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An Integrated approach for faults and fractures delineation with dip and curvature attributes

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Summary

Faults and fractures are the important components of structural information, mapping these faults/fractures can give valuable information about fluid flow inside the reservoir. Seismic attributes often provide a quick way to visualize the trends of faults and fractures, which are not visible in seismic amplitude information. These set of information from different seismic attributes can be used to form fault geometry, and further it can be used to optimize well locations.

In this article the delineation of faults and fractures is demonstrate using an optimum workflow. Our main goal was to identify faults and fractures trends in the study area. This study incorporated three key elements: The first element was to condition the given data by applying various structurally oriented median filters to improve its observations and imaging quality and to reduce the uncertain noise. Since faults & fractures information derived from single seismic attribute is not accurate, in the second element, several different attributes from the seismic data were derived to delineate the faults & fractures geometry, along with damaged zones. The third element was to discuss and compare the outputs of every attribute applied on enhanced data-set. Our work on these three elements has been presented in this paper.

Keywords: *3D Seismic, Seismic curvature attributes, Faults and fractures, Dip attributes*

Introduction

Faults and natural fractures can have significant effect on the permeability of reservoirs and it can have impact on productivity and efficiency (Neves et al., 2006; Chopra and Marfurt, 2007). For this reason, the characterization of fractured zones and faults within a reservoir comes among the important process in many seismic investigations. Fracture occurs at many scales but most of them are below the seismic resolution and thus are not easily visible in a standard seismic display (Singhal et al. 2010). Although the presence of fractures comes below the seismic resolution, fracture presence can brought out using various attributes. Seismic attributes based on discontinuity principle provide useful tools to characterize faults and fractures (Hakami et al., 2004; Chopra and Marfurt, 2007; Basir et al., 2013). Dip and Curvature are two important attributes, which can be used to extract faults and fractures information from seismic data. The accuracy and quality of these seismic attributes are directly proportional to the Signal to Noise ratio of the seismic data. This warrants conditioning of data, to enhance the visibility of faults and fractures in it (Basir et al. 2013). The conditioned data further can be processed to enhance the discontinuity features and thus attributes on these processed data will give better extractions of faults and fractures geometry. With an aim to illuminate the geometry and location of the various major and minor faults and fractures various seismic attributes have been applied on the given seismic data.

This paper, deals with the analysis of geometric attributes such as curvature, similarity, and dip to delineate faults and fractures.

Data and Methodology

The input data for this study is 3D pre stack time migrated data (PSTM) volume, located in the Tarapur low of Cambay Basin. The objective of the project is to detect faults and fractures in the pay zone section. Several wells have been drilled in this area on the up-dip

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direction of the flanks on various fault blocks. Faults are controlling entrapments of hydrocarbon and hence precise delineation of faults and fractures will be important for development and exploration of the field.

As noise distorts the image and makes the task of geological feature detection and interpretation difficult, conditioning of the data has been done to allow better interpretation of the data. Further additional filters has been applied to enhance the faults in the data-set, and then comparative study of Dip and Curvature attributes on the conditioned and fault enhanced filtered data is presented on a horizon slice. Workflow adapted in this study is shown in Figure 1. The OpendTect software was used for analysis of this data.

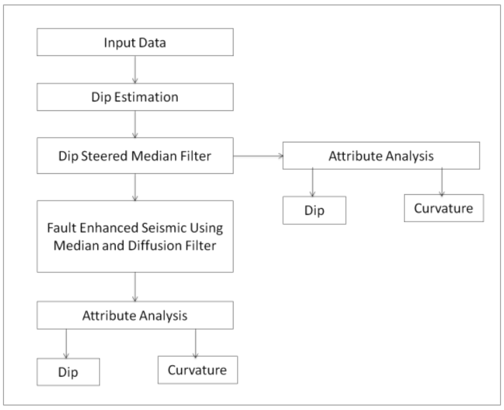


Figure 1 Workflow for data conditioning and preparing fault enhancement seismic with attributes.

Data Conditioning

Seismic attributes can provide essential details from seismic data, but noise present in the data-set often distort the outcome. To optimally remove noise, data conditioning was carried out in two steps, in the first step, a dip volume was created using Fourier transform based algorithm in inline and cross-line directions, at each data point from seismic amplitude data. This dip volume was then used as a reference, and a median filter was applied on the seismic data guided by prepared dip volume. It reduces the structurally oriented random and coherent noise and increases the continuity and visibility of faults and fractures by preserving and at the same time sharpening the edges.

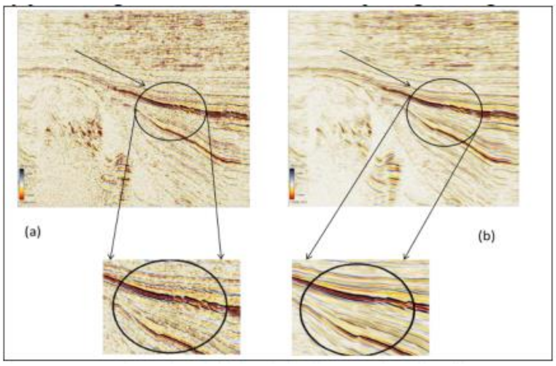


Figure 2 Comparison of (a) initial and (b) dip steered median filter (DSMF) data.

Figure 2 shows a seismic inline, before and after the application of dip steered median filter. It can be seen that the application of dip guided median filter has significantly reduced the random noise while preserving general properties of seismic data.

To extract the faults and fractures trends, data has been further processed in recursive steps primarily by a dip steered median filter and consequently following an iteration using the combination of dip steered diffusion filter and dip steered median filter with guidance from Similarity cube. It results into a Fault Enhanced Seismic (FES) data with preserved linear features and sharp edges.

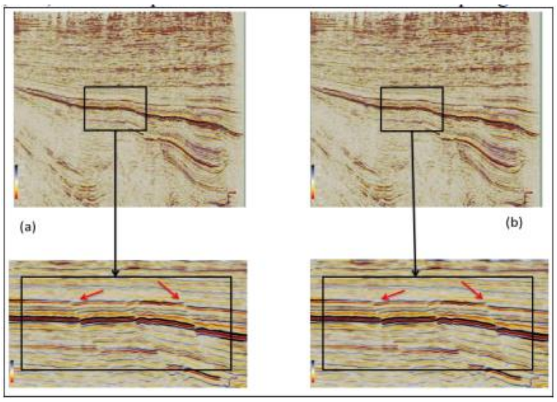


Figure 3 Comparison of (a) DSMF and (b) FES data. Arrows in highlighted area shows the sharpening of faults in FES data

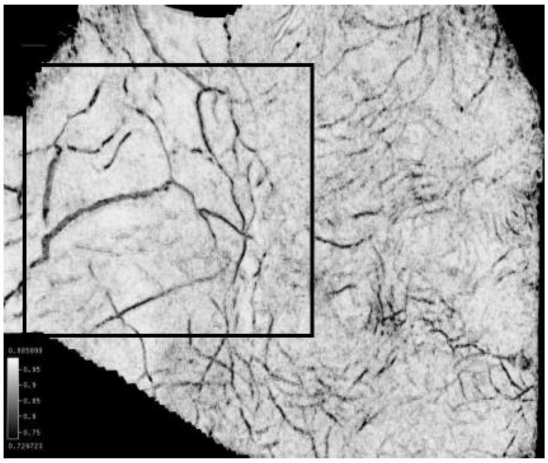
Figure 3 shows the application and comparison of fault enhance filter on the median filter data. It can be seen in highlighted area, that the combination of median and diffusion filter sharpen the seismic data at the fault location and improve the identification of discontinuity on seismic data.

Seismic Attributes

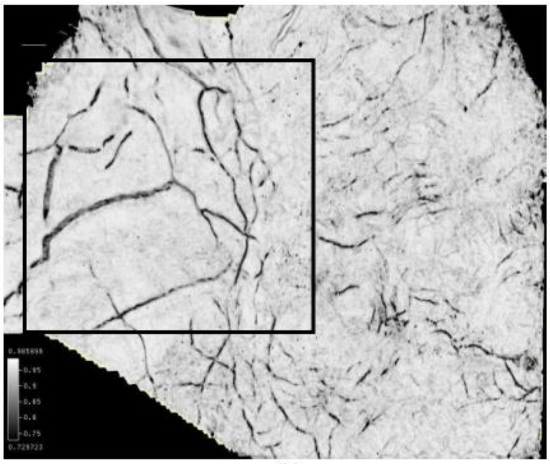
Now a days seismic attributes become the integral part of seismic interpretation projects. Fault detection can be enhanced by applying either discontinuity or curvature based attributes. Among various attributes Similarity, Variance, Dip attributes, Most Positive Curvature, Most Negative Curvature are proved to be successful for detection of faults and fractures (Chopra and Marfurt 2007). Seismic discontinuity attributes measures the similarity or dissimilarity of a particular point to its neighbors. Coherency, Variance or Similarity all provide measures of similarity of a particular trace to its neighbors. Curvature attributes measures the curvedness of surface at a particular point.

Similarity

Similarity is a coherency attribute that is highly sensitive to discontinuity in the data. Such directional attribute are often sensitive to noise and it is necessary to reduce noise and enhance the seismic quality before computing the attributes. To study the, discontinuities by similarity attribute a 3D seismic dataset of similarity is created and their effective parameters are explained only after enhancing the quality of the seismic data by different steering methods. Figure 4 shows the comparison of similarity attribute on the Horizon slice, it clearly shows the superiority of faults enhance filter over median filter in terms of faults illumination. The area highlighted using black rectangle show clear faults block in FES data.



(a)



(b)

Figure 4 Minimum Similarity maps using (a) DSMF (b) FES data. Note that the area highlighted with square in both the maps, Minimum similarity using Fault enhances filter shows better definitions of faults and fractures.

Dip attribute

Dip is a directional attribute which measures the shape of the reflector. Dip attributes can extract faults and fractures networks less than the seismic resolved wavelength. A seismic dip can be classified into the inline and crossline dip components.

Inline dip provides dip measures in inline direction, while crossline dip provides dip measures in crossline direction. There are other dip attributes that can be derived from dip measures like polar dip and dip azimuth. Azimuth gives significant detailed description about geographic information. The Polar dip attribute converts extracted inline and cross line dips to polar dip, or true (geological) dip.

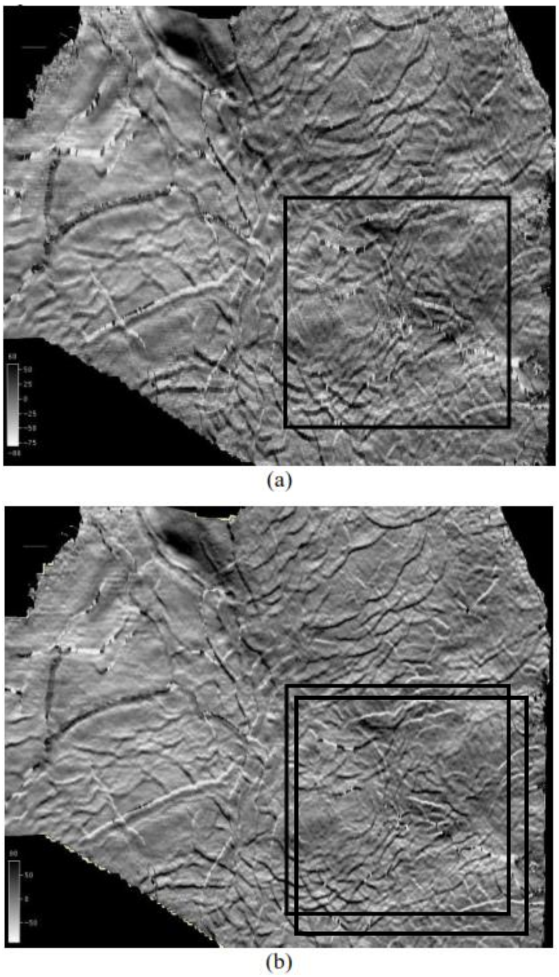

(a)

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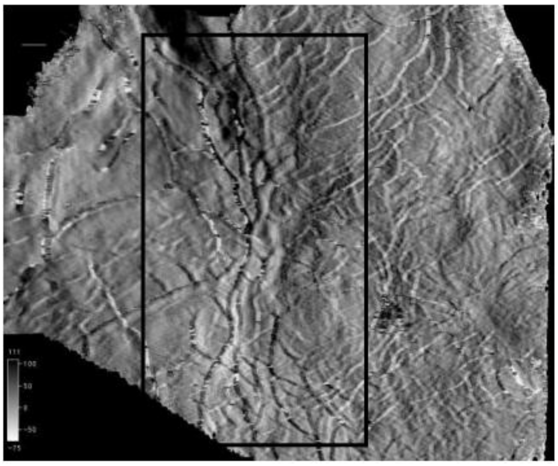
Figure 5 Inline dip attribute using (a) DSMF and (b) FES data. Note that the faults and fractures network are much clearer in FES data.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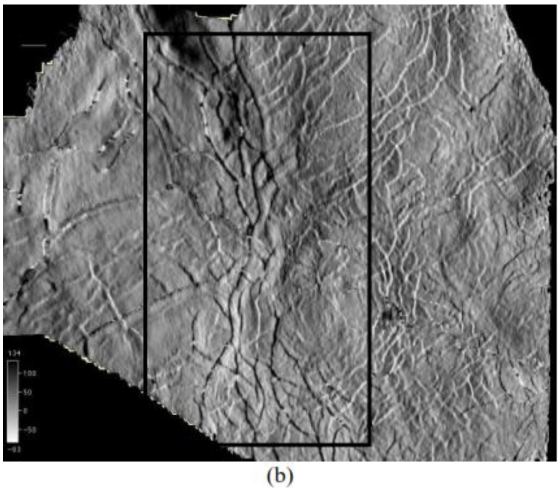
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Figure 6 Crossline dip attributes using (a) DSMF and (b) FES data. Faults along the crossline direction (vertical) in FES data shows major faults and associated minor faults.

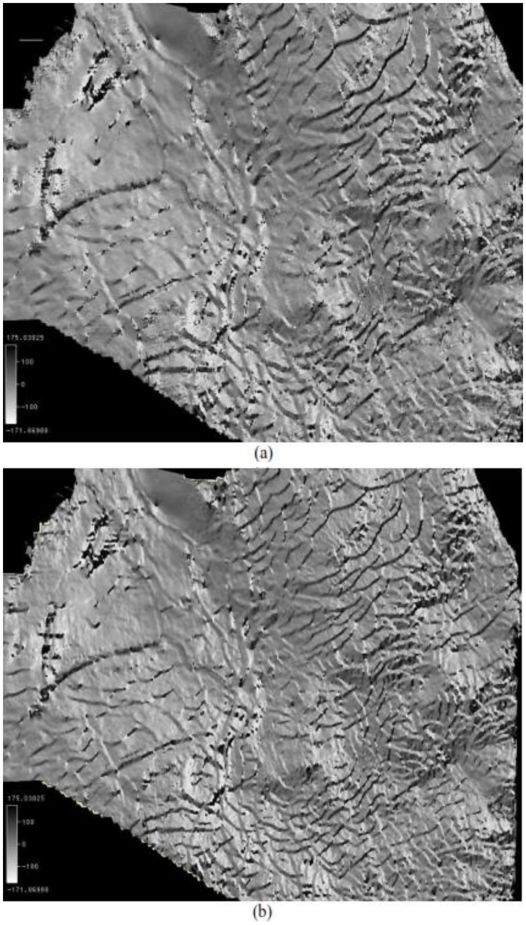
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Figure 7 Azimuth attribute using (a) DSMF and (b) FES data. Azimuth derived from FES data show clearer information of faults and fracture.

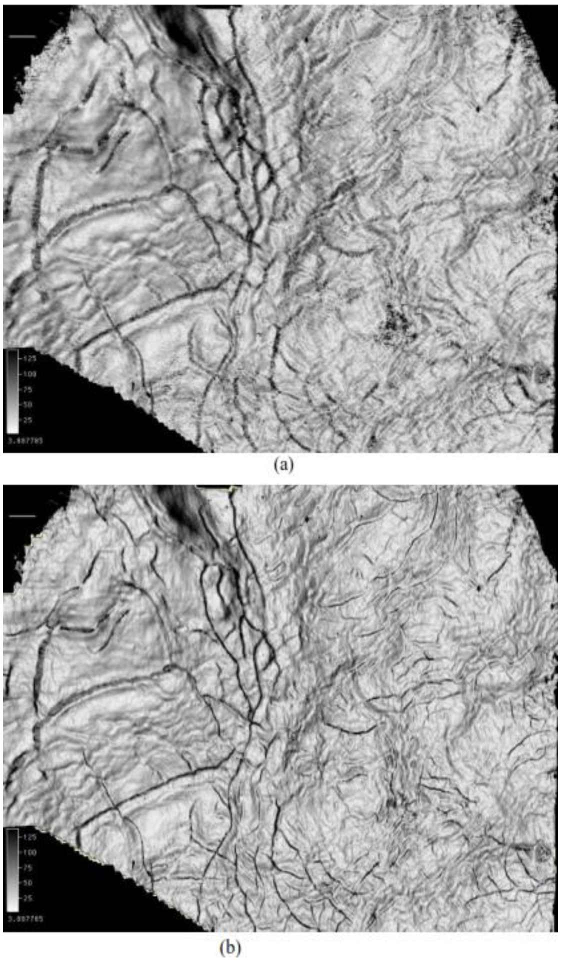
(a)
(b)

Figure 8 Polar dip attribute on (a) DSMF and FES (b) data. Polar dip using FES data brought out network of faults and fractures at greater extent.

Figures 5 to 8 shows the analysis of dip attributes using DSMF and FES data. Dip attributes from both the filtered data set highlights the faults blocks and fracture areas. But, dip attributes from FES data (Figure 5.b, 6.b, 7.b & 8.b) set brought out much clearer faults and fractures pattern as compared to DSMF data (Figure 5.a, 6.a, 7.a & 8.a) as the noise is better attenuated in the FES data. Inline dip and crossline dip shows continuity of fault pattern in inline and crossline direction respectively. Among all attributes polar dip using FES data able to extract full network of major and minor faults.

Curvature attributes

Curvature attributes provide important information above and beyond that derived from more commonly used seismic attributes. Geologic structures often exhibit curvature representing flexures, folds, faults kinks, fracture etc. Being second-order derivative measures of surface, they are sensitive to noise. Among all curvature attributes Most Positive curvature can clearly brought up up-thrown fault blocks while Most Negative curvature can bring down-thrown fault blocks (Chopra and Marfurt 2007). Thus in order to extract detailed information on subtle features, DSMF and FES data were used to create Most Negative and Most Positive curvature attributes. In addition to this Mean Curvature attributes was also used in this study to study its capabilities of fracture enhancement.

Figure 9 shows the comparison of Most Positive curvature using DSMF data and FES data. It should be noted that the fractures are more prominent in attribute extracted using FES data in comparison with DSMF data.

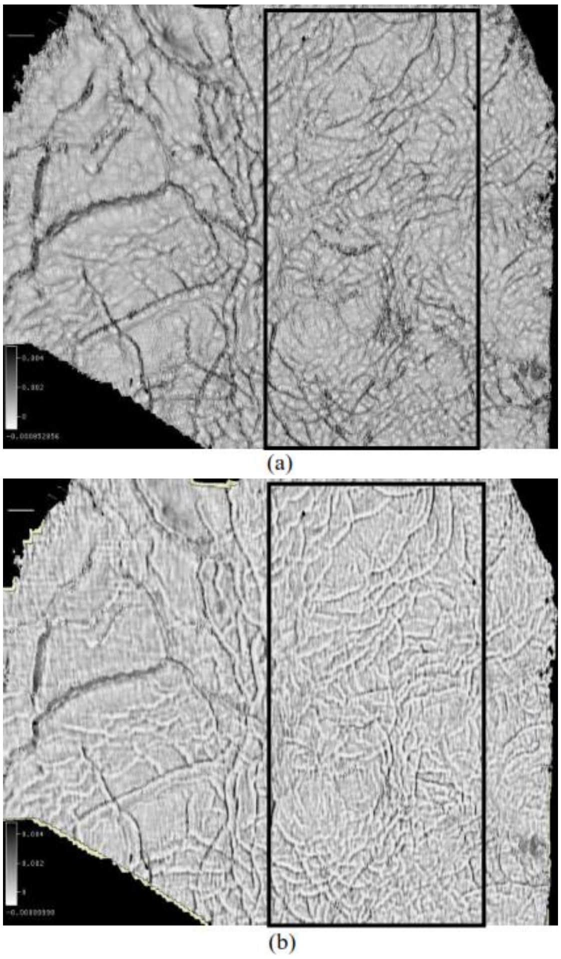
(a)
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Figure 9 Most Positive Curvature using (a) DSMF and (b) FES data.

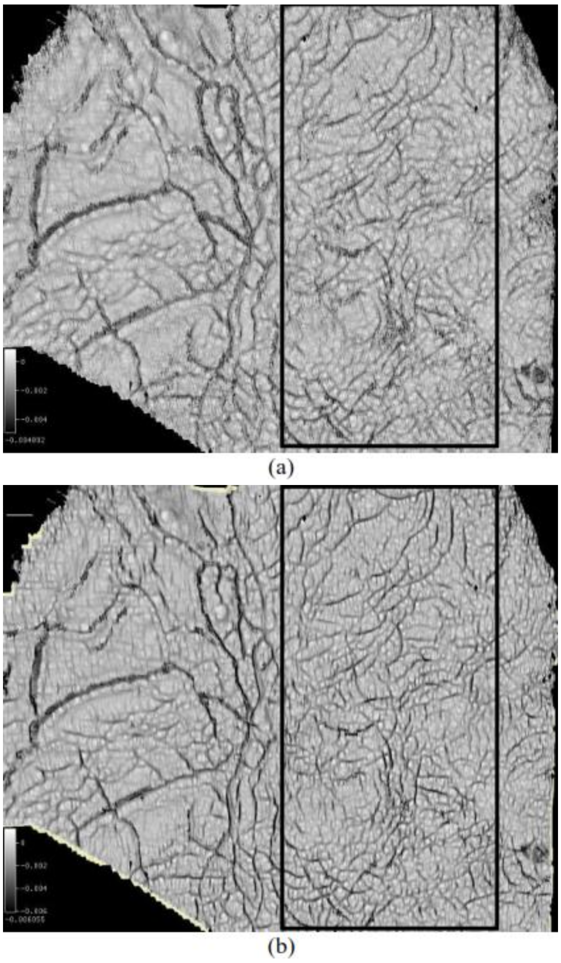
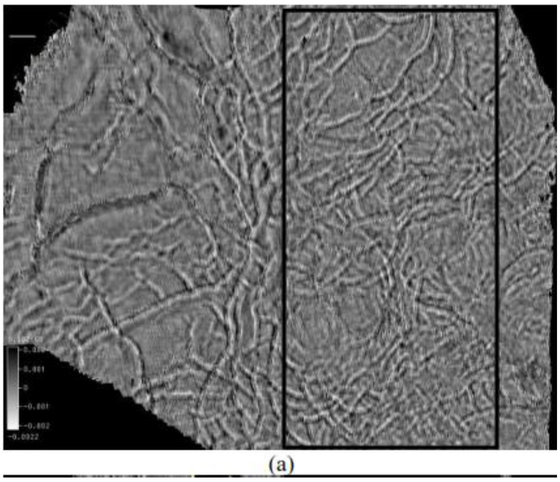


Figure 10 Most Negative Curvature using (a) DSMF and (b) FES data. Note that the fault throws become more visible in FES data.



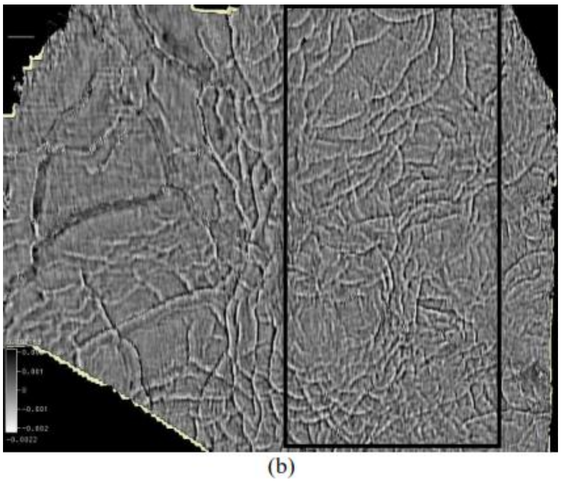


Figure 11 Mean curvatures on (a) DSMF and (b) FES data. Fracture network can be seen more preciously in attribute using FES data

A dip steered median filter data prepared from FES data(figure 9.b, 10.b, and 11.b), produced the best result as it didn’t smoothed the data and at the same time it enhanced subtle details envisaging the brittle deformation in the zones thereby producing structural details.

Most positive and most negative curvature attribute are highly sensitive to brittle deformation especially in the fault nose areas. High values of these curvature correlate directly with high values of brittle deformation. Most negative curvature is giving the best fault continuity among all. The result of this analysis help to appraise the fact that mean curvature (Figure 11) tends to enhanced the fractures while lateral continuities depicting fault lineaments are best produced by most positive and most negative curvature (Figure 9 & 10).

Conclusion

Seismic data conditioning, through the application of dip guided median filter tends to suppress the random and coherent noise. Noise removal was crucial to extract faults and fractures information from seismic data. To improve faults visibility in the data, the fault enhanced filter was also applied, and it's able to sharpen edges and enhance the faults to the maximum extent. After the application of distinct attribute sets with well-defined parameters on the given seismic data the following results are produced. Out of all the attributes tested, polar dip being a directivity driven parameter that enhances the edges and sharpens the fault to the best extent. For analysis of the fractured zones, mean curvature has brought out the most momentous results. The seismic images thus produced are complementary and are the best result produced by integration and implementation of filters and different attribute sets.

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