The Geophysical Corner is a regular column in the EXPLORER, edited by Satinder Chopra, chief geophysicist for Arcis Seismic Solutions, TGS, Calgary, Canada, and a past AAPG-SEG Joint Distinguished Lecturer.

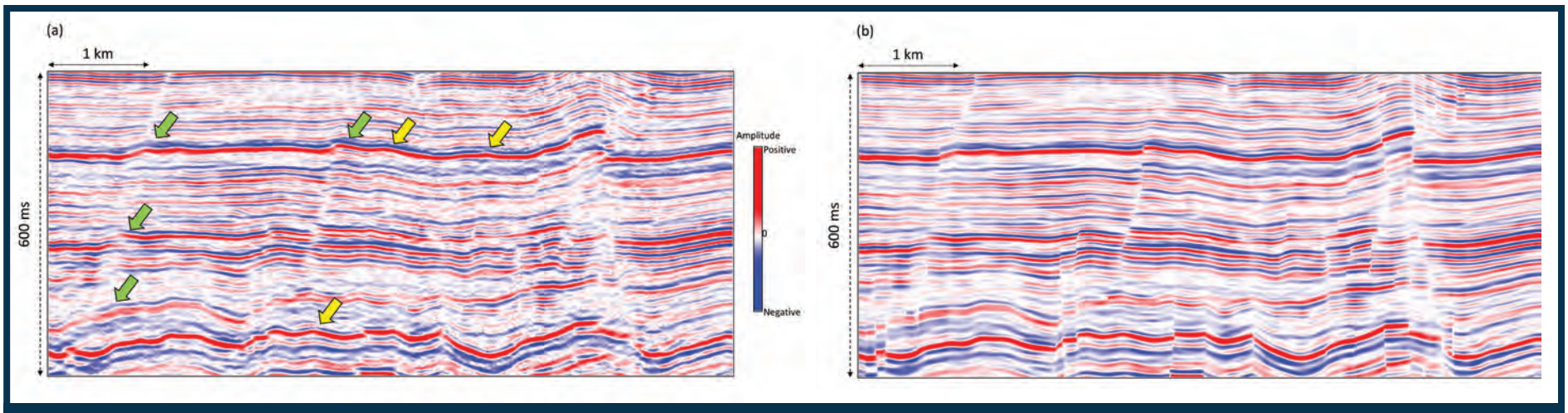

Figure 1: Vertical slices through the seismic amplitude volume (a) before and after (b) two passes of Kuwahara structure-oriented filtering. Notice how cross-cutting noise inconsistent with structural dip is suppressed, amplitudes consistent with structural dip are preserved, while discontinuities are sharpened with filtering. Green arrows indicate the footwall of a fault, while yellow arrows indicate folds that may be associated with pop-up features. Size of analysis window is 5 traces by 11 2-ms samples. (Data courtesy: Arcis Seismic Solutions, TGS, Calgary, Canada)

Volumetric Fault Enhancement Applications

By SATINDER CHOPRA and KURT J. MARFURT

Coherence is an iconic attribute available on most interpretation workstations and it helps with the characterization of small and large-scale faults, large structures, fault truncations, buried channels, reef edges and unconformities. There are various algorithms available for coherence computation, each having its advantages and limitations in terms of the quality of coherence imaging of the features of interest and run times associated with them.


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The quality of the input surface seismic data has a strong bearing on the quality of the coherence attribute generated, and for that matter any attribute that is generated therefrom. Due to operator aliasing, acquisition footprint and other noise, almost all coherence data volumes computed from 3-D land surveys benefit from further conditioning of the input amplitude data. Such data conditioning may include reduction of cross-cutting and random noise, sharpening or enhancement of discontinuities, spectral balancing and interpolation of missing traces.

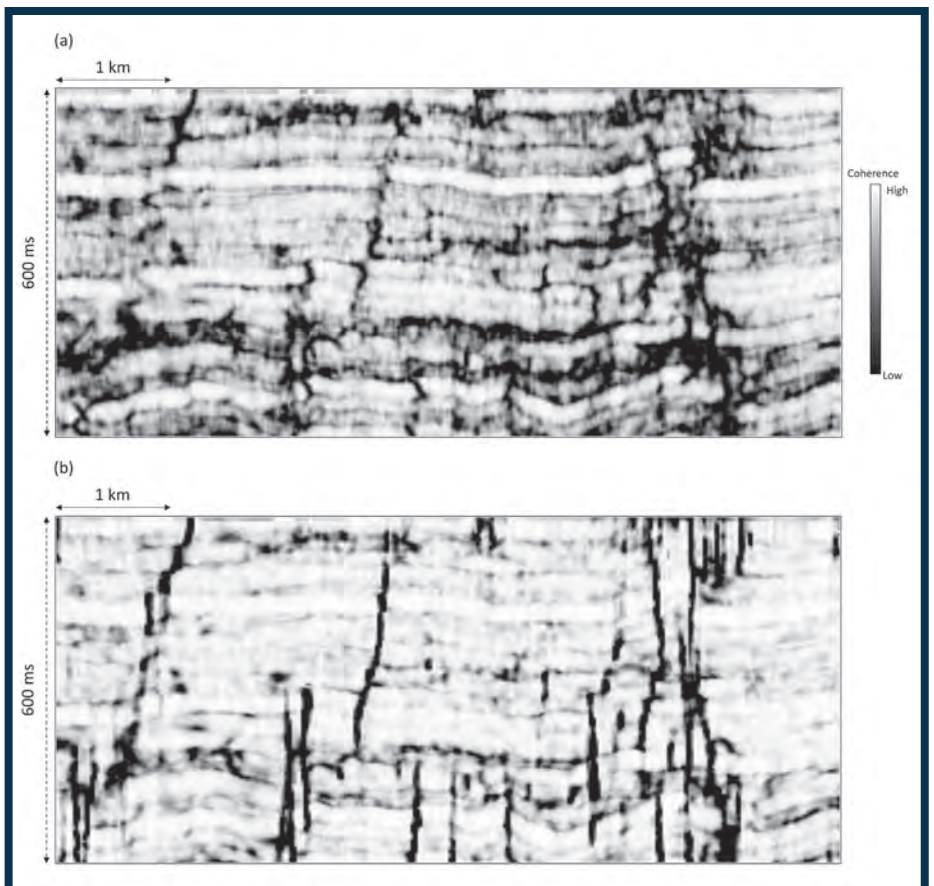

Figure 2: The same vertical slice as shown in figure 1, through the coherence volumes, (a) before, and (b) after data conditioning. The coherence attribute exhibits low values parallel to structure, some of which correlate to unconformities and others which correlate to areas of low signal-to-noise ratio.

In this article, we discuss the enhancement of faults and axial planes of folds by preconditioning of seismic data followed by directional smoothing and edge enhancement, thereby enhancing geological features of interest for effective interpretation.

The authors have discussed in detail the preconditioning of seismic data for attribute generation in the various articles they have published.

Such preconditioning suppresses noise and improves the lateral and vertical resolution of the signal for effective attribute analysis. One of the techniques for reducing noise and edge enhancement of discontinuities is the structure-oriented filtering with Kuwahara sharpening, which preserves the edges by selecting the most coherent patch of data around each sample in the seismic volume. With the use of overlapping windows, the best window can be determined for filtering such that not only the lateral, but vertical resolution can be improved about fault edges.

In figure 1, we show a vertical slice through a 3-D seismic volume from British Columbia, Canada. The seismic data were subjected to two passes of structure-oriented filtering with Kuwahara sharpening. Notice the crisp definition of the faults and the higher signal-to-noise ratio of the filtered amplitude data.

In figure 2, we show the equivalent vertical slices from the energy-ratio coherence attributes generated from the seismic data volumes before and after data conditioning. Notice that the near-vertical low-coherence anomalies corresponding to faults and large fractures are often overprinted by near-horizontal low-coherence anomalies parallel to stratigraphy. While useful for stratigraphic interpretation, these features often interfere with computer-aided fault interpretation.

Edge Enhancement

It is quite common to enhance edges on photographic images with the use of mathematical second derivative "Laplacian of Gaussian" filters. Similar filters have been used to enhance lateral structural and stratigraphic discontinuities in 3-D seismic data. Geological features comprising channels and fault trends seen on sharpened coherence displays are crisper and easier to interpret than they are on equivalent coherence displays without sharpening.

Similar but more focused workflows are now available that design directional filters, skeletonize discontinuities and generate preconditioned volumes for subsequent volumetric fault extraction.

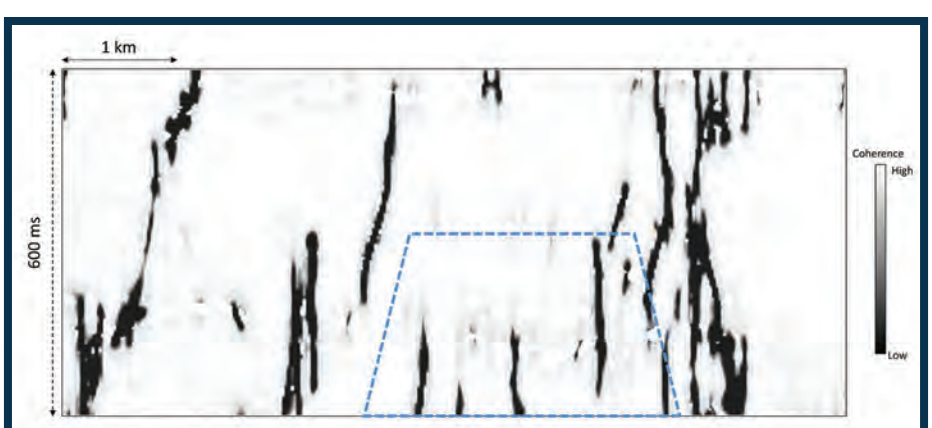

Figure 3: The same vertical slice as shown in figure 1, through the fault probability volume generated with seismic data put through two passes of Kuwahara structure-oriented filtering. The low coherence horizontal striping seen on the displays in figure 2 is now suppressed and the vertical discontinuities are seen clearly.

Fault Likelihood or Probability Attribute

When such preconditioned data are put through the workflow for volumetric fault enhancement mentioned earlier, one of the main attributes generated is the fault probability volume. In figure 3, we show an equivalent section from the fault probability volume, generated for seismic data with two-passes of Kuwahara structure-oriented filtering. Notice how the prominent fault probability lineaments image and align the fault discontinuities, while the smaller ones in the blue highlighted area are not quite well defined.

While the vertical displays shown

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Mission
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mathematics and science more relevant within public schools and to address the aging workforce in the engineering and geoscience fields. The industries are projected to lose 50 percent of their workforce to retirement in the next 10 years, she said. IPAA partnered with PESA in 2012. There are currently 1,225 students enrolled across the five academies.

The center's mission is to introduce students to careers in energy early on – not when they are looking for work – and provide an understanding of what it would be like to work for a petroleum company, Ford noted.

No matter where the price of natural gas falls, there will be a necessary need for a "crew change," Ford said, and that is why it is crucial to expose current and future generations to technology and innovation.

"Tomorrow's energy problems will be solved by today's young people pursuing challenging STEM academic studies and careers and entering the energy industry," Ford said. "Hence, the energy industry continues to invest in today's youth."

In August, the North American Prospect Expo Partners presents a $100,000 donation to the center. The money will help fund the center's guest speaker lectures on teamwork and business, college site visits and industry-related competitions at the five academies, among other things.

Collaboration

Meanwhile, students in North Dakota have the opportunity to learn about the oil and gas industry thanks to a combined effort between the industry and education leaders. The curriculum, called ENERGY: Powered by North Dakota, was launched in 2014 and follows science, social studies and common core standards at the fourth and eighth-grade levels, said Emily McKay, director of the Great Plains Energy Corridor at Bismarck State College's National Energy Center of Excellence.

It's important for students in the state to know about North Dakota's energy resources, McKay said.

"Not only is energy a vital industry and economic engine for our state, it's also a highly tech-advanced and innovative industry," she said. "As students learn about energy in the state, they get excited about STEM."

Students can watch videos of a dragline operator at work, the construction of a wind turbine, time-lapse of drilling and more, and then teachers can link that information to what's happening in the students' backyards, McKay said.

"Even with a downturn in the oil industry, a highly-skilled workforce is still needed for long-term industry jobs," she said. "These are great careers for our students, as they typically pay well and offer opportunities in continuing education and advancement."

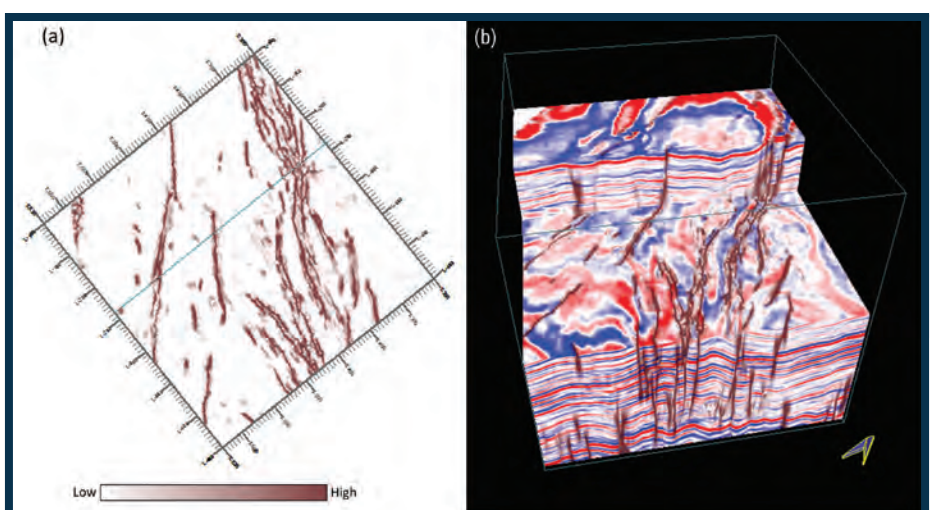

Figure 4: (a) Time slices at t=1300 ms through fault probability volumes computed with two passes of Kuwahara principal component structure-oriented filtering. Discontinuities subparallel to reflector dip have been suppressed. Note the improved continuity and extent of the faults where the fault enhancement algorithm has joined previously disjoint fault segments. (b) The seismic volume co-rendered with the fault probability volume, providing a useful way of carrying out fault interpretation.

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in the earlier figures convey the value-addition in terms of smoothing and crisp definition of the fault lineaments, in figure 4a we exhibit time slice at *t*=1300 ms from the fault probability volume generated for data with two-passes of Kuwahara structure-oriented filtering. Finally, we display 3-D volume visualization and correlation of the fault probability volume and its co-rendering with 3-D seismic data in figure 4b. Such fault-enhanced visualization facilitates their interpretation.

Conclusions

The volumetric fault image enhancement workflow described earlier provides a means of interpreting fault probability attributes for linear discontinuities. This approach helps in the manual interpretation of faults on workstations, and it provides a useful input for software designed for automatic extraction of fault planes. The methodology followed in this workflow enhances the desired orientation of linear geologic features, and their interpretations can be carried forward to the next step in terms of their correlations with production data.

We wish to thank Arcis Seismic Solutions, TGS, Calgary for permission to present this work.

(Editor's note: Kurt Marfurt is an AAPG Member and professor of geophysics at the University of Oklahoma.)