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INTEGRATED TECHNIQUES FOR DETERMINING THE VELOCITY FUNCTION IN THE SEISMIC REFLECTION: EXAMPLE OF LOW SIGNAL-TO-NOISE DATA

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ABSTRACT. In the hydrocarbon exploration activities, the reprocessing of old seismic reflection data, acquired with few channels and with low signal-to-noise ratio, is commonly undertaken to ameliorate the quality and reliability of the seismic images. In this context, a crucial and preponderant step to any data processing is the seismic velocity analysis of wave propagation, which is employed in several essential steps of the processing flow. However, the velocity analysis can become much more complex and expensive due to the low data quality motivated by the small number of receptor channels employed during acquisition. This work demonstrates the use of several techniques integrated simultaneously, to achieve the best, closest to real, velocity field. Despite the increase in total processing time, the method used here, making use of data with a small number of channels, was effective to discriminate the real field velocities, and to reduce uncertainties related to the quality of the processed data.

Keywords: seismic processing, velocity analysis, CVS.

RESUMO. É comum na exploração de hidrocarbonetos o reprocessamento de dados sísmicos antigos, por vezes com um baixo número de canais e baixa razão sinal/ruído, com o objetivo de gerar uma imagem de melhor qualidade e confiabilidade quando comparada àquelas já existentes. Neste contexto, um passo crucial e preponderante para qualquer processamento de dados é a análise da velocidade de propagação das ondas sísmicas que é empregada em vários passos essenciais do fluxo de processamento. Durante o reprocessamento, muitas vezes a análise de velocidade torna-se muito mais complexa e dispendiosa devido à baixa qualidade dos dados, em alguns casos, motivada pelo pequeno número de canais de receptores utilizados durante a etapa de aquisição de dados. Este artigo demonstra o uso de várias técnicas utilizadas de forma simultânea e integrada para alcançar resultados mais próximos do campo de velocidades real. Apesar do aumento do tempo de processamento total, a estratégia aqui empregada foi eficaz para discriminar o campo de velocidades real e reduzir as incertezas relativas à qualidade dos dados processados.

Palavras-chave: processamento sísmico, análise de velocidades, CVS.

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INTRODUCTION

According to Yilmaz (2001), the seismic exploration can be divided into three consecutive stages: acquisition, processing and interpretation of data. The processing step, in particular, helps to produce images with the highest similarity as possible to real geological, and petrophysical properties of the study area and, consequently, a significant level of trustworthiness to the interpretation.

Often during the process of hydrocarbon exploration, the presence of obstacles or noise, generated in oil platforms in the neighboring fields, impedes new seismic survey activities and can compromise the quality of new data. In these cases the reuse of old seismic data, frequently with a low number of channels and low signal-to-noise ratio is necessary.

The present study aims the detailed analysis of the velocity field for data with low signal-to-noise ratio. Similarly, the strategy used here can be employed in a wide variety of processing flows, and can help to increase the quality of the resulting image. For this purpose, five techniques of velocity field analysis were used to find the closest similarity as possible between the estimated field and the real field of seismic velocities in the subsurface. The paper also examines the implications of this process at different stages of the seismic data processing flow, such as spherical divergence correction, deconvolution, F-K filtering and migration.

DATABASE AND METHODS

For the present work, two parts of a seismic line located on the Rio de Janeiro State continental shelf, in southeast Brazil were used (Fig. 1). These lines were acquired by the Institute of Geophysics of the University of Texas (Austin) in 1979 and currently both are available for academic use. The WSA-01 PART A and WSA-01 PART B lines have 133.2 km and 198.1 km of extension, respectively.

The acquisition parameters of the seismic lines, according to Barker et al. (1983) and Gamboa et al. (1983) are described in the following table.

The low resolution quality and the low S/N ratio of seismic data can be directly attributed to the low number of channels, in the survey (implying a low fold). The presence of salt and halokinetic deformation also contributed significantly to the low quality of the data. These factors imply a greater complexity in the data processing and an increased difficulty in performing certain steps, such as the velocity analysis.

Seismic processing was performed with academic licenses of the software ProMax/SeisSpace version 5000.0.3.0., available at the Geophysics Department of the Federal University of Rio Grande do Norte (UFRN) by Halliburton/Landmark Software & Services, under grant contract.

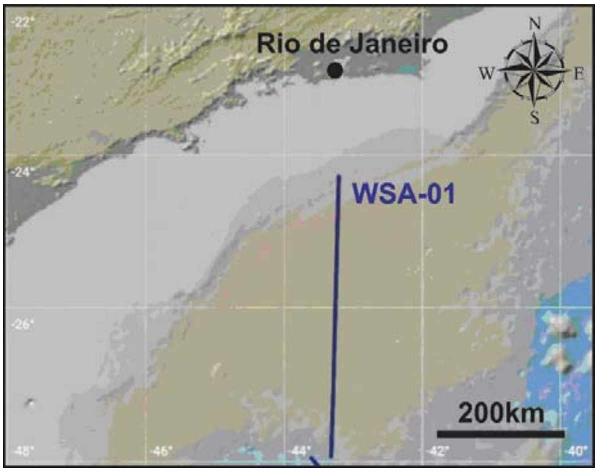

Figure 1 – Location of seismic line.

Typically, the velocity analysis is done using the technique of velocity spectrum, known as semblance. The main factors affecting the quality of the velocity analysis are: the low signal-to-noise ratio, the low multiplicity of the data, the spread length, and the complexity of the geology among others. As mentioned before, the seismic lines used in this study have a low number of channels when compared with current acquisitions and a great geological complexity, which provides a low S/N ratio and therefore, a great difficulty to perform the interpretation of the velocity field in an integrated way. Hence, it was necessary to develop a method to increase the trustworthiness of the velocity analysis. The methodology employed several techniques of velocity analysis simultaneously, in order to reduce the uncertainty affecting the correct analysis of the velocity field. Five different techniques were integrated as described below:

a) **Semblance** – This technique is based on the analysis of the coherence factor of CDP's families. The larger this coherence factor, the more efficient will be the corresponding velocity value to correct the effect of NMO. This coherence factor is given by the following equation (Duarte, 2011):

$$C(t,v) = \frac{\left[\sum_{j=1}^{n} A_j\right]^2}{\sum_{j=1}^{n} A_j^2} \qquad (1)$$

where T is the reflection time; V is the velocity for NMO correction; n is the number of samples added and A_j the amplitudes of the CMP data. From this, it is possible to plot picks to indicate the most suitable velocity for each event.

Table 1 – Description of the main acquisition parameters of WSA-01 PART A and WSA-01 PART B lines.

Parameters	Seismic lines	
–	WSA-01 PART A	WSA-01 PART B
Shot number	2654	3994
Shot interval (m)	50	50
Number of receivers	24	24
Spacing between receivers (m)	50	50
Minimum Offset (m)	316	316
Maximum Offset (m)	1466	1466
Fold	12	12
CDP interval (m)	25	25
Line length (km)	133.2	198.1

b) **CVS (Constant Velocity Stack)** – This technique consists in submitting the seismic data to a series of horizontal stacks. Each stack is made using constant velocities throughout the whole data, thereby generating numerous "zero offset" seismic sections, each section referring to a single velocity value of NMO correction. Thus, it is possible to associate the correct seismic velocity with the best amplitude of the stacked data. In order to allow direct verification of the continuity of events, this technique is especially useful for regions with complex geology (Yilmaz, 2001).

c) **CVP (Constant Velocity Panel)** – Is based on the NMO correction for groups of constant velocity, however, applied to panels of CDP's families. This technique allows to indicate the most appropriate velocity for each region of data by the direct verification of the level of horizontal correction of each event from the shallowest to the deepest.

d) **Hyperbola fitting and NMO correction** – Consists of fitting a hyperbola to events of a CDP family, or to apply the NMO correction for each reflection according to the adopted velocity (Fig. 2). This process is usually performed together with the semblance and the CVS.

e) **Superposition of seismic sections over velocity fields** – Allows to superimpose the seismic section on the interpreted velocity field to make use of the effects of the opacity and transparency. This technique enables to verify the relationship between the geophysical events and interpreted velocity field exerting an important function, mainly in the data quality control.

RESULTS

As illustrated in the flow chart (Fig. 3), three velocity analysis were made throughout the processing increasing the quality of the data.

The first velocity analysis was mainly applied to the correction of spherical divergence. The second analysis was designed to attenuate the multiple reflection first order events. In particular, the fk filtering process makes use of the velocity field to separate the primary reflection events from multiple, with the plunge as the discriminatory criterion. This discrimination is based on the velocity of each event. It is important to emphasize that the velocity discrimination can be done for multiple, intermediate or early reflections. In the present work, this velocity analysis was performed in relation to primary events due to lack of consistency for multiple events during the process of interpretation of the velocity field. The third velocity analysis aimed at providing the highest possible quality for the NMO correction and migration, in order to get the correct (or more precise) positioning of events.

The interpretation of the velocity fields was divided into three steps, described below.

- Viewing CVS panel to help determine the velocities for each region of data.
- Semblance analysis in combination with CVP (Constant Velocity panel) panels and automatic NMO correction or adjustment of hyperbola.
- Superposition of the seismic velocity fields over the seismic sections.

The first and second steps were performed simultaneously, from the identification of events in relation to time and number of CDPs, allowing the simultaneous use of four techniques for

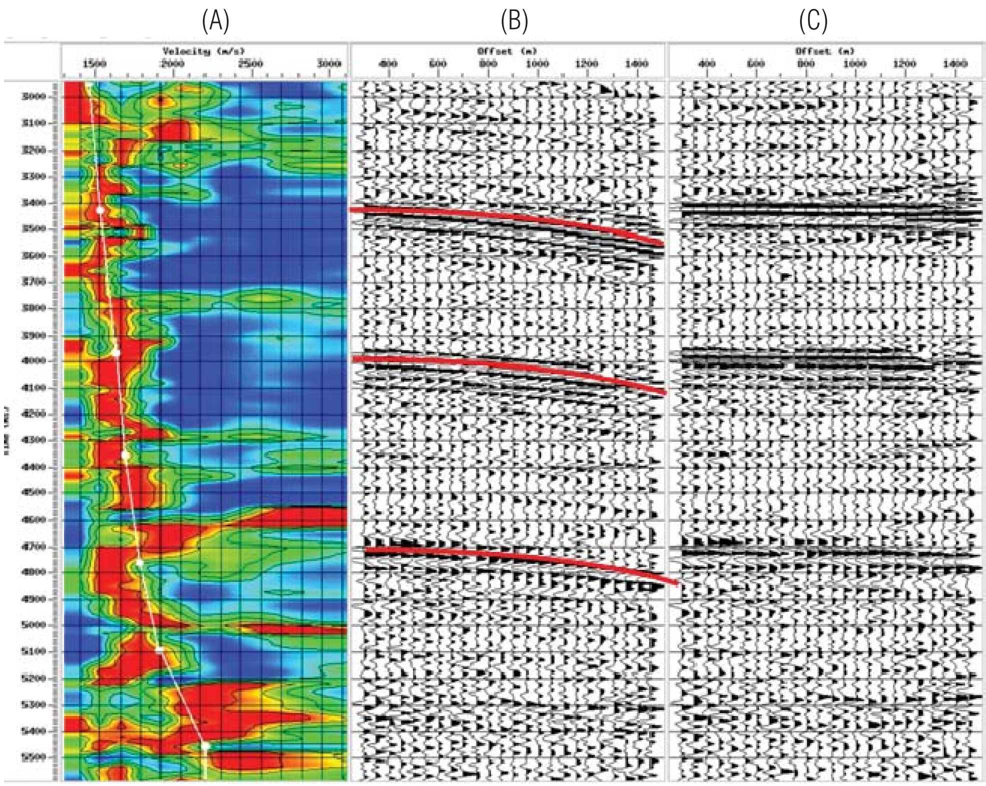

Figure 2 – Interpreted panel of velocity analysis. A) Semblance panel B) Automatic NMO correction C) Corrected NMO panel.

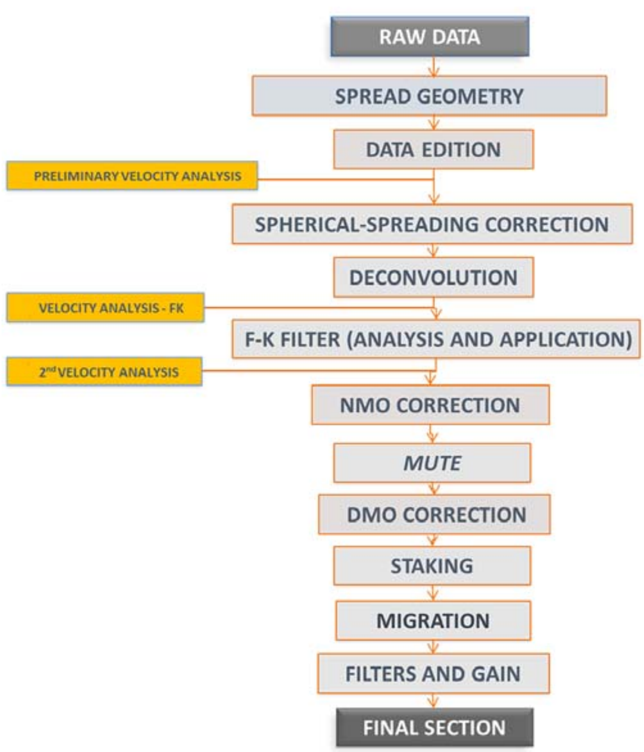

Figure 3 – Basic flow chart of seismic processing emphasizing the processes of velocity analysis.

the same point of data. The last step was used subsequently and served mainly as quality control.

In seismic line WSA01 PART A, the best stacking velocities for the region between 3000 and 4000 ms, using the CVS technique, were in the range from 1600 to 1700 m/s. For lower velocities, the reflectors were displaced and lost definition and for higher velocity values, the shallower reflectors are strongly attenuated (Fig. 4).

In the regions affected by salt deformation, better image definition was attained with velocities around 1760 m/s (Fig. 5). The first order multiple seafloor reflection is strongly apparent for velocities between 1400 and 1800 m/s, but was much attenuated on the CVS panel for velocities above 1700 m/s (Figs. 4 and 5). More appropriate interval velocities were picked during the semblance analysis, taking into consideration the careful examination of the CVS panels.

The discrimination of the velocity field was performed in order to get a satisfied automatic NMO correction panel. It is possible to check this relationship in Figure 6, which shows the effect of NMO correction on the seismic traces after picking the velocities for the CDP 2394, indicated by the red line in Figure 5.

After the completion of all the procedures described above, it was finally possible to obtain a satisfied interpretation of the velocity field. This interpretation was interpolated, and generated an image which was superimposed on the seismic section, allowing a qualitative assessment of the degree of correspondence between the seismic events and the interpretation of the velocity field along the CDPs (Fig. 7).

From the analysis of this superposition, it was possible to note a strong velocity increase above 5800 ms, and also a strong lateral variation of velocities, as shown in Figure 7. These observations are possibly related to the occurrence of salt and halokinesis. Figure 7 allows to verify the consistency of the lateral and vertical velocities distribution in comparison with the main seismic events, providing a means to verify the properness of the velocity model.

Figure 8 shows eight examples: The first four examples (A1, B1, C1, and D1) were obtained from conventional velocity analysis, using only semblance, CVP and automatic NMO correction. The other four examples (A2, B2, C2 and D2), were obtained after applying the processing flow described in this paper. It is worth to note the better definition, continuity and positioning of the seismic events, after applying the processing flux proposed herein.

A similar procedure was adopted to re-process seismic line WSA-01 PART B. The CVS's panels confirmed better results for velocities around 1600 m/s in the range of 3000 to 4000 m/s (Fig. 9). Above this velocity range, considerable decrease of definition were exhibited, especially for values above 1750 m/s. Above 2000 m/s, no region of the data had a good stack. For the depths between 4500 and 5200 ms and between CDPs 5500 and 7300, the best stacking velocity is near 1800 m/s (Fig. 10). It was

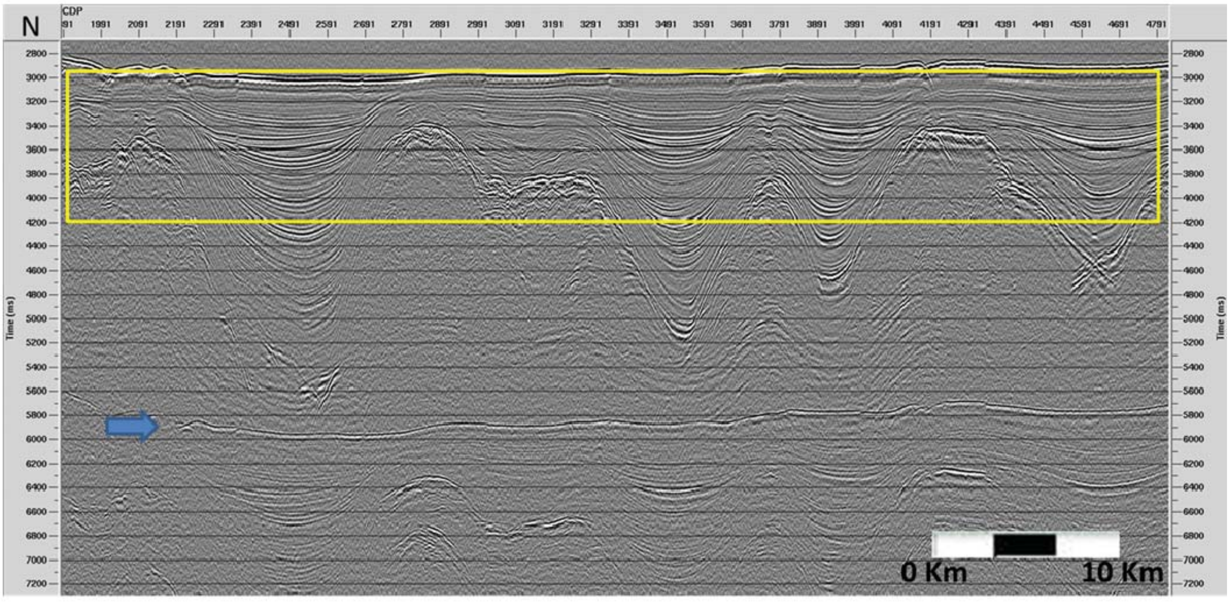

Figure 4 – CVS panel showing a partial area of the data for a constant velocity of 1600 m/s. The yellow rectangle shows the region between 3000 and 4000 ms, where the better stacking velocities are in the range between 1600 and 1700 m/s. The blue arrow indicates the first order multiple of the seafloor.

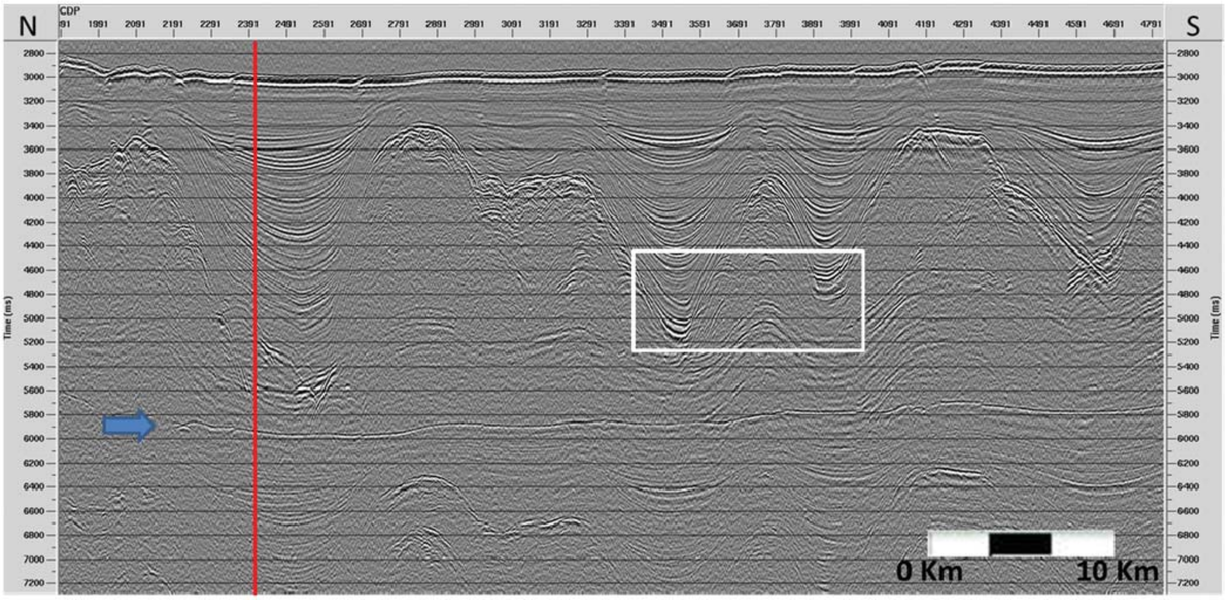

Figure 5 – CVS panel showing a partial area of the data for a constant velocity of 1760 m/s. The white rectangle indicates the area affected by salt deformation where the appropriate stacking velocities are in the order of 1760 m/s. The blue arrow indicates the first order multiple of the seafloor. Observe that the multiple reflector is much attenuated as in comparison with Figure 4. The red line indicates CDP 2493 illustrated in Figure 6.

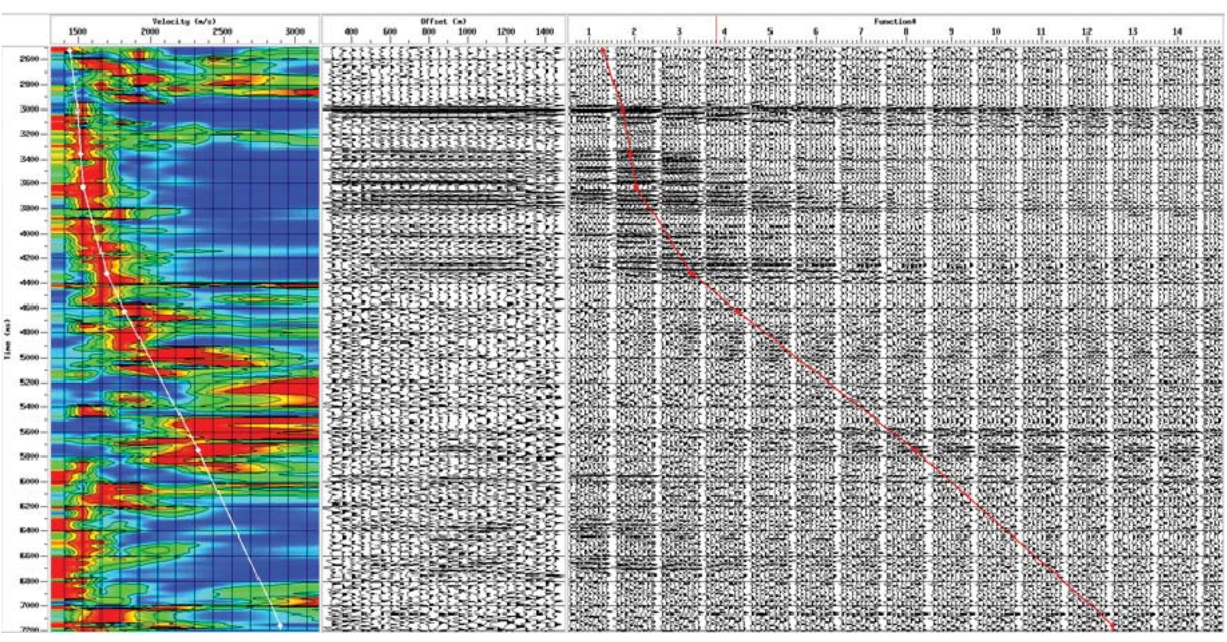

Figure 6 – Integrated panel of Semblance (A), NMO correction (B) and CVP (C) for the CDP 2493 (shown in red in Fig. 5) with interpretation of the velocity field.

also possible to discriminate velocities that best imaged diffractor points of hyperbolic events and therefore obtain a satisfactory result in an attempt to collapse these events during the migration phase.

The CVS also made possible to extract information regarding multiple events, which were more easily visualized in the range between the velocities of 1400 and 1700 m/s. Figures 9 and 10 show, respectively, CVS panels for velocities of 1600 and 1800 m/s, where it is possible to see the effect of the velocity variations along the data.

After analyzing the CVS panels, we performed the semblance and CVP analysis and the automatic NMO correction. The

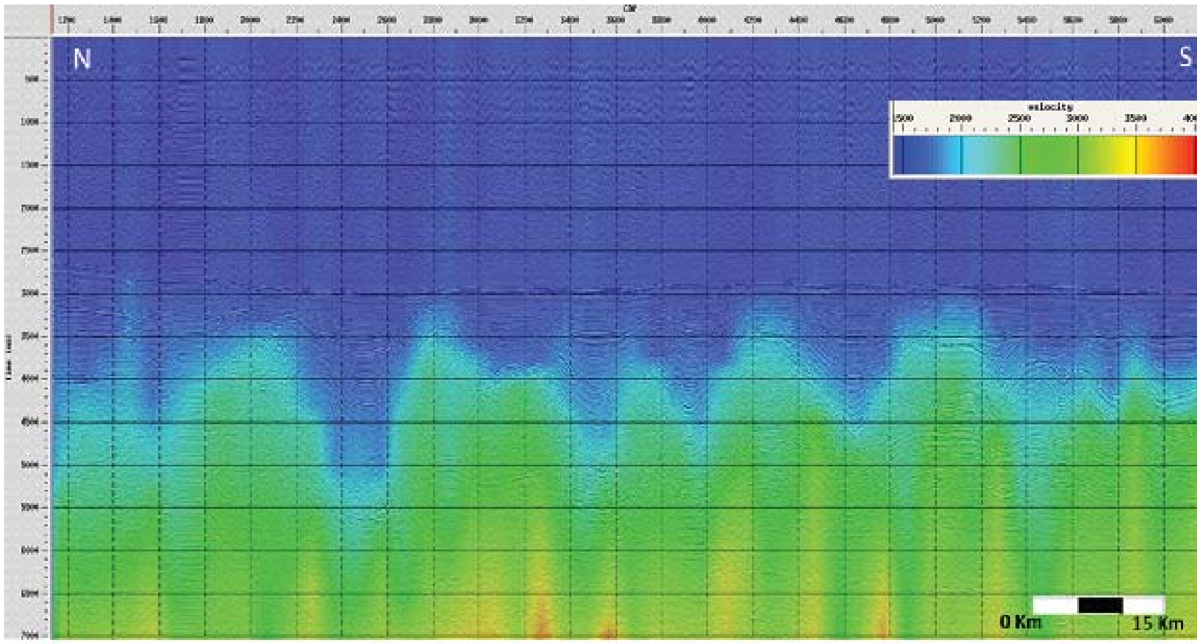

Figure 7 – Superposition of a seismic section on the velocity field showing great lateral variation of velocity and positive correlation between the velocity field and seismic events.

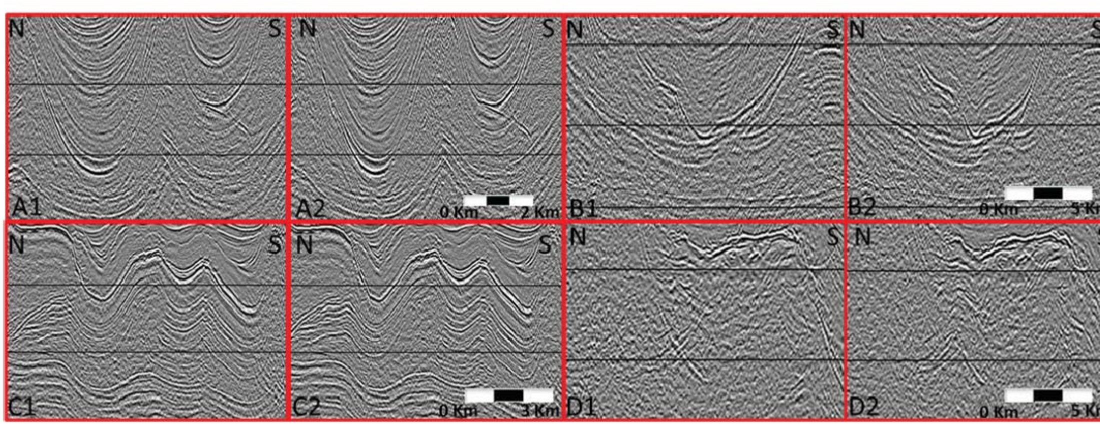

Figure 8 – Comparative examples. Where the examples A1, B1, C1 and D1 were based on the conventional method of velocity analysis. The examples A2, B2, C2 and D2 were defined based on the methodology proposed in this paper.

semblance analysis alone could not define the precise time of the events, including the ocean bottom, due to the inaccuracy data coherence. After the CVP analysis and NMO correction, it was possible to define the precise time for each event, including the ocean bottom, at 3400 ms in CDP 3294 (Figs. 10 and 11). Figure 12 shows the velocities field superimposed on one seismic section helping to validate the interpretation.

Finally, Figure 13 shows the comparison of three examples (A1, B1, and C1) which have used the conventional velocity analysis employing. Semblance, NMO correction and CVP with three other examples (A2, B2 and C2), applying the methodology adopted in this work (semblance, automatic NMO correction, CVS, CVP and superposition). This comparison shows a significant improvement in the amplitude of the events, as well as an increase in the definition and continuity of reflections.

CONCLUSION

The simultaneous integration of various processes for the analysis of the velocity field proved to be very efficient in the reduction

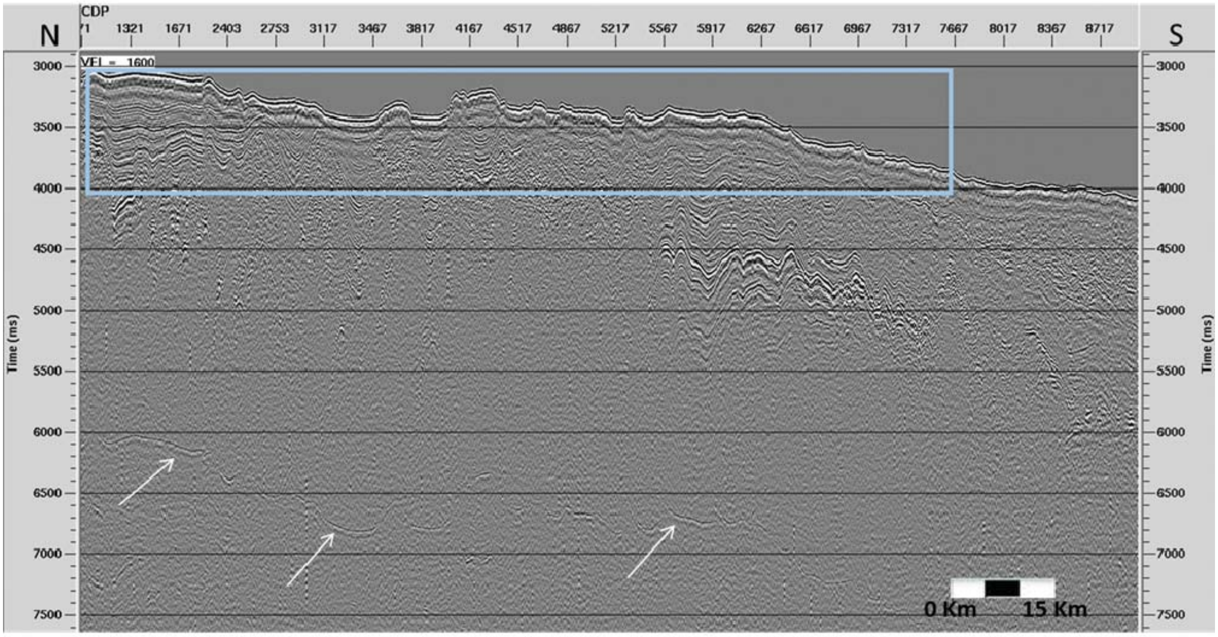

Figure 9 – CVS panel showing a partial area of the data for a constant velocity of 1600 m/s, where the rectangle indicates a region with good results of stacking between 3000 and 4000 ms. The arrows indicate the first order multiple of the seafloor.

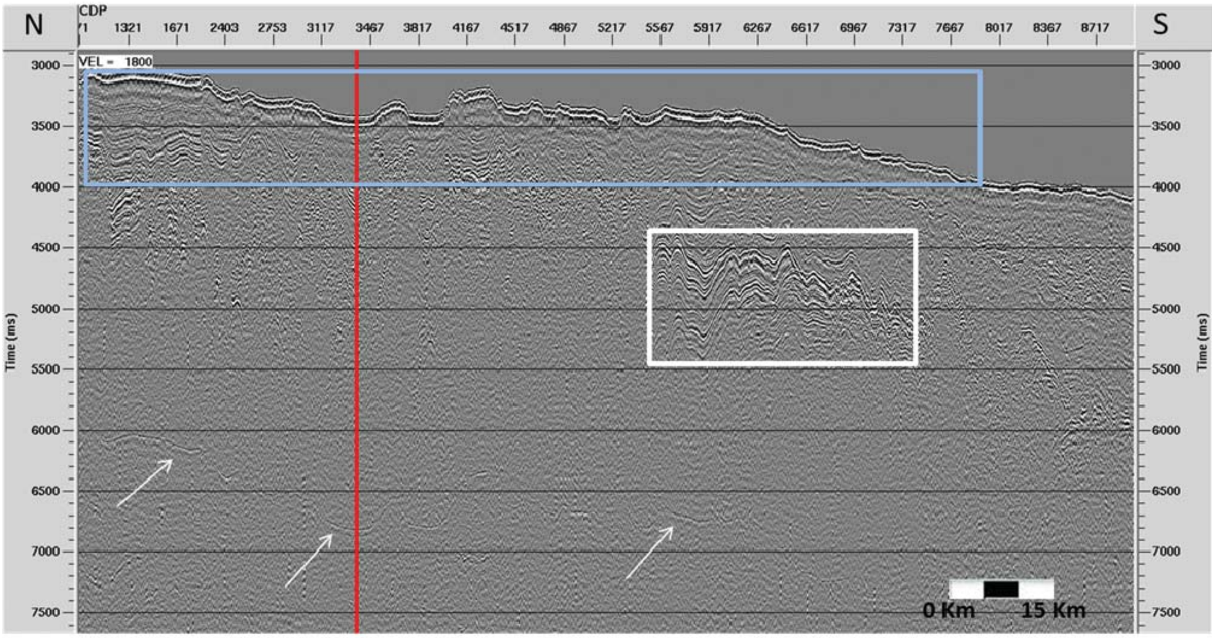

Figure 10 – CVS panel for a constant velocity of 1800 m/s. The white rectangle indicates a region with good stacking results between 4500 and 5200 ms and on CDPs 5500 and 7300. One can also check the attenuation of multiple events (indicated by white arrows) and shallower events (indicated by the blue rectangle) in comparison with Figure 9. The CDP 3294 is indicated by the red line.

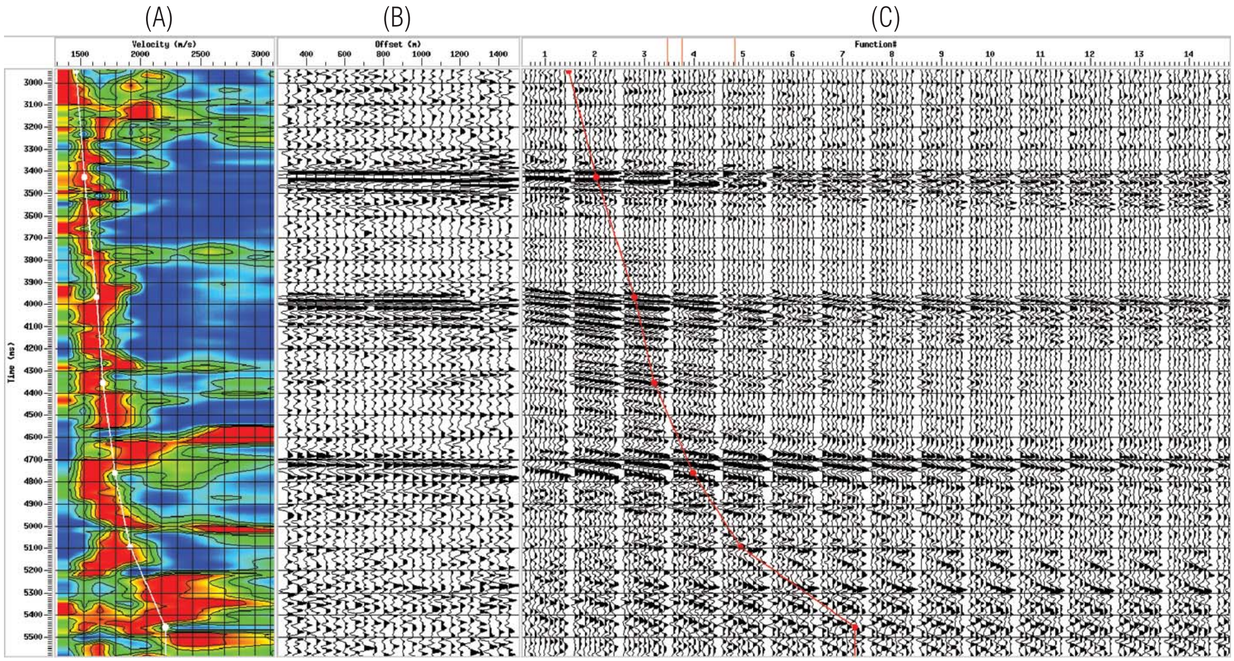

Figure 11 – Integrated panel of Semblance (A), NMO correction (B) and CVP (C) for the CDP 3294 with interpretation of the velocity field.

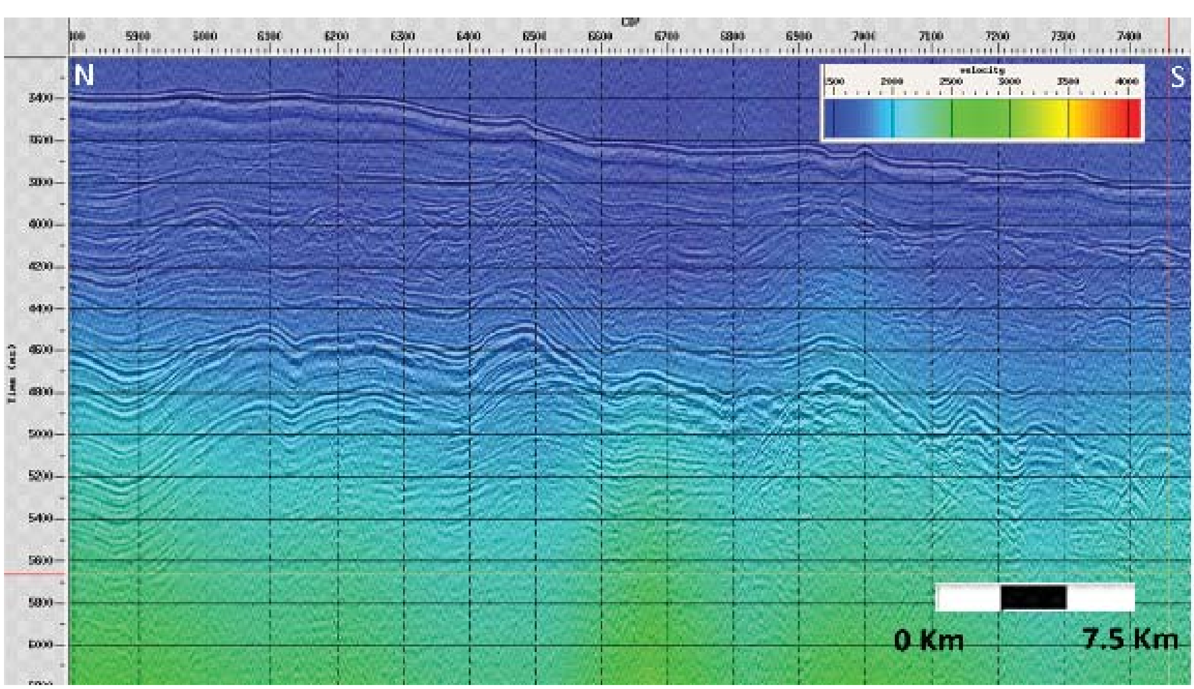

Figure 12 – The superposition of the velocity field over the WSA-01 PART B seismic section.

of interpretative ambiguities generated, particularly, when working in data with low S/N ratio and low multiplicity.

The use of multiple techniques together, also allowed to decrease the inaccuracy of information provided by an individual technique. As shown in the examples provided prominent information extracted from CVP and NMO correction panels were able to provide an estimate of the location of reflections related to the seafloor with respect to time, which could not be estimated using

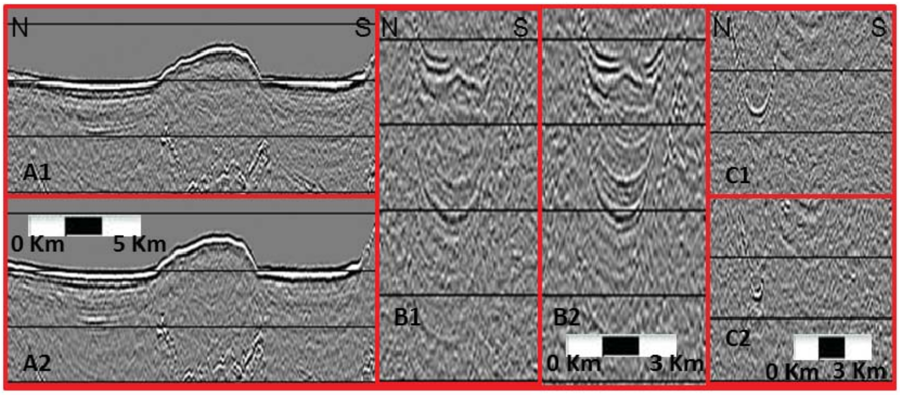

Figure 13 – Comparative examples where A1, B1 and C1 were processed with the conventional velocity analysis and the examples A2, B2 and C2 using methodology proposed in this paper.

only the content of information provided by the semblance panel. These estimates were confirmed with the CVS's panels, which offered the best velocities to define the position of the seismic events.

The superposition of the velocity field and the stacked seismic data contributed to a more careful analysis of the results obtained during interpretation, facilitating the quality control and contributing to the validation of the results obtained during discrimination of the velocity field.

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