Composite attribute from spectral decomposition for fault detection

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Summary

A composite fault detection attribute is produced by Adaptive Principal Component Analysis of attributes derived from spectral decomposition. The composite fault detection attribute looks similar in time slice view to conventional attributes such as coherency and curvature but is far more readily interpretable in vertical cross-section view. Detailed interpretation of time slices reveals that window based attributes such as coherence can exhibit discontinuities in the incorrect spatial position if the time slice does not correspond to the strongest event in the window. This problem is less severe on time slices of the composite fault detection attribute and faults are thus, more correctly located. These ideas are demonstrated in a case study in the Hitts Lake Field, where faults are verified by missing section in well logs.

Introduction

The use of geometric attributes, in combination with seismic data, is a standard procedure for structural interpretation. These are used for fault picking, structural model construction, and reservoir characterization, among other things. The application of these geometrical attributes helps the interpreter highlight seismic discontinuities, which then contributes to the construction of a structural model that uses the most information extracted from the dataset at hand.

We propose a composite seismic attribute that detects discontinuities while discriminating faults from interface reflections. This allows the user to interpret in vertical sections more clearly and with more precision and to observe a clearer structural view in time slice.

This technique applies a variety of geometrical attributes to the phase spectra obtained from spectral decomposition, allowing better definition of specific targeted discontinuities that are frequency dependent. These frequency dependent attributes are combined using Adaptive Principal Component Analysis.

Method

The proposed fault detection attribute, as other discontinuity detection attributes, is highly dependent on signal to noise ratio, therefore, the first step in the processing sequence is to suppress noise. The main objectives of this step are to remove random noise and generate an input for the attribute that is also amplitude balanced laterally. Once this is achieved, the following workflow (Figure 1, Modified from Barbato, 2013) is applied (Barbato, 2013, Qi and Castagna, 2013):

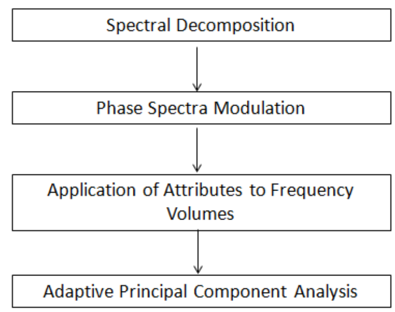

Figure 1. Workflow to produce the proposed attribute

The spectral decomposition method applied is Constrained Least Squares Spectral Analysis (Puryear, et al 2012). This spectral decomposition technique suffers less loss of frequency resolution as a result of windowing when compared to other methods and thus allows very small windows to be used. In this study a 20 ms time window is employed. The interpretation of the resultant frequency dependant volumes will be objective dependant. Different discontinuities will be imaged at different frequencies.

Browaeys (2009) comments that seismic discontinuities are more sharply observed in the instantaneous phase. Still subject to energy absorption effects (to a lesser degree than amplitudes), the discontinuities in the phase spectra are more clearly observed (Taner, 1992). The amplitude modulated cosine phase spectra are used to avoid phase unwrapping effects and to retain amplitude discontinuities even when phase is fortuitously continuous across a fault.

Various primitive geometrical attributes are applied to the spectra to better highlight discontinuities. Some of the commonly tested attributes are coherence, chaos, multiple curvatures, variance, phase derivatives, etc. This step produces multiple inputs for the Adaptive Principal Component Analysis. The list of primitive attributes to be used is user defined and usually chosen after testing various combinations in a particular case.

The Adaptive Principal Component Analysis combines the primitive attributes in a locally adaptive spatially and temporally varying manner into orthogonal variables that are not correlated to each other. The first few components represent the large majority of the variance in the input attributes, organized so as to discard background responses that are observed in the individual input attributes. The final combination is selected so as to emphasize discontinuities oblique to the regional dip and strike. Obviously, fault planes that are not discordant in three dimensions with stratigraphic layering will not be detected. Conversely, the attribute will not be confounded by layering as are most common discontinuity attributes.

Hitts Lake Field Example

The composite discontinuity attribute was applied to a 3D seismic survey shot over the Hitts Lake Field, with production over the Paluxy Formation (Caughey, 1977). The main structural features observed in the area are related to normal faulting and salt domes (Jackson, 1982). A series of grabens were formed by the "subsidence of the East Texas Basin with respect to the Ouachita Belt" (Barbato, 2013). The objective of this test is to best map the faults that form one of the grabens.

The amplitude spectrum of the input seismic is approximately from 10 to 70 Hz.

Figure 2 shows a vertical slice where we can observe the graben to be mapped on the a) seismic data and b) fault detection attribute. The third panel (c) shows an overlay of the attribute (changed to a black and white color scale and then setting the background as a transparency) over the seismic data. The excellent correlation between these visible discontinuities and the composite fault detection attribute is evident in this overlay.

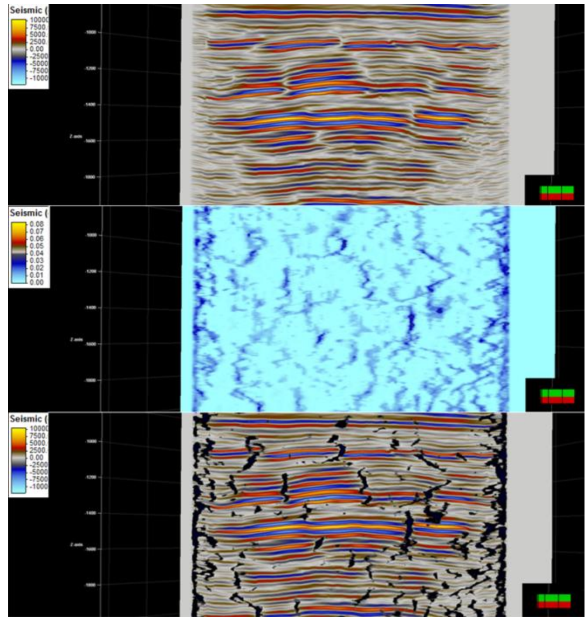

Figure 2. Seismic section showing the graben to be studied. a) Input seismic, b) fault detection attribute, c) fault detection attribute over the input seismic.

Figure 3 shows a time slice where the lateral extent of the graben can be observed. Poor data quality at the edges of the small 3D survey are apparent and should be ignored for this analysis. Again an excellent correlation between visible discontinuities on the input seismic and the response of the fault detection attribute can be seen.

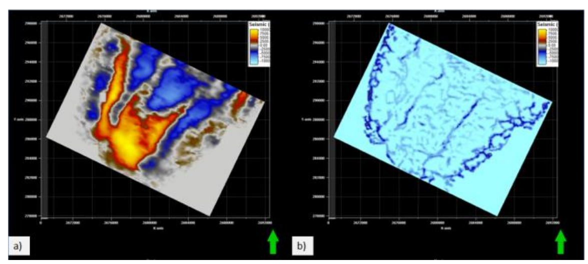

Figure 3. Time slice showing the lateral extent of the graben.

We can compare this result to some of the commonly used attributes in the industry. Figure 4 shows the proposed attribute versus Variance and Most Positive Curvature in a vertical section.

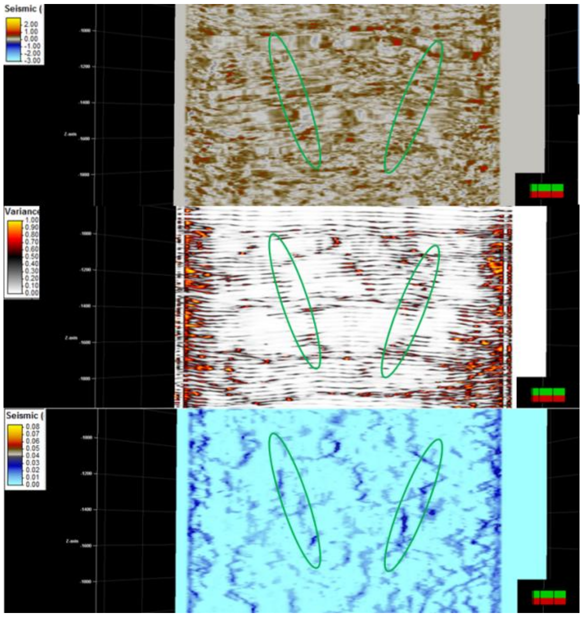

Figure 4. Vertical section showing a) Most Positive Curvature, b) Variance, and c) the composite fault detection attribute.

The vertical cross-section comparison of the fault detection to some of the commonly used attributes in the industry (Figure 4) indicates much better immunity from apparent discontinuities caused by stratigraphic layering. In time slice view, for conventional attributes, dipping reflectors can produce false fault traces. Figure 4 also shows an improvement of vertical connectivity of faults.

Figure 5 shows a time slice with the input seismic, the proposed attribute, Variance, and Most Positive Curvature. The faults that encompass the graben are clearly observed in the conditioned seismic and the proposed attribute. The Variance attribute shows events parallel to these faults, but appear to be laterally displaced. The curvature attribute shows both faults as well, but also show a crisscross pattern in between the faults that resembles acquisition footprint (not observed in the input seismic). Figure 6 shows a perspective of the time slice and vertical sections previously reviewed with (a) the conditioned seismic and overlays of (b) fault detection composite attribute (black), (c) fault detection composite attribute (black) and Variance (pink) and (d)fault detection composite attribute (black)and Most Positive Curvature (green). The yellow ovals show more clearly the spatial displacement of the faults picked by Variance and Most Positive Curvature, when compared to the seismic; the proposed attribute appears to place the faults in the correct location.

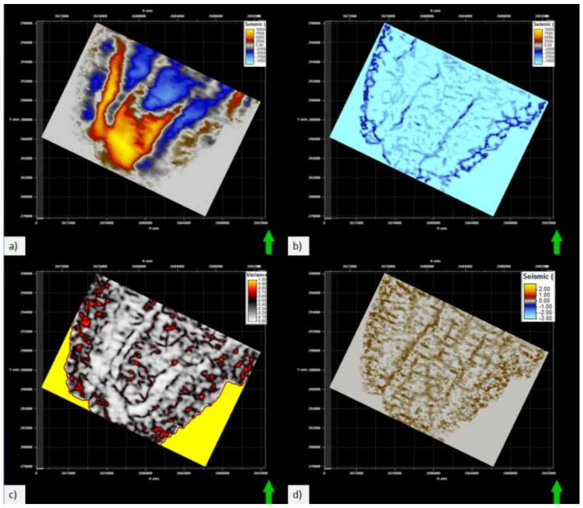

Figure 5. Time slice showing a) Conditioned Seismic b) composite fault detection attribute, c) Variance, and d) Most Positive Curvature.

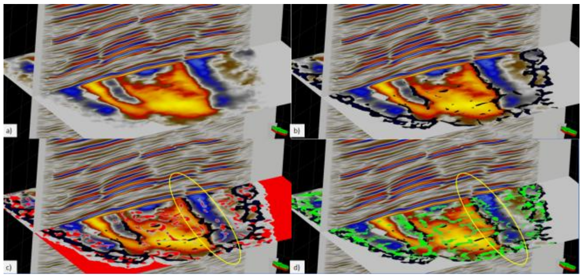

Figure 6. Time slice showing a) Conditioned Seismic and overlays of b) the composite fault detection attribute (black), c) Variance (red), and d) Most Positive Curvature (green) over the conditioned seismic.

Another method of validation of the technique is to observe the presence of these faults at well locations.

Figure 7 shows a cross-section with wells that go through some of these faults. The cross-section shows two dashed lines that correlate the formation tops in both wells. In between these two lines we can note the missing section, which allows us to place fault cut at the well location, at 6970 ft (red continuous line).

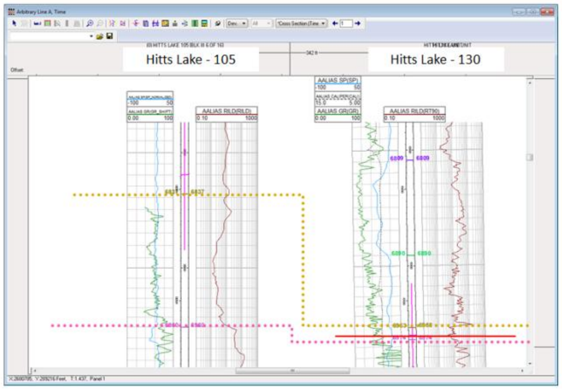

Figure 7. Close up on a cross-section where we can observe missing log sections. The logs observed are Gamma Ray (in green), SP (in blue), and Resistivity (in maroon). The dashed lines show the formation tops correlation and the red continuous line the fault at the well.

Figure 8 shows an arbitrary line that connects wells that have the previously observed fault present. The markings in the wells (for this fault, in pink) correspond to the fault cuts interpreted. The green box shows the fault cut observed in figure 7. It can be seen that the fault cuts are associated with a discontinuity indicated by the composite fault detection attribute. A very good correlation is also observed in other interpreted fault cuts

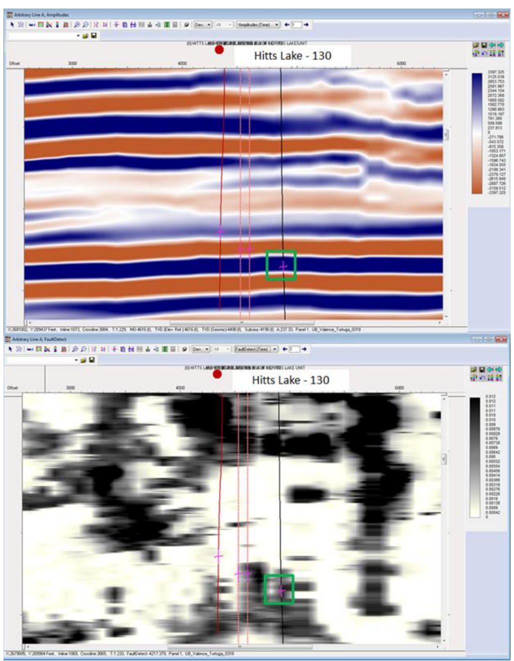

Figure 8. Vertical sections of a) input seismic, and b) composite fault detection attribute; showing the fault interpreted at the well.

The excellent correlation between well data, seismic data, and the composite fault detection attribute permits us some confidence regarding the effectiveness of the attribute to detect faults in this case.

Finally, figures 9 shows 2 vertical sections (a) the original seismic, and (b) the original seismic with a geobody extracted from the composite fault detection attribute. In light green we can observe the fault plane geobody of one of the seismic discontinuities related to the graben showing that the seismic discontinuities planes can be reasonably well tracked for geobody determination using the composite attribute. This is typically not possible with conventional fault detection attributes without resorting to methods such as ant tracking.

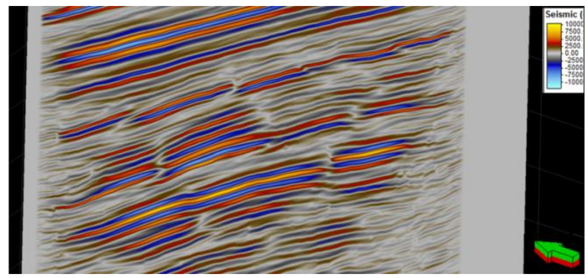

Figure 9a. Vertical section of the input seismic.

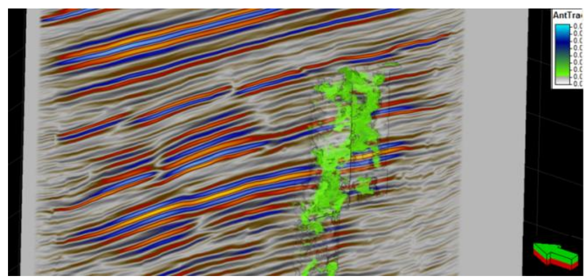

Figure 9b. Vertical section of the input seismic showing two faults related to the graben. In light green the fault plane of one of the main seismic discontinuities is displayed.

Conclusion

A composite fault detection attribute derived from Adaptive Principal Component Analysis of geometric attributes derived from spectral decomposition can be superior to conventional fault attributes in that the composite attribute (1) is more interpretable than conventional attributes in cross-section views such as inlines and crosslines, and (2) shows discontinuities that are spatially more correct on time slices. The detected discontinuities are verified by visual comparison to original seismic data and were verified by fault cuts in wells in the Hitts Lake Field.

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