[GC]Horizon Attribute Curvature Aids Stratigraphic Interpretation*

By

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General Comments

Horizon attributes (such as dip and azimuth) derived from horizons mapped in 3-D seismic volumes are commonly used by seismic interpreters to identify structural features. Curvature, another type of horizon attribute, is a two-dimensional property of a curve that quantifies the degree to which that curve deviates from a straight line.

Many different types of curvature may be defined for a surface that is curved (Figure 1). For example, curvature may be defined in the strike (K_S), dip (K_D) or contour (K_C) direction. The orientation of maximum (K_{max}) and minimum (K_{min}) curvature may be different from strike, dip or contour curvature.

Curvature analysis has been used in terrain sciences for various purposes, including the definition of drainage networks. In the late 1990s, Andy Roberts (then with Enterprise Oil) illustrated how curvature could be used to define subtle structures that compartmentalize reservoirs in a field from the North Sea.

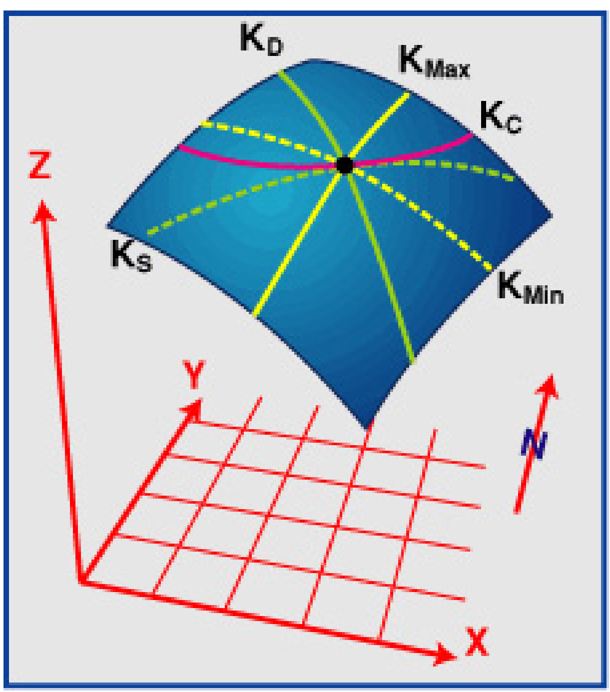

Figure 1. Curvature is a two-dimensional property. Many different types of curvature may be derived from a 3-D surface.

Horizontal Attributes in Defining Depositional Features

With this column we illustrate the use of horizon attributes to help define depositional features in 3-D seismic volumes from clastic and carbonate environments. We developed freeware that allows us to change the wavelength over which the curvature is calculated.

Curvature analysis of surfaces helps to remove the effects of regional dip, thus emphasizing small-scale features that might be associated with primary depositional features or small-scale faults. A tilted planar surface has dip but no curvature. When a surface is steeply dipping -- for example, on the limbs of a fold -- high dips can obscure subtle features on the surface. This problem is commonly referred to as "dip saturation." Curvature analysis identifies deviations from a planar surface, regardless of whether the surface is horizontal or tilted, and is therefore often more useful than conventional dip calculations for defining structural or stratigraphic features.

Examples

In the examples here we illustrate dip curvature draped over 3-D representations of surfaces. Curvature in the dip direction is a particularly useful tool because it emphasizes relief on a surface. We construct a color scale that gives approximately equal weight to both positive (concave down) and negative (concave up) curvatures.

Illumination angles were adjusted to further highlight features of interest. Ideally, viewing angle, illumination angle, zoom and color bars should all be adjusted interactively during the interpretation process.

Figure 2a shows a time-structure map of the top of a Tertiary channel-levee complex from a deep-water setting. The axis of the channel is clearly evident, as is a regional dip to the left. The contours show long, curvilinear trends of uncertain origin. Figures 2b and 2c show dip curvature draped over time structure, with illumination to further help emphasize subtle features on the surface. In these views, portions of the surface with no curvature in the dip direction are shown in yellow and areas of concave-up (orange and red) and concave-down (green and blue) curvature are highlighted. The general depositional dip to the left is de-emphasized, with the result that edges associated with smaller-scale features become more visible.

Note how the curvature visualization displays better define the faults, as well as details of the morphology within the channel itself. It is clear that the channel margins have been enlarged by meander loop migration. An erosional inner thalweg was subsequently cut, at least locally. Faults are clearly visible outside of the channel. Comparison of Figures 2b and 2c shows how changing the viewing angle, zoom and surface illumination angle may be used to emphasize different scales and types of feature.

Figure 3a shows a time-structure map of a Devonian horizon from the Williston Basin. The image shows a regional dip to the southwest as well as the presence of pinnacle reefs. Figure 3b shows the same surface, with dip curvature draped over time structure. As per the previous example, the regional dip is removed using the curvature attribute, thus emphasizing depositional features along the surface.

The broad aperture we used in this example helps to emphasize the flanks of the pinnacles. This particular viewing angle emphasizes an apparent alignment of the buildups and might suggest that the larger features are composite reefs that have amalgamated during growth.

Curvature is calculated from regularly sampled surfaces, such as horizons picked in 3-D seismic data. Digital elevation model data, swath bathymetry and even potential field data such as aeromagnetic data also may be used in curvature analyses. Point-based data (e.g., well tops) or horizons picked in 2-D seismic lines also may be analyzed using curvature—however, these data need to be gridded before analysis, and the results are highly sensitive to the gridding method used and input data density (i.e., small-scale features are poorly defined).

As a cautionary note we emphasize that, however helpful curvature-based visualization may be, seismic interpreters need to go beyond simple horizon-based analyses. This is because some morphologies can be formed by more than one process. Vertical transects through 3-D volumes need to be examined to help determine the origin of features identified through curvature analysis.

The software used to derive the curvature attributes, including curvature of different apertures, was developed during a Department of Energy funded project on naturally fractured tight-gas reservoirs and is freely available at http://www.eps.mcgill.ca/~hart/CURVZ_website.htm.

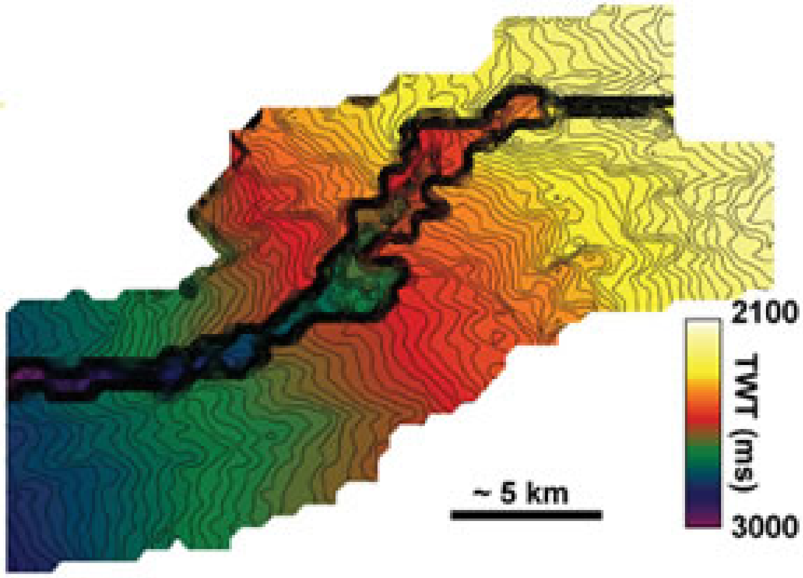

Figure 2a. Time-structure map of the top of a Tertiary channel-levee complex.

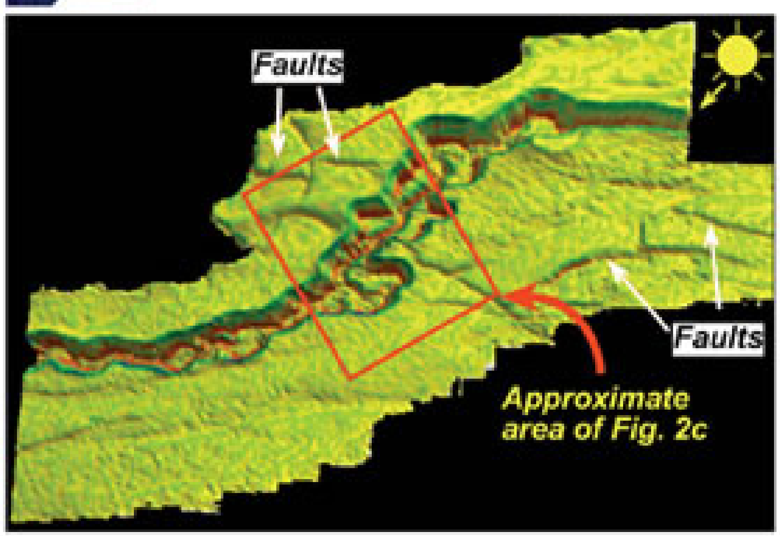

Figure 2b. Subtle structural and stratigraphic features are emphasized when dip curvature is overlain over the surface.

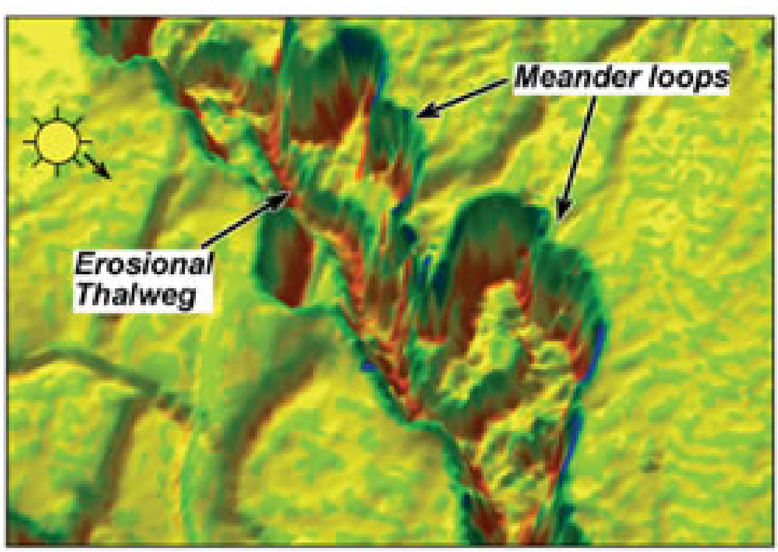

Figure 2c. Expanded and rotated view shows smaller scale features.

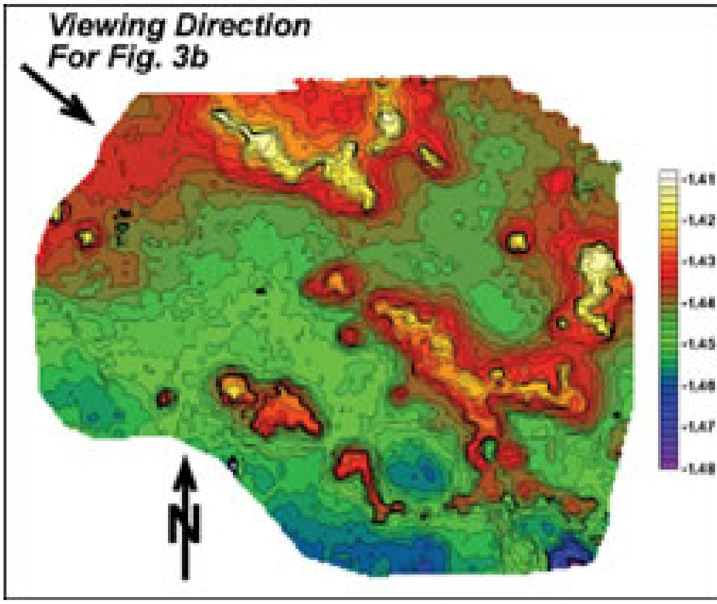

Figure 3a. Time-structure map showing Devonian pinnacle reefs in the Williston Basin.

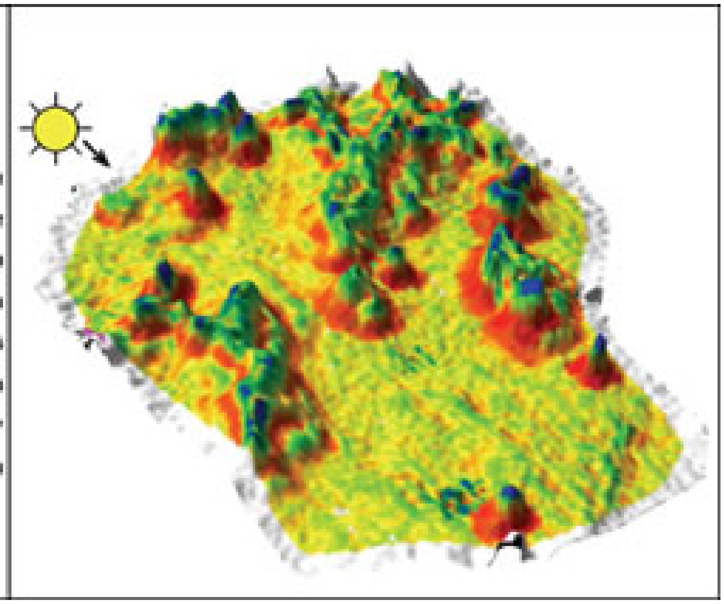

Figure 3b. The dip curvature visualization emphasizes the form of the pinnacles.