RECOVERING DIFFRACTIONS IN CRS STACKED SECTIONS

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ABSTRACT

The Common Reflection Surface (CRS) method is able to obtain simulated zero-offset sections with improved signal-to-noise ratio and the extraction of a greater number of attributes which characterize the geological medium than the traditional Common Midpoint (CMP) method. In the CRS method, reflected events are enhanced by stacking along a generalized hyperbolic moveout, referred as the CRS moveout. However, during this process, diffractions are likely to be attenuated or even destroyed. These diffracted events are important since they carry high-resolution information about the subsurface structure. Using a modified version of the CRS technique, diffractions can be enhanced in the same way as reflection events. This paper proposes a combined approach in which the conventional CRS stack is superimposed by a CRS diffraction-enhanced stack in such way that we can recover the diffractions in CRS stacked sections. The potencial of the method has been demonstrated using marine seismic data acquired offshore Brazil.

INTRODUCTION

The Common reflection surface (CRS) method (see, e.g., Jäger et al., 2001; Zhang et al., 2001) represents a natural generalization of normal moveout (NMO), which is valid for CMP gathers, to supergathers, in which the source-receiver pairs are arbitrarily located around a reference point, usually taken as a CMP. The method uses as stacking moveout the second order Taylor polynomial of traveltime squared, briefly referred to as the CRS moveout. In 2D, that simple moveout depends on three parameters, as opposed to conventional NMO, which depends on a single parameter (NMO velocity). The CRS method interprets subsurface seismic reflectors as an ensemble of reflecting elements, defined, not only by points, but also by dip and curvature. Consequently, the corresponding CRS stacking operator is not linked to a single CMP gather, but collects the reflection energy associated with a certain subsurface reflector element. Contributing traces include CMPs in the vicinity of the so-called central or reference CMP location, in which the stacked trace is to be assigned. In comparison with conventional CMP, the CRS stacking provides a strong increase in redundancy and signal-to-noise ratio, leading to clearer sections and more continuous events (see, e.g., Hubral et al., 1999; Hertweck et al., 2007).

Primarily designed as reflection enhancement technique, the standard use of CRS is bound, in many cases, to attenuate the diffracted wave contributions present in the seismic data. Such diffractions are known to carry useful information about small scale features as faults, pinch-outs and wedge-outs often linked to potential hydrocarbon reservoirs. As a consequence, it would be very desirable that diffraction events should, not only be preserved, but even enhanced by stacking. That goal can be achieved upon the simple observation that diffractions can be regarded as a limiting case of a reflecting element shrinking to a point. As well known, that provides an additional condition on the CRS parameters such that the corresponding moveouts, besides becoming simpler expressions, better approximates diffractions than reflections. Successful use of the diffraction-modified moveouts to a number of purposes has been already demonstrated in the literature. Examples are, among others, Asgedom et al. (2012); Faccipieri (2012).

Traditionally, enhancement of respectively reflections and diffractions has been carried out as two separate processes with two independent outputs. In the framework of the CRS method, we propose here to combine the two enhanced stacks to make further use of the fully potential of the CRS technique. The idea is that such a combination will ensure a signal-to-noise enhanced stack but also with the finer diffraction details preserved.

The combined approach to CRS enhancement is demonstrated using a field data example from the Jequitinhonha basin offshore Brazil. The results obtained were encouraging demonstrating the potential future use of the technique in target-oriented processing.

THE GENERALIZED HYPERBOLIC MOVEOUT OF 2D CRS

The CRS moveout in a 2D medium can be expressed as a function of three parameters, A, B and C, see Eq. 1. The expression represents a paraxial traveltime expansion around the traveltime t_0 of a zero-offset (ZO) reference ray emerging at a point m_0 on the acquisition surface. The parameter A contains information about the emergence angle of the reference (normal) ray, as well as the local near-surface velocity v_0. The parameter C is related to the curvature, K_{NIP}, of a hypothetical wavefront measured at the reference point m_0 and associated with a point source located at the point of incidence of the normal ray. The parameter B is related to the curvature, K_N, of another hypothetical wavefront that originates from a region in the vicinity of the same normal incidence point as an exploding reflector event. In Eq. 1, h is the half-offset of an arbitrary source-receiver pair with midpoint m located in the vicinity of the reference point m_0 and $m_D = m - m_0$ is the corresponding midpoint displacement. We have,

$$t^2(m_D, h) = [t_0 + Am_D]^2 + Bm_D^2 + Ch^2, \tag{1}$$

with the coefficients A, B and C given by

$$A = \frac{2\sin\beta}{v_0}\ , \ B = \frac{2t_0\cos^2\beta}{v_0}K_N \ \text{ and } \ C = \frac{2t_0\cos^2\beta}{v_0}K_{NIP}. \tag{2}$$

In this work we employ a search strategy based on two different subsets of the data volume. First, the measurements are sorted in the CMP domain which corresponds to setting $m_D = 0$ in Eq. 1. From that equation, it now follows that the resulting traveltime only depends on the single parameter C, namely,

$$t^2(0, h) = t_0^2 + Ch^2. \tag{3}$$

The search of parameter C is very similar to a conventional velocity analysis, with the identification $C = 4/v_{NMO}^2$ term. However, in CRS the parametric search is executed for all time samples. The optimal values of parameter C are extracted using semblance as a coherency measure.

The data can now be stacked using the velocity given by the parameter C to form a ZO section. This corresponds to setting $h = 0$ in Eq.1 leading to a simplified traveltime depending on two parameters, A and B,

$$t^2(m_D, 0) = [t_0 + Am_D]^2 + Bm_D^2. \tag{4}$$

The parameter A can now be estimated by a linear search, assuming $B = 0$ for small apertures. Finally, the parameter B can be estimated by introducing larger apertures employing the values of parameter A found in the previous estimate. In both parametric searches, semblance is used as a coherency measure.

HYPERBOLIC MOVEOUT IN CASE OF 2D DIFFRACTIONS

As earlier indicated, although the objective of CRS stacking is to enhance reflection events, the same approach can be adapted to the case of diffraction enhancement. This is possible by considering a point diffractor as the limiting case when the reflector shrinks to a point. By the very definitions of the NIP- and N-waves, it is readily seen that these waves coincide when the reflector collapses to a point. We have, thus, that $K_N = K_{NIP}$ which retranslates to $B = C$. That relation can be seen as a condition on the parameters to characterize a diffraction. By imposing this condition in Eq.1, it takes the simplified form

$$t^2(m_D, h) = [t_0 + Am_D]^2 + C[m_D^2 + h^2], \tag{5}$$

The above moveout is especially designed for diffracted events and can therefore be employed to enhance diffractions in the framework of the CRS stacking. Observe that, in case of diffractions, only two parameters (A and C) need to be considered. The parameter C is estimated from Eq.3 in the same way as in case of reflections. The parameter A can then be determined from the ZO diffraction-stack, setting $h = 0$ in Eq.5, namely

$$t^2(m_D, 0) = [t_0 + Am_D]^2 + Cm_D^2, \tag{6}$$

Estimation of parameter A using Eq. 6 and with fixed values of C from the CMP velocity analysis, often lead to only partially recovered diffractions. The reason is that when a diffractor is displaced relative the reference location m_0, the response can be interpreted in a similar way as that of a dipping reflector. Such an event is associated with an apparent velocity, which is different from the true local medium velocity. To take this phenomenon into account, as well as allowing for refinements of possible velocity errors, we introduce an alternative version of Eq. 6:

$$t^2(m_D, 0) = [t_0 + Am_D]^2 + \varepsilon Cm_D^2, \tag{7}$$

where the parameter C is multiplied with a perturbation factor ε. This implies that a simultaneous two parameter search of A and ε is needed.

FIELD DATA EXAMPLE

To illustrate the concepts of reflection and diffraction enhancements, as well as the combined CRS stacking approach advocated for in this paper, a marine seismic line was considered. The seismic line (line 214-2660) was acquired along a NE direction over the Jequitinhonha Basin. This basin covers a total area of 10.100 km2 and is located offshore Brazil near the Eastern Brazilian border. It is composed of sedimentary rocks from the tertiary and cretaceous ages (Davidson, 2007). The basin has been through two different tectonic phases (pre-salt and post-salt) which indicate the possibility of hydrocarbon accumulation. A discovery of light oil was also made in 2006, but the actual commercial potential of the reservoir is still uncertain (Mohriak et al., 2008).

The seismic line considered in this paper was acquired by the Brazilian oil company Petrobras in 1985 and has the following acquisition parameters: 1577 shots in intervals of 25 m with 120 receivers in intervals of 25 m and a recording time of 7 s with sampling of 4 ms.

The seismic line was processed using the ProMAX software package of Halliburton. Figure 1 gives a flowchart of the main preprocessing steps before conventional CMP stacking as well as the alternative CRS processing. They are as follows:

- Steps 1-3 involve reading data, defining the geometry and editing bad recordings;
- Step 4 corrects for amplitude losses due to spherical divergence. The correction factor is given on the form $1/(tV^2)$, where t is TWT and $V(t)$ is the root-mean-squared (RMS) velocity of the primary reflections;
- Step 5 recover higher frequencies and correct attenuation effects by employing, respectively, Minimum Phase Spiking Deconvolution and TV Spectral Whitening;
- In step 6, an Ormsby Zero Phase Bandpass Filter was applied to remove both low-frequency, as well as high-frequency ambient noise;
- The bathymetry of the seismic line is changing from shallow to deep water, and residual statics was applied in Step 7 to ensure a good stacking quality;
- Step 8 is related to the velocity analysis and conventional CMP stacking. In order to enhance the quality of the output image of the stack an AGC has been applied;
- Step 9 represents the alternative CRS stacking route. The outputs are now: conventional (reflection-enhanced) CRS stack, diffraction-enhanced CRS stack and the combined (mixed) CRS stack.

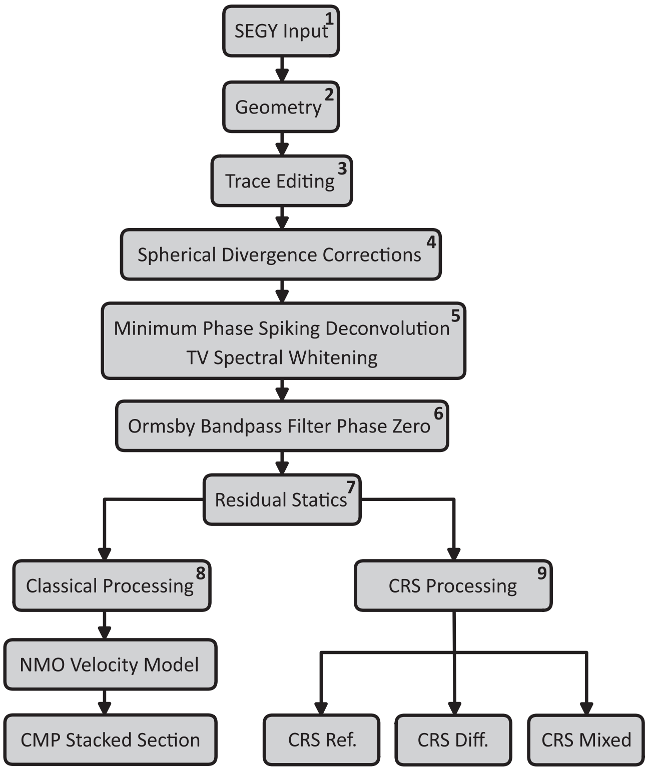

Figure 1: Processing flowchart.

The conventional CMP stack shown in Fig. 2 serves as the reference. In the following, we will only consider a part of the whole seismic line as defined by the rectangle in Fig. 2. This subset of the data has been chosen because of its richness of diffractions. Figure 3 shows the conventional CMP stack for this chosen target area. The conventional CRS stack is shown in Fig.4.

The search parameters used for determining A, B and C are summarized in Table 1. Direct comparison between Fig. 3 and Fig. 4 shows that the CRS stack has improved the signal-noise-ratio considerably, especially for the upper left part. We employed a small aperture in midpoint-space when estimating the parameter B in order to avoid smoothing of the reflectors. However, the diffractions have been partially destroyed during the process of reflection enhancement.

The corresponding diffraction-enhanced stack is shown in Fig. 5, as obtained using the search parameters summarized in Table 2. It can be seen that the enhancement of the diffractions has worked well across the chosen target area. Finally, Fig. 6 represents the combined CRS section formed by adding together the stacks in Fig. 4 and Fig. 5. On comparison with the standard CMP stack in Fig. 3, we can easily see that not only the signal-noise-ratio has been improved, but also that the finer details represented by the diffracted energy have been well preserved.

DISCUSSION AND CONCLUSION

The concept of CRS stacking is an attractive approach to enhance the signal-to-noise ratio associated with conventional CMP stacking. Used with care, this method can improve the stacking and imaging quality considerably. However, since CRS stacking is primarily devoted to the enhancement of reflections present in a given seismic data set, there is a risk that diffracted energy will be correspondingly attenuated and partially destroyed. After proper modification, the generalized moveout governed by CRS can also be used to enhance diffractions and correspondingly attenuate reflections. In this paper we propose to add this latter type of stack to the conventional CRS stack. In this way the balance between signal enhancement and resolution preservation is kept in a good manner. The signal-to-noise ratio is increased but not at the

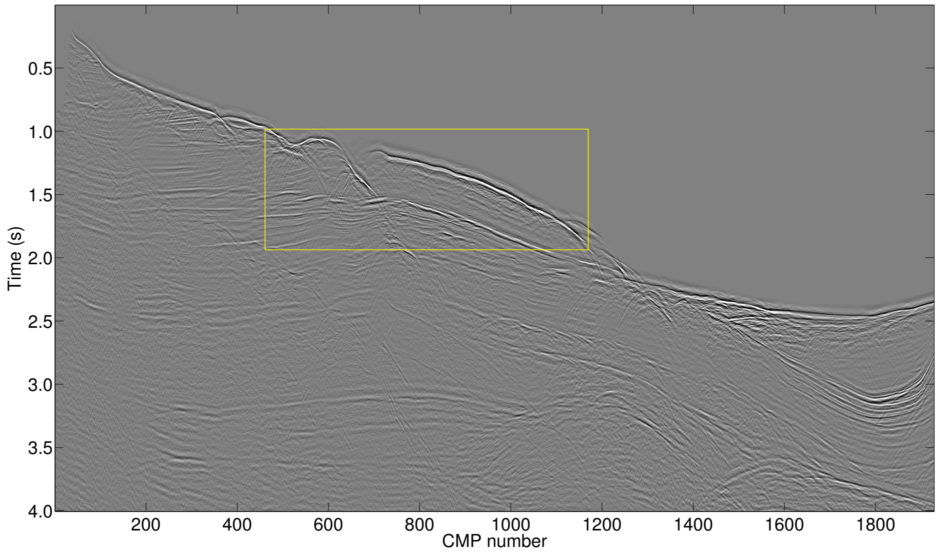

Figure 2: Conventional CMP stacked section.

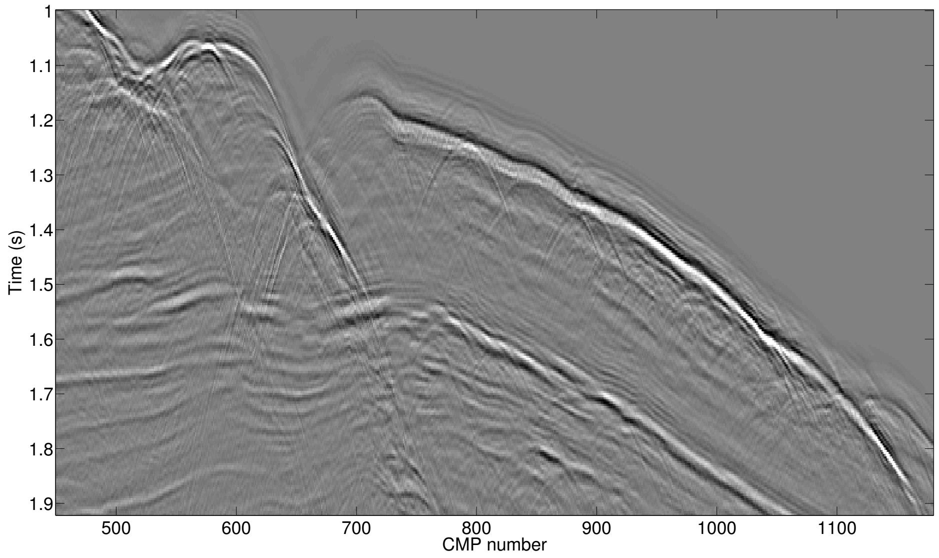

Figure 3: Conventional CMP stacked section within chosen target window.

1st Search - C parameter (CMP gathers)	
Aperture in offsets (first time sample)	400 m
Aperture in offsets (last time sample)	800 m
Search interval	2.1×10^{-6} to 1.98×10^{-7} m$^{-2} \cdot$ s^{2}
2nd Search - A parameter (ZO section)	
Aperture in offsets (first time sample)	60 m
Aperture in offsets (last time sample)	80 m
Search interval	-1.21×10^{-3} to 1.21×10^{-3} m$^{-1} \cdot$ s
3rd Search - B parameter (ZO section)	
Aperture in offsets (first time sample)	60 m
Aperture in offsets (last time sample)	80 m
Search interval	-5.33×10^{-11} to 5.33×10^{-11} m$^{-1} \cdot$ s

Table 1: Conventional CRS search parameters

1st Search - C parameter (CMP gathers)	
Aperture in offsets (first time sample)	400 m
Aperture in offsets (last time sample)	800 m
Search interval	2.1×10^{-6} to 1.98×10^{-7} m$^{-2} \cdot$ s^{2}
2nd Search - A parameter and ε (ZO section)	
Aperture in offsets (first time sample)	800 m
Aperture in offsets (last time sample)	1000 m
Search interval for parameter A	-1.21×10^{-3} to 1.21×10^{-3} m$^{-1} \cdot$ s
Search interval for ε factor	0.8 to 1.2

Table 2: CRS for diffractions search parameters

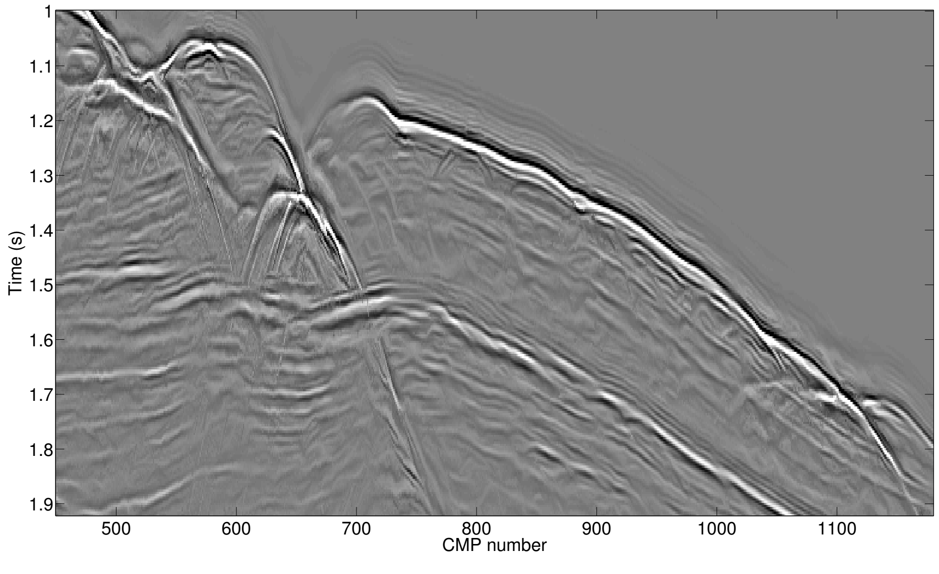

Figure 4: Conventional CRS stacked section (target window).

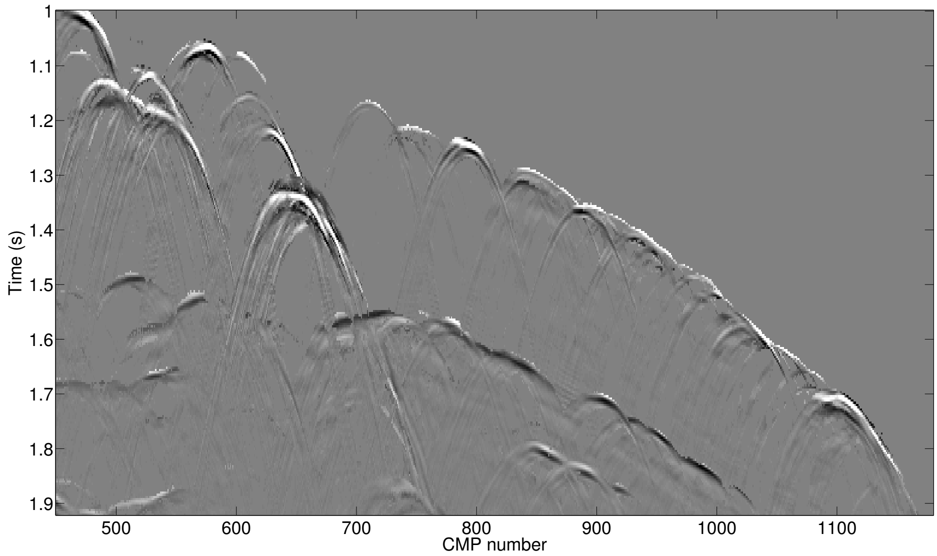

Figure 5: CRS enhanced diffractions (target window).

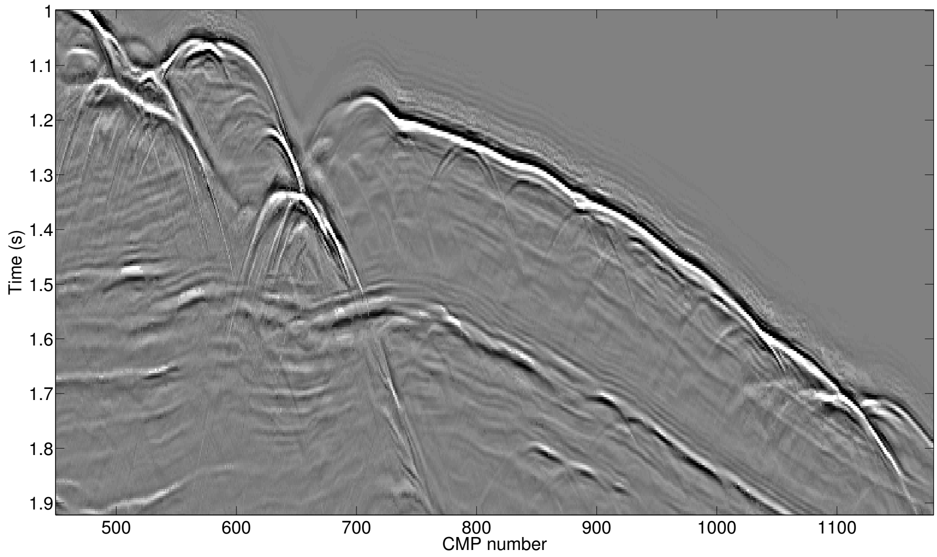

Figure 6: Combination of conventional CRS stack and CRS enhanced diffractions.

expense of the finer details associated with diffracted energy. The concept of combined CRS stacking has been tested with good results employing marine seismic data acquired offshore Brazil. Future work of the method should consider the generalization to a 3D geometry.

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