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Diffraction Imaging in Hard Rock Environments

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SUMMARY

Hard rock seismic exploration normally has to deal with rather complex geological environments. These types of environments are usually characterized by a large number of local heterogeneities. The seismic data from such environments often have a poor signal to noise ratio because of the complexity of hard rock geology. In such situations, the processing algorithms that are capable of handling data with a low signal/noise ratio and are able to image geological discontinuities and subvertical structures are essential. Herein we present a modification of the 3D Kirchhoff post-stack migration algorithm and diffraction imaging. The modification utilizes coherency attributes obtained by the diffraction imaging algorithm in 3D to weight or steer the main Kirchhoff summation. We applied diffraction techniques to a number of 3D seismic datasets from different hard rock mine sites.

Introduction

The main goal of seismic imaging is to reconstruct the subsurface structures from the recorded data. Hard rock seismic exploration is usually preforming in rather complex geological environments. These types of environments are usually characterized by a large number of local heterogeneities such as subvertical faults, fracture zones, and steeply dipping interfaces. The seismic data from such environments often have a poor signal to noise ratio caused by various reasons: rugged topography, heterogeneous structure of the regolith, high velocity contrast between overburden rocks and base formations, high ambient noise in case of the brownfield exploration etc. In such situations, the processing algorithms that are capable of handling data with a low signal to noise ratio and are able to image geological discontinuities and subvertical structures are essential.

The importance of diffraction for detection of geological heterogeneities has been studied for a long time and used as a tool that helps seismic interpretation. A significant amount of research on numerical and field seismic data has been performed to study characteristics of seismic diffractions. The separation techniques of the diffraction events from the specular reflections have been published by a number of authors, as well as the utilization of diffractions for a structural imaging and velocity analysis (Harlan et al., 1983; Landa et al., 1987; Vermeulen et al., 2006).

Signal enhancement and noise suppression often implicates mixing of seismic traces or summation along offset-traveltime curves. However, techniques, which are based on summation of traces with different levels of signal and noise, do not necessarily increase a signal to noise ratio and improve the final images. Several methods have been suggested to weight or limit seismic traces during summation, based on their signal to noise ratio (Liu et al., 2009; Nemeth et al., 2000; Landa and Keydar, 1998).

Herein we present a modification of the 3D Kirchhoff post-stack migration algorithm and diffraction imaging. The modification utilizes coherency attributes obtained by the diffraction imaging algorithm in 3D to weight or steer the main Kirchhoff summation. The coherency attributes form the 3D volumes of focused diffraction energy provides valuable information for hard rock exploration to detect subvertical objects and image other subsurface heterogeneities. The improvement in the Kirchhoff migration increases quality of the final seismic images by excluding noise during the summation process.

Diffraction Imaging and Steered Migration

Diffraction imaging produces the 3D seismic semblance volume (Alonaizi et al. 2013) of the focused diffraction energy from scattering points (D-volume). This seismic volume is used to trace local heterogeneities. The amplitudes of the seismic signal at the location of the local diffractors are enhanced on the D-volume. In the case of edge diffractions, there is the 180 degree phase change across the diffraction travel time apex (Trorey, 1970). This fact can be used in order to distinguish the diffractions produced from the edges of structural objects or mineral bodies and diffractions produced from symmetric linear mineralization zones and faults. To take into account the edge diffractions, we scan along all the possible azimuth and compute the semblance only along the part of the diffraction hyperbola that is perpendicular to the investigated direction of the potential edge. We can then use the resulting azimuth-dependent semblance values to filter out low signal/noise ratio from the Kirchhoff like summation.

By selecting only the stacking directions with the highest signal/noise ratio we can improve quality of the image. In practice we achieve this by weighting the summation by the semblance values along the different azimuths. We note that such procedure does not discriminate against point diffractors, since for the point diffractors the weighing is constant for all the azimuths. We refer to this procedure as diffraction steered migration (Tertyshnikov et al. 2013).

Diffraction imaging and steered migration have been successfully tested on a number of real seismic datasets from different hard rock prospect sites. Processing of the 3D seismic volume from O'Callaghans mine site (Western Australia) using diffraction algorithms enhanced the continuity of interfaces and signal to noise ratio, and also illuminated fractures and faults. The application of diffraction approaches allowed to highlight subvertical fault zones and associated copper mineralizations at Hillside mine site (South Australia). Figure 1 illustrates one example of the

application of the diffraction techniques to 3D seismic volume from 'Nautilus Minerals' Solwara 1 mine site (Papua New Guinea). There is a significant improvement of the image quality in the steered migration time-slice (Figure 1b). The structures represent low-angle extensional normal faults are clearly traceable at the D-volume (circled blue at Figure 1d) and undetectable at the Kirchhoff migrated section (Figure 1c).

Conclusions

Diffraction energy contains valuable information about subsurface structure. The presented imaging algorithms use parameters of diffracted waves to focus scattering energy and to weight the main Kirchhoff summation. The main features of the diffraction imaging and steered migration are improving the continuity of steep interfaces, highlighting the subvertical heterogeneities and dealing with noisy data. These benefits have potentially high value for seismic exploration in complex hard rock environments.

Figure 1. Time-slices at 2528 ms of the Solwara 1 3D seismic volume: a) Kirchhoff migration. b) Steered migration. In-line 150 of the Solwara 1 3D seismic volume: c) Kirchhoff migration. d) D-volume section. Concentrations of diffraction energy along linear features, which are unseen on the Kirchhoff image, are circled blue in the section.

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