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

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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


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

Deborah Sacrey and Rocky Roden
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
Objectives for using Seismic Attributes

- To take advantage of the seismic attribute analysis and today’s visualization technology, to mine pertinent geologic information from a huge amount of seismic data.

- The ultimate goal is to enable the geoscientist to produce a more accurate interpretation and reduce exploration and development risk.
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)
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**
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 *pore fluid and/or lithology*.

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

\[
RC(\theta) = A + B (\sin^2 \theta)
\]
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 $\times$ 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**.

## Methods

- 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
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)**

<table>
<thead>
<tr>
<th>Original Full Frequency</th>
<th>5 Hz</th>
<th>6.6 Hz</th>
<th>8.7 Hz</th>
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<td>26.2 Hz</td>
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<tr>
<th>11.4 Hz</th>
<th>15.1 Hz</th>
<th>19.9 Hz</th>
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<tbody>
<tr>
<td>35.5 Hz</td>
<td>45.5 Hz</td>
<td>60 Hz</td>
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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 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**
- Fractures
- Folds
- Faults

**Curvature Basics**

**2-D Curvature**

- Principal Curvature $K_1 = \text{Maximum Curvature}$
- Principal Curvature $K_2 = \text{Minimum Curvature}$
- Gaussian Curvature $= K_1 \times K_2$

Abele and Roden, 2012
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?
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

How many clusters do you expect?
Red

Orange

Blue
Search for Outliers

Drill here!
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.
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 **classify** data samples into categories based on their properties
- Properties may be of a geological or geophysical nature.
- 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

Neural networks address the Big Data problem
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
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

Well with few shows, mechanical problems – no production

Well with good shows, mechanical problems – minimal production
Arbitrary Line through well

Top Eagle Ford Shale
Top Buda
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

Time slice through Eagle Ford
SOM Details for Buda

<table>
<thead>
<tr>
<th>Metric</th>
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<tbody>
<tr>
<td>Average Energy</td>
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<tr>
<td>Dip Variance</td>
</tr>
<tr>
<td>Final Density</td>
</tr>
<tr>
<td>PSTM (Amplitude volume)</td>
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<tr>
<td>Poissons_Brittleness</td>
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<tr>
<td>Relative Acoustic Impedance</td>
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<tr>
<td>S_Impedance</td>
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<tr>
<td>Sweetness</td>
</tr>
<tr>
<td>Instantaneous Frequency</td>
</tr>
<tr>
<td>Envelope</td>
</tr>
</tbody>
</table>

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

Well with excellent shows, lost circulation, had to set liner, finally completed partial section flowing naturally at 300 BOPD, after 6 months is still producing 125 BOPD naturally.

No Shows

Did not penetrate Buda

Buda Sweet Spot
Conventional Type 2 AVO Yegua – thin pay

Seismic Attributes Employed for SOM Analysis

- **Far – Near**
  - Near = 0°-15°
  - Far = 31°-45°

- **(Far – Near) Far**

- **Gradient(B)**

- **Intercept(A) X Gradient(B)**

- **½ (Intercept + Gradient)**

- **Poisson’s Reflectivity(PR)**

- **Shuey 3 Term Approximation**
  \[ RC(\theta) = A + B \sin^2 \theta + C (\sin^2 \theta \tan^2 \theta) \]

- **Verm & Hilterman Approximation**
  \[ RC(\theta) = NIp \cos^2 \theta + PR \sin^2 \theta \]
Inline through well – amplitude data

Top Yegua Sand
Conventional PSTM Amplitude Map

Approximately 70 acres
SOM Classification – Base of Yegua Pay

- Slight horizon change NW of fault
- Drainage area now about 400 acres which supports engineering/pressure data
SOM Classification Inline

Slight horizon change NW of fault

SOM Classification Yegua 3 Base
2nd Successful Yegua well updip

SOM Classification

Arbitrary Line ~ NS

SOM Classification Yegua 3 Base

slight horizon change NW of red fault
Volume rendering visualization of specific neurons
<table>
<thead>
<tr>
<th>Attributes for Attenuation</th>
<th>Attributes for Flat Spots</th>
<th>Ten Attributes-HCI</th>
</tr>
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<tbody>
<tr>
<td>1) Final Raw Migration</td>
<td>1) Final Raw Migration</td>
<td>1) Final Raw Migration</td>
</tr>
<tr>
<td>2) Instantaneous Q</td>
<td>2) Instantaneous Frequency</td>
<td>2) Instantaneous Frequency</td>
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<tr>
<td>3) Envelope</td>
<td>3) Instantaneous Phase</td>
<td>3) Attenuation</td>
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<tr>
<td>4) Attenuation</td>
<td>4) Normalized Amplitude</td>
<td>4) Average Energy</td>
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<tr>
<td>5) Sweetness</td>
<td>5) Phase Breaks</td>
<td>5) Dominant Frequency</td>
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<tr>
<td></td>
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<td>6) Env. Time Derivative</td>
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<td></td>
<td></td>
<td>7) Rel. Acoustic Impedance</td>
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<tr>
<td></td>
<td></td>
<td>8) SD Env. Sub-band 33.5 Hz</td>
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<tr>
<td></td>
<td></td>
<td>9) Envelope</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10) Sweetness</td>
</tr>
</tbody>
</table>
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
Attributes for Flat Spots
1) Final Raw Migration
2) Instantaneous Frequency
3) Instantaneous Phase
4) Normalized Amplitude
5) Phase Breaks
Attenuation Attributes – Classification Display

Attributes for Attenuation
1) Final Raw Migration
2) Instantaneous Q
3) Envelope
4) Attenuation
5) Sweetness
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
Inline and Cross Line through well

Crossline (Dip)

- SW
- NE

Amplitude

Normalized Amplitude

Inline (Strike)

- NW
- SE

Amplitude

Normalized Amplitude

Crossline
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
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