GC Integration of AVAz/VVAz and Coherence/Curvature Seismic Attributes*

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General Statement

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."

An article on seismic anisotropy applications for determination of fractures was published in The Fabric, or Internal Structure, of Rocks – The Patterns of Anisotropy, Search and Discovery Article #42188.

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.

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.

Conclusion

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

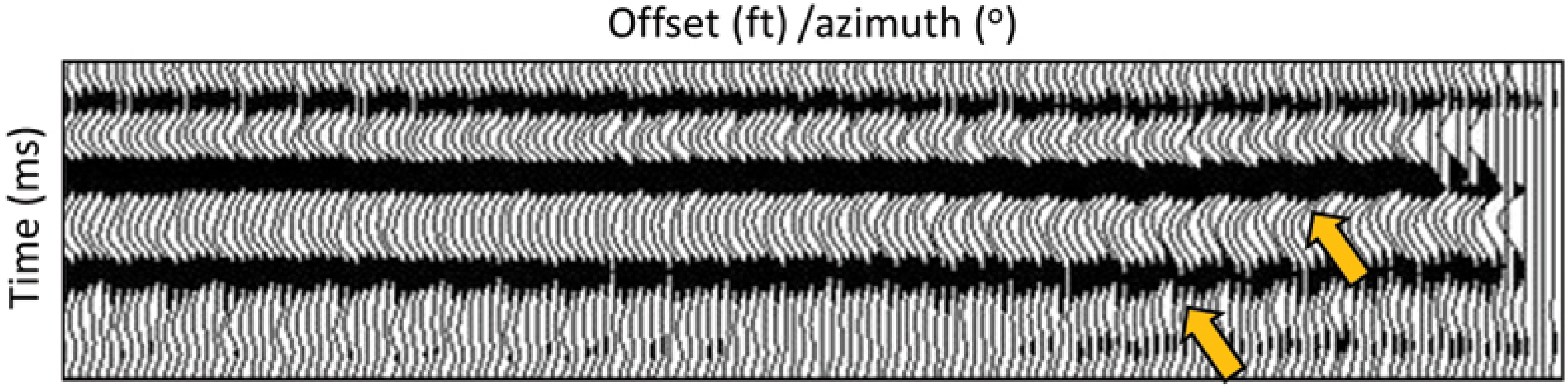

Figure 1. A common-offset common-azimuth or ‘snail’ gather depicting the variation of amplitudes with azimuth (yellow) on the mid-to-far offset range in prestack seismic data.

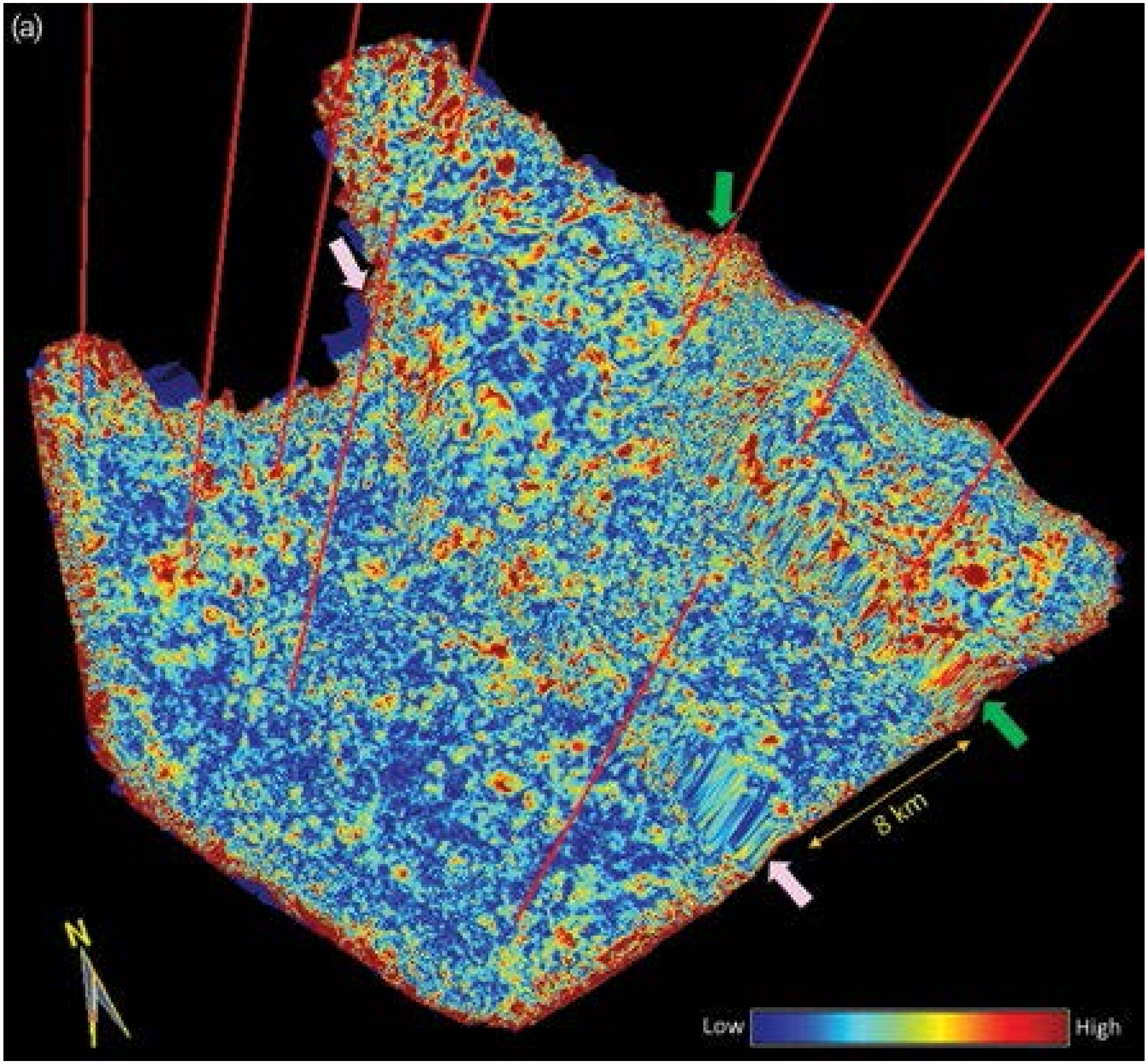

Figure 2. (a) Stratal slice from the azimuthal fracture intensity (VVAz) volume along the Mississippian marker. The two big faults indicated by the green (upthrown) and pink (downthrown) block arrows are shown clearly.

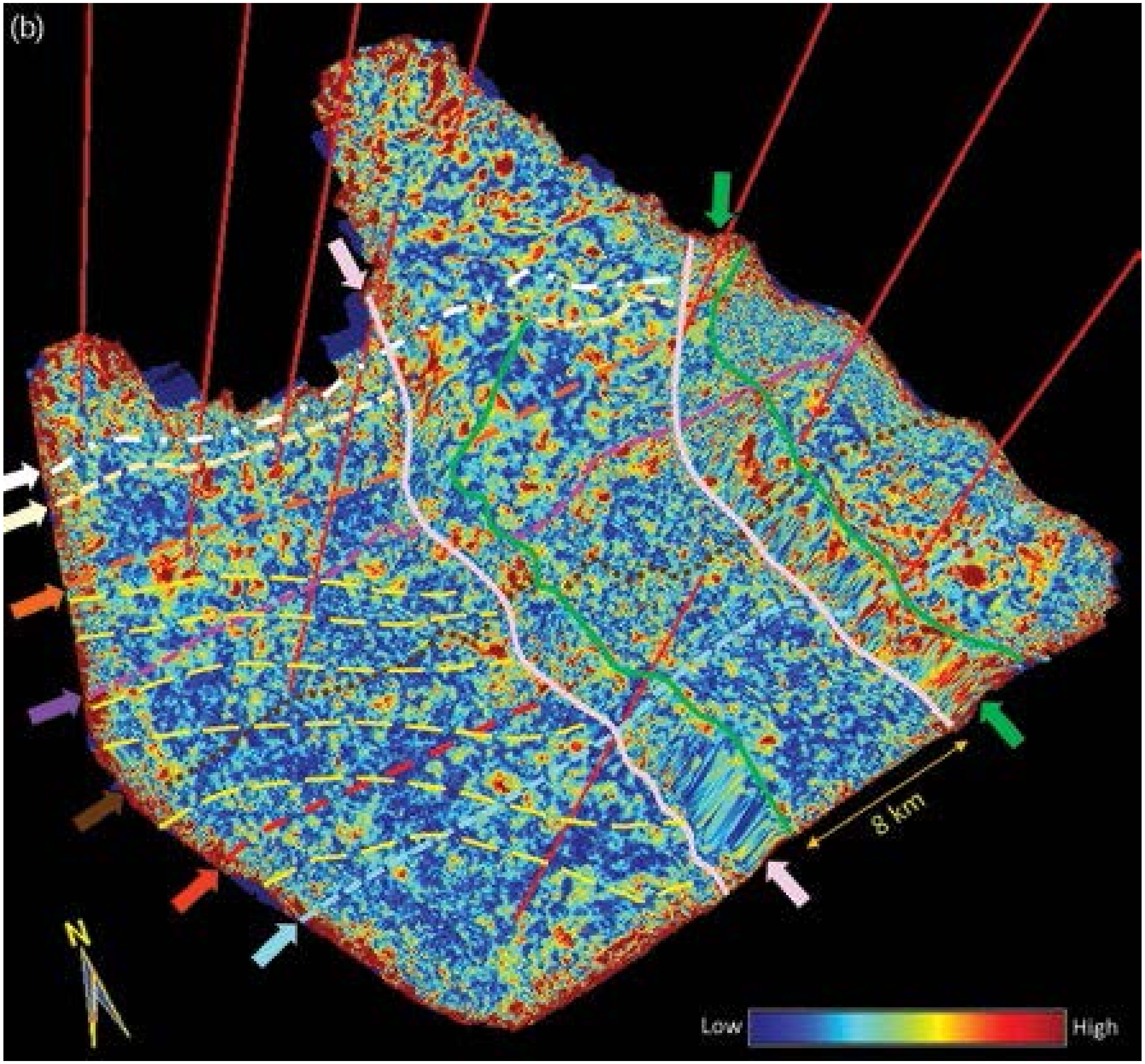

Figure 2. (b) There are many other smaller fault/fracture trends that are clearly seen on this display and are indicated with multicoloured dashed lines and block arrows.

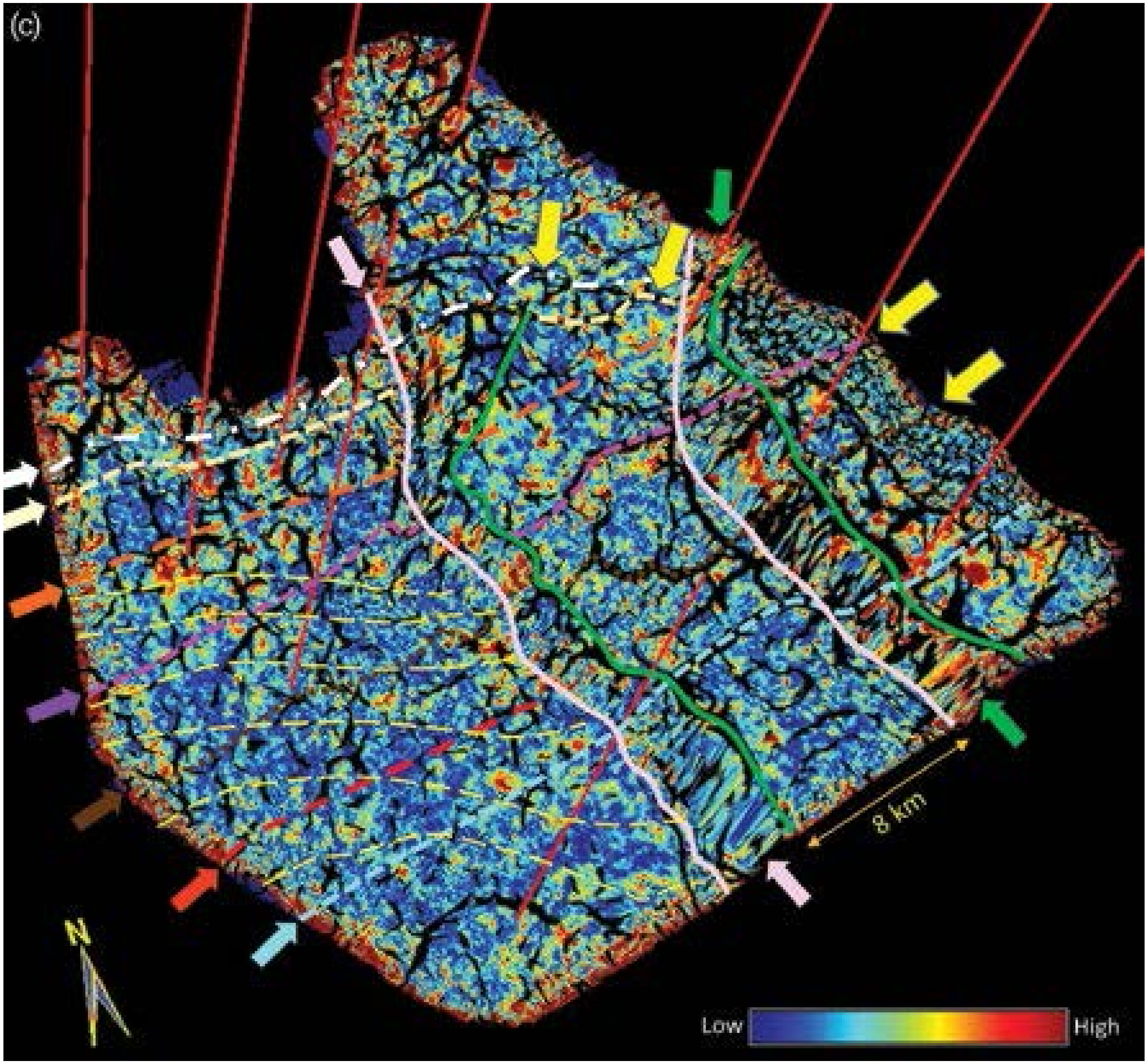

Figure 2. (c) The same slice shown in (b), but now co-rendered with the most-positive long-wavelength curvature. Notice many of the interpreted lineaments follow the trend on the curvature lineaments (bright yellow block arrows). Data courtesy of TGS, Houston.