Detecting stratigraphic features via crossplotting of seismic discontinuity attributes and their volume visualization

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Over the last decade, our industry has witnessed steadily increasing computer power, core memory, peripheral storage, and advanced display technology, as well as development of commercial software backed by dedicated research efforts. These developments have lead to a moderate acceptance of volume interpretation of 3D seismic data by the geoscience community. 3D volume rendering is one form of visualization that involves opacity control to view the features of interest "inside" the 3D volume. A judicious choice of opacity applied to edge-sensitive attribute subvolumes, such as curvature or coherence, corendered with the seismic amplitude volume can both accelerate and lend confidence to the interpretation of complex structure and stratigraphy.

In addition to corendering, we evaluate an interpretation workflow that crossplots pairs of edge-sensitive attributes. By crossploting coherence and an appropriate curvature attribute, we can define a polygon that highlights "clusters" that exhibit both low coherence (indicating a discontinuity) and high curvature (indicating smoother deformations). Modern volume-interpretation software allows us to link and display these interpreter-defined clusters in the seismic volume for further examination. We illustrate the application of this new workflow through application to two 3D seismic surveys recently acquired in western Canada and demonstrate that multi-attribute volume corendering and clustering provides a powerful tool that leads to a better understanding of the spatial relationships between seismic attributes and the geologic objectives being pursued.

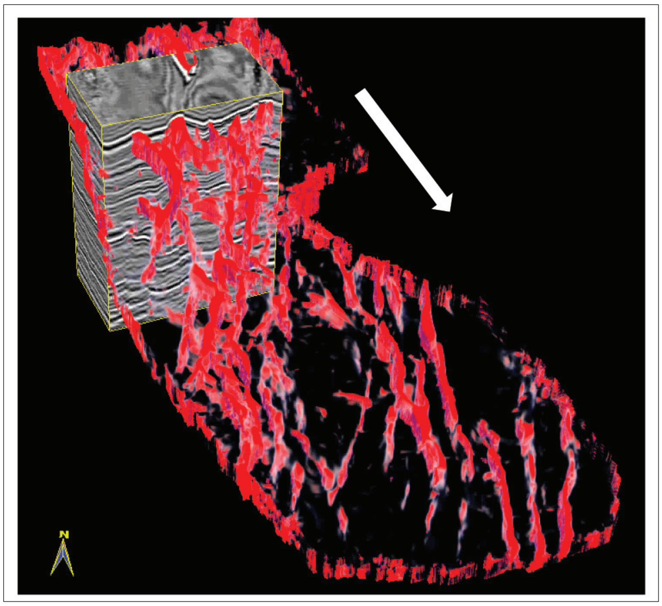

Figure 1. A stratal fault skeleton resulting from the most-positive curvature attribute being correlated with seismic data by interactively expanding the seismic subvolume in the increasing inline direction (indicated by the white arrow).

Introduction

Fold and fault geometries, stratal architecture, and large-scale depositional elements (e.g., channels, incised valleys, and turbidite fan complexes) are often difficult to see clearly on vertical and horizontal slices through reflection data. 3D visualization techniques provide an alternative, interactive means of viewing amplitude and attribute volumes that facilitates the extraction of meaningful information and improves interpretation accuracy and efficiency. Traditional 2D interpretation workflows consisted of picking faults and horizons on dip and strike lines to generate time-structure maps through gridding and contouring. With the advent of 3D data, this interpretation workflow was morphed into picking, say, every 10th inline and 10th crossline. Later improvements included direct interpretation of time slices and the use of automatic picking algorithms. Old and young geophysicists are familiar and adept at this traditional approach.

Early implementations of 3D volume rendering were limited to "upscale" interpretation packages running on rather expensive computer and graphics hardware. Driven by the rapid development of "computer gaming" hardware, high-performance graphics software is now available on almost any PC, including laptops. In spite of this increased availability, the acceptance of 3D visualization has been relatively slow, particularly by the "more experienced" members of the interpretation community.

3D visualization of seismic data is an efficient way of displaying structural or stratigraphic hydrocarbon traps in their true three-dimensional perspective, allowing interpreters to comprehend the complex geometric inter-relations of horizons with faults and deviated well penetrations. The interpreter chooses a seismic amplitude or attribute subvolume of interest, interactively adjusts and applies the opacity, thereby delineating geologic features of interest in their true disposition. The interpreter is able to rapidly evaluate structural relationships between reflectors, faults, and diapirs, and highlight depositional features such as channels and carbonate buildups, significantly enhancing the understanding of features seen on vertical sections and maps.

A judicious choice of opacity in the attribute subvolume is key to its correlation with the amplitude volume. If fault correlation in the zone of interest is the objective, a useful procedure that could be used is shown in Figure 1. First we generate a strat-cube encompassing the zone of interest from the most-positive curvature attribute volume. Then, using opacity control features, we retain only the high values displayed in red resulting in the fault skeleton which we corender with the seismic volume for visual correlation. Animation of the seismic inlines in the direction of the white arrow helps

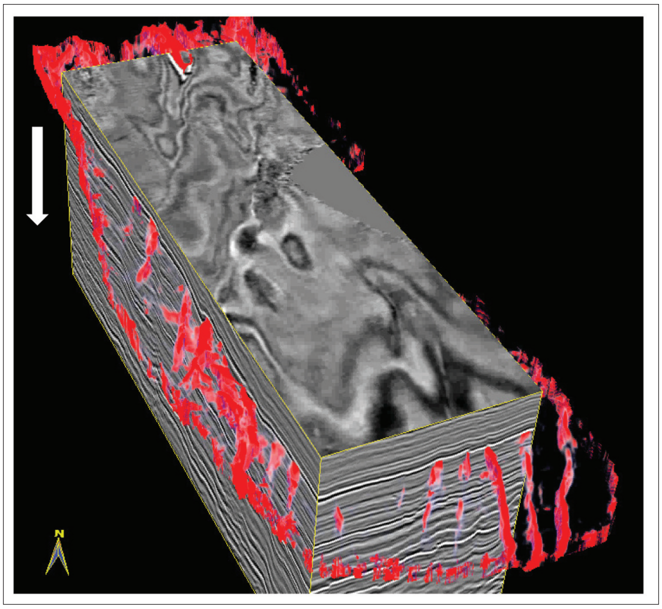

Figure 2. A stratal fault skeleton resulting from the most-positive curvature attribute being correlated with seismic data by interactively expanding the seismic subvolume in the increasing time direction (indicated by the white arrow).

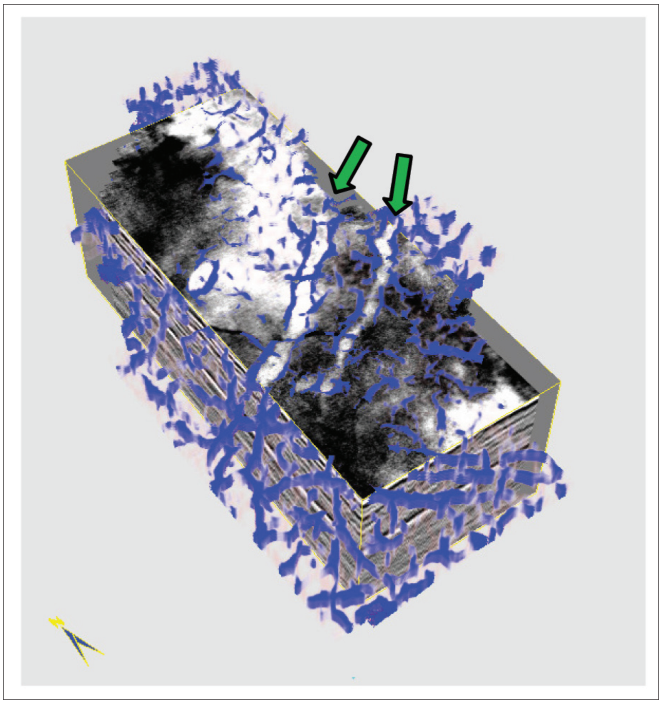

Figure 4. A fault skeleton resulting from the most-negative curvature attribute being correlated with seismic data exhibiting channels with differential compaction.

the interpreter determine whether the vertical red planes represent faults, axial planes of tight anticlines, or artifacts introduced through acquisition and processing. Once this is checked, similar animation should be carried out in the cross-line and time-slice directions (Figure 2).

In Figure 3, we show the correlation of the seismic signatures with the faults as seen on the stratal coherence skeleton. Notice that in addition to the main faults (some indicated

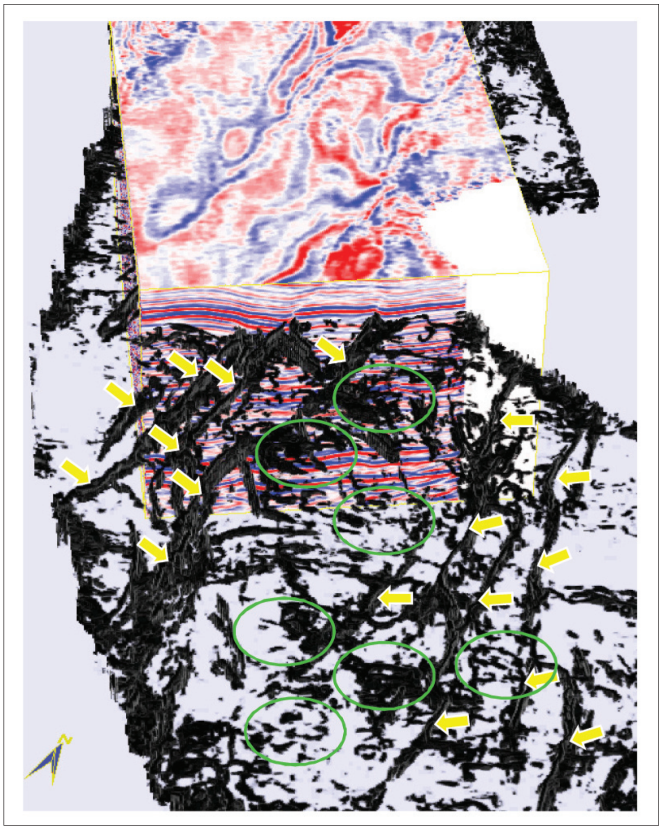

Figure 3. A stratal fault skeleton resulting from the coherence attribute being correlated with the seismic data volume. Notice that in addition to the main faults (some indicated with yellow arrows) which stand out clearly, a number of low-coherence features (some shown with green circles) clutter the display and create problems in fault interpretation.

with yellow arrows) which stand out clearly, a number of low coherence features (some shown with green circles) clutter the display and complicate our fault interpretation. We will address suppressing such unwanted features with the help of attribute crossplotting in the next section.

A similar workflow helps in mapping stratigraphic features such as channels. Careful line-by-line mapping of subtle amplitude anomalies sometimes associated with channels is a tedious, time-consuming process. With the aid of modern opacity control features, the channel can be rapidly isolated. Figure 4 shows the result of such an exercise, where due to differential compaction, the edges of the channel are seen clearly on the most-negative curvature instead of the usual most-positive curvature (and the channel axis, or thalweg, shows up as a positive anomaly on most-positive curvature).

Multivolume rendering

The previous workflow involved displaying an attribute volume with opacity controls and with opaque seismic lines and time slices. In Figure 5 we show a seismic volume corendered with coherence. We are also able to view multiple 3D volumes within the same congruent 3D space. We find corendering coherence or the most-positive (or depending on the geologic features of interest, most-negative) curvature

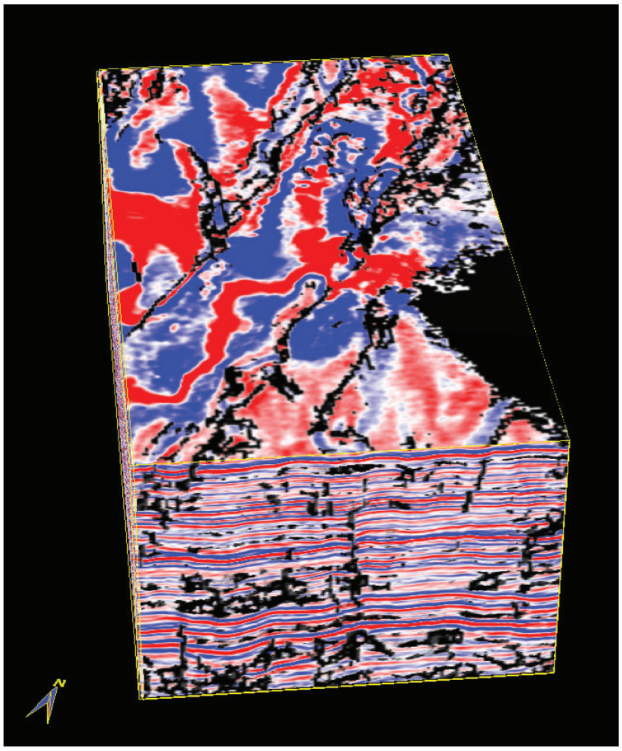

Figure 5. Corendering amplitude and coherence volumes allows the interpreter to see the correlation of discontinuities with the corresponding seismic signatures.

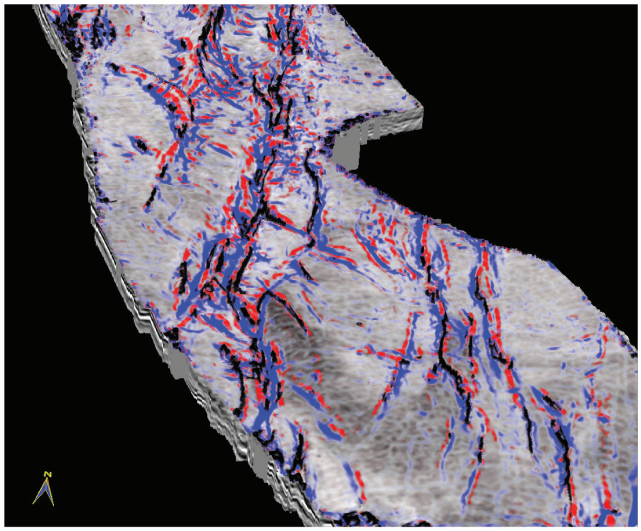

Figure 6. A composite strat-cube generated by corendering the seismic data volume (plotted against a gray scale) with the coherence (opaque low-amplitude values appearing as black lineaments), most-positive curvature (opaque high-positive-amplitude values appearing as red lineaments), and most negative curvature (opaque high-negative-amplitude appearing as blue lineaments) attributes.

volumes with the seismic amplitude volume as being particularly useful. The low-coherence or high-curvature values are set to be opaque and the other values transparent. These attributes serve as a guide while interpreting. Figure 6 shows such a visualization, where the coherence (low values in black), most-positive curvature (high values in red), and most-negative curvature (high negative values in blue) attributes are corendered with the seismic volume in a strat-cube. Notice how, in one single composite display, it is possible to interpret the change in the waveform discontinuities (black), the upthrown edges of the fault blocks (red), and the downthrown sides of the fault blocks (blue).

Crossplotting for visualizing faults/fractures

Crossplotting is routinely used in well-log and AVO analysis, as it provides a visual means for a human interpreter to see trends and correlations between mathematically independent measures that are correlated through the underlying geology. Since coherence (which is a measure of waveform discontinuity) and curvature (which is a measure of structural deformation) are mathematically independent attributes that can be used to identify faults, we anticipate that crossplotting them can improve delineation of discontinuities. Low-coherence discontinuities are typically displayed as black/dark grey anomalies using a grey-scale color bar. Similarly, most-positive curvature attribute displays are commonly displayed using a dual-gradational color bar, with high positive values corresponding to channel edges or upthrown sides of fault blocks being displayed (in our examples) as a dark red. Figure 7a shows a crossplot of these two attributes, with the low-coherence and high-curvature plot in the top left. By drawing a polygon around these points, we are able to highlight these correlations on either stratal or time slices (Figure 7b). Also, notice it is possible to control the number of points on the lineaments that come into these displays, so that only the lineaments of interest can be highlighted for interpretation. In Figure 8a, we shift the polygon (in black now) slightly to the right which brings in a slightly higher density of points on the lineaments (Figure 8b). This opens the door to generating a host of useful displays to aid the interpretation. In Figure 9, we show a strat-cube from the seismic volume with lineaments from the polygon in the crossplot shown in Figure 8a. In Figure 9a, the strat-cube top is shown at the horizon top (resulting in the uniform red color corresponding to the peak). As we step out of this peak by one sample (Figure 9b), the bright red color changes to dull red through zero and negative amplitudes (white and blue). In Figure 9c and Figure 9d, we move down by two more samples. Notice the fault skeleton defined by the black lineaments does not show the unwanted low-coherence noise patterns. These discontinuities can be overlain either on the seismic data or on contoured horizons.

Crossplotting provides a means of separating different types of faults. Faults that have significant drag may appear in both coherence and most-positive and most-negative curvature images. However, faults that do not have drag will often not appear on curvature. Very subtle faults exhibiting subseismic wavelet offset often do not appear in coherence. Crossplotting is an iteractive means of clustering such differences. The attribute volumes (coherence and curvature) used for

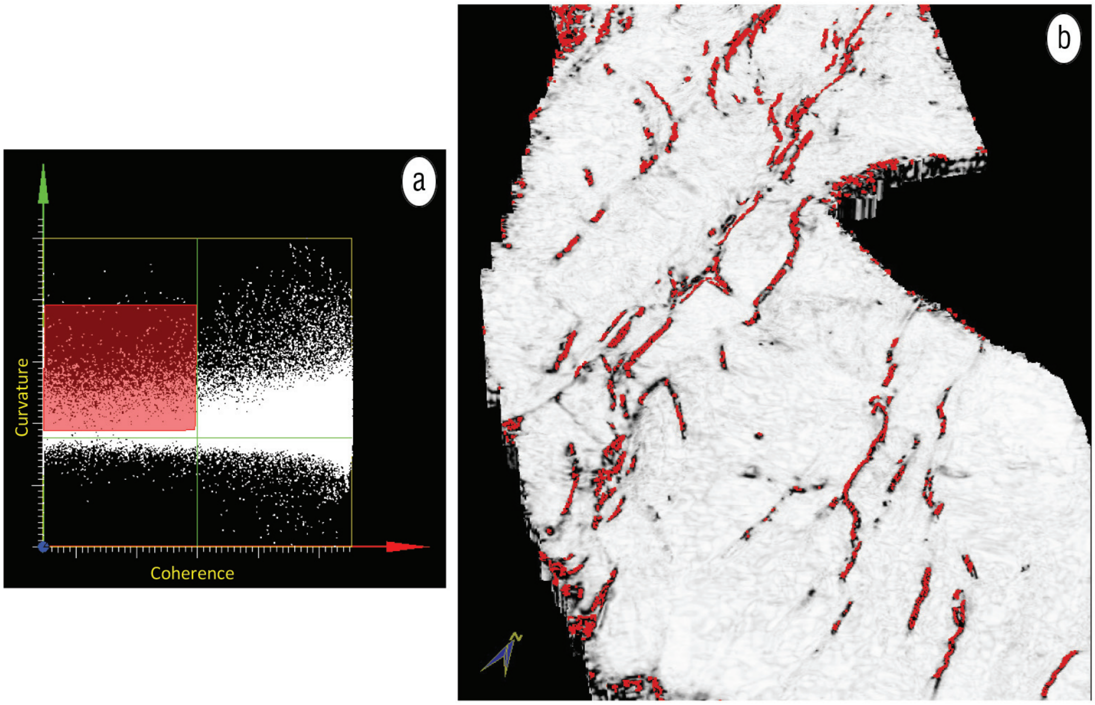

Figure 7. *(a) Crossplot of coherence versus most-positive curvature. The red polygon is drawn to capture the cluster points that have low coherence and high most-positive curvature. (b) Corendering the cluster of points, enclosed in a polygon on the crossplot of coherence versus most-positive curvature, on the coherence strat-slice. The cluster forms a fault skeleton. The red lineaments align with the faults that one would interpret on the coherence strat-slice.*

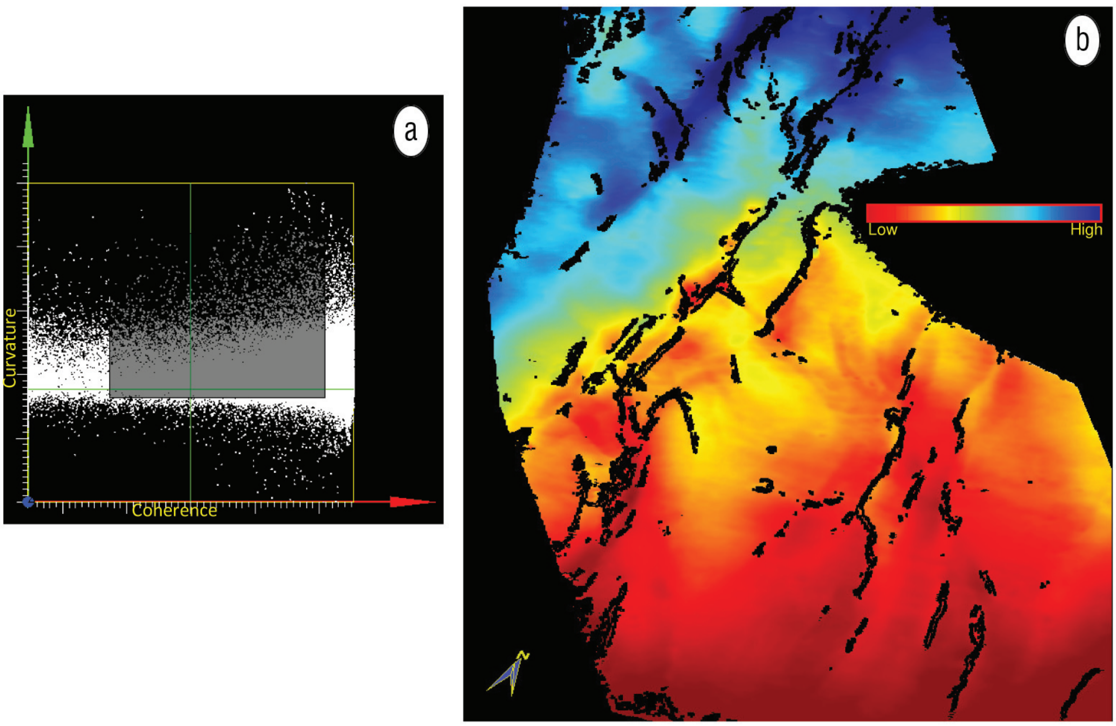

Figure 8. *(a) Crossplot of coherence versus most-positive curvature. The polygon is now moved slightly down and to the right as compared with the red polygon in Figure 7a. (b) Corendering the cluster of points enclosed in a polygon on the crossplot of coherence versus most-positive curvature, on an interpreted time-structure map. This cluster forms a fault skeleton. The black lineaments align with structural lineaments in the sculpted surface.*

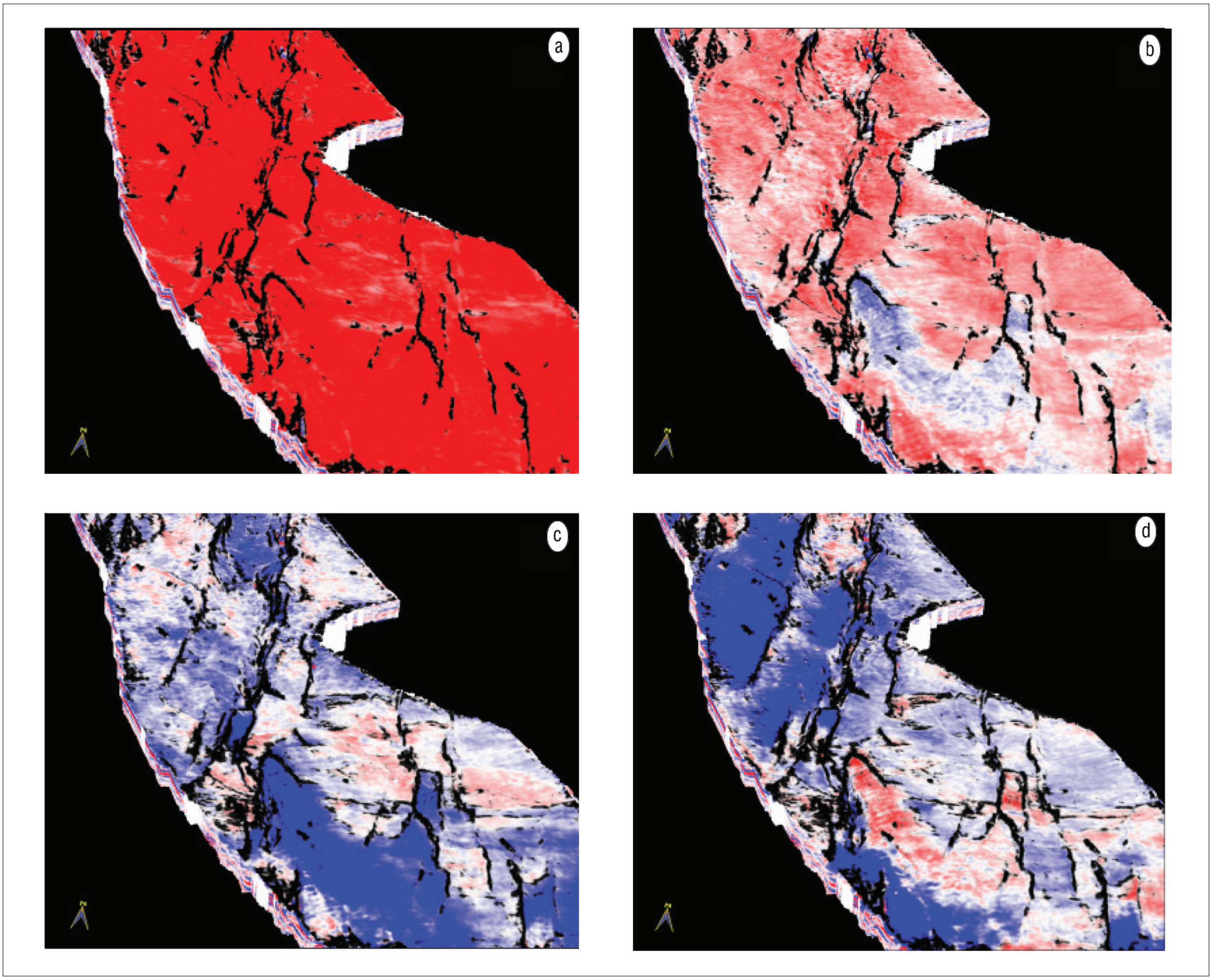

Figure 9. *Corendering the cluster of points, enclosed in a polygon on the crossplot of coherence versus most-positive curvature, on an interpreted horizon. This cluster forms a fault skeleton. The black lineaments align with the impression of faults that are visible on the horizon.*

crossplotting should be free from noise as much as possible. Acquisition footprint may easily fall in the quadrant used for polygon-connect and interfere with meaningful analysis. We recommend conditioning the data going into attribute computation through the application of structure-oriented filtering (PC-filtering) (Chopra and Marfurt, 2008).

Conclusions

Volume visualization can greatly aid 3D seismic interpretation by providing an accurate perspective of subsurface features. Clustering is routinely used by interpreters with the most common example being the association of structural highs (anticlines) and strong negative amplitude anomalies with hydrocarbon accumulations in Tertiary basins. Mathematically independent attributes (such as seismic amplitude, coherence, and curvature) are often clustered through the underlying geology. Crossplotting allows us to interactively cluster the attributes (by simply drawing a polygon in the crossplot) to enhance features of geologic interest. Such workflows allow an interpreter to separate curvature anomalies parallel to faults from anomalies that may correspond to fault ramps and small-offset splays. Such workflows save considerable time and effort by avoiding the laborious task of interpretation on individual profiles in the 3D volume.

Suggested reading. "Gleaning meaningful information from seismic attributes" by Chopra and Marfurt (*First Break*, 2008). "Seismic volume processing for geologic interpretation: A review of its use with 3D visualization software" by Kerr (presented at 2003 AAPG Convention). "Attribute extraction: An important application in any 3D seismic interpretation" by Rijks and Jauffred (*TLE*, 1991). TLE

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