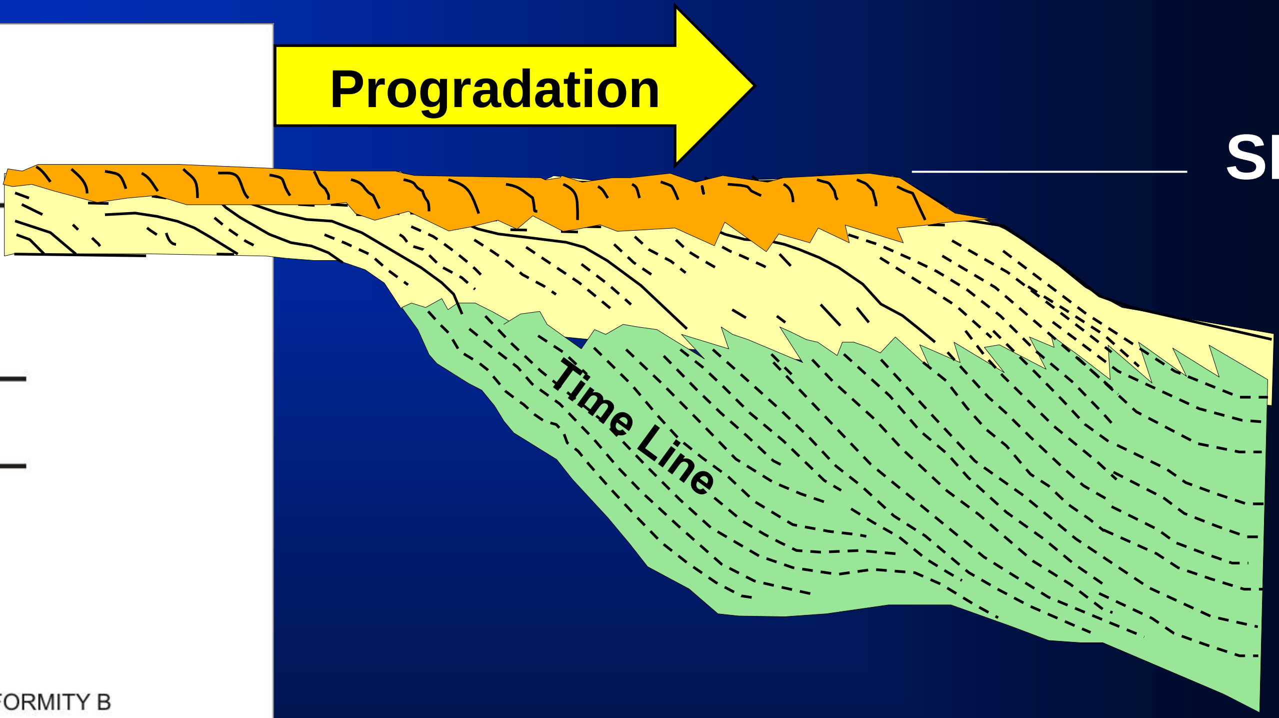




(Akintokumbo, 2007)

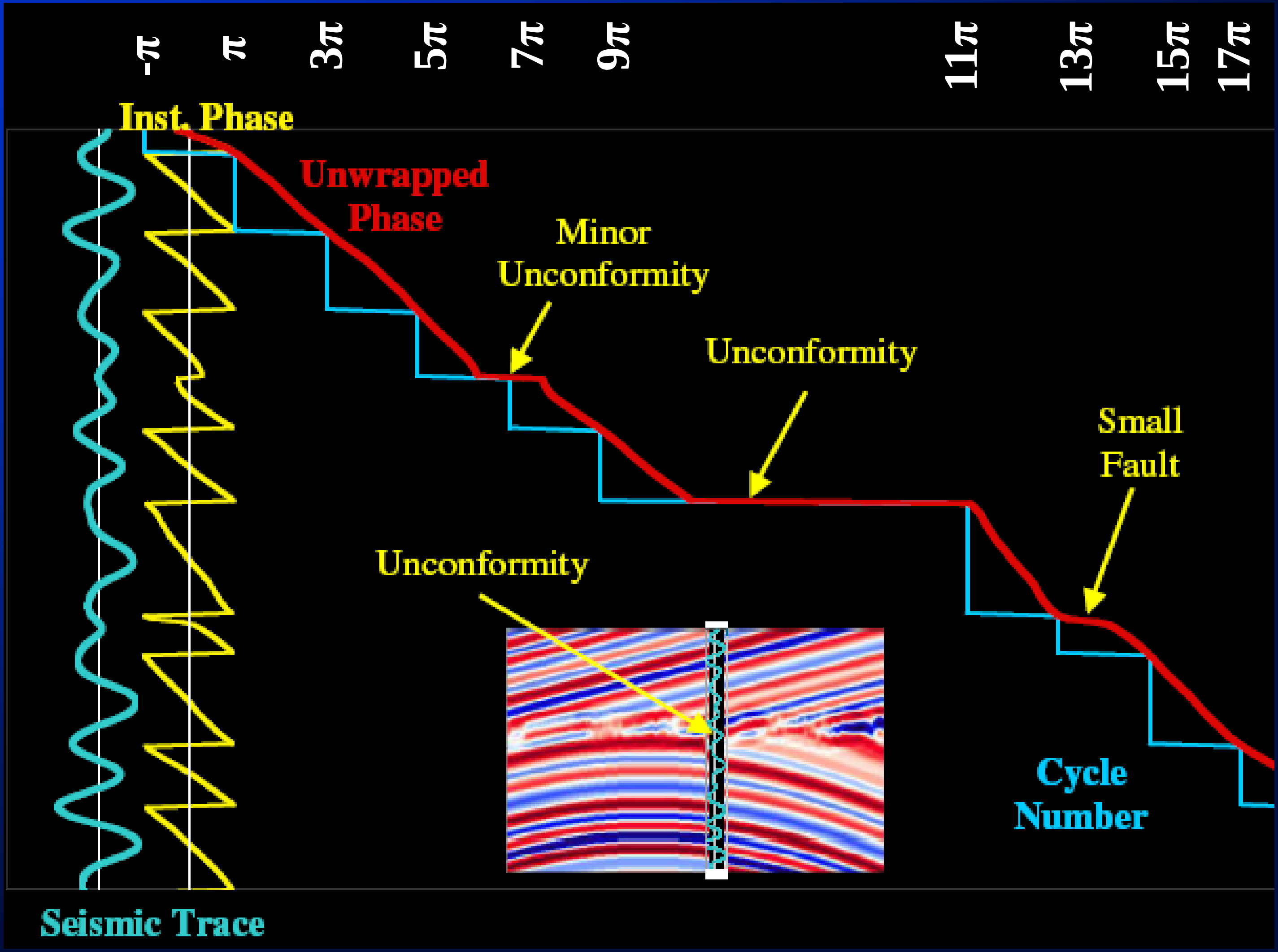
Phase unwrapping is based on reflection events which are in turn based on changes in impedance:
It is therefore a map *of lithostratigraphy*





(Zeng, 200x; Bjorlykke, 1989)

Unwrapping instantaneous phase – generating a seismic Wheeler diagram

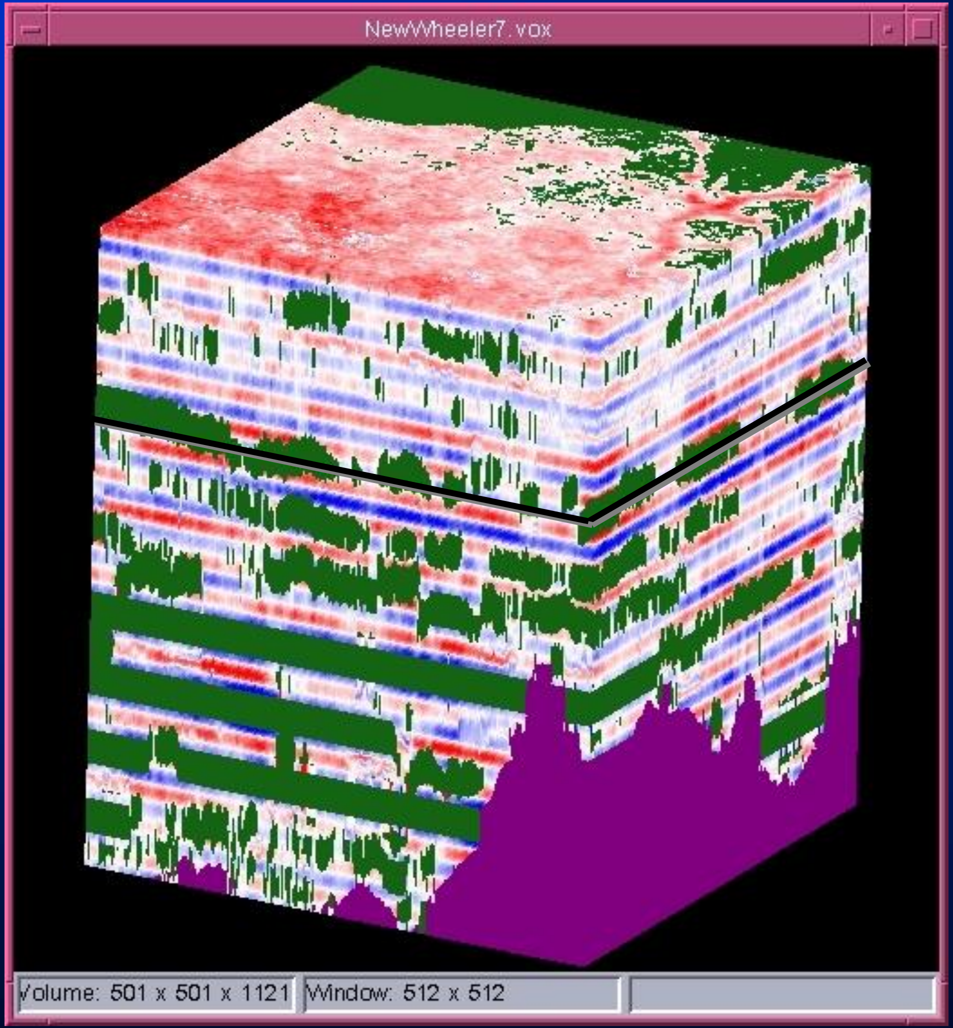


Phase unwrapping results of a single trace

(Stark, 2003)

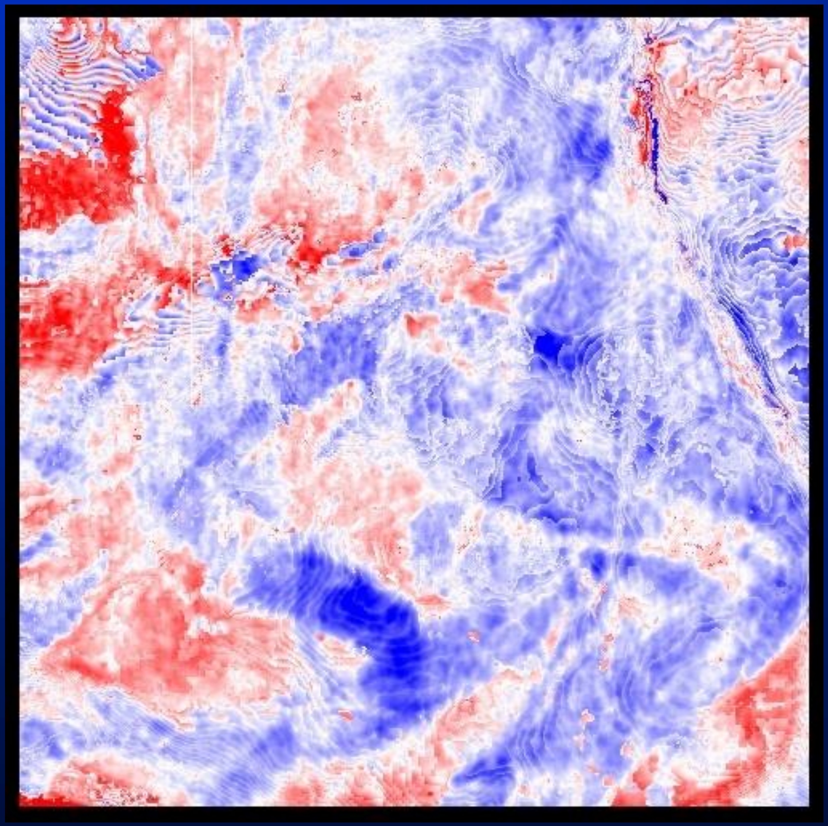
"Continuous" 3D Seismic Wheeler Volume

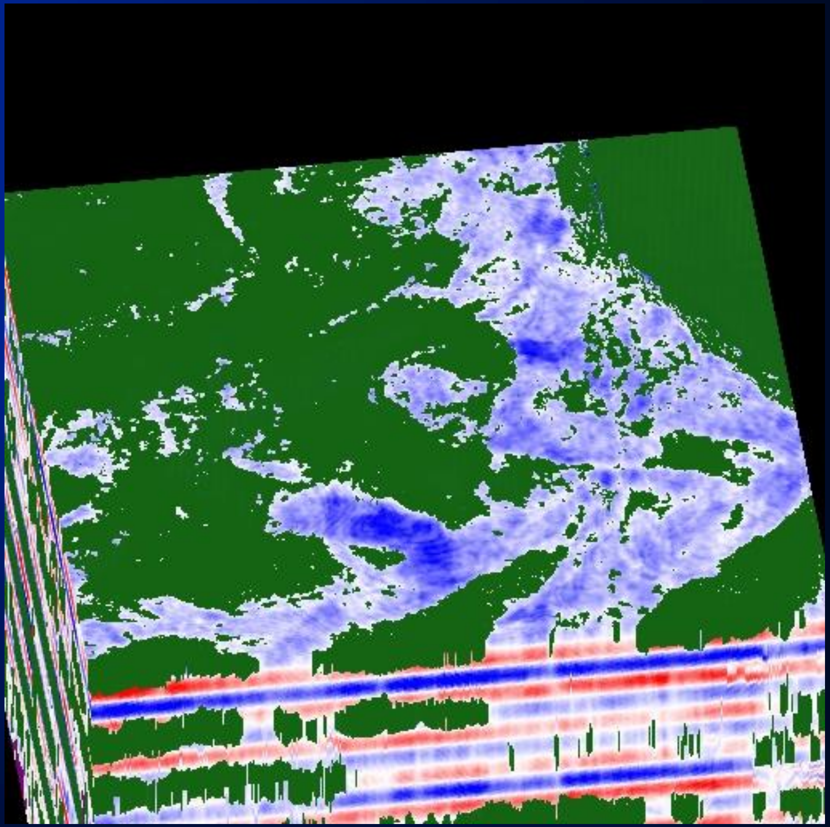
Phase



(Stark, 2007)

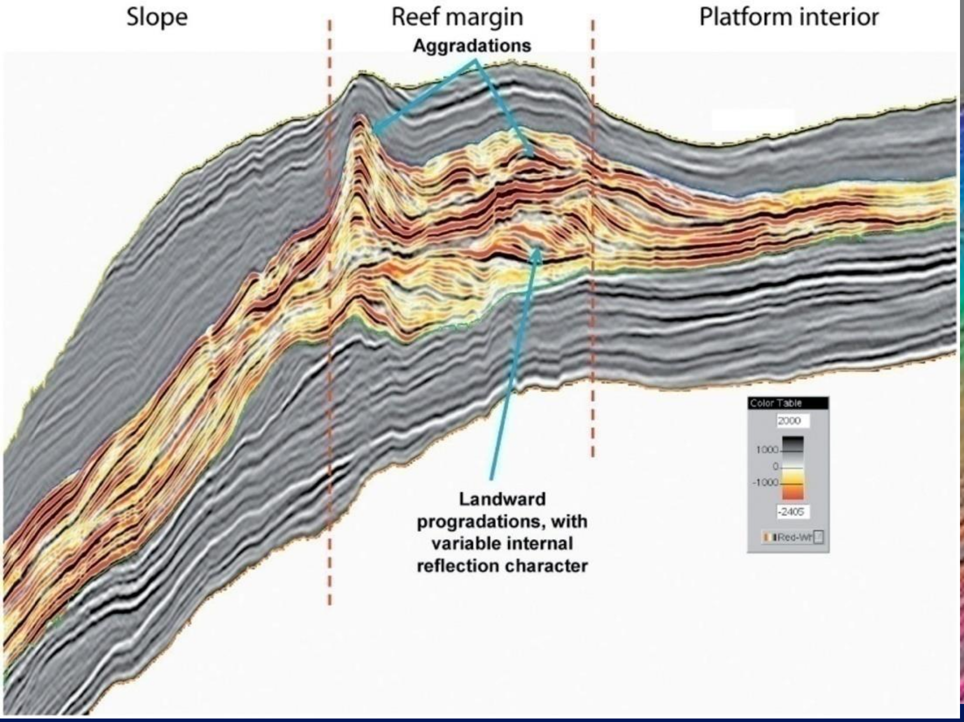
Stratal versus Wheeler Slices



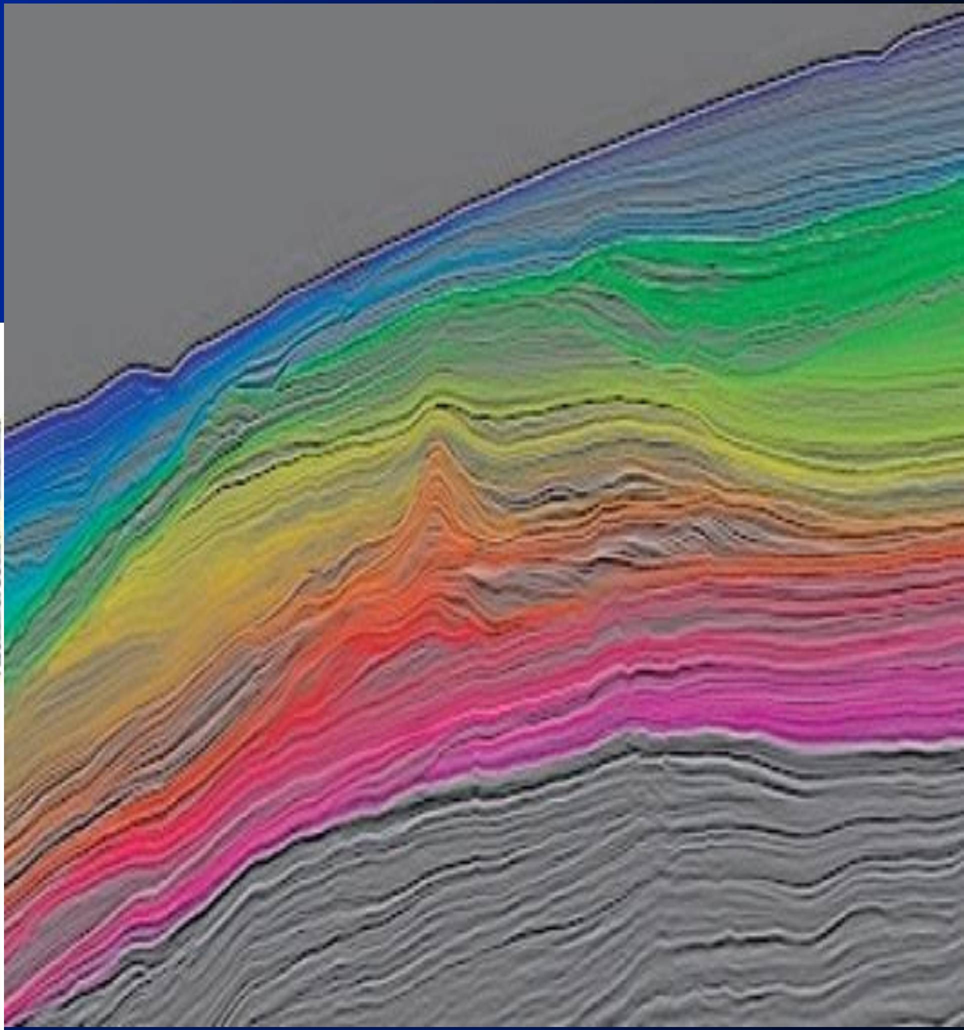


(Stark, 2007)

Seismic sequence stratigraphy

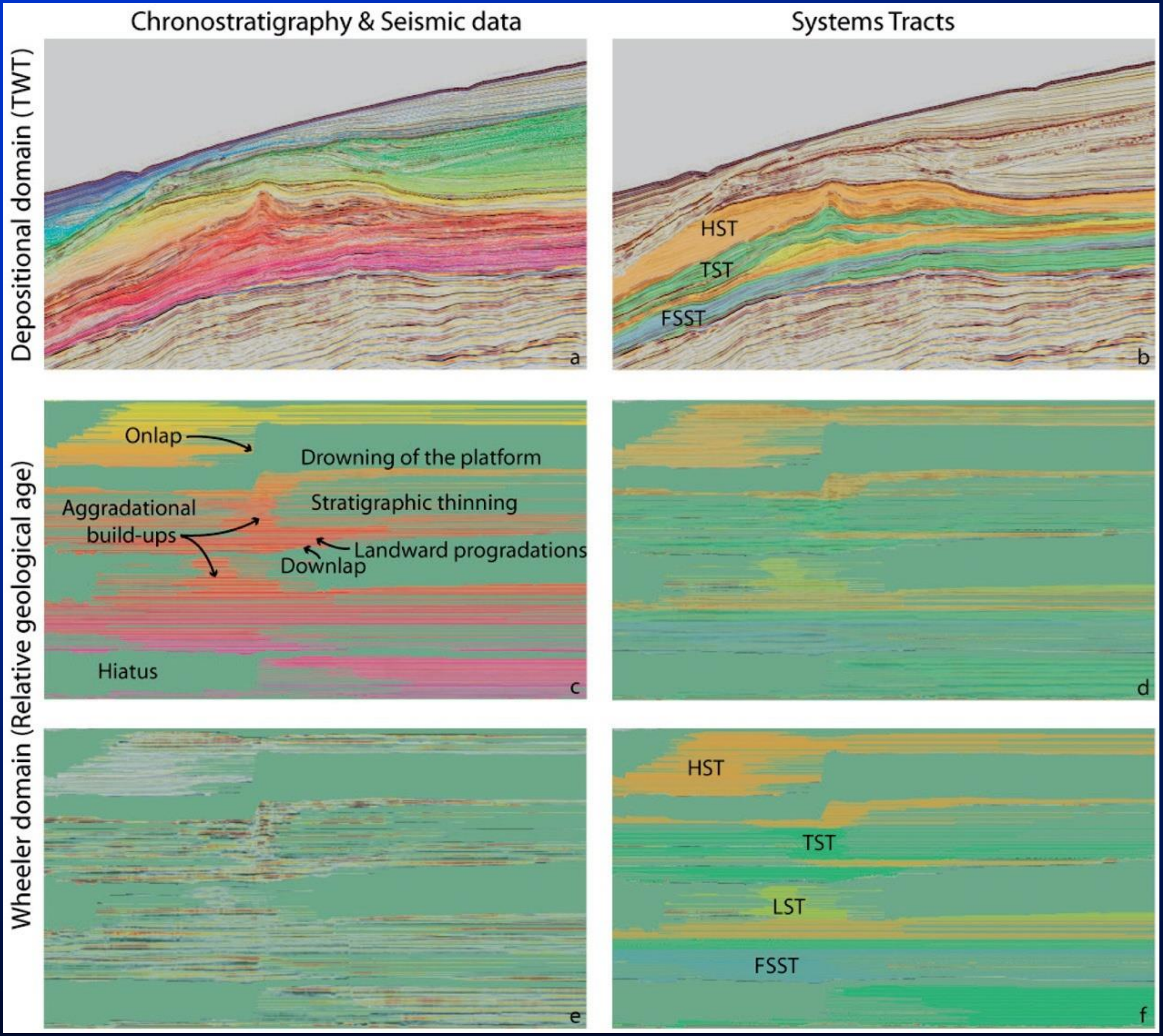


Seismic data



Chronostratigraphy from phase unwrapping

(deBruin et al., 2007)



Seismic sequence stratigraphy

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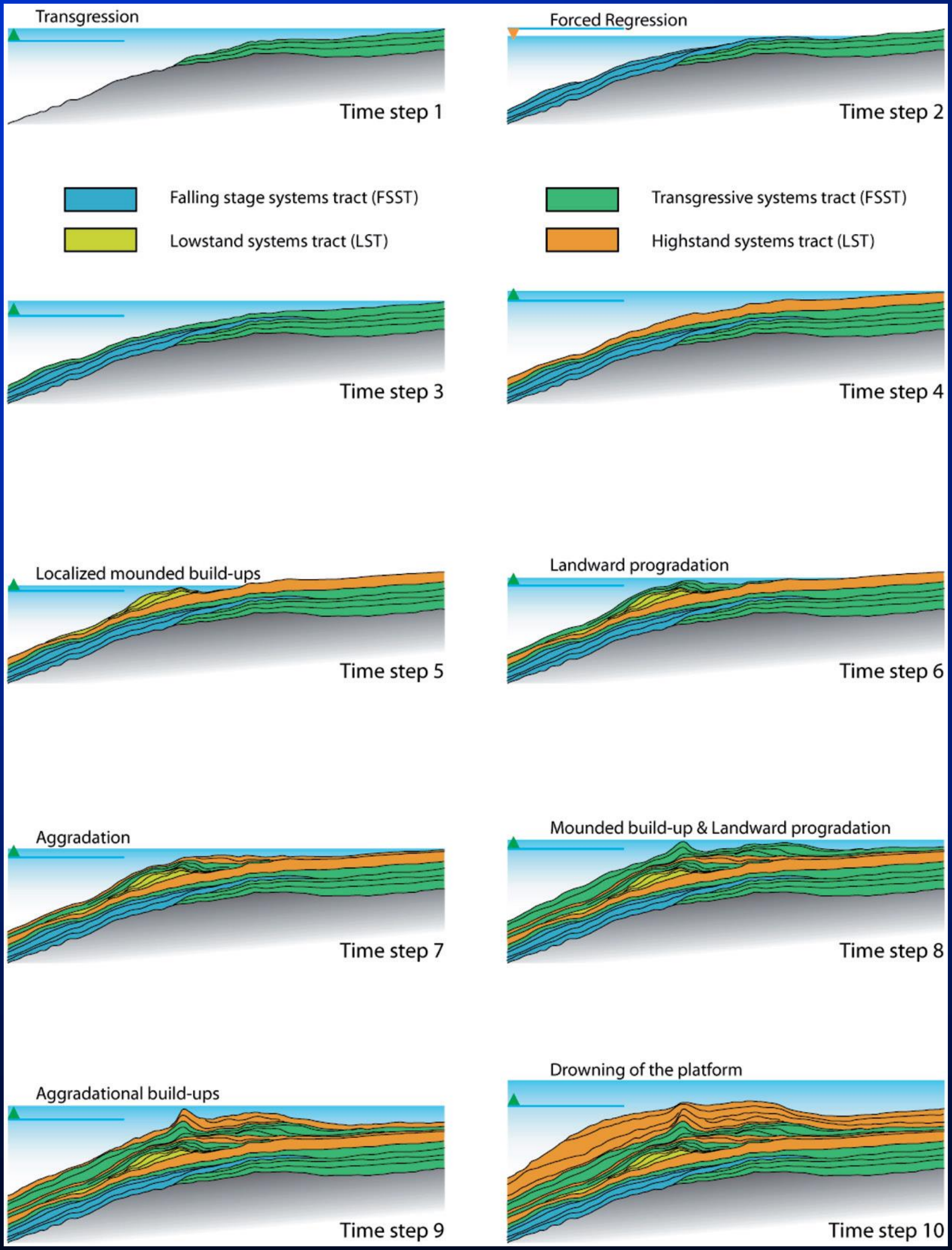
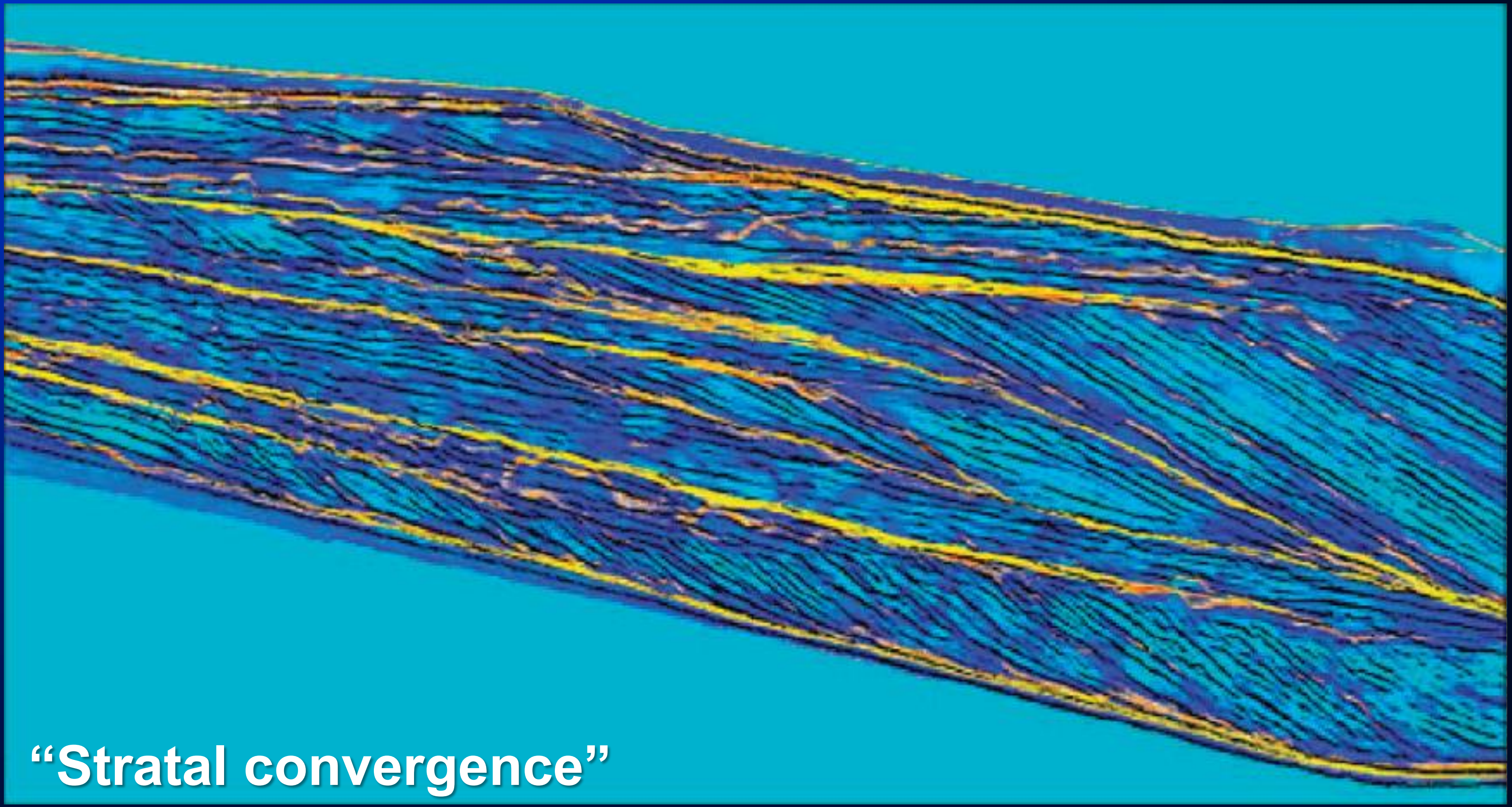


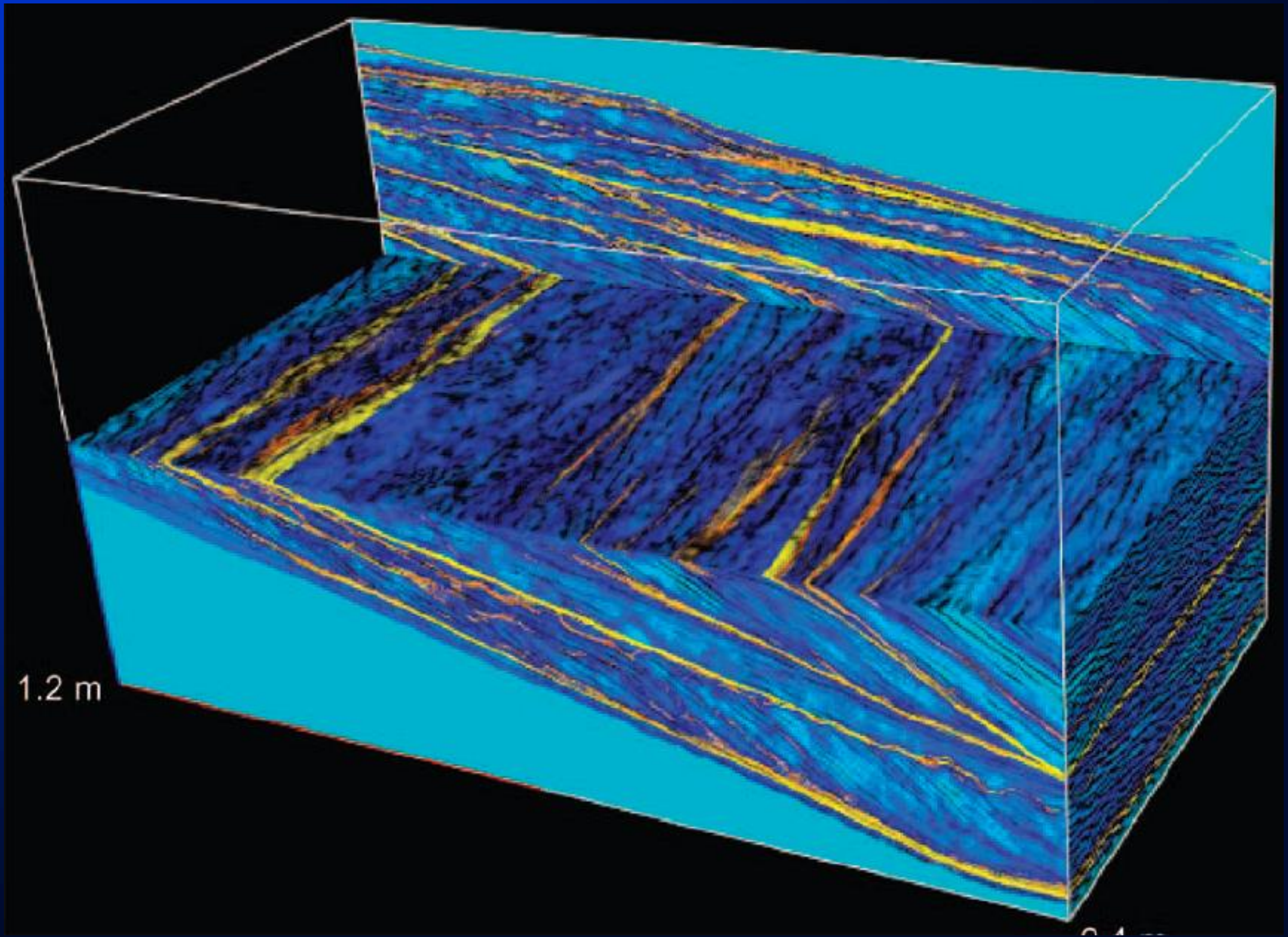
(deBruin et al., 2007)

Estimate of reflector terminations using phase unwrapping (synthetic data)



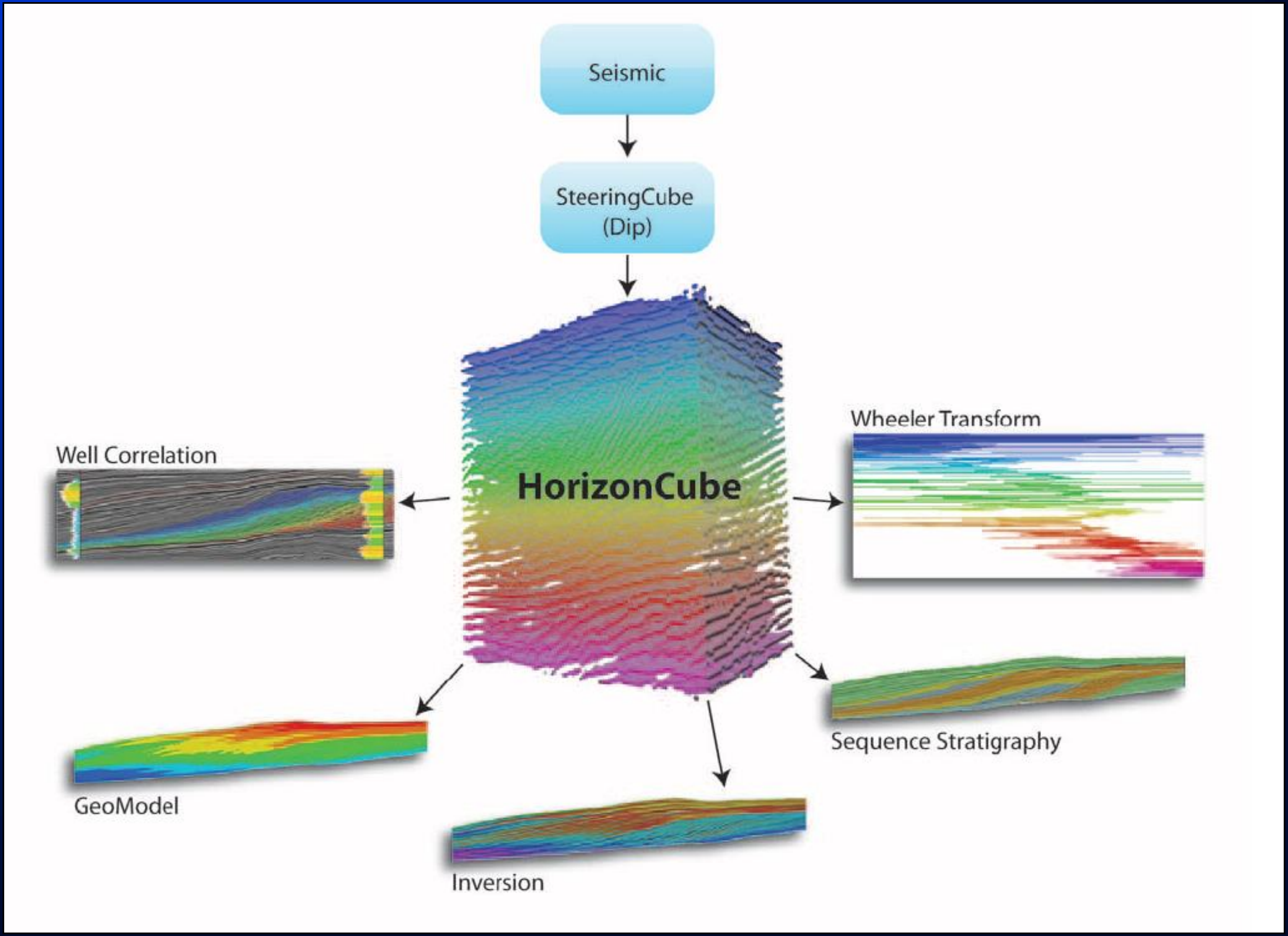
(Lomask et al., 2009)

Estimate of reflector terminations using phase unwrapping (synthetic data)



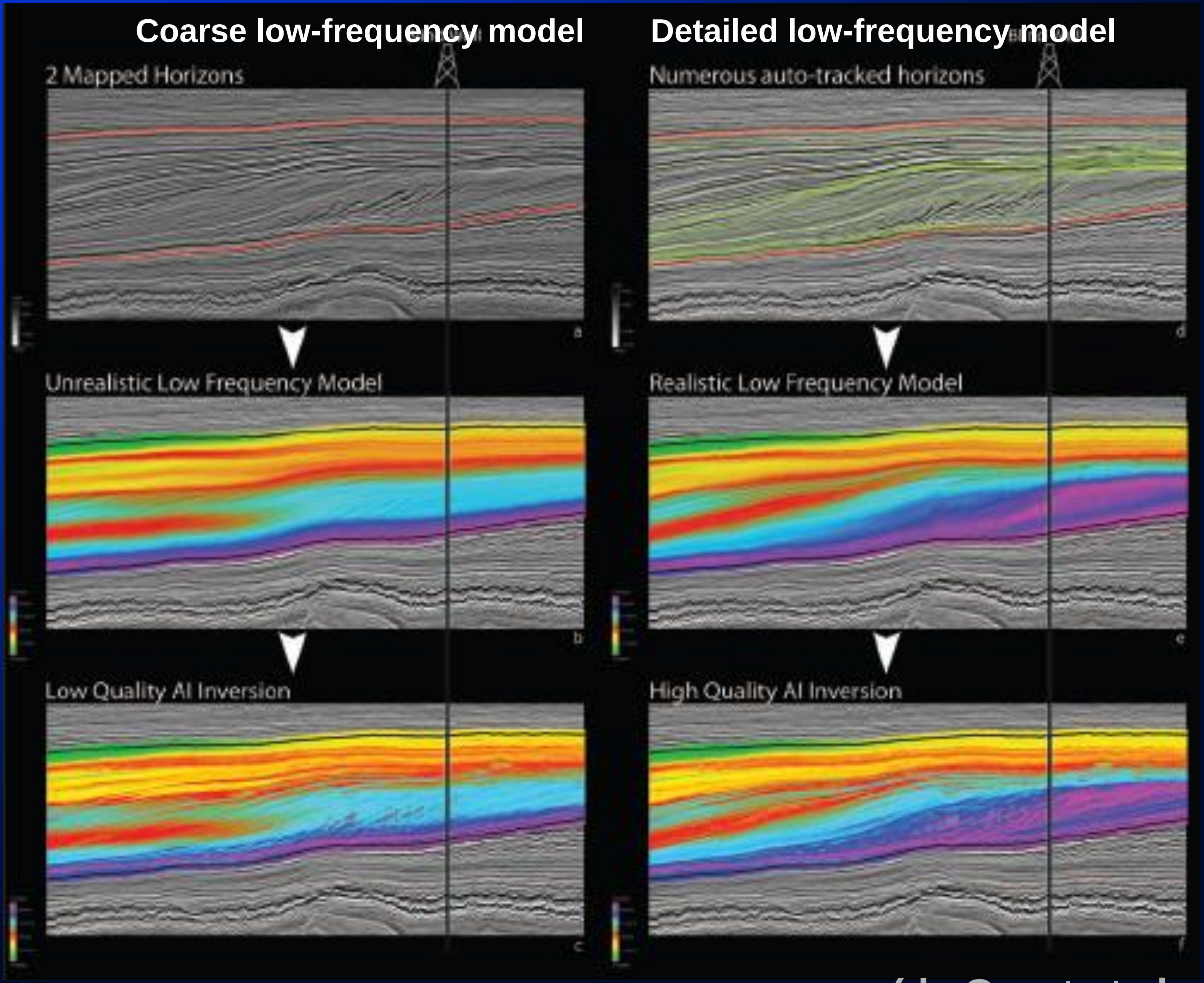
(Lomask et al., 2009)

Multiple uses of seismic "chronostratigraphic" horizons



(de Groot et al., 2010)

Impact of using multiple "chronostratigraphic" horizons on impedance inversion



(de Groot et al., 2010)

Summary

• Instantaneous attributes provide a crude but very fast estimate of the envelope, phase, and frequency of the seismic reflection

• Instantaneous attributes degenerate when multiple reflectors interfere with each other

• Wavelet (response) and weighted attributes are less sensitive to waveform interference than instantaneous attributes

• Complex attributes can be used as auxiliary volumes in 3D voxel interpretation to constrain autopicking of reflectors

• Phase unwrapping algorithms provide a means of correlating lithostratigraphic units, highlighting zones of non-deposition and erosion.