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Seismic inversion leading structural attribute computation for a lower Triassic slitstone reservoir, Montney Formation, NE British Columbia, Canada.

Ayon K. Dey
Sasol Canada E&P Ltd.

Summary

This work demonstrates a modern workflow that extracts high-resolution discontinuities from a seismic inversion based structural attribute. The workflow is successfully applied to an asset in the Farrell Creek area of NE British Columbia to extract a set of 3D discontinuities that are orthogonal to the primary stress direction.

Introduction

The principal objective is to provide the asset team with a rapid and independent view of the discontinuity network over a productive Montney section in the Farrell Creek area of NE British Columbia (see Figure 1). A critical business driver for this work is to have available an updated discontinuity framework for integrated production, reserves, and drill target analysis. This is a prerequisite step within Sasol Canada's iterative heat maps workflow and impacts base business.

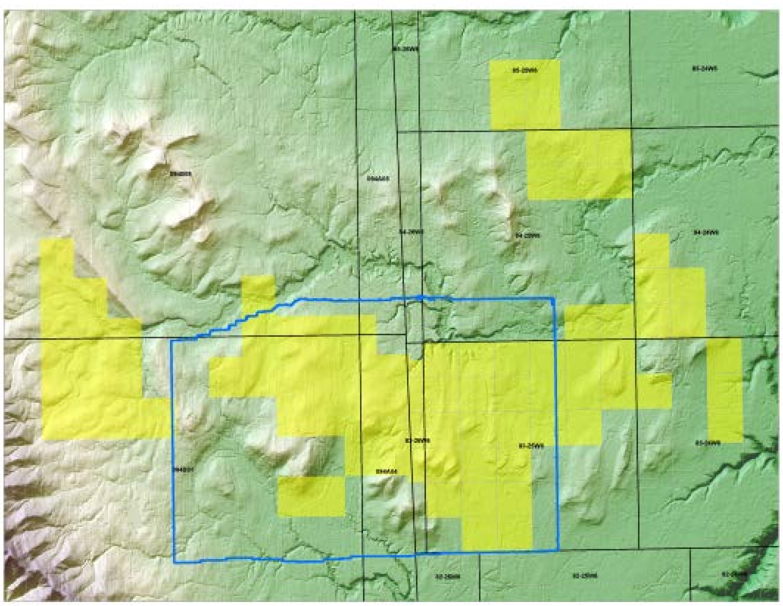

Figure 1: Acreage map highlighting the seismic coverage over the Farrell Creek area analysed.

There had not been an independent assessment of discontinuities over the area shown in Figure 1. Legacy discontinuities were being used by the asset. Unfortunately, the associated interpretation from which these were produced is not available. This being the case, a revised discontinuity framework is required and a workflow was developed to address this need. As a result, an initial data-driven set of discontinuities that are orthogonal to the primary stress direction now exist as a foundation for seismic structural characterisation.

Theory and Method

The many ray-parameter convolutional seismic data model for the compressional-to-compressional wave mode (Robinson and Treitel, 2000; Aki and Richards, 2002) forms the basis of this study. In matrix-vector form, it is represented as:

$$\mathbf{d}^{\mathrm{PP}}=\mathbf{W}^{\mathrm{PP}}\mathbf{K}^{\mathrm{PP}}\mathbf{x}=\begin{bmatrix}\mathbf{W}_1^{\mathrm{PP}} & \cdots & 0\\ \vdots & \ddots & \vdots\\ 0 & \cdots & \mathbf{W}_{\mathrm{np}}^{\mathrm{PP}}\end{bmatrix}\begin{bmatrix}\mathbf{A}_1 & \mathbf{B}_1 & \mathbf{C}_1\\ \vdots & \vdots & \vdots\\ \mathbf{A}_{\mathrm{np}} & \mathbf{B}_{\mathrm{np}} & \mathbf{C}_{\mathrm{np}}\end{bmatrix}\begin{bmatrix}\frac{1}{2}\Delta\ln\mathbf{Z}_{\mathrm{P}}\\ \frac{1}{2}\Delta\ln\mathbf{Z}_{\mathrm{S}}\\ \frac{1}{2}\Delta\ln\boldsymbol{\rho}\end{bmatrix};$$

where $\mathbf{W}^{\mathrm{PP}}$ is a block diagonal matrix with Toeplitz convolution matrices along the diagonal containing ray-parameter dependent imaged source wavelets, $\mathbf{K}^{\mathrm{PP}}$ is a matrix with diagonal submatrices $\mathbf{A}$, $\mathbf{B}$, and $\mathbf{C}$ that account for the wavefield kinematics in a layered earth (Dey and Gisolf, 2007), and $\mathbf{x}$ is vector of differential rock properties for the acoustic impedance, shear impedance and density (Debski and Tarantola, 1995). Using this as the forward data model for regularised ℓ_2-inversion (Menke, 1989; Tarantola, 2005) delivers optimal input for computing various structural attributes (Chopra and Marfurt, 2007). These attributes will have source, wavefield propagation, and random noise effects minimised. Figure 2 shows a block diagram capturing the workflow employed to exploit this concept.

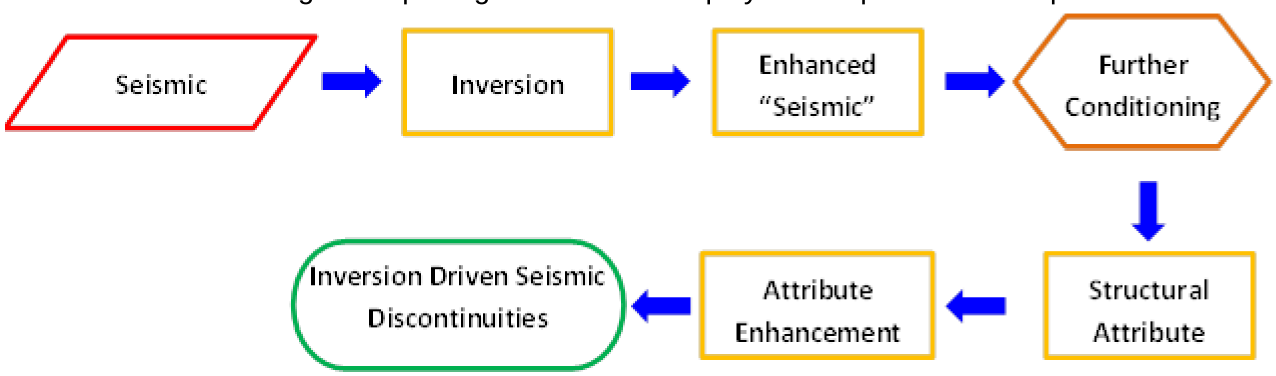

Figure 2: Seismic data-driven fault extraction workflow.

Examples

Figure 3 illustrates the "front-end" process for the computation of a higher fidelity and higher resolution structural attribute. The final processed seismic (a bandlimited interface property, shown in Figures 3A and 3D) is transformed to compressional (P-wave) impedance (a layer-based bandwidth enhanced rock property, Z_p, shown in Figures 3B and 3E) by simultaneously integrating well-log information and minimising wavelet and kinematic effects; as well as optimally supressing random noise. Its time/depth/vertical-domain derivative yields the compressional-to-compressional mode reflectivity (i.e. the P-wave reflectivity, R_{pp}). This is the base data from which the structural attribute is computed since it is richer in information than the full-offset stack.

Although the reflectivity is the optimal starting point for structural analysis, it can be improved further by geological preconditioning. This is achieved via small window median filtering along structural dip in good signal-to-noise ratio (S/R) areas and diffusion filtering in areas with a poor signal-to-noise ratio. As a result, the reflectivity is cleaner with sharper boundaries or "edges" (compare Figures 4A and 4B). The pre-conditioned reflectivity yields the discontinuity attribute shown in Figure 4C and its enhancement for discontinuities orthogonal to the primary stress direction is seen in Figure 4D. This enhancement is achieved via stereonet-controlled directional steering of the discontinuity enhancement algorithm. Should image log or dip meter analysis be available, then stereonets can be built to enhance the extraction of specific structural elements observed via downhole analysis.

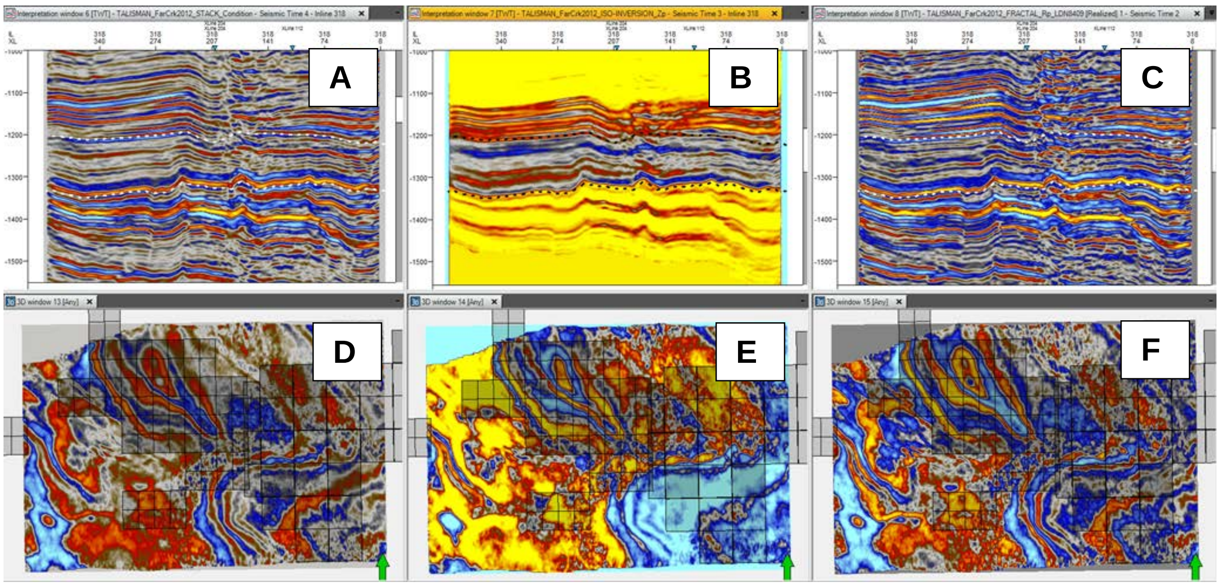

Figure 1: From seismic (A and D), through impedance (B and E), to reflectivity (C and F). Panels D, E, and F show time slices that are approximately half-way between the horizons shown in section view on the top row.

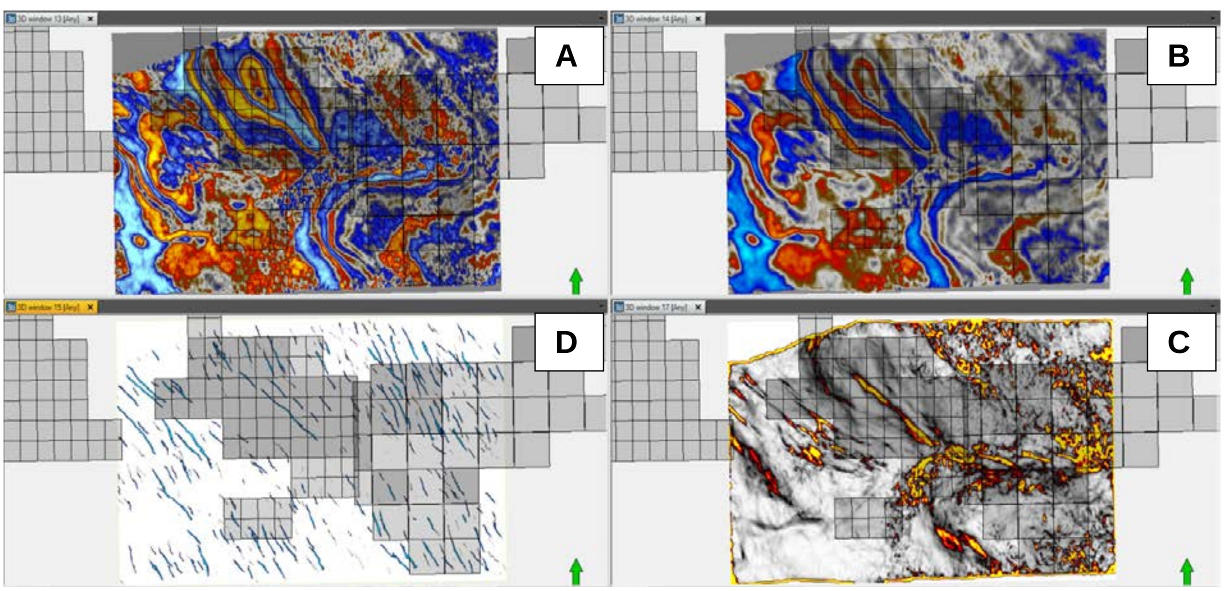

Figure 2: From reflectivity (A), through geological conditioning (B), to a higher resolution discontinuity attribute (C) and its enhancement via stereonet-tuned Ant Tracking© for discontinuities orthogonal to the primary SW-NE trending stress direction (D). Panels A through D show time slices that are at the same level as in Figure 3.

Displaying the discontinuity enhanced attribute in 3D orthogonal perspective with opacity set to highlight strong discontinuities allows the 1st-order lineaments to be visualised. These discontinuities are then extracted as geobodies. This allows for rapid prototyping of a structural framework and discontinuity model. The model is converted to an interpretation (Figure 5) that is analysed and extended as needed.

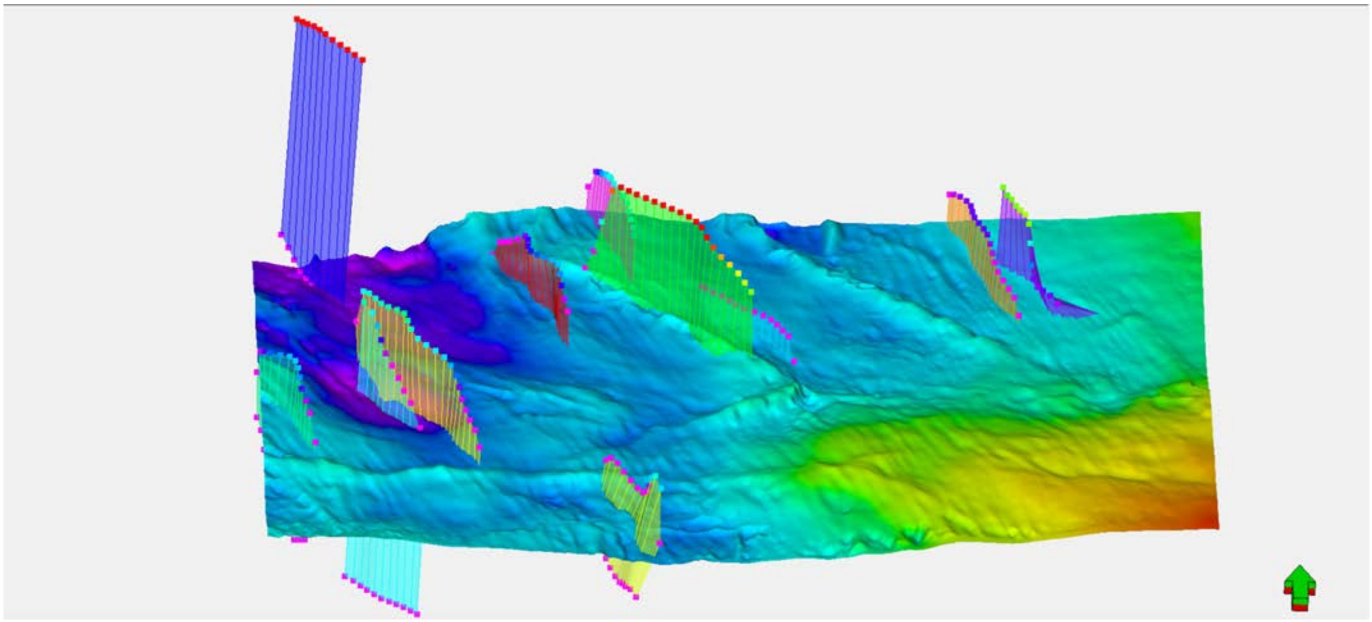

Figure 5: Data-driven discontinuity interpretation.

Conclusions

This work shows proof of concept that a data-driven approach to discontinuity characterisation is feasible. The discontinuities delivered via the proposed workflow are a first step and should be thought of as "seeds" for integrated structural characterisation. Moving forward will involve these seeds being analysed and extended by the interpreter's eye, then correlated to any downhole evidence of faulting or fracturing. Future work also involves investigating if other discontinuities (thrust, normal and/or strike-slip) can be initially characterised and extracted in the same manner.

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