2D CRS STACK: THE USE OF THE STACKING VELOCITY AS AN "A PRIORI" INFORMATION IN THE OPTIMIZATION OF CRS PARAMETERS.

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ABSTRACT

The Common Reflection Surface (CRS) Stack method simulates zero-offset (ZO) sections by means of summing the amplitudes of seismic events in the multicoverage data by using a stacking operator defined in the midpoint and half-offset coordinates. For 2-D media, this operator depends on three kinematics attributes, also called CRS stacking parameters. The main problem of the CRS stack method is the determination, from the muticoverage seismic data, of these three parameters for each sampling point of the ZO section to be simulated. In this work, this problem is solved by means of application of the global optimization algorithm Simulated Annealing (SA) to search simultaneously the three attributes, using as objective function the coherency measure Semblance. We presents the results of the one-step CRS stack implementation without using any bound constraints and introducing constrains derived from conventional velocity analysis, i.e., the stacking velocity model. The results using the bound constrained global optimization show better coherent noise attenuation and, as consequence, a ZO section with better quality.

INTRODUCTION

The CRS stack method developed as a data-driven and velocity-independent process produces ZO sections with a high signal-to-noise ratio and improved resolution. In fact, this method already has become a real alternative to the well-known common midpoint CMP stack method, and it is being used routinely in seismic data processing for several oil companies.

The CRS stacking operator is a second order hyperbolic traveltime approximation that depends, in 2D, on three kinematic attributes related to the hypothetical Normal Incident Point wave and Norma wave (Hubral, 1983), namely, the emergency angle of the normal ray, β_0, the radius of curvature of the NIP wave, R_{NIP}, and the radius of curvature of the normal wave, R_N. These three attributes are determined by means of optimization processes from pre-stack data, using as objective function a coherency measure of the seismic signal.

Based on the simplifications of the CRS operator and optimization strategies to search the CRS parameters several algorithms can be developed to implement the CRS stack method. In 2D, the well established optimization strategy was developed by Müller (1998) and Jäger et al. (2001), and after it was modified by Mann (2001). Another optimization strategy presented in Garabito et al. (2001) is based on the simplification of the general hyperbolic traveltime for the diffraction case. Both strategies use several steps to determine the initial CRS parameters and after the final refined or optimized parameters.

To avoid the use of several steps and improve the accuracy of the CRS parameters and also to improve the quality of the resulting images, Garabito et al. (2006) introduces the CRS stack implementation using one-step search strategy, where the three CRS parameters are determined simultaneously using the Simulated Annealing (SA) and Very Fast Simulated Annealing (VFSA) global optimization algorithms. A first comparison of the resulting images from the CRS implementations by using a multi-step parameter search strategy and the one-step strategy was presented in Garabito et al. (2007), where the last implementation showed better lateral continuity of the ZO primary reflections mainly in shallow part. Both implementations of the CRS method did not use any type of constrains during the search of the three kinematic attributes by means of global optimization.

In general, the CRS stack implementations that do not use constraints during the search for of the kinematic attributes produce high resolution results only from good quality, high fold and well pre-conditioned prestack datasets. In datasets with low signal-to-noise ratio and particularly with low fold, such as land datasets from old acquisitions, the CRS method does not produce satisfactory results because it incorporates coherent noise that interfere with the primary reflections in the ZO stacked sections. As an example of this kind of noise are the multiple reflections, that can be stacked as primary reflection where the CRS parameters are searched for without any restriction.

To attenuate multiple reflections in a similar way as the CMP method, the CRS stack can also use the stacking velocity information obtained from the conventional velocity analysis procedure. In CRS stack implementation proposed by Mann (2001) using the so-called "extended pragmatic search strategy", it was introduced constraints in the tested stacking velocity range to attenuating multiple reflections events, where the stacking velocity is used as a reference velocity model and a percentile variation is given to define the search interval.

Is this work we introduce similar constraints in searching simultaneously of three CRS stacking parameters. The stacking velocity model is used to calculate an initial value of the R_{NIP} parameter for optimization and also to define the bounds of the search interval. We apply this new one-step CRS stack implementation in a dataset of land real data of the Tacutu Basin, Brazil, and compare their results with the multi-step CRS stack implementation based on the pragmatic search strategy. To show the great importance of the use of bound constraints in searching the CRS parameters, we will apply them with and without use of a priori information in the optimization process.

TRAVELTIME APPROXIMATIONS

CRS-traveltime

The CRS traveltime is a second order hyperbolic traveltime approximation for rays in the vicinity of a normal incidence central ray. For 2D case, assuming a plane measurement surface and arbitrary positions for sources and receivers, the hyperbolic approximation is given by (Tygel et al., 1997)

$$t^2(x_m, h) = \left[t_0 + \frac{2\sin\beta_0}{v_0}(x_m - x_0)\right]^2 + \frac{2t_0\cos^2\beta_0}{v_0}\left[\frac{(x_m - x_0)^2}{R_N} + \frac{h^2}{R_{NIP}}\right]. \qquad (1)$$

This traveltime approximation is expressed in function of the midpoint, $x_m = (x_g + x_s)/2$, and half-offset, $h = (x_g - x_s)/2$, coordinates, where the x_s and x_g are the horizontal positions of source and receiver, respectively. The coordinate x_0 and time t_0 are, respectively, the emergence point and the two-way traveltime of the central ray. The parameter v_0 denotes the near surface constant velocity. The three kinematic attributes that define the CRS stacking operator are the emergence angle, β_0, of the central ray, and the two radii of curvature R_{NIP} and R_N, related to the two wavefronts at the emergence point of the central ray, corresponding to the hypothetical NIP wave and Normal wave, respectively.

Assuming known the three kinematic attributes for a certain ZO sample point on a reflection event, the CRS traveltime formula (1) defines a stacking surface, or so-called CRS operator, in the midpoint and half-offset plane. Then, in the CRS stacking method, the seismic amplitudes of the prestack data are summed along the stacking surface to simulate a ZO amplitude. The complete ZO staked section is obtained repeating this procedure for all sample point of the ZO section to be simulated.

CMP-traveltime

The general hyperbolic traveltime (1) can be reduced to the classical CMP configuration by considering the fixed midpoint to coincide with the central point, i.e. $x_m = x_0$, we obtain

$$t^2(h) = t_0^2 + \frac{2t_0 \cos^2 \beta_0}{v_0 R_{NIP}} h^2. \quad (2)$$

By comparison of the formula (2) with the well-known CMP hyperbola, we verify that stacking velocity, v_{stack}, can be expressed in terms of the CRS attributes, as given by

$$v_{stack}^2 = \frac{2v_0 R_{NIP}}{t_0 \cos^2 \beta_0}. \quad (3)$$

This formula relates the stacking velocity of the conventional CMP method with the parameters β_0 and R_{NIP}, of the CRS method. Through this relationship, the stacking velocity can be used as reference function in the determination of the R_{NIP} attribute.

CRS STACK STRATEGIES

The main problem of the CRS stack method is the determination of the three kinematic attributes from prestack data. This problem can be solved by the application of multidimensional global optimization algorithms, using as objective function the coherency measure of seismic signal. Due to the large amount of seismic data involved in calculating the objective function the global search process is very time consuming. Another difficulty in implementing this solution is to find an optimization algorithm that guarantees convergence to the global maximum, since the objective function is multimodal.

To overcome these difficulties, some strategies have been proposed to search the CRS parameters in several steps. The well known "extended pragmatic search strategy" initially proposed by Jäger et al. (2001) and after modified by Mann (2001) determines the three CRS parameters in four steps. In the first three steps are searched-for the initial estimates of the CRS parameters, and in the last step is applied a simultaneous local optimization to obtain the final CRS parameters. More details about the "extended pragmatic search strategy", referred in this work as multi-step strategy, can be found in the previously cited papers.

In Garabito et al. (2006) the optimization problem of the CRS method was solved by using the “simultaneous global search strategy”, where the three CRS stacking parameters are searched-for simultaneously by using the global optimization algorithms Simulated Annealing (SA) and Very Fast Simulated Annealing (VFSA). In this work, we use the CRS stack implementation that apply the SA algorithm and it is also referred as one-step strategy.

In both CRS stack implementations (multi-step and one-step) the stacking velocity is used to constrain the search interval of the stacking velocity in the optimization process. The expression (2) allows the use of stacking velocity that comes from conventional processing, as reference function in searching the parameters of CRS, which is introduced to attenuate coherent noise, such as the multiple reflections.

APPLICATIONS

We apply the multi-step and the one-step CRS stack implementations to real land dataset of the Tacutu Basin, Brazil. The dataset used in this work correspond to seismic line 50-RL-90, they were acquired in the Brazilian portion of Tacutu Basin in 1981, in the petroleum exploration project conducted by PETROBRAS. The shots records have 96 channels distributed along a split-spread recording geometry, with offset minimum and maximum of 150m and 2500m, respectively. Shot spacing is 200m and receiver spacing is 50m. The time sample interval is 4 milliseconds. Due to the low fold and high noise level of this dataset, usually, severe difficulties are encountered when this kind of dataset is processed using conventional CMP stack and pre-stack time migration methods. As example, in the Figure 1 we show the result of the CMP stack with the NMO/DMO corrections obtained by using a commercial seismic processing package, and the Figure 2 is the stacking velocity model resulting from the standard velocity analysis, that it will be used as a reference velocity function in the CRS stacking method.

To apply the CRS stacking method we use the same pre-processed data that is the input to obtain the stacked section by the CMP method. In the following, we present the results of the CRS method without any constraints during the search or optimization of the CRS parameters. The Figure 3 is the result of the multi-step CRS stack implementation and the Figure 4 is the result of the one-step CRS stack implementation.

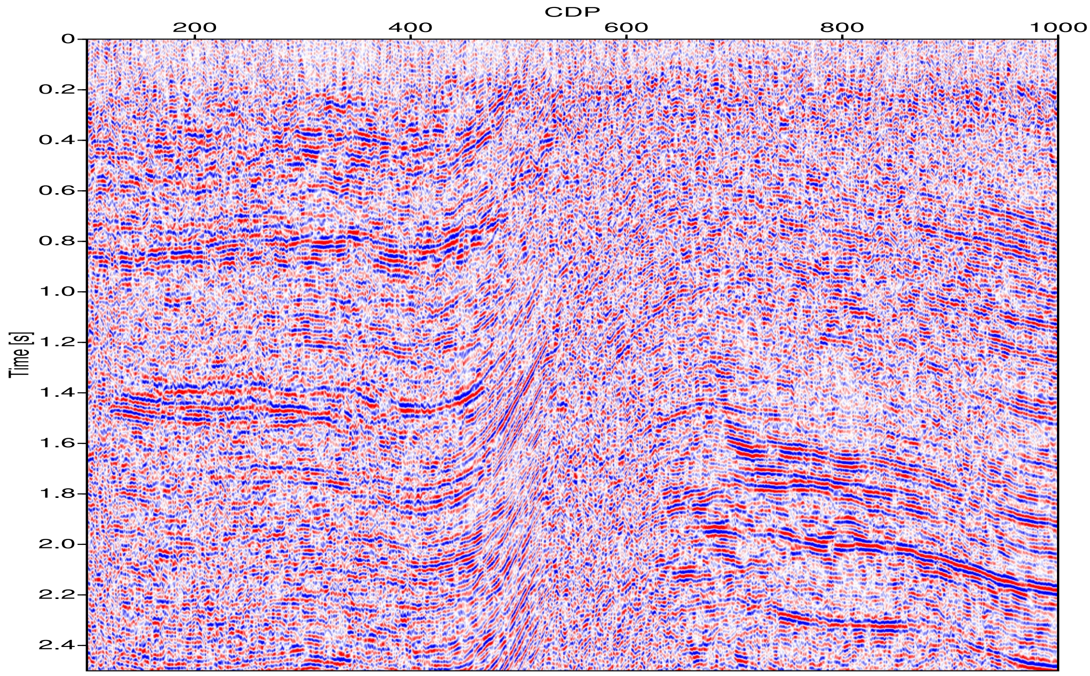

Figure 1: ZO stacked section obtained by the CMP (NMO/DMO) stack method.

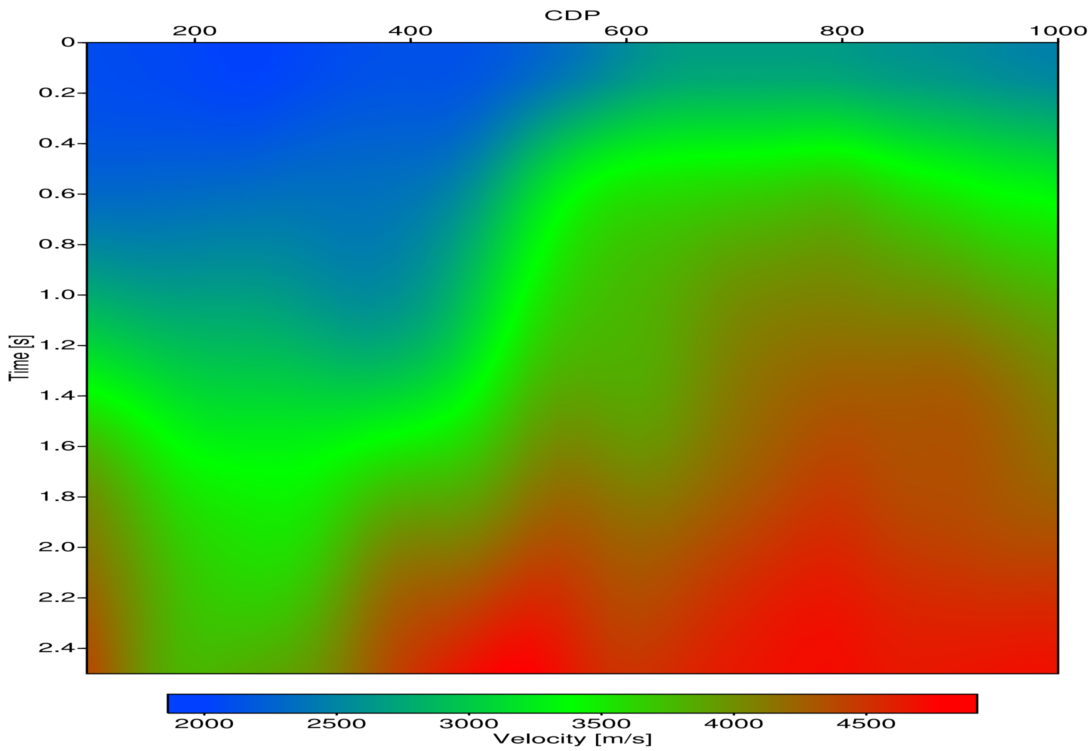

Figure 2: Stacking Velocity model resulting from the conventional processing.

In both cases we have used the same size of apertures in offset and midpoint coordinates, and the same time window size for coherency. To improve the result with the CRS multi-steps implementation several tests were performed to define an appropriate fixed interval for the stacking velocities, necessary in the first step or automatic CMP stacking. But even so, due to very low-fold of the dataset, this CRS stack implementation provides a result that is inferior or worst than the ZO section obtained by the conventional CMP stack method (Figure 1). We can see that ZO section resulting from CRS multi-step has low quality with absence of seismic events especially at the upper part. In contrast to the previous result, the ZO section obtained by one-step implementation has better quality, with seismic events better-defined in the whole section, but with the presence of coherent noise that interfere with some reflection events. Despite of the presence of such artifact related to coherent noise, we consider that this result has better quality and it shows events with better defined lateral continuity than the ZO stacked section obtained by CMP method.

By using the stacking velocity model showed in Figure 2 as reference function in searching the R_{NIP} parameter, we apply the multi-step and one-step CRS stack implementations whose results are shown in the Figure 5 and Figure 6, respectively. In both cases, it has used similar factors to compute the stacking velocity range from the reference stacking velocity function, to constrain the interval of searching the Rnip parameter. Comparing the last two results, we found again that the ZO section of the CRS one-step has better quality and it show the reflection events with better lateral continuity, mainly in the upper part of the section. In some parts, such as where you have events with strong dips, we can also observe some seismic events that do not appear in the ZO section of the CRS multi-step. In both results the coherent noise are attenuated.

CONCLUSIONS

The use of geological information as constraints in the automatic search of the CRS stacking parameter is an important problem to be solved for the CRS method. Also the CRS stack algorithm based on simultaneous search of the three CRS stack parameter is another important issue in the CRS method. In this work we have addressed both problems.

We apply in real land data with low-fold the well know CRS stack implementation based on “extended pragmatic search strategy” (multi-step) and the CRS stack based on “simultaneous global search strategy” (one-step). Both CRS implementations have the option to use the stacking velocity as a reference function to restrict the search interval to the Rnip parameter. The application of the CRS stack in low-fold dataset may provide results with low quality, especially the multi-step implementation whose result is less than the conventional CMP stack method. When the CRS multi-step uses the information of the stacking velocity, their result greatly improves. But due to the imprecision of the stacking velocity information and others factors, the CRS multi-step shows some limitation, mainly in stacking the events with steep dip, where there is strong lateral velocity variations. The CRS one-step, even without a priori information in searching the Rnip parameter, produces a result with high signal-to-noise ratio and well-defined events mainly in the deep part of the ZO section and where there events with strong dips. Finally, we show that the CRS one-step that incorporates the stacking velocity information, produces the best result even in the upper part of the ZO stacked section, where the coherent noise were interfering events of interest as observed in the result of the CRS one-step without any constraint.

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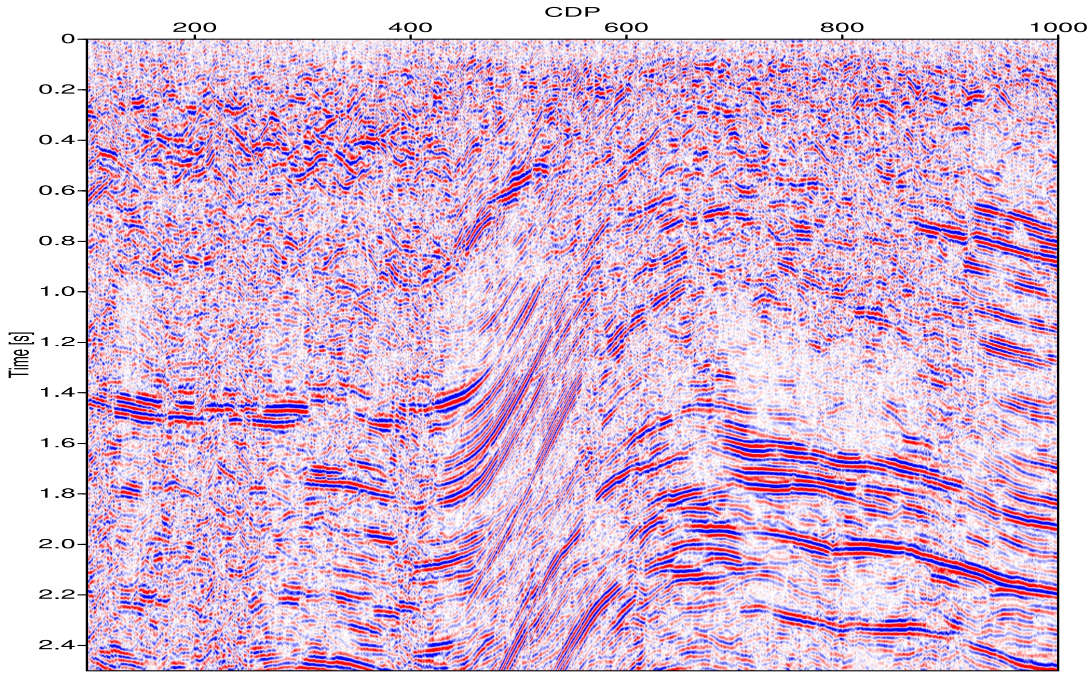

Figure 3: ZO stacked section obtained by the multi-step CRS stack without using the staking velocity.

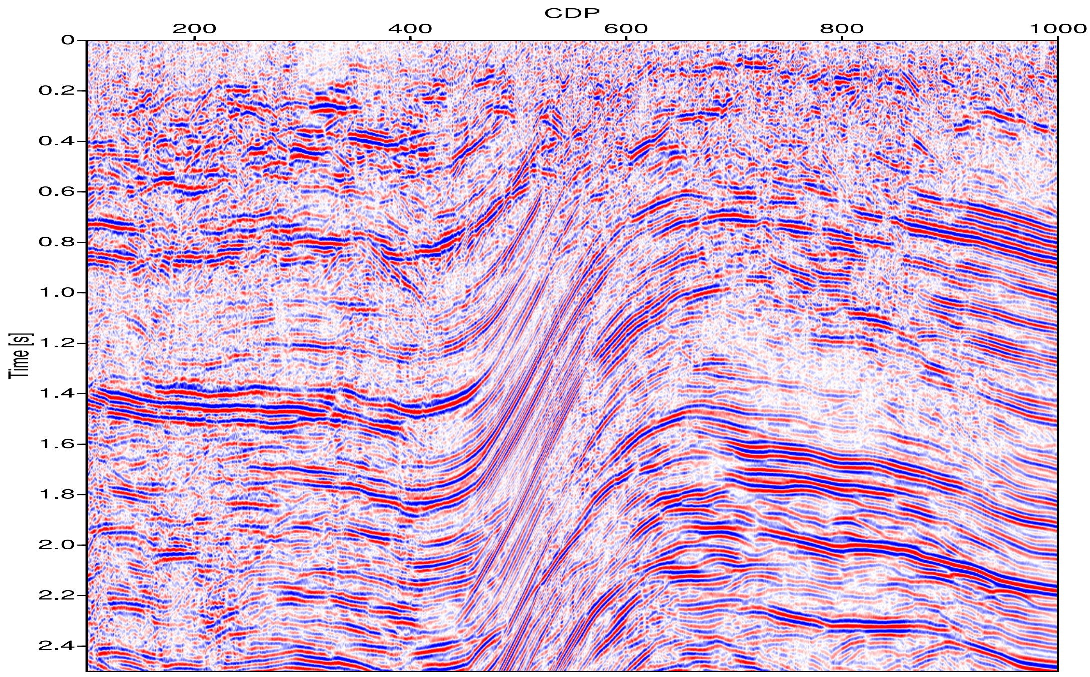

Figure 4: ZO stacked section obtained by the one-step CRS stack without using the stacking velocity.

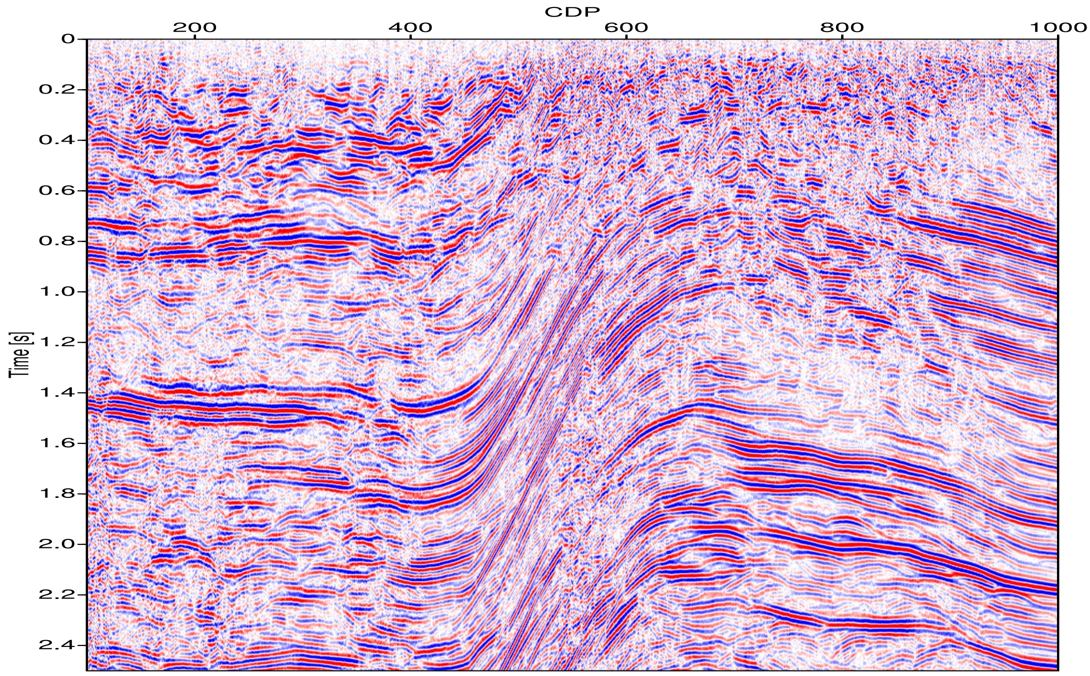

Figure 5: ZO stacked section obtained by the multi-step CRS stack using the stacking velocity.

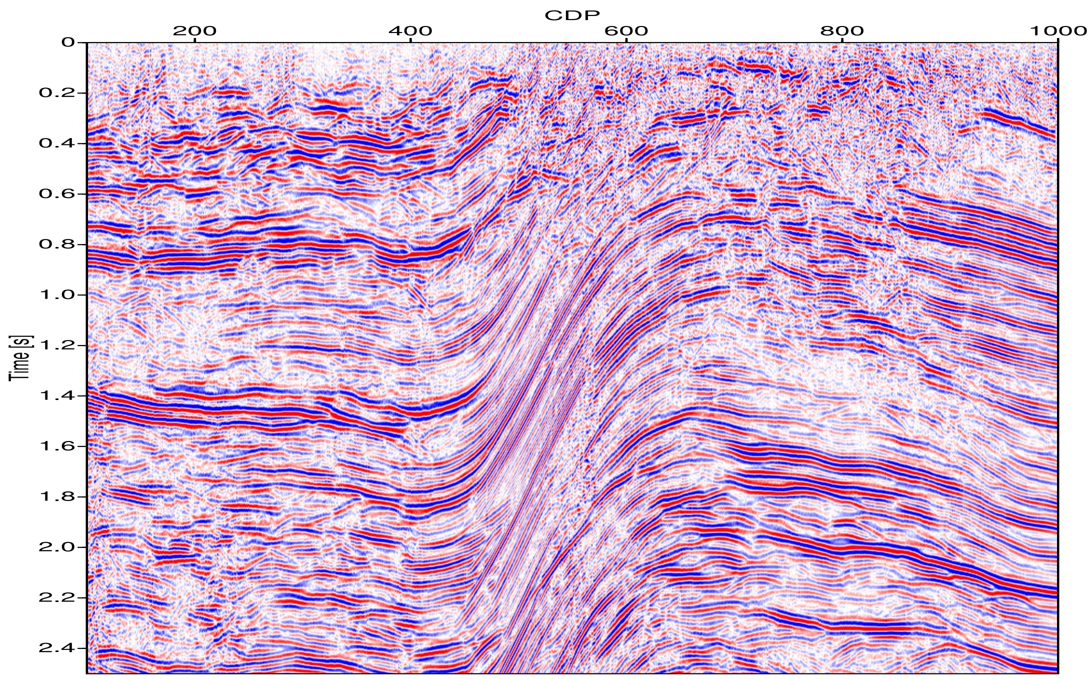

Figure 6: ZO stacked section obtained by the one-step CRS stack using the stacking velocity.

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