Influence of Topography and Low Velocity Layer on Seismic Imaging

Clériston Silva Gama,* CPGG/IGEO/UFBA, Milton José Porsani, CPGG/IGEO/UFBA & INCT-GP/CNPq/MCTI, Manoel Gontijo dos Santos, PETROBRAS S.A. and Wilker Eduardo Souza, CPGG/IGEO/UFBA.

Abstract

This work analyzes the effects of static field corrections and residual correction, and when this can be neglected, by comparing the results of modeling and processing of synthetic seismic data. Both direct modeling and processing were done using ProMAX/SeisSpace software. During processing, the following steps were applied: geometry, editing, static corrections, velocity analysis, stacking and residual static corrections. In the modeling phase, models were created in different situations to analyze the influence of static corrections, a very important step for the processing of land seismic data. The results show how impaired the seismic section is in terms of different degrees of variation of the topography and the thickness of the weathered layer.

Introduction

The static correction is fixed time correction which is applied to the traces in a common mid point (CMP) gather. It represents the most trivial process, with respect to distortions in the travel time associated to superficial layers and to vertical time displacements in the seismic traces of a CMP gather, that are similar to an acquisition done with constant elevation. The precise determination of static correction is one of the most important problems to be solved in land seismic processing (Cox, 2001). This correction was more used over time and its algorithms has been improved. Besides, several other methods have also been created. In general, the upper part of the earth's crust corresponds to the outcrop composed by rocky material with variable thickness, that is laterally heterogeneous and, through it, the seismic wave velocities are very low. Therefore it is known as the main factor of large distortions in the elastic waves and that is why the precisely determination of its characteristics, in order to develop increasingly effective methods to reduce its effects on seismic data, is a recurrent theme of study. This part of the earth's crust is called as Low Velocity Layer (LVL), Low Velocity Zone, Weathered Zone or even Heterogeneous Superficial Layer and it is constituted by rocks, which were totally or partially decomposed by the action of several types of weathering (physical, biological or chemical), that cause significant changes in their original elastic properties. A static correction corrects the errors associated to the LVL thickness, in a way which the data is approximated as if the acquisition had been performed on a flat surface or datum. In order to do that, information such as the velocity of the layer that is below the LVL, the shotpoint elevation, the receivers point elevation, the LVL's thickness and velocity, are necessary. The LVL by itself does not represent a problem because problems occur due to the variability of the thickness and velocity of the layers close to the surface, and due to our difficulty in properly defining the variations or compensating them (Marsden, 2007). On the other hand, the more abrupt the lateral and vertical velocity variations in the LVL, the greater the degradation and distortion effects on the seismic section quality, which influences the imaging accuracy of the underlying geological structures.

The high redundancy of the common depth point (CDP) technique related to the seismic acquisition foment the process of determining the static corrections because it consists in a problem in which there are more available equations than unknowns. Therefore, sophisticated algorithms can be applied to solve the problems. In many cases, the application of a secondary process of static correction is convenient: that is the residual static correction, which is done in the advanced processing in order to increase the accuracy of the applied field corrections.

Static Corrections

There are static field corrections and residual static corrections and these must be applied to the data seismic data in order to adjust two problems that are intrinsic to the acquisition, but that cause undesirable effects in the data. One problem corresponds to the topography variation, which changes the seismic wave travel time. Also, the LVL attenuates the signal and delay the seismic waves travel time. This poorly consolidated layer causes a strong attenuation in the seismic wave propagation because the LVL represents a very dispersive and heterogeneous medium, what causes displacements in the arrival times of the deepest reflections. If no correction is made, this fact can deteriorate the seismic sections quality, and it may compromise the investment, as it complicates the results interpretation, or even induces to misinterpretations (Gama et al., 2016). To make it clear, it is worth noting that the LVL mentioned here is not the same as the LVZ from Geology, that corresponds to a zone with hundreds of kilometers, that goes from the base of the lithosphere to part of the asthenosphere. For us, it represents a layer in the upper part of the earth's crust with a maximum of hundred of meters of thickness, and where the seismic wave velocities vary from 200 to 1500 km/s (Gama, 2016).

The static field corrections are applied in the preprocessing and it corrects the effects of LVL's weathering, topography variations and the effects of topography on the seismic waves travel times. On the other hand, residual static corrections, as well as the process of residual velocity analysis, is applied in the advanced processing steps and it takes into account the definition of the superficial consistency that states that the same static correction of a shot, in a given superficial position, must be the same independently of the positions of several receivers. Similarly, the static correction of a receiver, in a given position, must be the same for the signal that comes from various shot points.

Figure 2 shows what happens when static corrections are not applied and its consequences in stacking. When the errors produced by the lateral heterogeneities of the LVL have small extension in relation to the extension of the arrangement, they are named as short-period components. These errors make the stacking velocities determination difficult and it compromises the quality of the reflections. In contrast, long-period components, that are produced by lateral heterogeneities bigger than the arrangement extension, can create fake structures or mask true structures, as they cause distortions in the structural interpretation in subsurface, as we will see ahead. The methods of determining the static correction must be capable of defining both the short-period and long-period anomalies.

Therefore, static corrections have two components according to their basic objectives:

1. Static corrections due to weathering or refraction: It corrects the static errors that are caused by the thickness variation of the LVL.

2. Static corrections due to elevation : It correct the static errors that are provoked by elevation changes in the surface that contain the sources and receivers along the seismic line. It takes all the seismic data for a reference *datum*.

In seismic data processing, the static corrections are made in two different moments, as it was already stated:

1.Field static corrections: It corresponds to the first application made in the field data in order to simulate the result obtained as if the source and receivers were in the same *datum* and it includes the errors caused by the LVL variation. Then, it is composed of both elevation and refraction/weathering corrections.

2. Residual static corrections: It is applied in order to correct the unsolved errors by the field static corrections.

Field static corrections

The static correction corresponds to a vertical displacement in time that is applied to the seismic trace in order to eliminate the delay in the reflection, which are generated by the LVL's variations in topography and in thickness. The computation of these times is always done in relation to a level called as *datum* and it simulates the effect of the displacement of the source and the receiver in direction to this *datum*. Hence, depending on the choice of positioning of the reference level, the times that represents the statics can be added or subtracted from the seismic traces. They are added when the *datum* is above the line of sources and receivers and they are subtracted when the chosen *datum* is below the line of sources and receivers.

The static corrections are calculated by assuming that the trajectory of the reflected ray is vertical, directly below any source or receiver. Then, the ray travel time is corrected for the time taken to travel the vertical distance between the elevation of the source or receivers and the desired final *datum*.

Figure 1 illustrates the total field static correction calculation for a seismic trace. For each trace, there are two displacements. One corresponds to the source position T_f and the other corresponds the position of the receivers T_r. Therefore, the total field static static correction is expressed as

$$\Delta t = T_f + T_r \tag{1}$$

Considering the model shown in Figure 1, the components T_f and T_r are given by, respectively:

$$T_f = -\frac{E_{1f}}{V_1} - \frac{E_{2f}}{V_2} \tag{2}$$

$$T_r = -\frac{E_{1r}}{V_1} - \frac{E_{2r}}{V_2} \tag{3}$$

where

- E_{1f} corresponds to the distance between the source and the base of the LVL;
- E_{1r} corresponds to the LVL thickness, at the refractor position;
- E_{2f} is the vertical distance between the base of the LVL and the *datum*, at the source position;
- E_{2r} is the vertical distance between the base of the LVL and the *datum*, at the receiver position;
- V_1 corresponds to the seismic wave velocity at LVL;
- V_2 is the seismic wave velocity at the layer below the LVL.

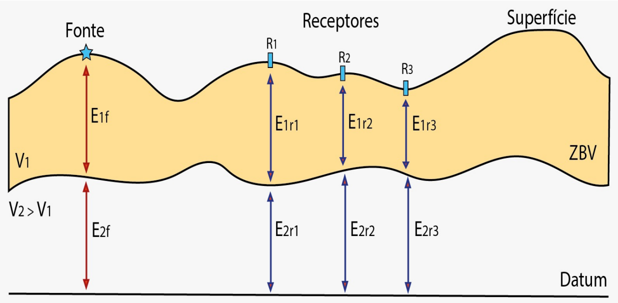

Figura 1: Exemplified model for the total field static correction calculation (Modified from Souza, 2016).

Residual Static Correction

Some static errors are not totally corrected during the field static corrections process and they are clearly observed after the application of the normal moveout (NMO) correction, where the reflection must have a perfect alignment, what can be seen in Figure 2b.

Softwares calculate the mean velocity of the first breaks that are restricted to the refractor selecter during the

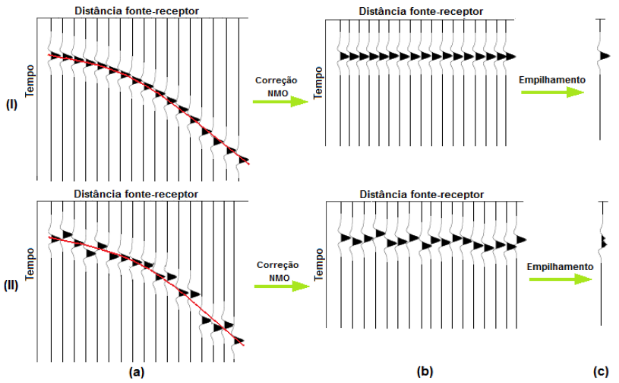

Figura 2: (I) Without LVL and topography's effects (II) With LVL and topography's effects.(a) CMP gather traces; (b) Effects of the separation between source and receptor corrected (*Normal Moveout*=NMO) e (c) Stacking in order to produce the seismic trace that simulates the zero offset (Modified from Cunha, 2010).

picking, which allows the user to apply a suitable time displacement. In this way, it removes the delay originated by the LVL. The majority of the algorithms that are used by the processing companies in order to calculate the residual statics are based on the superficial consistence that are applied to the static errors. When it is associated to the redundancy related to the data acquired from CDP, the success of these process is assured.

The basic goal of the residual static correction is to correct small effects produced by the application of the NMO correction (Siston, 1988). It also aims to increase the accuracy of the already performed corrections. In this way, the residual static correction leads to a better alignment of the reflection at CMP's traces. Although there are good programs for calculating residual static corrections, the best results are obtained when field statics are quite accurate (Amorim and Santos, 2007).

The times applied to the traces in order to compensate the residual statics are calculated as follows:

$$T_{ijk} = S_i + R_J + C_k + M_{kh} X_{ij}^2 \tag{4}$$

where

- T_{ijk} corresponds to the total displacement for a trace from the CDP k, whose the source and receiver are, respectively, at stations i and j.
- S_i is the static of the source that is placed at station i;
- R_j is the static of the receiver that is placed at station j;
- C_k corresponds to the arbitrary displacements for the CDP k (structural component);
- M_k is the residual NMO component for CDP k (LZL's velocity);
- X_{ij}^2 corresponds to the distance between the source at i and the receiver at j.

Methodology

From all geophysical methods that are applied by the industry in order to obtain the static corrections, the most accurate and economically feasible consist in the one that defines the static correction from the first breaks on the reflection seismograms because the first breaks corresponds to the head wave and to the critical refractions. The efficiency of the methods that use these refraction and reflection data in order to determine the static depends on the reliability of the picking (Yilmaz, 2001). Fundamentally, the use of the first breaks on the reflection seismograms make the quantity of offset curves to be big. Hence, it increases the redundancy of informations about the LVL and this redundancy can be appropriated for the application of least squares methods, for example. The synthetic models were created in the ProMAX/SeisSpace software, from Landmark-Halliburton, by using the ***Finite Difference Modeling*** modulus.

A preliminary synthetic seismogram was generated and it served as the input for the creation of the final synthetic seismogram. In this preliminary synthetic seismogram, the wavelet option was chosen and parameters as minimum and maximum offset and number of shots, for example, were defined. After that, a velocity model was built by using informations as the horizons, structures and velocities of the chosen layers. Thereon, the final synthetic seismogram was generated by the finite difference method. In summary, as the inputs for the preliminary seismogram were the CDPs numbers, it was necessary that the geometry had been already established for the velocity field definition .

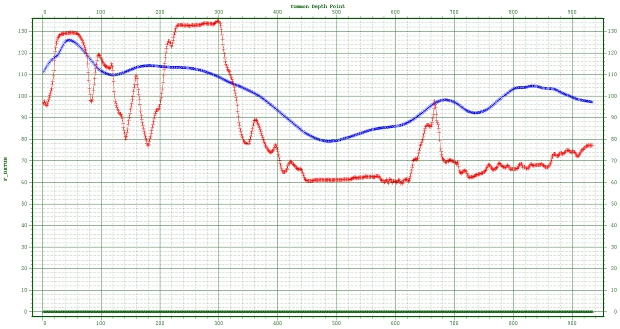

Figura 3: Seismic line elevation (red), floating *datum* (blue) and final *datum* (green).

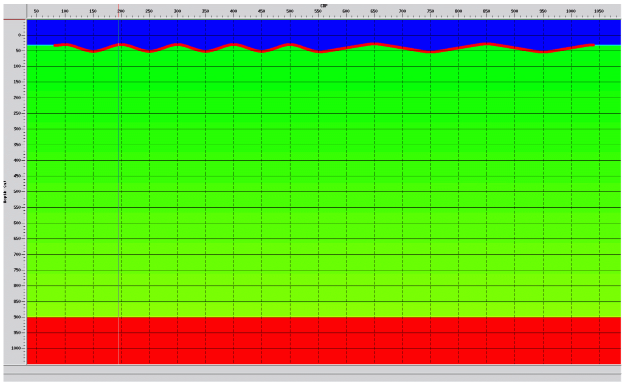

Figura 4: Example of the velocity field (Model 3) with the horizons of the LVL base.

In total, 4 models with two layers and the basement were created. In model 1, the topography and the base of the LVL are flat. In model 2, the topography is not flat, but the base of the LVL is. In model 3, the topography is flat, but the base of the LVL is not. In model 4, both topography and the base of the LVL are not flat. The velocity of the layers and the basement are based on real seismic facts about the Reconcavo Basin. For all models, the first layers has a velocity of 800 m/s, the basement has a velocity of 4500 m/s and the velocity of the second layer is based on a velocity gradient that has a sensibility of 4 meters from the top to the base of the model. Besides, the topography used in models 2 and 4 were the real topography of a seismic line at the Reconcavo Basin (Figure 3). In order to calculate the velocity gradient, the following equation is used:

$$V = 2600 + 0,6 \cdot z \qquad (5)$$

where V corresponds to the velocity in a point at the interface and z is the depth.

In order to generate this field, it was necessary to create the horizons which define the interfaces among the layers. In this way, the first horizon was set as a 30 m flat horizon in depth, the second horizon has its depth varying from 30 to 50 m and it was smoothed later, with a wave length equal to $\lambda = \alpha$ (half of the horizon) and later a wave length equal to $\lambda = 2\alpha$, in which α is a certain number of CDPs. Finnaly, the third horizon, which corresponds to the interface between the layer right below the LVL and the basement at a depth of 900 m. The velocity field used for model 3 is shown in Figure 4.

In relation to the processing of these data, the following steps were applied: geometry, edition with internal and external mutes for the head wave, edge effect and for the trace stretch, field static correction, residual static correction (when it was necessary), organization in CMP, NMO correction, velocity analysis and stacking. The modeling used the finite difference principles and took in account the inelastic and acoustic velocity model. Undesirable effects, such as the ground roll cone, that is caused by the superficial waves, were not generated. In Figure 10, for example, only the head wave is visible. The final *datum* was established as the sea level (0 m), which is generally the *datum* which the industry uses for real seismic data from the Reconcavo Basin.

Results

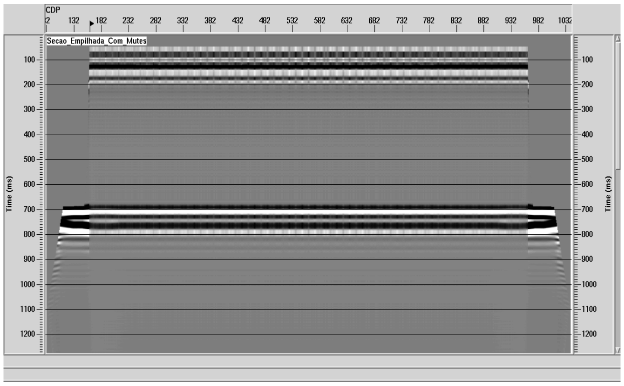

Figura 5: Stacked section for model 1.

Model 1

When both the data topography and the LVL base are flat, the static corrections are not necessary (Figure 5). Therefore, the LVL can attenuates the seismic wave energy, but if its interface is flat, no reflector is prejudiced and no undesired effect is created. In this way, it can be concluded that the presence of the LVL is not a factor that compromises the seismic section quality unless the topography varies, as it will be clear in the next models.

Model 2

If the topography varies and the LVL base is plan, it is necessary to apply both the elevation statics and the refraction statics. When only the elevation statics is applied, the results were not good enough. It may have been caused by two main reasons. The first one is that the finite modeling, that was used in the software, may have not been good to use the elevations presented in the header. The second one is the thickness of the LVL, which is big in some points and, thus, the errors would be calculated for both the elevation and thickness of the weathering layer. Figures 6 and 7 show the comparison between the stacked section without and with the filed static corrections for model 2. The left part of the stacked section had more static errors because this part has the largest topographic variation and also the largest thickness of the LVL. Nevertheless, the static corrections were able to improve the definition of the reflectors, as it is seen when Figure 6 is compared with Figure 7.

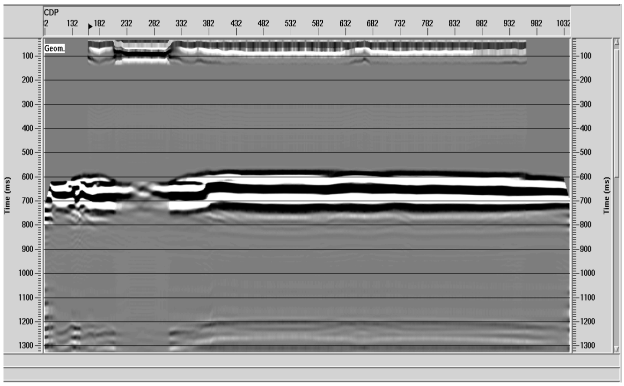

Figura 6: Stacked section of model 2 without the application of static corrections.

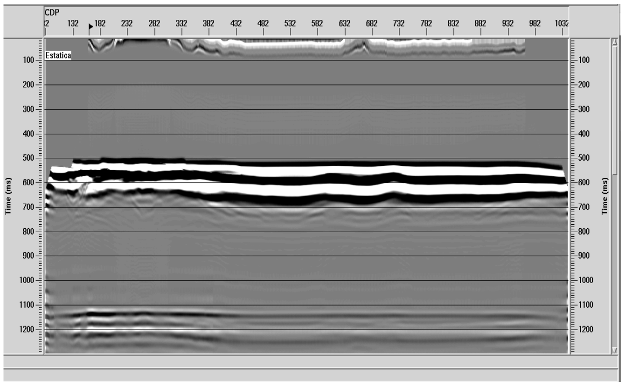

Figura 7: Stacked section of model 2 with the application of elevation and weathering static corrections.

Model 3

In model 3, the topography is flat and the LVL bases varies from a horizon with wave length λ = α of more or less 100 CDPs until half of the field. The other half has λ = 2*α with 200 CDPs. The result of the static errors was as expected. In the left part of the section, where the base of the LVL varied more, the static errors were the highest. On the other hand, the right part presented the smallest errors. It could be also noted in the seismograms.

It can be concluded that, despite the static errors would appear considerably small in the shot domain on the side of the receiver with $\lambda = 2 * \alpha$ when it is compared to the side with $\lambda = \alpha$, at the stacked section both modify the second reflector in order to create reflectors that do not exist. It totally proves the static correction efficiency for seismic processing and, as a consequence, for interpretation because the static errors create fake reflectors and they compromise the seismic imaging quality when they are not corrected. As the topography is flat, only the refraction/weathering correction was applied to this model. The results for this model are shown in Figure 8 and 9.

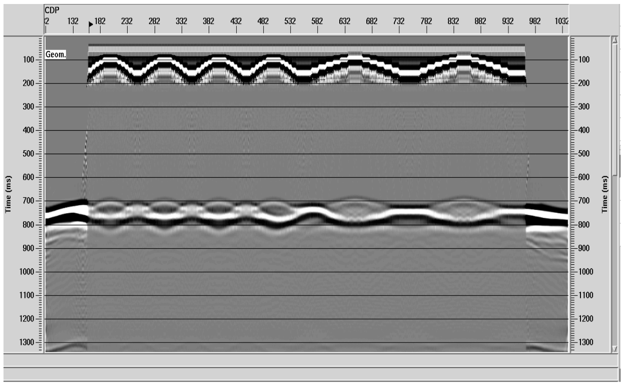

Figura 8: Stacked section of model 3 without the application of weathering static correction.

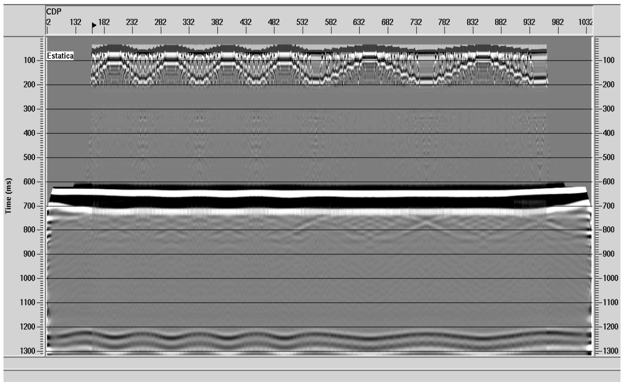

Figura 9: Stacked section of model 3 with the application of weathering static correction.

Model 4

As model 4 has both topography and the base of the LVL are not flat, it was necessary the application of residual statics for this model mainly because the static errors for some points in this case were bigger than for the previous cases. Figure 11 presents the stacked section without the application of any static correction. It is possible to see that the reflections were severely damaged. In Figure 10 the static errors causes by the variation of topography and the thickness of the LVL in a seismogram are shown. It is noticeable that, in the left side, both reflection and first breaks are distorted. On the other hand, in the right side, the application of the elevation and weathering static corrections improved the consistency of the reflections and linearizations of the first breaks.

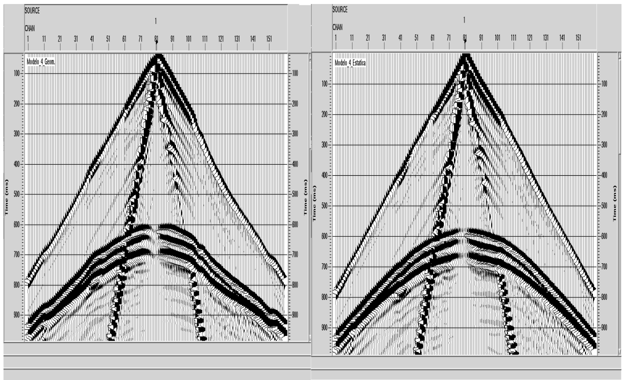

Figura 10: Seismogram of model 4 without and with the application of the static corrections.

In Figure 12, the results of the stacked section with the application of the elevation and weathering static corrections are presented. In order to further improve the linearization of the second reflect, the residual static was applied to the data. Figure 13 shows how the quality of stacked section was improved due to the application of the residual static correction. Therefore, it can be concluded that the residual correction must be applied to data when the field corrections are not capable of correcting all the static errors.

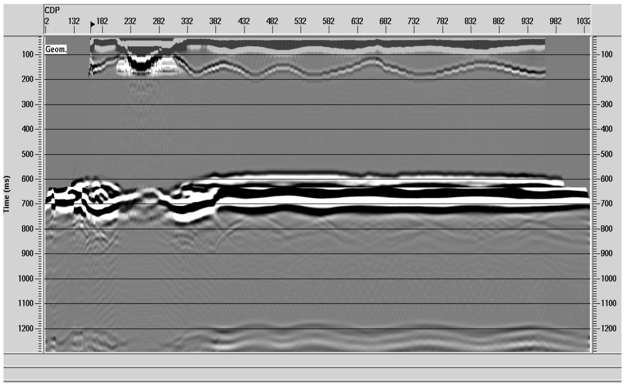

Figura 11: Stacked section of model 4 without the application of field static correction.

Conclusions

The modeling did not presented the expected static errors, as they should be bigger than what was shown. It could have happened due to the fact that maybe the modulus does not work well when the header elevation are used. Although, the presented errors were enough to prove the efficiency and importance of the static corrections, what

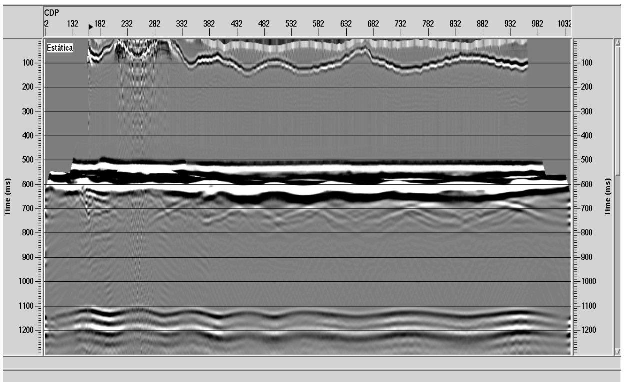

Figura 12: Stacked section of model 4 with the application of field static correction.

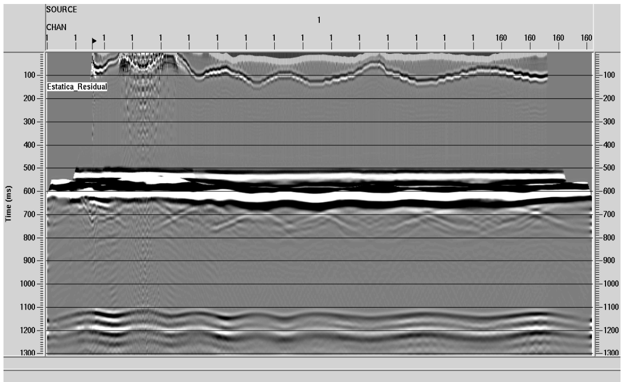

Figura 13: Stacked section of model 4 without the application of field and residual static corrections.

represents the purpose of this work. The presence of the low velocity zone and also small variation of the topography do not guarantee that the static correction will always be necessary. However, when the variations in topography are relatively big and abrup along the seismic survey and the thickness of the LVL also presents variations, the static correction are of the utmost significance.

As it was seen in this job, the application of static correction is very important for the processing of seismic land data. Sometimes the application of residual static correction is very valuable too because it can improve the definition and positioning of the reflectors, what upgrade the quality, coherence and reliability of the seismic section. Therefore theses corrections support the seismic interpretation as they lead to more realistic sections. Hence, if the static corrections are not applied in situations such as presented in models 2, 3 and 4 (there are more likely to happen than model 1), the investment will be put in risk, since the quality and reality of the seismic image is severely compromised.

Acknowledgments

The authors would like to thank CNPq and PETROBRAS for the support to the project INCT-GP/CNPq/MCTi. They also thank LANDMARK- HALLIBURTON for the SeisSpace/Promax software license granted to CPGG/UFBA and for the physical structure of CPGG(LAGEP-UFBA), where this work was done. Clériston S. Gama thanks INCT-GP for the scholarship.

References

AMORIM, W. N. DE and SANTOS, M. G., 2007. Correções Estáticas, PETROBRAS, Intern Publication.

COX, M. J. G., 2001. Static Corrections for Seismic Reflection Surveys. Society of Exploration Geophysicists - SEG, Tulsa.

CUNHA, R.S., 2010. Cálculo Das Correções Estáticas - Trabalho de Conclusão de Curso, Universidade Federal da Bahia, Instituto de Geociências, Salvador, Brasil.

GAMA, C. S.; SANTOS. M. G and PORSANI, M. J., 2016. Processamento Sísmico 2D : Linha 26-RL-1993 da Bacia do Recôncavo. Ouro Preto. VII Simpósio Brasileiro de Geofísica.

GAMA, C.S., 2016. Influência das Variações da Topografia e da Espessura da ZBV na Imagem Sísmica - Exemplos em Dados Sintéticos e Reais da Bacia do Recôncavo Trabalho de Conclusão de Curso, Universidade Federal da Bahia, Instituto de Geociências, Salvador, Brasil.

MARSDEN, D., 2007. Static Corrections a Review. The Leading Edge, pp. 115-120.

SISTON, PAULO R. P. (1988) - Utilização de Auto-imagens Complexas na Determinação de Correções Estáticas Residuais. Dissertação de Mestrado, Universidade Federal da Bahia, Salvador, Brasil.

SOUZA, W. E. 2016, Determinação Automática das Primeiras Quebras e Aplicações na Correção Estática e Processamento Sísmico da Bacia do Parnaíba. Dissertação de Mestrado. Universidade Federal da Bahia, Salvador, Brasil.

YILMAZ, O., 2001. Seismic Data Analysis: processing, inversion and interpretation of seismic data, Society of Exploration Geophysicists - SEG, Tulsa.