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Using Fresnel Zone to Characterise and Image Different Types of Diffractors in Low S/N Situations

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SUMMARY

We investigate the possibility to image and characterise the different types of diffractors – such as point, line, and edge – and separate them from reflections by limiting the aperture around the tangent point between the diffraction hyperbola and the relfection traveltime surface. To this end, we look at the tangents of the diffraction hyperbola with typical traveltime surfaces corresponding to the different diffrator types. We do this by studying the coherency of the recorded wavefield along the diffraction hyperbolae. The different types of diffractors show different energy distributions that can be used to characterise the diffractors and separate them from specular reflections. These areas of high energy correspond to the Fresnel zones of the particular diffractor type. Limiting the aperture of the diffraction hyperbola to the particular Fresnel zone results in improvement in S/N, while omitting the Fresnel zone corresponding to the reflections allows for imaging of the diffractors, which have larger Fresnels zones.

Introduction

A seismic wave encountering a small subsurface heterogeneity scatters in many directions. Such heterogeneities are called diffractors. Examples of diffractors in the subsurface include terminations of sedimentary layers at faults and edges of objects such as a reservoir (Pant et al., 1992; Papziner and Nick 1998), as well as intrusions, lenses and fractures. Since all these geological features are important for better understanding of the subsurface, imaging and inferring properties of seismic diffractors is an active area of research.

Krey (1952) showed the importance of diffraction for faults imaging. Trorey (1970) derived the theoretical response of a diffractor, which was followed by Trorey (1977) and Berryhill (1977). Since then there were many authors that studied diffractions and their application to seismic imaging (e.g. Harlan et al., 1984; Landa et al., 1987; Kanasewich and Phadke ,1988; Khaidukov et al., 2004; Vermeulen et al., 2006; Fomel et al., 2007; Klem-Musatov, 2008; Moser and Howard 2008; Tertyshnikov et al., 2013,). Alonaizi et al. (2014) showed the potential of diffracted wave analysis for monitoring CO_2 seepage by imaging the secondary gas accumulations. Alonaizi et al. (2013) developed a post-stack seismic imaging technique that locates linear features such as edges of objects and linear diffractors in 3D and suppresses moderately dipping specular reflections.

Imaging methods based on Kirchhoff type summation along diffraction hyperbolae usually assume global aperture. This means that the summation is performed along the entire diffraction traveltime surface, even though the energy is located only along the tangent of this surface to the traveltime surface of the actual reflection or diffractor. The extra aperture can introduce imaging artefacts and can increase noise in the resulting image (Sun, 1998). To reduce these effects, there were many suggestions how to reduce the aperture by finding the tangent point between the two surfaces and restricting the aperture around this point by the first Fresnel zone. Klokov and Fomel (2013) provide a brief summary of these works. Naturally, most of these methods result in enhancement of reflections and diminishment of the diffractors, whose migration aperture is greater than that of the reflectors. Herein we propose the opposite of the usual approach – limit the migration aperture to suppress reflections and enhance the diffractors while improving S/N by setting aperture appropriate to the diffractor type. The analysis is done on the pre-stack data.

Theory

We investigate the possibility to image and characterise the different types of diffractors – such as point, line, and edge – and separate them from reflections by limiting the aperture around the tangent point between the diffraction hyperbola and the relfection traveltime surface (such surfaces are illustrated in Figure 1). To this end, we look at the tangents of the diffraction hyperbola with typical traveltime surfaces corresponding to the different diffrator types. We do this by studying the coherency of the recorded wavefield along the diffraction hyperbolae. The different types of diffractors show different energy distributions that can be used to characterise the diffractors and separate them from specular reflections. These areas of high energy correspond to the Fresnel zones of the particular diffractor type.

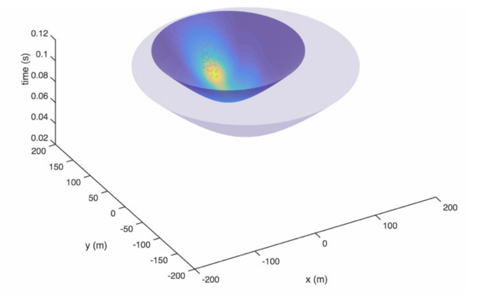

Figure 1 Kirchhoff type diffraction hyperboloid (blue) touching the traveltime surface corresponding to reflection from a horizontal plane (grey). The hot colour corresponds to the energy of the signal along the diffraction hyperboloid.

To better understand the behaviour of different diffrator types and see how they compare to a reflection, we consider the synthetic examples of the following four scatterers: reflector, edge diffractor, line diffractor, and point diffractor. The geometry of the synthetic examples is shown in Figure 2, where the scatterers are in depth of 50m in a homogeneous acoustic medium with velocity of 1600m/s. The wavefield was recorded on the surface with geophone spacing of 2m×2m. The dominant frequency of the wavelet is 120Hz.

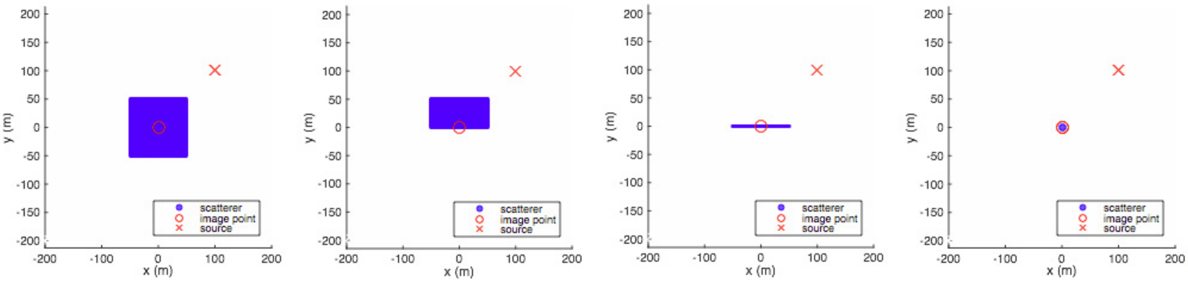

Figure 2 Geometry of different scatterers and the location of the source and image point for each scatterer type – from left to right: reflector, edge, line, point. The scatterers are shown in blue, the source as red cross, and the image point as red circles.

Since amplitudes themselves will be influenced by other waves propagating through the medium, we will study the coherency of the recorded signal along the diffraction hyperboloids. To do so, we use localised semblance along a fixed time window. Examples of such semblance analysis are shown in Figure 3 for the different types of scatterers.

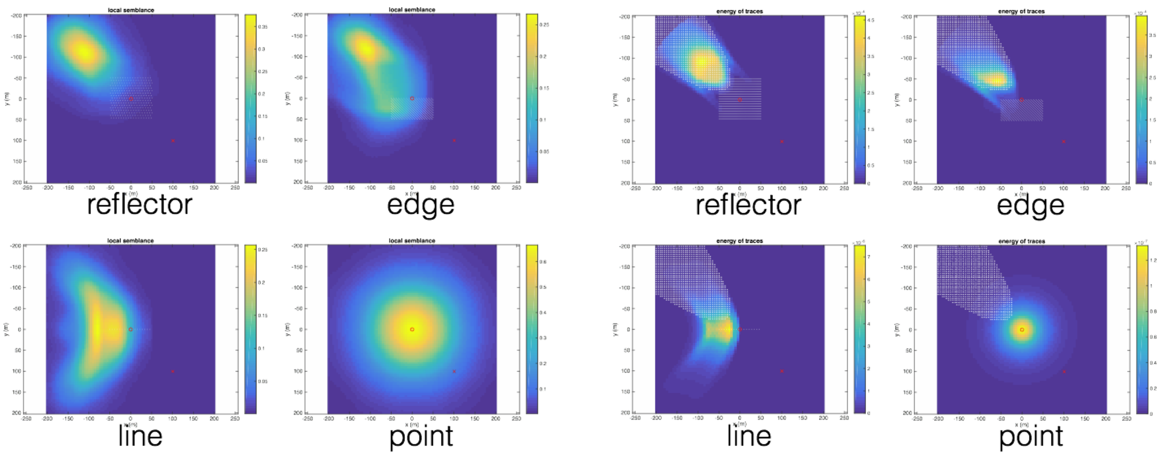

Figure 3 Left: Local semblance (moving window 5×5 receivers = 10m×10m and temporal window of 10ms) along the diffraction hyperbola for different scatterer types. Right: Energy of the signal corresponding to different scatterers together with the first Fresnel zone for a horizontal reflector within 10ms of the diffraction hyperbola (white).

Examining Figure 3, we can make the following points:

1) Each scatterer type produces its own signature on the diffraction hyperbolae that could be used to filter/characterise them.
2) To separate diffractors from reflectors, it is better to use local semblance rather than the energy,
3) An edge diffractor is the most difficult to distinguish from a reflector. This might not be obvious from using the local semblance, as an edge diffractor produces a phase change in the recorded signal, where the phase change happens at the tangent point to the reflection surface;

such phase change would negatively influence semblance if the semblance was computed in spatially large windows. The point is clearer by looking at the energy of the signal.

Example

We applied our analysis to field data recorded over a copper-gold discovery by Rex Minerals at the Hillside Project on Yorke Peninsula, South Australia. The area of the 3D survey was 470m×1315m with 5m × 35m geophone and 10m×30m source spacing. The result of filtering out reflectors with moderate dips and imaging edge diffractors by considering semblance of data with the polarity flip along the Fresnel zoned corresponding to edges is shown in Figure 4; the measured edge diffractivity mostly overlays steeply almost vertical features interpreted from drill cores.

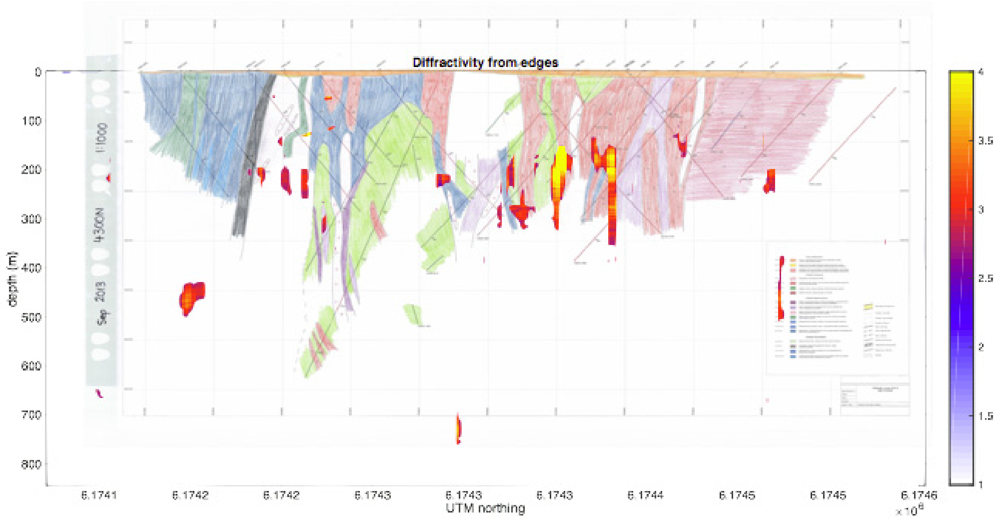

Figure 4 Diffractivity from edges are shown in the hot colours overlaid on a geological section interpreted from drilling data.

Conclusions

We proposed that semblance analysis of signal along the diffraction hyperboloids used for Kirchhoff type migration can be used not only for filtering (out) and characterising diffractors, but also can be used for enhancing S/N in high noise environments by avoiding stacking noise to the data.

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References

Alonaizi, F., Pevzner, R., Bóna, A., Shulakova, V. and Gurevich, B. 2013, 3D diffraction imaging of linear features and its application to seismic monitoring. Geophysical Prospecting, 61: 1206–1217.

Alonaizi, F., Pevzner, R., Bóna, A., Alshamry, M., Caspari, E. and Gurevich, B. 2014, Application of diffracted wave analysis to time-lapse seismic data for CO2 leakage detection. Geophysical Prospecting, 62: 197–209.

Berryhill, J.R. 1977. Diffraction response for nonzero separation of source and receiver. Geophysics 42, 1158-1176.

Fomel, S., Landa E., and Taner, M.T. 2007. Poststack velocity analysis by separation and imaging of seismic diffractions. Geophysics 72, U89-U94.

Harlan, W.S., Claerbout, J.F. and Rocca, F. 1983. Extracting velocities from diffractions. SEG Technical Program Expanded Abstracts 2, 574-577.

Kanasewich, E.R. and Phadke, S.M. 1988. Imaging discontinuities on seismic sections. Geophysics 53, 334-345.

Khaidukov, V., Landa, E. and Moser, T.J. 2004. Diffraction imaging by focusing-defocusing: An outlook on seismic superresolution. Geophysics 69, 1478-1490.

Klem-Musatov, K.D. 2008. Edge and Tip Diffractions: Theory and Applications in Seismic Prospecting. Soc of Exploration Geophysicists, ISBN 9781560801498.

Klokov, A. and Fomel, S. (2013). "Selecting an optimal aperture in Kirchhoff migration using dip-angle images." Selecting an optimal aperture in Kirchhoff migration using dip-angle images, 78(6), S243-S254.

Krey, T. 1952. The segnificance of diffraction in the investigating of faults. Geophysics 17, 843-858.

Landa, E. and Keydar, S. 1998. Seismic monitoring of diffraction images for detection of local heterogeneities. Geophysics 63, 1093-1100.

Landa, E., Shtivelman, V. and Gelchinsky, B. 1987. A method for detection of diffracted waves on common-offset sections. Geophysical Prospecting 35, 359-373.

Moser, T.J. and Howard, C.B. 2008. Diffraction imaging in depth. Geophysical Prospecting 56, 627-641.

Pant, D.R., Greenhalgh, S.A. and Zhou, B. 1992. Physical and numerical model study of diffraction effects on seismic profiles over simple structures. Geophysical Journal International 108, 906-916.

Papziner, U. and Nick, K.-P. 1998. Automatic detection of hyperbolas in georadargrams by slant-stack processing and migration. First Break 16, 219-223.

Sun, J., 1998, On the limited aperture migration in two dimensions: Geophysics, 63, 984–994

Taner, M.T. and Koehler, F., 1969. Velocity spectra-digital computer derivation applications of velocity functions. Geophysics, 34(6): 859-881

Tertyshnikov, K., Pevzner, R., Bona, A., Alonaizi, F. and Gurevich, B. 2013. Steering migration with diffractions in seismic exploration for hard rock environments. 75th EAGE Conference & Exhibition incorporating SPE EUROPEC 2013, London, UK, 10-13 June 2013, Expanded abstracts, We 01 07.

Trorey, A.W. 1970. A simple theory for seismic diffractions. Geophysics 35, 762-784.

Trorey, A.W. 1977. Diffractions for arbitrary source-receiver locations. Geophysics 42, 1177-1182.

Vermeulen, J., Gurevich, B., Urosevic, M. and Landa, E. 2006. Enhancing coherency analysis for fault detection and mapping using 3D diffraction imaging. SEG Technical Program Expanded Abstracts 25, 1108-1112.