Using New 3-D Seismic Attributes to Identify Subtle Fracture Trends in Mid-Continent Mississippian Carbonate Reservoirs

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ABSTRACT

Mid-Continent Mississippian reservoirs are primarily naturally fractured, solution-enhanced, multi-layered shallow shelf carbonates with strong bottom water drives. Oil production in these reservoirs is strongly influenced by fracturing. The fractures can either be open, permitting water channeling from the underlying aquifer, or shale-filled, providing compartmentalization of the reservoir.

New 3-D seismic volumetric reflector curvature attributes have the potential to reveal subtle lineaments that may be related to fractures in these reservoirs. Volumetric curvature attributes are calculated directly from a seismic data volume, with no prior interpretation required, and have been shown to be useful in delineating faults, fractures, flexures, and folds.

Volumetric curvature attributes applied to a 3-D seismic survey over a Mississippian reservoir in Ness County, Kansas, reveal two main lineament directions within the Mississippian, with orientations of approximately N45E and N45W. The NE-trending lineaments parallel a down-to-the-north normal fault at the northwestern corner of the seismic survey, and, on average, have greater length and continuity than the NW-trending lineaments. Geologic and production data suggest that the NE-trending lineaments may be related to shale-filled fractures forming reservoir compartments, while the NW-trending lineaments may be related to open fractures that are conduits for water. Both sets of lineaments are related to karst-enhanced fracturing related to the pre-Pennsylvanian regional unconformity.

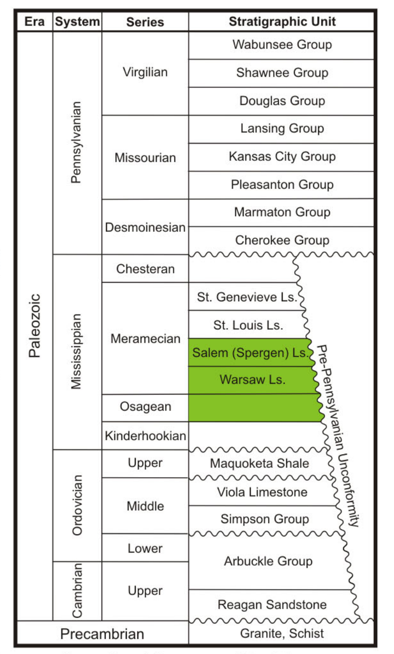
Understanding the orientations of open and filled fractures in Mid-Continent Mississippian reservoirs is an important pre-requisite for effectively using techniques such as targeted infill drilling, horizontal drilling, and gel polymer treatments to enhance production from these mature reservoirs.

MID-CONTINENT MISSISSIPPIAN CARBONATE RESERVOIRS

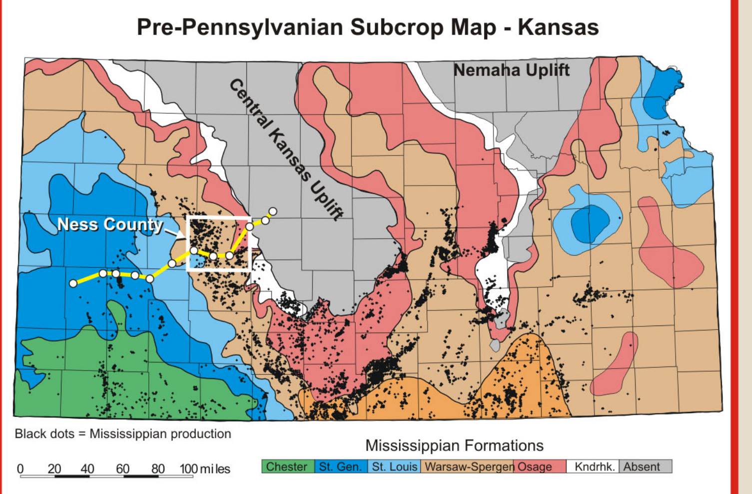
Typical Mid-Continent Mississippian carbonate reservoir

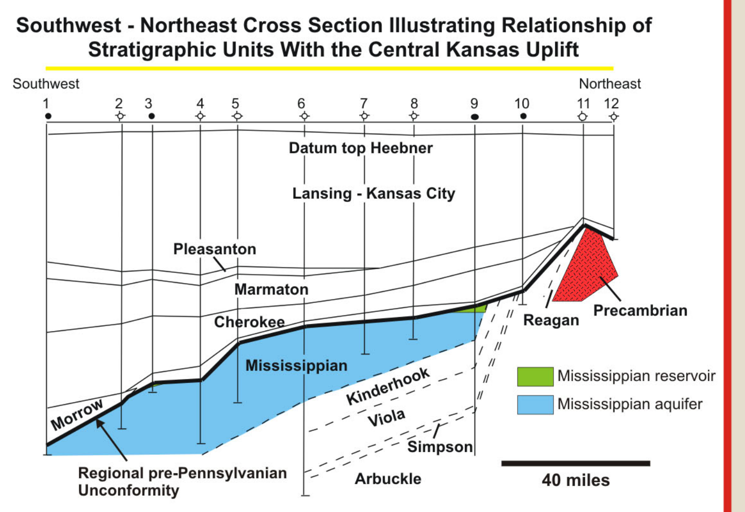
- subjacent to regional pre-Pennsylvanian unconformity and karst surface
- multi-layered shallow shelf carbonates
- solution-enhanced natural fractures
- strong bottom water drive

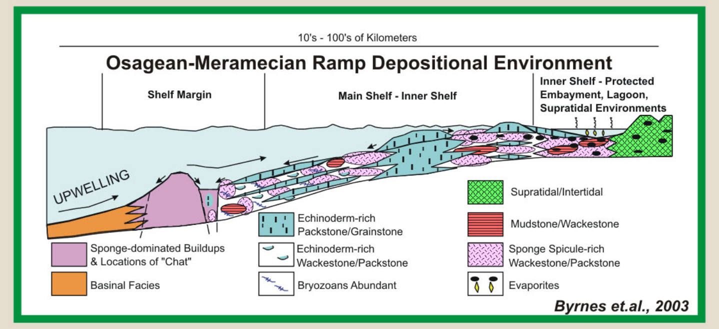
Oil production in these reservoirs is strongly influenced by fracturing. The fractures can either be open, permitting water channeling from the underlying aquifer, or shale-filled, providing compartmentalization of the reservoir.

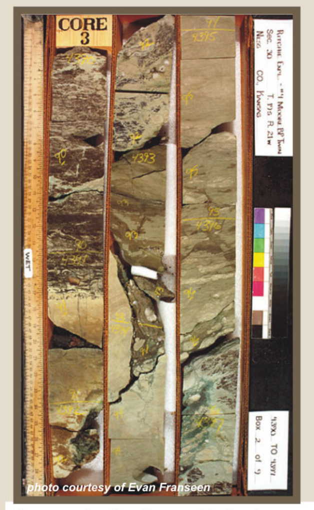


Generalized stratigraphic section for Kansas. Multi-layered shallow-shelf carbonate reservoirs are found in the Salem (Spergen), Warsaw, and Osagean intervals, subjacent to the Pre-Pennsylvanian unconformity surface.

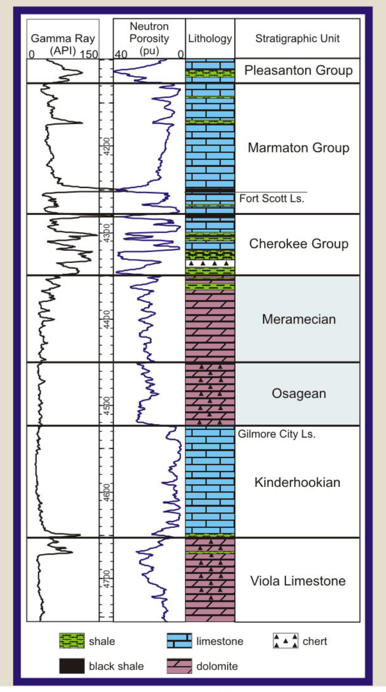






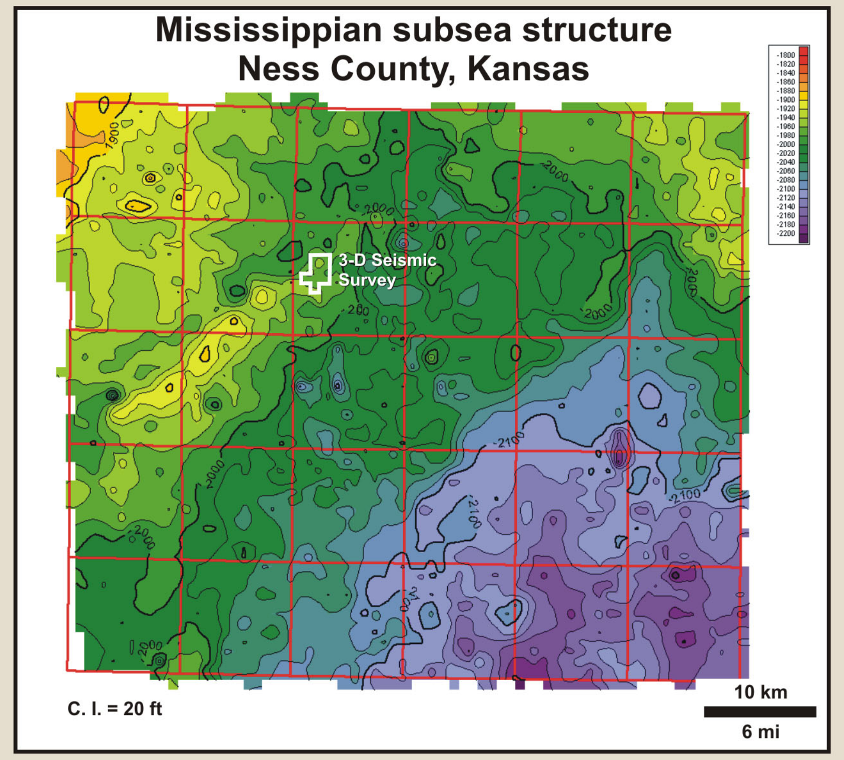


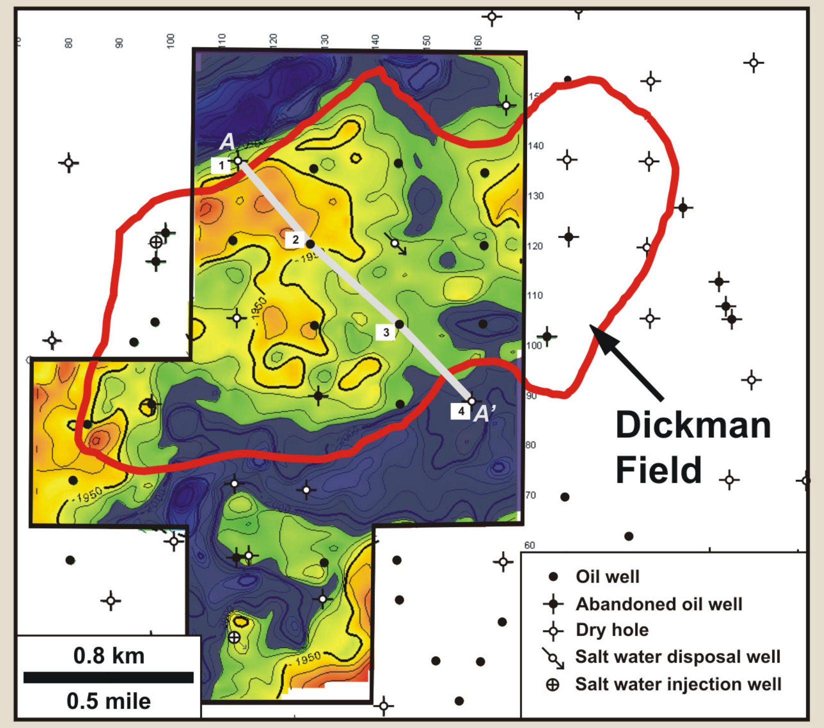
Core photo from Schaben Field, Ness County, Kansas, showing fracture and infill in the Osagean near the pre-Pennsylvanian unconformity surface.



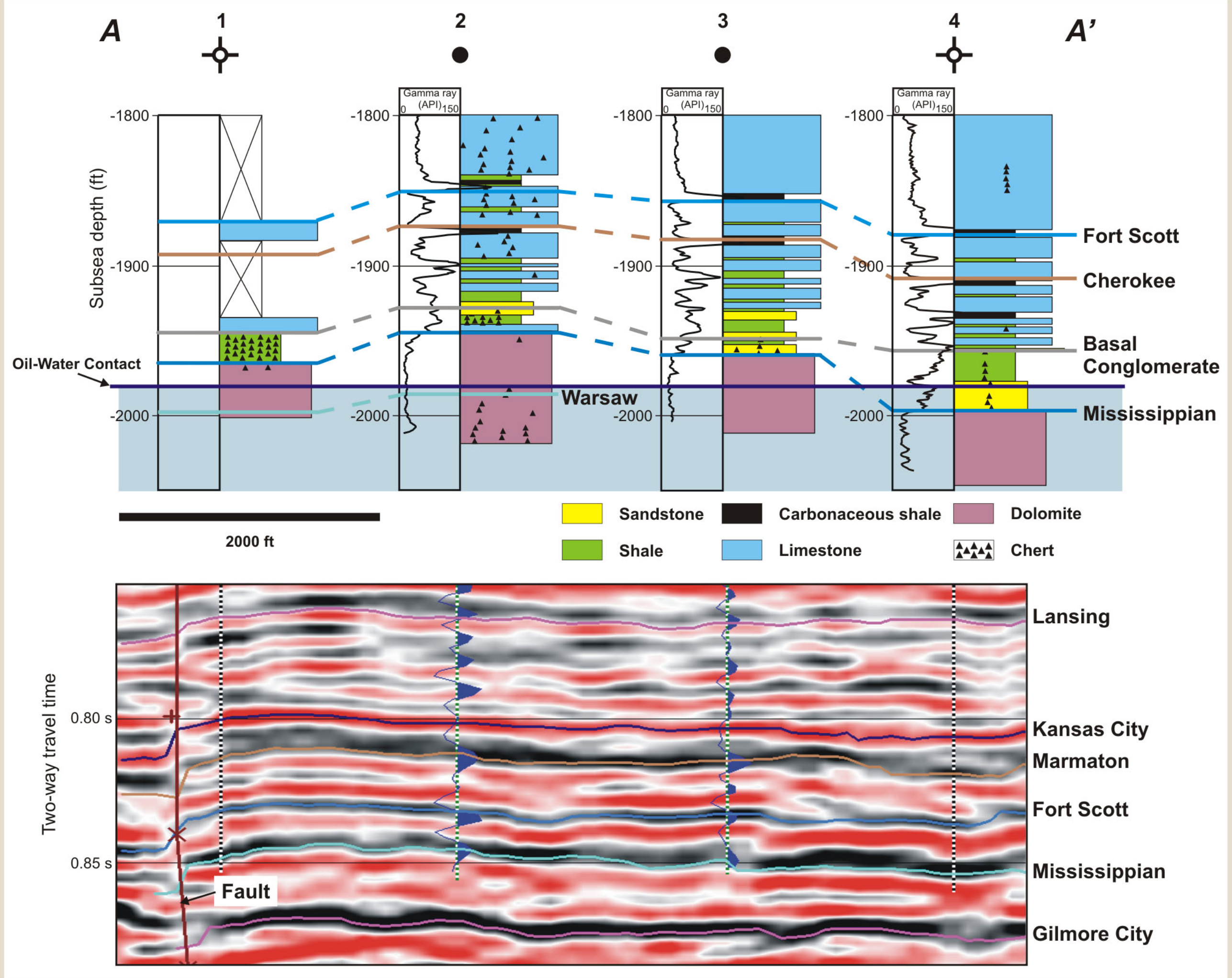
Stratigraphic section from a well in Dickman Field, Ness County, Kansas, showing the porous Mississippian dolomite aquifer (light blue), which supports the bottom water drive for the Mississippian reservoir. This aquifer extends down to the low porosity Gilmore City Ls. (top Kinderhook) throughout the Mid-Continent.

DICKMAN FIELD, NESS COUNTY, KANSAS





Location map for the Dickman Field 3-D seismic survey (black outline) showing detailed Mississippian subsea structure derived from 3-D seismic interpretations. C.I. = 10 ft. The blue shaded overlay indicates areas where the Mississippian is entirely beneath the oil-water contact.



Cross section *A-A'* across Dickman Field, showing lithologic (top) and seismic (bottom) data. Synthetic seismograms calculated from sonic logs in wells 2 and 3 are displayed in blue on the seismic section. Note that Dickman Field is bounded to the northwest by a fault.

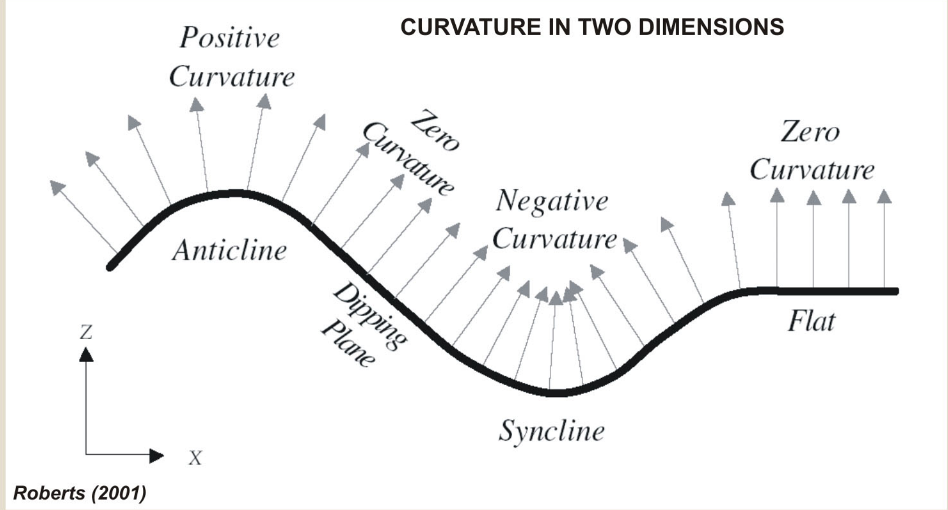
Dickman Field, in Ness County, Kansas, is a typical Mid-Continent Mississippian reservoir. The reservoir is composed of Meramecian shallow-shelf carbonates, subjacent to a regional pre-Pennsylvanian unconformity and karst surface. Since its discovery in 1962, Dickman Field has produced nearly 1.7 million barrels of oil, with a high water cut (greater than 94%).

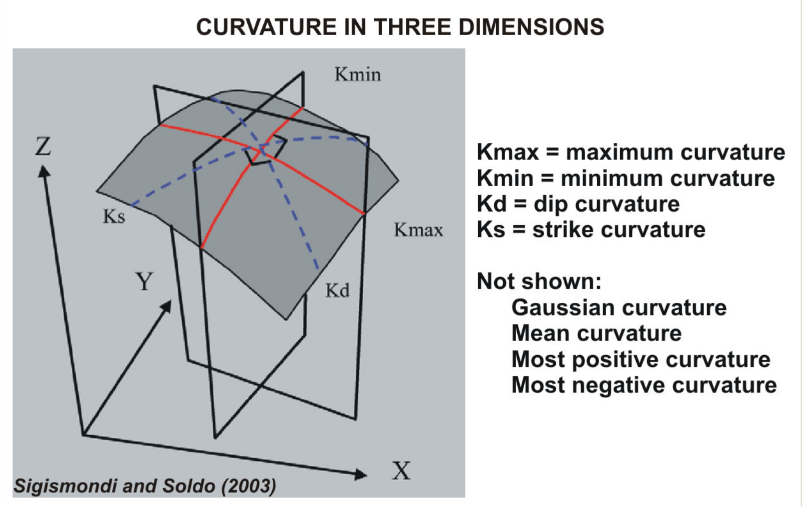
New seismic attributes were applied to a 3-D seismic survey over Dickman Field in an attempt to more effectively locate fractures influencing fluid flow in this reservoir.

CURVATURE ATTRIBUTES

Curvature describes how bent a surface is at a particular point and is closely related to the second derivative of the curve defining the surface. The more bent a surface is, the larger its curvature.

In two dimensions, positive curvature refers to an antiform feature, negative curvature refers to a synform feature, and zero curvature refers to a planar feature. In three dimensions, there are numerous curvature measures that can be extracted, related to the direction of the plane along which curvature is measured.

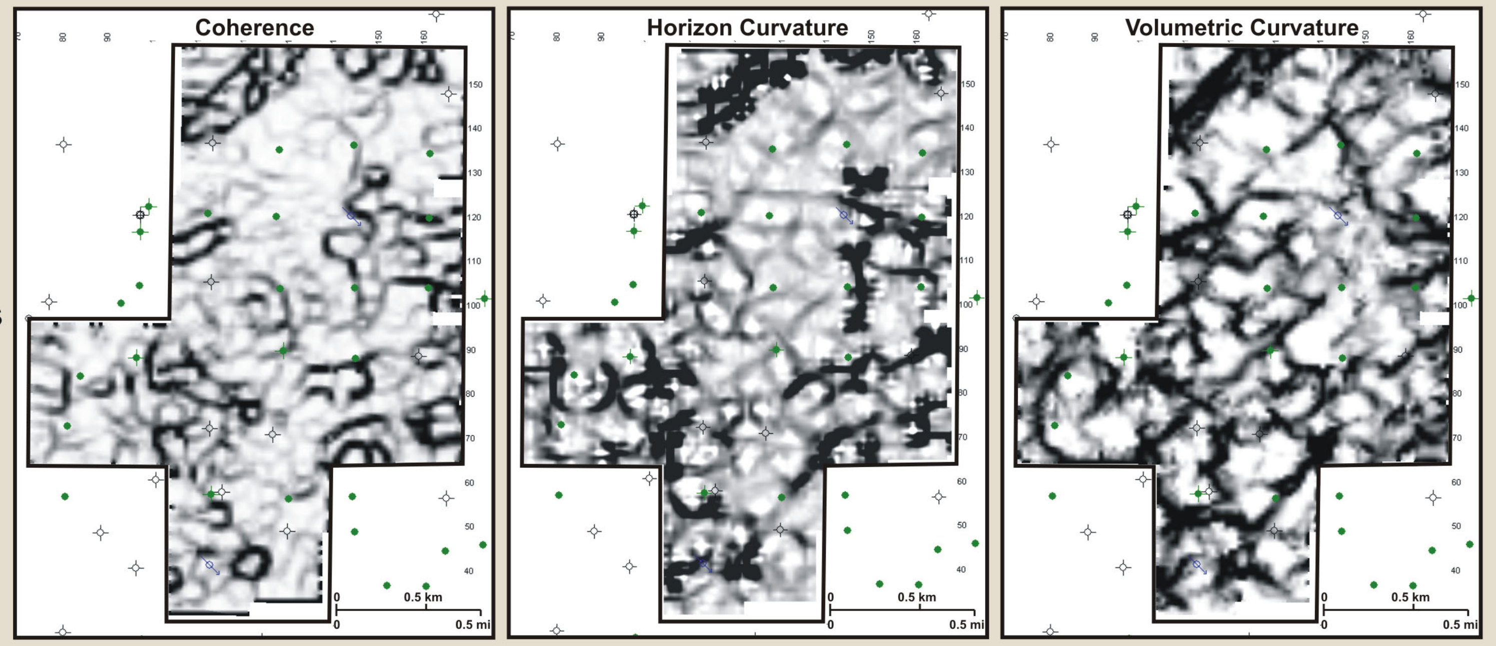




Various curvature attributes have been shown to reveal useful information relating to folds, faults, and lineaments contained within the surface (Roberts, 2001). Most published work of curvature analysis applied to 3-D seismic data has been limited to calculations based on gridded interpreted horizons (e.g., Hart et al., 2002; Masaferro et al., 2003; Sigismondi and Soldo, 2003)). However, recently, a suite of ***volumetric curvature attributes*** has been developed, where reflector curvature is calculated directly from the seismic data volume, with no prior interpretation required (al Dossary and Marfurt, 2005).

Of the numerous volumetric curvatures calculated, the most positive and most negative curvatures, which measure the maximum positive and negative bending of the surface at a given point, are the most useful in delineating faults, fractures, flexures, and folds (Al-Dossary and Marfurt, 2005; Blumentritt et al., 2003, 2005; Serrano et al., 2003; Sullivan et al., 2003, 2005). The most negative curvature volume appears to be the best for viewing fractures. There are several ways that fractures could cause negative bending of a seismic horizon. One possible explanation is that the fractures are open and locally decrease the average velocity of the rock. Another possibility is that the fractures are filled with a lower velocity material, such as shale.

Curvature has proven to be useful in identifying fractures that cannot be identified with conventional 3-D seismic attributes, including coherence. This is because fractures or small-offset faults (with offsets less than one-quarter wavelength) will not cause a break in the seismic reflector, and are thus not detectable by coherence. However, the subtle flexure in the horizons due to these features can be detected by curvature.



Comparison of coherence (left), most negative curvature from gridded, interpreted horizon (middle), and extracted volumetric curvature (right) for the Gilmore City horizon from the Dickman seismic survey. Note that oriented lineaments, which cannot be seen on the coherence map, are visible on the two curvature maps. Also note that the lineaments are better defined on the volumetric curvature map than on the horizon curvature map.