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Multi-spectral Volumetric Curvature Adding Value to 3D Seismic Data Interpretation

Satinder Chopra*
*Arcis Corporation, Calgary,
schopra@arcis.com
and
Kurt J. Marfurt+
+University of Oklahoma, Norman

Summary

Volumetric attributes computed from 3D seismic data are powerful tools in the prediction of fractures and other stratigraphic features. Geologic structures often exhibit curvature of different wavelengths. Curvature images having different wavelengths provide different perspectives of the same geology. Tight (short-wavelength) curvature often delineates details within intense, highly localized fracture systems. Broad (long wavelength) curvature often enhances subtle flexures on the scale of 100-200 traces that are difficult to see in conventional seismic, but are often correlated to fracture zones that are below seismic resolution, as well as to collapse features and diagenetic alterations that result in broader bowls. Such multi-spectral volumetric estimates of curvature are very useful for seismic interpreters and we depict a number of examples demonstrating such applications..

Introduction

Computation of volumetric curvature attributes is a significant advancement in the field of attributes. Until recently, curvature attribute applications on 3D seismic horizon surfaces were used for prediction of fault and fractures; some of these curvature measures have been shown to be correlated with open fractures measured on outcrops (Lisle, 1994) or through production data (Hart et al., 2002). Horizon-based curvature is limited not only by the interpreter's ability to pick, but also the existence of horizons of interest at the appropriate level in 3D seismic data volumes. Horizon picking can be a challenging task in datasets contaminated with noise and where rock interfaces do not exhibit a consistent impedance contrast amenable to human interpretation. Very recently, volumetric computation of curvature has been introduced, which dispels the need for consistent horizons in the zone of interest (Al-Dossary and Marfurt, 2006). By first estimating the volumetric reflector dip and azimuth that represents the best single dip for each sample in the volume, followed by computation of curvature from adjacent measures of dip and azimuth, a full 3D volume of curvature values is produced. There are many curvature measures that can be computed, but the most-positive and most-negative curvature measures are the most useful in that they tend to be most easily related to geologic structures. Volumetric curvature attributes are valuable in mapping subtle flexures and folds associated with fractures in deformed strata. In addition to faults and fractures, stratigraphic features such as levees and bars and diagenetic features such as karst collapse and hydrothermally altered dolomites also appear to be well-defined on curvature displays. Channels appear when differential compaction has taken place.

Multi-spectral volumetric estimation of curvature

Multispectral curvature estimates introduced by Bergbauer et al. (2003) and extended to volumetric calculations by Al Dossary and Marfurt (2006) can yield both long and short wavelength curvature images, allowing an interpreter to enhance geologic features having different scales. Tight (short-wavelength) curvature often delineates details within intense, highly localized fracture systems. Broad (long wavelength) curvature often enhances subtle flexures on the scale of 100-200 traces that are difficult to see in conventional seismic, but are often correlated to fracture zones that are below seismic resolution, as well as to collapse features and diagenetic alterations that result in broader bowls.

Al Dossary and Marfurt (2006) introduced a ‘fractional derivative’ approach for volume computation of multispectral estimates of curvature. They define the fractional derivative as

$$F_\alpha\left(\frac{\partial u}{\partial x}\right) = -i(k_x)^\alpha F(u), \qquad (1)$$

where the operator *F* denotes the Fourier transform, where u is an inline or crossline component of reflector dip, and where α is a fractional real number that typically ranges between 1 (giving the first derivative) and 0 (giving the Hilbert transform) of the dip. The nomenclature ‘fractional derivative’ was borrowed from Cooper and Cowans (2003); however, an astute mathematician will note that the *i* is not in the parentheses. In this manner we can interpret equation 1 as simply a low pass filter of the form $k_x^{(\alpha-1)}$ applied to a conventional first derivative.

The space domain operators corresponding to different values of α mentioned above are convolved with the previously computed dip components estimated at every sample and trace within the seismic volume. In additional the directional derivative is computed using a circular rather than linear window of traces, thereby avoiding a computational bias associated with the acquisition axes. Lower values of α decrease the contribution of the high wavenumbers, thereby shifting the bandwidth towards longer wavelength. Thus full 3D curvature attribute volumes are available for analysis at different scales, which helps extract meaningful and subtle information from seismic data.

Examples

In Figure 1 we show the strat-cube displays of long-wavelength and short-wavelength curvature of a fault/fracture system from Alberta. The surface displayed is at 1620 ms. Figure 1a shows the long-wavelength most-positive curvature strat-cube surface display correlated with the seismic crossline. Notice, the broad definition of the fault trends seen in bright red, correlating nicely with the upthrown signature on the seismic. The short-wavelength version of the most-positive curvature is shown in Figure 1c. Notice the higher resolution of the fault definition. The wider red lineaments as seen on the long-wavelength display is seen here as resolved into two or more lineaments. Such detail is useful for the picking up fracture information on curvature displays. Similarly, Figures 1b and d depict the long and short- wavelength versions of the most-negative curvature and the blue lineaments correlate with the downthrown signatures on the seismic sections.

In Figure 2 we show stratal slices through various attribute volumes. (a) Coherence shows a main channel along with what appear to be incised valleys feeding into it. (b) Structural ridges appear to be blue. Areas that have no ridge component are white. These appear to correlate to what we interpret to be low coherence interfleuve zones. (c) Structural valleys appear as red further supporting our interpretation of incised valleys feeding into a major channel. Areas that have no valley component are white. (d) Display of structural ridges and valleys together. Other structural shapes (domes, saddles, and bowls) also exist but are not displayed. (e) Coherence plotted on top of the structural valley image, where the most coherent values (c=1.0) are set to be transparent, showing that the channel axis is both valley-shaped and highly coherent. (f) A complementary image but now with the lowest ridge values set to be transparent, allowing us to see that high coherence (white) corresponds to the absence of ridges. Such correlations suggest improved delineation of channels through multiattribute cluster analysis or neural networks. Basically, channels in this survey appear to have both high coherence *and* a valley shape.

Calibration with well-log data

It is always a good idea to calibrate the interpretation on curvature displays with log data if possible. One promising way is to interpret the lineaments in a fractured zone and then transform them into a rose diagram. Such rose diagrams can then be compared with similar rose diagrams that are obtained from image well logs to gain confidence in the seismic-to-well calibration. Once a favorable match is obtained, the interpretation of fault/fracture orientations and the thicknesses over which they extend can be used with greater confidence for more quantitative reservoir analysis. Needless to mention such calibrations need to be carried out in localized areas around the wells for accurate comparisons.

Conclusions

Multispectral volumetric curvature attributes are valuable for prediction of fracture lineaments in deformed strata. Several applications of volume curvature have been completed in different geological settings, which are found to be useful for different stratigraphic features, ranging from imaging of channel boundaries, small scale faults to highly fractured zones.

Acknowledgements

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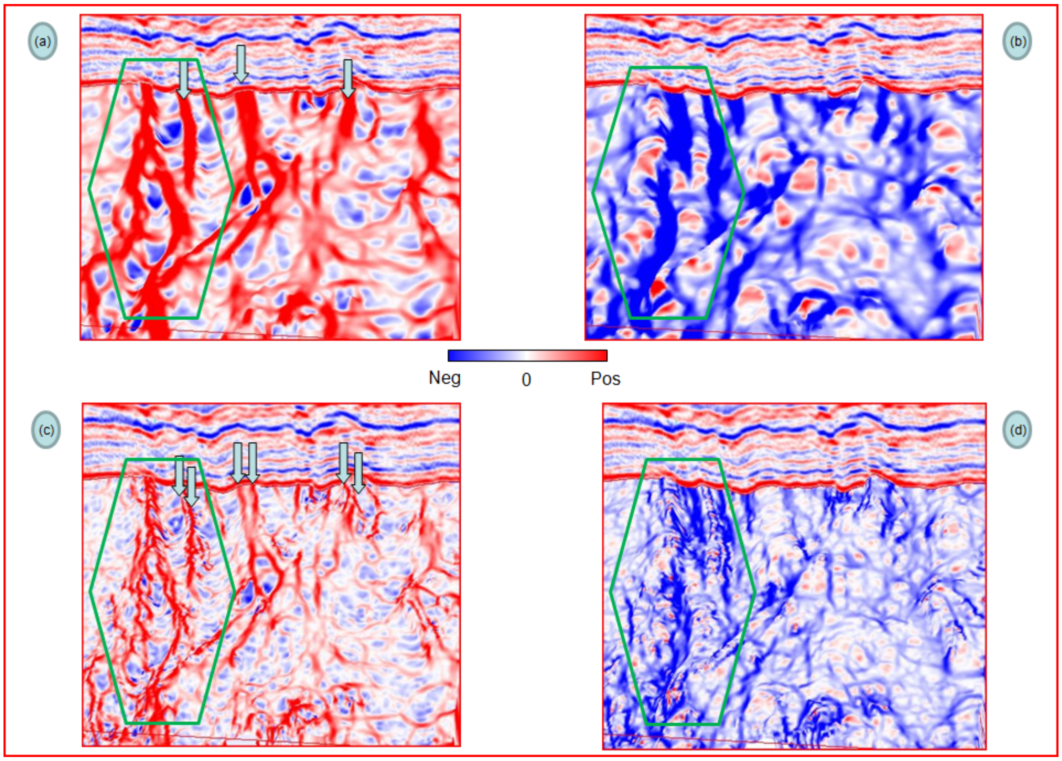

Figure 1. Zoom of chair-displays where the vertical display is a portion of a crossline through the original 3D seismic amplitude volume while the horizontal displays are strat slices through (a) coherence (b) most-positive (long-wavelength) (c) most-negative (long-wavelength) (d) most-positive (short-wavelength) and (e) most-negative (short-wavelength) attribute volumes. The lineament detail on the short-wavelength attribute displays is higher and crisper than similar lineaments on the long-wavelength displays. The fault lineaments correlate with the upthrown and downthrown signatures on the seismic. *(Data courtesy: Arcis Corporation, Calgary).*

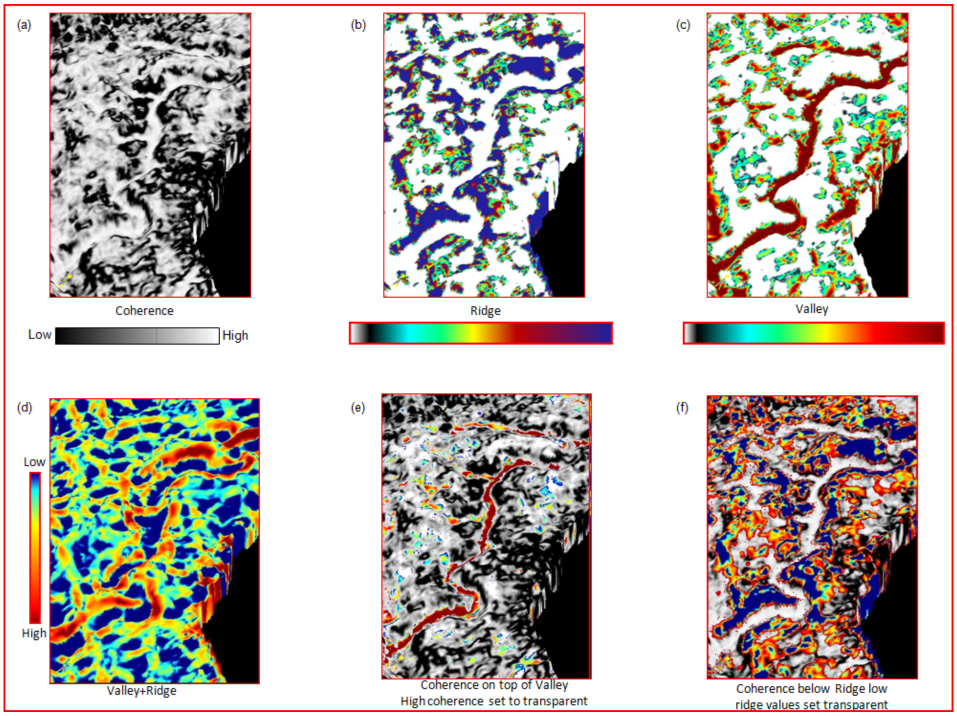

Figure 2. Stratal slices through various attribute volumes (a) coherence), (b) Structural ridges in blue (c) Structural valleys (d) Strcutural ridges and valleys together (e)coherence plotted on top of structural valley image, and (f) a composite image display.