## Geophysical Corner

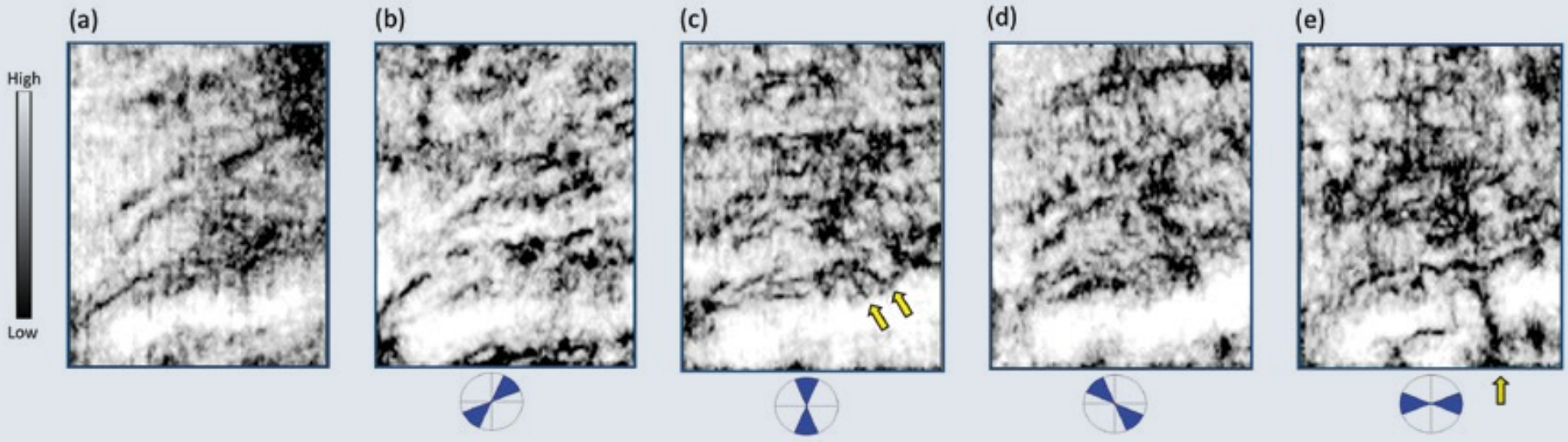


*Figure 1: Time slices at 1,312 milliseconds through coherence volumes from the all-azimuth coherence shown in (a), and azimuth-limited seismic volumes shown at 22.5 to 67.5 degrees, 67.5 to 112.5 degrees, 112.5 to 157.5 degrees, and 157.5 to 202.5 degrees (b) to (e). Noticeable differences can be seen between the coherence displays as indicated by the yellow arrows. The data are from offshore West Africa.*

# Multiazimuth Coherence Attribute Applications

In the July 2018 Geophysical Corner, we discussed the applications of the multispectral coherence attribute and demonstrated the resulting higher signal-to-noise ratio and enhanced discontinuity definition. The underlying assumption is that different frequency voice components (or more simply, the band-pass filtered version of the seismic data) see discontinuities differently. All interpreters have been annoyed when a clear through-going fault seen on a vertical slice through the seismic amplitude volume appears to have holes in the discontinuity on a vertical slice through the corresponding coherence volume. Most commonly, these holes occur when reflectors corresponding to different geologic horizons happen to "line-up" across the fault. While such alignments may occur on the broadband data (the sum of the spectral components), or even one or more of the spectral components, it is rare that they line up on all of the spectral components. For more details on the computation, please refer to the July Geophysical Corner.


CHOPRA

The concepts of coherence computed on multiple spectral components can be extended to coherence computed on multiple azimuthally-limited amplitude volumes. All three-dimensional seismic surveys are designed to record a range of azimuths, where discontinuities are better illuminated by some ray paths – typically those ray paths orthogonal to an edge, rather than ray paths parallel to the edge. Thus, the illumination of subsurface faults, fractures and stratigraphic edges varies with azimuth. During seismic processing, all offsets and azimuths are migrated (imaged) independently. While most interpreters pick horizons and faults and identify stratigraphic features on the stack of all these migrated traces, more quantitative interpretations use offset-limited (or incident-angle limited) sub-stacked volumes for amplitude variation with offset and prestack inversion analysis. Other technical specialists may use azimuthally-limited sub-stacks of the migrated traces to estimate the presence and orientation of fractures or of the intensity and orientation of the maximum horizontal stress. What many interpreters do not realize is that the cost of providing a full stack or of multiple offset-limited and/or azimuthally limited stacks is basically the cost of making extra intermediate volumes. The processing shop migrates the same

Continued on next page ▶

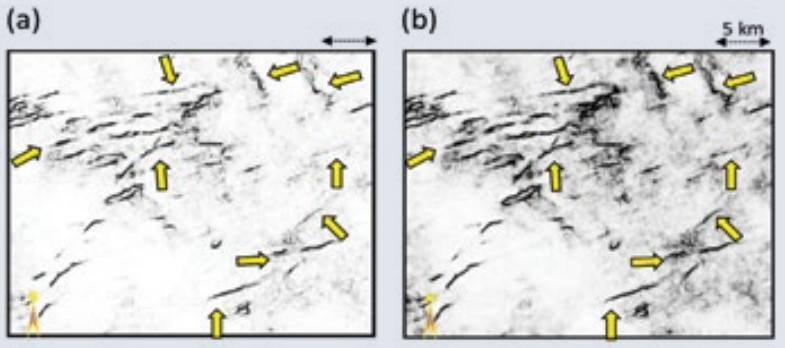


*Figure 2: Stratal slices 22 milliseconds below a marker horizon at approximately 1,950 milliseconds from (a) all azimuth energy ratio coherence, and (b) multi-azimuth energy ratio coherence. Notice the more emphasized definition of the fault lineaments on the multi-azimuth coherence. The seismic data is from the STACK trend in Oklahoma. Data courtesy of TGS, Houston.*

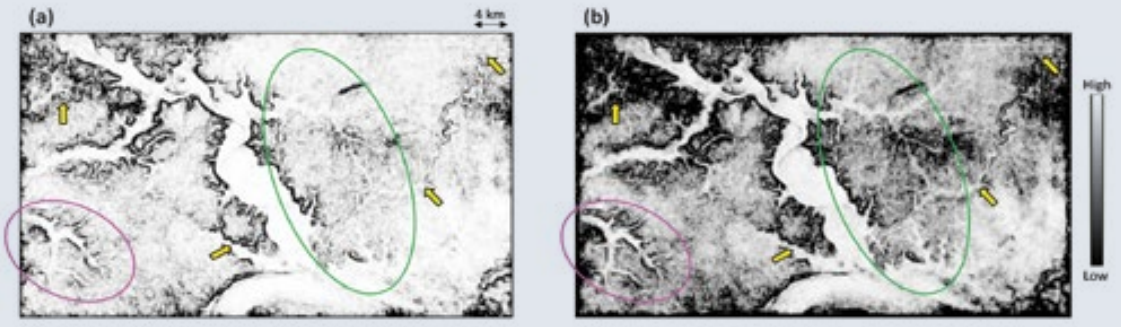


*Figure 3: Stratal slices 78 milliseconds below a marker horizon at approximately 1700ms from (a) all azimuth energy ratio coherence, and (b) multi-azimuth energy ratio coherence. Notice the enhanced definition of the channel features on the multi-azimuth coherence as shown in the magenta and green highlighted areas. The seismic data is from the STACK trend in Oklahoma. Data courtesy of TGS, Houston.*

◀ Continued from previous page

number of traces (and needs to construct an accurate velocity model) for all three of these workflows. It is critical that the oil company client explicitly request such intermediate volumes as part of the processing workflow, whether they anticipate using them immediately or not. Once the project is completed, these intermediate volumes are rarely archived.

Discontinuities are seen at different azimuths for three reasons.

The first is associated with the physics of wave propagation, where the larger amount of back-scattered energy is experienced by rays traveling perpendicular to a discontinuity. Rays travelling parallel to a discontinuity are also diffracted, but only as forward-scattered energy.

The second is geometrical, where a discontinuity imaged in the perpendicular direction will appear sharper, while the same discontinuity will appear more diffuse in a parallel direction.

The third reason is associated with seismic processing. Our seismic velocities are rarely perfect. A sharp discontinuity seen on a near-perpendicular azimuth can be stacked and then blurred with the smoother discontinuity seen on the parallel azimuth.

The value of computing coherence on azimuthally-limited sub-stacked volumes has been recognized almost from the beginning of coherence. Figure 1 shows an example from a wide-azimuth ocean bottom seismometer survey acquired offshore West Africa. On the basis of the orientation of faults in the volume, four azimuths were generated (22.5 to 67.5 degrees, 67.5 to 112.5 degrees, 112.5 to 157.5 degrees, and 157.5 to 202.5 degrees). Figure 1 shows time slices at 1,312 milliseconds through four coherence volumes computed from four azimuthally-limited seismic volumes. In addition to the strong northeast-southwest trending faults, the faults in the orthogonal direction are also imaged well, as shown by the yellow arrows. It has also long been recognized that attributes computed from such sub-volumes exhibit a lower signal-to-noise ratio than those computed from the full-azimuth stack.

AAPG Member Kurt J. Marfurt serves as the Frank and Henrietta Schultz professor of geophysics within the ConocoPhillips School of Geology and Geophysics at the University of Oklahoma in Norman, Okla.

## Multiazimuth Coherence

While OBS and node acquisition has become much more common over the past decade, wide-azimuth data acquisition has become almost standard in onshore 3-D surveys acquired in North America, particularly those acquired for resource plays where estimates of the maximum horizontal stress help define drilling and completion of horizontal wells. All of the larger acquisition companies can acquire and process wide azimuth 3-D seismic data that results in either offset-sector or offset-vector-tile binning. The key steps in the processing of these volumes are the azimuthally-compliant premigration noise attenuation, 5-D interpolation to a set of regularly sampled (typically at 30 degrees) azimuthal spokes (or sectors), azimuthal velocity analysis, and spoke by spoke post migration noise attenuation.

Similar to multispectral coherence, the covariance matrices are computed from the azimuthally-limited seismic volumes and oriented along structural dip, summed and then put through eigenvector computation of the summed matrix. Such a computation is referred to as multiazimuth coherence.

## Application to Modern Wide-azimuth Surveys

We demonstrate the application of multiazimuth coherence on a seismic volume from the STACK trend, in Oklahoma. In figure 2 we first show the stratal slices 22 milliseconds below a marker horizon at approximately 1,950 milliseconds, through the traditional

See **Resolution** page 22 ▶

## Resolution
from page 17

all-azimuth energy ratio coherence and the multiazimuth energy ratio coherence volumes. Note the enhanced definition of the northeast-southwest en echelon faults and the other east-west fault lineaments on the multiazimuth coherence display.

Figure 3 show a similar set of stratal slices 78 milliseconds below a marker at 1,700 milliseconds through the traditional all-azimuth energy ratio coherence and the multiazimuth energy ratio coherence volumes. Note the overall better definition of the main channel features, especially the smaller channel features enclosed in the highlighting magenta and green ellipses.

In summary, we state that multiazimuth energy ratio coherence computed by summing the covariance matrices in the computation windows from the different azimuthally-sectored seismic volumes exhibit higher signal-to-noise ratio and higher lateral resolution on the displays. We find such improved resolution coherence attribute volumes prove to be most useful in the interpretation of discontinuity features such faults and stratigraphic edges. With wide azimuth surveys becoming more commonly available, we encourage interpreters to request the resulting azimuthally-limited sub-stack volumes as part of their interpretation workflows.

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

## Wrightstone
from page 21

features a whiz-bang new IBM AI-based adviser computer technology. And another features the musings on climate change of someone who has not published a single peer-reviewed research paper on the topic and who is an employee of an "action tank" as well as a "think tank"( https://www.heartland.org/about-us/index.html) that advocates against action on climate change. Please explain to me how the editors of the EXPLORER have not violated AAPG Code of Ethics by featuring an article describing Gregory Wrightstone views? Mr. Wrightstone may be a good geologist but he is not an atmospheric scientist. AAPG loses credibility as a science and technology organization when it selectively chooses what science it accepts.

*James "Jim" Rine*

### Pseudoscience

I am appalled that AAPG Explorer would publish an article touting the "Benefits of Climate Change" without any mention of opposing views and relying entirely on the opinions of Gregory R. Wrightstone. Mr. Wrightstone's conclusions have never passed the scrutiny of scientific peer review nor has his work been published by a reputable scientific journal (including any of the scientific publications of AAPG). His book was self-published, as I presume that no legitimate publisher would take it. He uses "cherry-picked" published data and incomplete data sets to draw dubious conclusions. This is classic pseudoscience. In fact these standards are even lower than that of your average creationist publication. What this comes to is downright irresponsible journalism on the part of the EXPLORER staff. What is worse is that the quality of legitimate AAPG scientific publications is brought low in the eyes of the rest of the scientific community as well as the public. I already have to fight with colleagues who question the scientific quality of AAPG outlets where I publish. For the record, I have been a member of AAPG for 44 years. For the past 30 years I have taught and conducted research in sedimentary geology at major American and European Universities. I also have been employed, at various times, in the petroleum, minerals and environmental industries.

*Jay M. Gregg*

### Peer-Review EXPLORER

I think the time has come for AAPG to implement a peer-review system for the EXPLORER. GSA does it for GSAToday and AGU does it for Eos. As an active member of the organization, I find this a bit distressing.

Lorena Moscardelli

### Benefits of Global Warming

Thanks for publishing Wrightstone's article that brings back a geologist's perspective. The counterpoints in the comments to the article are filled with passionate words like "nonsense," "climate apologism," self-styled "distressing," "appalling," "garbage," "pseudoscience," etc.

Let's not forget that passion is inimical to rational thinking. Graham Brown has mentioned 'AAPG Studies in Geology No. 47 "Geological Perspectives in Global Climate Change.' To add, I request the members to watch BBC's "The Big Freeze" from the Earth Story series and read Rothman, D.H. 2002. "Atmospheric carbon dioxide levels for the last 500 million years: Proceedings of the National Academy of Sciences USA 99": (4167-4171).

Before turning abusive, we may like to ask ourselves these questions. a. Did warming and cooling happen umpteen number of times before humans appeared on Earth? If yes, have the natural factors controlling such events disappeared with the advent of humans? b. Did sea encroach and withdraw from land masses in past cycles; what do the oilfields producing from marine sediments deep inside the land masses tell us in that context? c. Isn't $CO_2$ plant feed and the rise in $CO_2$ results in spread of greeneries as Mr. Wrightstone postulates, quoting various third-party studies? d. Can we control solar activities and the ocean currents which are the biggest climate drivers or even smaller drivers like the volcanoes? e. in the name of controlling climate, aren't we trying to control pollution? That is a worthy cause to pursue. Why give it a big, self-deceptive name? Notwithstanding the larger than life ego the humans carry, they are a minor constituent of the natural system. It might be judicious to accept that one component of a particular system cannot comprehend the system as a whole, let alone control it. It would be definitely better and easier to adapt to changing climates rather than trying to discipline nature at a huge cost.

*Arijit Chaudhuri*