Diffraction separation workflow in time domain

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Abstract

Diffractions are important events to understand subsurface. They are useful to add structural information, to delineate geological features and have been used to estimate and to detail velocity field. However, the challenge is how to separate diffractions from specular reflections. A diffraction separation workflow is presented and tested in a synthetic dataset. It is part of time domain diffraction velocity analysis, it uses the premises of zero-offset survey geometry and is very effective to separate point diffractions. The method is successfully applied in synthetic dataset. The presented workflow may be extended to multi-channel seismic survey since the nearest offset is a tenth of events depth.

Introduction

Diffractions are important features to understand subsurface in seismic reflection data. Whenever the frequency content and size of high curvature reflector relation allow, a propagating wavefield may suffer scattering. More generally, a point may work as a scatter if there is omnidirectional high gradient contrast of impedance like an edge and a point.

Diffraction cluster geometry brings and complements structural information from seismic data. Also, there are several publications considering extract velocity field from diffractions. Harlan et al. (1984) isolate diffraction from coherent reflections and quantify focusing through statistical tools. Sava et al. (2005) use a wavefield continuation operator to link perturbations of interval velocities and perturbations of migrated images. The authors use a diffraction-focusing criterion instead of the flatness of migrated common-image gathers used in conventional migration velocity analysis.

Fomel et al. (2007) separate diffractions from reflections in poststack data and focus diffractions by velocity continuation (Fomel, 2003). Reshef and Landa (2009) use post-migrated dip angles in common-image gathers to distinguish diffractions from reflections and to estimate velocity. Dell and Gajewski (2011) use common-reflection-surface (CRS) attributes to separate diffractions and to perform poststack time migration velocity analysis. Burnett and Fomel (2011) combine velocity continuation methods with path integrals for diffraction imaging. Asgedom et al. (2011) separate diffraction in poststack domain using modified move-out equation of CRS technique. To ensure optimal diffraction selection the authors successfully use semblance and multiple signal classification (MUSIC) as coherency measure.

Santos et al. (2012) perform tomography of diffractions transit time, using additional effort to pick diffraction curves. Coimbra et al. (2013) develop a method for diffraction imaging and velocity model improvement in the depth domain using the moveout of unfocused diffraction events in a migrated seismic section. Bauer et al. (2017) develop wavefront tomography for diffractions using CRS concepts. Decker et al. (2017) perform seismic diffraction imaging and time-migration velocity analysis separating diffractions from specular reflections and decomposing them into slope components, applied for single channel seismic and multi-channel seismic data. Santos et al. (2020) incorporate diffraction velocity analysis (DVA) in single channel seismic data workflow and show the benefits of better velocity field and imaging.

All cited publications above need a procedure to isolate diffractions from specular reflections. In this paper we explore and detail the method described in Santos et al. (2020) to isolate diffractions from specular events. To reach this objective we explain the workflow in the following topic. There, we explain and adapt the workflow presented at Santos op. cit. to separate diffraction in time domain (Diffraction Separation Workflow (DSW)). In the next topic we apply DSW a synthetic data set that gave support to the workflow presented in Santos et al. (2020). We discuss the results and finally we conclude.

Diffraction separation workflow in time domain

For field seismic data set, the workflow starts with pre-processing of zero-offset seismic data. It includes editing traces with anomalous amplitude, null traces remotion and interpolation, remotion of spikes and too noisy segments or traces, application of static shift and filtering, geometric spreading correction and deconvolution. Those steps are important, but they are not discussed in this paper as we are using a synthetic data set. We focus in the steps below that are the proposition to separate diffractions from specular events. Modeling and pre-processing were made with our own codes. Part of pre-processing and visualization, including the sections below, were made with available tools at Seismic Unix (Stockwell and Cohen, 2002).

The first step (Figure 1) is to migrate the data with several constant rms-velocities. One migration for each velocity.

The velocity range, from v_{min} to v_{max}, may contain the expected rms-velocities of the site under study. For a seismic section, all migrated data must be gathered composing a single volume to be scanned in the next step. For a zero-offset seismic volume (3D), the procedure is the same, but, the migrated data compose together a 4D volume. The second step (Figure 2) is the application of path integral Burnett and Fomel (2011). It consists of obtaining $U_s(x,t)$ with the equation

$$U_s(x,t) = \int_{v_{\min}}^{v_{\max}} U_{\mathrm{mig}}(x,t,v)\,dv \quad , \qquad (1)$$

where U_{mig} (x,t,v) contains in the plane space-time (x,t) the migrated panel with rms-velocity.

In step 3 we perform the plane wave destructor (PWD) operator (Fomel, 2002). It attenuates coherent and laterally consistent events. However, PWD can not prevent remaining small plane segments, steep dipping horizons and other small events that may be similar to diffractions. To circumvent this, in step 4 we apply an amplitude filter because those features may have smaller absolute amplitudes than point diffractors.

We realize step 4 is necessary but is not enough to avoid non diffractors. In step 5, we apply equation 2 below. This equation searches for the highest migrated amplitude in the volume U_{mig} (x,t,v). Equation 2, then, delivers a panel ($v(x_i,t_i)$) with the best v_{rms} to migrate a certain diffraction curve (Santos et al., 2020).

$$v(x_i,t_i) = \arg_v \max\{\mathrm{abs}[U_{\mathrm{mig}}(x_i,t_i,v)]\}. \qquad (2)$$

Finally, in step 6 we make use of geological characteristic expressed in rms-velocity (v_{rms}) behavior. Usually, v_{rms} just increase with higher time. We apply a quality control (QC) that avoids: $v_{rms}(x_i,t_{i+1}) < v_{rms}(x_i,t_i)$. With this procedure geologically feasible diffractors remain and specular events vanish.

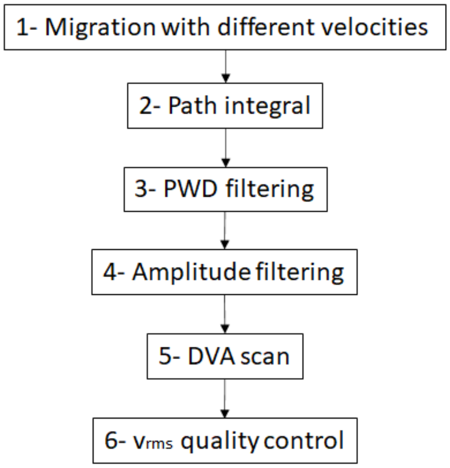

Figure 1: Diffraction separation workflow (DSW) in time domain.

Application

We apply the DSW (Figure 1) in a synthetic dataset inspired in the same seismic line presented in Santos et al. (2020). Modeling was made taking planar and point diffractors with meaningful amplitudes from original migrated dataset referred in Santos et al. (2020). The data was deconvolved and time-to-depth converted. The events worked as sources and their initial amplitude (energy) were proportional to the reflectivity of deconvolved events in an exploding reflector seismic simulation using an acoustic version of finite difference code (modmac2d at http://www/faladaterra.com). The resulting seismic section is the one at Figure 2.

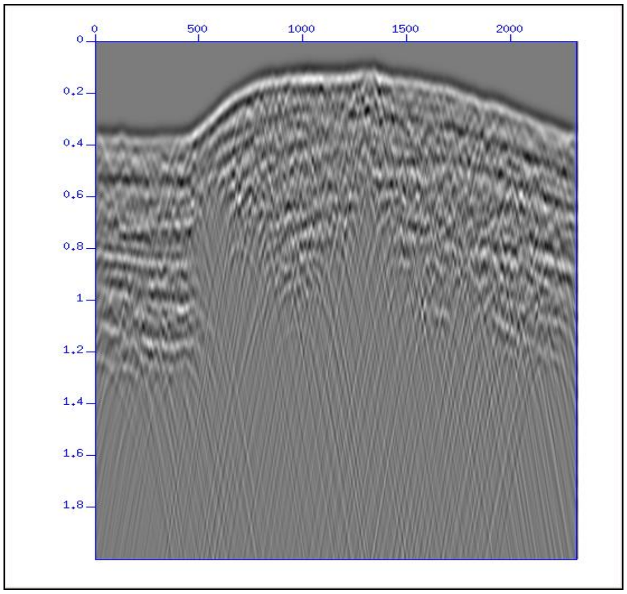

Figure 2: Synthetic seismic line before migration.

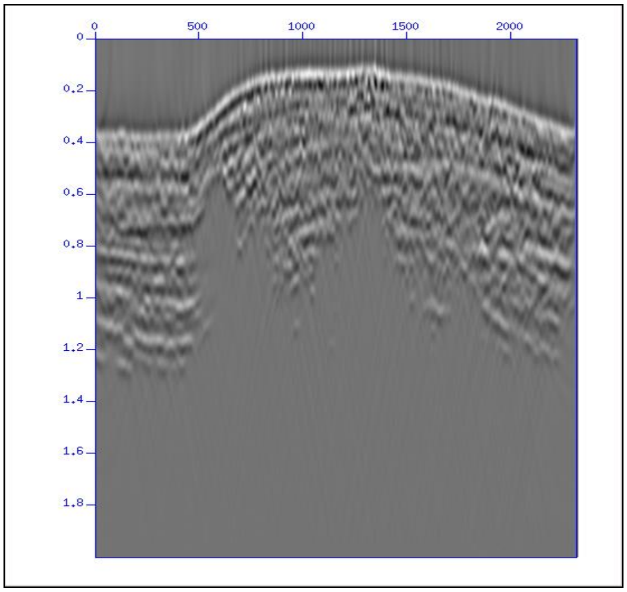

Figure 3: Seismic line after path integral.

At step 1, we perform constant velocity Kirchhoff migration in time with v_{rms} ranging from 1410 to 1710 m/s at a regular pace of 10 m/s. Path integral, step 2 (Figure 1) is applied delivering the section at Figure 3.

Next, we apply PWD filtering. Several coherent and laterally persistent events are eliminated. However, after PWD several non-diffractors remain in the section (Figure 4).

To significantly reduce the number of non-diffractors, we need to apply an amplitude filter. In this step, it is better to make tests for suitable threshold after normalization for the dataset. After, DVA scan is applied to locate rms-velocity that best focuses a diffraction (equation 2). Finally, QC is used which outputs the section at Figure 5, where just diffractors remain.

After quality control, we interpolate the rms-velocity and perform Kirchhoff modeling considering diffractors as point sources. The resulting section is the diffraction curves without the wavelet effect (Figure 6).

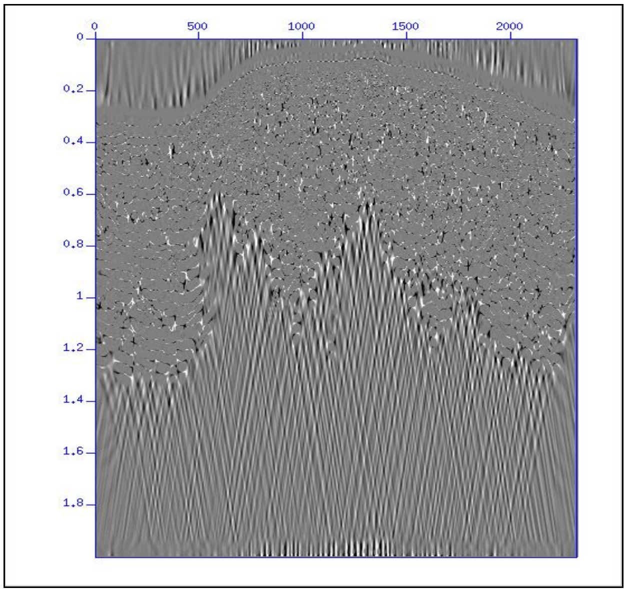

Figure 4: Section after PWD filtering.

Discussion

The method described in this work supports diffraction velocity analysis described in Santos et al. (2020). The proposed DSW in time domain is very worth to the hard task of diffraction separation in seismic data. It completely vanishes non-diffractors. Some diffractors expressed in the original data with very weak amplitude may be erased in this process. It is a point to be further studied and fixed.

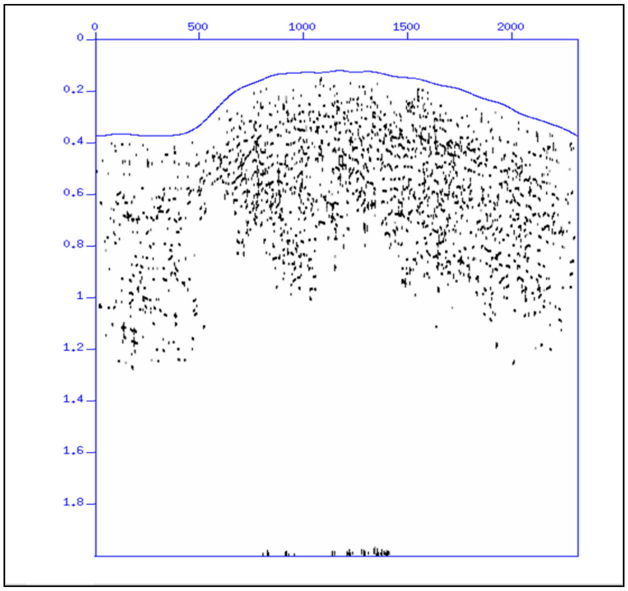

Figure 5: Section after diffraction separation workflow.

After sixth step, we use separated diffractors as point sources. Using the v_{rms} velocity field we generate a seismogram through Kirchhoff forward modeling. We recommend this last procedure to constitute the seventh step. The resulting seismogram contains only diffractions (Figure 6). This diffraction section (Figure 6) may be compared to the non-migrated seismic section (Figure 2). DSW procedure does not create any artificial diffractor.

This technique has been successfully applied to real data in deep water environment, with very short offset, in single channel seismic surveys (Santos et al., 2020). The procedure, however, may be applied to any common offset section whenever the offset is at least a tenth of the event depth (Santos et al., 2012).

Conclusions

DSW may be applied to seismic data in time domain and is recommended to estimate diffractors position and correlate them to geological features as faults, pinch-outs, edges and particular seismofacies.

The Kirchhoff wavefield extrapolation using just separated diffractors may be included in the diffraction separation workflow as the seventh step. It also works as a quality control of DSW process.

The procedure can be extended to multi-channel seismic data set along near offsets common-offset sections. The application to near stack data may be tested.

Acknowledgments

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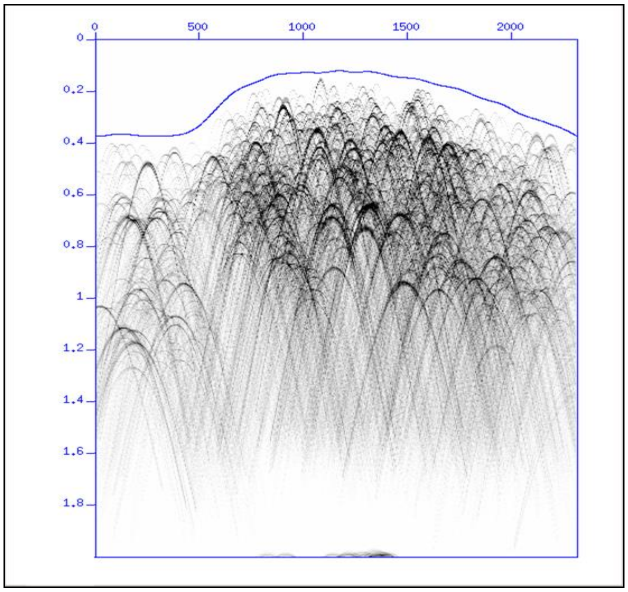

Figure 6: Section after diffraction separation workflow and Kirchhoff forward modeling.

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