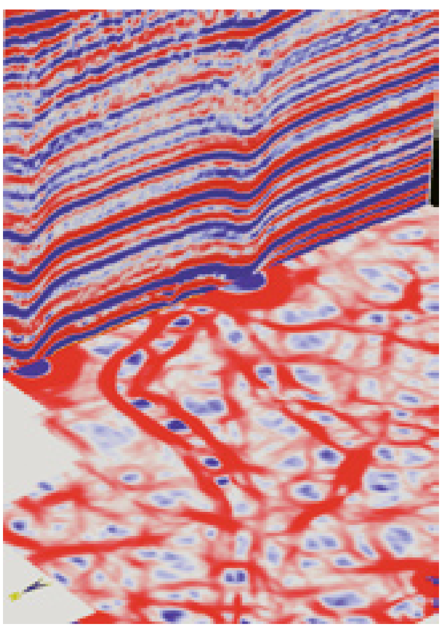
Volumetric Curvature:
The Next Step in Seismic Attributes

In 1828, Johann Gauss developed his theorema egregium, Latin for remarkable, to deal with curvature in 3-dimensional space. Now, through the use of volumetric curvature attributes, geoscientists apply this remarkable tool to seismic interpretation without the need of a picked horizon.

Thomas Smith, Associate Editor



Sedimentary features, such as the channel shown in this chair-display, are clearly seen using volumetric curvature attributes and correlate closely with their seismic signatures. The horizontal display is a time slice through the most-positive curvature attribute volumes.

Attributes are information extracted from seismic data. They have been used for nearly four decades, however most significant attribute developments and applications did not appear or gain acceptance until the pervasive use of 3-D seismic technology in the early 1990's.

Curvature is an effective attribute method that provides geoscientists with alternative images of faults and subtle fractures and stratigraphic features, such as channels and mounds. By using a volume or a vertical interval on the seismic data to calculate curvature, this imaging tool becomes more powerful and useful even when no continuous horizon is present.

How Curvature Works

In general, curvature is a measure of how bent or deformed a surface is at a particular point. The more deformed the surface, the larger its curvature.

Curvature measures various morphologic forms like domes, ridges, valleys, bowls, and well, you get the idea, it has to do with shape indices.

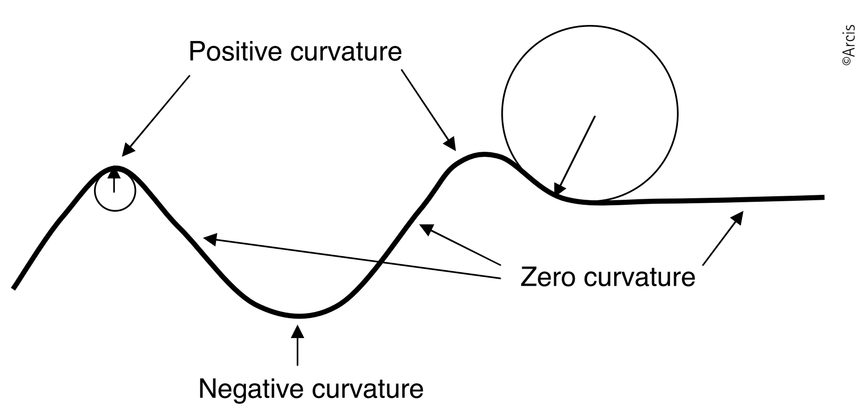
This simple definition of curvature for a two-dimensional (2D) curve can be extended to a three-dimensional (3D) surface by imagining the surface being intersected by an orthogonal set of two vertical planes. An easy way to picture this is to take a point on the side of your coffee mug. Here, along a horizontal plane, the maximum curvature is positive and has a value of 1/radius of the cup. The minimum curvature is perpendicular to the maximum and lines up vertically along the side of the mug. It has a value of zero. The maximum curvature is commonly used to map faults.

Using curvature to image flexures and folds, combined with more conventional seismic images, geoscientists can use established models of structural deformation coupled with well control, to predict areas favorable to natural fractures. Curvature also allows the mapping of stratigraphic features such as channels and mounds, and diagenetic features such as karsts in carbonate rocks.

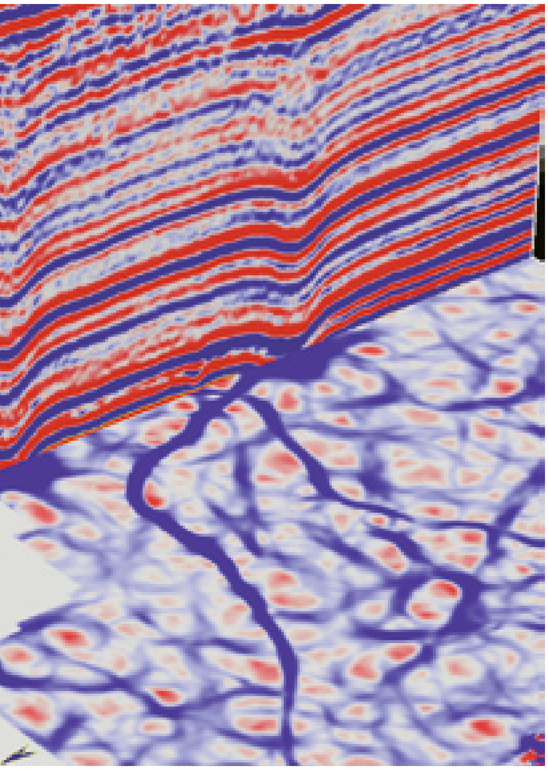
Until recently, this interpretation tool relied on a picked horizon to base curvature calculations. What if no continuous surface exists or if footprint artifacts from survey design obscure or distort imaging from this powerful interpretation tool?

Accidental Discovery

"A Saudi graduate student at the University of Houston, Saleh al-Dossary, was looking for better edge detectors," explains co-developer Kurt Marfurt, currently with the University of Oklahoma. "By chance, we started applying algorithms similar to the filters used in Adobe Photo Shop that are used to enhance 2D images. Saleh applied what I call "cowboy math" (low order fractional derivatives or calculus) to quantify curvature at varying wavelengths, resulting



Simply put, curvature will be large for a curve that is tightly folded and will be zero for a straight line, whether horizontal or dipping. As a convention, anticlinal features are assigned a positive and synclinal surfaces a negative value.



Chair-display with vertical seismic section and time slice through the most-negative curvature volume.

in great images."

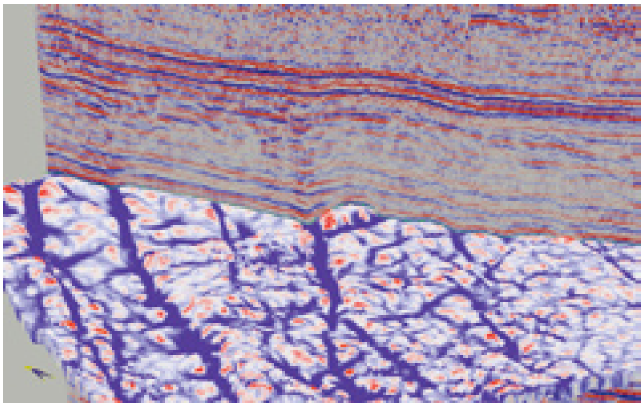
This 2006 discovery led to computing curvature (dip and azimuth) using a small analysis window (a volume rather than a picked horizon) in the seismic data. The examples in this article use a volume that consists of 9 traces by 10 milliseconds (ms.).

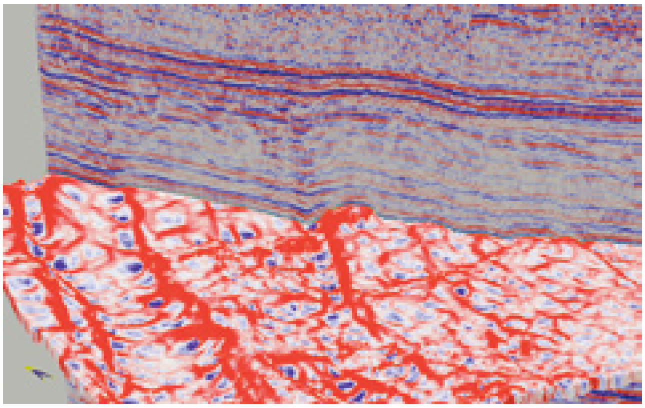
Advantages

"Volumetric estimation of curvature alleviates the need for picking horizons, and is especially useful in regions through which no continuous surface exists. The estimates are computed, not from one picked sample, but rather from a vertical window of seismic samples, such that they are statistically less sensitive to backscattered noise and consequently have a higher signal-to-noise ratio," says Satinder Chopra of Arcis Corporation, Calgary. "This method also allows us to image geologic features that do not fall along a horizon that can be interpreted, such as a channel system."

"Our investigations have shown that horizon-based curvature estimates can suffer from artifacts created by limitations in survey design, coherent noise, or systematic errors in the processing. These artifacts remain even after spatial filtering and have little direct correlation to the subsurface geology, but rather correlate to the source and receiver geometry," says Chopra. "Computing curvature using a vertical analysis window is less sensitive to acquisition footprint resulting in estimates of dip and azimuth that better reflect the actual geology."

Satinder Chopra is the Manager, Reservoir Services at Arcis Corporation in Calgary, Canada. His research focus concerns special processing of seismic data and the use of seismic attributes in reservoir characterization. "We find the most-positive and most-negative curvatures to be the easiest measures to visually correlate to features of geologic interest," says Satinder.





Data from the Middle East clearly show the fault lineaments to correlate with the upthrown and downthrown signature on the seismic.

The Proof

"Stratigraphic features that are often obscured seem to jump right out of the screen using volumetric curvature attributes," says Kurt Marfurt. "The example shown here (most-positive curvature chair-display at the beginning of the article) defines the flanks of the channels and potential levees and overbank deposits. The most-negative curvature (shown below) highlights the channel axis or ?thalweg."

"Curvature displays are particularly helpful in bringing out the definition of subtle faults and fractures and can help in the placement of horizontal wells," Satinder Chopra adds. "It is used extensively for well placement in the Barnett Shale play in Texas. The example below shows the red peaks on the fault lineaments (most-positive curvature) to correlate with the upthrown signature on the seismic. Similarly, the most-negative curvature strat-slice shows the downthrown edges on both sides of the faults highlighted in blue. Density and orientation of the fault lineaments can be plotted as a rose diagram and compared to similar data obtained from image logs."

"Like all attributes, curvature is valuable only when coupled with a geologic model of structural deformation, stratigraphic deposition, or diagenetic alteration," both Kurt Marfurt and Satinder Chopra explain. "Curvature can be a powerful tool in mapping stratigraphic and structural features, particularly in older rocks that have undergone differential compaction as these examples show. Volumetric calculation of curvature allows imaging that can better reflect the actual geology and be used in zones where seismic horizons are not traceable."

Further, "A computer or a clever computer algorithm is never going to replace an experienced human being. Humans have evolved to be experts at pattern recognition. Being able to better illuminate faults, joints, collapse features, and stratigraphic details allows these experienced human beings to put their wells in the best possible location."