Fault detection using coherency attribute in Khangiran gas field, Iran

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ABSTRACT

The final step of a seismic exploration project is data interpretation which is a blend of art and science. In modern interpretation procedures use of attributes are inevitable. In other words, the interpreter cannot extract full information from seismic data without use of these kinds of tools. Today, attributes have a proven role in recognition of buried deltas, river channels, reefs, fans, faults and similar structures. Generally, seismic attributes describe relation between seismic data and measure of seismic characteristic of interest. The growth of attributes is very high and many attributes have been introduced by researchers so far. Each one of these attributes work on different mathematical basis and can show special aspects of data.

One of modern seismic attributes is coherency which has an important role in interpretation of structural discontinuities and stratigraphy features in 3D data. This attribute measures the similarity of traces in three dimensions and therefore present interpretable changes in these cases. The similar traces are mapped with high coherency coefficients while anomalies as well as discontinuities have low coefficients. The output of this algorithm is a coherency cube. In this cube, structural discontinuity and stratigraphic faces will be depicted with a better resolution.

The objective of this study is fault detection using coherency attribute based on crosscorrelation and eigenstructure. We showed the output of these algorithms on 3D synthetic models of low SNR. Also, we applied this attribute on Khangiran gas field data. As the results show this attribute can facilitate faults recognition. The comparison of crosscorrelation and eigenstructure methods shows the latter one can map faults with a better lateral resolution and vertical resolution.

KEY WORDS: crosscorrelation, eigenstructure, fault, analysis cube, eigenvalue, coherency cube

INTRODUCTION

Seismic attributes are all the information obtained from seismic data, either by direct measurements or by logical or experience-based reasoning (Taner, 2001). Generally, they describe seismic data which represent an interface property wherein reflection events are seen due to relative changes in acoustic impedance of adjacent layers. Coherency is a mathematical measure of similarity, which gives an indication of the continuity between two or more windowed seismic traces (Gersztenkorn and Marfurt, 1999). In effect, attribute computations decompose seismic data into constituent attributes.

Coherency cube is a cube of coherency coefficient that depicts faults and other stratigraphic anomalies clearly, on time or horizon slices. These images show up data characteristics. So, coherency cube can extract detail features from data cube with a good efficiency.

There are three algorithms to measure coherency: crosscorrelation, semblance and eigenstructure that are based on continuity of traces in time/depth windows. Input of this attribute is a 3D seismic data. Similar traces are mapped with high coherency coefficients and no similar traces get low coefficients. The first coherency algorithm based on crosscorrelation was proposed by Bahorich and Farmer (1995). The second one introduced by Marfurt et al. (1998) based on semblance. And the third coherency algorithm introduced by Gersztenkorn and Marfurt (1999) based on eigenstructure.

COHERENCY ALGORITHM BASED ON CROSSCORREALTION

This algorithm (Bahorich and Farmer, 1995) uses time-lag crosscorrelation to estimate the apparent dips in the in-line and x-line directions for three traces. This algorithm is based on normalized crosscorrelation.

For coherency computation the base trace and two traces in its adjacent are selected. Then, coherency is measured in the in-line and x-line directions for the specific time window. After normalizing, results are summed with each other. This coherency is assigned to the center of the time window of the base trace. This process is applied to all time windows of the base trace. Then, it moves to the other traces of the seismic volume for generating the coherency cube.

COHERENCY ALGORITHM BASED ON EIGENSTRUCTURE

Gersztenkorn and Marfurt (1999) introduced this algorithm. Traces continuity is estimated using covariance matrix. For coherency estimation, a subvolume of 3D data cube is selected, that is defined as analysis cube. It moves throughout data volume in all 3 directions (in-line and x-line directions trace by trace and time/depth direction sample by sample). Value of coherency is assigned to the center of analysis cube. Size and shape of analysis cube depends on geological features. In order to find the final coherency value of this cube we reshape this 3D matrix to a 2D matrix (matrix D). Traces are placed successively in the in-line direction; the order of traces are not important (e.g., 3 in-line traces by 3 x-line traces for a total of 9 traces). After obtaining matrix D, covariance matrix is defined as
equation (1):
\[ C = D^T D \] 
where, \( C \) represents the product of transpose of matrix \( D \) by matrix \( D \).

Eigenvalues are calculated in order to estimate coherency of eigenstructure. The largest eigenvalue is divided by sum of eigenvalues. This value is eigenstructure coherency estimate for specific analysis cube. This process will be repeated for other analysis cubes and finally, coherency cube is obtained.

SYNTHETIC DATA

Coherency attribute is applied to 3D synthetic models of low SNR. Results showed that it can detect faults with short vertical duration. It depends on three parameters: dominant frequency, SNR and time window (crosscorrelation) or analysis cube (eigenstructure).

The 3D synthetic model has dominant frequency of 30 Hz and SNR=2. This model consists of three horizontal layers and two dipping layers. Size of synthetic model is 2500 m in the in-line direction and 2500 m in the x-line direction and 1200 ms in the time direction. Trace interval is 25 m and sample interval is 4 ms.

Figure 1a shows vertical cross-section in the in-line direction. Figures 1b and 1c show two vertical cross-sections based on crosscorrelation and eigenstructure algorithms, respectively. Comparison of figures 1b and 1c show that these algorithms could detect f, g and h fault planes. These figures show that resolution of coherency attribute derived from eigenstructure is better than from crosscorrelation.

REAL DATA

Real data is a time migrated 3D from one of the oil fields situated in north eastern of Iran (Khangiran). The size of data is 2525 m in the in-line direction, 1775 m in the x-line direction with 1 sec length. Trace interval is 25 m and sample interval is 4 ms.

Figures 2a and 2b show two time slices at 260 ms and 848 ms, respectively. Figure 3a shows vertical cross-section in the in-line direction (AA’ line) of the 3D seismic data. Figures 3b and 3c show two vertical cross-sections based on crosscorrelation and eigenstructure algorithms, respectively. Figure 4a shows vertical cross-section in the x-line direction (BB’ line) of the 3D seismic data. Figures 4b and 4c show two vertical cross-sections based on crosscorrelation and eigenstructure algorithms, respectively.

Figures 5a and 5b show time slices through the crosscorrelation and eigenstructure based on coherency volume at 260 ms, respectively. Figures 6a and 6b show time slices through the crosscorrelation and eigenstructure based on coherency volume at 848 ms, respectively.

As these figures show, the coherency attribute can depict fault planes much better in comparison with using amplitude view. According to figures 3 to 6, comparison of coherency cube images show the resolution of eigenstructure based on coherency attribute is better than crosscorrelation based on coherency attribute in faults detection both in lateral and vertical direction.

RESULTS

The efficiency of coherency attribute was tested on both synthetic and real seismic data. This attribute showed its potential to delineate fault planes with very small movement. In this paper, crosscorrelation and eigenstructure coherency approaches where tested. The latter one showed that is much more powerful in small faults delineation than the former one.

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REFERENCES


Figure 1. Efficiency of coherency attribute for fault detection on a synthetic model; (a) seismic cross-section with SNR=2, (b) coherency cross-section based on crosscorrelation and (c) coherency cross-section based on eigenstructure. Resolution of coherency attribute based on eigenstructure is much better.

Figure 2. Two time slices through 3D seismic data cube at (a) 260 ms and (b) 848 ms. AA’ line and BB’ line are cross-sections in the in-line and x-line directions, respectively. Blue indicates low coherency and red indicates high coherency.
Figure 3. Efficiency of coherency attribute for fault detection on AA' line; (a) seismic cross-section, (b) coherency cross-section based on crosscorrelation and (c) coherency cross-section based on eigenstructure. Resolution of coherency attribute based on eigenstructure is much better. Dashed lines indicate faults.
Figure 4. Efficiency of coherency attribute for fault detection on BB’ line; (a) seismic cross-section, (b) coherency cross-section based on crosscorrelation and (c) coherency cross-section based on eigenstructure. Resolution of coherency attribute based on eigenstructure is much better. Dashed line indicates fault.
Figure 5. Efficiency of coherency attribute for fault detection at 260 ms; (a) coherency time slice based on crosscorrelation, (b) coherency time slice based on eigenstructure. aa’ shows the fault much better in comparison with figure b.

Figure 6. Efficiency of coherency attribute for fault detection at 260 ms; (a) coherency time slice based on crosscorrelation, (b) coherency time slice based on eigenstructure. The faults aa’, bb’ and cc’ are showed better in comparison with figure b.