Seismic Meta-Attributes and the Illumination of the Internal Reservoir Architecture of a Deepwater Synthetic Channel Model*

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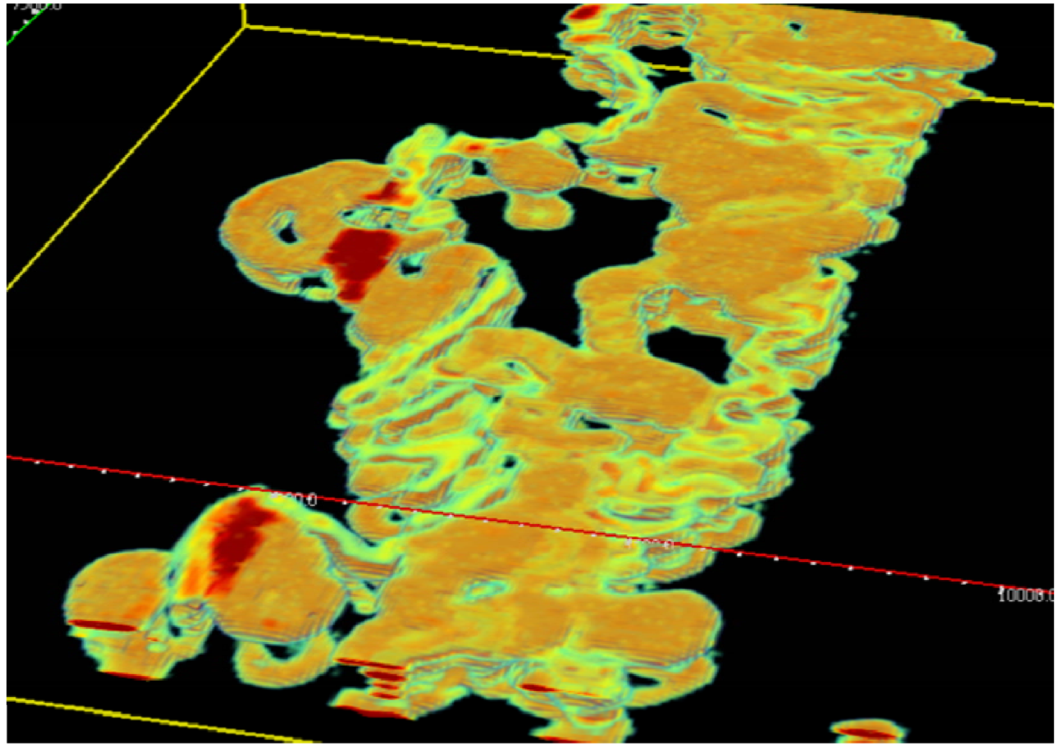
Abstract

We applied workflows of seismic attribute analysis and facies classification to a synthetic 3-D seismic volume, which was generated from velocity and density volumes in a 3-D turbidite facies model. The turbidite facies model was simulated based on a process-oriented method and is able realistically to capture major features in a turbidite environment. Because we had a priori knowledge of the geologic structure in the synthetic post-stack seismic volume, we were able to examine the efficacy of different seismic attribute analysis methods in delineating turbidite facies in the deepwater system. Based on attribute-analysis results of this synthetic seismic volume, we investigated the use of new seismic meta-attribute calculations for the detection of internal reservoir characteristics within deepwater reservoirs. New meta-attributes were created for characterizing features such as: the lateral continuity of amplitude response, the lateral continuity of similarly thick beds, and multiple combinations of geometric and response, energy, and instantaneous attributes, which are coined “ponding attributes.” The proposed meta-attributes were also used as input to neural-network seismic facies classification, which resulted in a closer match to the “ground-truth” facies model than conventional attributes.

References Cited

Hardage, B., 2010, Instantaneous seismic attributes calculated by the Hilbert Transform: Search and Discovery Article #40563 (2010) (website accessed January 26, 2014).

Chopra, S., and K.J. Marfurt, 2005, Seismic attributes - a historical perspective: Geophysics, v. 70/5, p. 3SO-28SO.



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Seismic Meta-Attributes and the Illumination of the Internal Reservoir Architecture of a Deepwater Synthetic Channel Model

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Outline

- Construction of deepwater channel-levee complex synthetic seismic dataset
- Instantaneous attributes
- Volume curvature
- Meta-attributes
- Semblance
- Spectral decomposition
- Color blending
- Principal Component Analysis (PCA)
- Neural network facies classification

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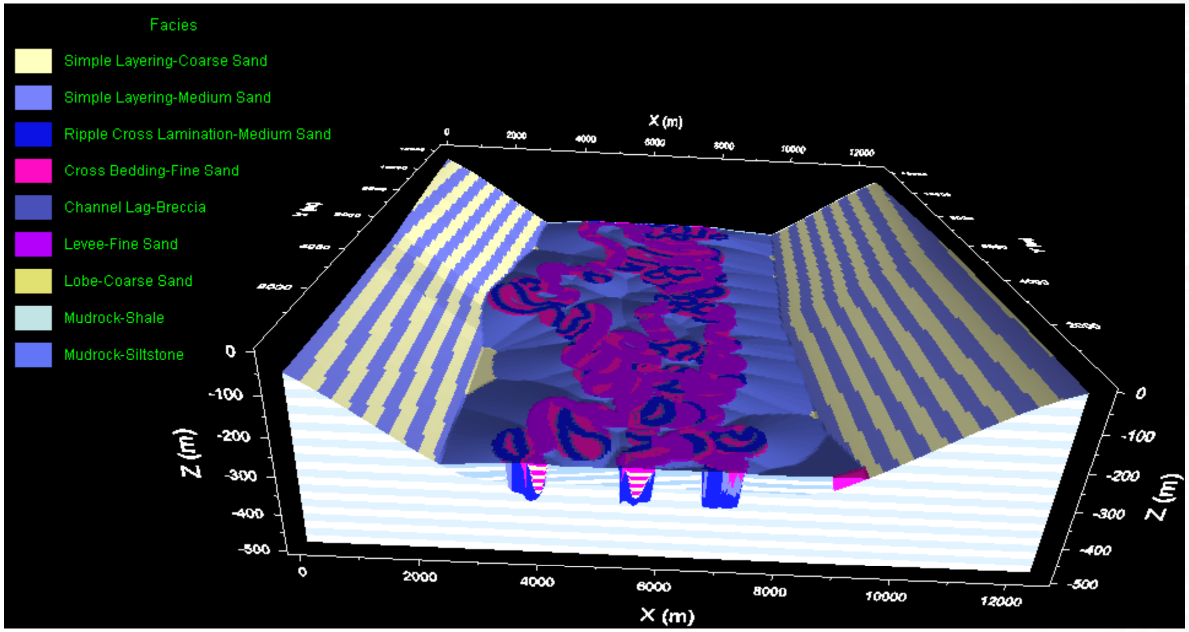
Synthetic Deepwater CLC Facies Model

- A deepwater channel-levee complex model was built using process-oriented methodology, in which three fan channels are responsible for the deposition and erosion over time of 9 distinctive lithofacies.



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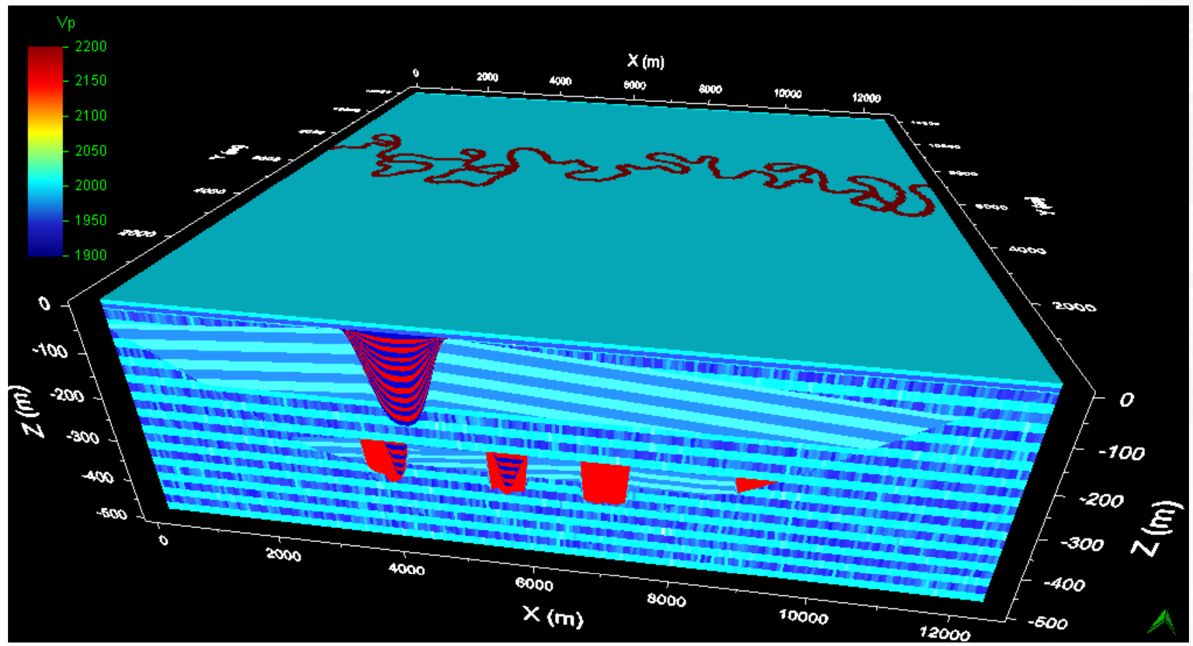
CLC Model –Velocity and Density

- The facies model was populated with seismic velocities (Vp) and densities using the conventional geostatistical method by assigning mean, standard deviation and variogram models for each lithofacies.
- Each lithofacies was populated with distinctive Vp and density statistics.
- An acoustic impedance volume was then calculated from the Vp and density volumes.



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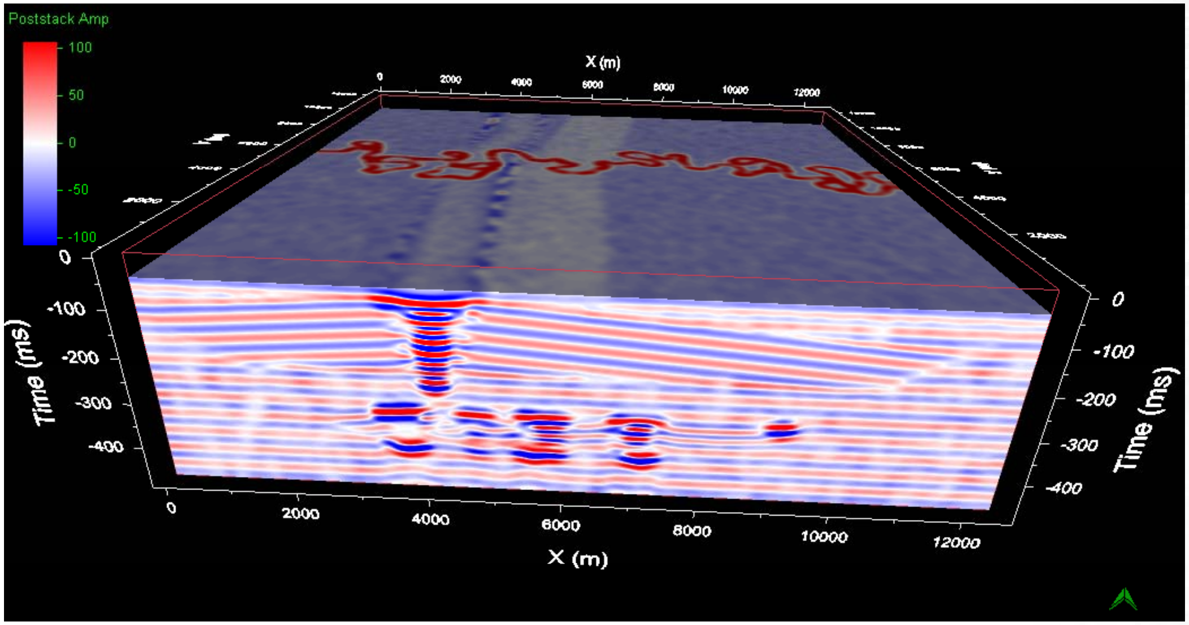
CLC Model – Seismic Response

- A 3-D seismic post-stack volume was generated by using a 30 Hz Ricker wavelet and the acoustic impedance volume calculated from velocity and density volumes, through a 1-D convolutional process. Major characteristics of deepwater turbidite channels seen in actual seismic data are re-created in this synthetic model.
- We applied workflows of seismic attribute analysis and facies classification to this synthetic 3-D seismic volume.
- Because we know the “ground-truth” facies model resulting in this 3-D seismic model, we were able to examine the efficacy of different seismic attribute analysis methods in revealing the initial facies model.



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Basic Seismic Attributes

- In reflection seismology, seismic attributes represent a quantity derived, or extracted, from the seismic wavelet(s), such as phase/frequency/amplitude.
- Attributes can be analyzed either post-stack or pre-stack (CMP gathers).
- Instantaneous attributes are typically extracted from a single trace, but more complex attributes are calculated across multiple traces within a defined window.

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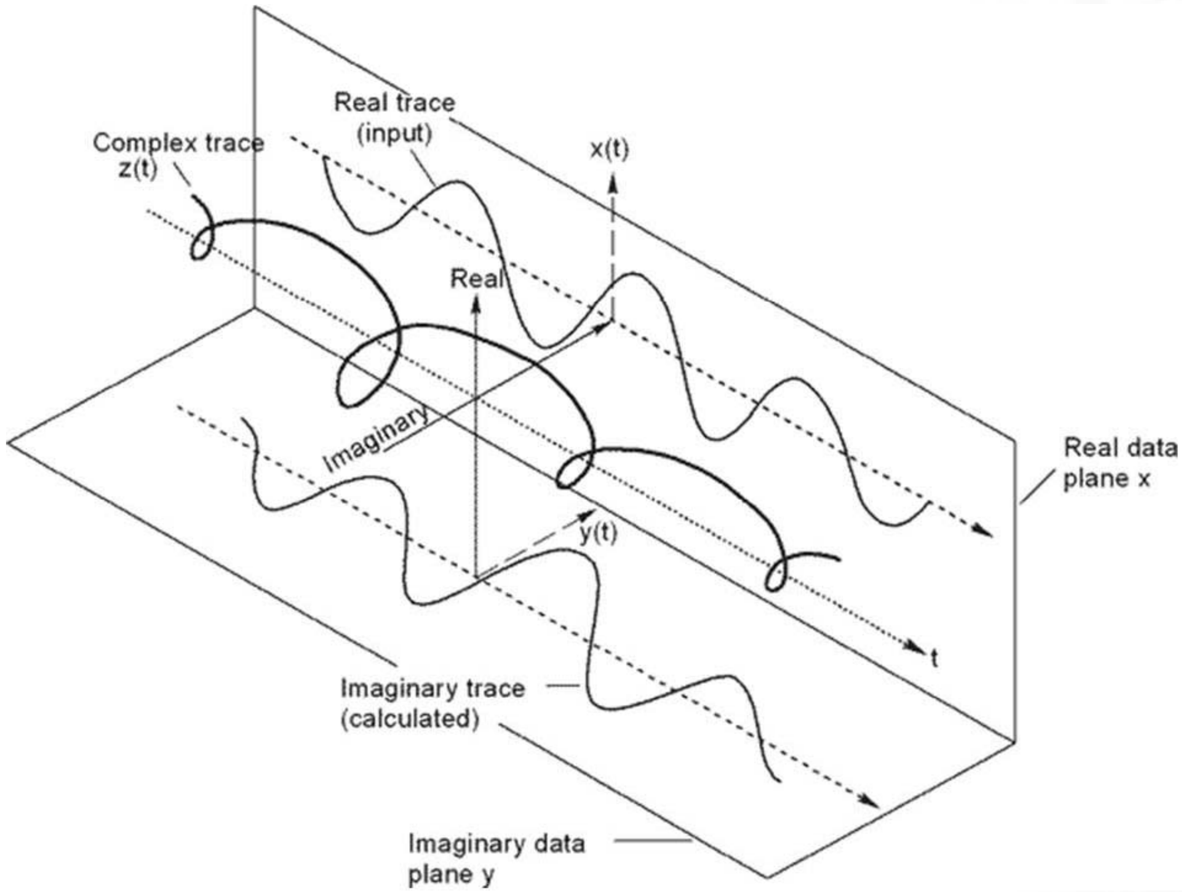
Instantaneous Attributes

- The first attributes were derived from the 1-D complex seismic trace.
- The recorded seismic trace is known as the real part of the complex trace. By performing a 90° phase rotation, known as the Hilbert Transform, the imaginary part of the complex trace is revealed.
- From this complex trace, such attributes as instantaneous amplitude/phase/frequency can be calculated.



(Hardage, 2010)

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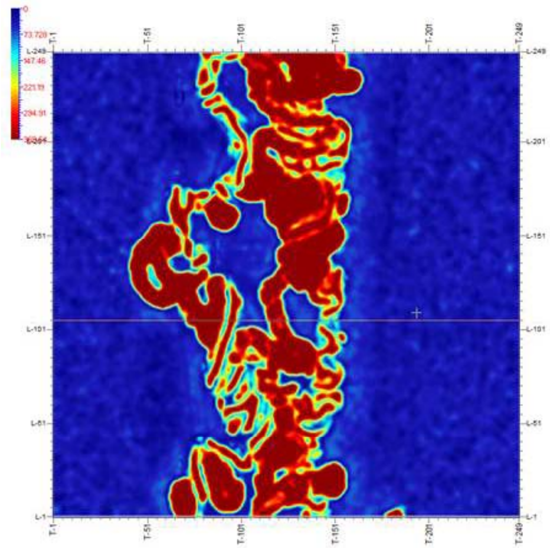
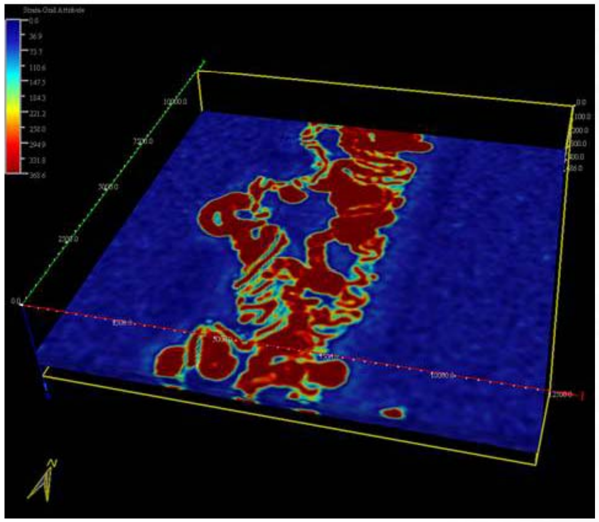
Instantaneous Amplitude

- At any coordinate on the time axis, a vector a(t) can be calculated that extends perpendicularly away from the time axis to intercept the helical complex trace z(t).
- The length of this vector is the amplitude of the complex trace at that instant of time – hence the term "instantaneous amplitude."





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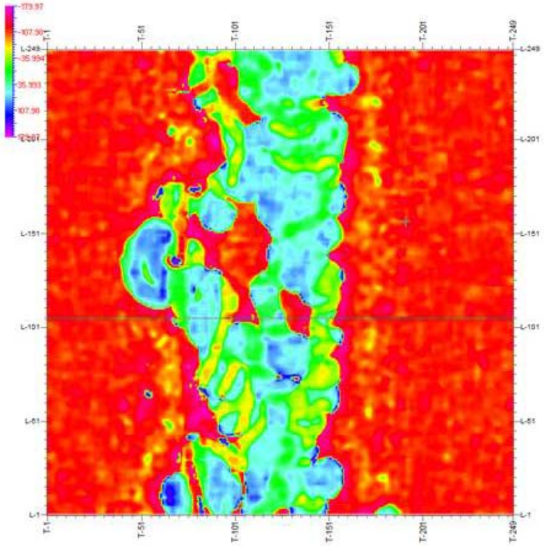
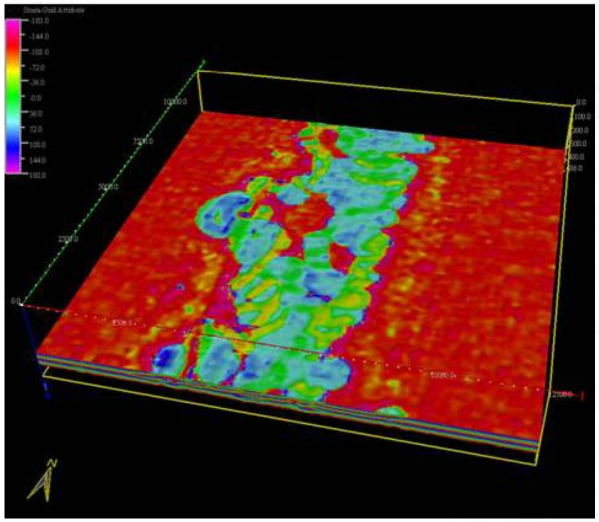
Instantaneous Phase

- The phase at one instant along a trace, independent of trace amplitudes.
- Excellent indicator for lateral continuity of reflection events.





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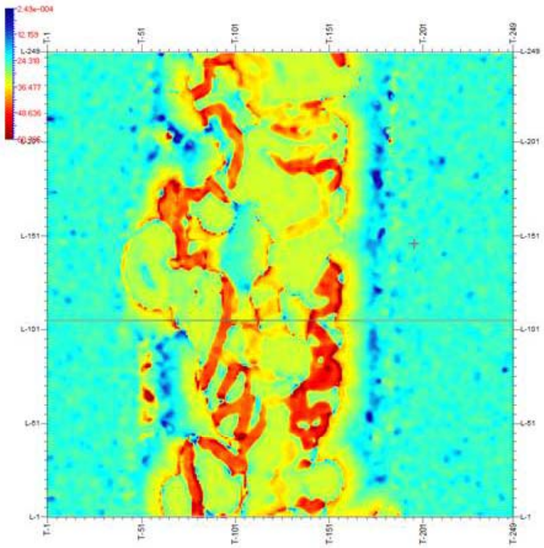
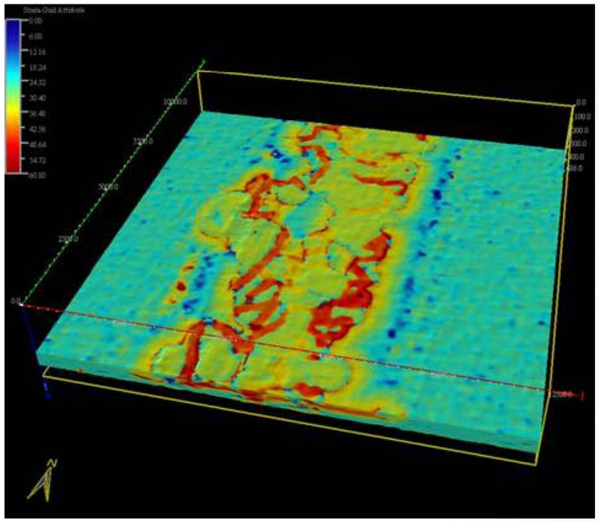
Instantaneous Frequency

- The rate of change of phase over time.
- Good indicator for porosity, thickness, and presence of hydrocarbons.





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Meta-Attributes

- For the purposes of this article, meta-attributes are considered to be any combination of seismic attributes designed to enhance the signal of the wavelet.
- The most well known of these is the Sweetness attribute:

$$\frac{\text{Instantaneous Amplitude}}{\sqrt{\text{Instantaneous Frequency}}}$$

- Sweetness works because frequency is an excellent indicator not only for porosity and thickness, but for hydrocarbons. It has been observed that siliciclastic reservoirs stand out from the background much better than when employing a single attribute.

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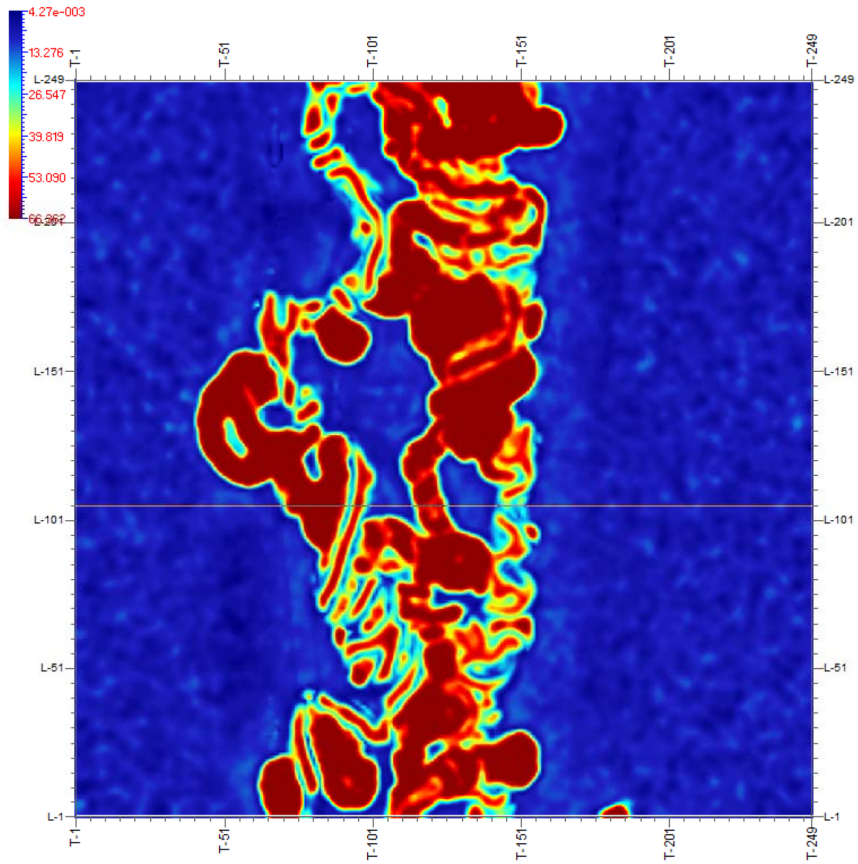
Sweetness



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New Meta-Attributes

- During the analysis of the synthetic data, we derived a number of new meta-attributes, including:
  - Continuity of Amplitude Responses
  - Amplitude Response of Similarly Thick Bodies
  - Continuity of Similarly Thick Bodies
  - Ponding Meta-Attributes

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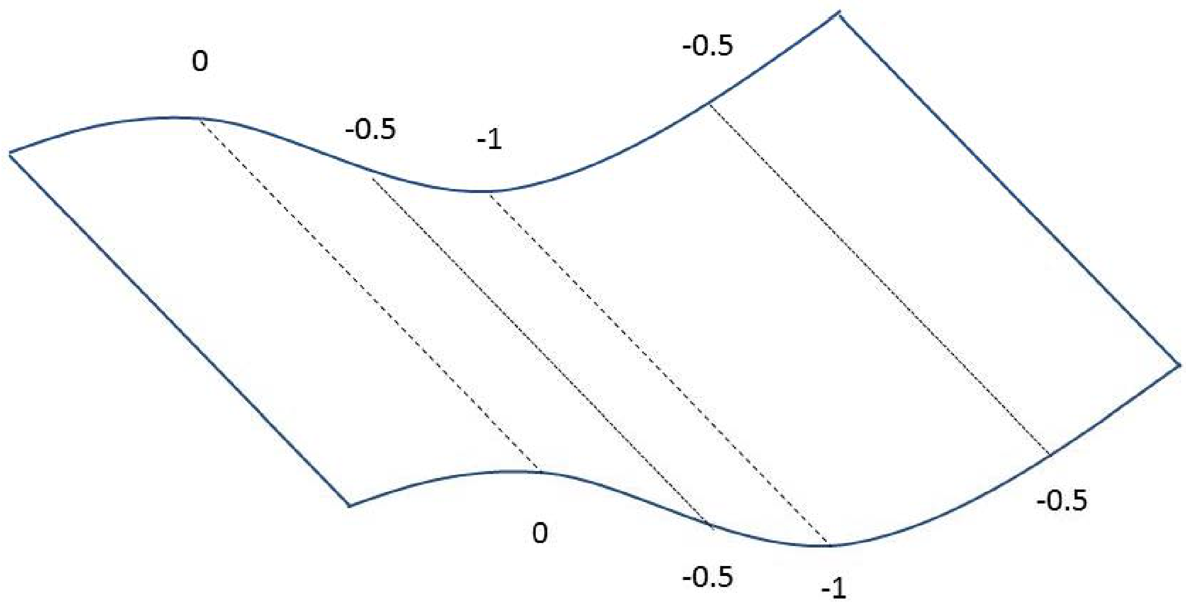
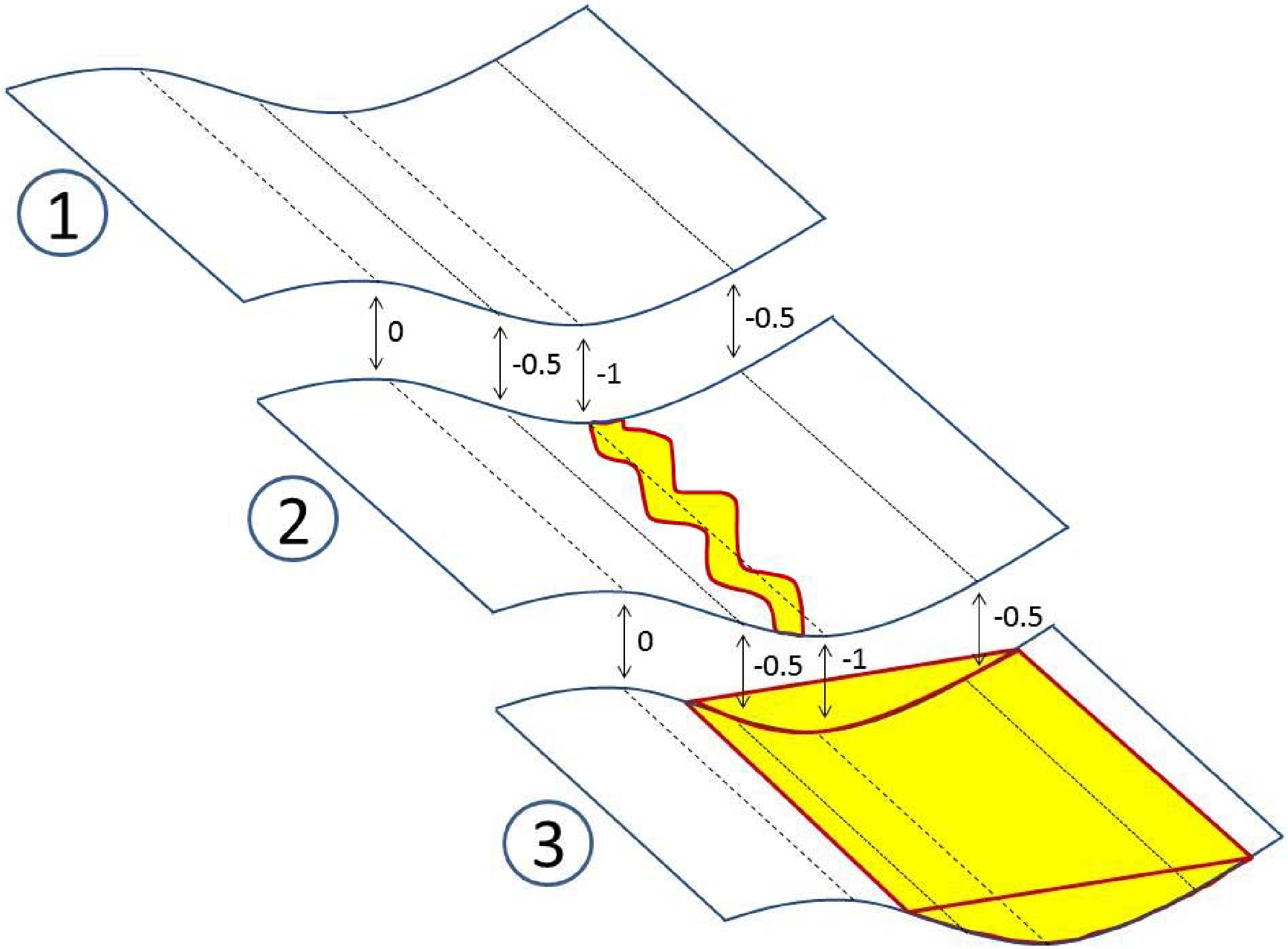
Ponding Attributes

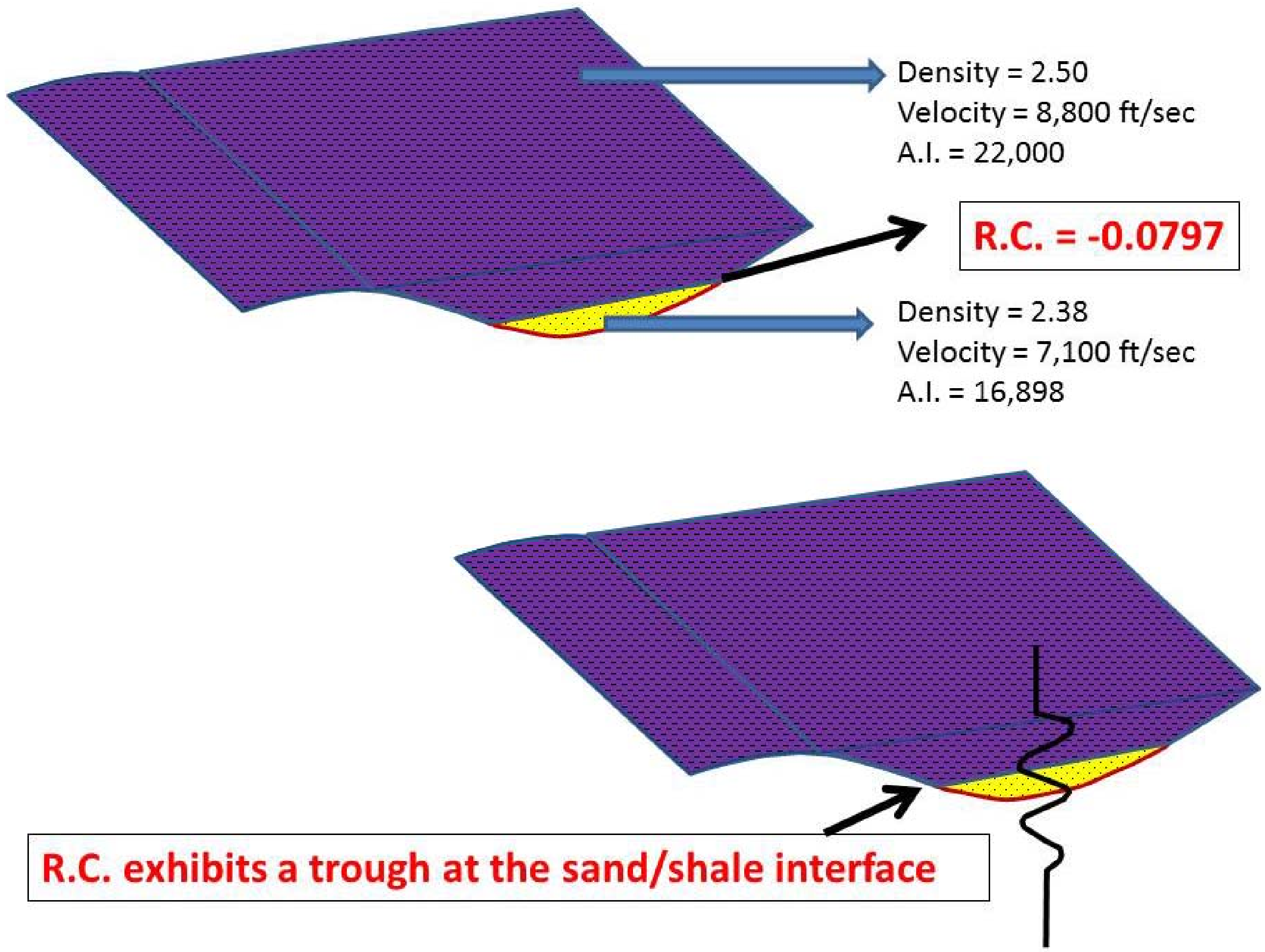


MOST NEGATIVE CURVATURE

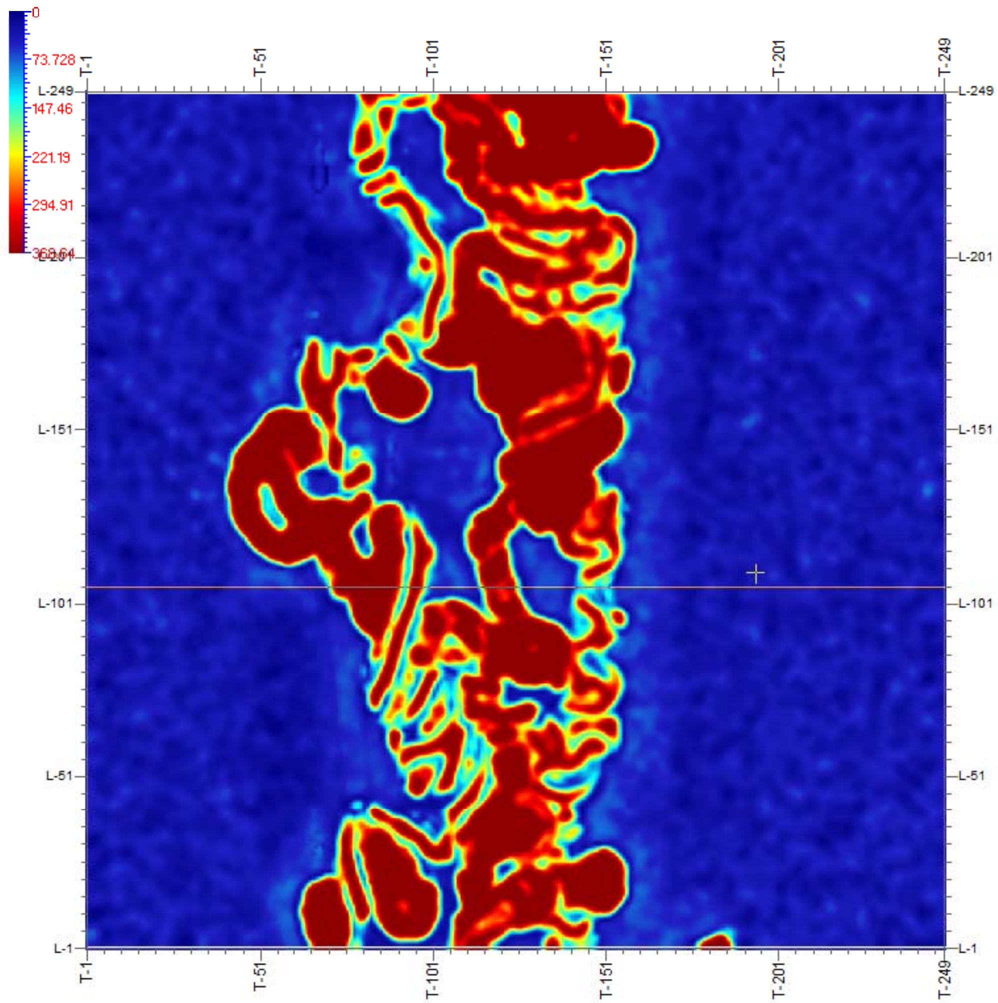
Ponding Attributes



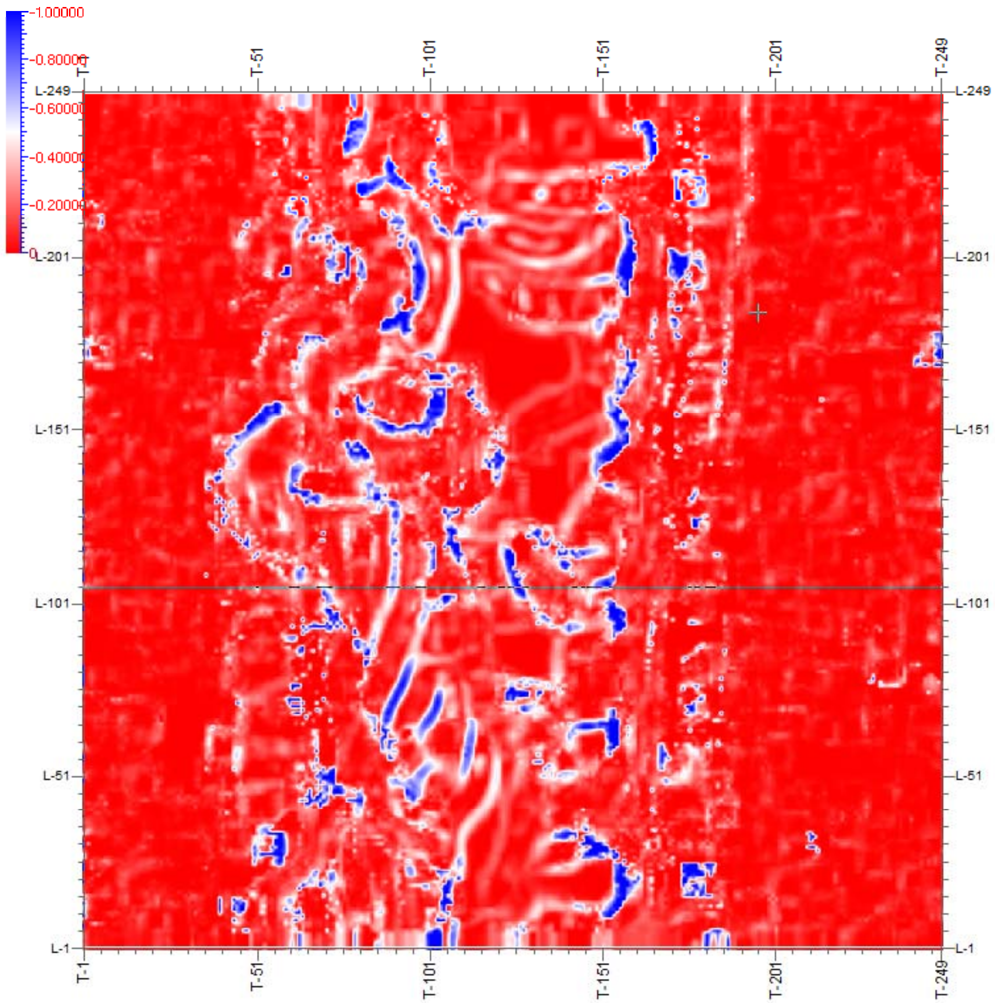
Ponding Attributes



Instantaneous Amplitude



Most Negative Curvature



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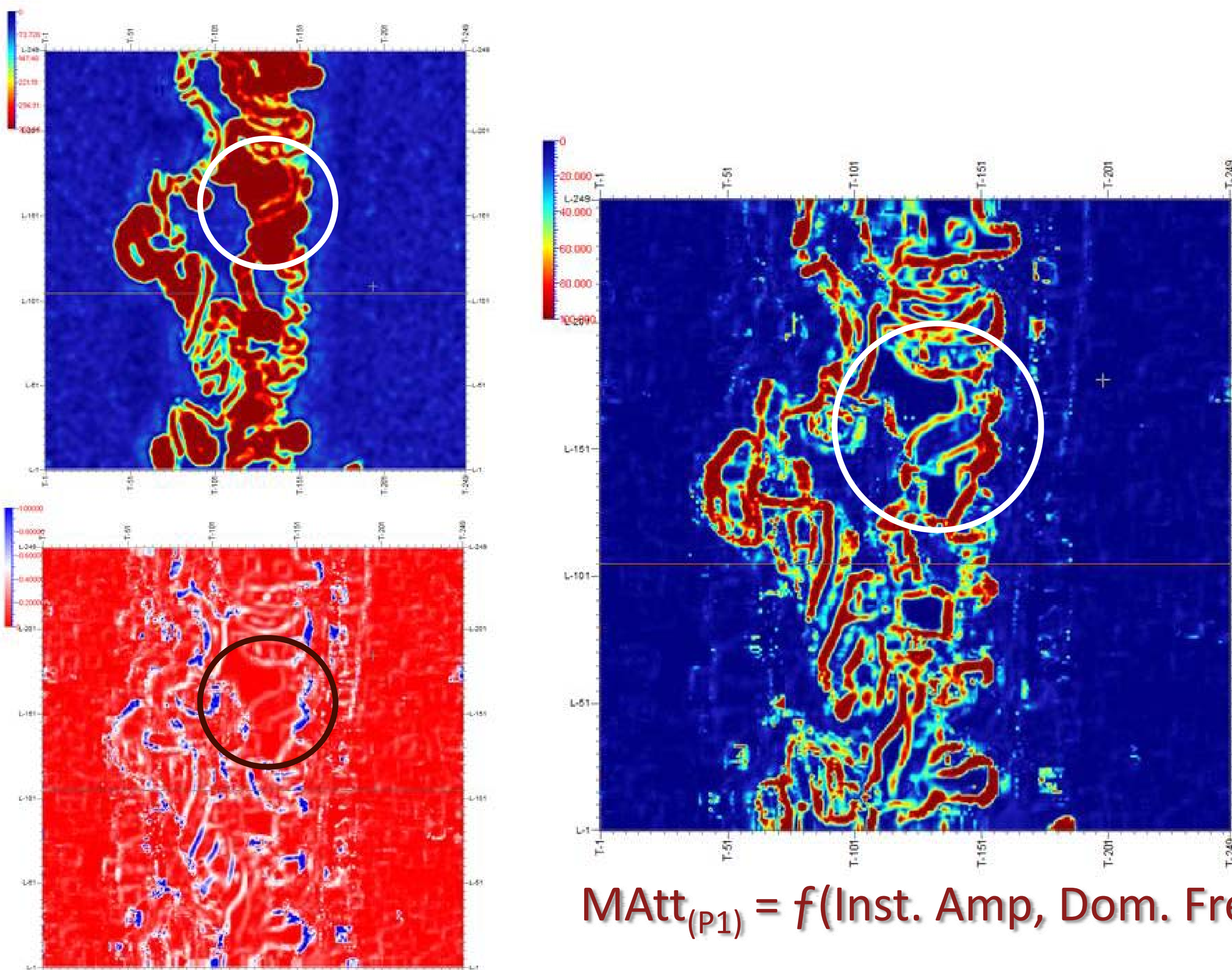
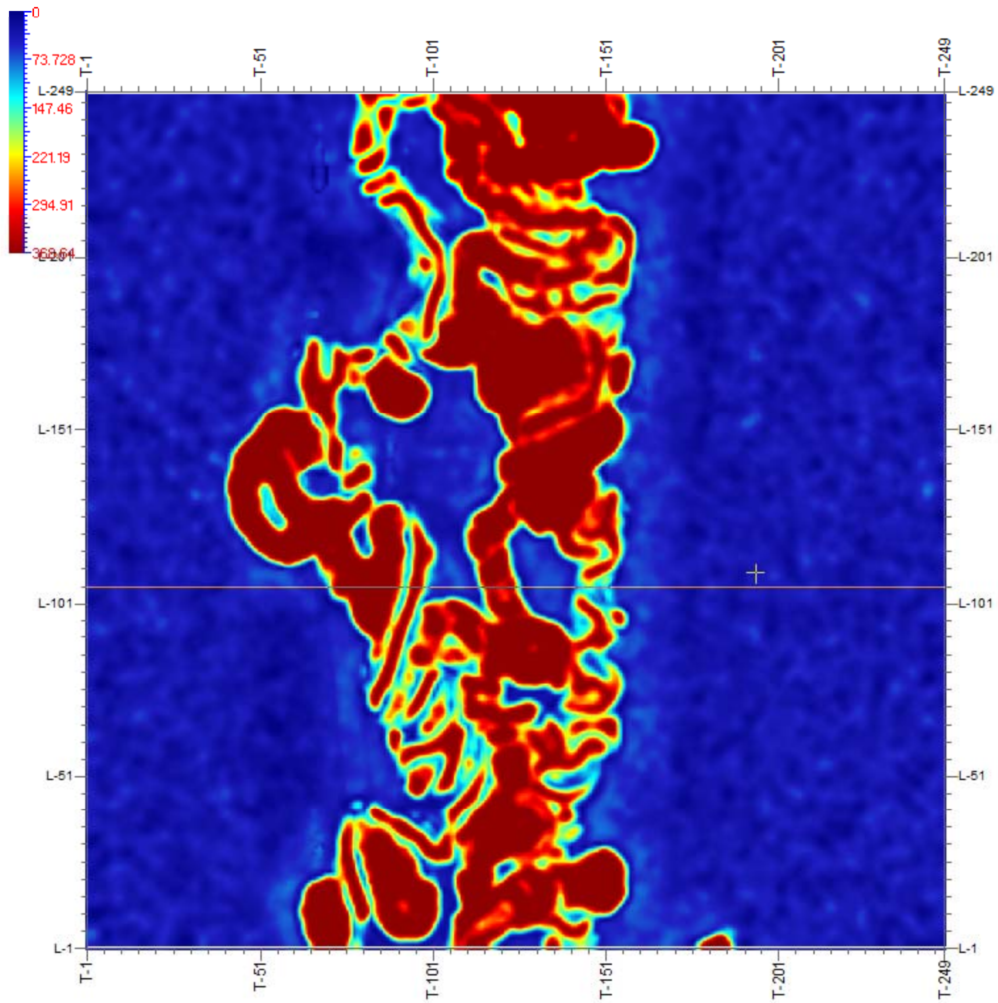
Ponding Attribute 1

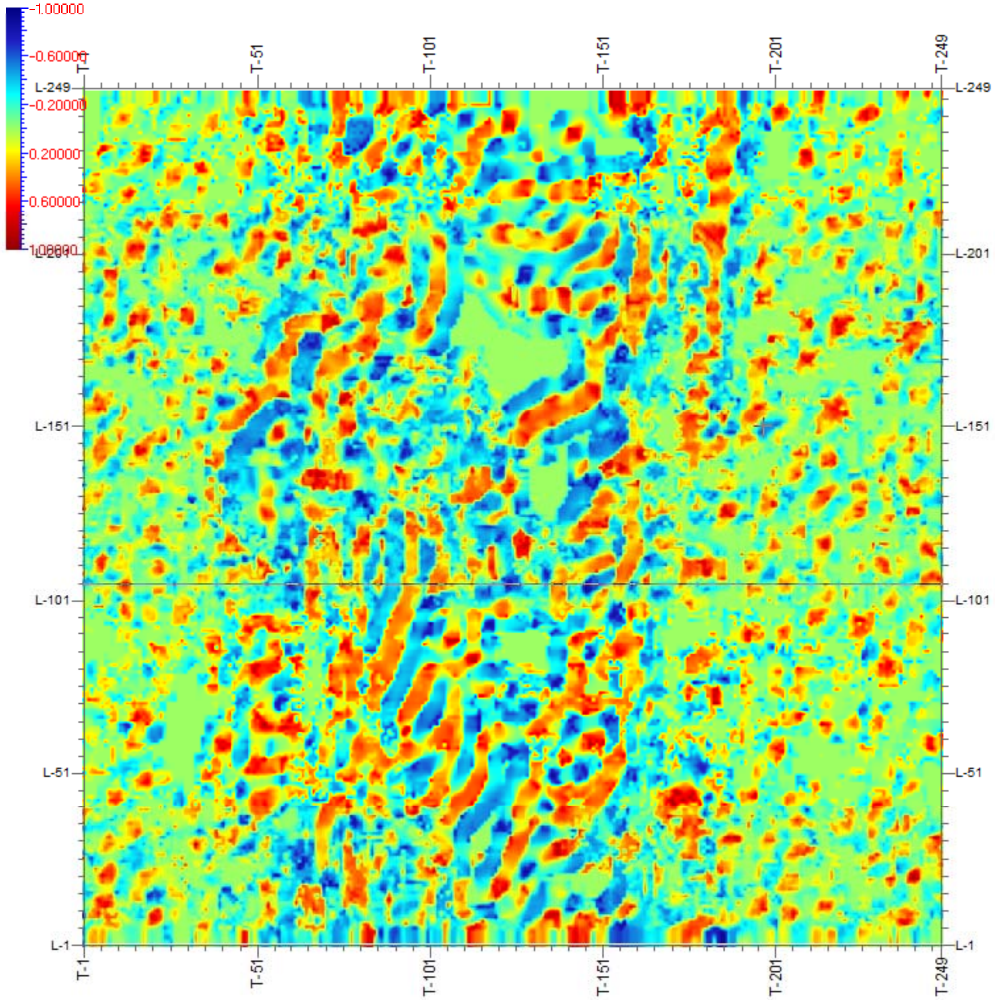


$MAtt_{(P1)} = f$(Inst. Amp, Dom. Freq, Most Neg. Curv.)

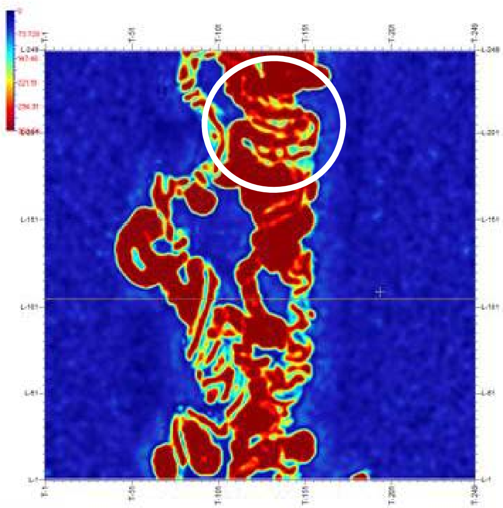
Instantaneous Amplitude

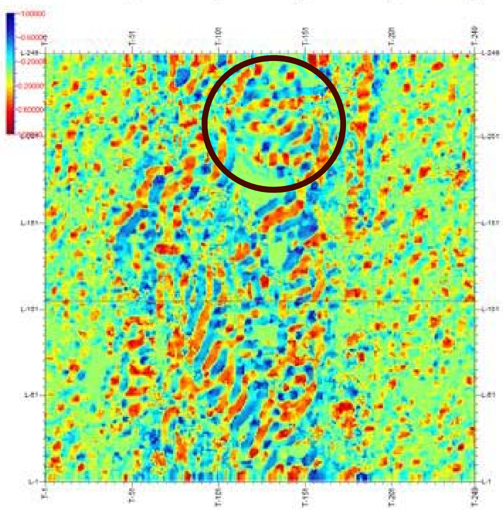


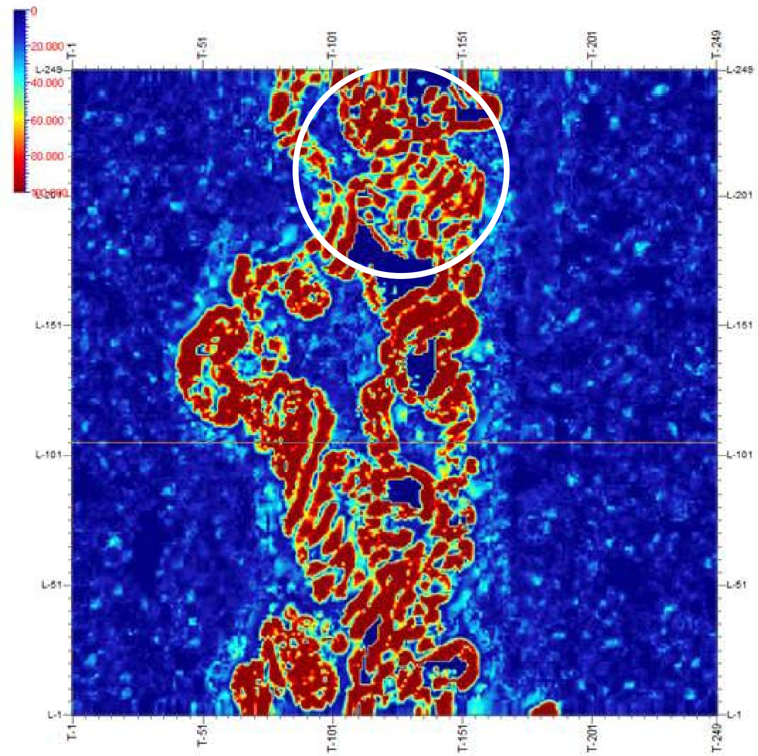
Shape Index


-1.00000
-0.60000
-0.20000
0.20000
0.60000
1.00000
T-1
T-51
T-101
T-151
T-201
T-249
L-249
L-201
L-151
L-101
L-51
L-1

Ponding Attribute 2

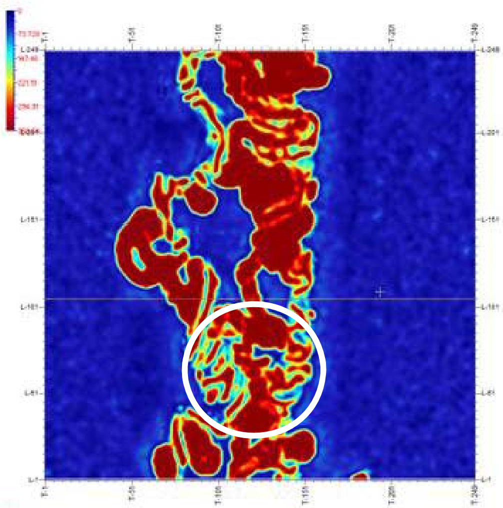


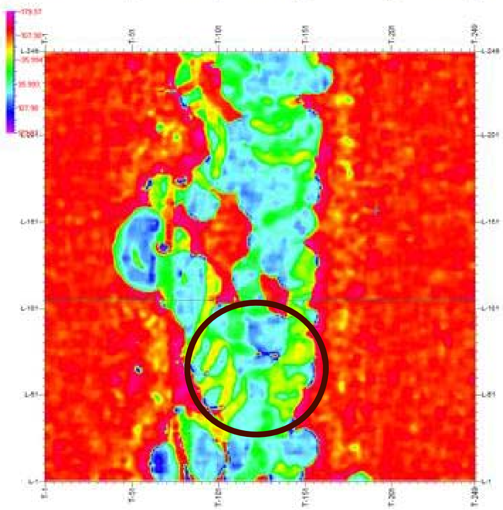


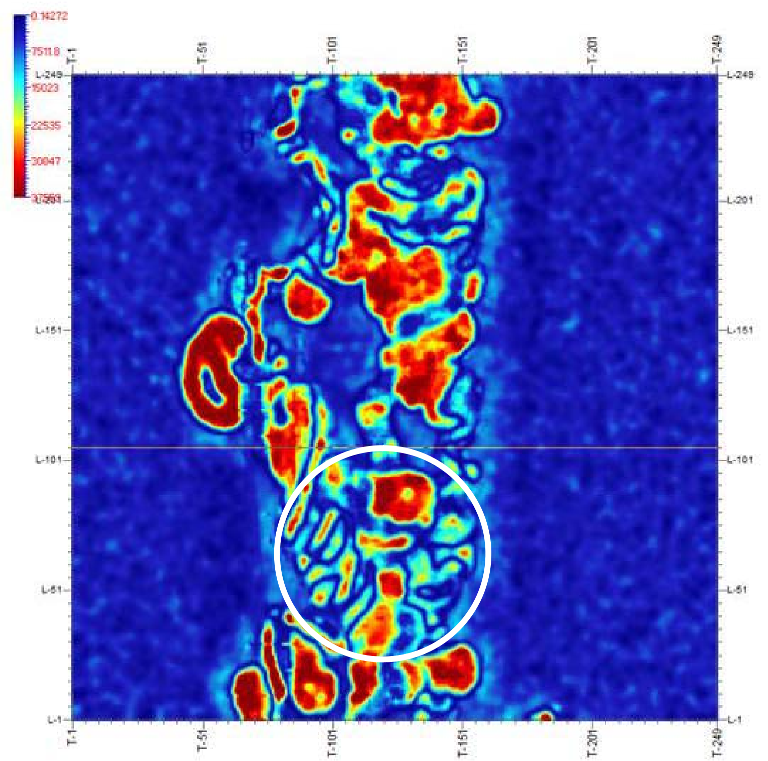


$MAtt_{(P2)} = f(\text{Inst. Amp, Dom. Freq, Shape Index})$

Continuity of Amplitude Responses







MAtt$_{(CAR)}$ = f(Inst. Amp, Inst. Phase, Dom. Freq)

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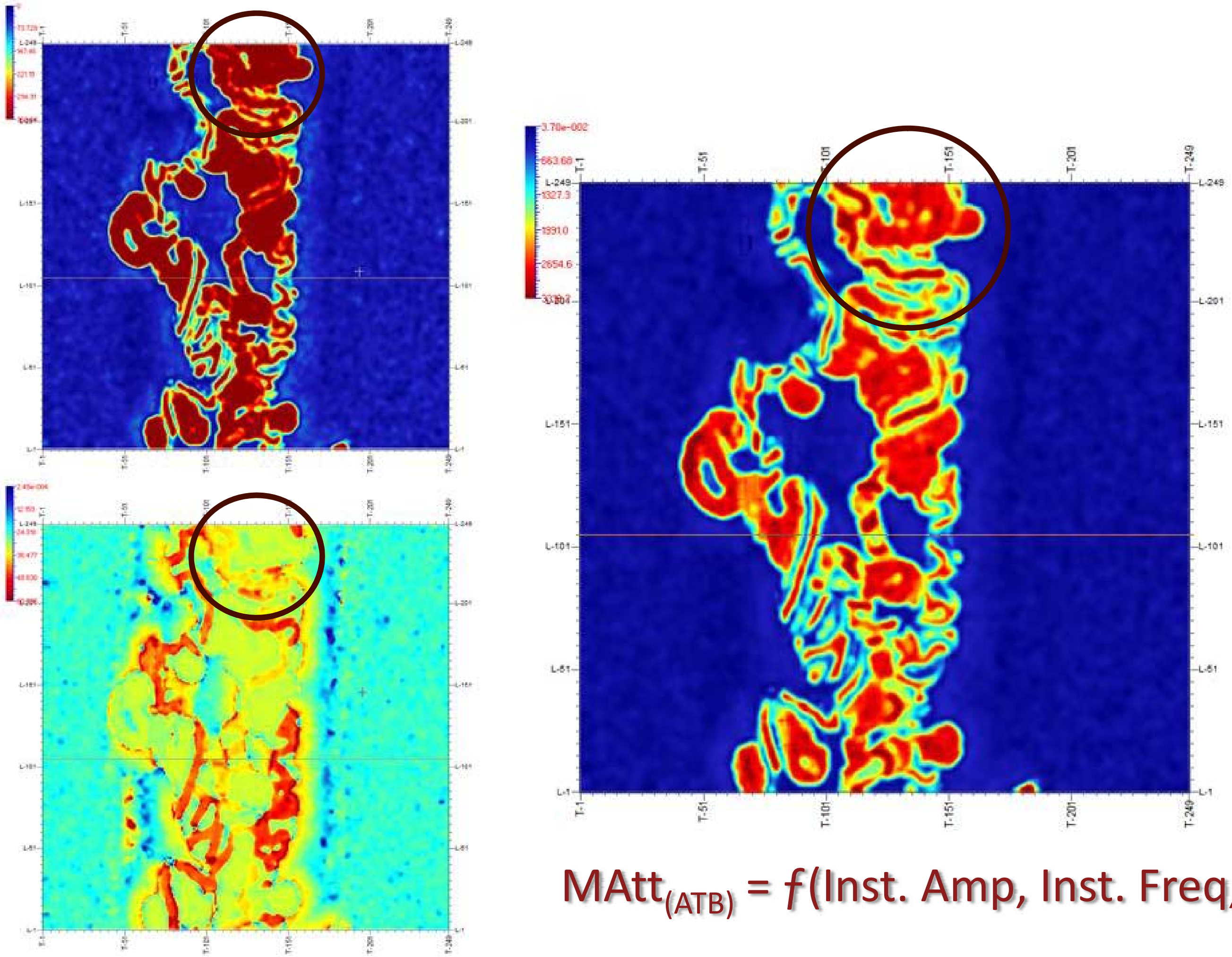
Amplitude Response of Similarly Thick Bodies



$MAtt_{(ATB)} = f(\text{Inst. Amp, Inst. Freq, Dom. Freq})$

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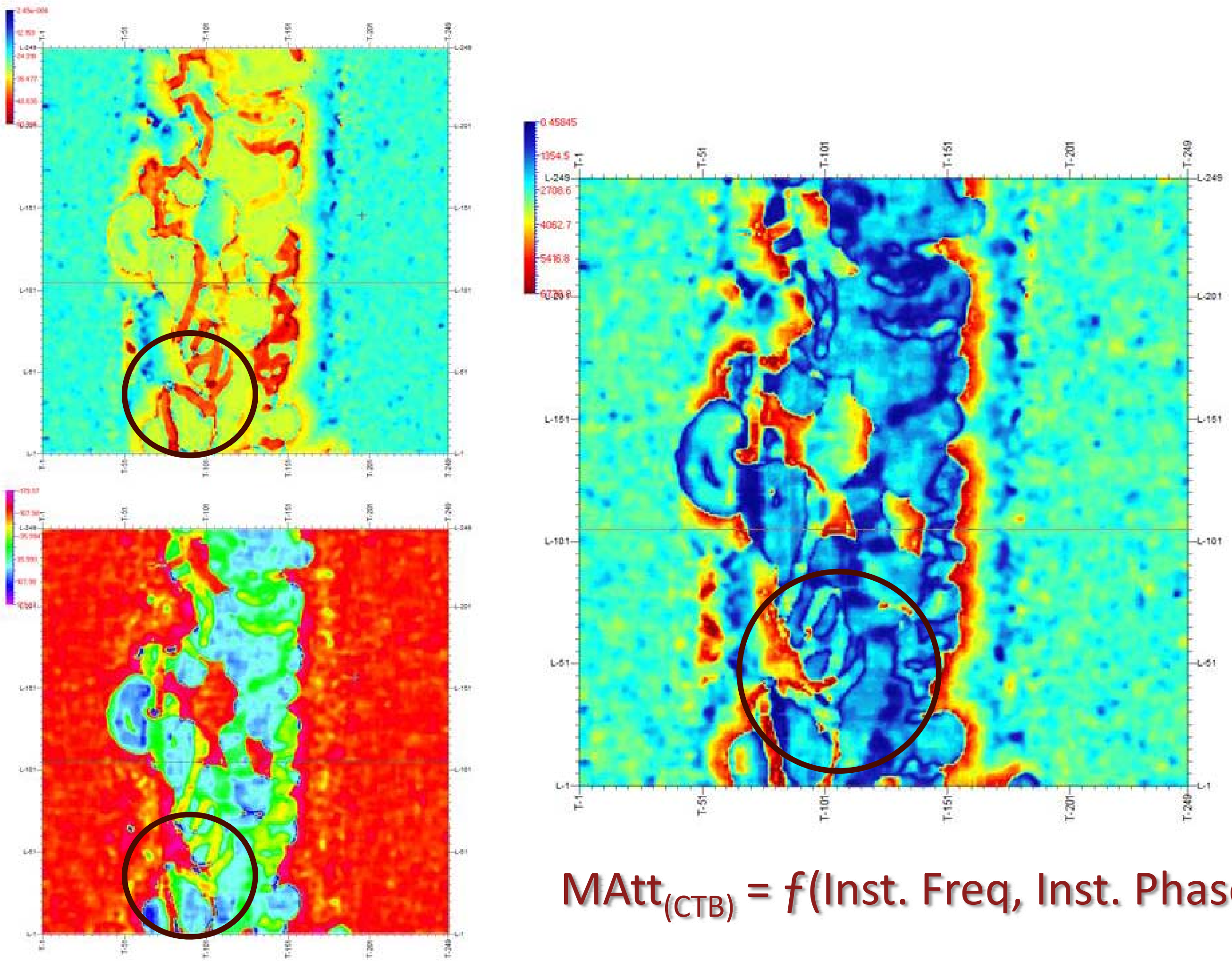
Continuity of Similarly Thick Bodies



$MAtt_{(CTB)} = f(\text{Inst. Freq, Inst. Phase})$

Refining Semblance

- Seismic coherency (semblance) is a measure of lateral changes in the seismic response caused by variation in structure, stratigraphy, lithology, porosity, and the presence of hydrocarbons (Chopra and Marfurt, 2005).
- Typically semblance involves comparing the waveform of adjacent traces to one another via the calculation of reflector dip/azimuths throughout the data volume.
- However, potential banding from the zero-crossing can occur when the dip/azimuths are calculated, manifesting artificial anomalies in the data.

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Refining Semblance

- Semblance was calculated on the post-stack dataset.
- The post-stack volume was phase-rotated 90° to obtain the imaginary trace component.
- The semblance from the imaginary trace was calculated.
- The rotated semblance volume was subtracted from the original semblance volume.

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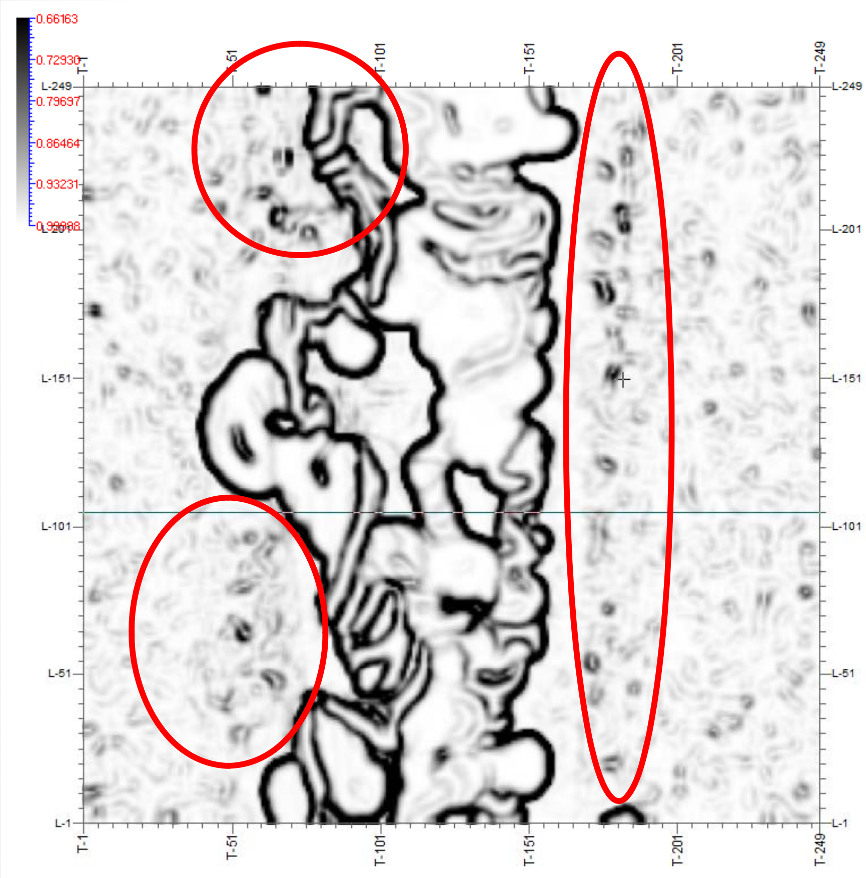
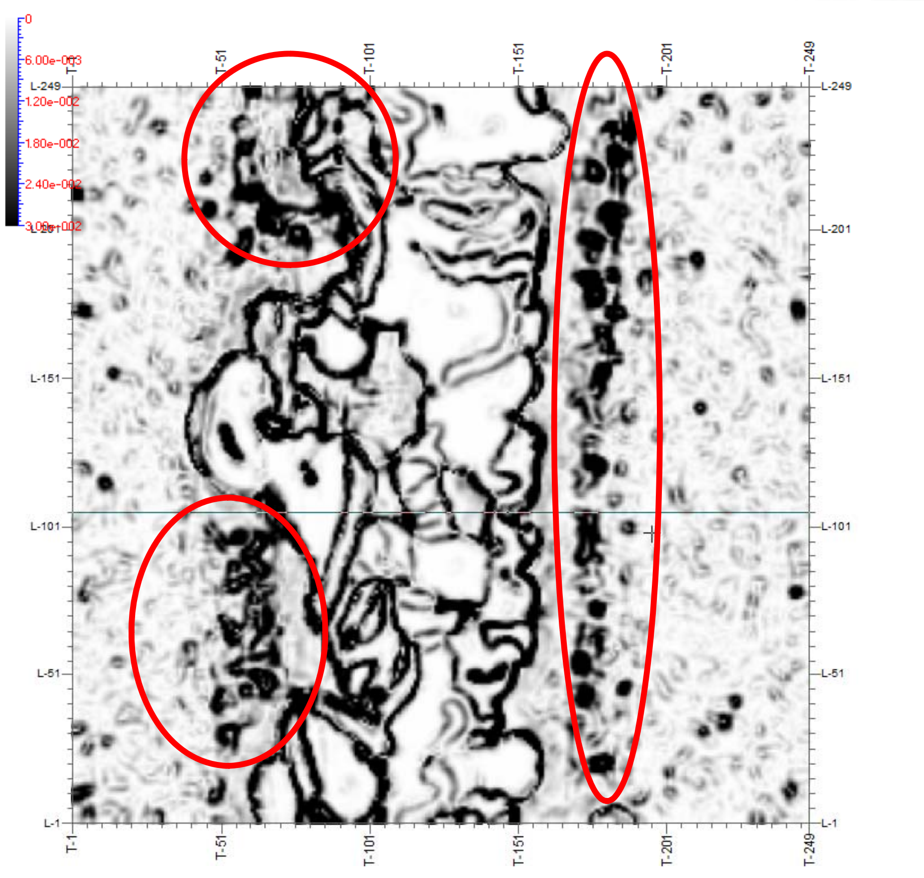
Refining Semblance

Original Semblance



Refined Semblance



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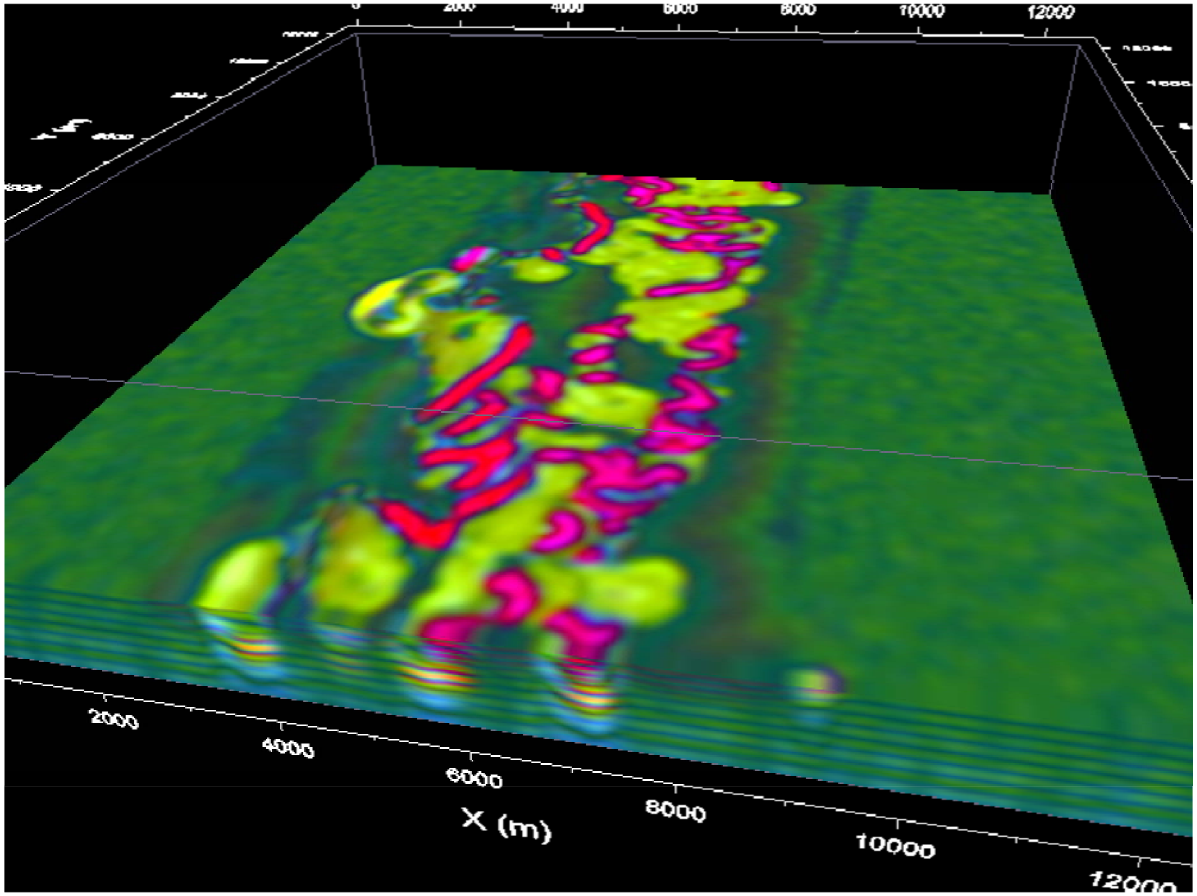
Color Blending



- Color-blending of the first 3 Principal Component Analysis (PCA) components calculated by S-transform methodology of Spectral Decomposition.

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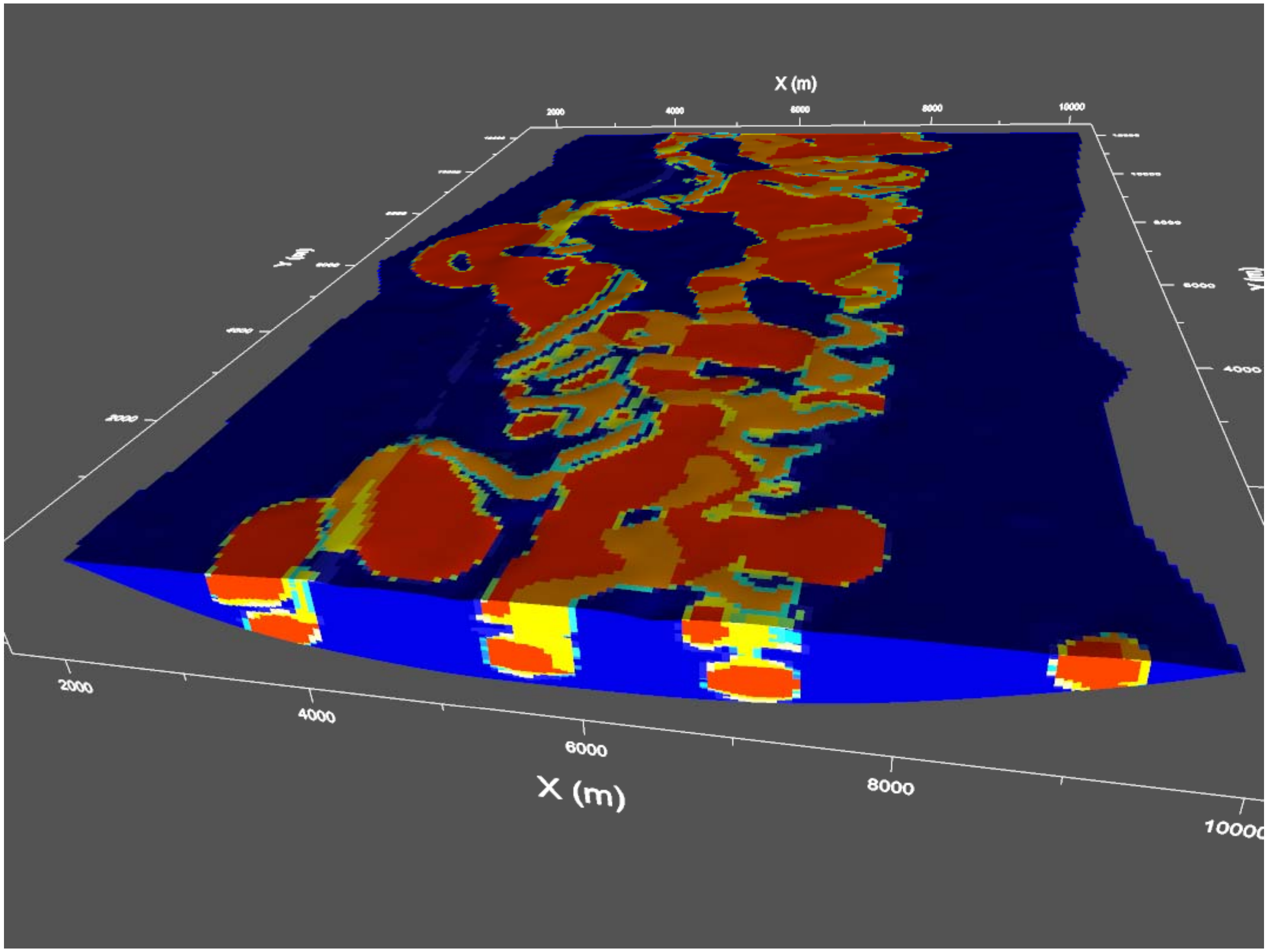
Volume Facies Classification



- A neural network classification scheme was used to derive a seismic lithofacies volume based on the input of multiple seismic attributes.

Summary and Conclusions

- Construction of a synthetic 3-D seismic response to a deepwater channel-levee complex model allowed controlled analysis of the efficacy of individual and meta-attributes.
- Meta-attribute analysis of a South Texas dataset – and subsequently, an Alberta dataset – revealed significant correlations to well log data, which were stronger than those for individual attributes. Development and testing of these and other new meta-attributes continues.
- Other quantitative post-stack techniques performed by the interpreter also illuminate internal reservoir architecture.
  - Spectral Decomposition
  - Stratal Slices/Strata-Grids
  - Facies Classification (trained and untrained)
  - Color blending

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