Which curvature is right for you? Part - 1

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Summary

There are close to twelve different types of surface-based curvature attribute measures that have been introduced during the last few years. Many of these attributes have been extended to volume computations and implemented on interpretation workstations. Of these different curvature attributes, the most-positive and the most-negative principal curvatures are the most popular. Not only are these intuitively easy to understand, they also provide more continuous maps of faults and flexures than the maximum and minimum curvatures, which can rapidly change sign at fault and flexure intersections. Other attributes such as the mean curvature, Gaussian curvature and shape index have also been used by a few practitioners. Since they are second-order derivatives, structural curvature attributes can enhance subtle information that may be difficult to see using first-order structure derivative attributes such as the dip magnitude and the dip-azimuth. Structural curvature provides quantitative measures of quadratic shapes – domes, ridges, saddles, valleys, bowls, and if no deformation exists, planes. As a result, these attributes form an integral part of most seismic interpretation projects.

In this study we describe the theory and application of Euler curvature, which is a generalization of the dip and strike components of curvature in any user-defined direction, to the interpretation of surface seismic data. This attribute is useful for the interpretation of lineament features in desired azimuthal directions, say, perpendicular to the minimum horizontal stress. If a given azimuth is known or hypothesized to be correlated with open fractures or if a given azimuth can be correlated to enhanced production or effective horizontal drilling, an Euler-curvature intensity volume can be generated for that azimuth thereby high-grading potential sweet spots.

We illustrate the value of these attributes through examples from Alberta, Canada.

Introduction

Using well tops rather than seismic data, Murray (1968) is perhaps the first to publish the use of structural curvature in mapping fracturing hydrocarbon reservoirs. After Roberts' (2001) extension of such calculations to picked seismic horizons, curvature has gradually been incorporated in interpretation workflows, and has found its way into most commercial software packages. Horizon-based structural curvature is a 2D second-order derivative of time or depth structure, or a 2D first-order derivative of inline and crossline dip components. As a derivative of dip components, structural curvature measures subtle lateral and vertical changes in dip that are often

overpowered by stronger, regional deformation, such that a carbonate reef on a 20^0 dipping surface gives rise to the same structural curvature anomaly as a carbonate reef on a flat surface. Such rotational invariance provides a powerful analysis tool that does not require first picking and flattening on horizons near the zone of interest. Al-Dossary and Marfurt (2006) showed how curvature computations can be computed from volumetric estimates of inline and crossline dip components. By first estimating the volumetric reflector dip and azimuth that best represents a hypothesized reflector about each single sample in the volume, followed by computation of curvature from neighboring measures of dip and azimuth, a full 3D volume of structural curvature values is produced.

Euler curvature is simply the apparent curvature seen as surface cuts any azimuthally-aligned vertical slice. If the alignment is along the strike or dip direction of the reflector, it is also called the strike or dip curvature (Roberts, 2001). Euler curvature is useful for the interpretation of lineament features in desired azimuthal directions, say, perpendicular to the minimum horizontal stress. If a given azimuth is known or hypothesized to be correlated with open fractures or if a given azimuth can be correlated to enhanced production or effective horizontal drilling, an Euler-curvature intensity volume can be generated for that azimuth, thereby high-grading potential sweet spots.

Euler curvature

Algorithm description

Just as apparent dip (routinely used in interactive ‘sun-shading’ of picked horizons) can highlight subtle features of interest (e.g. Rijks and Jauffred, 1991) so can apparent, or Euler, curvature. If (k_1, ψ_1) and (k_2, ψ_2) represent the magnitude and strike of the most-positive and most-negative principal curvatures then the Euler curvature at an angle ψ in the dipping plane tangent to the analysis point (where the vectors corresponding to ψ_1 and ψ_2 are orthogonal) is given as

$$k_\psi = k_1\cos^2(\psi - \psi_2) + k_2 \sin^2(\psi - \psi_2). \quad \ldots\ldots (1)$$

Since reflector dip magnitude and dip azimuth can vary considerably across a seismic survey, implementation requires equally sampling the azimuths of Euler curvature to define lines in the horizontal *x-y* plane, projecting these lines onto the local dipping plane of the reflector at each analysis point, and applying equation 1. The flow diagram in Figure 1 explains the method for computing Euler curvature.

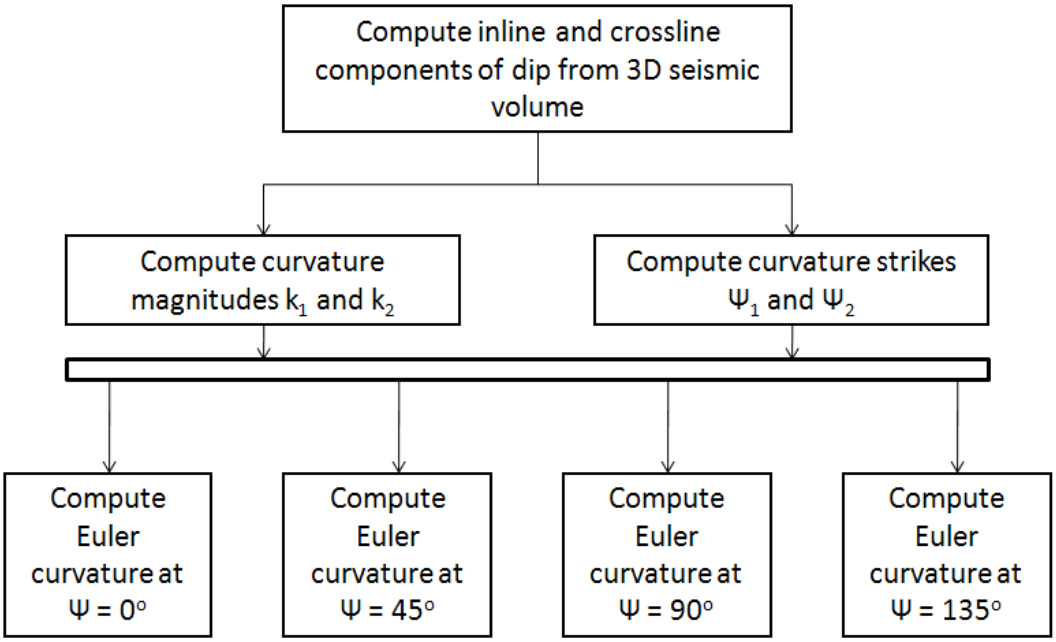

Figure 1: Flow diagram showing the computation of Euler curvature

Application

Mapping the intensity of a given fracture set has been a major objective of reflection seismologists. The most successful work has been using attributes computed by azimuthally-limited prestack data volumes. Chopra *et al.* (2000) showed how coherence attributes computed from azimuthally-restricted seismic volumes can enhance subtle features hidden or blurred in the all-azimuth volume. Vector-tile and other migration-sorting techniques are now the method of choice for both conventional P-wave and converted wave prestack imaging (e.g. Jianming *et al.*, 2009) allowing one to predict both fracture strike and intensity.

Curvature, acoustic impedance, and coherence are currently the most effective attributes used to predict fractures in the post-stack world (e.g. Hunt *et al.*, 2010). Rather than map the intensity of the strongest attribute lineaments, Singh *et al.* (2008) used an image-processing (ant-tracking) algorithm to enhance curvature and coherence lineaments that were parallel to the strike of open fractures, at an angle of some 45^0 to the strike of the strongest lineaments. Henning *et al.* (2010) use related technology to azimuthally filter lineaments in the Eagleford formation of south Texas. They then compute RMS maps of each azimuthally-limited volume that can be correlated to production. Guo *et al.* (2010) hypothesize that each azimuthally-limited attribute volume computed from k_1 and ψ_1 corresponds to open fractures. Each of these volumes is then correlated to production to either validate or reject the hypothesis.

Daber and Boe (2010) showed how Euler (or what the called 'azimuthal') curvature can avoid footprint-related noise in poststack curvature volumes. Specifically, they show that if the

azimuthal direction is set to the inline direction, then the curvature computation would be relatively insensitive to noise in the crossline direction.

We describe here the application of Euler curvature to two different 3D seismic volumes from northeast British Columbia, Canada. We propose an interactive workflow, much as we do in generating a suite of shaded relief maps where we display apparent dip rather than apparent (Euler) curvature. In Figure 2 we show 3D chair view displays for Euler curvature run at 0°, 45°, 90° and 135°. The left column of displays shows the long-wavelength version and the right display the short wavelength displays. Notice for 0^0 azimuth (which would be the north), lineaments in the E-W direction seem to stand out. For 45^0s, the lineaments that are almost NW-SE are seen pronounced. Similarly for 90^0s the roughly N-S events stand out and for 135^0s the events slightly inclined to the vertical are more well-defined. The same description applies to the short-wavelength displays that show more lineament detail and resolution than the long-wavelength display. Their value in running Euler curvature on post stack seismic volumes in that the azimuth directions can be carefully chosen to highlight the lineaments in the directions known through image logs or production data to better correlate to open fractures. This does not entail the processing of azimuth-restricted volumes (usually three or four) all the way to migration and then passing them through coherence/curvature computation.

We follow up on the other curvature attribute computations in part-2 of the abstract.

Conclusions

Euler curvature run in desired azimuthal directions exhibit a more well-defined set of lineaments that may be of interest. Depending on the desired level of detail, the long- or the short-wavelength computations can be resorted to. For observing fracture lineaments the short-wavelength Euler curvature would be more beneficial. This work is in progress and we hope to calibrate the observed lineaments with the image logs in terms of rose diagram matching. This would serve to enhance the interpreter's level of confidence, should the rose-diagrams match.

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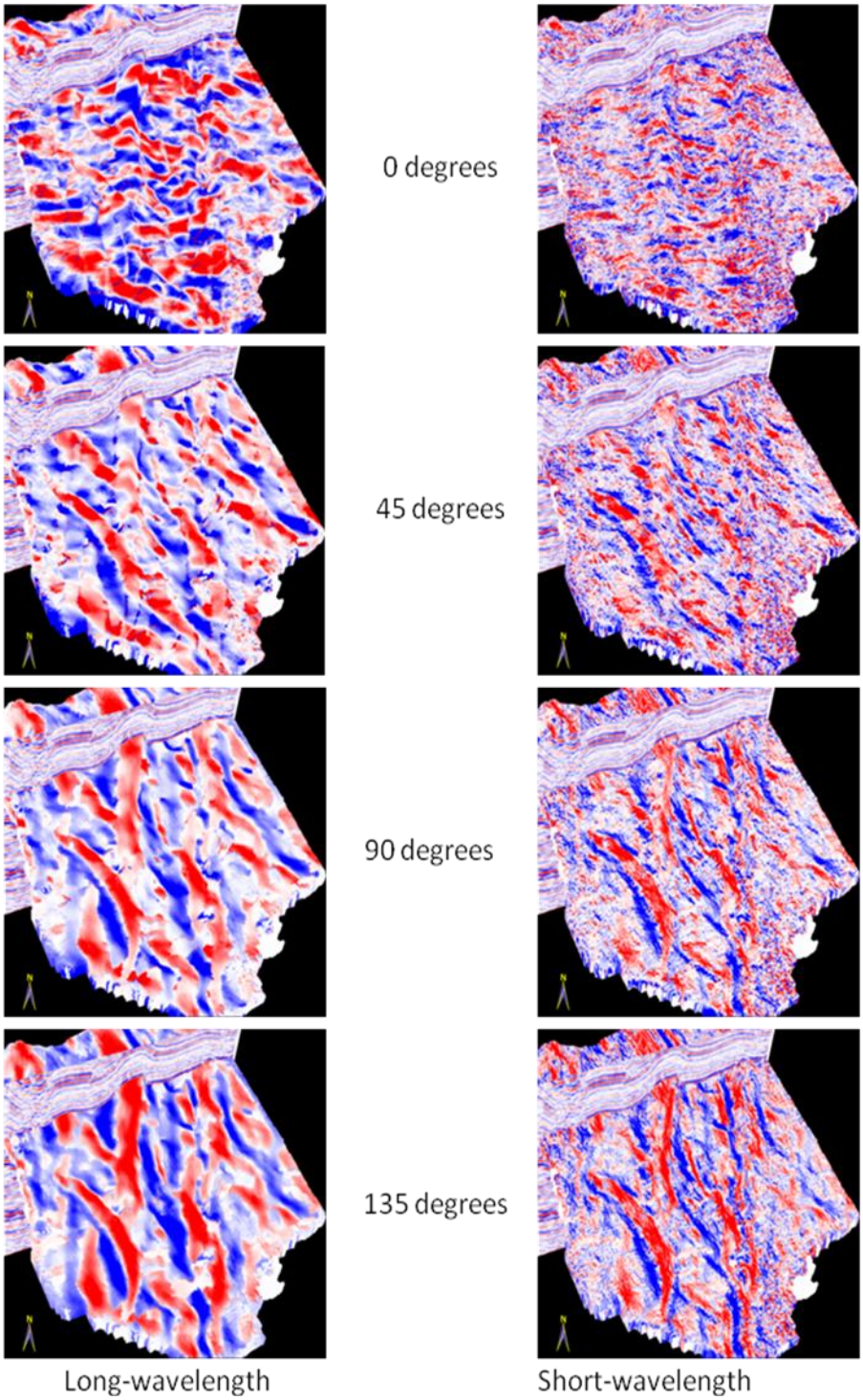

Figure 2: 3D chair views showing the correlation of an inline vertical slice through the seismic amplitude volume with the strat-cube through a suite of Euler curvature attribute volumes run at different angles as indicated and for both long-wavelength (left column) and the short-wavelength (right column). For each azimuth angle, the orthogonal lineaments appear more well-defined than those in other directions.