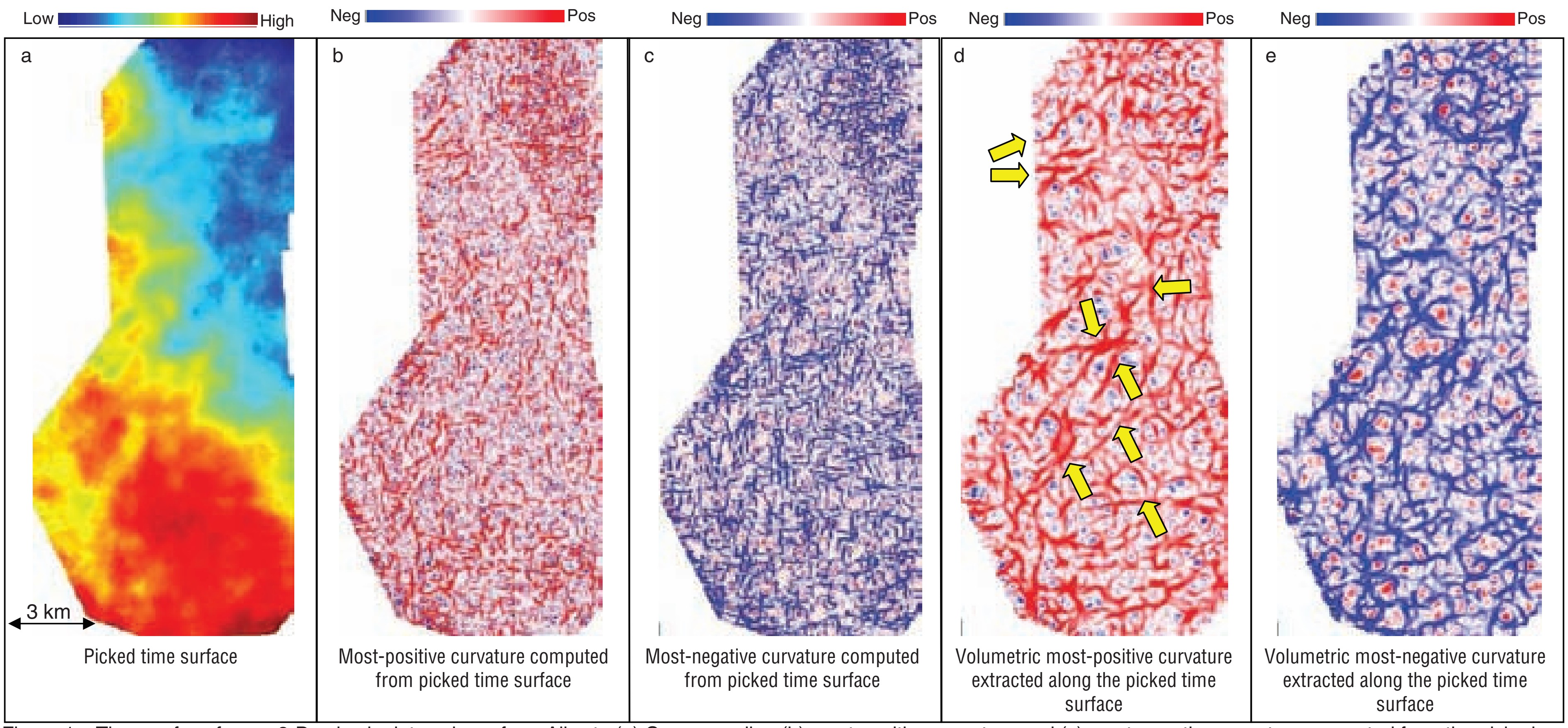

Figure 1 – Time surface from a 3-D seismic data volume from Alberta (a) Corresponding (b) most-positive curvature and (c) most-negative curvature computed from the picked horizon. Note the NS and EW trending acquisition footprint. Horizon slices through volumetric calculations of (d) most-positive (long-wavelength) and (e) most-negative (long-wavelength) curvature. Block arrows indicate broad geologic flexures seen in the vertical seismic while the footprint artifacts seen on the horizon-based displays are not seen.

Data courtesy of Arcis Corporation, Calgary

GEOPHYSICAL CORNER

Using Curvature to Map Faults, Fractures

(The Geophysical Corner is a regular column in the EXPLORER, edited by Bob A. Hardage, senior research scientist at the Bureau of Economic Geology, the University of Texas at Austin. This month's column, the first of a two-part series, deals with seismic curvature attributes: mapping faults and fractures.)

By SATINDER CHOPRA
and KURT J. MARFURT

Curvature is a measure of the deviation of a surface from a plane. The more a surface is structurally flexed, folded or faulted, the larger its curvature.

Curvature can indicate domes and sags associated with salt and shale diapirism, differential compaction and diagenetic dissolution and collapse, as well as predict paleostress and areas favorable for natural fractures.

Curvature is usually computed from picked horizon surfaces interpreted on 3-D seismic data volumes. An interpreter defines surface patches of a given size, which appropriate software algorithms then fit with a mathematical quadratic surface.

Curvature measures computed from the coefficients of this quadratic surface include:

- ✓ Curvedness.
- ✓ Azimuth of minimum curvature.
- ✓ Shape index.
- ✓ Minimum, maximum, most-positive, most-negative.
- ✓ Dip.
- ✓ Strike curvatures.

We find the most-positive and most-negative curvatures to be the easiest measure to visually correlate to features of geologic interest.

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Figure 1a shows a time-structure map at about 1850 ms, interpreted from a 3-D seismic volume acquired in Alberta, Canada. The horizon was manually picked across a grid of control lines to generate the horizon-based curvature images displayed in figures 1b and c.

Both of these displays are contaminated by strong NS and EW acquisition footprints. Whether due to limitations in the survey design, coherent noise or systematic errors in data processing, an acquisition footprint is related to the source and receiver geometry and has little correlation to the subsurface geology.

Horizons picked on noisy seismic data contaminated with acquisition footprint, or picked through regions where no consistent impedance contrast exists (such as channels, turbidites, mass transport complexes and karst), can lead to inferior curvature measures.

A significant advance in curvature analysis has been the volumetric estimation of curvature, which alleviates the need for picking horizons in regions through where no continuous surface exists.

Even when spatial filtering is used to minimize effects of an acquisition footprint, horizon-based curvature estimates may still suffer from footprint artifacts. In contrast, curvature attribute values extracted from volumetric curvature computations yield displays that are free of artifacts and make more geologic sense.

For example, figures 1d and e show the most-positive and most-negative volumetric curvature attributes extracted along the horizon surface in figure 1a.

Notice that these displays are free of the NS and EW artifacts seen in figures 1b and c, and show arcuate folds indicated by yellow arrows.

The advantages of volumetric attributes are two-fold:

✓ As shown in figure 1, the images have a higher signal-to-noise ratio. Volumetric estimates of curvature are computed not from one picked data sample, but rather from a vertical window of seismic samples (in our case, 11 samples) and are statistically less sensitive to noise.

✓ Not every geologic feature that we wish to interpret falls along a horizon that can be interpreted. Often the target of interest falls above or below a strong, easily picked horizon.

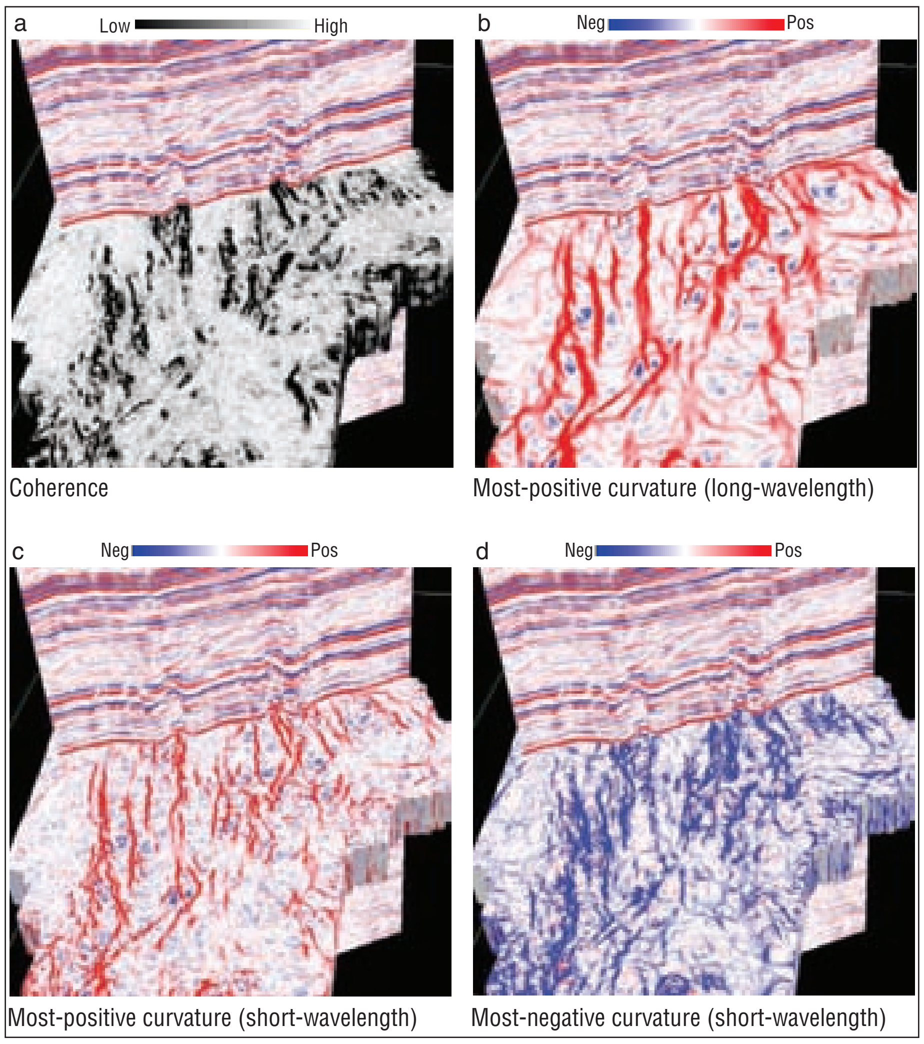

Figure 2 – Zoom of chair-displays where the vertical display is a dip line through the 3-D seismic volume and the horizontal displays are time slices from (a) coherence, (b) most-positive (long-wavelength), (c) most-positive (short-wavelength) and (d) most-negative (short-wavelength) curvature attribute volumes. The fault lineaments correlate with the upthrown and downthrown signatures on the seismic.

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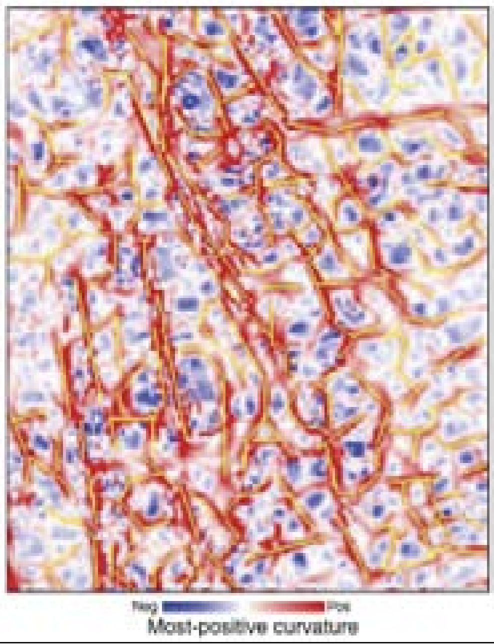

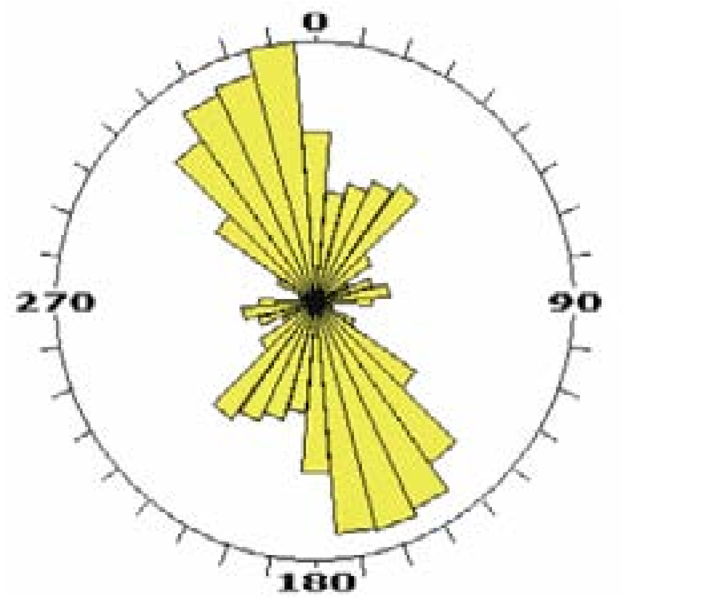

Figure 3 – Horizon slice (a) extracted from the most-positive (long-wavelength) curvature attribute with lineaments corresponding to the faults marked as yellow lines. Orientations of the marked lineaments (yellow) in (a) combined in the form of a Rose diagram (b).

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Curvature images having different spatial wavelengths provide different perspectives of the same geology. Tight (short-wavelength) curvature delineates small details, such as intense, highly localized fracture systems. Broad (long-wavelength) curvature enhances smooth, subtle flexures that are difficult to see in conventional seismic data, but which are often correlated to fracture zones that are below seismic resolution and to collapse features and diagenetic alterations.

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Figure 2 shows displays of strat-cubes near 1620 ms from coherence, most-positive (both long-wavelength and short-wavelength) and from short-wavelength, most-negative curvature volumes that intersect a random line that cuts across the fault/fracture trends.

The red peaks (figures 2b and c) on the fault lineaments (running almost north-south) correlate with the upthrown signature on the seismic data.

The most-negative curvature strat-slice (figure 2d) shows the downthrown edges on both sides of the faults highlighted in blue.

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Figure 3a shows the horizon slice extracted from the most-positive curvature volume at a zone of interest.

There are a number of fracture lineaments delineated by yellow picks. The density and orientations of these lineaments have been combined into the rose diagram shown in figure 3b, which retains the colors of the lineaments. This rose diagram can be compared with a similar diagram obtained from borehole image logs to gain confidence in the seismic-to-log calibration.

Once a favorable match is obtained, the interpretation of fault/fracture orientations and the intervals over which they dominate can then be trusted for a more quantitative analysis – which, in turn, is useful for optimal characterization of reservoirs.

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Next month's column will illustrate the application of these attributes for mapping channels, levees and other stratigraphic features – particularly in older rocks that have undergone differential compaction. ❑

(Editor's note: Chopra is with Arcis Corp., Calgary, Canada; Marfurt is with the University of Oklahoma. Both are AAPG members.)