Application of unconventional seismic attributes to enhance fault detection in a tight volcanic reservoir from Barmer Basin

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Keywords

Fault/Fracture detection, Semblance, Curvature, Thinned Fault Likelihood, Fracture Proximity and Fracture Density

Summary

Seismic characterization of naturally occurring faults and fractures is one of the main goals in unconventional reservoirs. It is crucial in understanding the geological history; identify optimal locations for development drilling and to maximize production in these tight reservoirs. The objective of this paper is to discuss and compare the application of unconventional fracture attributes with respect to conventional geometric attributes to enhance fault detection within the tight volcanic reservoirs of Raageshwari Deep Gas field, Barmer Basin. Seismic data is first filtered with a structurally oriented filter to reduce random noise and improve the imaging quality. As a second step, traditional geometric attributes such as semblance and curvature were applied. These attributes successfully identified fault and fracture geometries. Additionally a new unconventional fault attribute known as Fault Likelihood, defined as a power of semblance, was then used to capture and delineate faults and fractures in the same area. This attribute scans for a range of fault dips and provides maximum likelihood of fault presence in the value ranging 0 and 1. Further 'thinning' filter is applied to obtain sharper fault plane geometries. In comparison with the conventional geometric attributes, the faults and fractures are better visualized by the new method. In addition, the new 'Thinned Fault Likelihood' attribute can further be used for characterizing faults by extracting fracture attributes known as Fracture Proximity, Fracture Density and analyzing their connectivity. Results of this study will be used for optimal placement of development wells for enhanced field productivity.

Introduction

The current study area, Raageshwari Deep Gas (RDG) field is situated in the southern part of onshore Barmer Basin in Rajasthan, India. The field contains a gas condensate reservoir with excellent gas quality within the dominantly volcanic formations (Basalt and Felsic) and overlying clastic Fatehgarh Formation. These are tight reservoirs and optimal field development necessitates reasonable characterization of faults and natural fractures thereby aiding well placement by targeting areas of enhanced permeability for better well performance. Faults and Fractures are generally represented as discontinuous reflection patterns on seismic data. Manual fault picking is a typical exercise and a time consuming task. In seismic Interpretation, faults are routinely detected through geometrical attributes such as dip, azimuth, semblance, variance, coherency etc. A point to note here is that minor faults below conventional seismic resolution may not be detected in these attributes. However, minor sub-seismic faults are essential in fracture characterization of tight reservoirs. Therefore, it is essential to have a high definition fault detection tool to aid fracture characterization or automated 3D mapping or extraction of faults.

The objective of this paper is to discuss the application of unconventional fracture attributes to enhance fault detection that helps in characterization of fracture network, fracture density and their connectivity. The unconventional attributes discussed in this paper are Thinned Fault Likelihood, Fracture Proximity and Fracture Density (Jaglan et. al., 2015) extracted using Opendtect™ software. Thus, these new unconventional attributes are of special significance for a complete characterization of fault and fractures which is crucial to optimally place development wells and maximize field recovery.

Methodology

Seismic data / QC

A 3D wide azimuth seismic survey was acquired over the study area in 2014. Subsequently azimuthal Pre-Stack Depth migration (PSDM) processing was performed in 2016 incorporating the new 5D interpolation technique (Trad, 2009) that helps to remove artifacts (eg., acquisition footprints) caused by sub optimally sampled data during geometrical attribute computations. This achieved adequate image quality in the target reservoirs and helped better seismic interpretation that was carried out as a part of this study. Further, Seismic data is filtered with a mild structurally oriented filter to reduce random noise and improve the imaging quality.

Conventional fault/fracture detection

Semblance / coherency attribute

This is an edge detection method. Lateral correlation of adjacent traces along a given reflector over a particular interval is computed. This provides a direct measurement of any lateral discontinuities in seismic data in the value ranging from 0 to 1. When the adjacent traces are quite similar in their response, then the similarity value is closer to 1. If the value is below 0.6, then the traces do not correlate properly, suggesting dissimilar waveforms, discontinuities or in other words faults and fractures.

In this case, three dimensional measure of semblance attribute was extracted. Figure-1a shows semblance attribute at the top volcanic (Basalt) of the Raageshwari volcanic complex and it showed a shattered, broken network of faults with varied throws. Consistent with the geological model and the tectonic settings of the basin, these faults have a major orientation in the NNW-SSE direction. This method is successful in detecting seismically resolved faults. Minor faults below conventional seismic resolution may not be detected in Semblance data. Knowledge of which is valuable for the estimation of reservoir flow characteristics.

Curvature attribute

Curvature is defined as the reciprocal of the radius of a circle that is tangent to the given curve at a point (Chopra and Marfurt, 2007). Curvature is an alternate geometric attribute that measures structural deformations. This attribute enables mapping of geological structures, such as folds or faults, which are characterized by high curvature (positive or negative). In this study, 'Most-Positive' and 'Most-Negative' curvature were used to delineate up-thrown and down-thrown side of fault blocks respectively.
Curvature inherently provides high detailed lineaments than other geometric attributes allowing subtle faults to be detected in seismic. Also it is very sensitive to noise in the seismic data which can be handled during seismic processing and pre-conditioning. A major pitfall of using curvature attributes in quantifying for fracture characterization is that both 'Most-Positive and Most-Negative' curvature attributes provides lineaments that are slightly displaced laterally from the exact fault boundary by an amount depending on the operator size of the attribute. Figure-1b and Figure-1c shows 'Most-Positive' and 'Most-Negative' curvature extracted at top volcanic in RDG Field.

Unconventional attributes for fault/fracture detection

In this study, Fault likelihood, Fracture Proximity and Fracture Density unconventional fracture attributes are extracted in the study area using Opendtect^{TM} software. (Hale 2013, and Jaglan et al., 2015)

Fault Likelihood

This is defined as power of semblance that is computed based on a specified range of dips and strike. This attribute searches for 3D orientation in coherence volume along which the coherency is low, thereby identifying most likely presence of fault. Therefore this method produces faults with true geological dips and strikes. Further 'thinning' filtering is performed to highlight only the local maxima within the Fault Likelihood volume to achieve a sharper fault plane. This reduces uncertainty in fault positioning on seismic data. Fault likelihood values ranges from 0 to 1. Figure-1d shows Thinned Fault Likelihood (TFL) attribute extracted at top volcanic in RDG Field.

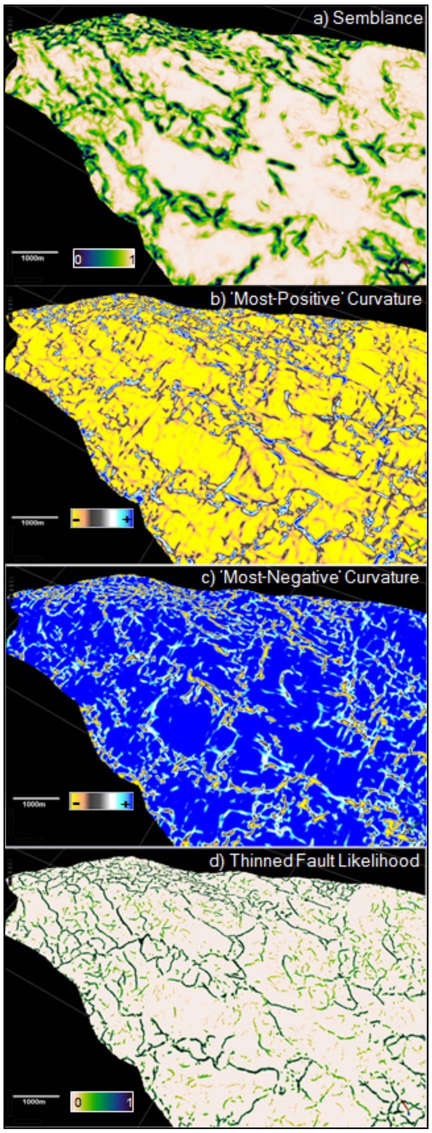

Figure-1: Attribute extracted at top volcanic in RDG Field- a) Semblance, b) Most-Positive curvature, c) Most-Negative curvature and d) Thinned Fault Likelihood

Fracture Proximity

This attribute requires coherency or curvature or Fault Likelihood attribute as input along with a user specified threshold that determines potential fracture anomaly. It computes the lateral distance of any trace in consideration from a trace location classified as fault/fracture. For interpretation and to understand production behavior, it is important to analyze proximity to fractured zones; lower attribute value denotes closeness to the center of fractured zone which indicates the possibility of associated natural fracture presence.

Fracture Density

This attribute computes ratio of seismic traces classified as fault/fracture to the total number of seismic traces present in a given radius of investigation. This is useful in identifying areas of maximum fracture presence as optimal location for drilling. Figure-2 shows the Fracture Proximity and Fracture Density computed using 'Thinned Fault Likelihood' threshold of 0.2 extracted at top volcanic in RDG field.

These unconventional fracture attributes improves visualization of potential fracture anomalies and helps in analyzing the connectivity of these fracture networks. It is further useful in designing a good hydraulic fracturing plan that considers interaction between the induced fractures with the natural fractures.

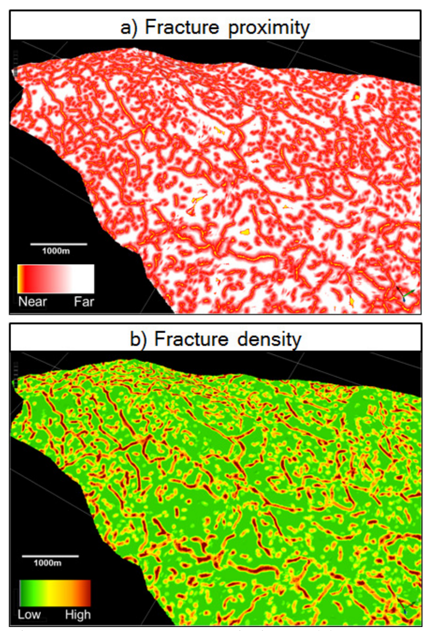

Figure-2: a) Fracture Proximity and b) Fracture Density extracted at top volcanic in RDG Field

Results and discussion

Detection of fault/fractured zones in tight RDG reservoirs were initially carried out using conventional geometrical attributes like semblance and curvature. The semblance attribute presented along top volcanic horizon reveal presence of major faults. However curvature attributes at top volcanic level does reveal more detailed lineaments allowing subtle fault detection. But curvature lineaments are laterally shifted from the actual fault position representing either upthrown or downthrown sides of faults.

Subsequent to extraction and analysis of conventional attributes, unconventional attributes likeThinned Fault Likelihood, Fracture Proximity and Fracture Density were extracted in the study area. Thinned Fault Likelihood (or TFL) was computed along the top volcanic reservoir as in Figure-1d showing significantly detailed fault and fractures detection which provides better understanding of the distribution of fracture networks. Few comparison of Semblance versus TFL attribute is shown in Figures 3, 4 and 5 demonstrating the substantial high resolution fault/fracture lineaments and powerful 3D visualization using the TFL attribute.

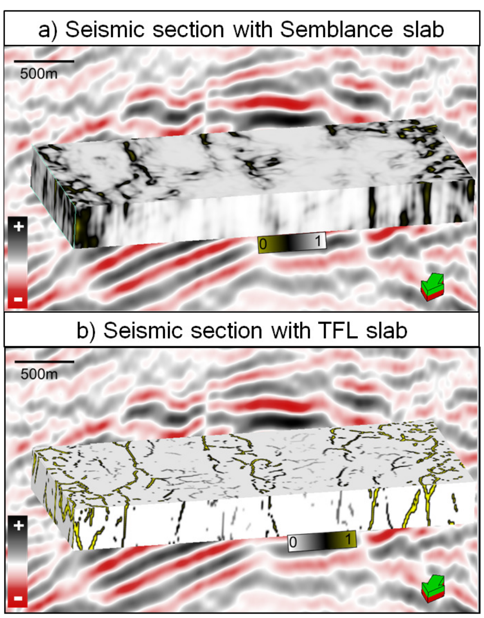

Figure-3: Comparsion of seismic profile with inserted time slab of a) semblance and b) TFL attribute

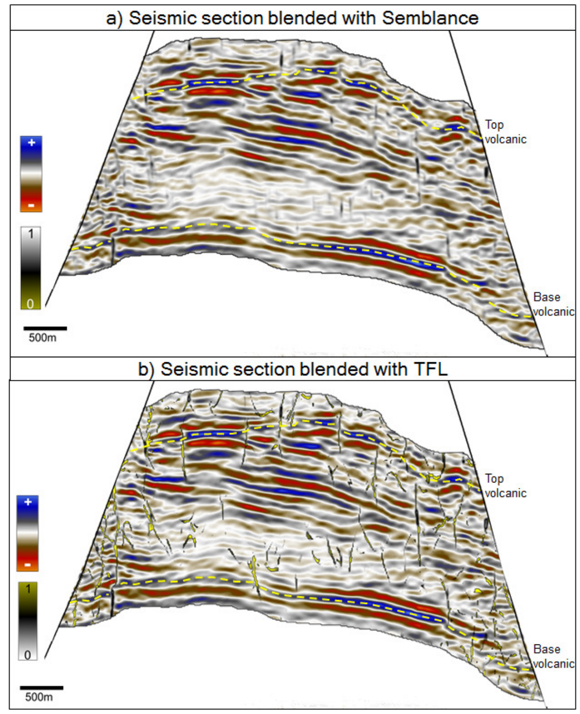

Figure-4: Comparsion of seismic profile with blended display of a) semblance and b) TFL attribute

Figure-3 shows a comparsion of seismic profile with inserted time slab of semblance and TFL attribute. It is observed that semblance reveals major faults that are resolved in seismic. Whereas TFL brings out high resolution fault lineaments indicating both major and minor faults discriminated using the likelihood values. Figure-4 shows comparison of seismic profile blended with semblance and TFL attribute. As TFL attribute is not just a mathematical 'power of semblance' but also includes scanning for specific range of positive or negative dips to maximize likelihood for faults thereby this offers powerful vertical visualization by providing true geological dips and strikes. Figure-5 compares the 3D visualization of seismic profile (inline and crossline) blended with semblance and TFL along with respective time slice at base basaltic lithology. Certainly it can be observed from these Figures that TFL provides more powerful and meaningful detection of Fault/fracture zones with a clear discrimination of major faults with high likelihood and subtle faults with low likelihood values. These interpretation can be supplemented with calibartion procedure with image log data and microseismic measurements and production data to gain further confidence in applying these unconventional attribute to understand production behavior.

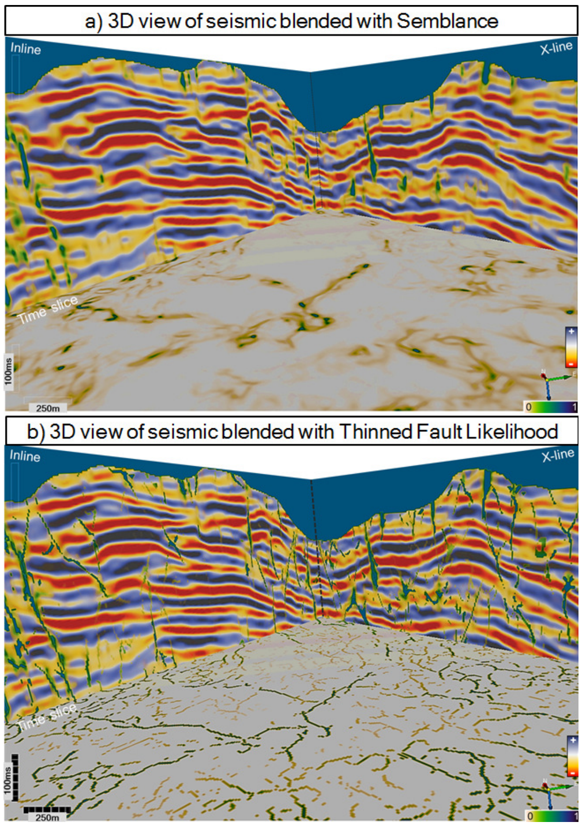

Figure-5: 3D view comparsion of seismic profile with blended display of a) semblance and b) TFL attribute with time slices displayed near base basaltic lithology

Conclusions

This study shows the application of conventional and unconventional attributes for delineating presence and geometry of faults/fracture networks in tight volcanics reservoirs of RDG field. Seismic data conditioning is a first vital step performed using a structurally oriented filter to denoise reflectors and improve the imaging quality. This conditioned seismic was used for application of conventional and unconventional attributes. Conventional geometrical attributes such as semblance and curvature attributes were extracted. Semblance was only able to outline major faults. In addition, the curvature attribute namely 'Most-Positive' and Most-Negative' attribute was partially successful in bringing out the fine detail about the fracture networks. However the application of the unconventional Thinned Fault Likelihood (TFL) attribute provided the best delineation of fault geometries and fracture network in 3D. The 'thinning' filter used in this attribute provides sharper fault lineament facilitating the structural interpretation and reducing the uncertainty in fault position. This TFL attribute was further utilized to extract Fracture Proximity and Fracture Density attributes. These two attribute help analyze fracture connectivity to understand production behavior of existing wells and identify most optimal locations for future development drilling of the field to maximize Estimated Ultimate Recovery (EUR).

Acknowledgements

We thank Cairn Oil and Gas, Vedanta Limited and our JV partner, ONGC Ltd, for allowing us to publish this paper.

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