Revealing the rift associated with the Transbrasiliano Lineament at the Parnaíba Basin from seismic reflection data

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Abstract

The Transbrasiliano Lineament is a shear zone on South America with a SW – NE trend. To observe the subsurface structures related to this lineament and its origin rifting process, a seismic line was processed and interpreted. While in the processing, four different filters were applied trying to recover most of the significant part of the data and compare to test which could also better remove the ground roll. Also, due the lack of actual height values to be used in the static correction, these were replaced from satellite height observations, providing a less usual and ideal but still functional alternative. Each of the filtering techniques results provided stacked sections, that after compared, one was picked to be interpreted. Thus, we noticed that the section is placed at the beginning of a rift, not being able to observe the main faults associated to the Transbrasiliano Lineament, but the secondary ones. Still, there are sills all along the section close to the limits between the geological groups.

Introduction

South America was subjected to severe transformations during the Brasiliano Cycle and during the Gondwana breakup. One of the remarkable results is the Transbrasiliano Lineament (LTB), a long shear zone crossing this continent. Although might be possible to observe some superficial structural hints along part of the lineament, when it reaches the area covered by the sedimentary rocks of the Parnaiba Basin, there aren't noticeable superficial structures anymore.

The Parnaiba basin (Figure 1) is located on the Northeast Brazil and placed on six different states, covering an area of more than 600 000 km². Since 1970, the basin has been through intense studies, in which were acquired over than 8 000 km of reflection seismic data and 36 wells (Góes and Feijó, 1994; Vaz et al., 2007).

The basin is divided in 5 main sequences (Figure 2). The Silurian sequence, correspondent to the Serra Grande Group and the Middle Devonian–Lower Carboniferous is related to the Canindé Group. The depositional environment of these sequences is mainly controlled by the changes of the ocean level (Almeida et al., 1981).

The Upper Carboniferous – Lower Triassic sequence is associated with the Balsas Group, and due the diversity of depositional environments, many types of rocks may be found. The Jurassic sequence is composed only by the Pastos Bons Formation. The Cretaceous sequence consists of the Codó, Corda, Grajaú and Itapecuru Formations (Góes et al., 1990; Góes and Feijó, 1994; Vaz et al., 2007).

Magmatic rocks are intruded, named by Mosquito and Sardinha Formations, in which the first was caused by the Central Atlantic opening and the last by the South Atlantic opening (Milani and Thomaz-Filho, 2000).

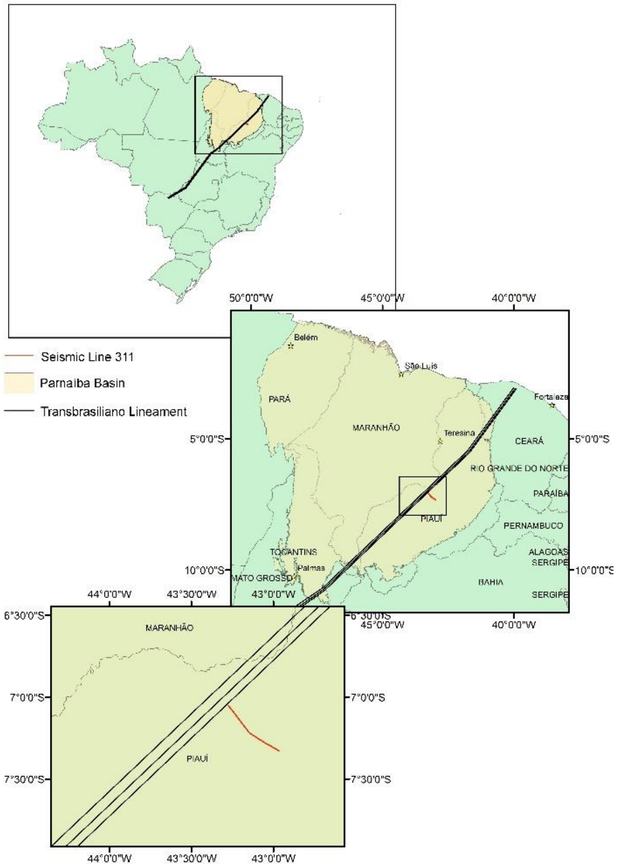

Figure 1 – Location of the Parnaíba Basin and the seismic line survey. The Transbrasiliano is compound of a shear area with minor lineaments with the same trend.

The Transbrasiliano Lineament (LTB) is a huge shear zone that cross South America, from Argentina until the Brazilian Northeast (Schobbenhaus, 1975; Brito Neves e Fuck, 2013). The structure was originated during the Brasiliano-Pan African cycle, where the old Goiás-Pharusian ocean was closed and the LTB was generated as the junction among the two great domains, named by Brito Neves and Fuck (2013) as the Amazonian and Brasiliano domains.

There are many kilometers of seismic data acquired at the basin possessed by the Agency of Petroleum, Natural Gas and Biofuels (ANP), and it was required for the

Transbrasiliano Project managed by the Geosciences Institute of the University of Brasilia.

Thus, the processing and interpretation of the seismic line aimed to identify structures related with the LTB and its geological origin.

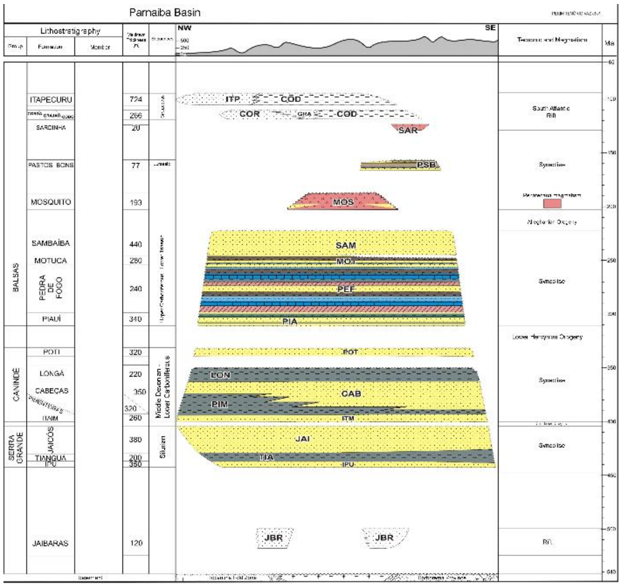

Figure 2 - Lithostratigraphy chart of the Parnaiba Basin. The 5 main sequences above the basement and its relative thicknesses are shown, as well a related origin event. Adapted from Vaz et al. (2007).

Method

The chosen seismic line is placed in the Floriano region, near to the limit between the states Maranhão and Piauí. In the process of choosing between the available seismic lines, the 0240_311 was the one because of its localization, crossing perpendicularly the main direction of lineaments, which is NE-SW, while the direction of line is NW-SE.

The data was acquired by a Petrobras team back in 1996 (Table 1). Acquisition parameters used were a high cut filter of 128 Hz, besides a Notch filter of 60 Hz. Among the 1567 planned shots, only 1516 were actually shot due to obstacles found in the field.

Table 1- Acquisition Parameters.

Acquisition Parameters	
Profile length	47.09 km
Number of shots	1567
Shots interval	30 m
Receivers interval	30 m
Number of active channels	96
Recording length	5 s

The agency provided information about the shot and receiver locations, as well height values, since these are needed for the static corrections to be applied in the data. However, the given heights didn't prove to be correct, and accordingly to the Figure 3, there is a huge difference between the given values by ANP and the values from the TOPODATA database. The TOPODATA database provides a Digital Elevation Model (DEM) for Brazil, but with an additional Kriging to increase the precision from 3'' to 1' (Valeriano and Rossetti, 2012). Thus, the used height values were extracted from the DEM for the respective seismic line acquisition points

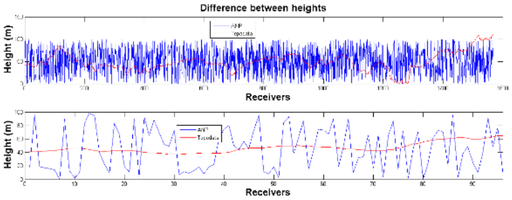

Figure 3 - Comparison between heights obtained from ANP and TOPODATA. There is a significant difference between the two sources, thus the most reliable values were from TOPODATA because the variation presented in the heights from ANP don't match the topography. The TOPODATA values were normalized in order to be compared.

The refraction statics applied to the data used a search window of 300 ms to identify the first breaks of each trace. The usage of satellite height values didn't bring the actual result of a correct static to the data, thus, it is always needed to have the correct values for each shot and receiver position obtained in field with an accurate equipment.

The trace edition consisted in killing the traces with very discrepant values from the average of the seismic data, it means those traces with very high or low frequency or amplitude values. These traces damage the amplitude control process. A mean scale was applied to recover the lost amplitudes in the higher times, limited in a time gate until 2000 ms. To recover the killed traces and set an equal spacing for each trace, the traces were interpolated for a distance of 30 m. Although originally the average distance between the traces is said to be 30 m, some have higher or smaller distances.

The shots are very noisy, making it difficult to identify the deepest reflections. To attenuate multiples and increase the temporal resolution of the traces, it was applied a predictive deconvolution, with a 70 ms operator length and 100 ms lag prediction.

First, to remove the noise, it was applied an f-k filter, which is a two-dimension filter that transforms data from the t-x domain to the f-k (frequency – wave number) with the application of a double Fourier Transform. In the f-k domain, events with different velocities are presented at different regions, thus being possible to remove the noise. The f-k spectrum in which the filter was designed is not very clear to determine the different types of waves, therefore it was adopted a not very aggressive one.

The lack of shot gathers where the main reflections were visible encouraged the application different types of filter, so that the results could be compared.

The f-x filtering consists of the applications of a single Fourier Transform to each trace, in respect to time. A model consisting of a defined number of traces is summed up to build a new trace for each frequency and spatial location. It is assumed that the reflection is stationary and the surface waves have linear velocities and differ in phase from trace to trace (Goebel and Evans, 1987). The f-k – f-x is a filter that uses both domains. The filter is built in the f-k domain then converted with the data to the f-x domain, where the filter is applied and converted back to the t-x domain. The limits of the filter are defined by the slowness, minimum 0.5 ms/trace and maximum 100 ms/trace, and the spatial operator length of 1000.

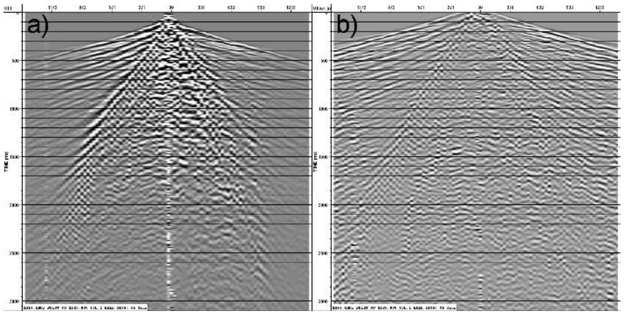

Figure 4 - Raw shot a) and after the predictive deconvolution b).

The radial trace transformation (RTT) turns the data from the t-x domain to a new domain ruled by the injection angle θ and the two-way travel time t, and can be called r-t domain (Henley, 1999). Linear events have their frequency lowered in the r-t domain and are spread around the chosen origin, hence can be removed with the application of a low cut filter (Henley, 2003). The applied RTT used velocity limits of -5000 m/s and 5000 m/s, besides a low-cut filter of 5 Hz.

The tau-p aims to map the data from t-x domain to intercept time (t) and horizontal slowness (p). Seemly to other transformations, the events in the t-x domain become different in the new domain. Reflections are mapped from hyperbolas into ellipses, and even a high number of primary reflections, they never cross each other in the t-p domain. Linear events don’t appear the same way as reflections, being converted into points (Dunne and Berestordt, 1995).The designed tau-p filter was limited to a minimum slope of – 0.005 s/m and maximum 0.005 s/m.

Each dataset originated from the filtering was stacked accordingly to the velocity model created, thus generating four stacked sections. Because of the poor reliability of the prior statics, there was a need to apply the Residual Statics, with a window of 200-2500 ms. A Kirchhoff post-stack migration was applied followed by a predictive deconvolution, due the migration effect of decreasing the temporal resolution.

Results

The application of a noise removal technique looks to ensure that the final result is the cleanest, so that the interpretation becomes easier and more accurate. The four produced results show the direct effects of each processing technique in the stacked section, and are seen in Figure 5. There is no scale applied so that the amplitudes of the filtered gather could be compared to the extracted noise.

It is clear that the f-k filter damages the data. The effects of the prior aliasing that hasn’t been completely removed are shown up specially on the region once dominated by the ground roll. The noise shows the removal of some of the aliasing, although it wasn’t very effective. The surface waves were removed, but the refractions and direct waves weren’t removed at all.

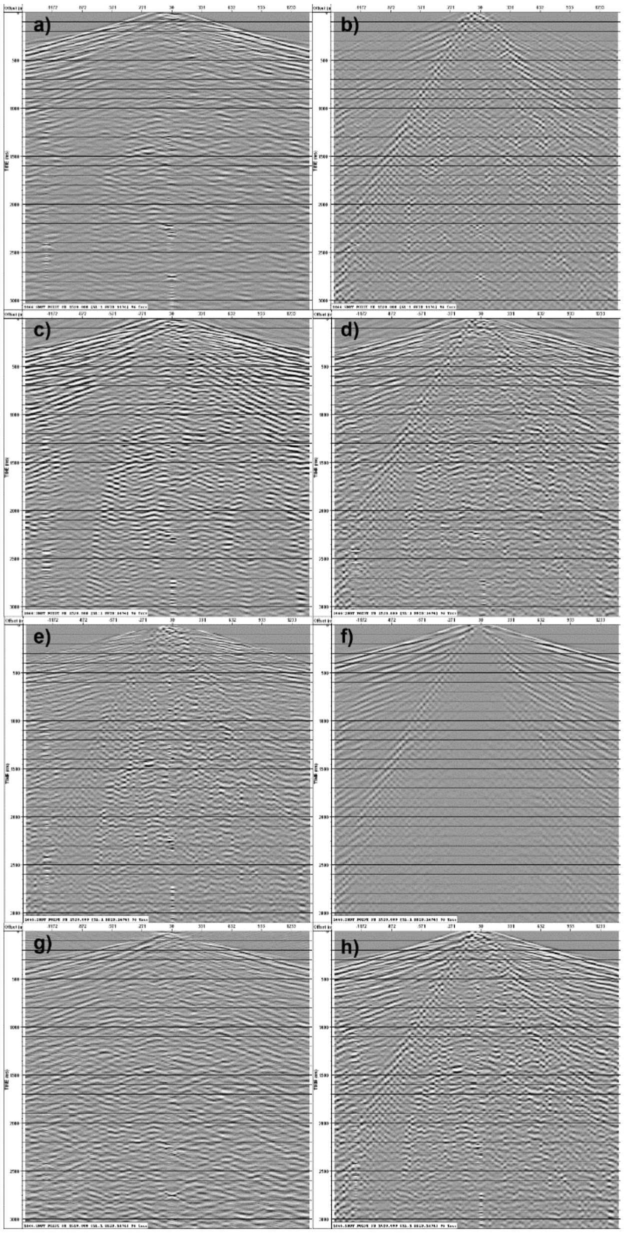

Figure 5 - Data filtered and noise subtracted, respectively, for: f-k, a) and b); f-k - f-x, c) and d); RTT, e) and f); tau-p, g) and h).

The f-k – f-x removed more energy from the surfaces waves than from the direct wave and the refraction. The interest data suffered less from the application of the filter as can be seen from the amplitudes intensity, but even so there was an attenuation of the noise.

The RTT is very efficient in removing the noise. The filtered shot presents very clear reflections, mainly for early times. The noise subtracted is very clear and shows basically the surface and air waves and refractions. This transformation however, doesn’t remove incoherent noise. The application of a second RTT could have provided better results and more defined reflections.

The tau-p transform has a problem with the spatial aliasing as well, but removed the unwanted signal. In the early times for the removed noise, some energy from the reflections was subtracted too, which can be due to its proximity to the direct and refracted waves in the t-x domain.

The stacked sections from the transforms are shown at Figure 6. The figure with the f-k stacked section has a lot of noise, such that it is hard to identify properly the layers. A remarkable characteristic of the use of the f-k filter is the presence of a dipping signal overlapping the layers, strongly in some regions of the sections, as around the CMP 1003.

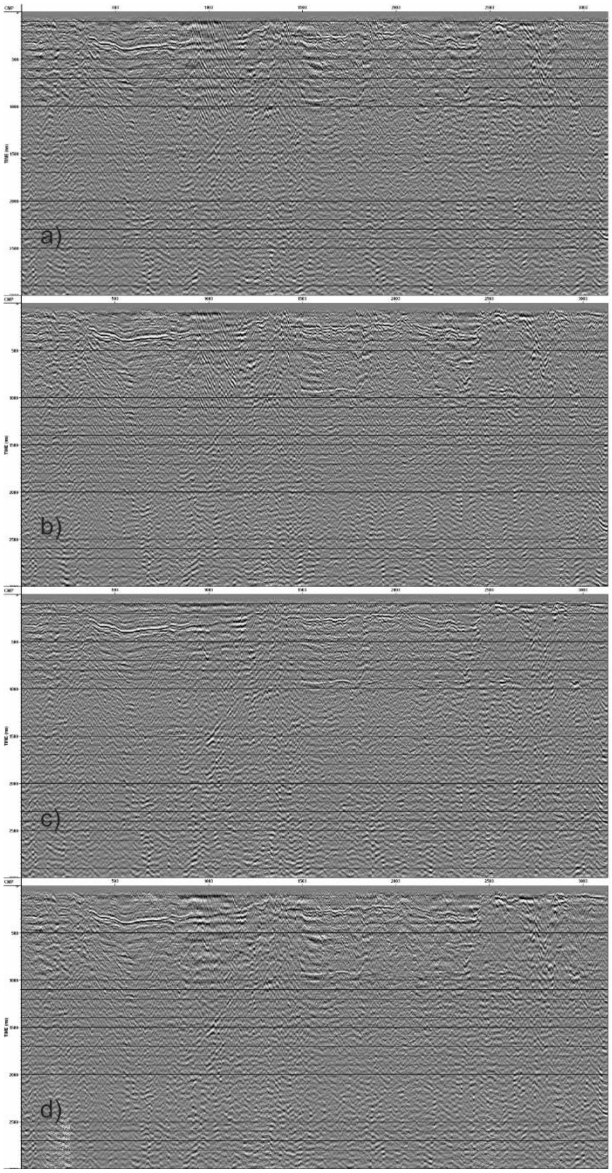

Figure 6 - Stacked section resulted from removal noise technique: a) f-k, b) f-k - f-x, c) RTT and d) tau-p. Each section presents a different pattern of non-removed noise.

The next section generated from the f-k – f-x filter still has the effects of the dipping events, however, as long with the noise, they aren't as strong as they are in the f-k section. Due to the attenuation of the noise, the identification of the layers is better, and becomes possible to notice a horizontal continuity of these layers.

As in the previous analysis, the RTT revealed to be a very sophisticated technique. Among all the sections, the one created from this transform is the less noisy. The tau-p section, even with the use of a predictive deconvolution doesn't have a very good temporal resolution, being poorer than the others presented.

Gathering information from all the stacked sections, the one generated from the RTT technique presented a better section to be interpreted, because is the less noisy section and with the best temporal resolution among them all.

Authors such as Neto et al. (2013), Santos et al. (2013), Castro et al. (2016) and Michelon et al. (2016) have been studying the Parnaiba Basin and the Transbrasiliano Lineament using the seismic method, and the previous knowledge was used during the interpretation, to limit the interfaces and to identify potential structures.

As observed in the Figure 7, above the basement is the Jaibaras Group. Its origin is related to the basin rifting process that occurs all over the basin (Daly et al., 2014), with the deepest area being coincident with the LTB. However, as this seismic line doesn't cross the LTB, it is only possible to observe the beginning of the rift.

The Serra Grande Group was deposited above the Jaibaras Group. The interpretation of this group is rather poor because the quality of data. The Canindé Group, that is the thickest among the groups, is limited both above and below by sills, besides there is one more sill inside the group. Sills are found in the Parnaiba Basin due to magmatic intrusion triggered by the Atlantic Ocean opening (Milani and Thomaz-Filho, 2000). The limit between different types of rocks is weaker and therefore allows the intrusion to break into the rocks.

Conclusions

All the applied techniques were successful to remove the noise; however, each one presents a particularity. The f-k is rough filter and needs to be applied carefully, and the RTT and tau-p are very efficient to remove the linear without damaging the data, but the application parameters need to be set carefully.

The statics with satellite height is not ideal to be applied, however due to the lack of reliable data it provides a satisfactory result, but it still visible in the data the lack of real statics, which compromised the final result in certain aspects.

Regarding the interpreted section, the faults are believed to be caused as a reflex of the accommodation due the geological rift setting. The initial area of the rift is visible as the deep plateau, and it continues to the north-west direction.

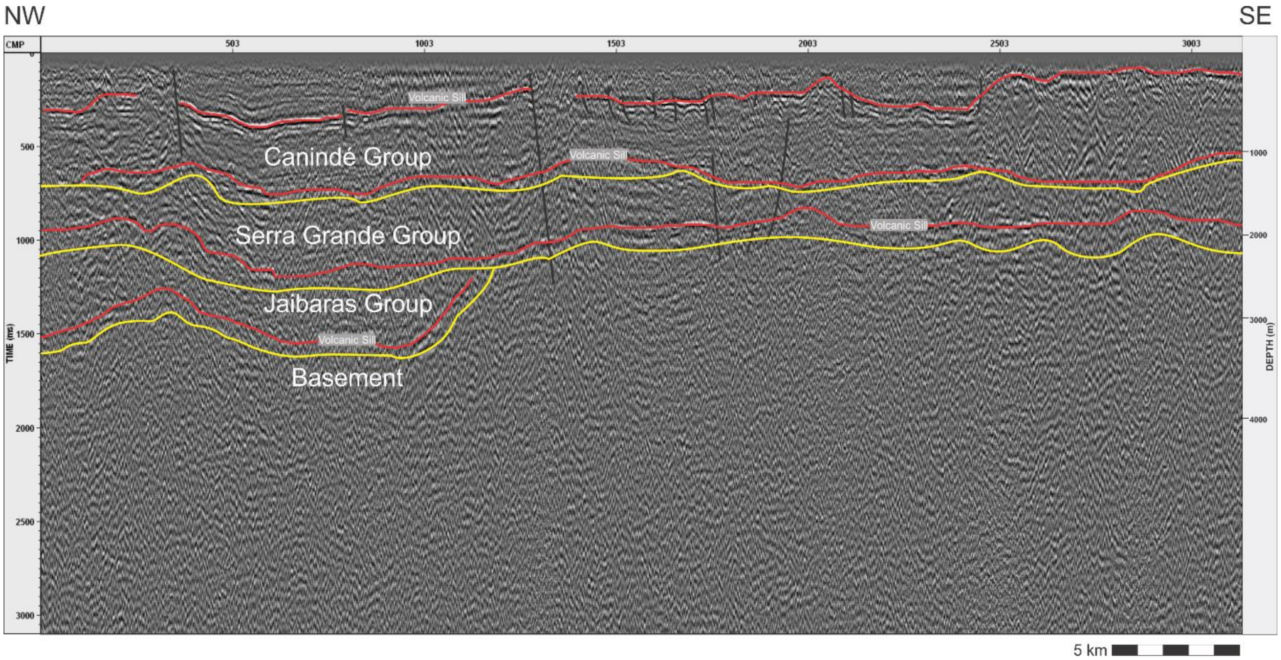

Figure 7 – Interpreted section. Highlighted are the division of each sedimentary group: Jaibaras, Serra Grande and Canindé. Due to the late magmatic activity, sills intruded into the layers, especially close to the group limits. The deepest plateau states the beginning of the rift.

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