Diffraction imaging enhancement using spectral decomposition for faults, fracture zones, and collapse feature detection in carbonates

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Summary

Diffraction imaging can improve spatial resolution. Spectral decomposition and color blending of diffraction imaged data can provide a method to further enhance edges for detecting faults, fracture zones, and collapse features. Spectral decomposition can also be used to separate low frequency reflection noise from imaged diffraction data.

Introduction

Understanding the spatial distribution of fractures and small-scale faults in the reservoir and the overburden can be important to reservoir development, well placement, and reaching production goals. Small-scale faults and fractures zones can contribute to early water breakthrough. Fracture clusters and/or corridors can impact fluid flow and overall sweep in carbonates. Overburden conditions create additional challenges. Shallow collapse features above the reservoir can deteriorate seismic imaging and create drilling hazards.

Diffraction imaging can be used to directly image fracture/fault systems. In the analysis presented here, spectral decomposition is subsequently performed on imaged diffraction data to determine the frequencies which best identify features in the data. Frequency volumes are then combined using color blending to enhance edge detection of small-scale faults, fracture zones, and collapse features. Mud loses from drilling show improved spatial correlation with collapse feature edges detected on imaged diffraction data compared with conventional reflection seismic imaged data.

Method

Diffraction imaging has gained interest recently as an alternative approach to fracture detection using surface seismic, based on the concept that diffractions are the direct seismic wavefield response to intermediate-scale discontinuities (Burnett et al. 2015). Diffraction imaging improves the horizontal resolution enhancing edge detection of features in carbonate reservoirs (Decker et al., 2015; Guilloux et al., 2012; Popovici et al., 2015).

Spectral decomposition allows interpreters to utilize frequency components of the seismic bandwidth to interpret subtle details of subsurface stratigraphy (Partyka et al., 1999, Marfurt and Kirlin 2001). Spectral decomposition images are complementary to coherence and edge-detection attribute images (Liu and Marfurt, 2007).

Diffraction image processing, for this project, was performed by Z-Terra (Liu et al., 2015). Spectral decomposition and color blending was applied subsequent to Z-Terra's diffraction image processing. Spectral decomposition and color blending improved edge detection on diffraction imaged data. Spectral decomposition and color blending of diffraction imaged data demonstrated superior edge detection in comparison with conventional reflection imaged data for the same frequencies (Figure 2).

The importance of acquisition footprint removal is also demonstrated in the Figure 2. In the Figure 2 comparison, the bottom shows the uplift of Z-Terra's acquisition footprint removal prior to diffraction imaging. In top of Figure 2, acquisition footprint plagues the image quality of the conventional reflection imaged data.

When using color blending, the interference between different frequency bands can reveal startling detail within the color blend (McArdle and Ackers, 2012). In this analysis, frequency volumes were selected with more overlap decolorized the color blend and emphasizing the edge detection. Figure 1 displays the frequencies used for the color blending derived from the diffraction imaged data in the shallow collapse features displayed in Figure 2. The color of the frequencies distribution curve indicates the RGB component for the color blending... The frequency magnitude of the diffraction imaged data for the shallow section is displayed as a black curve in the background.

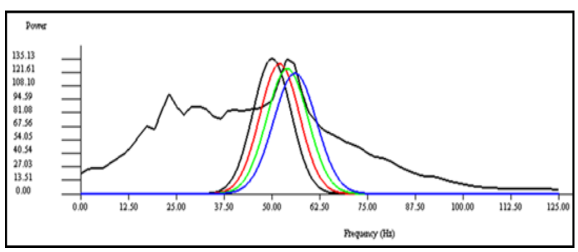

Figure 1: Spectral decomposition for shallow collapse features. The color of the frequency distraibution curve indicates the RGB component for the color blend. The frequency magnitude of the shallow section is the black curve displayed in background.

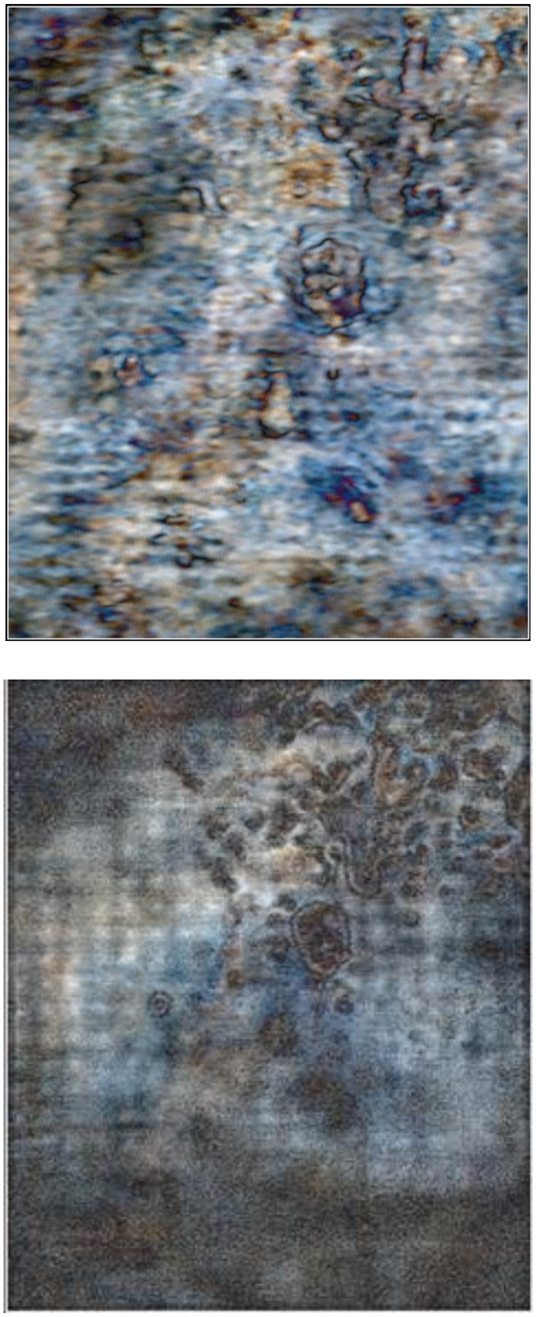

Figure 2: On the top spectral decomposition and color blending using reflection imaged data compared with spectral decomposition and color blending of diffraction imaged data on the lower. The comparison shows edge detection and spatial resolution enhanced with diffraction imaged data.

Examples

A comparison of diffraction imaged data with and without edge enhancement using spectral decomposition and color blending is shown for the reservoir interval (Figure 4) and shallow collapse features above the reservoir (Figure 5).

In Figure 4 (on the left) a time slice is displayed in the reservoir for diffraction imaging data without edge enhancement. In Figure 4 (on the right) the same time slice is displayed with edge enhancement using frequency decomposition and color blending. Spectral decomposition also allows for the separation of low frequency residual reflection noise from the diffraction imaged data. The edge-enhanced data shows better detection of fault and fracture zone features in the reservoir. Fault and fracture zone features oriented in the northeast/southwest direction, barely detectable on the diffraction image without edge enhancement, are clearly visual on the edge-enhanced data. Linear features in the southern portion of the reservoir are also more easily detected on the edge enhanced data.

Figure 3 displays the spectral decomposition for the reservoir interval. The frequency distributions are chosen over wider ranges to increase the temporal resolution of features detection in the reservoir. The color of the frequency distribution curve indicates the RGB component for the color blending. The frequency magnitude of the diffraction imaged data for the reservoir is displayed as a black curve in the background.

In Figure 5 (on the left) a time slice without edge enhancement is displayed for the shallow collapse features, above the reservoir. In Figure 5 (on the right) the same time slice through the shallow collapse features is displayed with edge enhancement. The collapse features show significantly improved spatial resolution of the collapse features using edge enhanced diffraction imaged data.

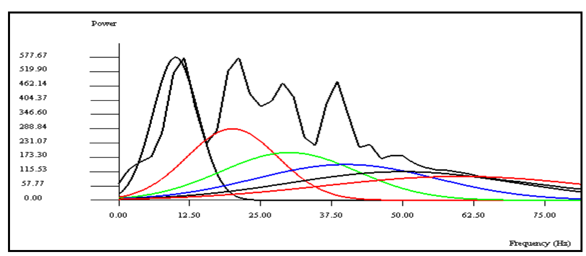

Figure 3: Spectral decomposition for resevoir interval. The color of the frequency distraibution curve indicates the RGB component for the color blend. The frequency magnitude of the shallow section is the black curve displayed in background.

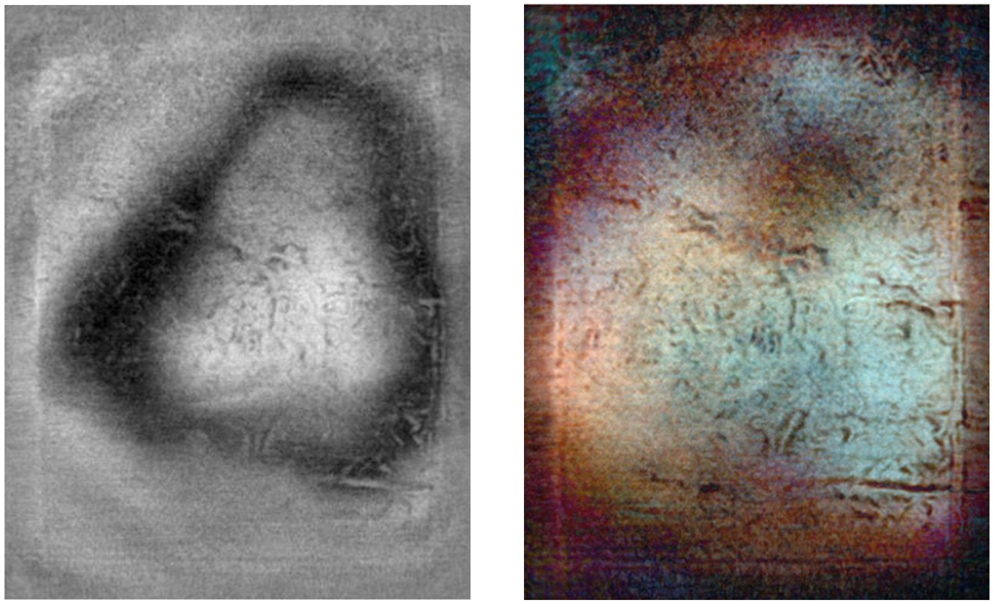

Figure 4: Before (left) and after (right) edge enhancement using frequency decomposition and color blending of diffraction imaged data for fault and fracture zone detection in the reservoir

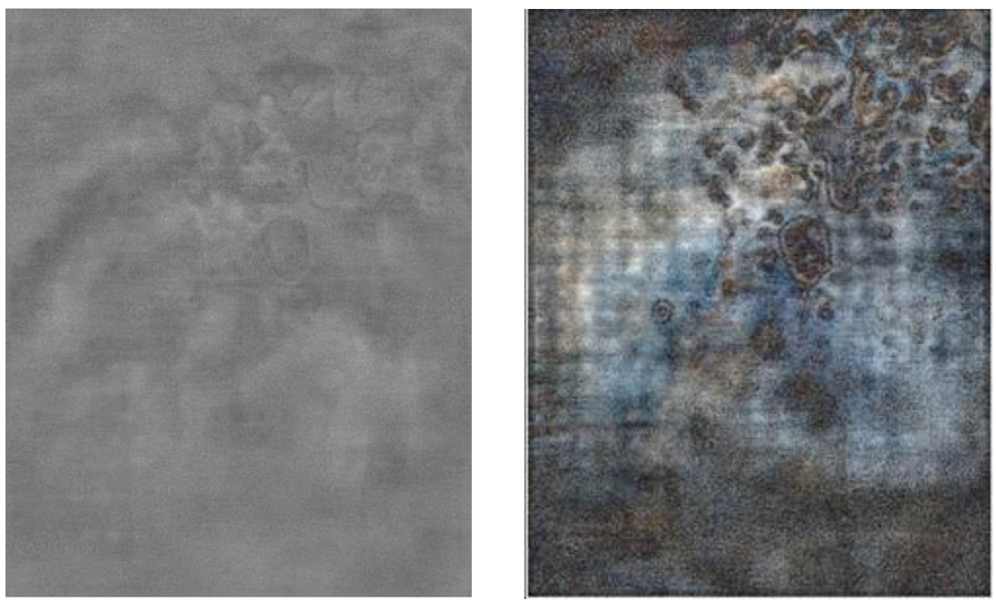

Figure 5: Before (left) and after (right) edge enhancement using frequency decomposition and color blending of diffraction imaged data for shallow hazard collapse feature detection

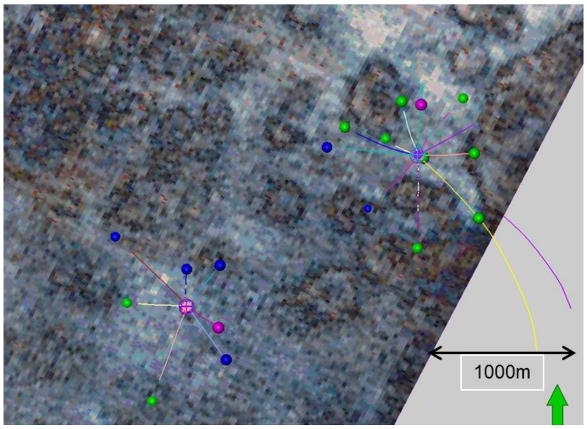

Figure 6: Diffraction imaging with edge enhancement and drilling mud loss data. Blue represents partial losses, green is complete and purple is no losses.

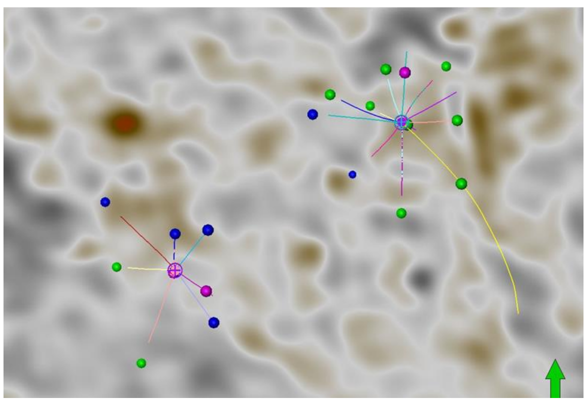

Figure 7: Reflection imaging with drilling mud loss data. Blue represents partial losses, green is complete and purple is no losses.

Figures 6 and 7 provide a comparison of the spatial correlation of drill mud losses with diffraction imaging and edge enhancement using spectral decomposition and color blending versus convention reflection imaged data. The mud losses coincide with the edges of the collapse features displayed in the edge enhanced diffraction imaged data. Conventional reflection imaged data show no visible spatial correlation with drilling mud losses. In both figures 6 and 7, blue circles represent partial losses, green is complete losses, and purple is no losses. The edge enhanced diffraction imaged data provide clearer features for identifying potential drill hazards associated with collapse features above the reservoir.

Conclusions

Diffraction imaging improves the horizontal resolution in carbonate reservoirs Spectral decomposition and color blending complement diffraction imaging, providing a data enhancement method for improving edge detection of faults, fracture zones, and collapse features in carbonates. Spectral decomposition can also be an effective tool for separating low frequency reflection data from diffraction imaged data.

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EDITED REFERENCES

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REFERENCES

Burnett, W. A., A. Klokov, S. Fomel, R. Bansal, E. Liu, and T. Jenkinson, 2015, 3D Seismic diffraction interpretation at Piceance Creek: Interpretation (Tulsa), **3**, SF1–SF14, http://dx.doi.org/10.1190/INT-2014-0091.1.

Decker, L., X. Janson, and S. Fomel, 2015, Carbonate reservoir characterization using seismic diffraction imaging: Interpretation (Tulsa), **3**, SF21–SF30, http://dx.doi.org/10.1190/INT-2014-0081.1.

Guilloux, Y., I. Tarrass, J.L. Boelle, E. Landa, V. Buzlukov, A. Lafram, and M. Radigon, 2012, Wide azimuth seismic processing for UAE carbonate reservoir characterization: SPE-162324.

Liu, E., Johns, M., Zelewski, G., Burnett, W., Wu, X., Zhang, J. and Molyneux, J., Skeith, G., Obara, T., El-Awawdeh, R., Sultan, A. and Al Messabi, A., 2015. Fracture characterization by integrating seismic-derived attributes including anisotropy and diffraction imaging with borehole fracture data in an offshore carbonate field, UAE: IPTC-18533.

Liu, J., and K. J. Marfurt, 2007, Instantaneous spectral attributes: Geophysics, **72**, no. 2, P23–P31, http://dx.doi.org/10.1190/1.2428268.

Marfurt, K. J., and R. L. Kirlin, 2001, Narrow-band analysis and thin-bed tuning: Geophysics, **66**, 1274–1283, http://dx.doi.org/10.1190/1.1487075.

McArdle, N. J., and M. A. Ackers, 2012, Understanding seismic thin-bed responses using frequency decomposition and RGB blending: First Break, **30**, 57–65, http://dx.doi.org/10.3997/1365-2397.2012022.

Partyka, G. A., J. Gridley, and J. Lopez, 1999, Interpretational applications of spectral decomposition in reservoir characterization: The Leading Edge, **18**, 353–360, http://dx.doi.org/10.1190/1.1438295.

Popovici, A. M., I. Sturu, and T. J. Moser, 2015, High resolution diffraction imaging of small scale fractures in shale and carbonate reservoirs: SPE-178538.