Summary

Geometric attributes such as coherence and curvature are commonly used to map structural deformation and (coupled with principals of geomorphology) depositional environment. Coherence often illuminates faults, collapse features, and channel edges, while curvature images folds and flexures, subseismic antithetic faults that appear as drag or folds adjacent to faults, diagenetically altered fractures, karst, and differential compaction over channels. In spite of these advantages, neither of these two attribute families provide much value in visualizing components of classic seismic stratigraphy analysis which was based primarily on stratigraphic terminations.

Curvature computations assume that any local region of a reflector in the earth can be approximated by a quadratic surface. Obviously, the earth contains many non-quadratic surfaces, such as those that are cut by faults or truncated by erosion. In this work, we propose a suite of attributes build on the rotation of the vector dip volume to represent reflector convergence (onlap, offlap, and erosional unconformities) and rotation about the reflector normal (wrench faults and asymmetric syntectonic deposition).

Curvature of a quadratic surface

A geometry poorly-represented by curvature attributes

<table>
<thead>
<tr>
<th>$k_{max}$</th>
<th>$k_{min}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{1}{R_{max}}$</td>
<td>$\frac{1}{R_{min}}$</td>
</tr>
</tbody>
</table>

Geometries well-represented by curvature attributes

<table>
<thead>
<tr>
<th>$k_1$, $k_2$</th>
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</thead>
<tbody>
<tr>
<td>$k_1 &lt; 0$</td>
</tr>
<tr>
<td>$k_1 = 0$</td>
</tr>
<tr>
<td>$k_1 &gt; 0$</td>
</tr>
<tr>
<td>$k_2 &lt; 0$</td>
</tr>
<tr>
<td>$k_2 = 0$</td>
</tr>
<tr>
<td>$k_2 &gt; 0$</td>
</tr>
</tbody>
</table>

Curvedness: $c = [k_1^2 + k_2^2]^{1/2}$

Background

Scanned copy of a slide used by Tury Taner in the AAPG-sponsored school on seismic stratigraphy during the middle 1970s and the 1980s. (Courtesy of Tury Taner, Rock Solid Images).

One of the first reflector convergence estimates generated by Barnes (2000). Inline component of reflector convergence shown on (left) a vertical slice, and (right) a 3D cropped volume view.

Workflow developed by Masaferro et al. (2003) that maps clinoforms (reflector convergence) by (above) first flattening on a reference horizon and then (left) computing the volumetric dip. The image on the left was extracted 16 ms below the flattened horizon.
Beyond curvature – volumetric estimates of reflector rotation and convergence

Kurt J. Marfurt, The University of Oklahoma, and Jamie Rich, Devon Energy

Theory

Computing the normal from apparent dip components

\[ n_x = \frac{p}{\sqrt{1 + p^2 + q^2}}, \quad n_y = \frac{q}{\sqrt{1 + p^2 + q^2}}, \quad n_z = \frac{1}{\sqrt{1 + p^2 + q^2}} \]

Divergence of the normal (like mean curvature):

\[ k_{\text{mean}} \approx \nabla \cdot \mathbf{n} = \frac{\partial n_x}{\partial x} + \frac{\partial n_y}{\partial y} + \frac{\partial n_z}{\partial z} \]

Rotation vector:

\[ \psi = \nabla \times \mathbf{n} = \left( \frac{\partial n_z}{\partial y} - \frac{\partial n_y}{\partial z} \right) \hat{i} + \left( \frac{\partial n_x}{\partial z} - \frac{\partial n_z}{\partial x} \right) \hat{j} + \left( \frac{\partial n_y}{\partial x} - \frac{\partial n_x}{\partial y} \right) \hat{k} \]

Reflector rotation about the normal:

\[ r = \mathbf{n} \times \psi = n_x \left( \frac{\partial n_z}{\partial y} - \frac{\partial n_y}{\partial z} \right) + n_y \left( \frac{\partial n_x}{\partial z} - \frac{\partial n_z}{\partial x} \right) + n_z \left( \frac{\partial n_y}{\partial x} - \frac{\partial n_x}{\partial y} \right) \]

Reflector convergence

\[ c = \mathbf{n} \times \mathbf{c} = \left[ n_y \left( \frac{\partial n_z}{\partial y} - \frac{\partial n_y}{\partial z} \right) - n_z \left( \frac{\partial n_y}{\partial x} - \frac{\partial n_z}{\partial y} \right) + \hat{k} \left( \frac{\partial n_z}{\partial y} - \frac{\partial n_y}{\partial z} \right) \right] \]

Workflow

Attributes based on volumetric dip and azimuth

Seismic amplitude

Inline dip

Crossline dip

Quadratic surface?

yes

no

Principal curvatures

Strike of principal curvatures

Reflector rotation about normal

Reflector convergence

Shape components

Lineament volumes

Principal curvatures \( k_1 \) and \( k_2 \)

Shape components

Time (s)

Curv. Opacity

Positive

0

Negative

1
Central Basin Platform, west Texas.

Vertical slices along line AA’

Seismic amplitude

Reflector dip-azimuth

Reflector rotation about the normal, n \cdot \psi

Reflector convergence

Time (s)

Central Basin Platform, west Texas.
Time slices at t=1.1 s

Coherence

Reflector dip-azimuth

Reflector rotation about the normal, n \cdot \psi

Reflector convergence co-rendered with coherence

Time (s)
Conclusions

Reflector terminations and angular unconformities are one of the most important components of seismic interpretation, particularly when interpreting within a sequence stratigraphic framework. Careful calibration will allow us to more rapidly and quantitatively map sediment progradation, syntectonic deposition, Diapirism, withdrawal, angular unconformities and many other features of interpretational interest. We have also introduced a more accurate method of computing reflector rotation about discontinuities, which may be particularly valuable in mapping wrench faults. As with other geometric attributes, convergence and rotation work best in extracting subtle features from good-quality data, and need to be used with care when significant pull-up, push-down, or other velocity effects have not been properly accounted for.

Acknowledgements

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References


Taner, M.T., and R. E. Sheriff, 1977, Application of Amplitude, Frequency, and Other Attributes to Stratigraphic and Hydrocarbon Determination: Section 2. Application of Seismic Reflection Configuration to Stratigraphic Interpretation, in P. Vail and R. Mitchum, eds,