Resolution of Seismic Attributes in Defining Fracture Systems

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Summary

Characterizing fractured reservoirs and in-situ stress induced anisotropy by using seismic techniques is of great interest in hydrocarbon exploration and production. The commonly used seismic methods include measuring azimuthal velocity variation, amplitude variation with incident angle and azimuth, and similarity between adjacent seismic traces. The resolution of these measurements is different. It is mainly determined by their relation to rock physical properties that they measure. We conducted a study on the resolution of azimuthal AVO, elastic rock property inversion, and coherence analysis. The results show that integration of the attributes from these methods produces an enhanced description of a fracture system.

Introduction

Several seismic methods can be used to describe the subsurface fracture systems. These methods include azimuthal velocity analysis, azimuthal AVO analysis, and the methods calculating the similarity between adjacent traces such as coherence analysis and the recently developed texture attribute analysis. It has been recognized that the seismic attributes obtained using these methods have different resolution with respect to a given fracture system. The resolution is decided by the physical rock properties reflected in the travel time, amplitude, and discontinuity of seismic signals. Azimuthal velocity analysis produces low frequency component of velocity in the subsurface. Azimuthal AVO is based on seismic reflections and thus has a resolution within seismic bandwidth. The methods for adjacent trace similarity have high resolution to large scale discontinuities. Notice that the physical rock properties obtained from the first two methods are effective rock properties. To explore these differences, we conducted azimuthal AVO processing, elastic rock property inversion and coherence analysis on a 3D from the Western Canadian Basin. In this paper, we present a comparison of these methods and demonstrate the benefit in integrating the seismic attributes to define fracture systems.

Attribute Analysis

In this study, three methods were used to generate seismic attributes for a 3D with a size of 6.25 km x 6.25 km. These methods are azimuthal AVO, elastic rock property inversion and coherence analysis. The azimuthal AVO technique assumes that the fractured reservoir is a horizontally transverse isotropic (HTI) medium. An amplitude surface is fitted to an azimuthal AVO response at a given time to solve for both the fracture orientation and fracture density. An ellipse can be then formed based on the intercept and gradients solved in two major axes. One of the major axes gives the direction of the fracture. The ratio of the axes - the eccentricity of the ellipse - provides

an estimation of the fracture density. Figure 1 shows the 3D and the horizons corresponding to the target interfaces. In this study, we focused on the top of the Wabamun limestone and the top of a shale layer in the deeper section. Figure 2 shows an example of the input gather, the CMP gather reconstructed by using the intercept and gradients that were solved in azimuthal AVO processing, and their difference. Notice that the traces in the gathers were sorted based on offset.
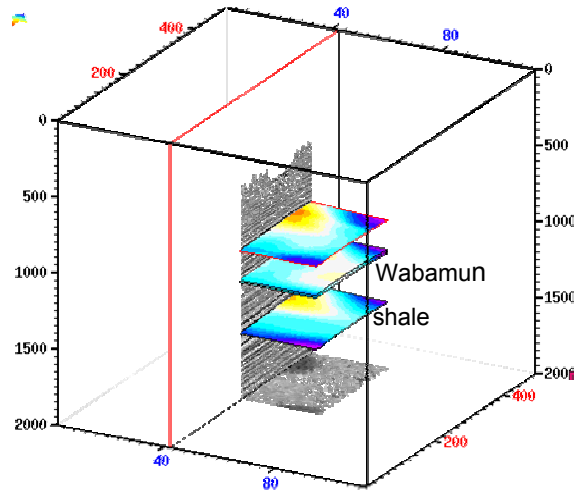

Figure 1. PSTM stacked volume and the horizons of the studied formations.
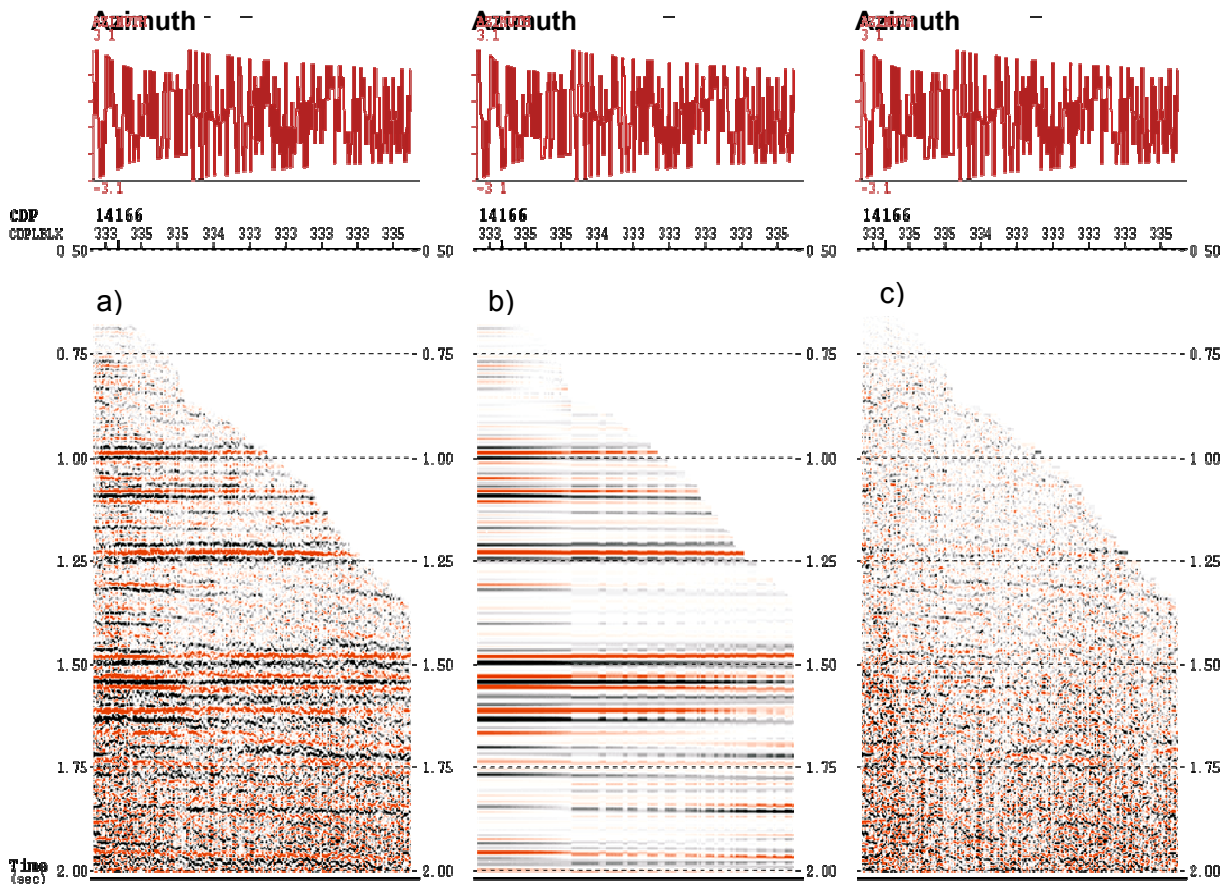

Figure 2. CMP gathers in azimuthal AVO processing: a) input gather, b) reconstructed gather using intercept and gradients, and c) the difference between a) and b).
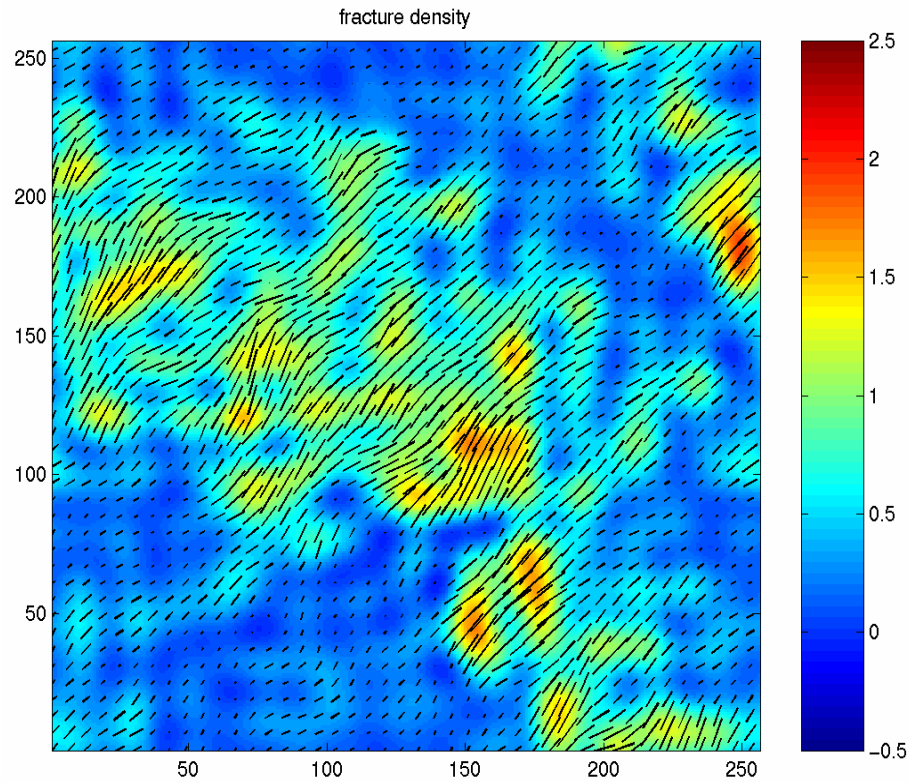
Figure 3. Fracture orientations and density across the top of Wabamun limestone.
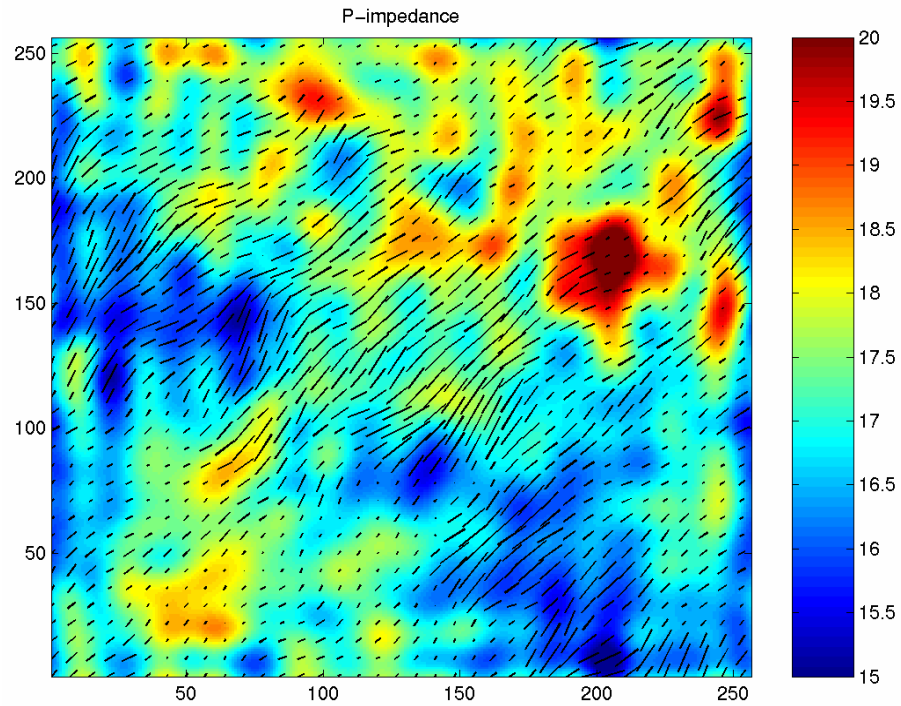

Figure 4. Fracture orientations and density overlying impedances

In the azimuthal AVO processing, the intercept and maximum and minimum gradients were produced. We derived S-reflectivity using the intercept and the maximum gradient. We then conducted P- and S-impedance inversion and calculated the Vp/Vs ratio as well as porosity based on an empirical relation. Figure 3 shows the fracture orientations and density across the top of the Wabamun limestone. We see that there is a major fracture area in the middle of the 3D with the fracture orientations aligned in the northeast-southwest direction. Figure 4 shows an example of

integrating azimuthal AVO attributes with impedance. It can be seen that low impedance corresponds to the fracture zones.
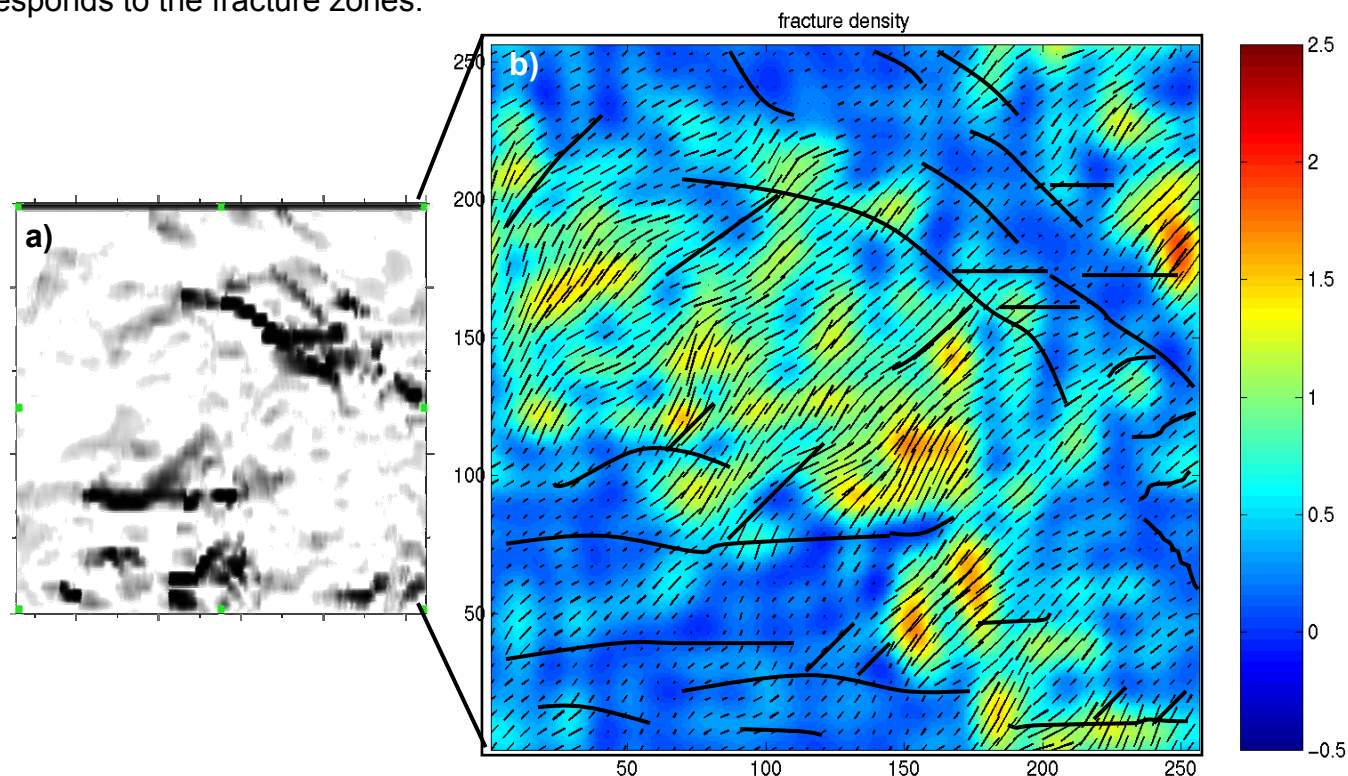

Figure 5. Integration of the attributes: a) coherence attribute, and b) interpreted major discontinuities from the coherence attribute overlying the fracture orientations and density from azimuthal AVO analysis.

In Figure 5b, we overlaid the interpreted discontinuities from the coherence attribute on the attributes of fracture orientation and fracture density. It is evident that coherence attribute provides additional information on the fracture system. The coherence attribute defines large scale discontinuities that control the fracture system defined by the azimuthal AVO attributes. In addition, there are two sets of the large discontinuities. One is in the same direction as the fracture orientations from azimuthal AVO, and the other is in the west-east direction in the South and the northwest-southeast direction in the North. We see that the combination of the azimuthal AVO attributes and the coherence attribute gives a more complete definition of the fracture system.

Conclusions

The seismic methods that are used to describe fracture systems have different resolution. Three of them, azimuthal AVO, elastic rock property inversion, and coherence analysis, have been performed on a 3D dataset. The results show that all these methods provide useful information in defining the fracture systems. The azimuthal AVO analysis gives detailed information on fracture orientations and density as well as the distribution of fracture system. Elastic rock property inversion confirms the azimuthal AVO analysis with low impedance corresponding to the fractured areas. Th coherence analysis defines the large scale discontinuities. The integration of the attributes from coherence and azimuthal AVO analysis enhances the description of the fracture system.