Seismic Fracture Detection in the Second White Speckled Shale: Anisotropic Perspectives on an Isotropic Workflow*

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Abstract

Direct methods for seismic fracture detection typically require an azimuthal analysis of the recorded wavefield. However, conventional data acquisition practices often provide insufficient azimuthal and offset coverage for proper application of azimuthal techniques. Therefore in most cases, alternative methods must be used for fracture detection.

This study investigates the ability of seismically derived isotropic properties in the delineation of fractures within the Second White Speckled Shale. Fracture systems with structural controls were identified through attributes that are sensitive to changes in the structure of the seismic image. Elastic properties were derived from the seismic measurements to determine the optimal conditions for fracture formation and the elastic response of fractures. In addition, travel-time anisotropy effects in shales were analyzed to determine its relationship to fracturing. The analysis yields a set of attributes that are sensitive to fractures and are used in the reduction of uncertainty for the delineation of the associated fracture systems.

Introduction

The Second White Speckled Shale (SWS) is an Upper Cretaceous marine mudstone deposited throughout the Alberta Basin. It is believed to be a regionally continuous hydrocarbon system serving as both a source and reservoir rock. Production from the SWS is attributed to preferential fracturing that creates sufficient room for storage and permeable pathways for fluid flow, providing the conditions for a self-sourcing hydrocarbon system. Exploration in the SWS therefore amounts to the detection of fractured zones within the formation.

Direct methods for the detection of fractures require an azimuthal analysis of the seismic wavefield, where the presence of aligned fractures introduce anisotropy in the medium and manifest as azimuthal variations in the seismic response. Reflection amplitudes can be inverted for fracture parameters (i.e. Downton and Roure, 2010), however the large number of parameters required for the description of anisotropic media requires sufficient azimuthal and offset sampling of the wavefield to provide a well-posed inverse problem. In most situations, the data requirements for inversion are not fulfilled and therefore inhibit the use of azimuthal analysis for fracture characterization. Alternative means for fracture detection are then necessary given the limitations in resource availability.

In this study, we investigate the ability of seismically derived parameters from an isotropic workflow in the delineation of fracture systems in the SWS. The study consists of a multi-attribute analysis which includes the use of a pattern recognition algorithm to identify fracture patterns from the seismic image, an inversion for elastic properties to determine the optimal conditions for fracturing based on failure criterions, the elastic response of fractures and an analysis of the travel-time anisotropy effects.

Fracture Detection

In this study, the expected fracture orientations in the SWS are classified by the stress regime under which it was formed. Throughout its stress history, the SWS experienced a thrust faulting stress regime during the compression of the basin and a strike-slip to normal faulting stress regime upon relaxation and additional deposition of post-Cretaceous sediments.

Since the thrust fractures are believed to be accompanied by structural deformation, seismic attributes that highlight structural changes were used to identify areas that are likely to be fractured. The Ant-Tracking workflow (Cox and Seitz, 2007) was chosen due to its ability to single out specific features in the seismic image, where filters can be applied to extract only desired orientations. Since the features of interest are thrust fractures, events that are oriented orthogonal to the direction of basin compression were tracked to provide an image that highlights the areas with an increased likelihood for thrust fractures to form. Figure 1 shows the results of the Ant-Tracking workflow.

The strike-slip and normal fractures are not believed to have formed in conjunction with structural changes. Therefore, the detection of these fractures was achieved through an investigation into the elastic properties that control failure. To determine the elastic properties, an amplitude variation with offset (AVO) inversion was performed to extract the P- and S-wave velocities and density. Subsequently, the constitutive relations were applied for the transformation to geomechanical properties that are important in fracture mechanics.

Various elastic properties were derived to determine the optimal conditions for fractures to form and the elastic response of fractures. Using the Coulomb failure criterion (Coulomb, 1773), uniaxial strain model and the Griffith crack propagation criterion (Griffith,1920), it can be shown that a material with a relative low in Poisson's ratio and Young's modulus represents a more favorable condition for fractures to form. Additionally, using an effective medium theory such as Hudson's penny shaped crack model (Hudson, 1981), it can be shown that the P-wave velocity decreases with an increasing crack (or fracture) density. Therefore, areas with a low value of the Poisson's ratio, Young's modulus and P-wave velocity represent an increased likelihood for fractures to be present.

In addition, the degree of VTI anisotropy can be used as an indicator for the likelihood of fracture formation. It can be shown that the disorder in the alignment of clay platelets leads to varying degrees of VTI anisotropy (Sayers, 1994). As the clay platelets become increasingly aligned, the VTI anisotropy also increases. The corresponding stresses due to loading then decrease with a decrease in the degree of VTI anisotropy, resulting in a more favorable condition for fractures to form. Therefore, the characteristic "curl up" of reflection events due to VTI anisotropy could be used to provide an additional attribute for fracture detection, where lower levels of VTI anisotropy (less negative moveout) represent an increased likelihood for fractures to form. Figure 2 shows the various attributes used to identify areas of increased likelihood for strike-slip or normal fractures to be present.

The above analysis provides possible responses due to the presence of fractures. However, the responses are non-unique and could be the result of phenomenon that has not been considered. Therefore, in reducing the uncertainty associated with the non-uniqueness issue, we can combine all the attributes to provide an image that represents areas that are most likely to be fractured. Figure 3 shows the multi-attribute map where threshold values were used to flag areas that fit a certain criteria for the strike-slip and normal fracture attributes. In addition, the Ant-Tracking results were overlaid for the identification of areas with an increased likelihood for thrust fractures to form. The red point indicates the location of a producing well within the survey and suggests that the proposed methodology was able to identify a zone where fractures are known to exist.

Conclusions

Fractures in the SWS were identified through a multi-attribute analysis which includes structural attributes extracted from the seismic image, elastic properties extracted through an AVO inversion process and travel-time anisotropy effects. The structural attributes identified areas with an increased likelihood for the formation of fractures related to a thrust faulting stress regime. The elastic properties identified areas that represent the optimal conditions for failure. In addition, the travel-time response was used to determine the degree of VTI anisotropy to identify areas that are more likely to be fractured.

In situations where the seismic data is not in the proper condition for azimuthal analysis, alternative means for fracture detection are possible. Additional information can be extracted from conventional isotropic seismic analysis techniques for the detection of subsurface fractures.

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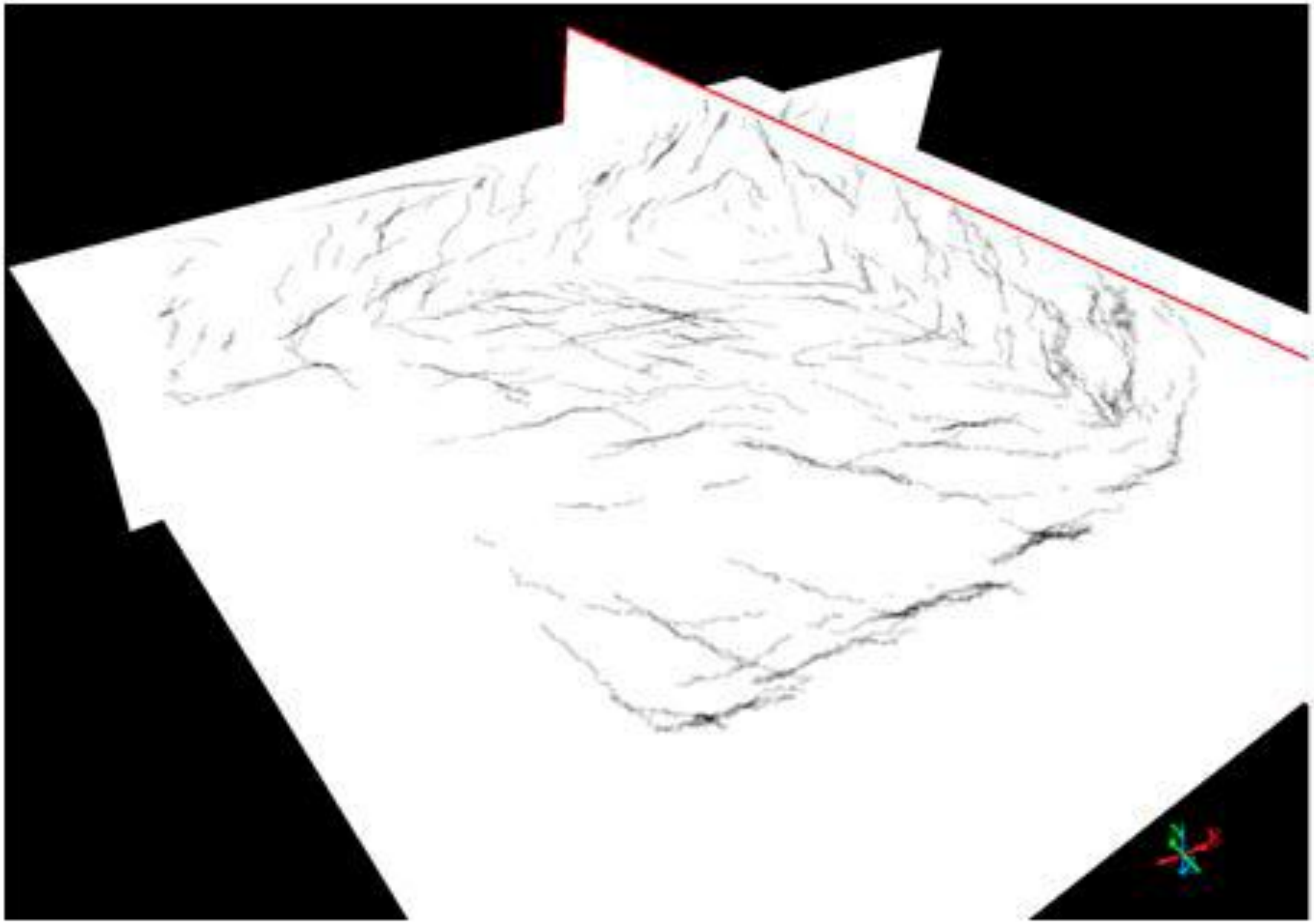

Figure 1. The Ant-Track image illustrating areas of increased likelihood for thrust fractures to form. The image shows an in-line, cross-line and time slice through the Ant-Track volume.

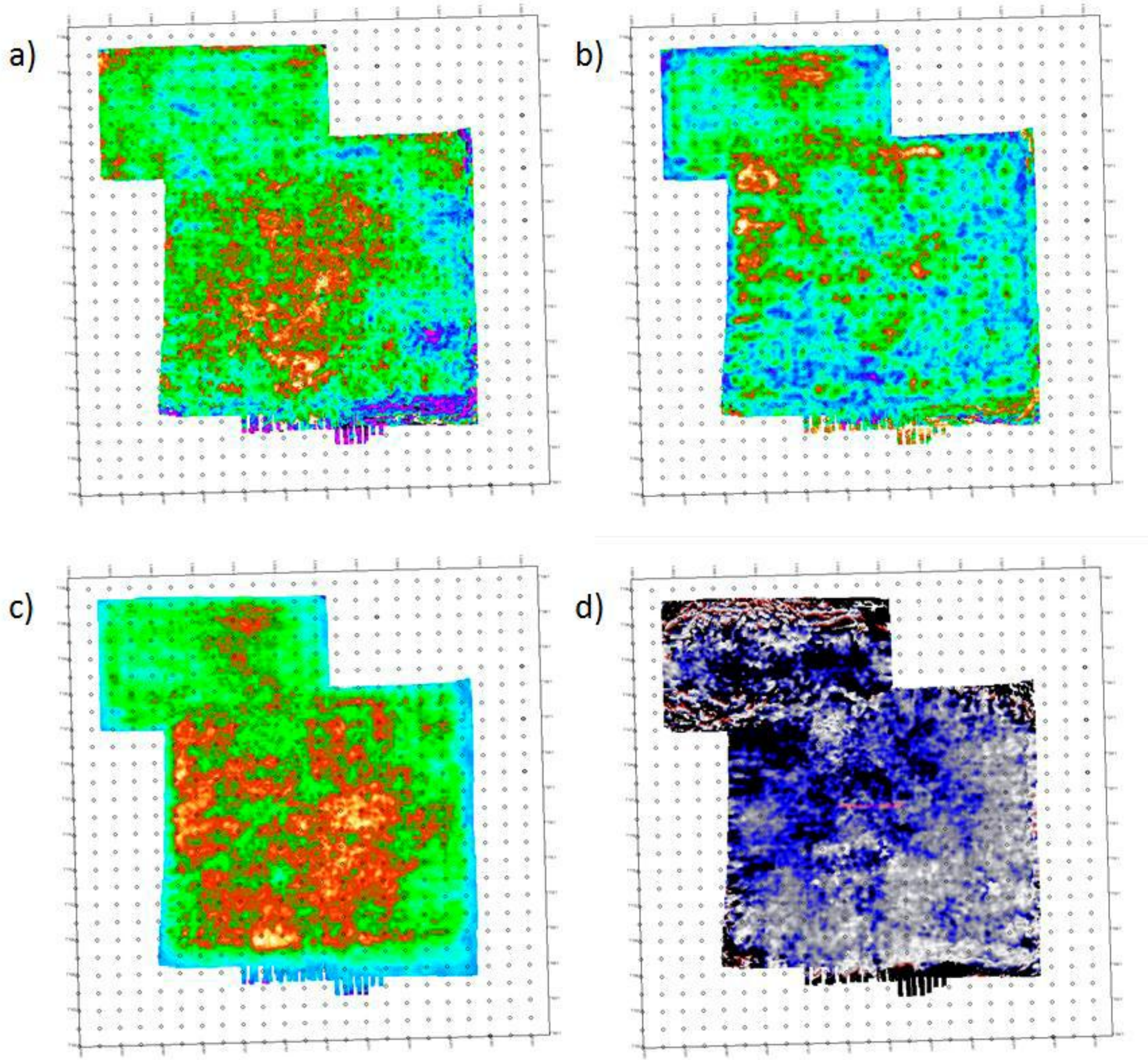

Figure 2. Attribute maps for (a) Poisson's ratio, (b) Young's modulus, (c) P-wave velocity, and (d) residual moveout. Hot colors represent low values for (a) to (c) and dark colors represent large residual moveout values for (d).

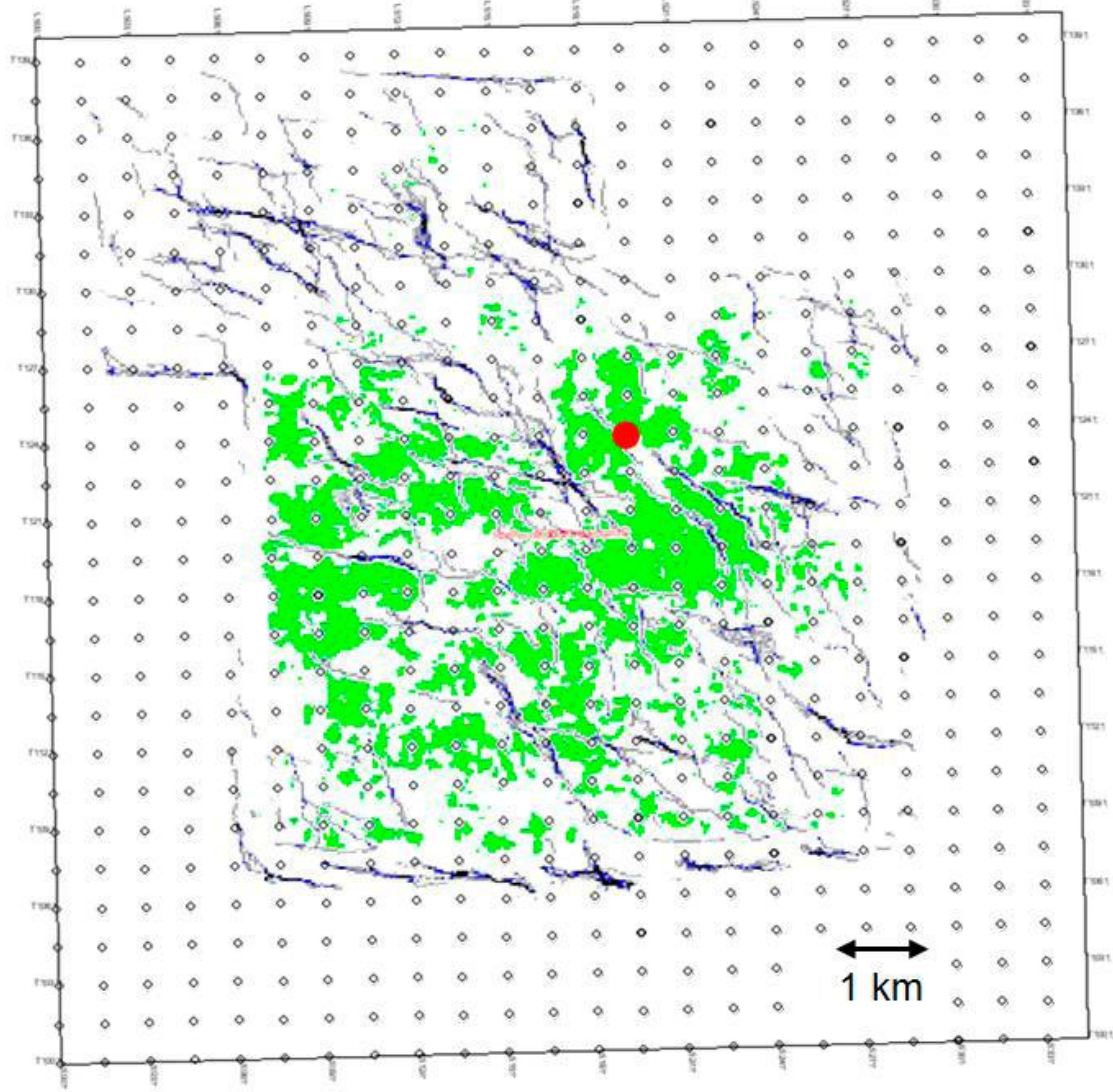

Figure 3. Multi-attribute map for fracture detection. Red point indicates the location of a producing well.