Understanding Attributes and Their Use in the Application of Neural Analysis – Case Histories Both Conventional and Unconventional*

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Search and Discovery Article #41473 (2014)**
Posted October 27, 2014

*Adapted from oral presentation given at the Geoscience Technology Workshop, Permian and Midland Basin New Technologies, Houston, Texas, September 4-5, 2014

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Abstract

This presentation explores the many categories of seismic attributes created in the last 20 years and their general use in an interpretation workflow. Unsupervised Neural Analysis of seismic attributes has been shown to be effective in understanding variations in unconventional resource geological deposition, finding "sweet spots" and understanding complex structural and fracture trends. Neurons find natural clusters in the data and classify into Self-Organized Maps. A neural map is a 2D representation of the result of classifying and associating the data, which may be in "n" dimensions, such as many attributes in a 3D volume. A series of case histories, both unconventional and conventional in nature are shown in which neural mapping have helped find production, understand reservoir properties, fracture trends and even pressure zones in data.

Selected References

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PARADISE

Understanding Attributes and Their Use in the Application of Neural Analysis – Case Histories Both Conventional and Unconventional

Deborah Sacrey and Rocky Roden

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What is a Seismic Attribute?

A measurable property of seismic data, such as amplitude, dip, frequency, phase and polarity. Attributes can be measured at one instant in time or over a time window, and may be measured on a single trace, or on a set of traces or on a surface interpreted from seismic data.

Schlumberger Oilfield Dictionary

Seismic attributes reveal features, relationships, and patterns in the seismic data that otherwise might not be noticed.

Chopra and Marfurt, 2007

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Objectives for using Seismic Attributes

- ***To take advantage of the seismic attribute analysis and <u>today's visualization technology</u>, to <u>mine</u> pertinent <u>geologic information</u> from a huge amount of seismic data***

- ***The ultimate goal is to enable the geoscientist to produce a more accurate interpretation and <u>reduce</u> exploration and development <u>risk</u>.***

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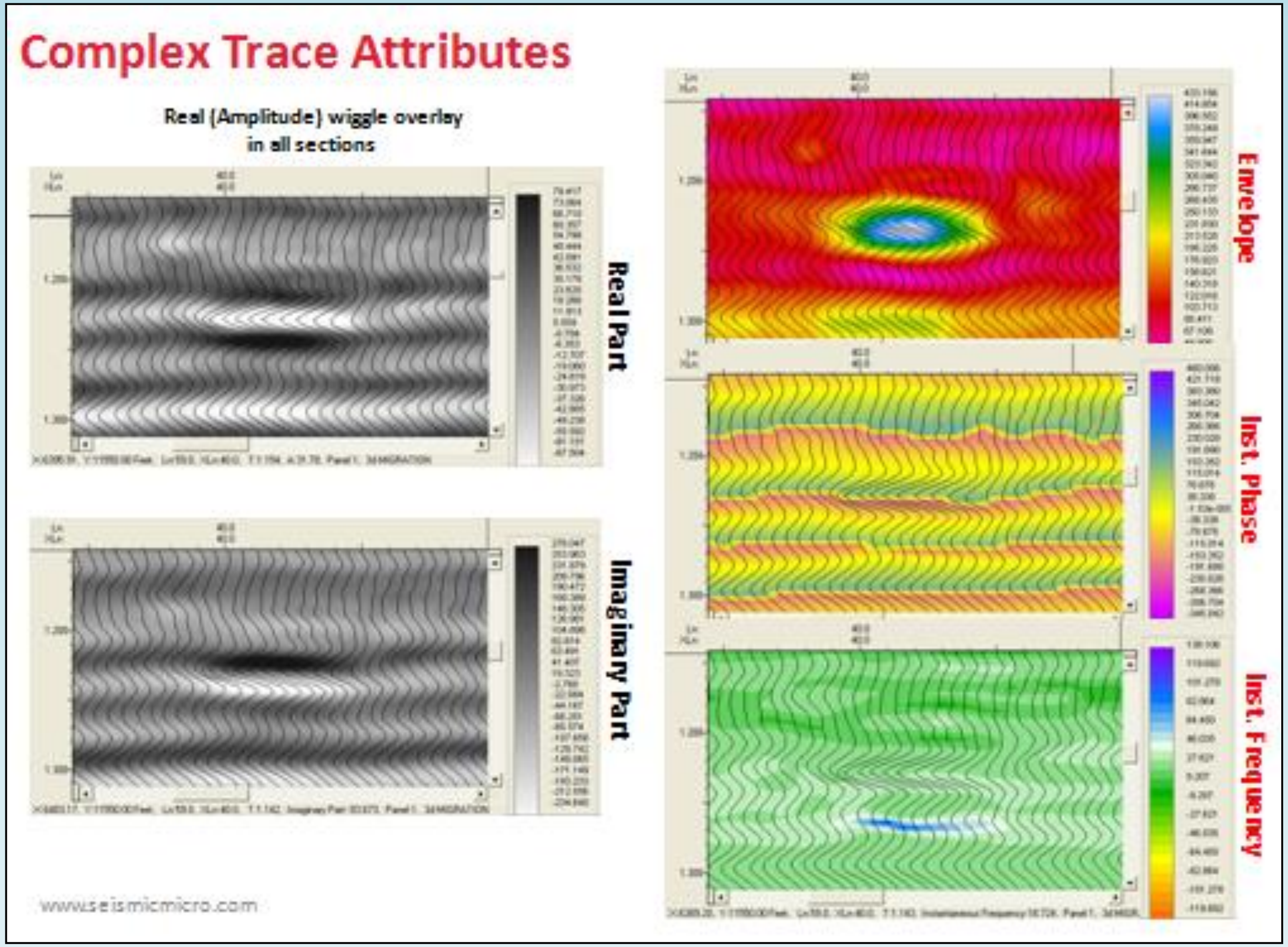
First Attributes Applied for Interpretation



Instantaneous Envelope (Reflection Strength)

Instantaneous Phase

Instantaneous Frequency

Balch (1971)
Anstey (1971)
Taner and Sheriff (1977)
Taner, Koehler, and Sheriff (1979)

Development of Seismic Attributes

- *Since the Taner et al. (1979) paper, there have been hundreds of different types of seismic attributes developed.*
- *There have been so many seismic attributes developed that there is no standard methodology to categorize them.*

Most Common Seismic Attributes for Interpretation

Instantaneous attributes

(trace envelope, instantaneous phase, instantaneous frequency)

Amplitude defining attributes

(Average Energy, Sweetness, RMS)

Coherency/Similarity

AVO Attributes

Inversion

Spectral Decomposition

Curvature

Instantaneous Attributes

Reflection Strength *(trace envelope, instantaneous amplitude)*

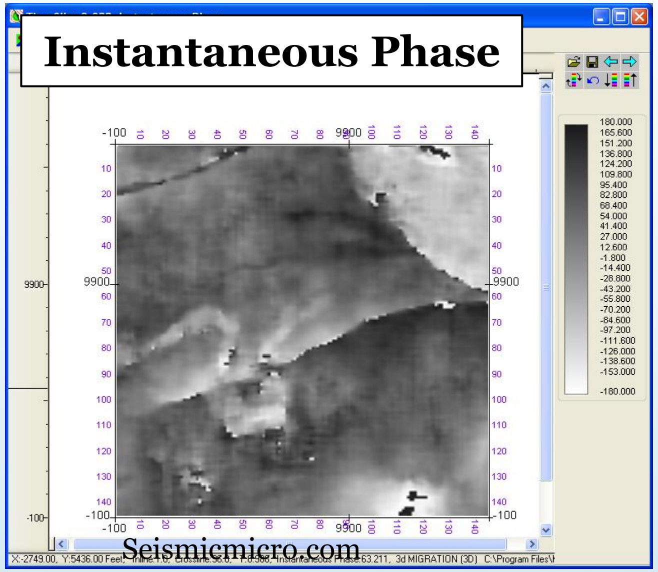
- ***Lithological contrasts***
- ***Bedding continuity***
- ***Bed spacing***
- ***Gross porosity***
- ***DHIs***

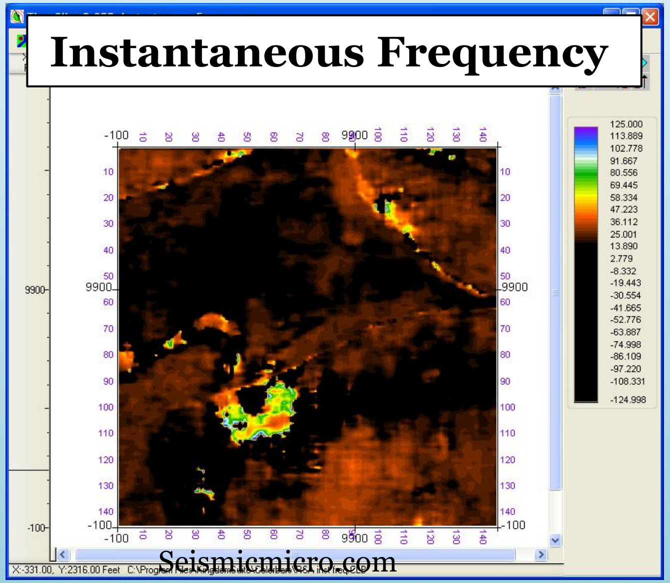
Instantaneous Phase

- ***Bedding continuity***
- ***Visualization of unconformities and faults***

Instantaneous Frequency

- ***Bed thickness***
- ***Lithological contrasts***
- ***Fluid content (frequency attenuation)***



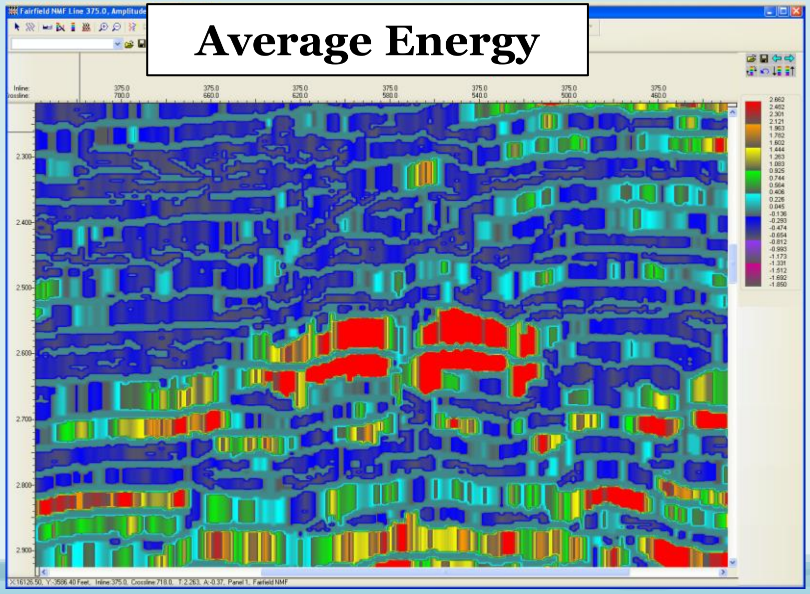


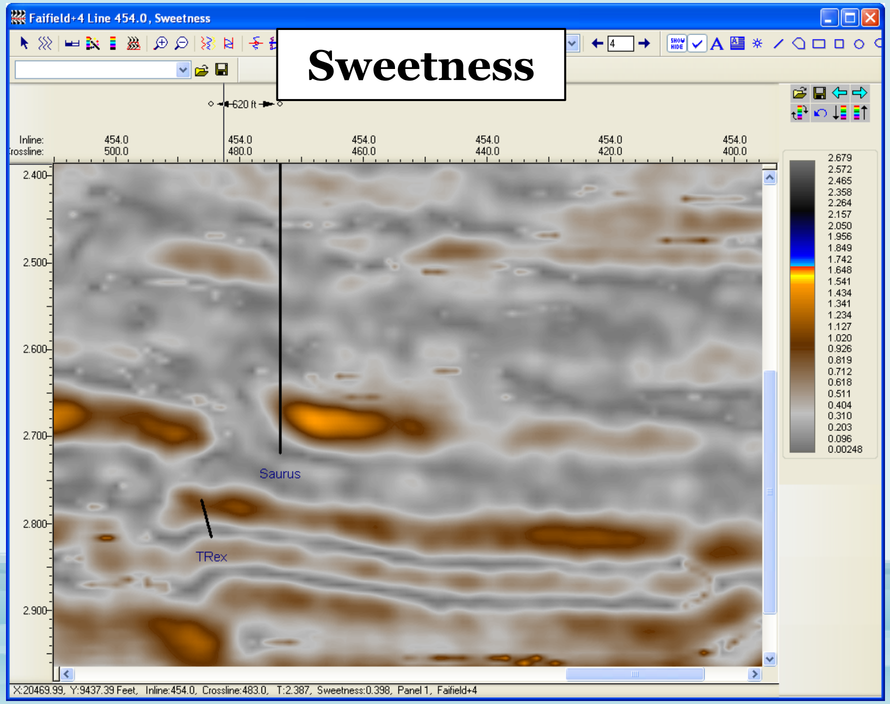
Amplitude Accentuating Attributes

These attributes help define how the amplitude stands out against surrounding reflectors and background events.

Average Energy
Sweetness (frequency weighted envelope)
RMS
Relative Acoustic Impedance

- ***DHI characteristics***
- ***Stratigraphic variations***
- ***Porosity***
- ***Lithology variations***





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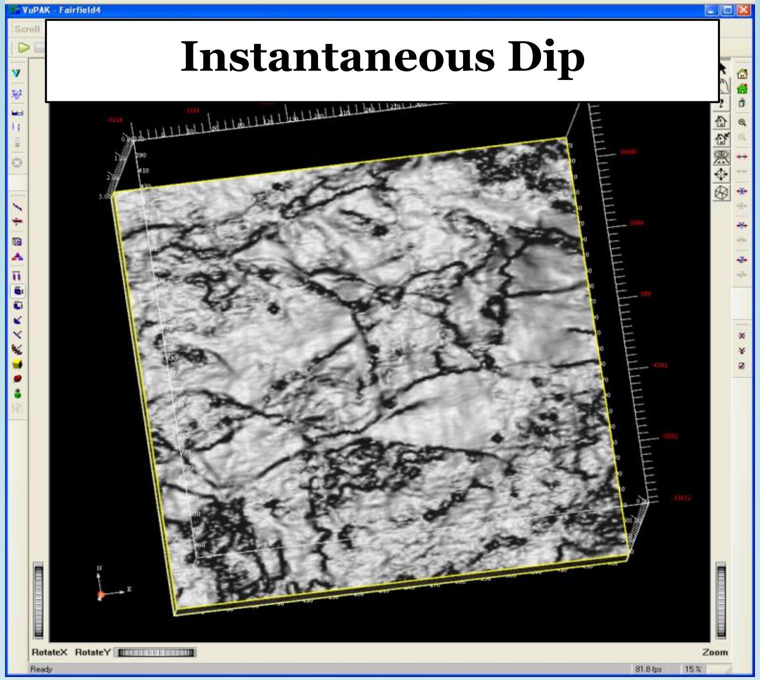
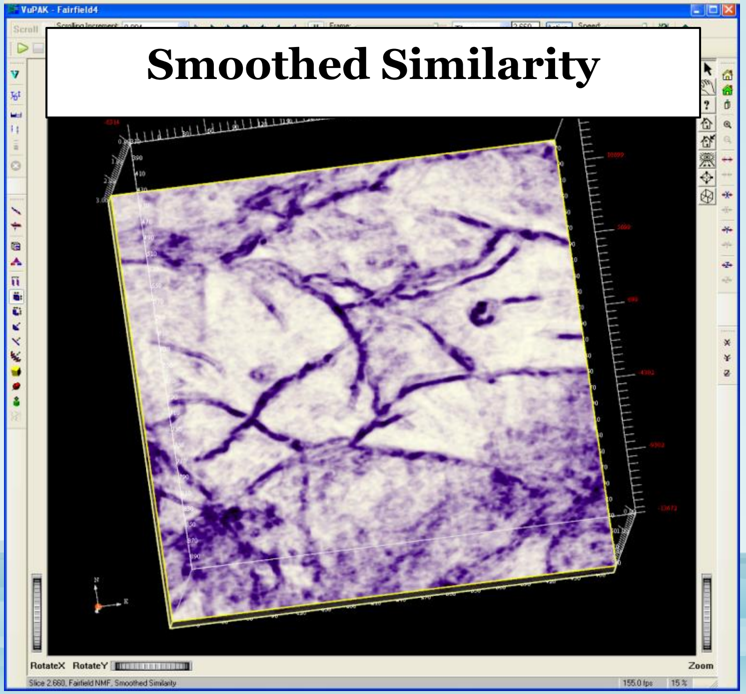
Coherency /Similarity

Coherency, similarity, continuity, semblance and covariance are similar and relate to a measure of similarity between a number of adjacent seismic traces (multi-trace analysis). They convert data into a volume of discontinuity that reveals faults, fractures, and stratigraphic variations.



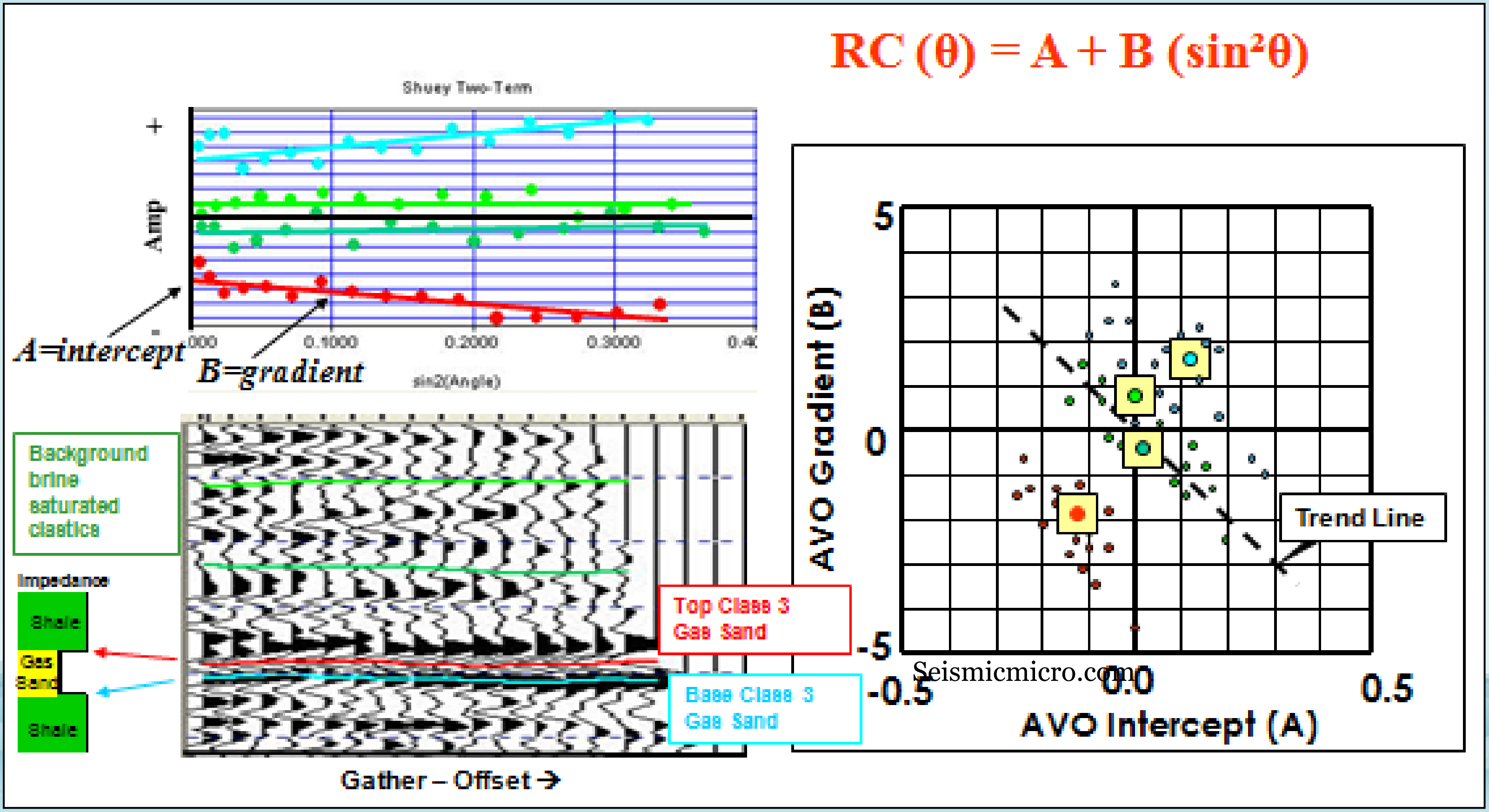


Cross-correlation-Based Coherence
Semblance-Based Coherence
Variance-Based Coherence
Eigen structure-Based Coherence
Gradient Structure Tensor-Based Coherence
Least-Squares-Based Coherence

AVO Attributes

AVO attribute volumes are computed from prestack data (gathers) . They include combinations of near, mid, and far offset or angle stacks and depending on approximations of the Knott-Zoeppritz equations, various AVO components. Most of the AVO attributes are derived from intercept and gradient values or equivalents. They are employed to interpret <u>pore fluid and/or lithology</u>.

Intercept (A)
Gradient (B)
Curvature (C)
A*B
A-C
½ (A+B)
½ (A-B)
Far-Near
(Far-Near)Far
Poisson Reflectivity
Fluid Factor
Lambda-Mu-Rho



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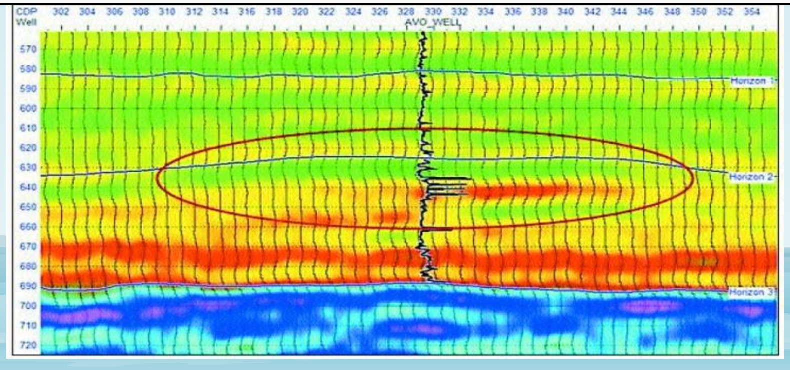
Seismic Inversion

- *Inversion transforms seismic reflection data into rock and fluid properties.*
- *The objective of seismic inversion is to convert reflectivity data (interface properties) to layer properties.*
- *To determine elastic parameters, the reflectivity from AVO effects must be inverted.*
- *The most basic inversion calculates* ***acoustic impedance*** *(density X velocity) of layers from which predictions about lithology and porosity can be made.*
- *The more advanced inversion methods attempt to discriminate specifically between* ***lithology, porosity, and fluid effects****.*

Recursive Trace Integration
Colored Inversion
Sparse Spike
Model-Based Inversion
Prestack Inversion (AVO Inversion)
- **Elastic Impedance**
- **Extended Elastic Impedance**
- **Simultaneous Inversion**

Stochastic Inversion
- **Geostatistical**
- **Bayesian**

Simultaneous P-Impedance Inversion



Russell and Hampson, 2006

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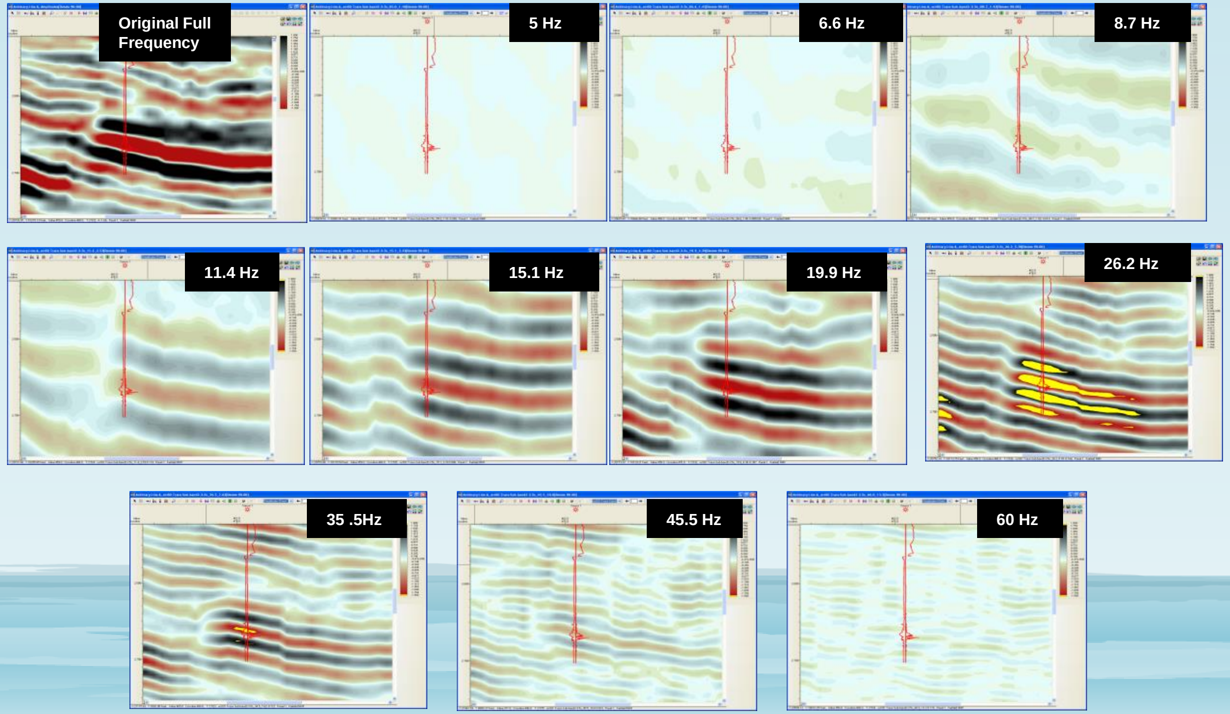
Spectral Decomposition

Use of small or short windows for transforming and displaying frequency spectra (Sheriff, 2005 Encyclopedic Dictionary of Applied Geophysics). In other words, the conversion of seismic data into discrete frequencies or frequency bands.

- ***Layer thickness determinations***
- ***Stratigraphic variations***
- ***DHI characteristics (e.g. shadow zones)***

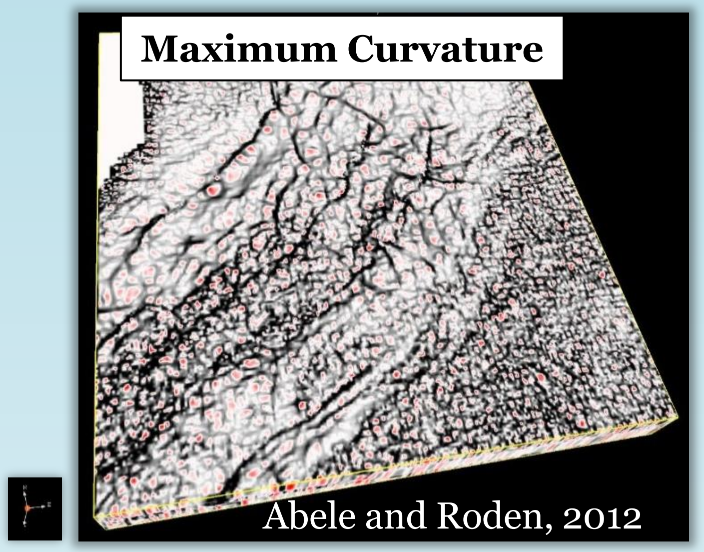
Discrete Fourier Transform
Fast Fourier Transform
Short Time Fourier Transform
Maximum Entropy Method
Continuous Wavelet Transform
- **Gabor**
- **Gabor-Morley**
- **Gaussian**

Spice
Continuous Wavelet Packet-Like Transform
Wigner-Ville Distribution
Smoothed Wigner-Ville Distribution
Matching Pursuit
Exponential Pursuit



Curvature

Curvature is a measure of bends and breaks of seismic reflectors. Another way to describe curvature for any point on a seismic reflecting interface is the rate of change of direction of a curve.

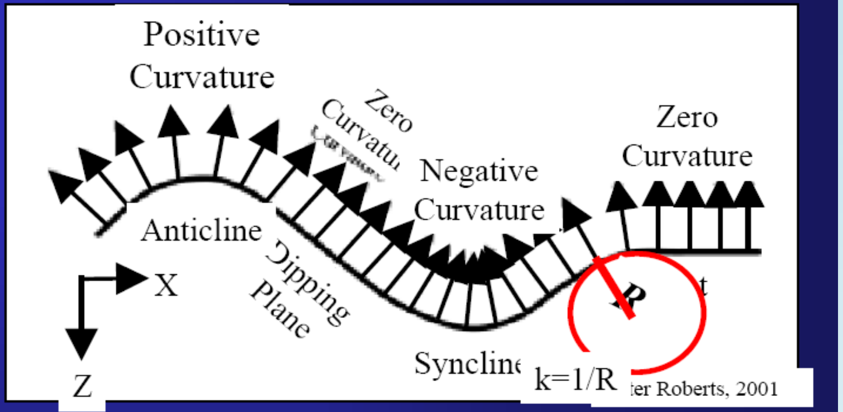


- ***Fractures***
- ***Folds***
- ***Faults***

Mean Curvature
Maximum Curvature
Minimum Curvature
Gaussian Curvature
Most Positive Curvature
Most Negative Curvature
Shape Index Curvature
Dip Curvature
Strike Curvature
Curvednessv

Curvature Basics

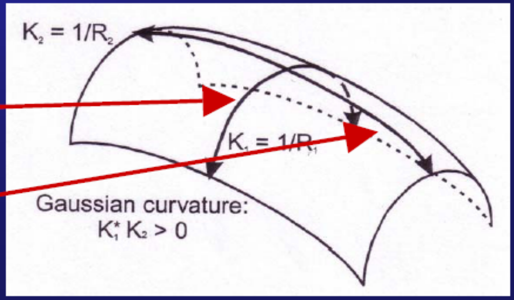
2-D Curvature



Principal Curvature K_1 = Maximum Curvature

Principal Curvature K_2 = Minimum Curvature

Gaussian Curvature = K_1 * K_2



Wynn and Stewart, 2003

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What if you could............

- Reduce interpretation cycle by advanced reconnaissance of your data?
- Reduce risk in drilling marginal/dry holes?
- Understand reservoir characteristics better?
- Employ an analysis to help sort through the mountains of attributes generated from your data?

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The main task for geologists and geophysicists is to identify and ascribe the geologic meaning to observable patterns in their seismic data.

The isolation of such patterns and the use as possible identifiers of subsurface characteristics constitutes attribute analysis and can significantly impact reducing risk in hydrocarbon prospecting.

***Self-Organizing Maps (SOM)* is a powerful cluster analysis and pattern recognition approach that helps interpreters identify patterns in their data that can relate to geological characteristics such as lithology, porosity, fluid content, facies, depositional environment, etc.**

Cluster Analysis

starshadow78/Flickr

How many clusters do you expect?

Round

Square

Red

Orange

Blue

Animate

starshadow78/Flickr

Inanimate

Search for Outliers

Drill here!

starshadow78/Flickr

Not your "Daddy's" Neural Analysis

- Unsupervised neural analysis has been around for some time – but the technology has drastically changed because of increased computer power and the invention/creation of hundreds of new attributes from advanced processing of seismic data.
- This is NOT "black box", but employs advanced understanding of various attributes and their contribution to finding solutions to specific problems in the seismic world. It can be "GIGO" if not used carefully.

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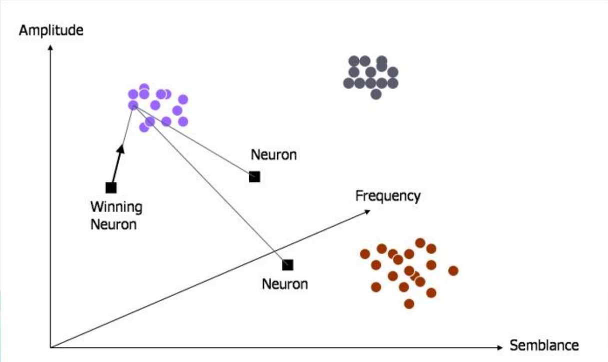
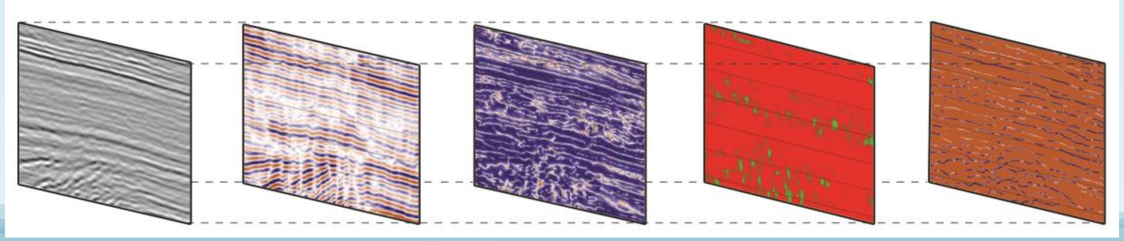
Neuron and Self-Organizing Map (SOM)

- **A neuron is a point that identifies a natural cluster of attributes**
- **Clusters and data, identified by neurons, have geologic significance**
- **A SOM is a collection of neurons which <u>classify</u> data samples into categories based on their properties**
- **Properties may be of <u>a geological or geophysical</u> nature.**
- **A neural map is a 2D representation of the result of <u>classifying and associating</u> the data, which may be in 'n' dimensions, such as many attributes in a 3D volume**



Neurons classifying data in 3 dimensions

Neural networks address the Big Data problem



Amplitude Spec. Decomp. Curvature Dip Azimuth Sweetness

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Why Self Organizing Maps Now?

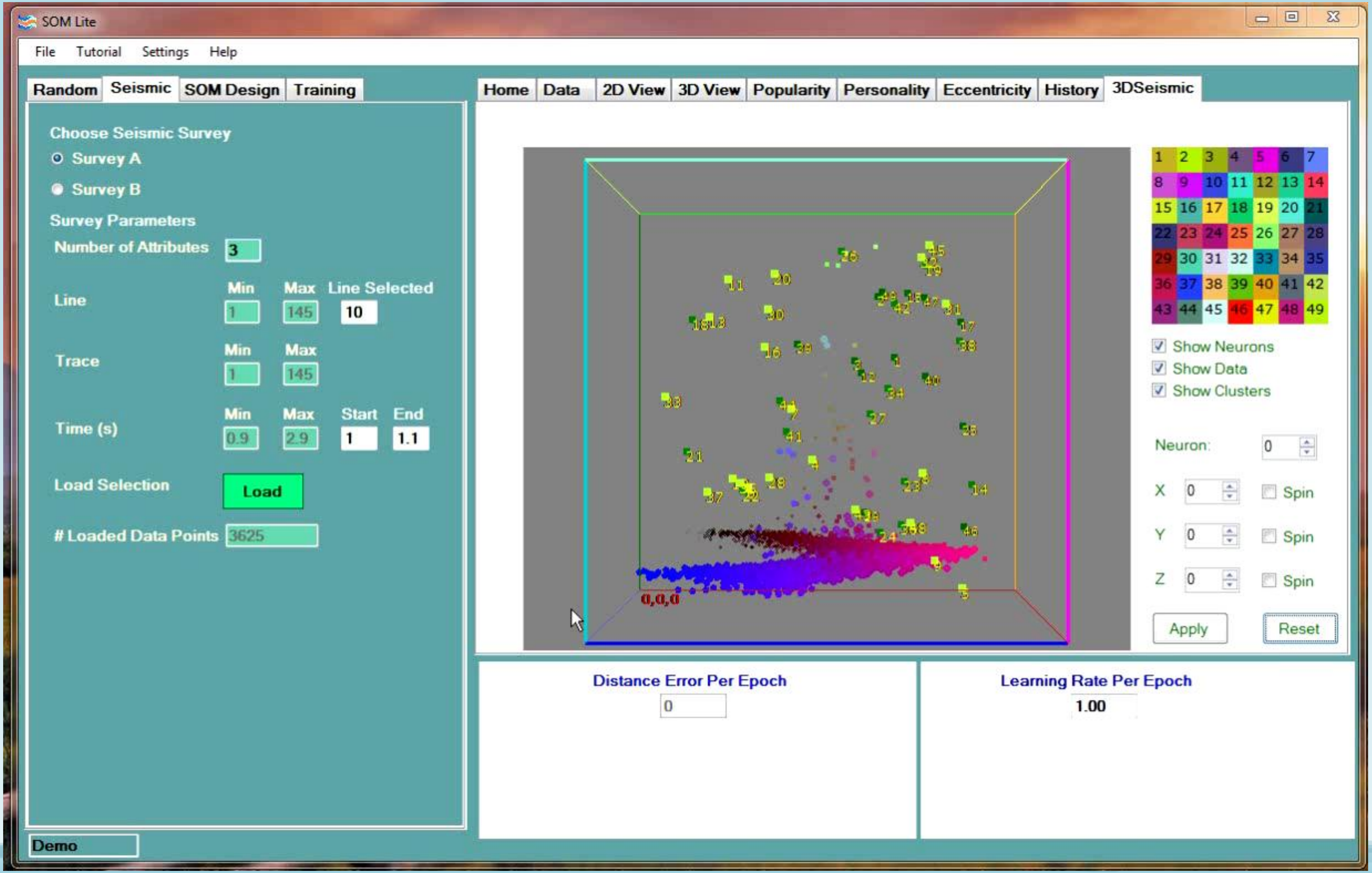
Computer power – ***parallel processing***

Visualization techniques – ***2D color maps, neuron isolation***

Understanding of necessary input parameters – ***amount of neurons, which attributes, epochs, etc.***

Analysis at every sample

Understanding of probability factors


SOM Lite
File
Tutorial
Settings
Help
Random
Seismic
SOM Design
Training
Home
Data
2D View
3D View
Popularity
Personality
Eccentricity
History
3DSeismic
Choose Seismic Survey
Survey A
Survey B
Survey Parameters
Number of Attributes
3
Line
Min
Max
Line Selected
1
145
10
Trace
Min
Max
1
145
Time (s)
Min
Max
Start
End
0.9
2.9
1
1.1
Load Selection
Load
Loaded Data Points
3625
0,0,0
Show Neurons
Show Data
Show Clusters
Neuron:
0
X
0
Spin
Y
0
Spin
Z
0
Spin
Apply
Reset
Distance Error Per Epoch
0
Learning Rate Per Epoch
1.00
Demo

Case Histories

Unconventional Resource Plays

The essential elements of unconventional resource plays encompass the following categories:

Reservoir Geology: ***thickness, lateral extent, stratigraphy, mineralogy, porosity, permeability***

Geochemistry: ***TOC, maturity (Ro-heat), kerogen % (richness)***

Geomechanics: ***acoustic impedance inversion, Young's modulus, Poisson's ratio (Vp/Vs), pressures***

Faults, Fractures, and Stress Regimes: ***coherency (similarity), curvature, fault volumes, velocity anisotropy (azimuthal distribution), stress maps***

SOM Details for Eagle Ford

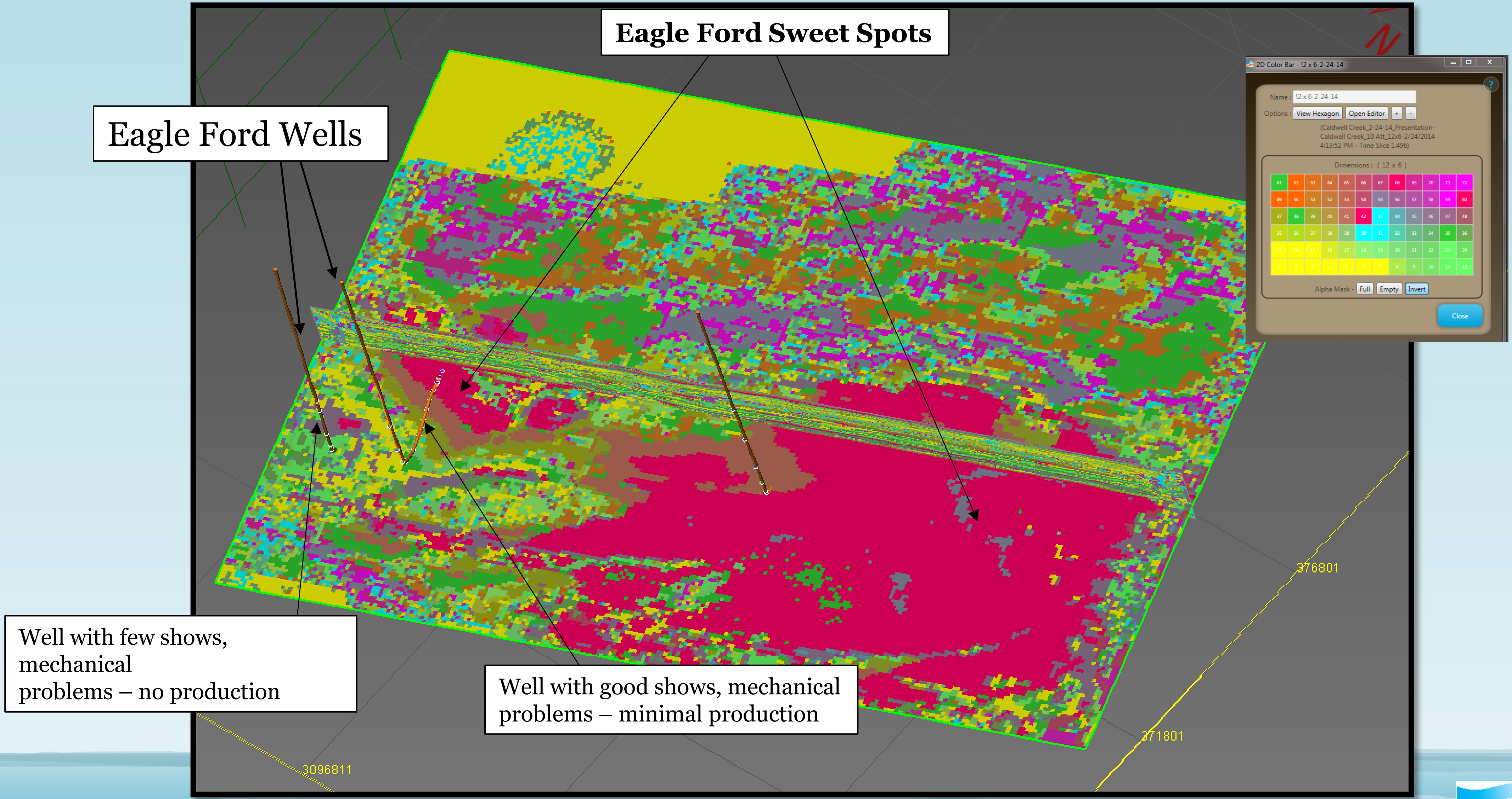
Attributes from Client:

Brittleness Coefficient
Final Density
LambdaRho
MuRho
P_Impedance
S_Impedance
Poisson's Ratio
Poisson's Brittleness
Young's Brittleness

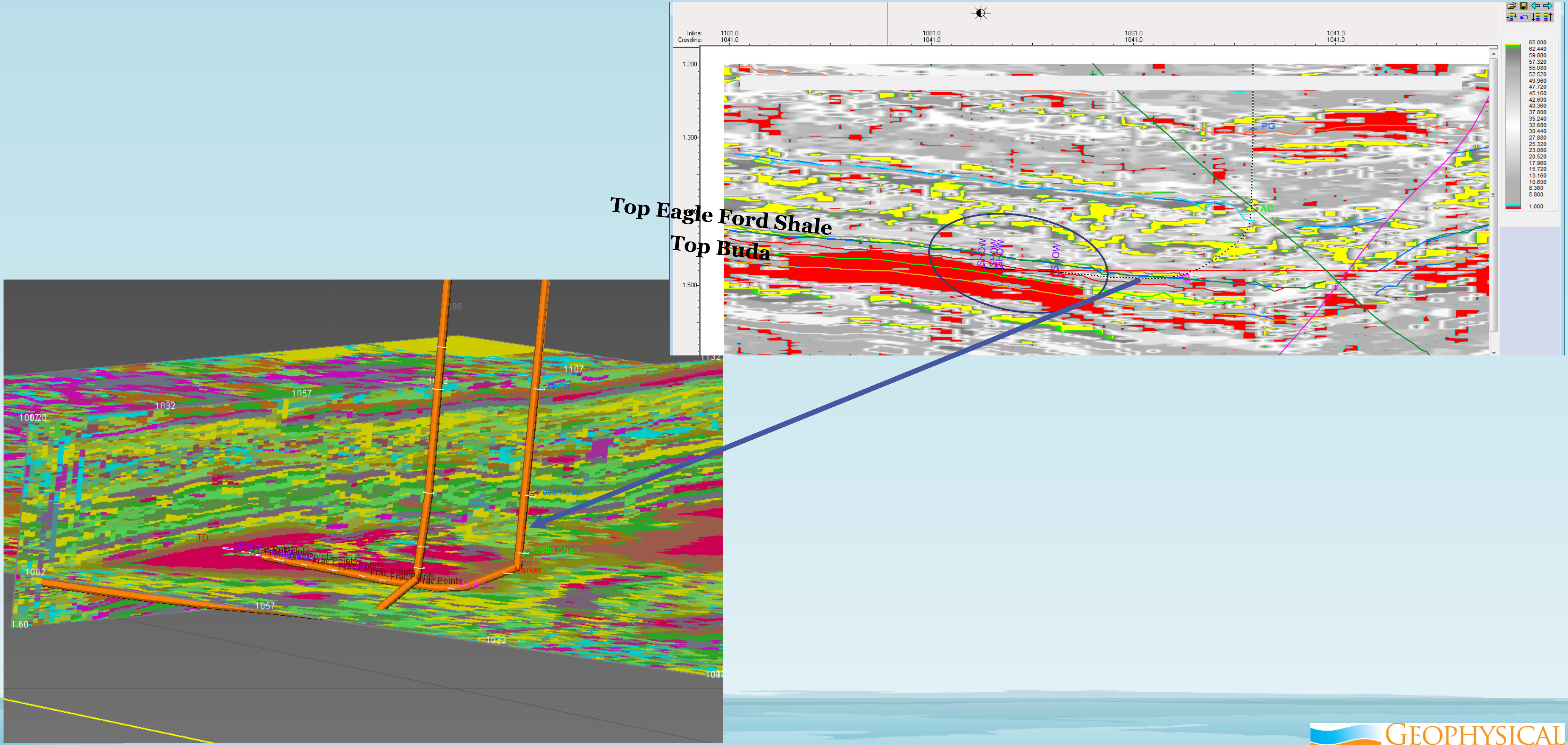
Curvature in Dip Direction
Envelope Slope
MuRho
PSTM (Amplitude volume)
S_Impedance
Trace Envelope
Youngs_Brittleness
Attenuation
Bandwidth
Instantaneous Q

Run with 12 x 6 topology
80 Epochs
Time: 1.2 – 1.6 seconds

Eagle Ford Results – Sweet Spot



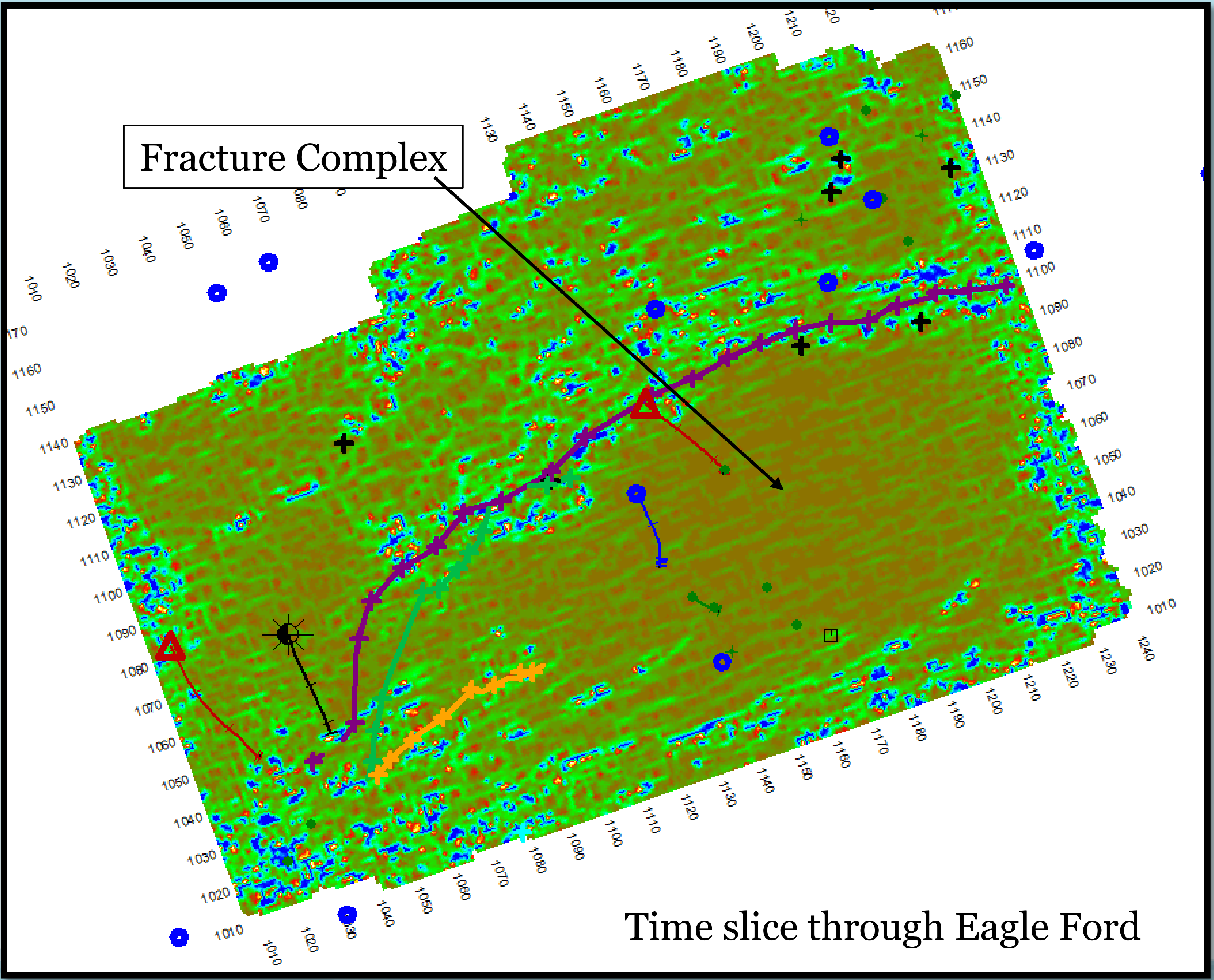
Arbitrary Line through well



Fracture systems

Selected Attributes

- Curvature: in Dip Direction_TriCon
- Curvature: in Strike Direction_TriCon
- Curvature: Maximum_TriCon
- Curvature: Minimum_TriCon
- Curvature: Most Negative_TriCon
- Curvature: Most Positive_TriCon
- Dip Of Maximum Similarity_TriCon

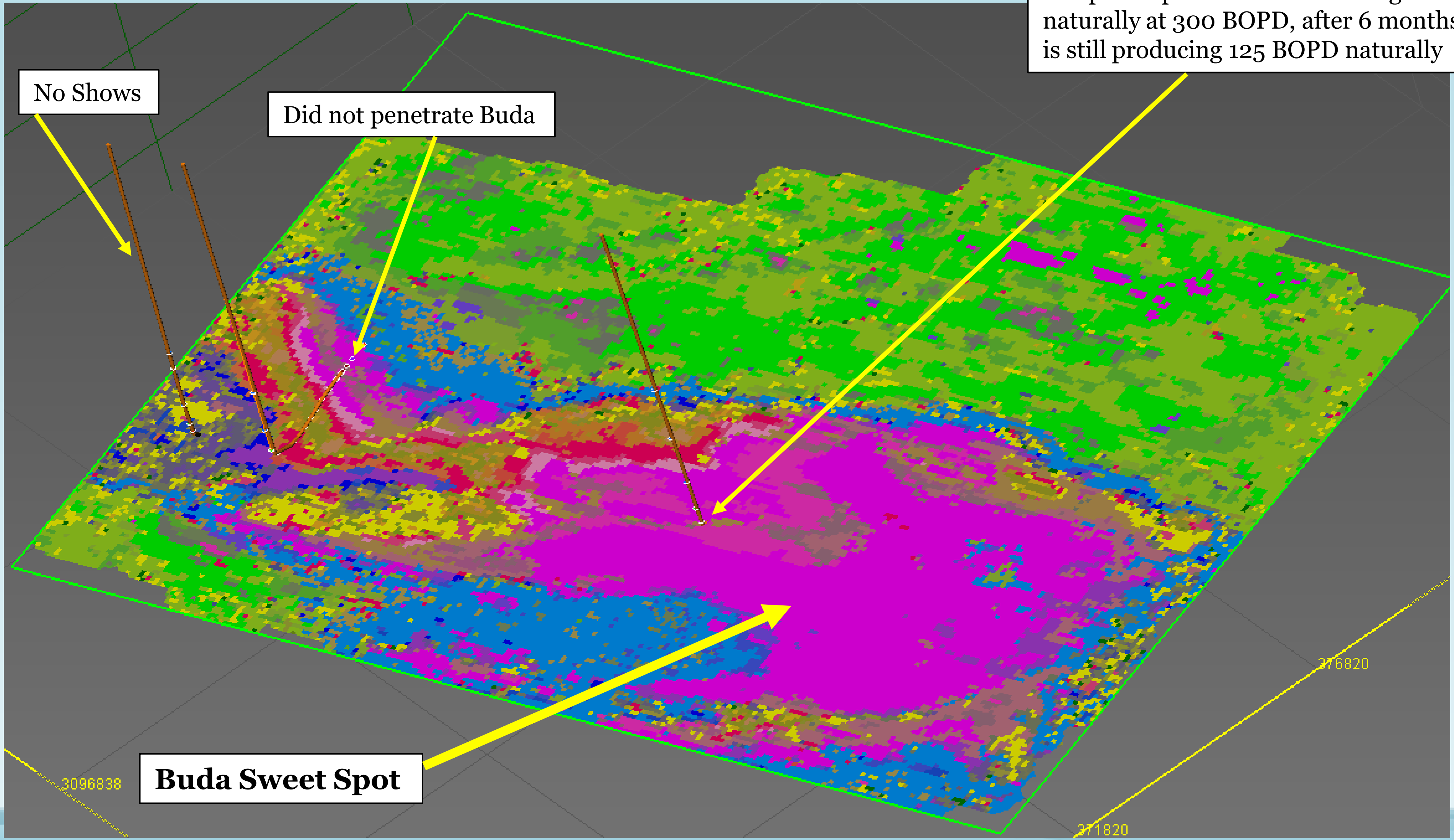


SOM Details for Buda

Average Energy
Dip Variance
Final Density
PSTM (Amplitude volume)
Poissons_Brittleness
Relative Acoustic Impedance
S_Impedance
Sweetness
Instantaneous Frequency
Envelope

Run with 8 x 8 topology
80 Epochs
Time: 1.2 – 1.6 seconds

Buda Objectives



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Conventional Type 2 AVO Yegua – thin pay

Seismic Attributes Employed for SOM Analysis

Far – Near

(Far – Near) Far

Near = 0°-15°
Far = 31°-45°

Gradient(B)

Intercept(A) X Gradient(B)

½ (Intercept + Gradient)

Shuey 3 Term Approximation

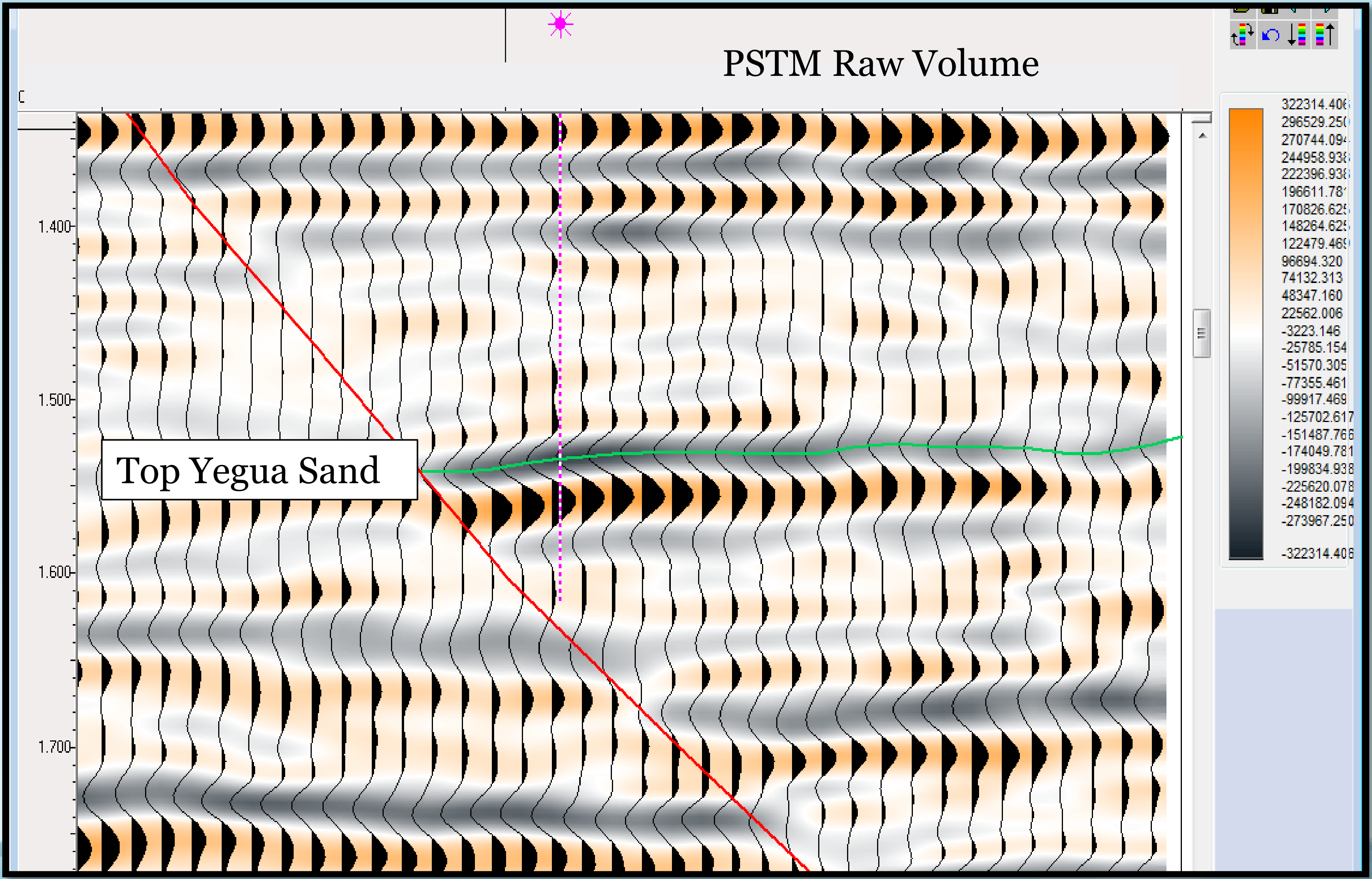
$$RC(\Theta)=A + B \sin^2\Theta + C (\sin^2\Theta \tan^2\Theta)$$

Poisson's Reflectivity(PR)

Verm & Hilterman Approximation

$$RC(\Theta)=NIp \cos^2\Theta + PR \sin^2\Theta c$$

Inline through well – amplitude data



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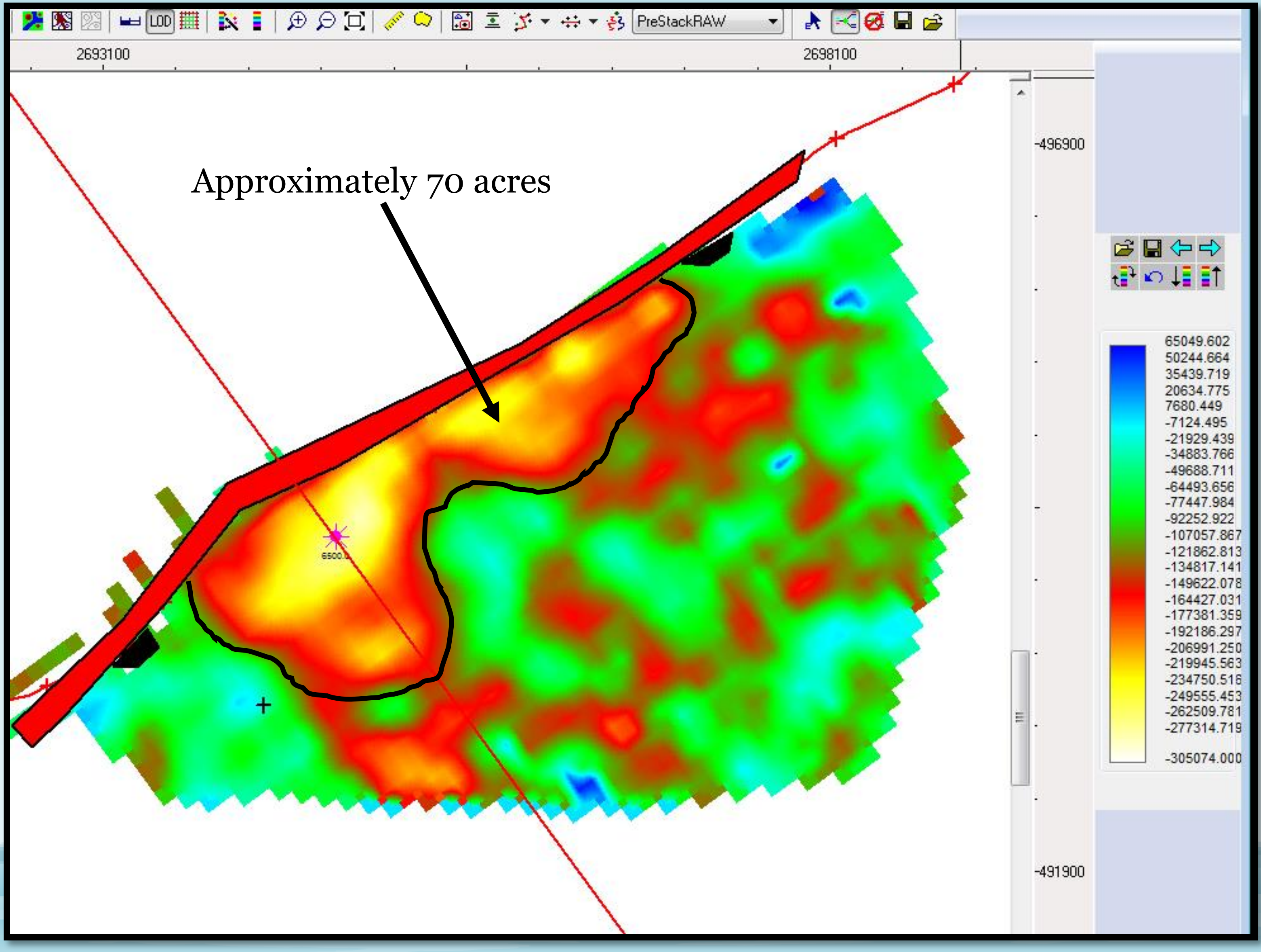
Conventional PSTM Amplitude Map



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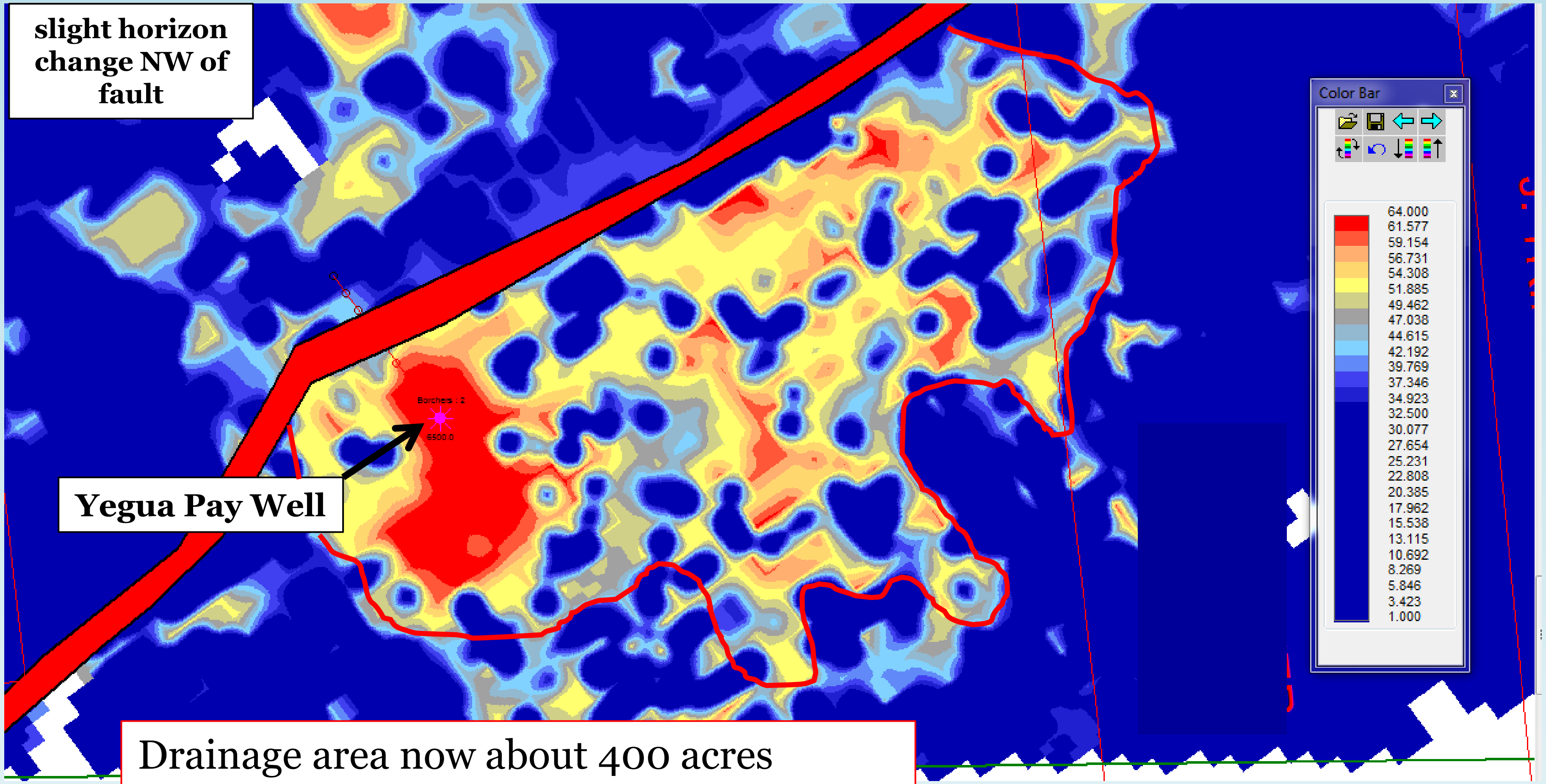
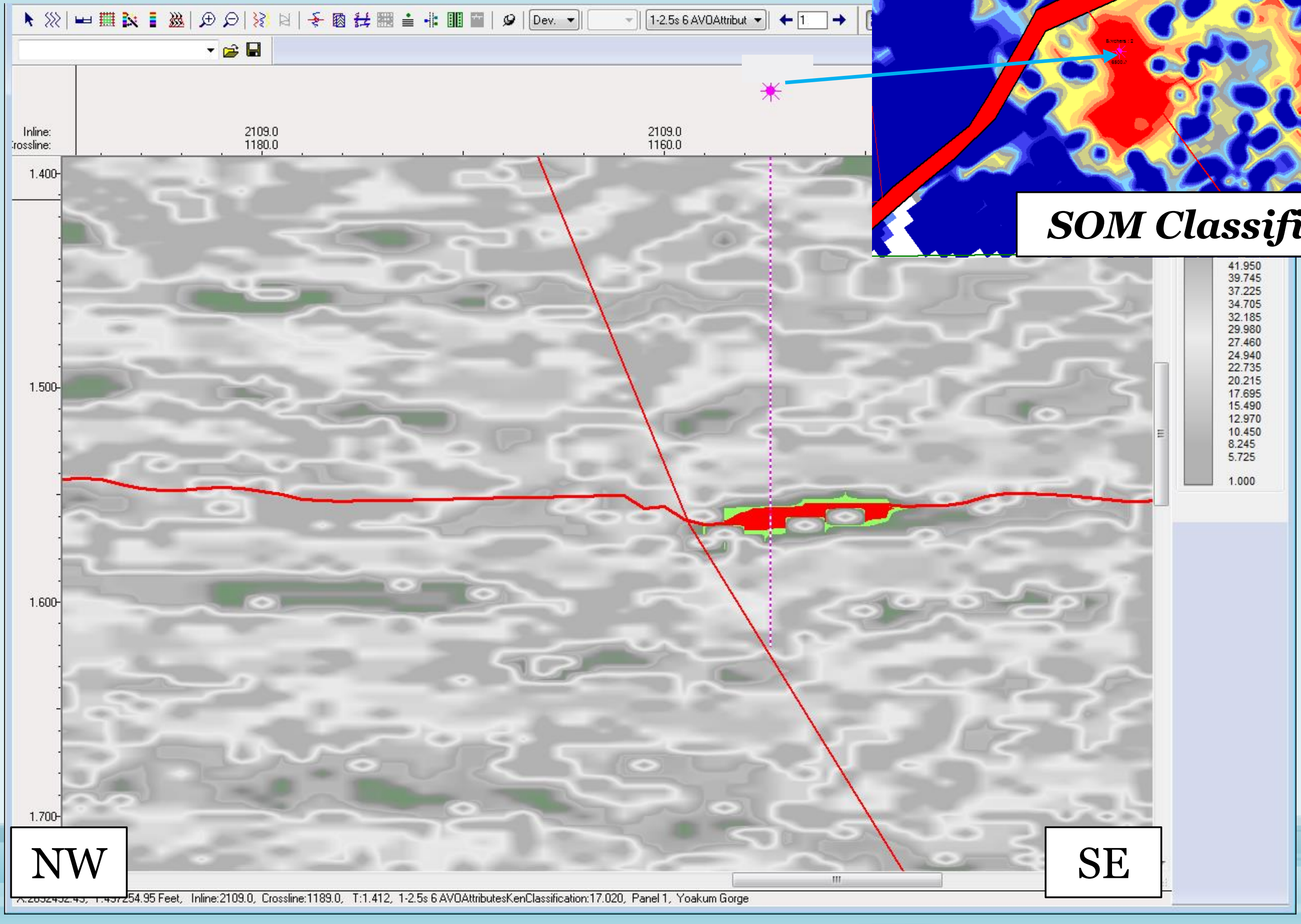
SOM Classification – Base of Yegua Pay

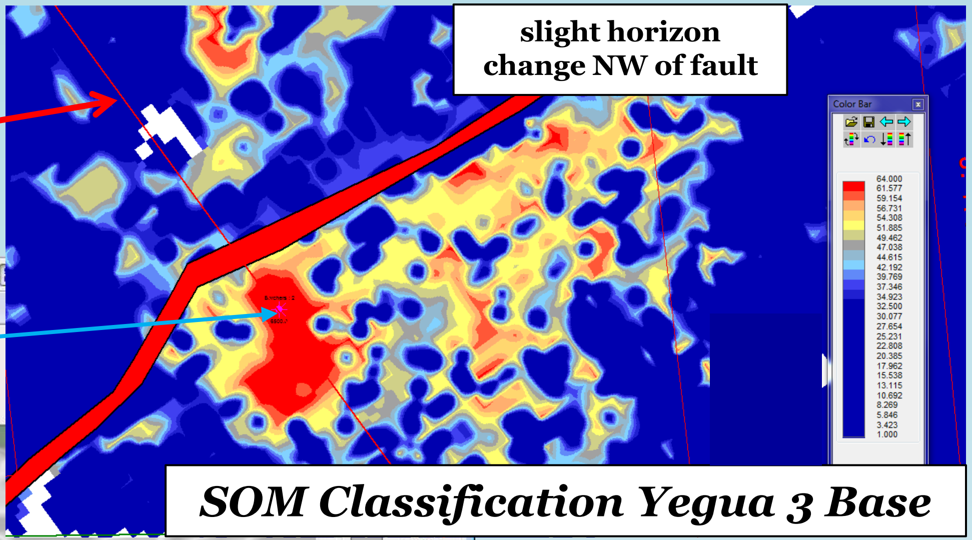


Drainage area now about 400 acres which supports engineering/pressure data

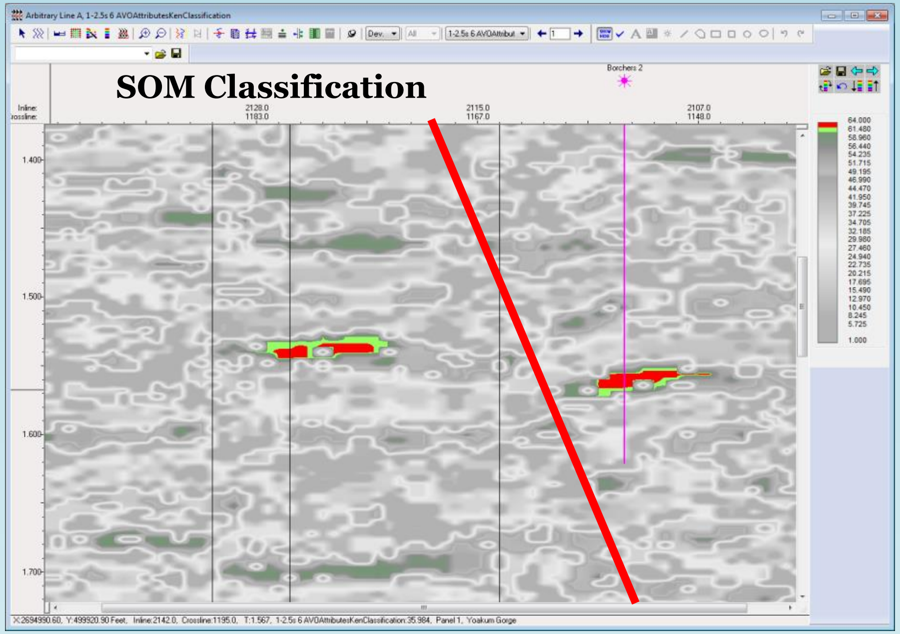
SOM Classification Inline

SOM Classification Inline

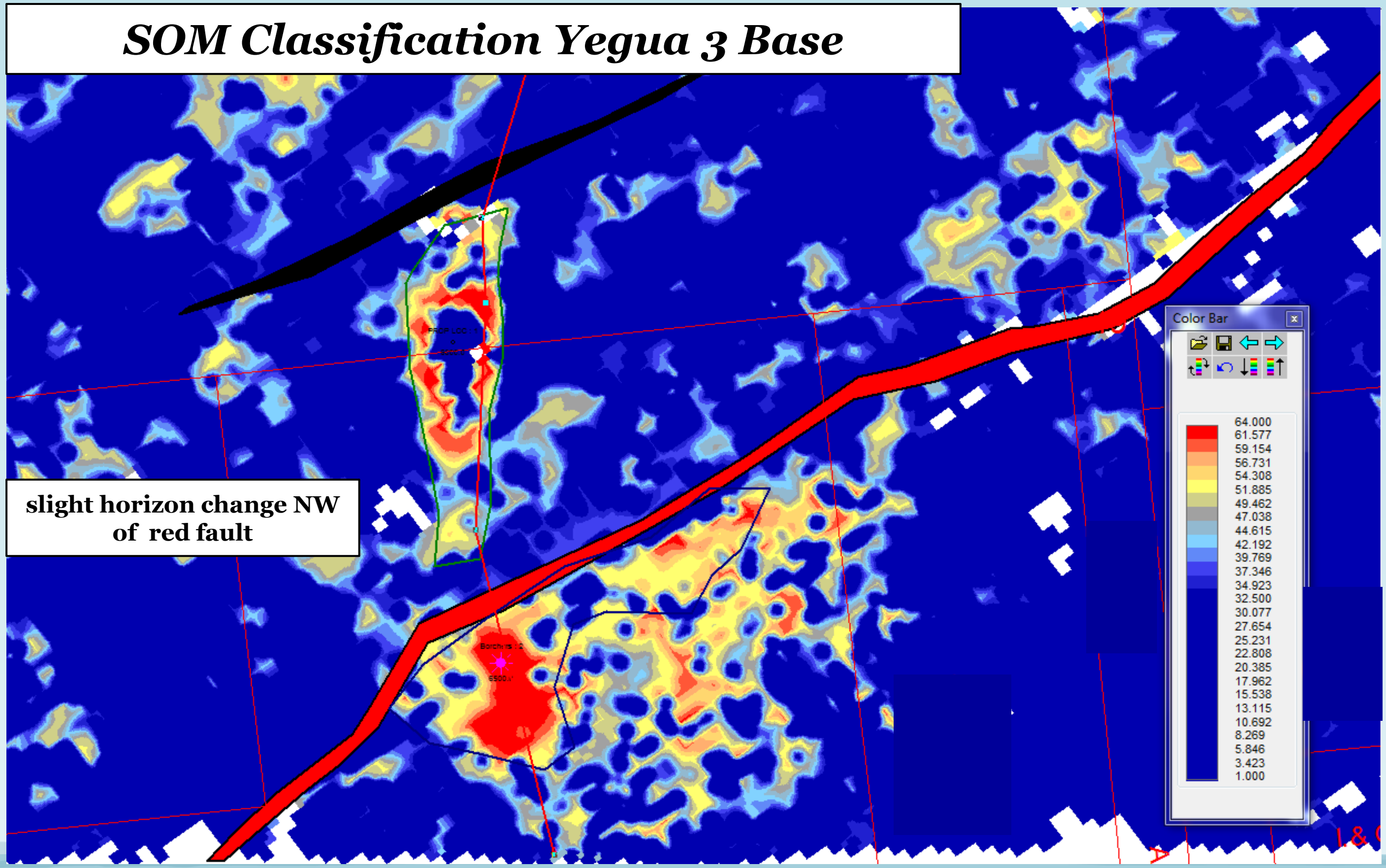




2nd Successful Yegua well updip



Arbitrary Line ~ NS



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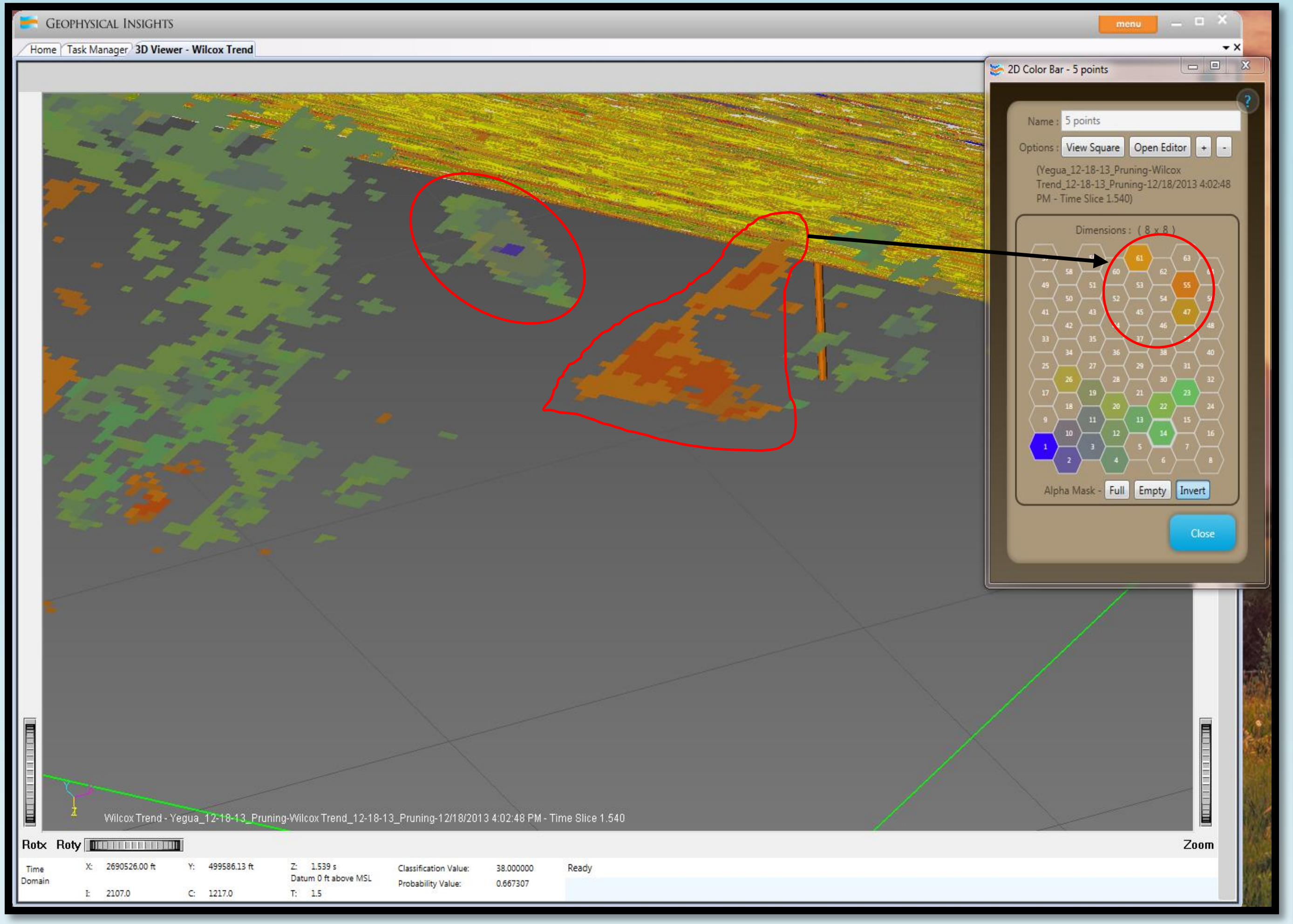
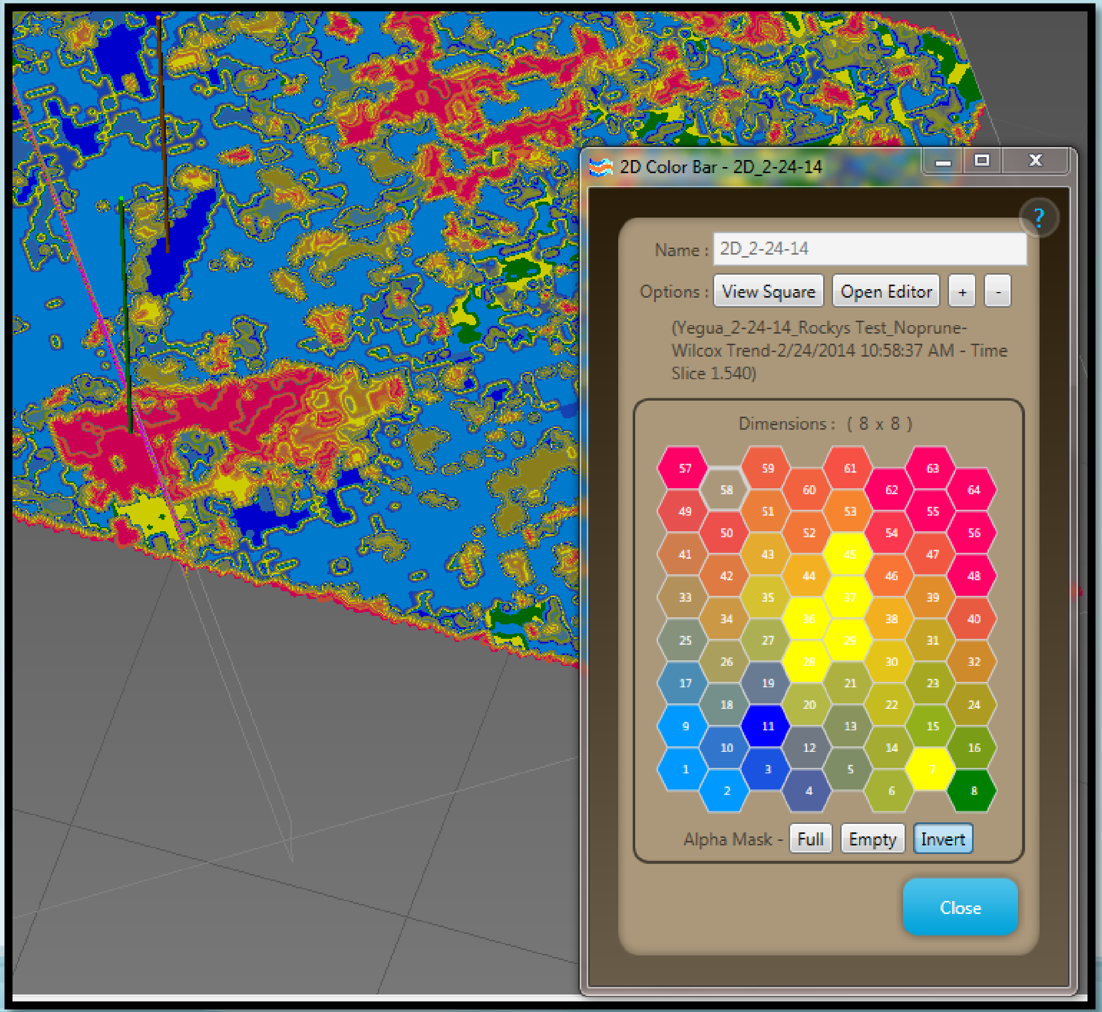
Volume rendering visualization of specific neurons





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Offshore Gulf of Mexico – Class 3 AVO

Three Sets of Seismic Attributes for SOM Analysis

Attributes for Attenuation

1) *Final Raw Migration*
2) *Instantaneous Q*
3) *Envelope*
4) *Attenuation*
5) *Sweetness*

Attributes for Flat Spots

1) *Final Raw Migration*
2) *Instantaneous Frequency*
3) *Instantaneous Phase*
4) *Normalized Amplitude*
5) *Phase Breaks*

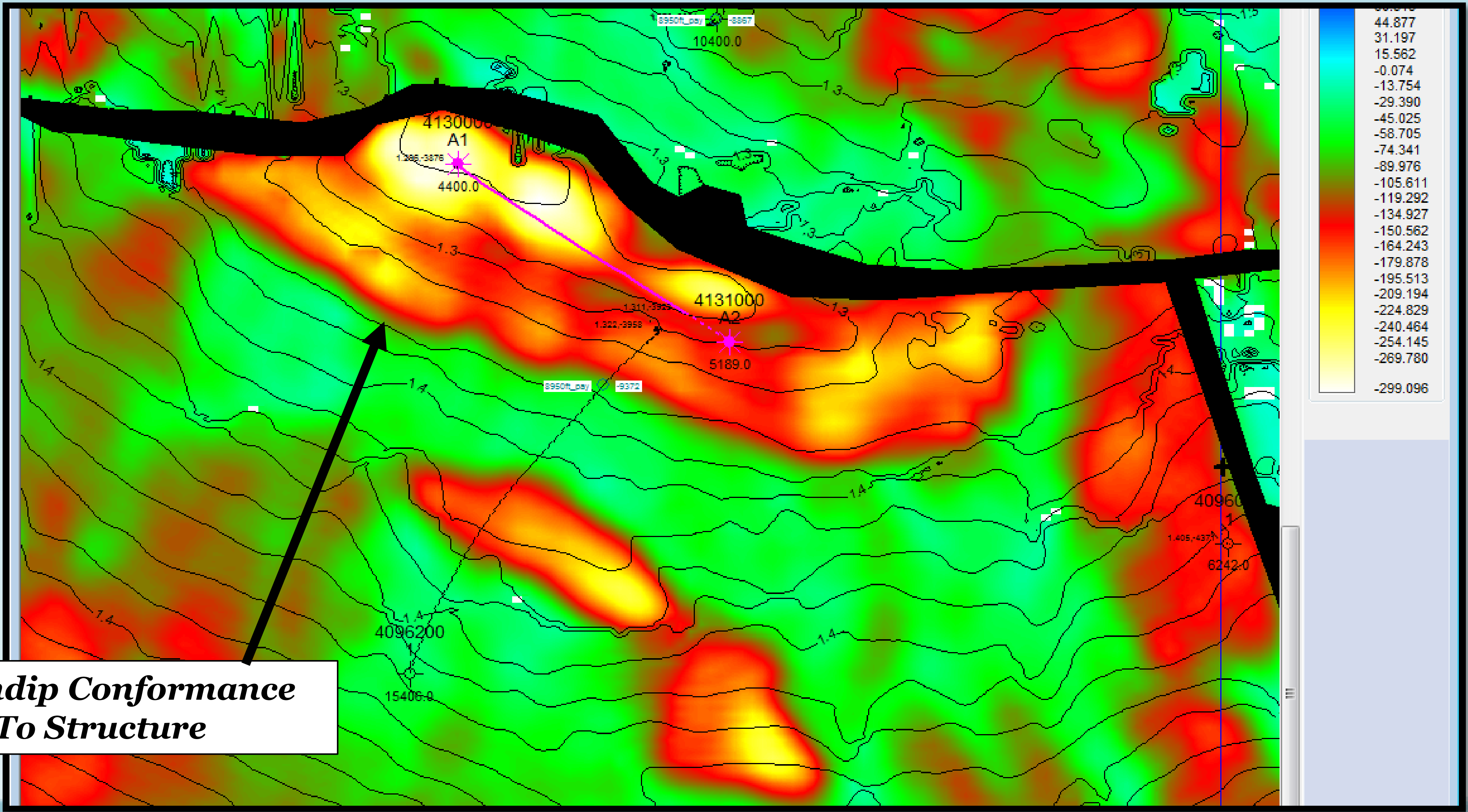
Ten Attributes-HCI

1) *Final Raw Migration*
2) *Instantaneous Frequency*
3) *Attenuation*
4) *Average Energy*
5) *Dominant Frequency*
6) *Env. Time Derivative*
7) *Rel. Acoustic Impedance*
8) *SD Env. Sub-band 33.5 Hz*
9) *Envelope*
10) *Sweetness*

3900’ Reservoir

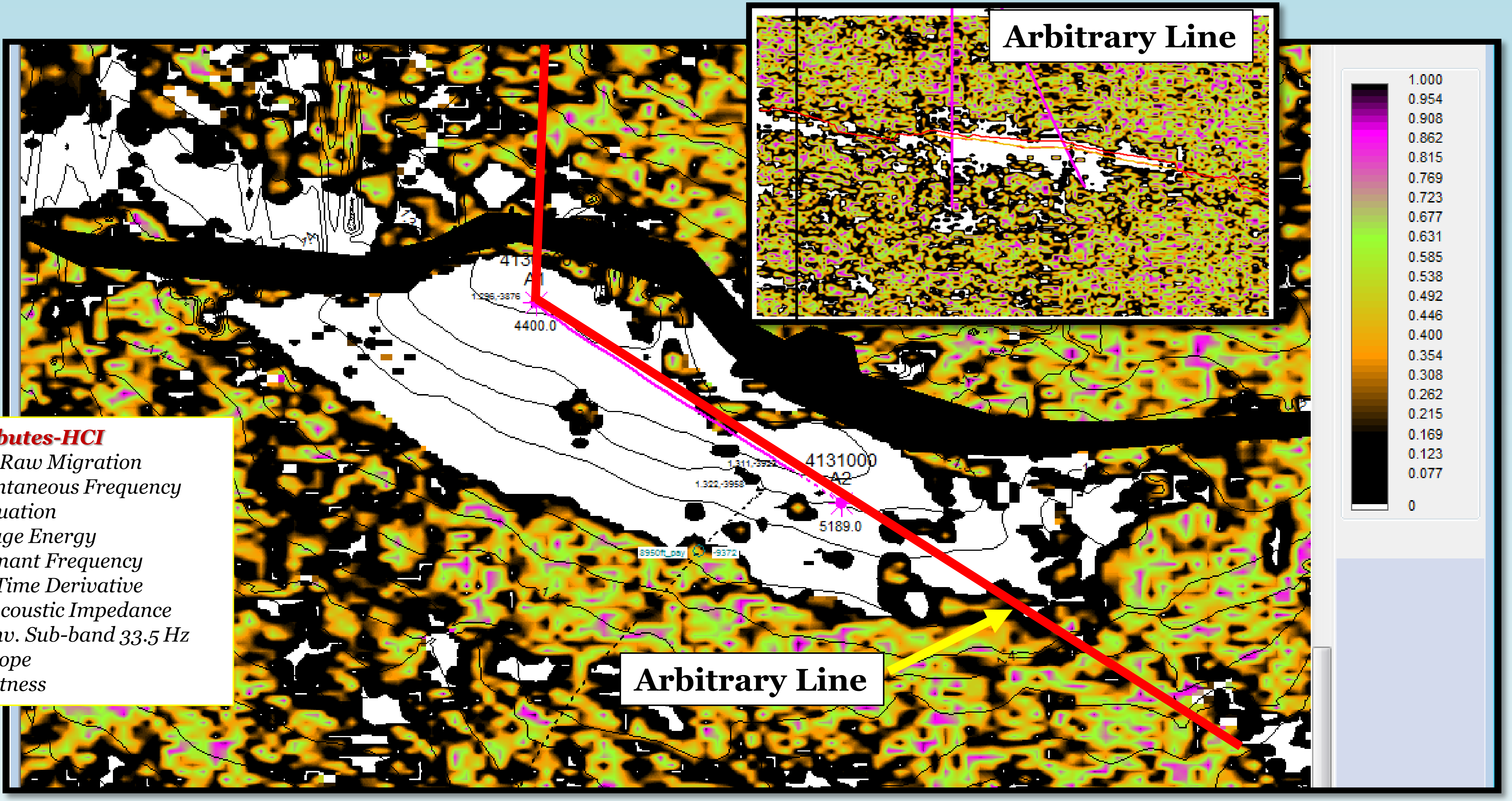
- Upthrown Fault Closure
- Approximately 100’ Reservoir Sand
- Two Producing Wells
  - #A-1 (gas on oil)
  - #A-2 (oil)

Amplitude Map at Top of Reservoir



Downdip Conformance To Structure

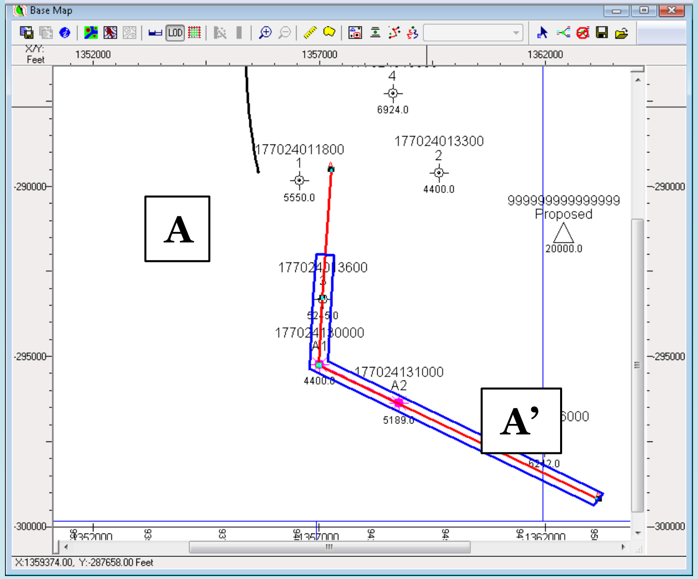
SOM – Ten Attributes with Probability volume

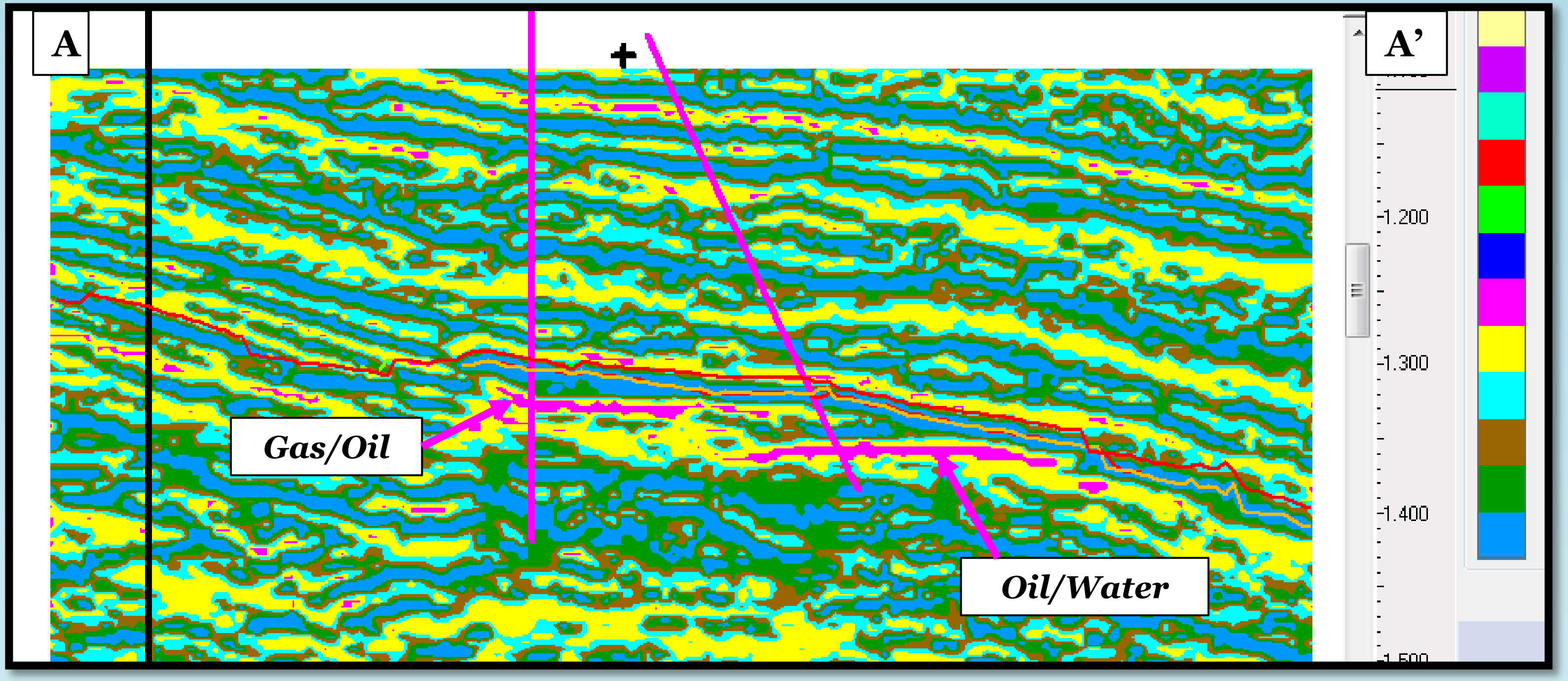


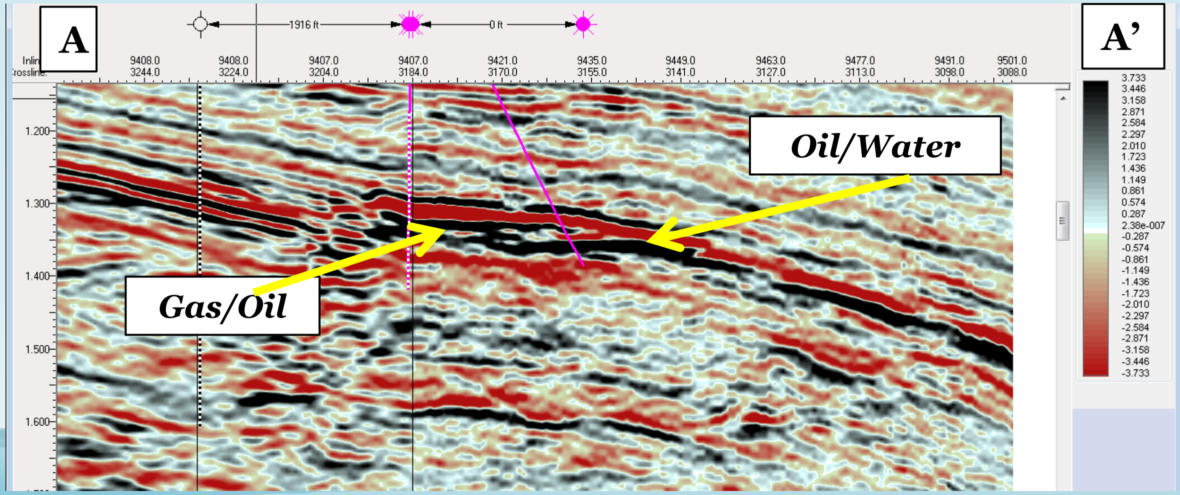
Ten Attributes-HCI

1) *Final Raw Migration*
2) *Instantaneous Frequency*
3) *Attenuation*
4) *Average Energy*
5) *Dominant Frequency*
6) *Env. Time Derivative*
7) *Rel. Acoustic Impedance*
8) *SD Env. Sub-band 33.5 Hz*
9) *Envelope*
10) *Sweetness*

Flat Spot attributes







Attributes for Flat Spots

1) *Final Raw Migration*
2) *Instantaneous Frequency*
3) *Instantaneous Phase*
4) *Normalized Amplitude*
5) *Phase Breaks*

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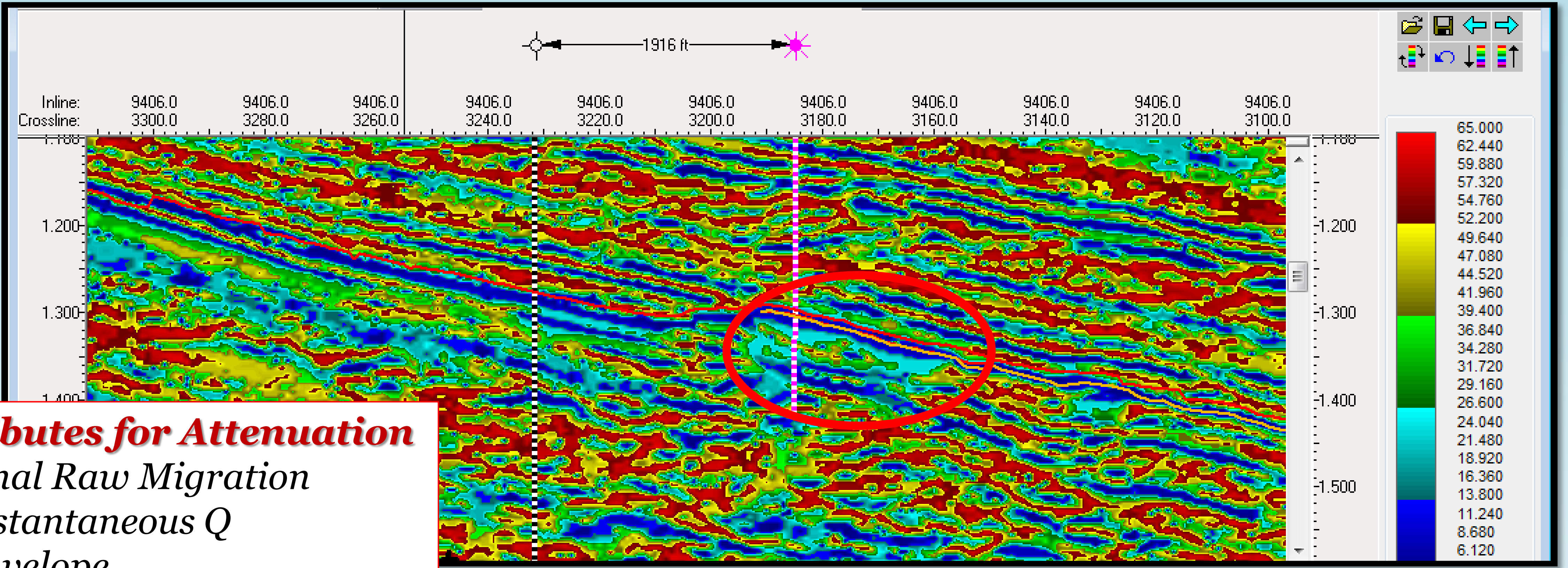
Attenuation Attributes – Classification Display



Attributes for Attenuation

1) *Final Raw Migration*
2) *Instantaneous Q*
3) *Envelope*
4) *Attenuation*
5) *Sweetness*

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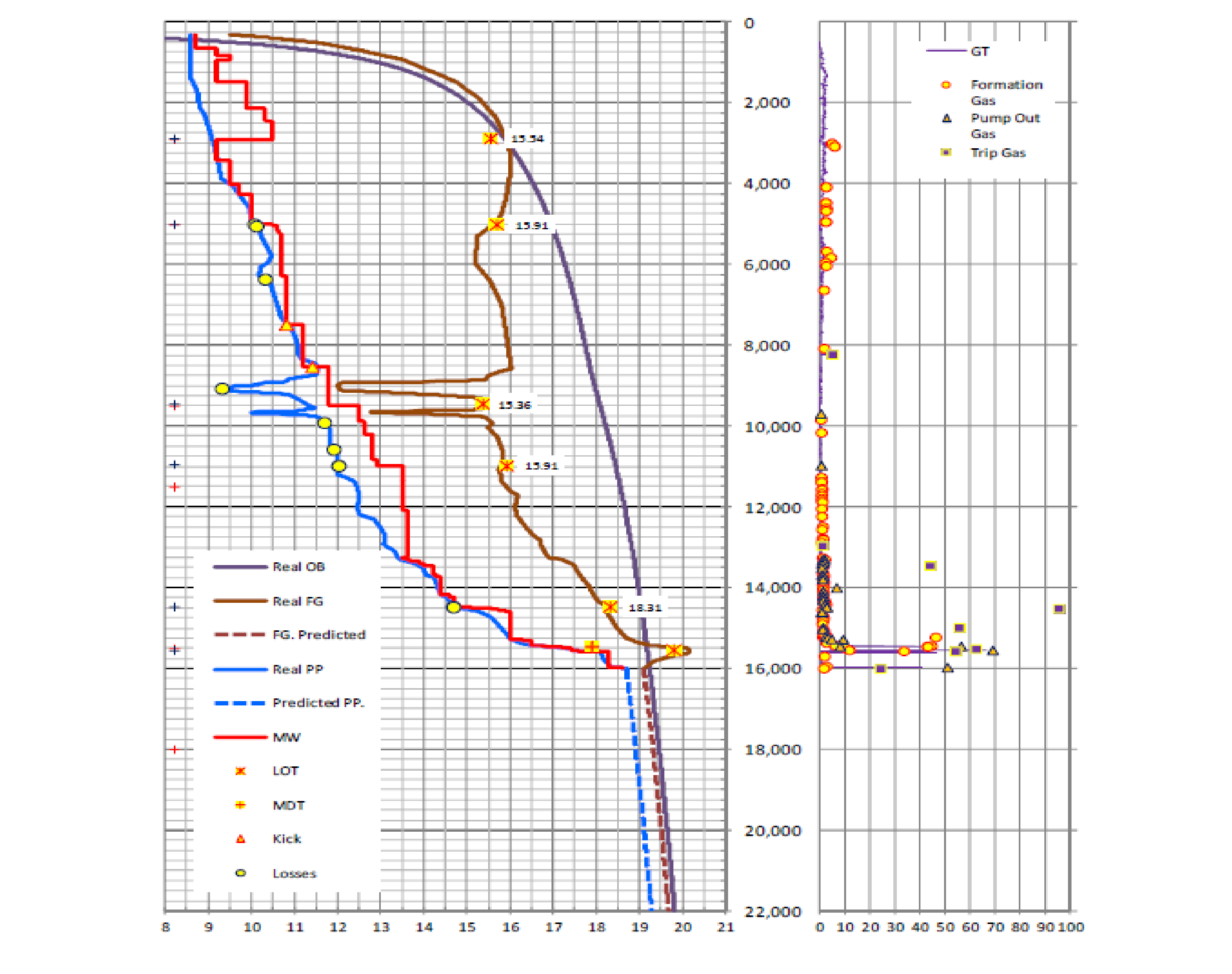
SOM analysis for Non-Hydrocarbon Problems

Client had to stop drilling when they encountered unusually high pressures which had not been predicted

Conventional seismic analysis could not "see" pressure in section

Series of 5 analyses shows solution in the use of the 2D color bar to isolate specific neurons.

Final Pore Pressure Profile



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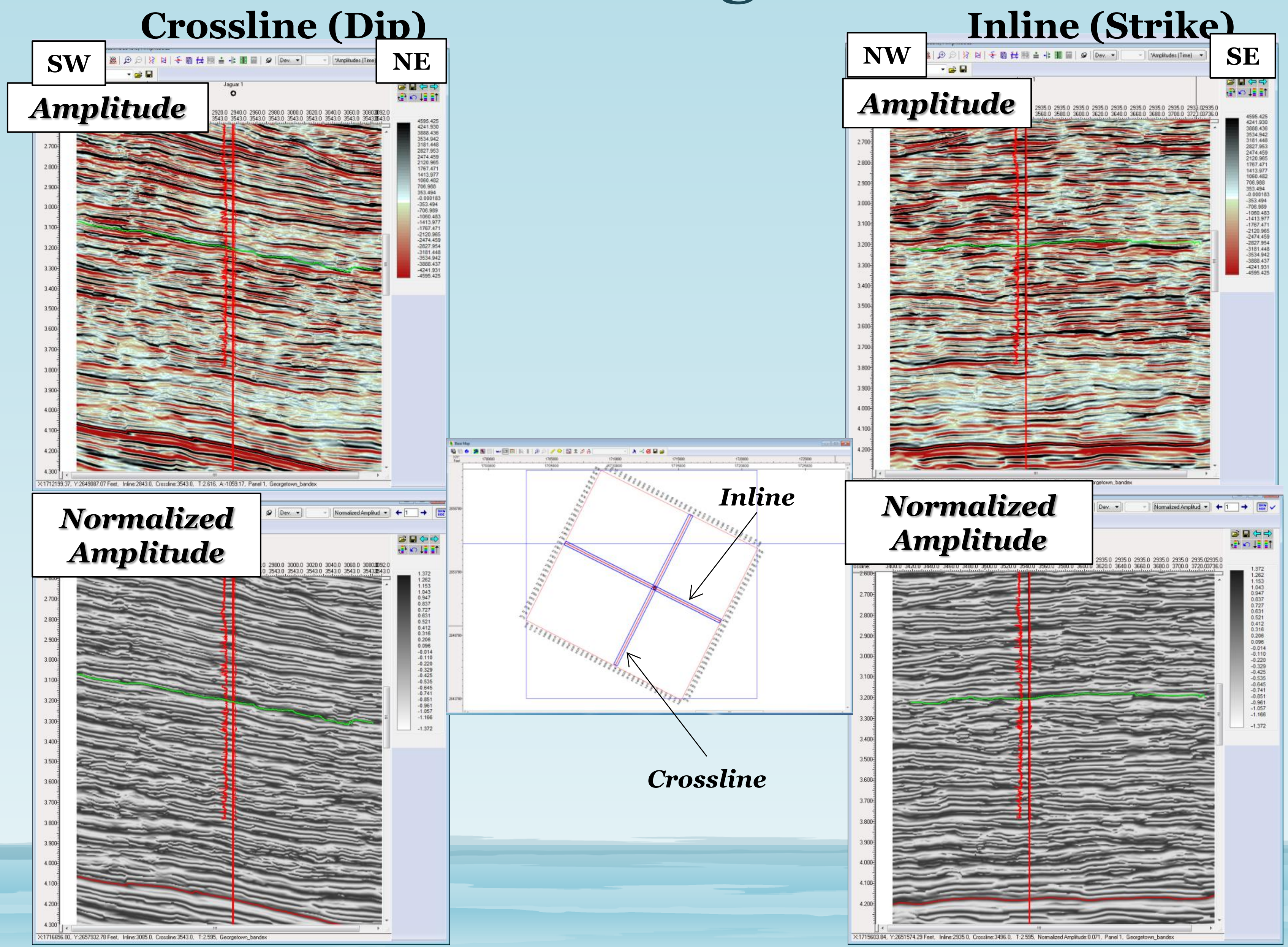
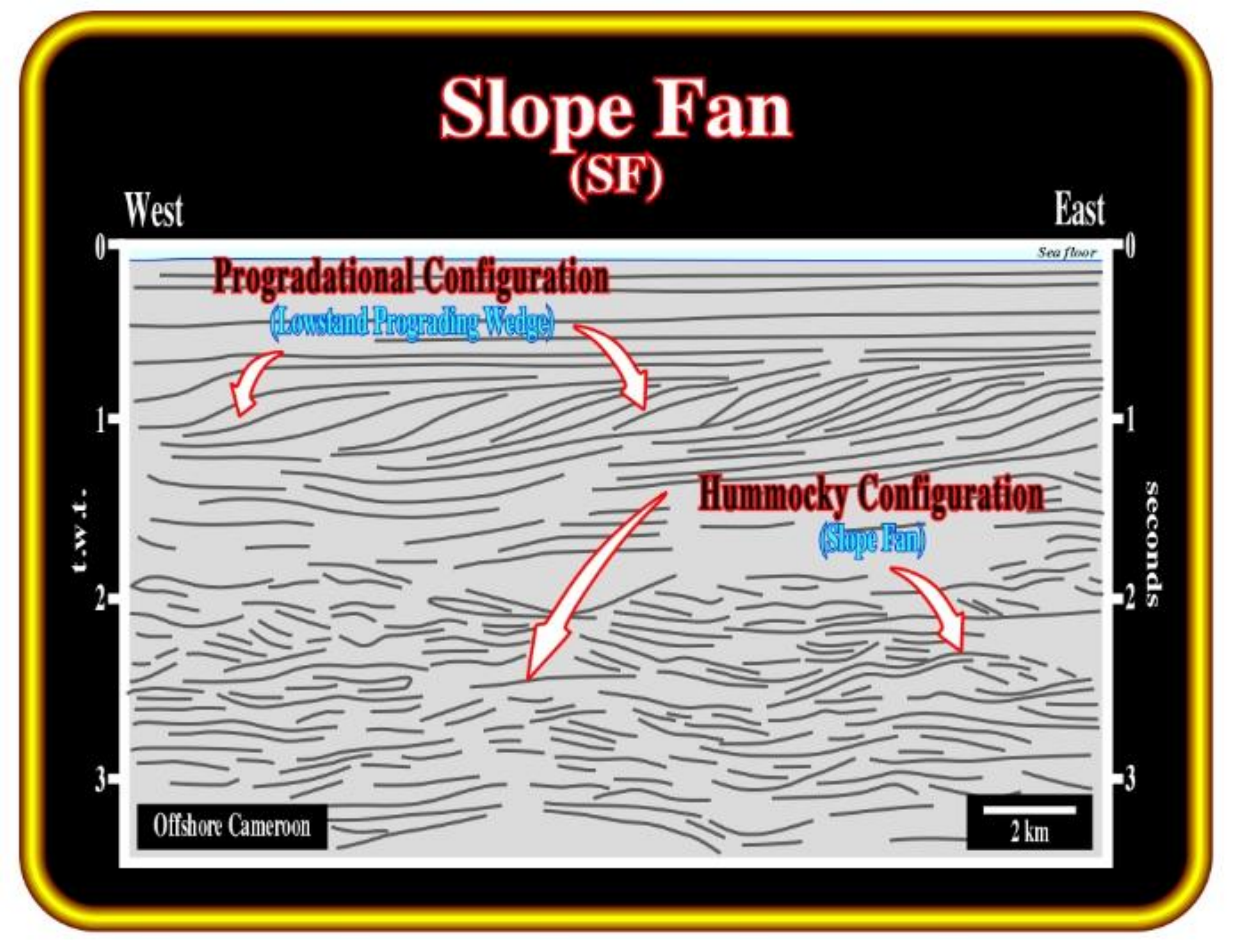
Inline and Cross Line through well



Depositional Environment – Slope Fan

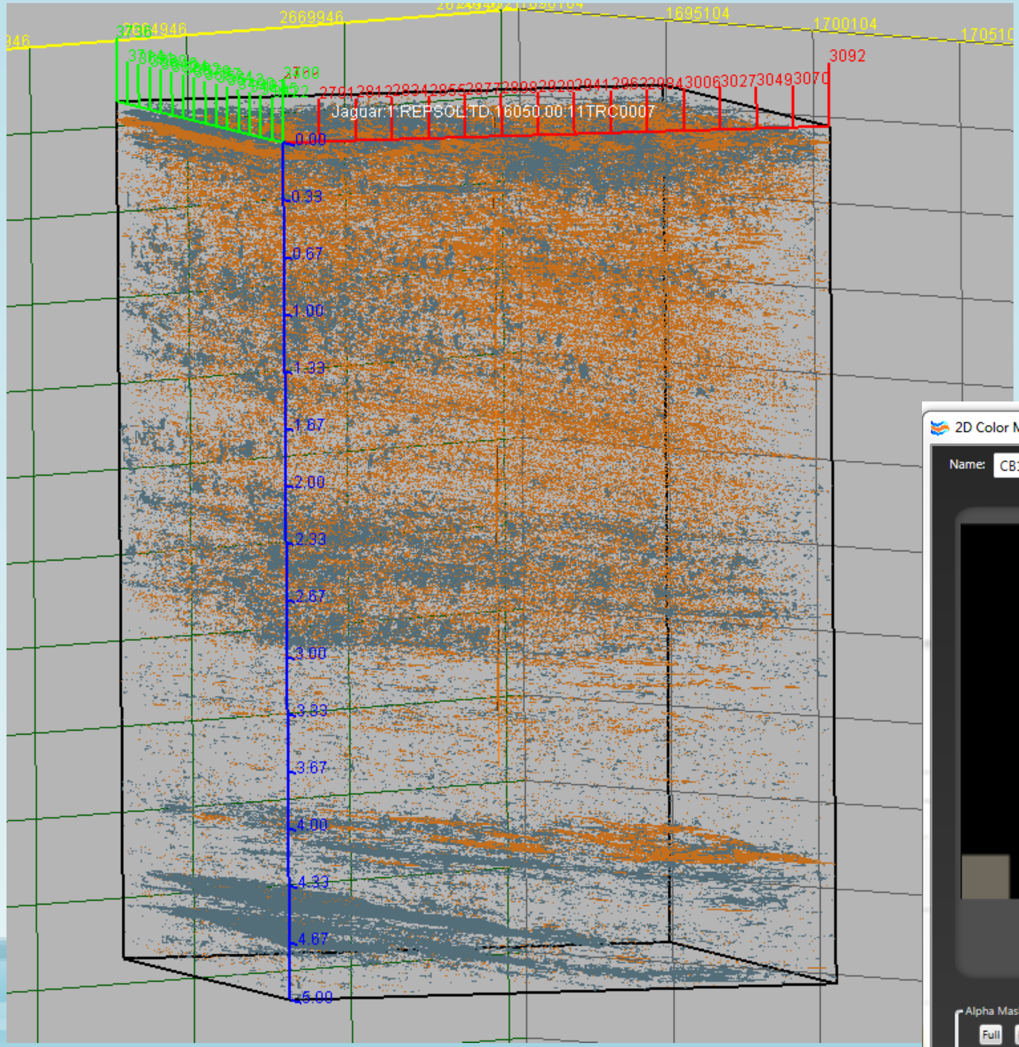


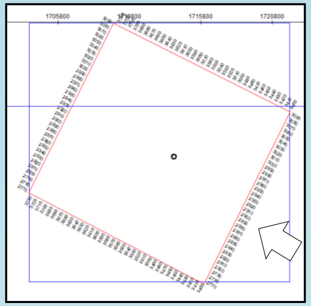
Very often, as on this seismic line, from the offshore Cameroon, the identification of the slope fans is mainly based on undulated or hummocky configuration of the seismic reflectors ("gull wings" of P. Vail), which is induced by the overbank deposits dipping in opposite directions.

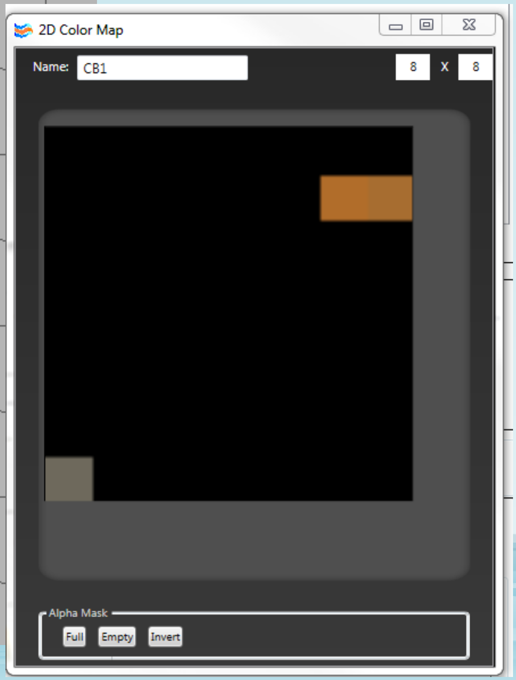
Seismic Attribute Set #2

#2
Dip Azimuth
Similarity Variance
Smoothed Similarity
Relative Acoustic Impedance
Imaginary Part
Envelope Slope

Classification Volume with #2 SOM







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Summary and Conclusions

- Unsupervised neural network analysis (SOM) employing specific sets of attributes can be used to reduce risk and identify solutions to problems within the seismic data.
- The more information used (wells, production, etc.) the better the solution can be tuned with targeted attribute selections.
- Neural analysis can be done on 2D data or 3D data
- **It is important to understand the functionality of the attributes one chooses for the neural analysis in order to understand the results**

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