AAPG EXPLORER

GEOPHYSICAL CORNER

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 deals with a comparison of structural and amplitude curvatures.

Curvature Computations Enhance Exploration

By SATINDER CHOPRA and KURT J. MARFURT

Curvature attributes have become popular with seismic interpreters and have found their way into most commercial seismic-interpretation software packages.

Curvature estimates were introduced as computations performed on interpreted 2-D seismic surfaces, and 3-D computations based on volumetric estimates of inline and crossline dip soon followed.

CHOPRA

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A 3-D volume of curvature values is produced by estimating reflector dip and azimuth at each data sample in a seismic volume.

We denote the output of such calculations as structural curvature because the calculations are performed on time-based or depth-based seismic data that define the geometrical configurations of subsurface structure.

A second type of curvature attribute can be calculated by using seismic reflection amplitudes rather than geometrical shapes of structure. When an interpreter creates a 3-D horizon through a seismic amplitude volume, inline and crossline derivatives of amplitude-magnitude variations can be calculated across this horizon.

Attributes that define the gradient behavior of reflection amplitude in X-Y space across a horizon are called amplitude curvature and are valuable for delineating the edges of bright spots, channels and other stratigraphic features that produce lateral variations in reflection magnitudes.

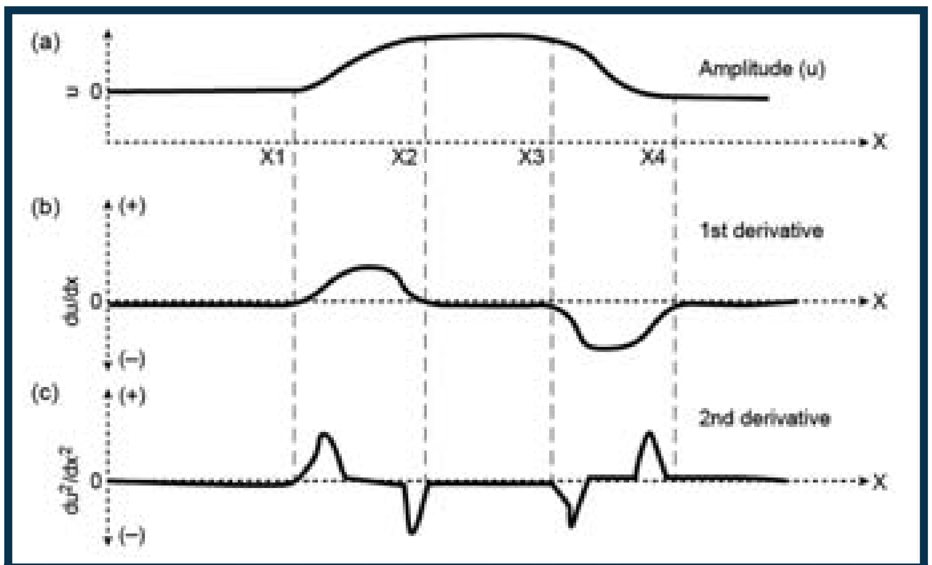

Figure 1 – (a) Absolute magnitude of seismic amplitude along image coordinate X. A seismic bright spot occurs between coordinates X1 and X4. Absolute magnitude is always a positive quantity. (b) First derivative of the amplitude function, which has positive and negative values. (c) Second derivative of the amplitude function, which also has positive and negative values. Note how the extrema in (c) define the edges of the amplitude anomaly.

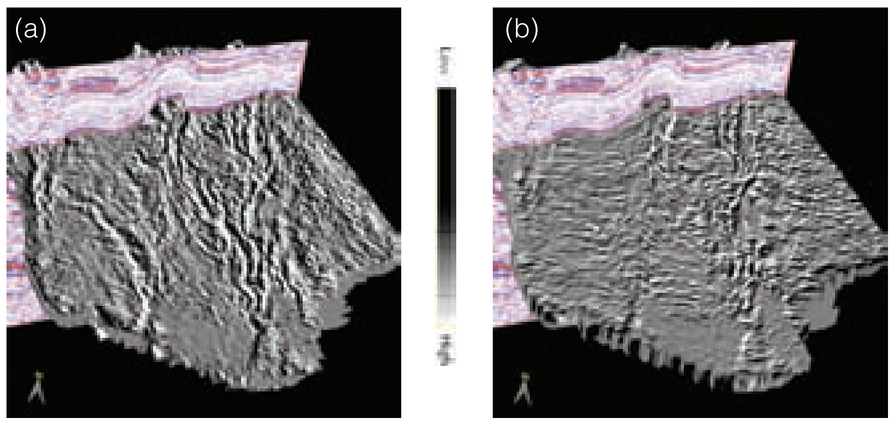

Figure 2 – Three-D chair views showing a seismic inline correlated with (a) inline energy gradient and (b) crossline energy gradient. Each strat-cube shows information that may not be easily seen in the companion display.

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In figure 1a we show a schematic diagram of the magnitude of a hypothetical seismic amplitude anomaly along image coordinate X. This curve shows an increase in reflection amplitude between image coordinates X1 and X4, with maximum amplitudes occurring between X2 and X3.

Next, we compute the first and second spatial derivatives of this amplitude behavior with respect to X, and show the results in figures 1b and 1c.

Note how the extrema of the second derivative in figure 1c define where the amplitude anomaly undergoes a change in magnitude.

In a 3-D seismic volume, amplitude gradients are computed along structural dip by taking derivatives in inline and crossline directions. Figure 2 shows 3-D chair views of an inline vertical slice through a seismic amplitude volume and the correlation of that profile with energy-weighted amplitude gradients calculated in the inline direction (figure 2a) and in the crossline direction (figure 2b). Both images show independent views of north-south oriented main faults and features related to those faults.

A geological structure has curvature of different spatial wavelengths at various locations across the structure. Thus structural curvature computed at different wavelengths provides different perspectives of the same geology.

Short-wavelength curvature tends to delineate details showing intense, highly localized faulting. In contrast, long-wavelength curvature enhances subtle flexures on a scale of 100, 200 or more image traces that are difficult to see on conventional seismic data.

These long-wavelength features often correlate to fault-generated patterns that

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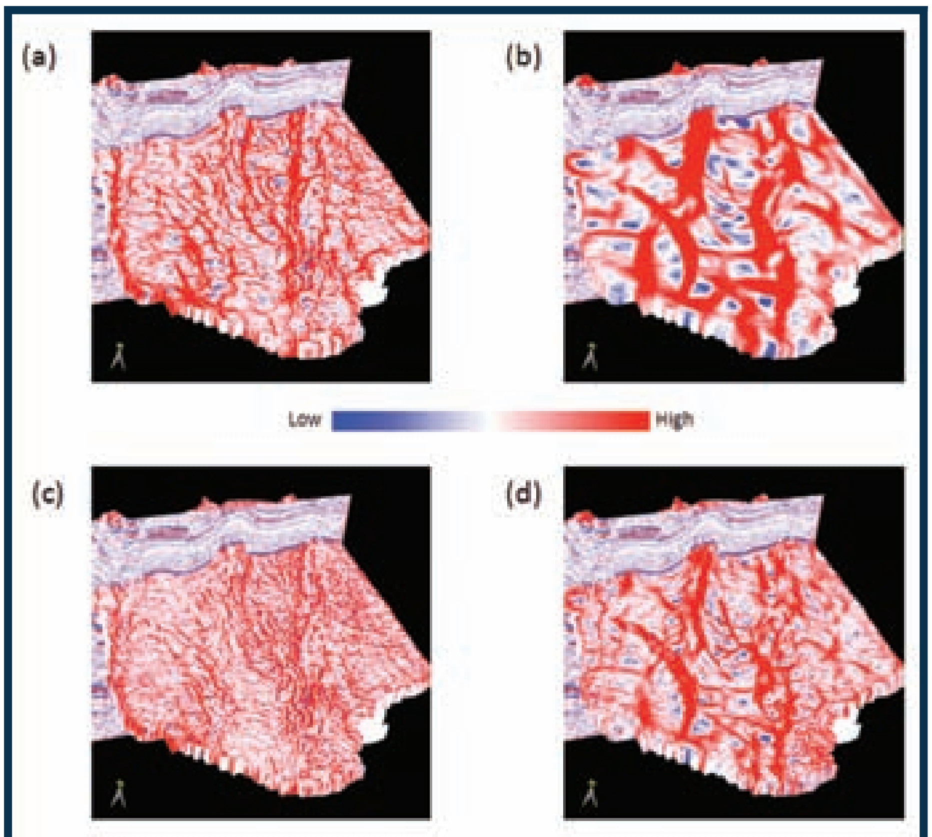

Figure 3 – Three-D chair views showing an inline vertical slice through a 3-D volume intersecting (a) most-positive amplitude curvature (long-wavelength), (b) most-positive structural curvature (long-wavelength), (c) most-positive amplitude curvature (short-wavelength) and (d) most-positive structural curvature (short-wavelength). Notice the higher level of detail on amplitude-curvature displays (a and c) compared with that on structural-curvature displays (b and d).

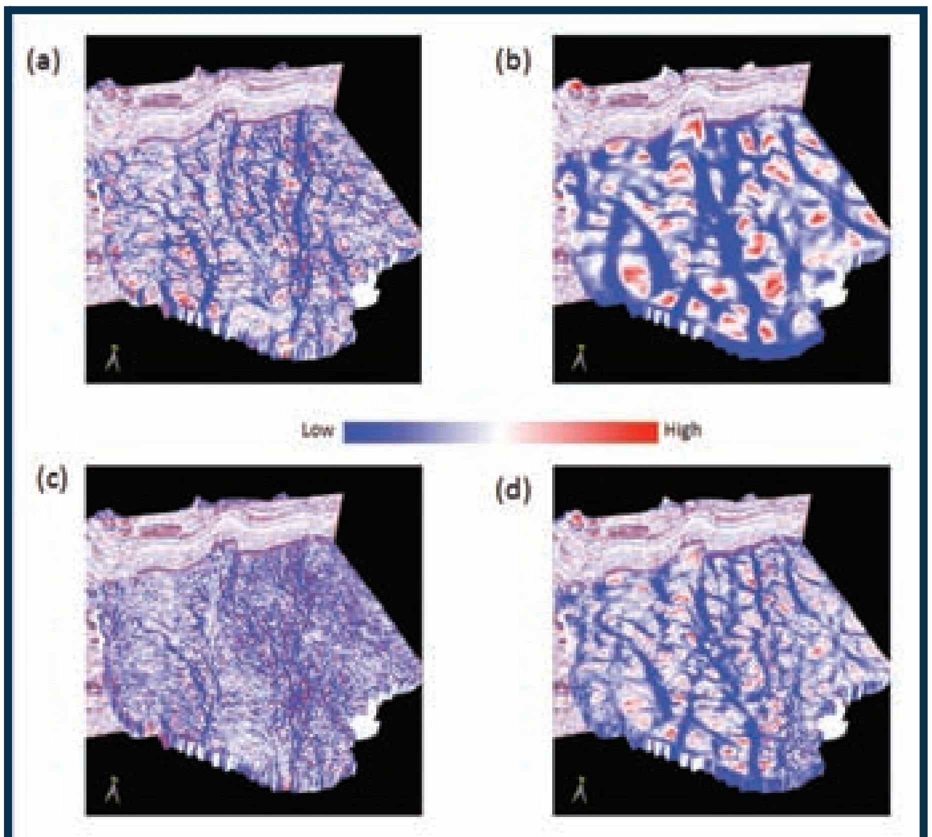

Figure 4 – Three-D chair views showing an inline vertical slice through (a) most-negative amplitude curvature (long-wavelength), (b) most-negative structural curvature (long-wavelength), (c) most-negative amplitude curvature (short-wavelength) and (d) most-negative structural curvature (short-wavelength). Notice the higher level of detail on amplitude-curvature displays (a and c) compared with that on structural-curvature displays (b and d).

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are below seismic resolution, shallow bowl-shaped collapse features or modest dome-shaped carbonate buildups.

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Figures 3 and 4 compare long-wavelength and short-wavelength computations of most-positive and most-negative amplitude curvatures and structural curvatures.

In figure 3, note that for both long and short wavelengths, most-positive estimates of amplitude-curvature (figures 3a and 3c) provide considerable detail, whereas most-positive structure-curvature displays (figures 3b and 3d) show larger-scale features.

The same physics occurs for estimates of most-negative curvature – amplitude curvature (figures 4a and 4c) depicts fine detail, but structural curvature (figures 4b and 4d) shows larger features.

Amplitude curvature is not a better seismic attribute than structural curvature; it is simply a different attribute. Although structural highs and ref ection amplitude anomalies are mathematically independent, they may be coupled by geology.

For example, gas trapped by structure may create a bright spot. In such a case, the second derivatives of structure curvature and ref ection amplitude curvature may be related.

Conclusions

When seismic data are processed with amplitude-preserving procedures, amplitude variations can be diagnostic of geologic information – such as changes in porosity, thickness or lithology.

Computing curvature of ref ection-amplitude gradients enhances the detection of gas-charged fractures, mineralized cleats in coal seams and other subtle features.

We hope to extend the work shown here to generate rose diagrams of lineaments observed on amplitude-curvature maps and compare these with rose diagrams obtained from image logs.

Acknowledgements

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(Editor's note: AAPG member Satinder Chopra is with Arcis Corp., Calgary, Canada, and AAPG member Kurt J. Marfurt is with the University of Oklahoma, Norman, Okla.)

Discovery

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was Triassic," exploration manager Dave McDonald recalled years later.

Kopsen, now a veteran North West Shelf consultant in Perth, described it recently as 'the experience of a lifetime.'

"I was there for the discovery, had a week off, and was back for the final logging run," he recalled. "I was the first geologist to see the logs. It was unbelievable. I still remember the gas-water contact, too: 10,667 feet."

Discovery Channels

The first test f owed 12.8 MMcfd, with 25 bbl/Mcf of condensate: North Rankin was declared a gas discovery. Original reserves were about 11.5 Tcf and 200 MMbbl of condensate.

Rankin-1, Angel-1 and Goodwyn-1 followed consecutively. All were major gas discoveries, with large condensate reserves, cumulatively about 7 Tcf of gas and 400 MMbbl of liquids.

The Rankin Trend is now seen to be the uplifted and eroded shoulder of the Jurassic rift system that formed the Barrow and Dampier sub-basins. The gas in the thick f uvial Triassic sandstones are sourced mainly by interbedded and underlying coals and shales, and sealed by Cretaceous shales deposited on the subsiding Australian margin.

Boutakoff's "highs" turned out to be horst blocks formed in the extensional regime associated with break-up of eastern Gondwana – not folds within a compressive geosyncline province, but he was certainly right about them being "suitable for considerable accumulation of petroleum," albeit mainly gas.

Exploration manager McDonald recalled years later in an interview, 'Every day it was almost ho-hum. We would drill another 100 feet of pay."

Woodside and BOCAL merged soon after the discovery and Woodside Burmah Oil NL became the new operator. Turbulent years lay ahead – first, a nationalistic Federal Labour government opposed export of gas and threatened nationalization, and then Burmah's financial troubles forced it to sell its interests to Shell and BHP and Shell became the dominant force in guiding and staffing the Woodside operating office.

Much to Celebrate

In 1977, with strong support from Western Australian State Premier Sir Charles Court and the new federal government, Woodside commenced the project planning stage.

Two decisions in subsequent years were critical:

- First, the decision to complete a domestic gas development before the LNG phase.
- Second, Court's decision to contract gas for domestic power generation on a take-or-pay basis.

The decision to proceed with the Domgas project was announced in September 1980. The hub of the North West Shelf Venture, as it became known, was the platform on the North Rankin field, very close to that first well site.

First gas f owed ashore in July 1984 and onto domestic customers the following month.

Geoff Donaldson retired later that year, having guided the company for nearly three decades.

The size and costs of the LNG project forced Woodside and partners to rearrange their JV interests: Japanese companies Mitsubishi and Mitsui, purchased one-third of Woodside's 50 percent interest, with BHP and Shell acquiring one-sixth each. The first LNG shipment left for Japan in July 1989.

To celebrate the 40th anniversary of the North Rankin-1 gas discovery, BOCAL veterans are planning celebrations later this year in Perth and London. They have a lot to celebrate: The Rankin Trend fields have produced about 15.8 MMcfd of gas and 630 MMbbl of condensate to end 2010, with vast reserves remaining, and are an important part of the Australian economy.

No doubt there will be a toast or two to BOCAL/Woodside's many exploration successes and surprises, but none more so than this first well where it all started.