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Seismic pattern recognition in shale resource plays

New computing techniques help identify sweet spots.

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Various approaches have been developed for workflows to exploit unconventional resource plays. For example, Slatt et al. (2008) describes a workflow that includes characterization of multiscale sedimentology and sequence stratigraphy, relating stratigraphy to log response, seismic response, petrophysical and geomechanical properties, and organic geochemistry. Newsham and Rushing (2001) tie together geology, petrophysics and reservoir engineering with geomechanics. Britt and Schoeffler (2009) describe a shale play in terms of mineralogy, rock mechanics and geomechanics and how these approaches can be used to optimally complete and fracture stimulate any unconventional reservoir.

The essential elements of unconventional shale resource plays are described as:

1. Reservoir geology: thickness, lateral extent, stratigraphy, mineralogy, porosity and permeability;
2. Geochemistry: total organic carbon, maturity and percentage of kerogen (richness);

FIGURE 1. PCA in the Paradise software displays highest eigenvalues for 3-D inlines in the upper portion with selected largest eigenvector (red); then all eigenvalues for the inline are shown in the lower left from largest (yellow) to smallest. The lower right portion shows the attributes and their proportion for the eigenvector corresponding to the largest eigenvalue. (Source: Geophysical Insights)

3. Geomechanics: acoustic impedance inversion, Young's modulus, Poisson's ratio (Vp/Vs) and pressures; and
4. Faults, fractures and stress regimes: coherency (similarity), curvature, fault volumes, velocity anisotropy (azimuthal distribution) and stress maps.

There is, of course, overlap in these various categories, and how these various elements are interrelated also depends on the objective, which might be to define sweet spots to drill, optimize drilling locations, define completion operations or even determine economic viability.

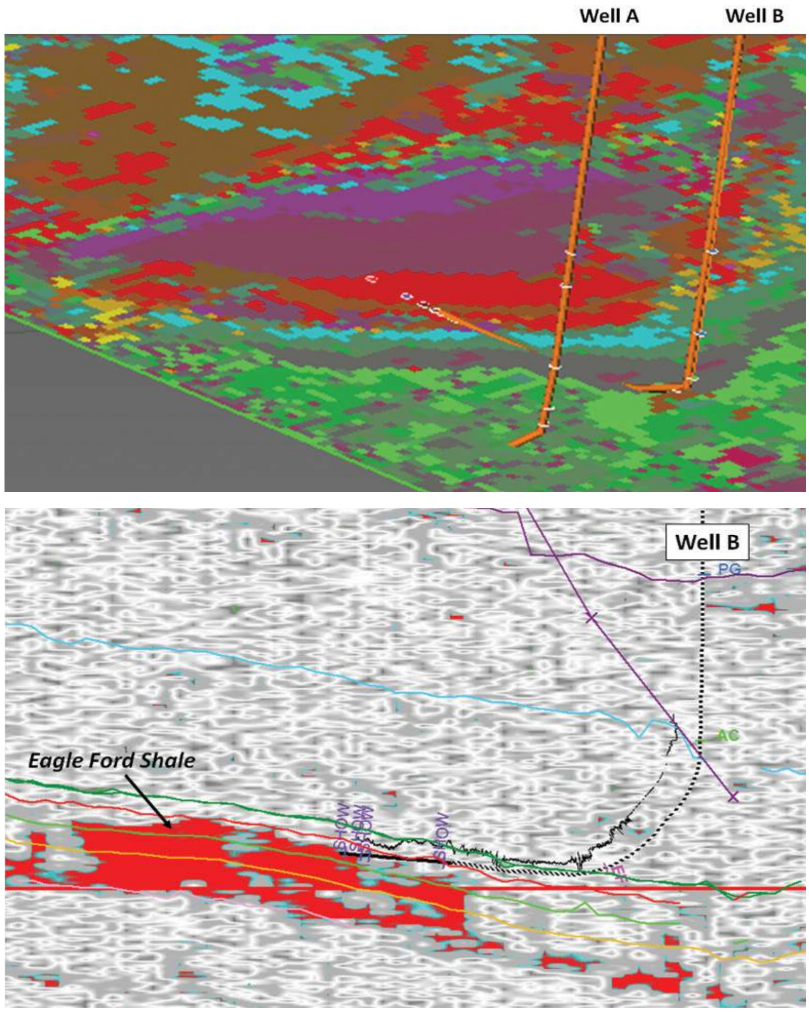

FIGURE 2. (Top) SOM classification from the Paradise software shows the Eagle Ford interval displaying dry hole Well A and good Well B; (bottom) vertical seismic display through Well B indicates shows as the well entered the Eagle Ford interval. (Source: Geophysical Insights)

Seismic attributes

In shale resource plays, conventional seismic data are one of the few tools geoscientists have at their disposal to interpret regional trends and guide locations and orientation of infill wells. In shale resource plays the interpretation of seismic data can be quite challenging because of resolution issues and anisotropy, and even though shales make up 70% of sediments, knowledge of shales as reservoirs is limited. Seismic attributes are often generated to help interpret the seismic properties of shale resource plays, which, of course, are a valuable guide to understanding the geology. Seismic attributes such as amplitude, dip, frequency, phase and polarity are measurable properties of seismic data. Attributes can be measured at one instant in time/depth or over a time/depth window and may be measured on a single trace, on a set of traces or on a surface interpreted from seismic data. Seismic attributes reveal features, relationships and patterns in the seismic data that otherwise might not be noticed (Chopra and Marfurt, 2007).

There are literally hundreds of seismic attributes in dozens of categories. In shale resource plays some of the most commonly employed seismic attributes are listed in Table 1. Often in shale resource plays seismic attributes are calibrated with well logs, microseismic results, production data and completion information.

SOMs

The next level of interpretation requires pattern recognition and classification of subtle information embedded in the seismic attributes. Taking advantage of today's computing technology, visualization techniques and understanding of appropriate parameters, self-organizing maps (SOMs, Kohonen, 2001) efficiently distill multiple seismic attributes into classification and probability volumes (Smith and Taner, 2010). SOM is a powerful nonlinear cluster analysis and pattern recognition approach that helps interpreters identify patterns in their data that can relate to desired geologic characteristics as listed in Table 1. Seismic data contain huge amounts of data samples and are highly continuous, greatly redundant and significantly noisy (Coleou et al., 2003).

The tremendous amount of samples from numerous seismic attributes exhibit significant organizational structure in the midst of noise (Taner, Treitel and

Smith, 2009). SOM analysis identifies these natural organizational structures in the form of clusters. These clusters reveal significant information about the classification structure of natural groups that is difficult to view any other way.

Principal component analysis

The first step in a seismic multiattribute analysis is to determine which seismic attributes to select for the SOM. Interpreters familiar with seismic attributes and what they reveal in their geologic setting may select a group of attributes and run a SOM. If it is unclear which attributes to select, a principal component analysis (PCA) may be beneficial. PCA is a linear mathematical technique to reduce a large set of variables (seismic attributes) to a small set that still contains most of the variation in the large set, in other words, to find the most meaningful seismic attributes. Figure 1 displays a PCA analysis where the blue histograms on top show the highest eigenvalues for every inline in that seismic survey. An eigenvalue is the value showing how much variance there is in its associated eigenvector, and an eigenvector is the direction showing the spread in the data. An interpreter is looking for what seismic attributes make up the highest eigenvalues to determine appropriate seismic attributes to input into a SOM run.

The selected eigenvalue (in red) on the top of Figure 1 is expanded by showing all eigenvalues (largest to smallest left to right) on the lower leftmost portion of the figure. Seismic attributes for the largest eigenvector show their contribution to the largest variance in the data. In this example S impedance, MuRho and Young's brittleness make up more than 95% of the highest eigenvalue. This suggests that these three attributes show significant variance in the overall set of nine attributes employed in this PCA analysis and may be important attributes to employ in a SOM analysis. Several highest ranking attributes of the highest and perhaps the second-highest eigenvalues are evaluated to determine the consistency in the seismic attributes contributing to the PCA. This process enables the interpreter to determine appropriate seismic attributes for the SOM evaluation.

Eagle Ford Shale evaluation

Once a set or perhaps several sets of seismic attributes are selected, these sets of seismic attributes are input into separate SOM analyses. The SOM setup allows the interpreter to select the number of clusters, window size and various training parameters for a SOM evaluation. Figure 2 displays the classification results from an evaluation of the Eagle Ford Shale. The seismic attributes employed in the SOM analysis are a combination of attributes from prestack simultaneous inversion, instantaneous attributes and a curvature attribute. The westernmost well A had few shows and no production in the Eagle Ford interval. Well B to the east was drilled into a cluster identified from the SOM analysis as the region in red. This well encountered good shows in the Eagle Ford. The vertical seismic display through Well B in Figure 2 shows how the well encountered good shows as it entered into the Eagle Ford interval. Therefore, the cluster associated with the red areas in Figure 2 is defining apparent sweet spots or optimal productive zones in the Eagle Ford.

The application of PCA can help interpreters identify seismic attributes that show the most variance in the data for a given geologic setting and help determine which attributes to use in a multiattribute analysis using SOMs. Applying current computing technology, visualization techniques and understanding of appropriate parameters for PCA and SOM enables interpreters to take multiple seismic attributes and identify the natural organizational patterns in the data. E&P

References available.

CATEGORY	TYPE	INTERPRETIVE USE
Geometric Attributes	Coherency/Similarity, Curvature	Faults, Fractures, Folds, Anisotropy, Regional Stress Fields
AVO and Seismic Inversion	Poisson's Ratio, Young's Modulus, Lambda Rho, Mu Rho	Brittleness, TOC, Porosity
Instantaneous Attributes	Reflection Strength, Instantaneous Phase, and Instantaneous Frequency	Lithology Contrasts, Bedding Continuity and Thickness
Amplitude Accentuating Attributes	RMS Amplitude, Relative Acoustic Impedance, Sweetness, Average Energy	Porosity, Stratigraphic and Lithologic Variations
Spectral Decomposition	Continuous Wavelet Transform, Matching Pursuit	Layer Thicknesses, Stratigraphic Variations

TABLE 1. These are typical seismic attribute categories and types employed in shale resource plays and their associated interpretive uses. (Source: Geophysical Insights)


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