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CRS-based Seismic Imaging in Complex Marine Geology

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SUMMARY

The present work represents an extension of the efforts described previously by the authors, now to marine data, and we demonstrate that Common Reflection Surface (CRS) stack and imaging gives results that clearly improves: (1) the signal-to-noise ratio; (2) the continuity of reflection events; (3) enhances the surface multiple; and (4) that the CRS operator approximates a pseudo-migration. The workflow is summarized as: (1) Preprocessing; (2) CRS stack; (3) Residual static correction; (4) Prestack data enhancement; (5) CRS stack; (6) Pseudo-migration. The CRS stack has been described by several authors, and the tecnology supports subsequent processing based on the wavefront attributes. The preprocessing steps were performed with the free seismic processing package CWP/SU. Marine geological structural features of the survey area are described for sedimentary basins of the passive continental shelf of the Brazilian South Atlantic.

Introduction

The present work represents an extension of the efforts described in Leite et al. (2008) to marine data, and we demonstrate that Common Reflection Surface (CRS) stack and imaging give results that clearly improves: (1) the signal-to-noise ratio; (2) the continuity of reflection events; (3) enhances the surface multiple; and (4) that the CRS operator approximates a pseudo-migration. The workflow of the present work is summarized as: (1) Preprocessing; (2) CRS stack; (3) Residual static correction; (4) Prestack data enhancement; (5) CRS stack; (6) Migration. The CRS stack has been described by Müller et al. (1998) and Mann (2002), and to support subsequent processing as described in Duveneck (2004), Gamboa (2003), and Koglin et al. (2006), among others. The preprocessing steps were performed with the free seismic processing package CWP/SU (Cohen and Stockwell, 2005). Marine geological structural features are described by Mohriak et al. (2008) for sedimentary basins of the passive continental shelf of the Brazilian South Atlantic.

Method

A short description of the CRS stack can start with the semblance $S(t_0;\mathbf{m})$ measure of the corrected trace amplitudes ($\overline{u}$), as given by Bernabini et al. (1987):

$$S(t_0;\mathbf{m}) = \frac{\frac{1}{N_t}\sum\limits_{t=t_0-\delta t}^{t=t_0+\delta t}\frac{1}{N_x}\sum\limits_{x=x_F}^{x=x_L}\left[\frac{1}{N_h}\sum\limits_{h=h_F}^{h=h_L}\overline{u}(h,x;t_0)\right]^2}{\frac{1}{N_t}\sum\limits_{t=t_0-\delta t}^{t=t_0+\delta t}\frac{1}{N_x}\sum\limits_{x=x_F}^{x=x_L}\frac{1}{N_h}\sum\limits_{h=h_F}^{h=h_L}\overline{u}^2(h,x;t_0)}, \quad (where \quad 0\leq S\leq 1); \tag{1}$$

$S(t_0;\mathbf{m})$ is a function of a set of parameters $\mathbf{m}$ of the stacking trajectory. The summation goes from a first half-offset $h = h_F$ to a last half-offset $h = h_L$ with N_h points, from a midpoint x ranging from x_F to x_L with N_x points, and in a time window specified by some δt around t_0. $S(t_0;\mathbf{m})$ takes values in the interval (0,1) regardless of the absolute signal amplitude, and it quantifies the uniformity of the signal polarity across the corrected gather amplitude $\overline{u}(t_0;\mathbf{m})$. Following Schleicher et al. (2007), the hyperbolic approximation for the two-way traveltime of primary reflections from a curved interface on a flat observation surface that defines the CRS stack operator is given by:

$$t^2_{hyp}(x_m,h;\mathbf{m}) = \left[t_0 + \frac{2\sin\beta_0(x_m-x_0)}{v_0}\right]^2 + \frac{2t_0\cos^2\beta_0}{v_0}\left[\frac{(x_m-x_0)^2}{R_N}+\frac{h^2}{R_{NIP}}\right]. \tag{2}$$

The parameter vector takes the values $\mathbf{m} = (R_{NIP}, R_N, \beta_0; v_0)$, where $\mathbf{m}$ is searched for, with v_0 fixed, as an optimization problem with the semblance (1) as object function, and the CRS operator (2) as the forward model. The search is classified as a nonlinear ill-posed problem, and it is achieved by controlled direct search, as described by Müller et al. (1998). Mann (2002) describes the problem related to conflicting dips in the stack sections, and Soleimani (2009) addresses this problem by proposing a strategy that considers a multitude of different values of β_0 for each ZO sample, with the forward model (2) under the condition $R_N = R_{NIP}$, to improve the continuity of reflection events and diffraction events, in a process named common-diffraction-surface stack.

A Kirchhoff-type time migration scheme is integrated in the CRS stack algorithm as described by Mann (2002). It considers that the CRS attributes allow to approximate the (hypothetical) diffraction event associated with reflection event in the data. The apex of the ZO diffraction response provides an approximation of the image location for time migration. Due to the symmetry considerations, $\partial t_{hyp}(x_m, h = 0)/\partial x_m = 0$ for the ZO plane $h = 0$, and this yields the apex location given by:

$$x_{apex} = x_0 - \frac{R_{NIP}t_0v_0\sin\beta_0}{2R_{NIP}\sin^2\beta_0 + t_0v_0\cos^2\beta_0}, \tag{3}$$

$$t_{apex}^2 = \frac{{t_0}^3 v_0 \cos^2\beta_0}{2R_{NIP}\sin^2\beta_0 + t_0 v_0 \cos^2\beta_0}\,. \tag{4}$$

This approximate ZO diffraction response can be parametrized in terms of the apex location (x_{apex}, t_{apex}) instead of the ZO location (x_0,t_0):

$$t_{hyp}^2(x) = t_{apex}^2 + \frac{4(x - x_{apex})^2}{v_c^2} \quad , with \tag{5}$$

$$v_c^2 = \frac{2v_0^2 R_{NIP}}{2R_{NIP}\sin^2\beta_0 + t_0 v_0 \cos^2\beta_0}\,. \tag{6}$$

The already available stack value, computed along the CRS operator, can be assigned to the apex (x_{apex}, t_{apex}).

Aiming at increasing resolution, the static residual correction strategy has been applied under the concept of virtual source-receiver vertical and horizontal displacements, and in terms of communication theory looking for better correlation between the ZO trace and its corresponding family's traces under small shifts. Koglin et al. (2006) describe the CRS-based residual static correction as an iterative process similar to the super-trace cross-correlation method as presented by Ronen and Claerbout (1985). Each prestack trace is included in many different supergathers, and it contributes to more cross-correlations than in methods using only individual gathers. The searched for residual time shifts are expected to be associated with the locations of the maxima in the cross-correlation stacks with the pilot ZO trace, and they are used to correct the prestack traces. The stack result after residual static correction is integrated in the data process, and one can observe an improvement in resolution.

The concept of prestack data enhancement by interpolating new CDPs based on the CRS stack operator is described by Baykulov and Gajewski (2007). This process has been integrated into the workflow, and it has contributed more to resolution than the static residual correction. Using the CRS attributes β_0 and R_{NIP}, the corresponding operator is given by:

$$\begin{aligned} t_{par}^2(x_m, h) \quad = \quad & \left(-\frac{h^2\cos^2\beta_0}{v_0 R_{NIP}} + \sqrt{\left(\frac{h^2\cos^2\beta_0}{v_0 R_{NIP}}\right)^2 + t_{hyp}^2(x_m, h)} + \frac{2\sin\beta_0}{v_0} x_m \right)^2 \\ & + \quad \frac{2\cos^2\beta_0}{v_0} \left(-\frac{h^2\cos^2\beta_0}{v_0 R_{NIP}} + \sqrt{\left(\frac{h^2\cos^2\beta_0}{v_0 R_{NIP}}\right)^2 + t_{hyp}^2(x_m, h)} \right) \\ & \left(\frac{x_m^2}{R_N} + \frac{h^2}{R_{NIP}} \right). \end{aligned} \tag{7}$$

Depending on the quality of the data and on the acquisition geometry, the lateral windows for stacking can be optimized in the directions x_m and h. In our examples the sizes were the same as chosen in the CRS stack.

Results and Conclusions

The selected figures were distributed in the following order: (1) Optimized-Fresnel stack; (2) Optimized-Fresnel posttime migration interpreted section caracteristics. Results are controlled by the distribution values of the coherence panels, and it is expected that subsurface structures to be represented by definite patterns, and better images should be given by stronger patterns of continuity and higher values of coherence. The analysis is made on the stack panel of Figure 1 that shows the bottom of the water layer followed by the response of basin sediments with several reflectors with similar geological attitude. The entire section has across it the free reinforced surface multiple and strong disturbing diffractions.

On the other hand, the migration panels present themselves without the effect of the diffractions by showing the collapsing points. The time panels of kinematic CRS wavefield attributes R_{NIP}, $1/R_N$, β_0 and coherence are not shown here due to space considerations. We are here limited to geometrical

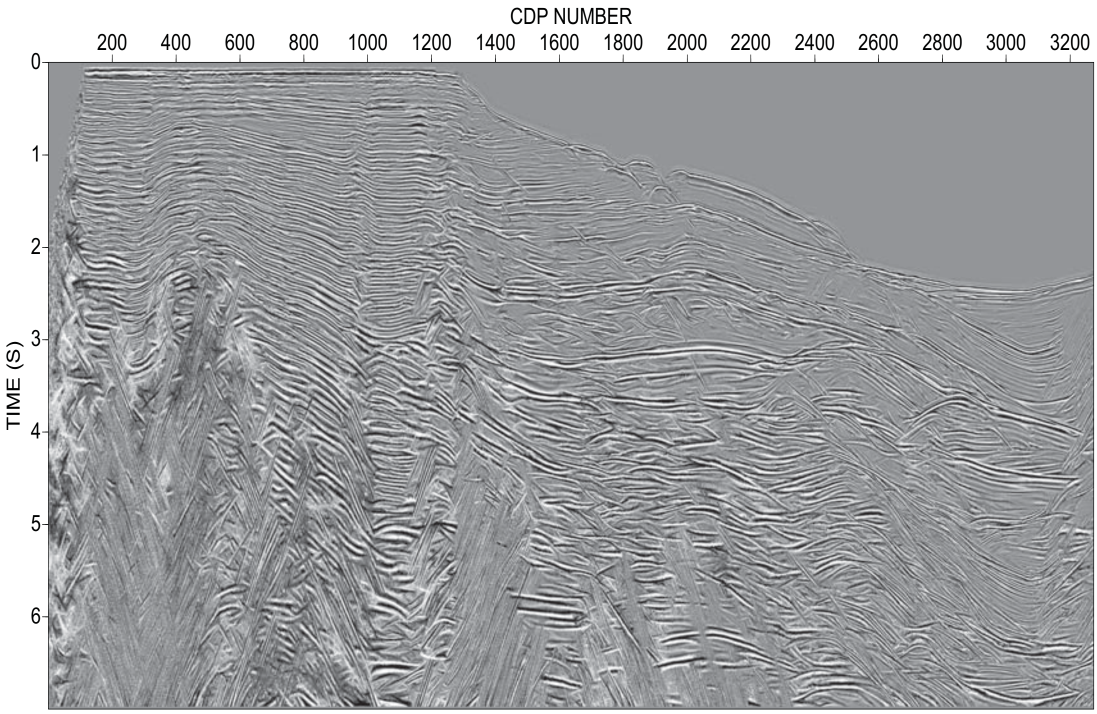

Figure 1 *Optimized CRS Fresnel supergather stack with gain control.*

interpretation of the caracteristics carried out mainly on the pseudo-migration and stack sections. The main figure selected for the conclusion was the CRS-Fresnel-stack in Figure 1, but with the version with color lines traced on it not shown here for space reason.

The pseudo-migration in Figure 2 was obtained from Figure 1, and the color lines drawn on this figure 2 are the same lines as in the interpreted version of Figure 1. We can observe that these lines have almost no shift with respect to Figure 1, showing the colapse of diffrations in grainy form, and saying that the stack operator behaves also as a pseudo-migration in this context. The basement is not easily traced, and the left part of the section would need more attention for structures to be better recognized due to strong diffraction events. Therefore, the challenge for better stack-imaging with CRS around the continental shelf continues.

The quality of the marine seismic data should not be a decisive limitation in enhancing different parts for the imaging of the selected line. The intention is to geometrically trace structures, and to demonstrate the applicability of the CRS stack-and-migration towards basin reevaluation providing good basis for geological interpretation, and hopefully for a successful drilling.

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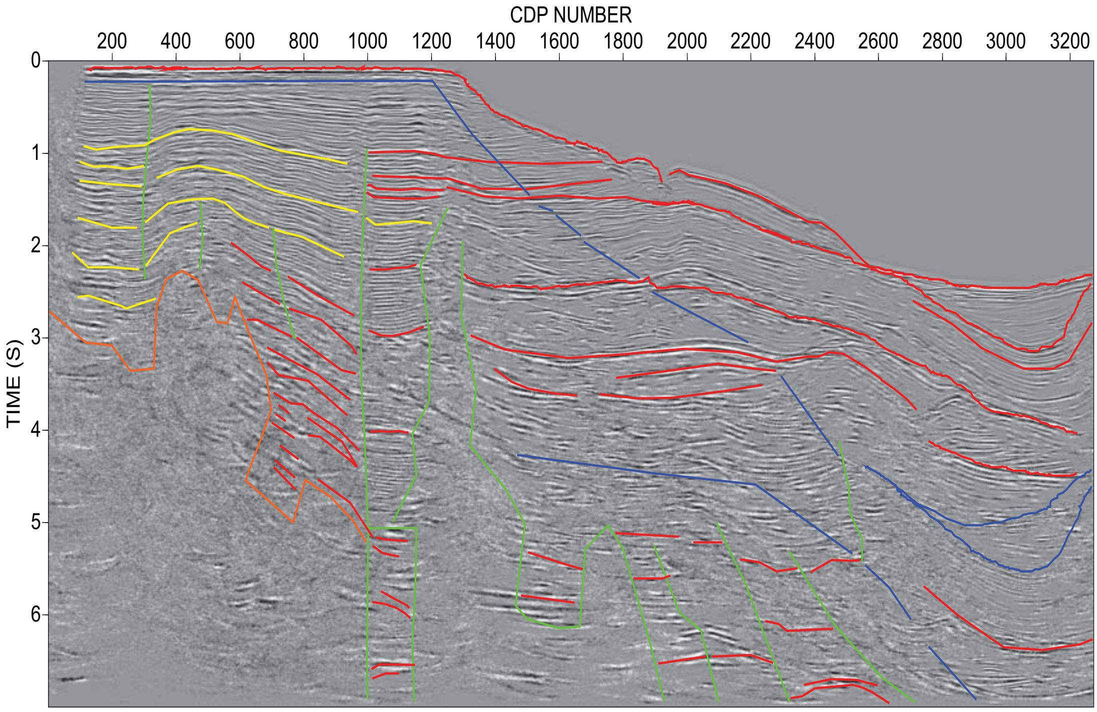

Figure 2 *Interpreted optimized CRS supergathers post-time Kirchhoff-type migration for geometrical structures. The interpreted colored lines were transported directly from the CRS stack section.*

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