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Prestack Diffraction Separation in the Deep Waters of Bonaire Basin, Venezuela

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Abstract

This study explores the application of a diffraction separation technique to enhance seismic interpretation and improve the delineation of complex geological features within the Bonaire Basin, Venezuela. We applied a two-stage diffraction enhancement methodology considering the BOL-11 2D marine seismic data, characterized by a complex stratigraphy including normal faults, mass transport complexes, canyons, and unconformities. The first stage attenuates seismic reflections and the second enhances diffraction events based on their kinematic characteristics. The application of such technique demonstrated effectiveness in attenuating seismic reflections and separating diffractions in the non-migrated pre-stack domain, improving interpretation of features previously obscured within strong seismic reflection events. These findings highlight the potential of diffraction imaging as a valuable tool for detailed seismic characterization within complex sedimentary basins.

Introduction

Accurate seismic interpretation plays a crucial role in various applications, including hydrocarbon exploration, geothermal energy and more recently carbon capture and storage. However, reflection events may obscure finer details in complex geologic media, such details are crucial to an effective interpretation. To overcome these challenges, seismic diffraction data can provide valuable information about scatterers such as faults, pinch-outs and channels. Nevertheless, the effective separation of diffractions represents a challenging task. Several techniques have been developed to produce diffraction images, including plane-wave destruction filters (Taner et al., 2006), multiparametric traveltimes (Coimbra et al., 2019) and anti stationary phase filtering (Moser and Howard, 2008). Post migration separation methods using dip-angle gathers are also gaining attention (Klokov and Fomel, 2012).

In this work, we propose a two-stage approach for separating diffractions in the prestack non-migrated domain. Each stage is presented in both the non-migrated and migrated domains and resulting diffractions are employed to support fault interpretation in conjunction with the original dataset.

Method

To achieve diffraction separation in the prestack domain, our methodology consists of two stages: reflection attenuation and diffraction enhancement. These stages are described in detail below.

Stage 1 - Reflection attenuation: Reflection energy is attenuated by performing a sample-by-sample subtraction of a reconstructed dataset (an estimate of the reflection component) from the original dataset. This reconstructed dataset is created using the Offset-Continuation (OCO) Stacking operator (Mundim et al., 2024a) to estimate kinematic parameters for each time sample at each seismic trace of the dataset. The resulting kinematic parameters are then used to apply an amplitude spreading process on the original seismic data. Due to a small lateral amplitude variation of reflection events in midpoint direction, the spreading process will not affect its amplitudes as much as diffractions, which exhibit more significant amplitude variations in the same direction. Subtracting this reconstructed dataset from the original will attenuate all amplitudes related to reflections and leave a residue composed of noise and diffraction events.

Stage 2 - Diffraction enhancement: The dataset obtained from stage 1 is then processed using a Double Square Root (DSR) operator (Mundim et al., 2024b), which models the traveltime response of diffractions in prestack domain within a homogeneous velocity medium. For each sample of the original dataset (or potentially on a new prestack regularized geometry), a new set of kinematic parameters is estimated. The subsequent DSR stacking selectively enhances events that exhibit kinematic behavior consistent with diffractions, effectively attenuating noise. This process ultimately yields a prestack diffraction volume and a similar spreading process is applied to attenuate noise.

Bonaire Basin Application

The BOL-11 2D seismic dataset from the Southeast Caribbean and Venezuela Margin was considered to apply the diffraction separation technique. This dataset was acquired during the R/V Maurice Ewing expedition EW0404 (2004) (Mann et al., 2008). The stratigraphic record of the region consists of five second-order seismic sequences with igneous-metamorphic basement beneath them, characterized by regional unconformities, sedimentary regimes variations, and faulting features.

Data pre-processing, migration and analysis was performed with ShearWater Reveal. Stages 1 and 2 were applied using in-house implementations of the OCO and DSR stacking operators. Figure 1 shows the diffraction separation process by comparing a preprocessed original CMP gather with the results from Stages 1 and 2. Stage 1 removes most reflections, preserving diffractions and residual reflections and noise. Stage 2 further attenuates remaining reflections and noise while enhancing the diffractions. An amplitude gain was applied to improve visual comparison with the original data. These results are also shown in the stacked domain in Figure 2. The stacked sections clearly illustrate the effectiveness of reflection attenuation and diffraction enhancement. The improved visibility of diffractions in the prestack domain demonstrates the method's potential to aid structural interpretation and improve migration velocity analysis through better diffraction focusing.

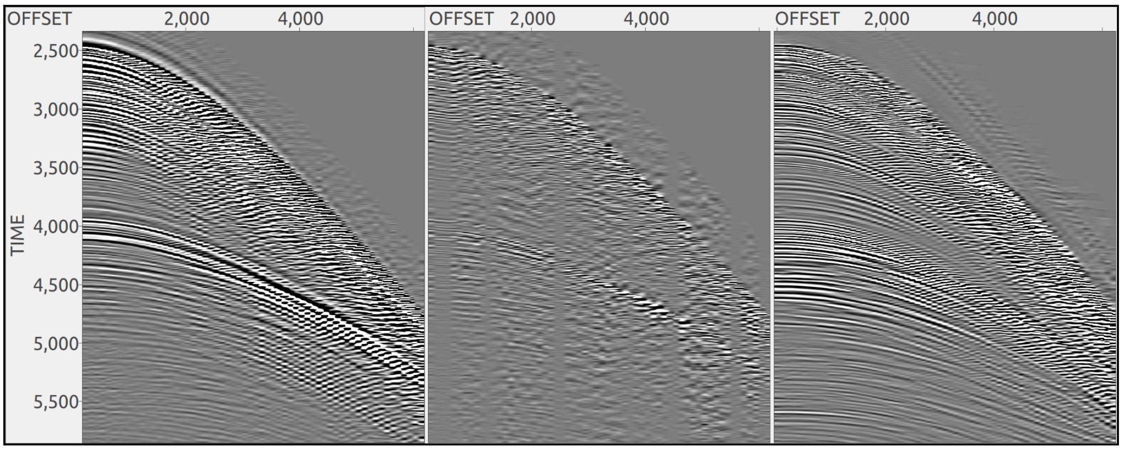

Figure 1: CMP gather 3003 - Preprocessed original dataset (left), Stage 1 results for reflection attenuation (center), Stage 2 results for diffraction enhancement (right).

Kirchhoff Prestack Time Migration (PSTM) was applied to preprocessed original data and extracted diffractions. Figure 3 shows the migrated region from Figure 2. Collapsed diffractions maintain the consistency observed in the stacked section, validating the separation. Irregular structures at 2.6 s (CMPs 5400–5600) and a potential reservoir at 2.9 s (CMPs 5200–5800) are clearly imaged. Mass transport complexes at 3.5 s (CMPs 6000–6400) are evident in both original and diffraction data, where slumped material is observable downslope.

Figure 4, in the middle-left seismic image, reveals unconformities and rugose surfaces. Diffraction images highlight diffractors along these surfaces (2.7–3.1 s, CMP 2000–2500), correlating with sharp edges from the diffraction image, potentially indicating pinch-outs and small faults. The central region of Figure 4 shows normal faults, better illuminated in the diffraction image (3.4–3.6 s, CMPs 2300–2800). Additional diffractions correlate with the structural high in the lower part, indicating significant deformation.

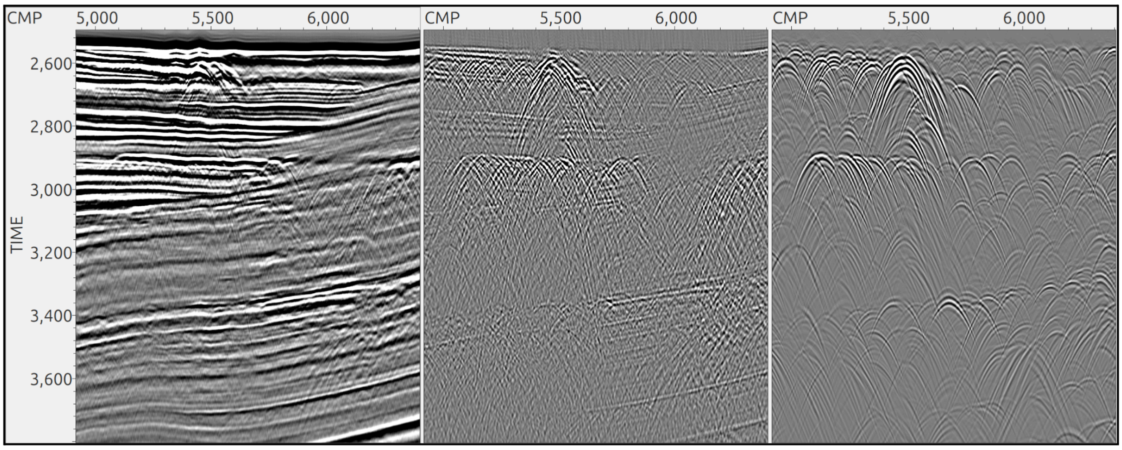

Figure 2: Detailed view of the stacked sections obtained with the original (left), Stage 1 (center) and Stage 2 (right).

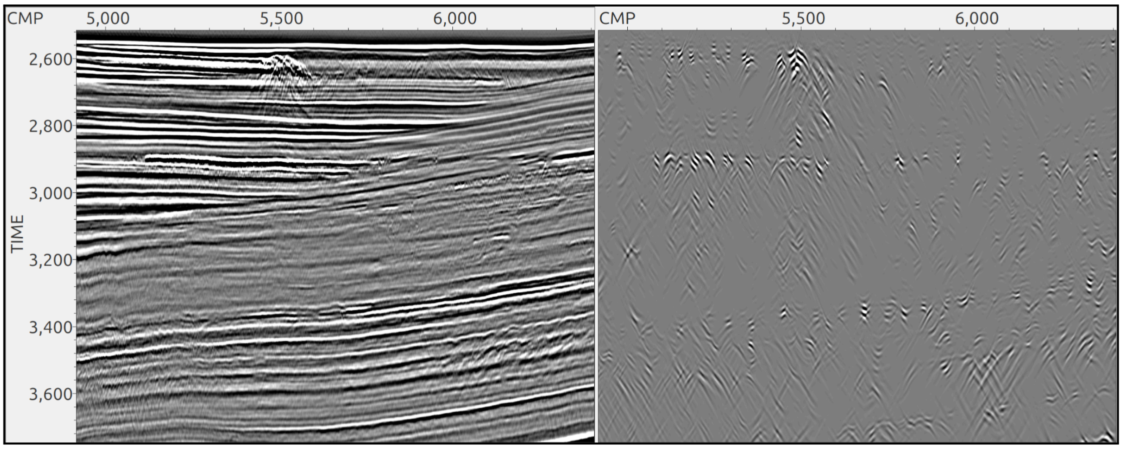

Figure 3: PSTM of the original dataset (left) and the corresponding diffractions obtained after Stage 2 (right), both displayed for the same region shown in Figure 2.

Conclusions

Diffraction imaging techniques offer significant advancements in seismic interpretation, facilitating the precise delineation of geological features critical for reservoir characterization, including canyons, pinch-outs and faults. We effectively applied a two-stage methodology to achieve separation of events in the prestack domain to the Bonaire Basin dataset, which encompasses a complex geological setting characterized by normal faults, mass transport complexes, canyons, and unconformities. Stage 1 effectively attenuated reflection events that obscured the diffraction events. Subsequently, stage 2 further refined diffraction separation, isolating diffraction signatures that were previously hidden within seismic reflections. These results demonstrate the utility of these techniques for improved seismic interpretation and detailed geological feature characterization within complex sedimentary basins. In-depth analysis of these isolated diffraction events can be used to validate and update migration velocity models, infer anisotropic properties from their shape, and be combined with migrated reflection data to interpret fault planes and highlight small-scale geological features.

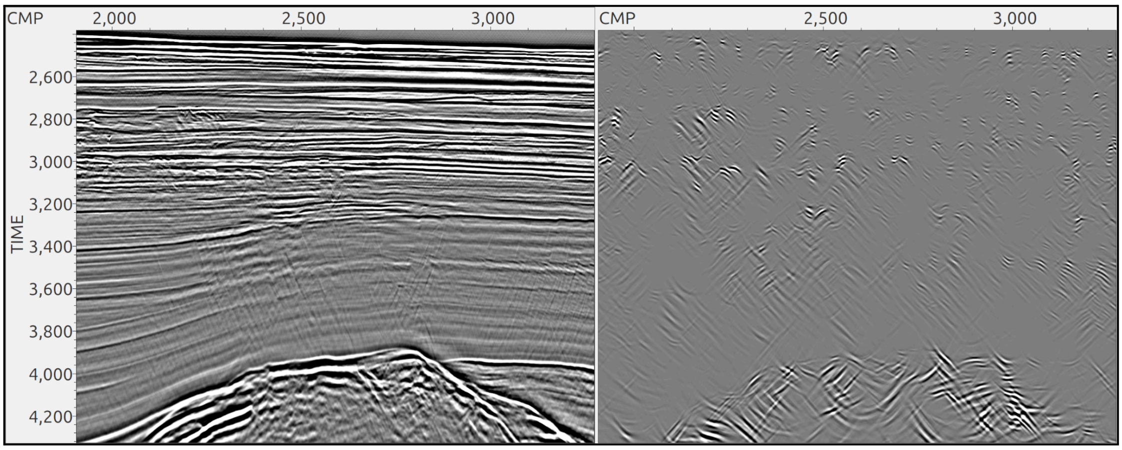

Figure 4: PSTM of the original dataset (left) and diffractions obtained after Stage 2 (right), corresponding to a different segment of the seismic line.

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