

Seismic Attributes for Fractures and Structural Anomalies: Application in Malaysian Basin

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Abstract: Seismic attributes are proved to be powerful tools for studying geological features on seismic data. In Malaysian Basin, intense efforts starting from this decade in seismic data acquisition and processing have resulted in significant improvement in data quality and hence the success of attribute application. Depending on the method used to calculate the attribute as well as the structure's characteristics, one attribute can be more convenient than others for the desired objectives. Here, the focus is on detecting faults and anticlines in Central Luconia, Sarawak Basin. Therefore, different attributes useful for this purpose have been examined and compared to select the optimum selection of the attributes for further study of the data. Based on the results, different attributes provide different information for the same geological event. So, it is better to combine the outputs obtained from attributes that can identify the anomaly at the required resolution level.

Keywords: Seismic Attributes Fault identification; Carbonate Build-up; Malaysian Basin

1. Introduction

1.1 test

Central Luconia gas province is one of the most important explorations and production prospects in Sarawak basin. From the structural point of view, this area is located between a subsidence and faulting zone in the north and tectonic compressional zones in the south from lower to mid-Tertiary. This area shows a low degree of structural deformation. From Oligocene to lower Miocene and then lower to mid-Miocene, there have been some faulting activities that the latter has produced horst and grabens. The horst blocks have been a suitable place for reefal activities and lots of reefal carbonate build-ups have been produced here ^[1].

The existence of fault and fractures, as well as build-up structures in these carbonates, is of great importance affecting subsurface studies from hydrocarbon accumulation to drilling program to well productivity. Three-dimensional seismic data is one of the most powerful tools to study the existence and extent of such events. There have been lots of efforts to extract such information from seismic data especially with the help of seismic attributes ^[2-5]. Seismic attributes commonly used in the interpretation of discontinuities provide different information such as similarity of a trace to its neighbors, slope, azimuth, and curvature of layers. Depending on the characteristics of the subsurface events, the performance of an attribute can be superior to others.

Data used in this study was three-dimensional seismic data from central Luconia, Sarawak covering 437 sq. km. The sampling interval was 2 millisecond (ms) and the total recording time was 5700 ms. Data quality was good and the seismic cube after migration was examined here. Eight seismic attributes were used to study the fault and fractures of the survey area. Comparing the results, the attribute with the better resolution to detect the desired features was selected for further studies. The software used in this study was GVERSE Attributes from LMKR and it should be noted that the attributes applied here may have different commercial names in other industrial programs.

1.2 Methodology

The seismic attributes used in the study of the faults are those that can detect disruption of the data. Attributes used here are discontinuity, coherence, semblance, dip-magnitude, azimuth, and most positive and most negative curvatures. A brief review of these attributes is given below ^[6]:

Discontinuity shows the dissimilarity of amplitude and phase of reflections between traces. Faults are one of the features causing abrupt changes in seismic data, hence, can be detected using discontinuity attribute.

Coherence is, in fact, complimentary of the discontinuity. It shows the degree continuity of seismic events. There are

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different methods for calculating coherence among which the eigenvalues method has been used here. Since the existence of faults results in the low similarity of reflections with the surroundings, areas with low coherence can be an indication of such phenomena.

Semblance like coherence is a measure of comparability in seismic data. In this case, as the name suggests, the method used to compute similarity is semblance. Having geological features like channels, faults, and sharp changes in sedimentological facies results in a decrease of the similarity of the data; therefore, low semblance.

Dip-magnitude computes the slope in different directions in data and considers the highest value as a dip. Consequently, events with different dips can be differentiated with the aid of this attribute. Faults causing layer movement on the fault plane sides can be seen as dipping events on seismic data. Although, it should be considered into account that like other attributes, they are not the only geological events that can produce anomalies in data. Also, strike-slip faults are not accompanied by vertical movements and may not be seen using this tool.

Azimuth attribute computes the direction of the maximum dip at each location. It usually accompanies the dip-magnitude attribute. Using this property, dipping events with different orientations can be separated.

Curvature quantifies the rate of change of dip and azimuth of seismic events. Since the dip and azimuth change in different directions, curvature produces a series of values including maximum curvature, minimum curvature, Gaussian curvature, most positive curvature, most negative curvature, ... among which the last two have shown to be more useful in fault study. Faults usually cause positive curvature on the upthrown and negative curvature on the downthrown side of the fault plane. Hence, they can be seen on the curvature attribute.

1.3 Results and Discussion

A case history from Malaysian basin illustrates the application of multi-attribute for faults and fractures enhancement in the data. Time slice at 1950 ms of the original migrated seismic cube was chosen for the study purpose as shown in Figure 1. Two events are apparent in data near each other (the green arrow shows a fault and the yellow box is surrounded by an anticline). To evaluate the significance attributes to differentiate such geological features the study was focused on the selected area shown with the brown box in Figure 1.

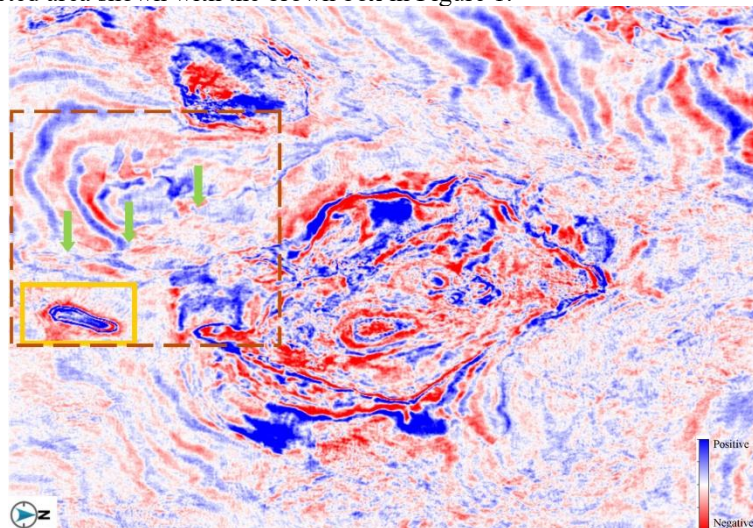


Figure 1. A Time slice from the input data at 1950 ms. The green arrows mark a Major fault plane and the yellow box encloses an anticlinal structure. For a more detailed study, the area shown by the brown box is zoomed in following figures.

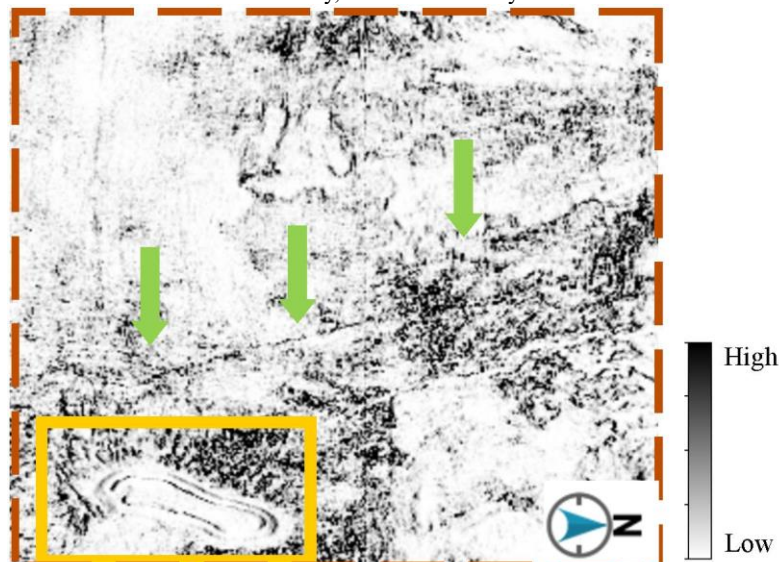


Figure 2. Application of discontinuity attribute applied to the full-migrated seismic data. The green arrows mark a Major fault plane and the yellow box encloses an anticlinal structure. The continuity of major fault in the study area is represented by these green arrows.

Figure 2 shows the result of applying the discontinuity attribute on the seismic data at the zoomed part of the same time slice selected in Figure 1 higher similarity of the reflection to its neighbors results in the lower value of this attribute. On the contrary, the presence of abrupt changes in data produces bigger values. In case of a fault in data (green arrows), the color is black, while for the anticline (yellow box), the values are lower shown by whitish color. The anticline boundary shows a nearly perfect picture of the anomaly which is the result of discontinuities in the structure.

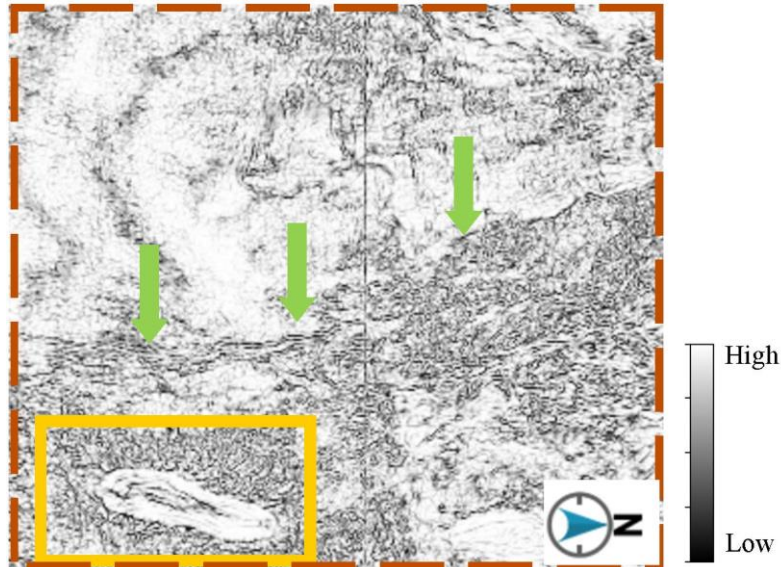


Figure 3. Coherence attribute applied to the input seismic data. The green arrows mark a Major fault plane and the yellow box encloses an anticlinal structure.

The result shown in Figure 3 is the application of Coherence attribute. In this attribute, on the contrary of the previous attribute, the lower similarity results in lower values. Though the fault trend is recognizable, the general resolution of the output data seems lower, compared to Figure 2. However, more details are visible here. For the anticline, coherence has high values (toward white) which confirm the results of the previous attribute; and more details are seen both around and on the structure itself.

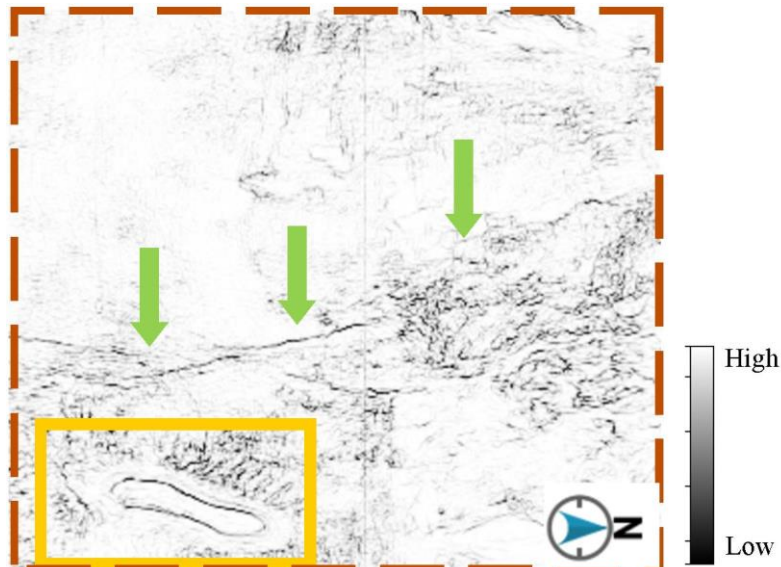


Figure 4. Semblance attribute applied to the migrated seismic data. The green arrows mark a Major fault plane and the yellow box encloses an anticlinal structure.

Semblance is the one of the attributes applied to the data (Figure 4). This attribute has the same nature as the coherence, but the method of calculation is different. In fact, the three attributes are applied to differentiate the similar and dissimilar features in seismic data; those are commonly used interchangeably and called discontinuity attributes in general. Comparing the results with Figure 2 and 3 with Figure 4 demonstrate that the resolution is higher while details are preserved. Both fault and anticline are well preserved by this discontinuity attribute.

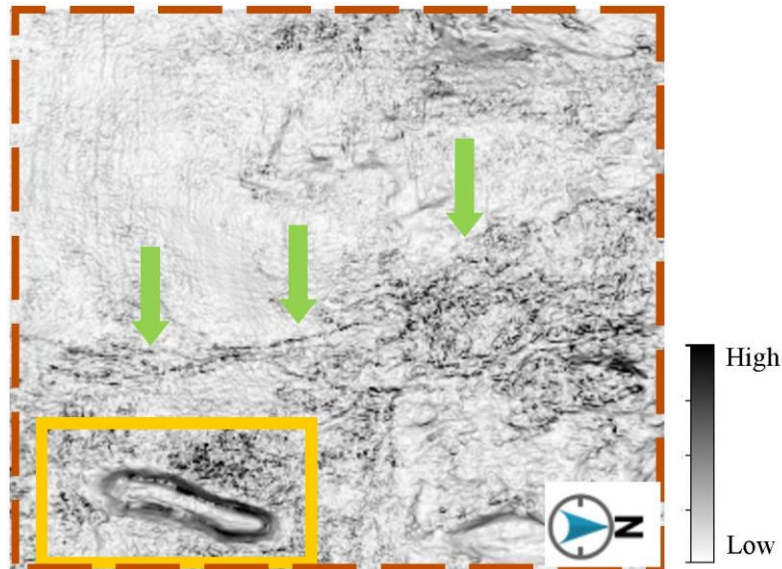


Figure 5. Application of Dip-magnitude attribute to the input seismic data. The green arrows mark a Major fault plane and the yellow box encloses an anticlinal structure.

Figure 5 shows the application of dip-magnitude attribute that identifies the calculation of geological events and the differentiation is done based on the inclination of the structure. The fault is reasonably spotted in this figure with higher dip values. This indicates that the layers on the sides of the fault plane have moved vertically, creating a dipping fault surface. The anticlinal structure is also presented very well as its limbs have high values while near the hinge the color shows lower values.

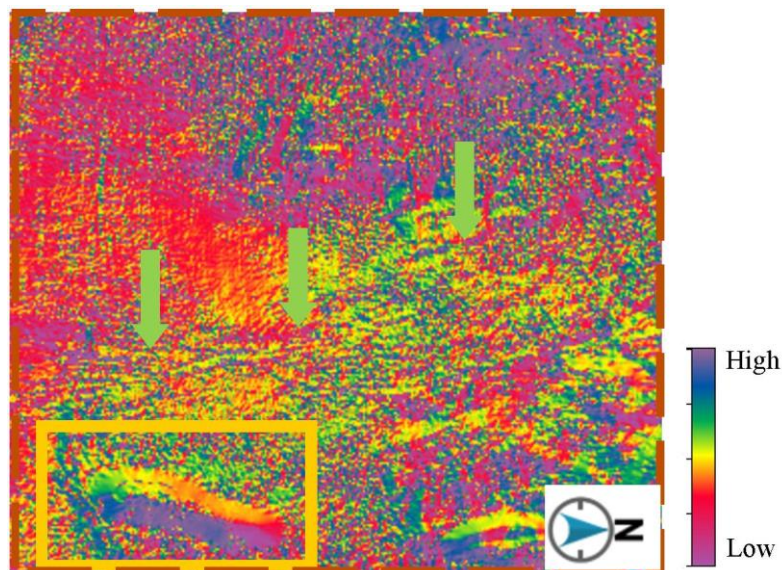


Figure 6. Presentation of Azimuth attribute to the input migrated seismic. The green arrows mark a Major fault plane and the yellow box encloses an anticlinal structure. The green arrows do not follow the same trend in this attribute.

The attribute evaluated here is the Azimuth as shown in Figure 6. Dip and azimuth attribute usually accompany each other because the azimuth shows the direction of dip at each location. Although the fault plane is not distinguished by this attribute, there are lots of east to west features with a good resolution not well visible by other attributes used till here. It may be because the fault plane is not a straight line so it is not seen as a continuous plane, while those features no matter how small have the same direction. In contrast, the anticline in the section is seen with a high resolution and its hinge is picked easily. The difference between the two limbs is nearly 180 degrees as expected.

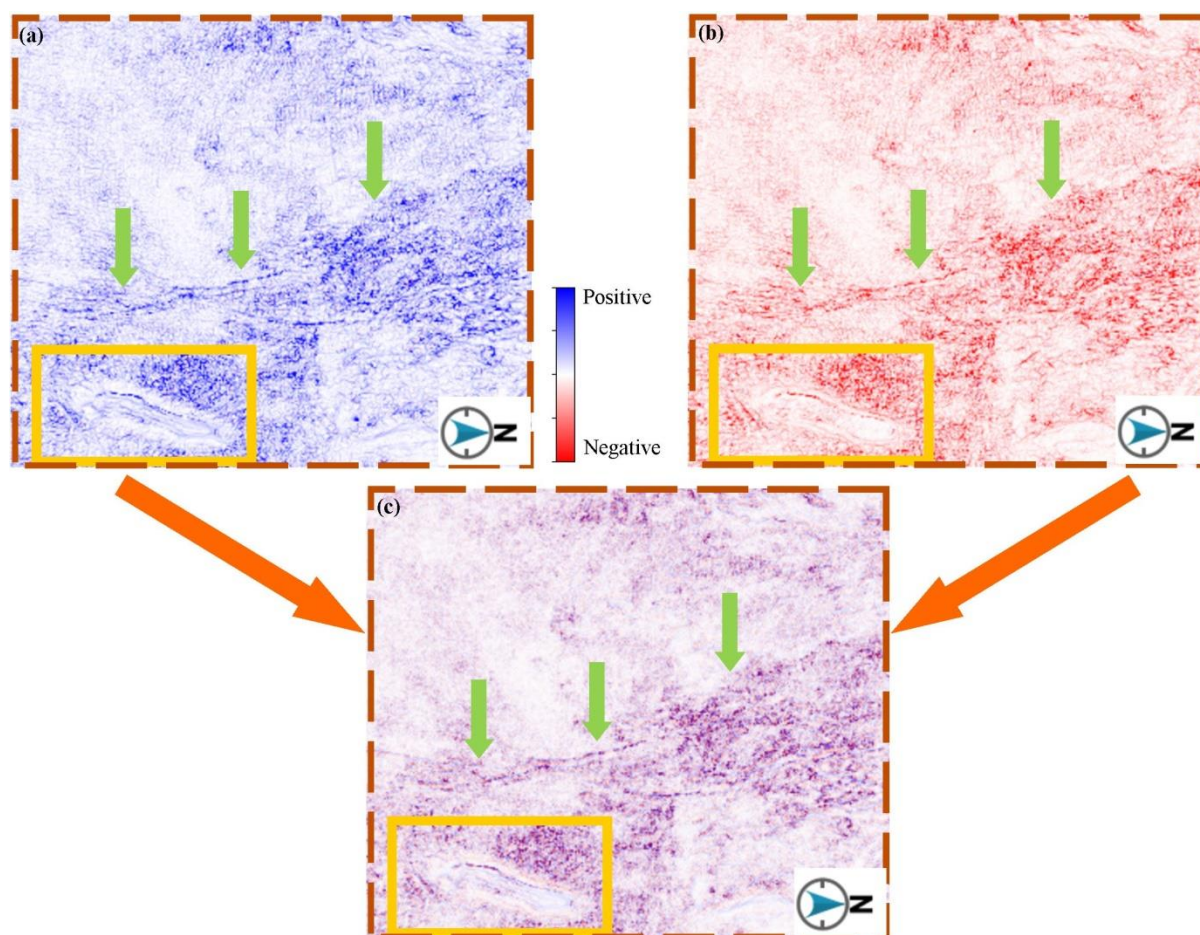


Figure 7. Multi-attribute application based on curvature, (a) Most positive curvature, (b) most negative curvature, and (c) co-blended attributes. The green arrows mark a Major fault plane and the yellow box encloses an anticlinal structure. The location of the fault plane is slightly different in (a) and (b) showing the upthrown and down thrown sides of the fault plane respectively.

The final testing of attributes study that is applied to the data here is the curvature. Two mostly well-known curvature attributes for discontinuity study are selected: most-positive curvature and most-negative curvature which are shown in Figure 7a and b respectively. As mentioned previously, the upthrown side of the fault has the positive curvature; hence, shown in most positive curvature. On the other hand, the downthrown side is expected to be seen on the most negative data. This result in some relocation of the fault plane when comparing the results of the two curvature attributes as seen in the co-blended attribute (Figure 7c). This phenomenon provides additional information about the layer movement on the sides of the fault plane. In the case of the anticline, the interesting point is the higher resolution of the most-positive curvature attribute compared to the most-negative one. This is obviously a consequence of positive curvature in anticlines. The boundary, of course, is better indicated on the most-negative curvature attribute.

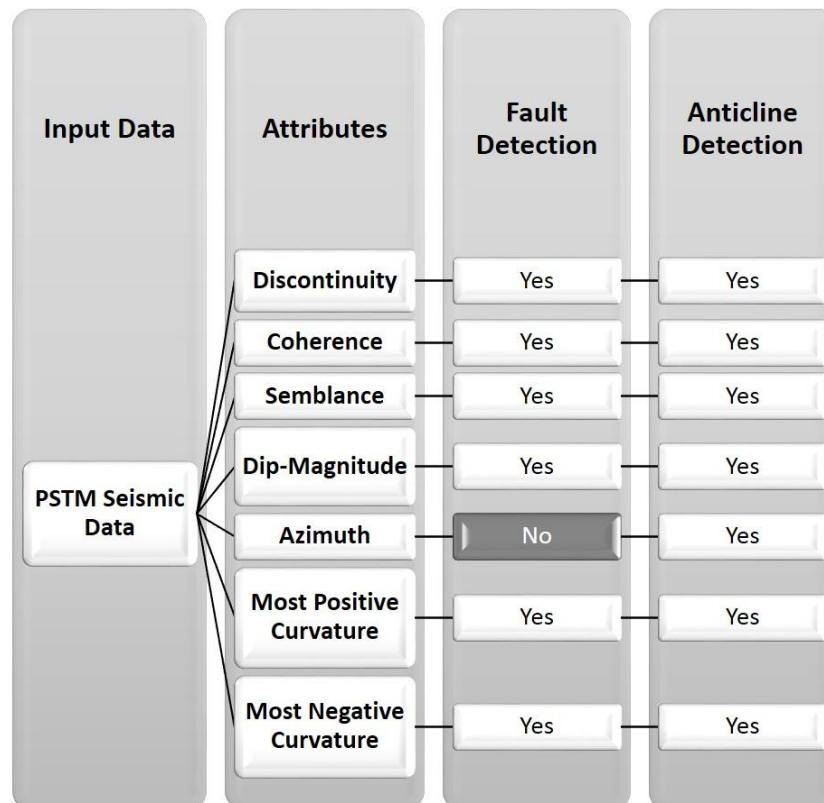


Figure 8. Summary of the results based on the study in Malaysian Basin.

Performance of different attributes in this study is summarized in Figure 8. The results show that all attributes used for this case can identify the fault (except the azimuth) with different resolution and details. The anticlinal structure, on the other hand, is singled out by all attributes and the azimuth can additionally mark the hinge of the structure. Therefore, it was decided to use all the studied attributes for the area of interest and combine the extracted the geological anomalies together.

2. Conclusion

Most of the stratigraphic interpretation begins with structural identification because the multi-attribute analysis can reveal lots of data that was not available by using just one attribute. An integrated approach is used to study the structural patterns and faults identifications. Although seismic attributes are powerful tools for identifying geological anomalies, their performance is mainly dependent on the characteristics of the geological settings. In the area of study, nearly all attributes (except azimuth) could determine the general trend of the fault. For the anticlinal structure though, all attributes provided good results. As it was shown, the single attributes could not identify all the desired geological details. To compensate for this, it is better to extract the geological events with different resolutions using different attributes based on the level of details needed and combine the results to get the desired output.

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