Seismic detection of faults and fractures*

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Characterization of natural faults and fractures in the subsurface is essential to the design of effective drilling programs and exploitation of tight reservoirs as well as the improved performance of conventional reservoirs. The presence of naturally occurring fracture networks can lead to unpredictable heterogeneity leading to sweet spots and bypassed pay within many reservoirs. If they can be mapped, fractures may provide high permeability pathways that can be exploited to extract reserves stored in a low permeability rock matrix. The need to detect and characterize fractures has motivated the development of new and rejuvenation of older geophysical technologies concerned with or related to fractures. Some of the commonly used methods are the azimuthal AVO method, the use of coherence and curvature seismic attributes, wide azimuth data, multicomponent data and passive seismic techniques. Azimuthal AVO has been used in the industry and has proved to be a promising tool when the assumptions for its application are met. Seismic attributes such as coherence and curvature can be used for both qualitative and quantitative interpretation of fractures. Both these methods will be discussed in the talk. One useful feature, which is not practiced routinely in our industry, is to make use of these two methods together in that unified displays of attributes from these methods should be used for interpretation of fractures.

In general, curvature is an excellent measure of paleo deformation. With an appropriate tectonic deformation model, structural geologists can predict where the fractures were formed. However, since their formation, such fractures may have been cemented, filled with overlying sediments or diagenetically altered. Furthermore, the present-day direction of minimum horizontal stress may have rotated from the direction at the time of deformation, such that previously open fractures are now closed, while previously closed fractures may now be open. For this reason, prediction of open fractures requires not only images of faults and flexures provided by coherence and curvature coupled with an appropriate model of deformation, but also measures of present day stress provided by breakouts seen in image logs and seismic anisotropy measures.

To reach this stage, the input seismic data used for the generation of coherence and curvature attributes should be relatively noise free and should have optimum frequency content for meeting the desired goals. Certain types of noise can be addressed by the interpreter through careful structure-oriented filtering or post migration footprint suppression. Other problems such as multiple contamination or poor imaging due to inaccurate velocities or irregular geometries require that the data go back to the processing team for remediation. Another common problem with seismic data is their relatively low bandwidth. For detection of fractures, the seismic data should have an optimum frequency bandwidth and for this reason frequency enhancement of the input seismic data should be undertaken. I will emphasize the application of a couple of the newer methods for fracture detection. These will include the *spectral decomposition-based inversion for seismic reflectivity*, a process that removes the time-variant wavelet from the seismic data and extracts the reflectivity to image thicknesses below conventional expectations of seismic resolution. In addition to enhanced images of thin reservoirs, these frequency-enhanced inverse images have proven very useful in mapping subtle onlaps and offlaps, thereby facilitating the mapping of parasequences and the direction of sediment transport.

Finally, I will illustrate some of the latest curvature measures such as *Euler curvature* for observing fracture lineaments, and *structural curvature* versus *amplitude curvature.* Applications of additional recent newer volumetric attributes such as *reflector convergence* and *reflector rotation* about the normal to the reflector dip have shown promise and will be touched upon. While the former attribute is useful in the interpretation of angular unconformities, the latter attribute determines the rotation of the fault blocks across discontinuities such as wrench faults. Such attributes can facilitate and quantify the use of seismic for stratigraphic workflows and for large 3D seismic volumes.