Geophysical Corner

Integration of AVAz/VVAz and Coherence/ Curvature Seismic Attributes

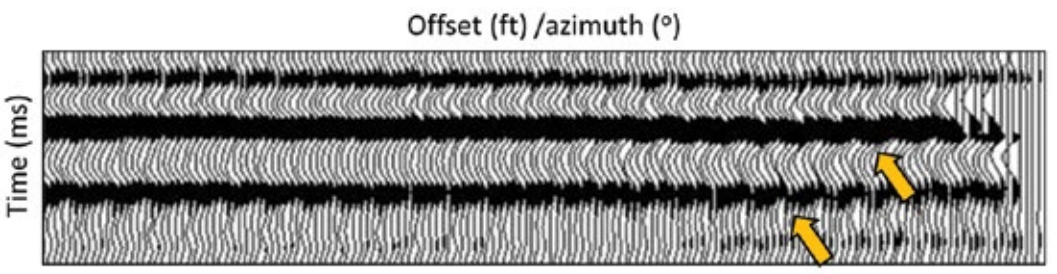

Figure 1: A common-offset common-azimuth or 'snail' gather depicting the variation of amplitudes with azimuth (yellow) on the mid-to-far offset range in prestack seismic data.


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Coherence and curvature attribute computations are usually carried out on stacked seismic data volumes to delineate faults, flexures and large fractures.

If the vertically-aligned parallel fractures in the subsurface are filled with fluid, or weakly cemented, the P-wave velocity across the fractures will be slower than that parallel to the fractures. These differences give rise to a velocity variation with azimuth (VVAz). Because impedance is the product of density and (in this case, anisotropic) velocity, such fractures also give rise to amplitude variation with offset (AVAz). Such variations can be expressed in the form of sinusoids or ellipses (in polar coordinates) whose ellipticity is proportional to fracture density and its major and minor axes delineate the orientation of the fractures. In conventional reservoirs, such fractured zones may represent sweet spots of enhanced permeability. In unconventional reservoirs, such fractured zones may be more easily stimulated during the completion process, where previously cemented fractures can be "popped open."

A couple of articles on seismic anisotropy applications for determination of fractures were published in the February and March 2018 installments of Geophysical Corner.

The desire to estimate azimuthal anisotropy from surface seismic measurements justified the construction of many of our earliest "wide-azimuth" survey designs. Since that time, seismic processors learned that wide-azimuth recording provided not only greater leverage against ground roll and multiples, but also provided improved statistics for velocity analysis and surface consistent statics and deconvolution processes. For these latter reasons, in 2018-9, the majority of 3-D surveys for unconventional resources were acquired in wide-azimuth mode. Ironically, many of these surveys are carefully analyzed for azimuthal anisotropy.

'Snail' Gather

A convenient way to display prestack seismic data containing both offset and azimuth information for each location is in the form of a 'snail' gather, where within the increasing offset bands the azimuthal variation from north to south is included (figure 1). Notice the variation of seismic amplitudes in different azimuths as indicated with the yellow arrows.

The general requirements on input seismic data for such an analysis are that it should have a wide azimuth, high fold, a reasonably small bin size, an even distribution of offsets and azimuths, a high signal-to-noise ratio and amplitudes preserved during processing.

Fractures are commonly associated with abnormal amounts of strain, which can be measured by attributes such as coherence and curvature. For this reason, we wish to determine if the anomalies provided by prestack AVAz/VVAz attributes correlate to those mapped using poststack attributes.

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Kurt Marfurt currently serves as the Frank and Henrietta Schultz Professor of Geophysics within the ConocoPhillips School of Geology and Geophysics. Marfurt also served as the EAGE/SEG Distinguished Short Course Instructor for 2006 (on Seismic Attribute Mapping of Structure and Stratigraphy), and the SEG Distinguished Short Course Instructor for 2018 (on Seismic Attributes as the Framework for Data Integration throughout the Oilfield Life Cycle).

To evaluate this correlation, we examine a modern 1,050 square-kilometer 3-D wide-azimuth seismic volume acquired by TGS in the Delaware Basin as mentioned in close proximity to the Central Basin Platform. Multiple exploration objectives include the characterization of the Bone Spring, Wolfcamp, Barnett and Mississippian formations.

In figure 2a we display a stratal slice at the Mississippian level through the azimuthal fracture intensity volume computed using VVAz analysis. Two large faults can be seen clearly on the display indicated by the green (upthrown) and pink (downthrown) arrows. A number of other lineaments in different directions can also be interpreted on this display, shown by dashed lines in figure 2b. This lineament interpretation displayed is not complete in the sense that other similar lineaments could be interpreted on this display. Such fracture detail can be very useful while considering the orientation of the horizontal wells by engineers. Finally, in figure 2c we use transparency to co-render the most-positive curvature attribute lineaments (in black) with the previous VVAz image. Notice, many of the larger curvature lineaments in black coincide with the lineaments interpreted on the VVAz display.

Not all anisotropy anomalies correlate to curvature anomalies. The orientation of the

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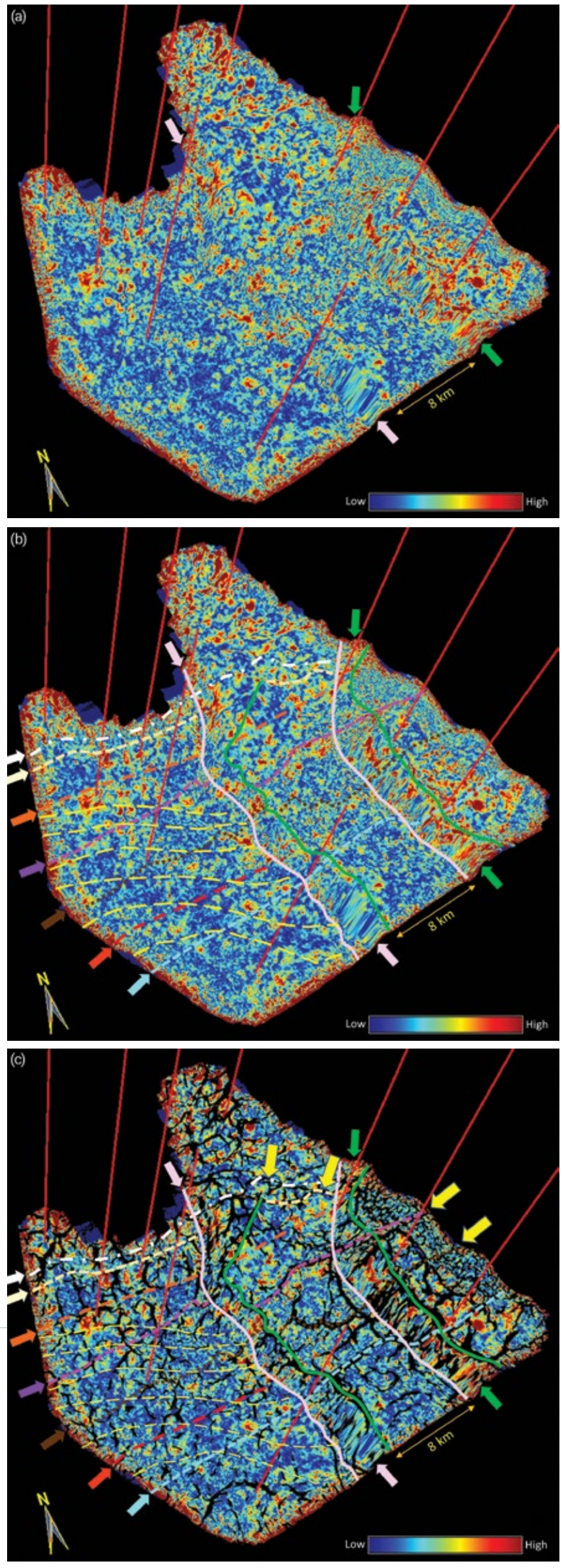

Figure 2: (a) Stratal slice from the azimuthal fracture intensity (VVAz) volume along the Mississippian marker. The two big faults indicated by the green (upthrown) and pink (downthrown) block arrows are shown clearly. (b) There are many other smaller fault/fracture trends that are clearly seen on this display and are indicated with multicoloured dashed lines and block arrows. (c) The same slice shown in (b), but now co-rendered with the most-positive long-wavelength curvature. Notice many of the interpreted lineaments follow the trend on the curvature lineaments (bright yellow block arrows). Data courtesy of TGS, Houston.

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maximum (S_H) and minimum (S_h) horizontal stresses will result in opening microcracks perpendicular and slower velocities parallel to the S_h direction. However, today's stress orientation will often be different from the stress orientations associated with structural deformation (and the creation of fractures) in the geologic past. Furthermore, the regional orientation of stresses may be modified by subsurface faults and other zones of weakness. For this reason, azimuthal anisotropy measures are sensitive not only to the orientation of natural fractures, but also to the regional and locally modified present-day stress directions. Ideally, both poststack and prestack anomalies should be integrated with an appropriate tectonic framework and then validated with image logs and microseismic data to construct a geologic model that defines both the past deformation and present-day stress regime.

(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.)

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efficiencies and increase value in their projects," he added.

Gneiss also sees regional/geographic consolidation as a core theme for the year, "as larger entities with more appropriately scaled operating costs provide a significantly more robust investment proposition," Fitzpatrick noted.

In mature areas, a leaner and disciplined approach to operations will be essential to extracting value, he said.

"The growing prominence of energy-focused, (private equity)-backed startups, particularly in the North Sea, are seen as sector-disruptive players who are looking to fill the void as the 'traditional' players exit a mature basin," Fitzpatrick observed.

"The application of leaner-and-meaner operating models to extract value in mature assets and push forward new developments, and synergies around partnerships in the upstream and services sectors, remain at the core of dealmakers thoughts," he said.

Capital Discipline

Companies now are challenged by multiple demands on capital available for investment, a common theme for the industry, Aitken said. Capital allocation "is a question all oil and gas companies wrestle with constantly," he noted.

"I think the big dilemma over the last year or so has been about how much to invest in growth. I'd say more companies have tended toward being prudent, opting to pay down debt, strengthen balance sheets and return cash to shareholders," he said.

Companies stretched with existing large capital commitments, like investment in LNG developments, "obviously tend not to be acquirers," Aitken noted, though those companies may sell assets to fund development or reduce capital commitments elsewhere.

"This usually affects particular companies rather than the whole industry at once. There's a big infrastructure build-out going in the Permian just now, but a lot of this is being done by midstream and downstream companies," Aitken said.

Today, deal proposals appear to hinge on a well-defined path to profitability. Andrew Dittmar, M&A analyst for Drillinginfo in Houston, said Wall Street "is ready to punish buyers who do deals without a clear profit strategy."

"Investors continue to demand that companies deliver a clear line-of-sight to positive free cash flow," Dittmar noted.

Andrew Latham, vice president of global exploration for Wood Mackenzie, said discipline is now key for upstream activities.

"The exploration industry has made huge strides to reset its economics and has been back in the black since 2017. Current prices are sufficient for disciplined explorers to continue to make good returns, but the watchwords remain 'capital discipline,'" he said.

Wood Mackenzie expects more exploration to be completed in both the United Kingdom and Norway in 2019 compared to last year, with similar small increases in activity in many other international plays, Latham said.

Majors are the companies to watch most closely, since they will be operating many of the key wildcat wells scheduled for the year ahead, he noted.

"There are concerns that attitudes in the wider public arena are turning against the industry, with various bans enacted in several countries around the world. The risk that these may spread more widely is a concern," Latham said.

For now, the consensus among analysts is that the industry remains just strong enough to be attractive for additional investment, especially if the annual average Brent crude price hovers around $65 a barrel.

Instead of "Show me the money," the operative slogan for deals at AAPEX 2019 seems to be, "Show me a clear path to profit."

"APPEX should be abuzz with companies looking for high-quality exploration opportunities that offer a ready route to market in a success case," Latham said.