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Maximize the potential of seismic data in shale exploration and production – Examples from the Barnett shale and the Eagle Ford shale

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Summary

To improve the success rate in shale plays we must drill with knowledge and a correct understanding of targeted shale formation. Seismic data provides valuable information related to geology, rock mechanical properties and in-situ stress. Properly processed, imaged and analyzed the seismic data becomes an important source of information facilitating the decision making processes such as sweet spot identification, fracturing stimulation and completion design. A full azimuth depth domain imaging technique has been implemented that recovers the true subsurface azimuth, thereby providing a foundation for accurate estimation of in-situ stress and its orientation through anisotropic velocity analysis and azimuthal AVO technique. Geomechanical property generation requires input of reflection angle data to initially invert for P and S wave impedances. Poisson's ratio and Young's modulus (*Rho) are calculated and analyzed to yield a 3D distribution of shale brittleness. Varieties of seismic attributes such as structural attributes, trace shape (facies) attribute and frequency dependent attribute contribute to the understanding of the shale formation in term of structural style and features (faults and Karst), changes in rock properties and thickness.

Introduction

Today the shale plays represent sources of opportunity for oil and gas companies and the global oil and gas economy. The major challenge for shale reservoir exploration and production is to increase profitability by increasing drilling, stimulation and completion success and reducing cost. To do so we must drill at the targets favorable in fluid content, in-situ stress and rock properties.

Seismic data carries information on stress and rock properties and provides much needed information to support sweet spot identification, fracturing stimulation and completion design.

This paper focuses on how the current technologies can be applied to shale plays to determine fracture/stress intensity and orientation; to estimation shale brittle/ductile quality and to map shale spatial distribution, seismic scale discontinuity and its heterogeneity using the examples from the Barnett shale and the Eagle Ford shale.

In-Situ Stress

Seismic data responds to stress. This can be observed as the azimuthal dependent behavior of the seismic amplitude and the seismic velocity. Proper analysis of the azimuthal behavior of the seismic data requires preservation of continuous and in-situ azimuth sampling in depth. To preserve true sub-surface azimuth, we adopt a technology which decomposes and images the seismic data into full azimuth reflection angle gathers and full azimuth directional angle gathers. Full azimuth reflection angle gathers carry rich reflectivity information ideally suited for velocity anisotropy and azimuthal AVA determinations.

The AVAZ approach measures the changes in amplitude variation with reflection angle and azimuth affected by the anisotropic media. Horizontal transverse isotropic (HTI) media is assumed for the Eagle

Ford shale as the formation is preferentially stressed. The Eagle Ford shale layer is relatively flat and the structural change is mild in the study area. Typical AVAZ attributes created by the HTI AVAZ inversion include anisotropic gradient, stress intensity and azimuth of symmetry axis. Interpretation and visualization techniques are critical to extract and map the stress intensity and its orientation. Figure 1 is a co-visualization of stress intensity and curvature map with stress vector superimposed for the Eagle Ford Shale interval.

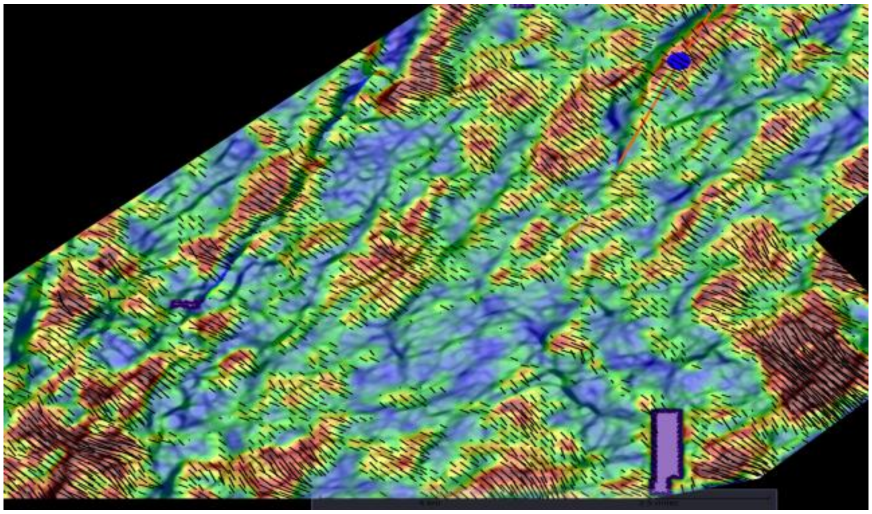

Figure 1: Co-Visualization of stress intensity and curvature map with stress vector superimposed. An Eagle Ford shale example

Velocity anisotropy is a classical seismic response to fracture or stress. In a horizontal transverse isotropic media, the effective fast velocity direction is observed along the fracture plane (the maximum horizontal stress direction) and the slow velocity direction is observed perpendicular to this direction. An expression of the velocity anisotropy is illustrated in Figure 2 which shows a full azimuth gather at a constant 25 degree (opening) reflection angle with 0 to 180 degree azimuthal sampling. The second strong positive event is the reflection between the Barnett shale and the underling Ellenburger limestone. If the formation did not exhibit an and azimuthal velocity dependency, the event would be flat cross the azimuth. The reflection event over the azimuth range from 40 to 75 degrees appears to have a larger traveltime than the rest of the reflection events and corresponds to the slow velocity orientation. Visualization of continuous azimuth angle gathers further confirms the observation (Figure 3). This display shows the reflection amplitude for all angles and azimuths at a single common reflection point in 3D. The mirror effect of azimuthal dependent behavior is clear when the data is displayed in 360 degree azimuth. Velocity inversion is carried out over all of the full azimuth gathers to automate the determination of stress orientation and intensity for every full azimuth gather in the study area.

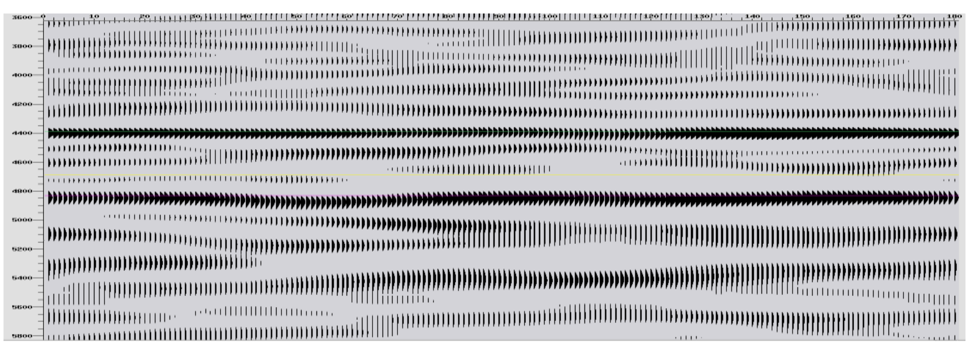

Figure 2: Two dimensional representation of a Full azimuth reflection angle gather at a constant 25 degree (opening) reflection angle

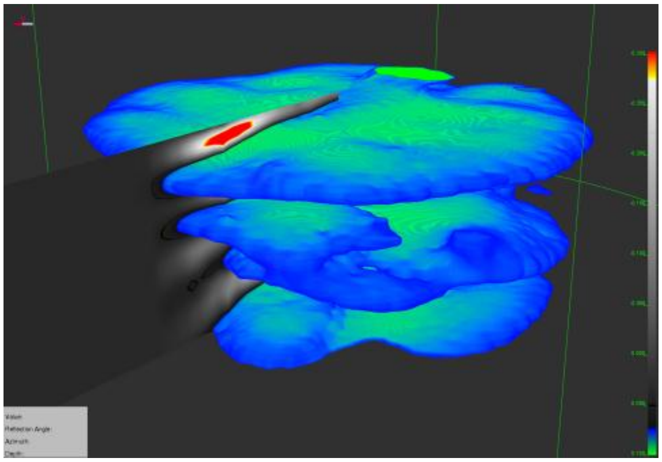

Figure 3: Full azimuth reflection angle gather

Shale Brittle/Ductile Spatial Distribution

The shale brittle/ductile quality can be estimated using the mechanical attributes such as Poisson's ratio and Young's modulus. Relatively, low Poisson's ratio and high Young's modulus correlate to brittle shale zones and high Poisson's ratio and low Young's modulus correlate with ductile shale zones. Prestack seismic inversion incorporates seismic data and well data in the inversion process and generates P and S impedances simultaneously and further Poisson's ratio Young's modulus (*Rho) can be estimated. Figure 4 shows relative high brittle shale distribution in an Eagle Ford area. Such information is not only important in the process of sweet spot identification but also in estimating fracability and the relative fracture width and barriers.

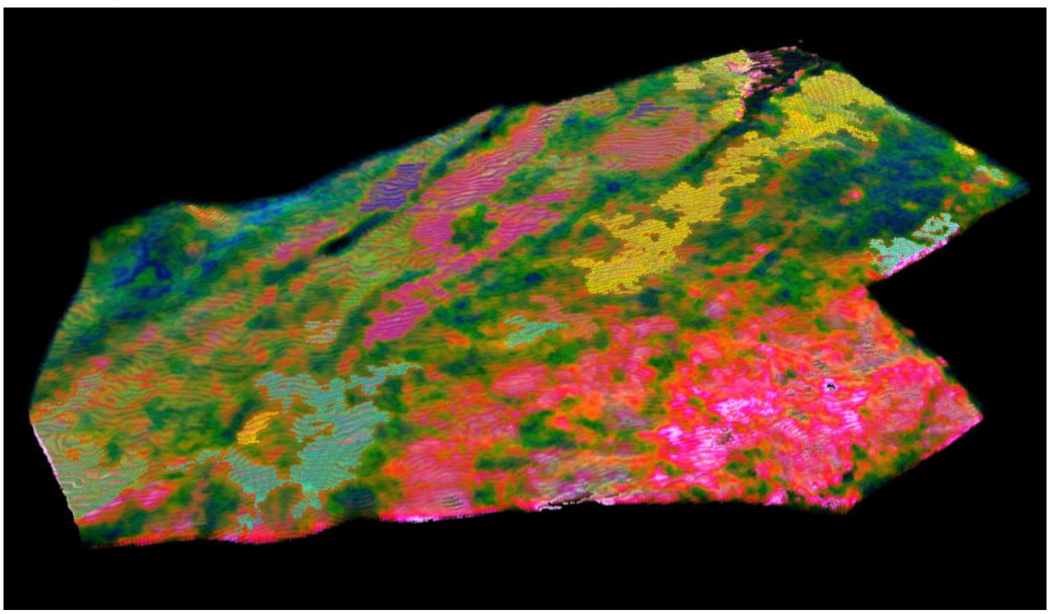

Figure 4: Relative brittleness spatial distribution through seismic inversion

Shale Heterogeneity

Shales are not created equally, therefore successful shale reservoir exploration and development requires an understanding of shale heterogeneity. Seismic data samples changes in lithology, fluid, mineral composition and thickness etc. Geophysical technology advancement provides opportunities to generate varieties of seismic attributes from which insights on the studied shale formation can be developed. Structural attributes such as curvature and coherence attributes are used to delineate seismic scale discontinuities such as Karst (Barnett Shale Study) and faults. Organized classification attributes based on trace shape similarity, for example, are useful in detecting changes in facies, lithology, and rock properties. Physical attributes like spectral decomposition sample seismic instantaneous energy variations with frequency and can be useful in evaluating thin bed effects, like tuning. Shown in Figure 5 is an overlay of the curvature and facies attributes along the Eagle Ford interval. The color represents different trace shape (facies). The background discontinuity is the curvature attribute. Co-visualization of structural and stratigraphic attributes reveals the following observations: 1) there are a few dominant faults trending North-East to South-west and one of the wells was drilled in a fault; 2) some of the faults appear to be boundaries of facies; 3) trace shape varies in the shale interval indicating the shale's compositional, depositional, and structural heterogeneity.

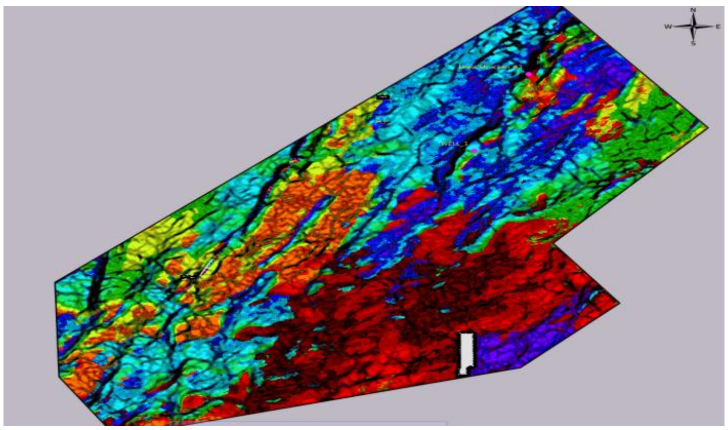

Figure 5: Co-visualization of Curvature and Seismic Facies

Conclusions

Seismic data carries valuable information much needed for the process of sweet spot identification, fracturing stimulation and completion design in the shale play exploration and production. Geophysical technologies are available to ensure the seismic data is properly processed and imaged and suitable for the purposes of in-situ stress estimation and rock property delineation. Velocity anisotropy and AVAZ in a HTI media provides estimation on the differential horizontal stress and its orientation. Prestack inversion incorporating seismic data and well data generate rock mechanical properties which are further used to estimate shale brittleness spatial distribution. Varieties of seismic attributes such as structural attributes, trace shape (facies) attribute and frequency dependent attribute contribute to the understanding of the shale formation in term of structural style and features (faults and Karst), changes in rock properties and thickness.

Acknowledgements

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