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PRE-CONDITIONING OF 3D SEISMIC DATA USING THE STRUCTURAL FILTERS FOR FAULT INTERPRETATION

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Abstract

Complex geological structures and varying data quality present a unique challenge for seismic interpretation and pitfalls related to normal fault interpretation. Therefore, seismic conditioning and structural filters are necessary to improve faults and horizon interpretation and to obtain high-quality seismic attributes. This study applied structure-oriented conditioning with filters along 3D seismic data to reduce noise and increase seismic resolution. To achieve this enhancement in the seismic data, it is essential to differentiate between the dip and azimuth of the reflection signal and that of the noise. Two methods were applied in this study to get the dip and azimuth of the reflection signal: first, by applying structural smoothing on the seismic volume to get a smoothed version of the dip, and second, by applying structural attributes. The structural smoothing filter is used in this study to minimize noise, enhance structural imaging, and generally improve the volume for seismic interpretation and the application of other volume attributes. It is concluded that the seismic section with dip-guided variance attribute showed better results in enhancing fault edges. Larger values of this filter reduce noise effectively and smear the detected edges' sharpness. The results also demonstrate the effectiveness of variance attributes for edge detection of faults compared with dip-deviation and curvature attributes. Also, this study showed that for 3D seismic data, an anti-track filter for fault identification is the most effective filter to detect faults.

Keywords: Faults; seismic conditioning; structural smoothing; anti-track filter.

1. Introduction

Faults are important targets for identifying fluid flow, especially oil and gas. Therefore, fault interpretation is very crucial. Seismic data are usually affected by noise, making seismic interpretation (fault and horizon picking) difficult. If the data is not appropriately migrated or is affected by long-period multiples, it is not easy to improve the data (Chopra & Marfurt, 2007;

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AL-Rahim & Abdulkareem, 2023a & b). However, random and coherent noise can be removed or reduced using structure-filters to improve faults and horizon interpretation by applying high-quality seismic attributes.

Seismic conditioning is a key process due to the sensitivity of seismic data to lateral changes in noise. It plays an important role in identifying the location of small and large faults. It is crucial to image the subsurface as carefully as possible because even minor changes in the shape of the reflector can reveal significant changes in the seismic data, such as lithology changes or fault continuation (Montgomery, 2000). This research focused on fault interpretation, an essential target for identifying fluid flow, especially hydrocarbons (Bacon et al., 2004; Ligtenberg, 2003), therefore, seismic conditioning and structural attributes (Neves et al., 2004; Chopra & Marfurt, 2008; Chopra & Marfurt, 2007) are used to identify the location of small and large faults. The main aim of this study is to pre-condition the 3D seismic data to improve the resolution of the seismic data and reduce the noise. Hence, it interprets or picks faults with fewer errors and less time.

2. Structural Geology of the Study Area

The main structural trend in the study area consists of a set of faults striking ENE – WSW. Neogene normal faults have developed above the reactivated Mesozoic structures (Figure 1) (Langhi et al., 2010; Gartrell et al., 2006) with only a few of these faults extending to the seafloor. Some faults show maximum offsets at the mid-to-late Miocene horizon, while others displace the sediments directly above them. Currently, the maximum horizontal stress (SHmax) direction is oriented NNE – SSW, which is nearly perpendicular to the regional fault strike (de Ruig et al., 2000).

3. Data and Methodology

3.1. Data

3D seismic data provided by Geoscience Australia from a chosen oil field in North-West Australia (Northern part of the Bonaparte Basin), were used to pre-condition the 3D seismic data using Petrel software. Structural filters (Structural smoothing) were used to reduce the noise in the seismic data by applying different structural attributes and enhancing fault interpretation.

3.2. Methodology

The workflow for this research starts with applying a structurally oriented mean noise filter that uses precomputed dip and azimuth volumes using petrel software to lead the filter. These filters aim to reduce the noise accompanied by the seismic data and increase the data's lateral continuity. First, structural smoothing is applied to the seismic volume; second, structural attributes are applied, including 1) Dip deviation; 2) Variance; 3) Curvature, and 4) Anti-track filter for fault identification, then compared the resulting faults after applying the different structural attributes. The methodology is described in (Figure 2), and explained below:

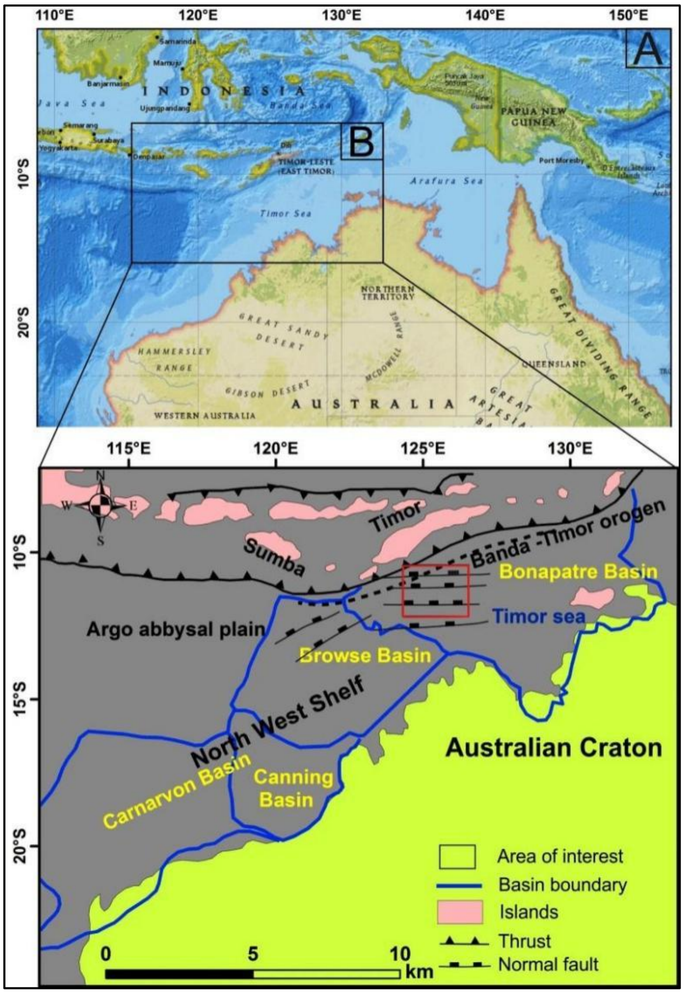

Figure 1. A) Topographic and bathymetric map of the Northwest Shelf of Australia; and B) structural map showing the study area and the main basins.

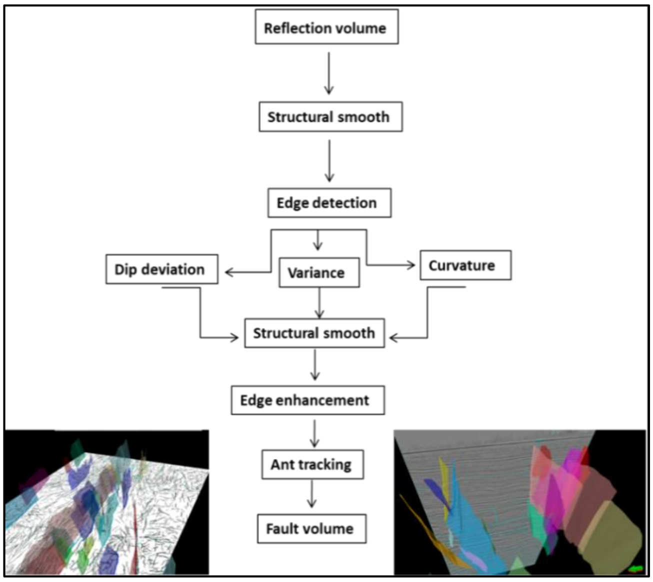

Figure 2. The methodology of conditioning the seismic volume which includes; structural smoothing; edge detection and edge enhancement attributes. Note: the figures show the final result of the faullt interpretation.

3.2.1. Structural smoothing

Structural smoothing is applied to the seismic volume to determine the dip and azimuth of the seismic data. This filter could be accessed from the volume attribute in Petrel software, which is defined by a Gaussian function. Several steps are followed in this study, aimed at improving the resolution of the seismic data by reducing the noise, computing the attribute, and enhancing it. First, the seismic volume is chosen to apply the structural smoothing; dip guided is applied to perform the Gaussian function, and edge enhancement is applied to detect subtle edges. The filter initially used only the dip-guided option (Figures 3a and b), and then the dip-guided with edge enhancement was applied to the seismic volume to show the difference in enhancing fault edges. The edges of the faults are improved and clearly show the discontinuities, providing clear and effective results (Figures 4a and b).

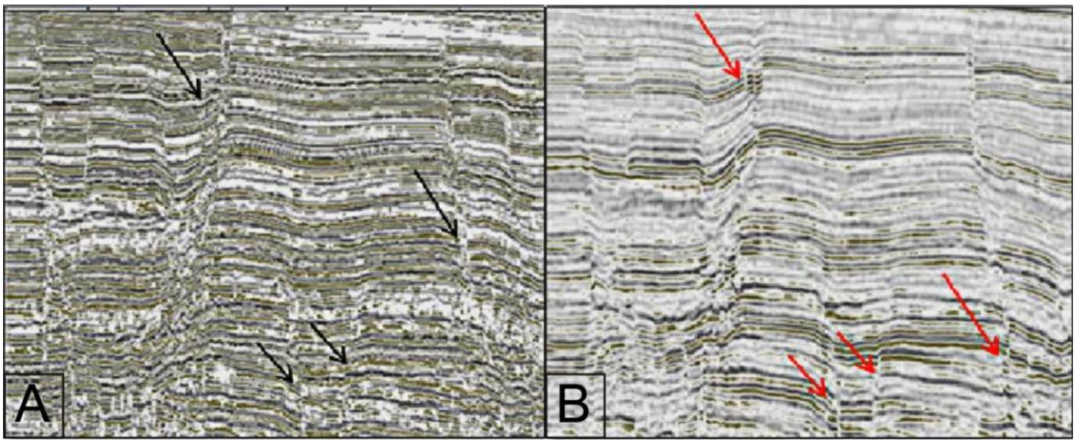

Figure 3. Seismic section: A) Before applying structural smooth; and B) Seismic section after applying structural smooth, dip guided. Note: the differences of fault edges on the seismic section.

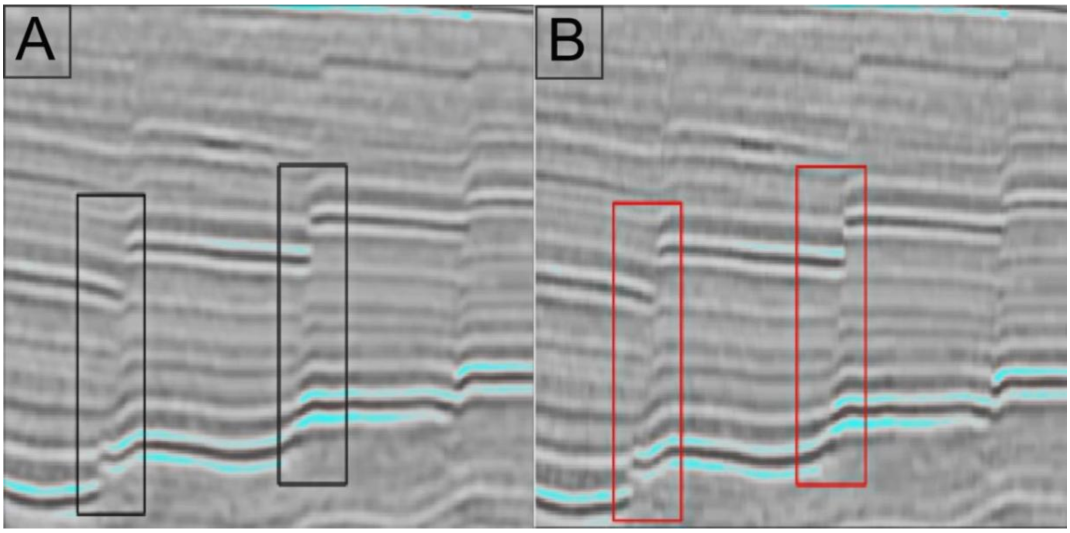

Figure 4. Seismic section: A) Dip-guided attribute only; and B) Dip-guided and edge enhancement attributes. Note the difference in enhancing fault edges within the boxes.

3.2.2. Edge detection attributes

Following the application of the structural smoothing; three attributes are applied, which include dip deviation for (low-angle faults), variance (high-angle faults), and curvature using the seismic volume with the structural smooth and edge enhancement applied.

a. Dip deviation

Dip deviation (dip magnitude and azimuth) is measured from the apparent dips of inlines and crosslines. It is an edge detection method that detects rapid changes in the local dip of faults (Basir et al., 2013). The first application of dip deviation to the seismic volume showed the rapid changes in the edges of the fault, especially for low-angle faults. Figures 5a and b demonstrate the application of this attribute with and without fault interpretation. Dip deviation is a straightforward method, particularly for faults with displacements having offsets less than the width of the seismic wavelet, making it more user-friendly than other attributes.

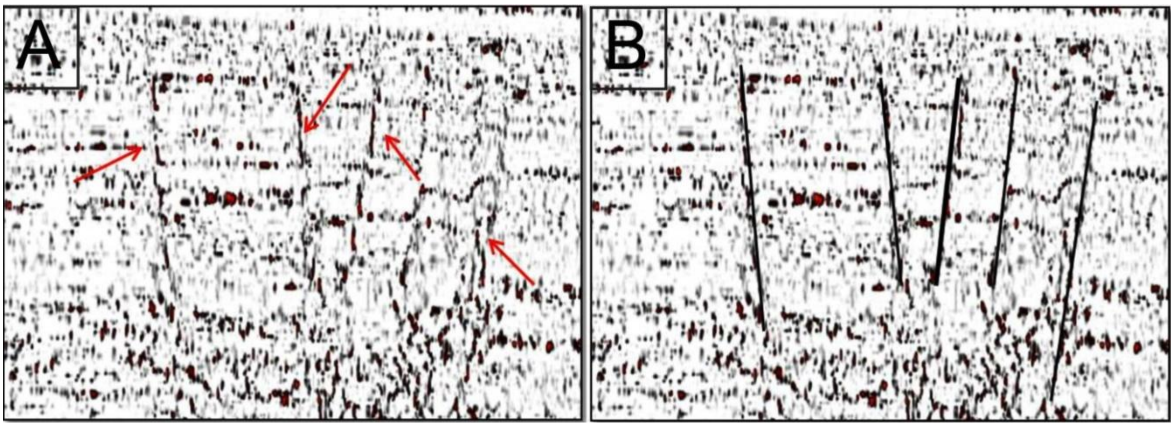

Figure 5. The seismic section shows the application of dip deviation attributes A) Without fault interpretation and B) Seismic section with fault interpretation.

b. Variance attribute

The variance attribute can isolate edges from the input data set. By edge, this means discontinuities in the horizontal continuity of amplitude. Variance, as a stratigraphic attribute, is not limited to fault interpretation. Running with a short window can bring out many depositional features, including reefs and channels, showcasing its broad applicability.

Variance attribute, particularly dip-guided variance, significantly confirms structural features, especially faults (Chopra & Marfurt, 2008). It is also used to extract a reflection continuity or edge attribute volume from an input seismic volume. The process involves applying the variance attribute without dip–guided correction and computing the variance in a horizontal plane (Figure 6a). Then, dip correction is added to calculate the variance along a dipping plane (Figure 6b). The dip-guided algorithm computes variance along a dip plane with a corresponding measure of the dip estimate confidence. Areas, where the computed confidence is above the selected confidence threshold, will apply dip-guiding. Areas with confidence below the threshold will revert to standard horizontal variance. First, the variance attribute was applied without the dip correction; the filter size was set to 3×3 with vertical smoothing of 15 (Figure 6a). Then, the dip correction was applied with the variance attribute. The dip correction parameters (Direction) were set to 3×3×3 and a plane confidence threshold of 0.9 (Figure 6b).

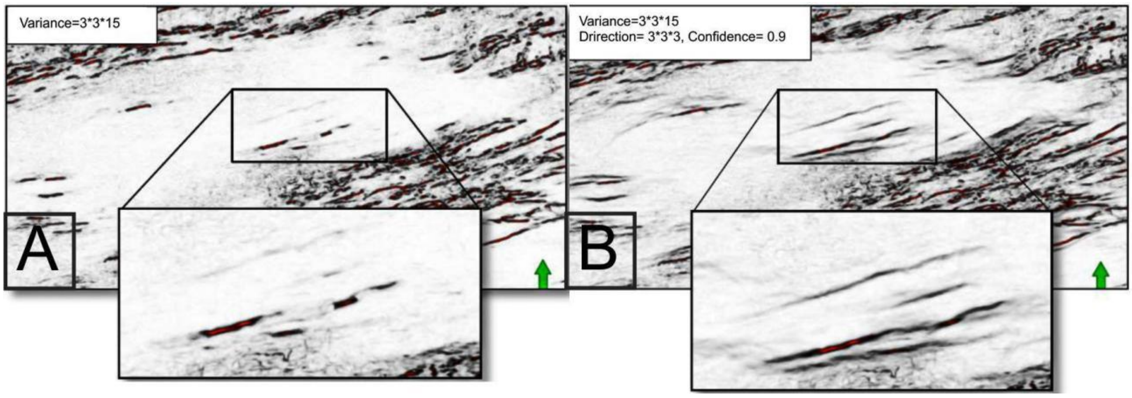

Figure 6. Fault enhancement filter for variance attribute: A) Time slice with variance attribute without the dip correction; the filter size was set to 3×3 with vertical smoothing of 15; and B) Time slice with dip-guided variance attribute; dip correction parameters of 3×3×3 and plane confidence threshold of 0.9.

c. Curvature attribute

Curvature, a two-dimensional curve property, describes the degree of bend in a curve at a specific point. It is a powerful tool that can detect faults with very low displacement, which may be challenging for coherency (Basir et al, 2013). This seismic attribute significantly enhances the features, such as the positive curvature with anticlinal features. It is particularly sensitive to fractures, faults, and the negative curvature that indicates synclinal features. Features with a constant dipping place would show a curvature close to zero (Chopra & Marfurt, 2007) (Figure 7). Once these features are identified, structural features can be derived from the data (Roberts, 2001; Kim et al., 2021; Ibekwe et al., 2023). Applying the curvature attribute (Figures 8a and b) reveals both large and small-scale features in the subsurface.

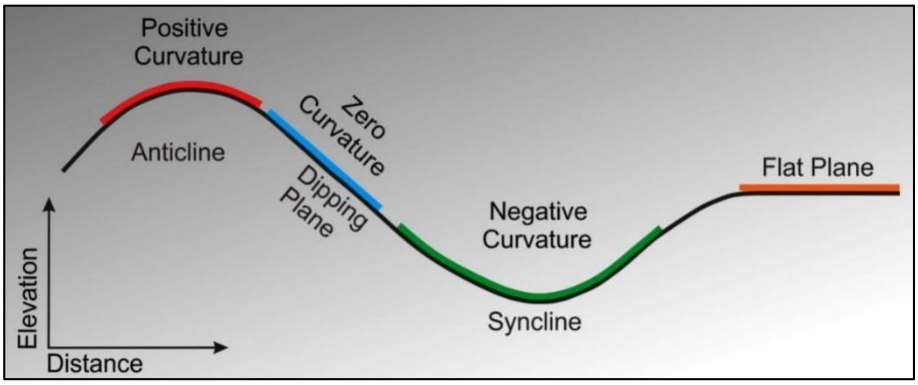

Figure 7. 2D curvature of a line, positive curvature exists with anticlinal features and is particularly sensitive to fractures and faults, the negative curvature that indicates synclinal features; and features with constant dipping place show a curvature close to zero (Chopra & Marfurt, 2007).

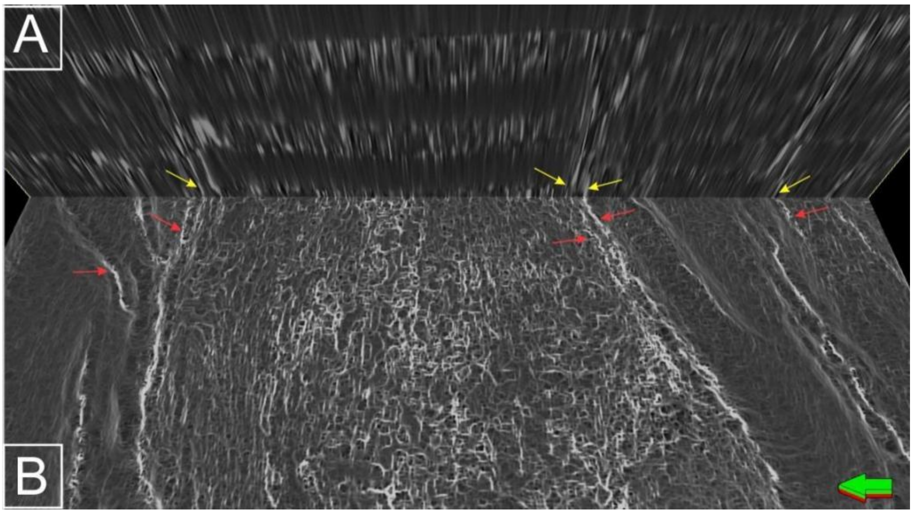

Figure 8. A) Seismic cross line with curvature attribute; B) Time slice with curvature attribute. Red arrows refer to faults along the time slice and yellow arrows refer to the same faults along the seismic cross line.

4. Anti-Track Filter

Following the seismic volume processing, which involves seismic conditioning (structural smoothing) and edge detection (curvature, dip deviation, and variance), the volume is subjected to intelligent software agents (ants) or an anti-track filter. This filter is a fully 3D process that helps to derive detailed information from the attribute (Ibekwe et al., 2023; Silva et al.,2005).

The anti-tracking attribute, a powerful edge enhancement filter, was applied to the other fault attributes, such as curvature, dip deviation, and variance.

In this study. The main idea of the ant-track algorithm is based on the ant colony systems to detect trends in noisy data. This process improves the discontinuities in an edge-detection volume because it only captures features that are continuous and reflect the existence of faults (Basir et al,2013). Then, manual fault interpretation can be performed on any of the edge-detected or edge-enhanced seismic volumes. This filter's result shows a seismic volume with sharp and detailed faults (Figures 9a and b).

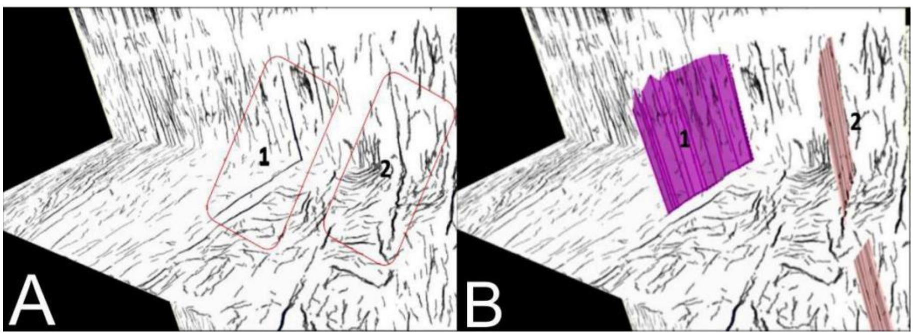

Figure 9. A) Seismic cross line and time slice line with applying ant-track filter; and B) Time slice and seismic cross line with applying ant-track filter and fault interpretation.

5. Fault Interpretation

The final step in this study was fault interpretation. After conditioning the seismic data, faults were interpreted manually every 10 crosslines using Petrel software. The seismic volume with the anti-track attribute was used as it shows the location of faults more clearly due to its significant role in enhancing fault traces. A time slice with the anti-track attribute was used to correlate the location of faults interpreted along the seismic crosslines (Figures 10a and b).

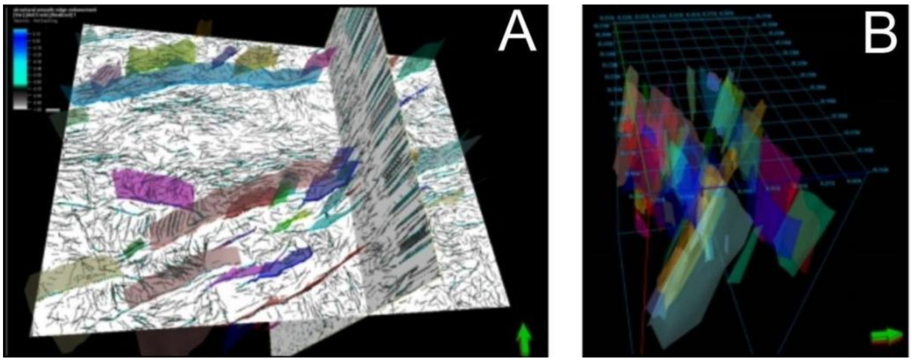

Figure 10. Fault surface interpretation which was picked based on the anti-track attribute; A) Fault interpretation applied on the anti-track volume; B) Fault volume showing fault interpretation.

6. Results and Discussion

Our comparison of the resulting faults after applying different structural attributes demonstrates a significant improvement in fault detection accuracy. Faults in Figure 3b are clearly shown after applying the structural smoothing; in Figure 4b, edge enhancement is used with the structural smoothing, and this filter not only improves the edges of faults but also sharpens them, reducing the noise accompanied by the seismic data and thereby enhancing fault detection accuracy.

The dip-guided variance attribute (Figure 6b) applied to the seismic volume demonstrates its effectiveness in isolating the edges from the input data or any discontinuities in the amplitude, making faults easily detectable compared with faults before applying the dip-guided process (Figure 6a). The curvature attribute (Figure 8) and dip deviation (Figure 5) help identify faults. However, the variance attribute highlights the discontinuity zones related to faults more clearly (Figure 6), enhancing fault detection.

Figures 11a, b, and c show the final result of applying structural attributes to the seismic volume. When comparing the results in (Figures 12d, e, and f) from applying dip deviation, variance, and finally, the anti-track filter on the seismic volume, it becomes clear that the anti-track filter in (Figure 12f) is sufficient in imaging major and minor faults. It also reveals the extension of many faults not shown or interpreted when using the variance or dip deviation attributes. This structural processing enhances interpretation accuracy and makes faults and fault surfaces easily interpretable, providing a wealth of information. The anti-track filter, in particular, is a time-saving tool, allowing for a more efficient interpretation process. For this reason, we depend on the anti-track seismic volume to interpret fault surfaces (Figure 10). The structural attributes have been applied for the first time in the study area. The results of this study are compatible with other studies that used the structural attribute (Basir., et al., 2013; Roberts, 2001). However, results could vary based on the type of seismic data, whether it is 2D or 3D seismic data, and the filter used. For example, the anti-track filter is a fully 3D process that works more efficiently with 3D seismic data.

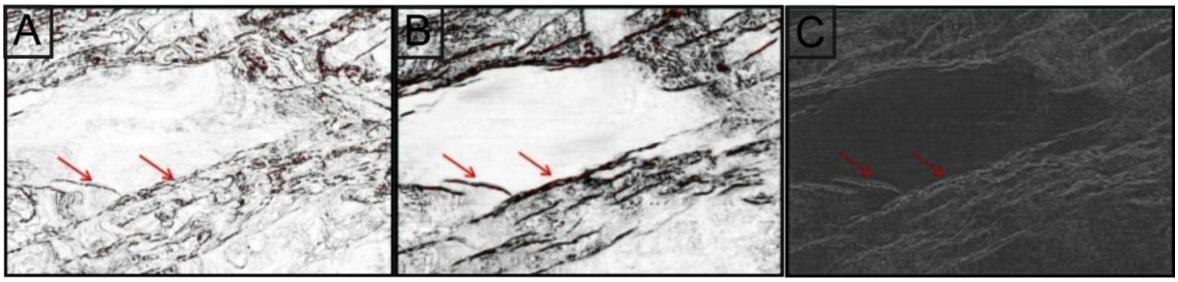

Figure 11. Seismic time slice showing the result of applying edge detection attributes A) Dip deviation; B)Variance; and C) Curvature.

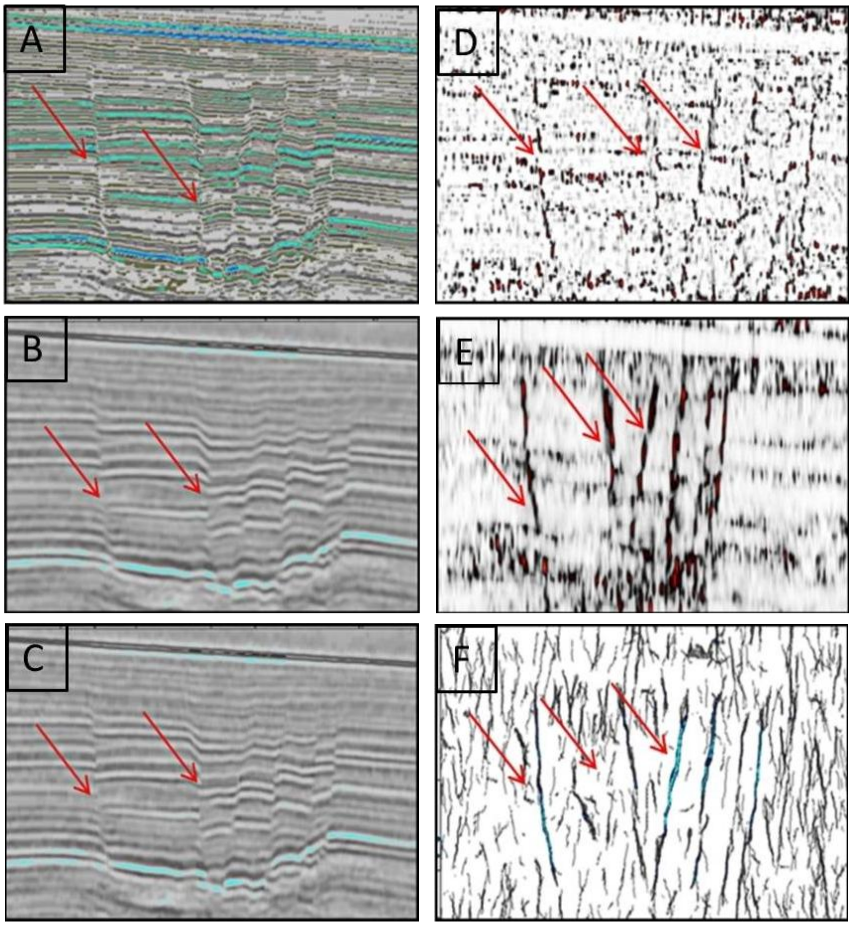

Figure 12. Result of applying the anti-track filter on the seismic volume after applying the structural smoothing and the edge detection attributes; A) Original seismic; B) Seismic section with structural smoothing; C) Seismic section with structural smoothing and edge-enhancement; D) Dip deviation; E) Variance; and F) Ant-tracking. Note: arrows indicate the location of faults.

7. Conclusions

Four main findings were concluded from this study in terms of the efficiency of the used methods: (a) This study demonstrates the effectiveness of seismic conditioning in this context, showing how it can reduce noise, enhance structural imaging, and improve the volume for seismic interpretation and the application of other volume attributes. (b) It is concluded that the seismic section with the dip-guided variance attribute yields superior results in enhancing fault edges. Larger values of this filter can effectively reduce noise and also smear the sharpness of the detected edges. (c) The results demonstrate the effectiveness of variance attributes for edge detection of faults compared with dip-deviation and curvature attributes. And (d) a comparison of the final result of the structural attribute for 3D seismic data reveals that the anti-track filter is the most effective filter for fault identification, empowering researchers with a powerful tool for fault detection.

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