Conventional seismic processing flow analysis: 2D line of the Rio Grande Chain region Southeastern Brazil

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Abstract

Seismic reflection is one of the most important tools for the oil and gas industry, both in the exploratory and in the production phase. It is divided into three components: acquisition, processing and interpretation. This work is inserted in the context of seismic data processing. For this, the processing of a real 2-D line acquired in 1979, located in the region of the Rio Grande Chain, southeast of Brazil, was made using the software ProMAX/SeisSpace. In order to generate a representative image of the geological framework of the area, a conventional processing flow that includes two different procedures was applied: procedure 1 and procedure 2, which are respectively related to the application of post and pre-stack migrations. The steps of the processing flow were submitted to different parameterizations, and the inputs and outputs were compared aiming to evaluate how they work to improve the seismic data. Based on the processing flow used, the best result obtained for the final seismic section was the one corresponding to the Kirchhoff pre-stack time migration, due to its better seismic aspect.

Introduction

The seismic reflection method uses the reflection of seismic waves to map acoustic impedance contrasts between layers across the subsurface. It is the geophysical method which aims to obtain travel times and depths of the layers with different values of density and/or P wave velocity (Dentith & Mudge, 2014). However, the reflections recorded by the receptors do not always represent accurately the geological behavior of the subsurface due to intrinsic characteristics of the raw data, which can compromise the interpretation, such as noise or weak signals. Therefore, the seismic processing goal is to make the subsurface geological model correlatable to the image generated from the processed seismic reflections. Thus, within acquisition-processing-interpretation, the main three divisions of the seismic reflection method, the processing is one of the most important. It is capable of making the interpreter able to infer geological features such as lithological boundaries, contacts between fluids (water/gas, gas/oil, water/oil) and geological/geophysical interpretations, among other features of interest. This paper shows the importance of the seismic processing through the results and contributions of a processing flow applied to a real 2D seismic data obtained for free for academic purposes from the University of Texas at Austin's database. In order to that, it was used Landmark's ProMAX/SeisSpace software, with UFRN's academic licenses.

The data processed for this paper was acquired to serve as support to the International Phase of the Ocean Drilling Project in the South Atlantic Ocean (Shipley et. al., 2005). The line was surveyed in 1979 in the Rio Grande Chain region, near Rio de Janeiro's coast, southeast of Brazil. Researchers Thomas Shipley and John Ladd led the survey (Barker, 1983; Gamboa, 1983). Only a part of the seismic line shown in figure 1 was processed. Table 1 shows the acquisition parameters of the seismic survey.

Figure 1: geographic location of the seismic line WSA-01 (in red).

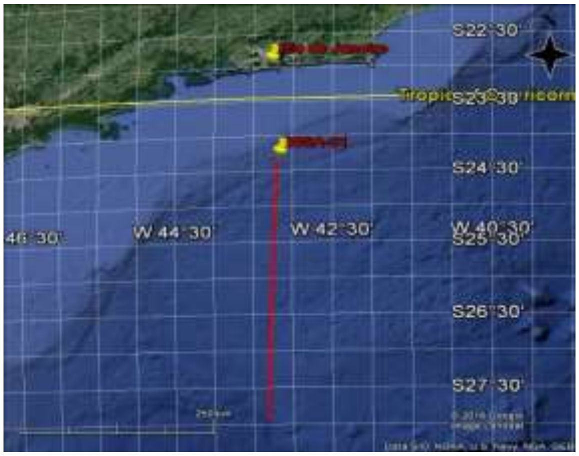

Table 1: acquisition parameters of WSA-01 line (ar08 part)

Source	AirGun
Receiver	Hydrophone: Streamer
Datum	WGS72
Number of shots	2654
Shot interval (meters)	50
Number of receivers	24
Receiver interval (meters)	50
Minimum offset (meters)	316
Maximum offset (meters)	1466
Number of CDPs	5330
CDP interval (meters)	25
Fold	12

Method

The processing flow applied in this work is a conventional one, covering most of the steps within seismic data processing. However, several other processing flows can be applied on a given data depending on the goals set for the each situation. Figure 2 shows, schematically, the processing flow used in this work.

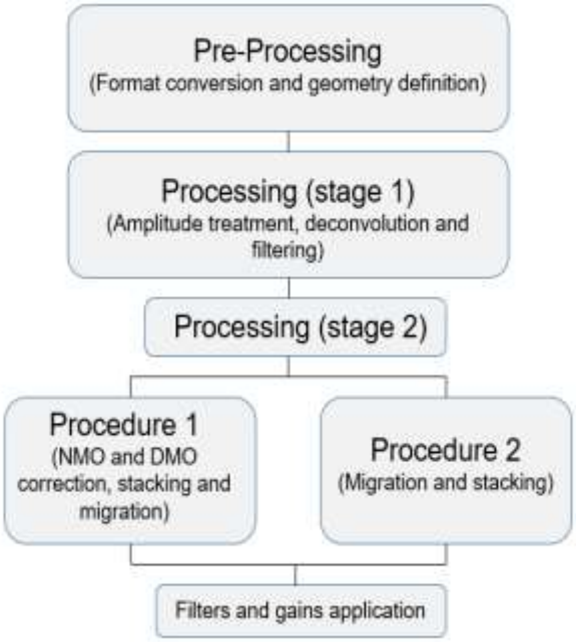

Figure 2: Conventional processing flow used. Notice that the flowchart is branched into procedure 1 and procedure 2, which are respectively related to the application of post and pre-stack migrations.

The first step of the processing is the conversion of the raw data, originally obtained in SEG-Y format, to a format consistent with the ProMAX/SeisSpace environment. Then, the geometry of the data is parameterized. This procedure is performed to provide the software technical features about the seismic survey. Therefore, in this step, informations such as spreading, number of receivers, number of shots, minimum and maximum offsets, spacing between receivers and equidistance of shot points are loaded into the converted data.

Before the amplitude correction, a preliminary velocity analysis was conducted to characterize the subsurface field velocity (figures 3 and 4). In addition, a quality control was performed to eliminate traces with high noise content. For the amplitude correction, the effects of the geometric spreading were revised by the spherical divergence correction that aims to equalize the energy density of the wavefront as it propagates in subsurface. After this correction, the traces received a homogeneous gain in amplitude, which permitted the visualization of more seismic reflectors, mainly in the highest times of the section.

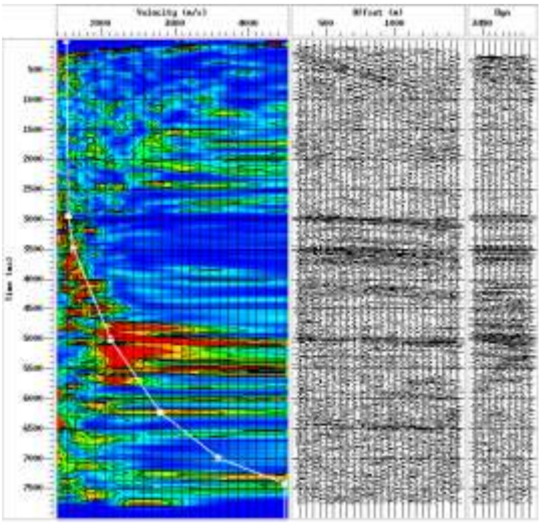

Figure 3: Velocity function semblance of the supergather related to the CDP 3493. The white line represents the interpreted velocity function.

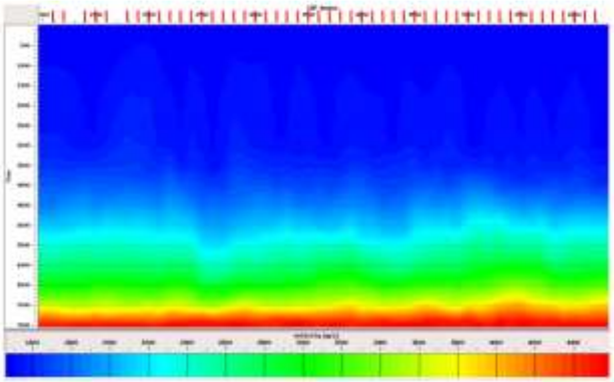

Figure 4: Seismic section's preliminary velocity field.

Once the previous step is completed, deconvolution is applied. This process is important to increase the temporal resolution by means of the compression of the input pulse. In other words, it allows the visualization of a bigger number of reflectors. Among the various types of algorithms for deconvolution, it is possible to highlight the Spiking and the Predictive ones. The first aims to shorten the seismic pulse to a spike in order to make the trace as close to the reflectivity function as possible, and the second one attempts to estimate and remove predictable parts of the seismic trace (usually multiple reflections), and changes the shape of the input pulse. Both were tested. Comparing the two results, the Predictive deconvolution effectively attenuated noises in the seismic section. However, the Spiking deconvolution, although it did not aid in the same way in the noise removal, increased the vertical resolution of the data, which was the objective of this stage. Therefore, the Spiking deconvolution was chosen to continue the processing flow.

After the deconvolution, the attenuation of first order seafloor multiples was made. One of the ways to perform this correction is by analyzing and applying the f-k filter, where the data leaves the time domain and goes to the frequency domain through a two-dimensional Fourier Transform and returns to the time domain after the filter is applied.

In order to identify first order multiples based on their doubled time of reflection, a preliminary NMO correction is carried out. This correction can be made based on the analysis of the multiple reflections' velocities. Thus, multiple events are horizontally aligned and have, in the frequency domain, wavenumber approximately equal to zero (Yilmaz, 2001). Therefore, by applying the f-k filter, the part of the data relative to the wavenumber equal to zero is rejected and the multiple reflection is attenuated. Figure 5 shows these reflections being positioned to the wavenumber zero. This strategy was able to substantially reduce the noise related to the first order multiples, although it did not remove its effects entirely. Figure 6a shows part of the seismic section before the application of the filter and figure 6b shows the result of its application.

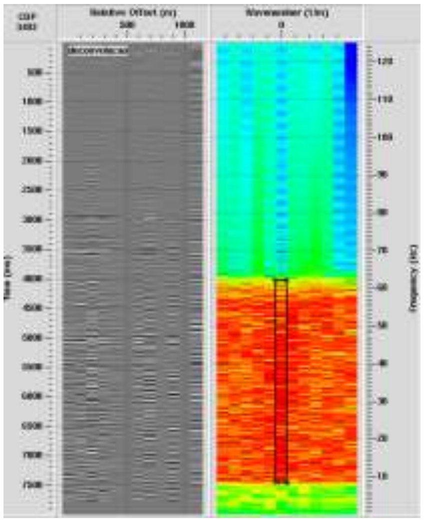

Figure 5: Analysis of the CDP 3493 in the f-k domain, related to the application of the filter, defined by the rectangle with black contour.

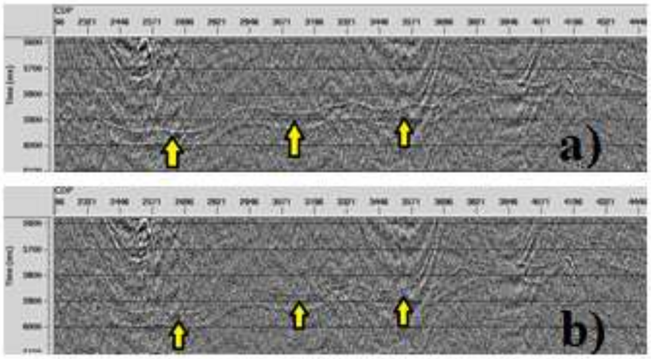

Figure 6: a) Stacked section with zoom after deconvolution. Notice the first order multiple marked by the yellow arrows. b) Stacked section with zoom after the application of the f-k filter. Notice the attenuation of the multiple reflection pointed by the yellow arrows.

Procedure 1

The next step of the flow, included in procedure 1, is the NMO correction, performed in the CMP domain. It removes the effect of source-receiver offset that causes an increase in reflection time as distance increases. This correction causes the trace to be positioned at zero offset (source and receiver theoretically in the same position) and converts the reflectors from curved into horizontal. Because this correction is dynamic, the traces are stretched, so a muting of traces that exceeded 40% of stretching was employed. In addition, to remove the moveout effect caused by dipping reflectors the DMO correction (Dip Moveout) was applied. Following the DMO correction, another velocity analysis was included in the flow, this time in order to obtain a more precise velocity function to carry out stacking and migration steps. Next, the data was stacked. Stacking consists of a horizontal summation of traces that belong to the same CMP family, transforming them into a single trace. This increases signal-to-noise ratio and yields the seismic section (Kearey et al, 2002).

The next step of this processing is migration. In seismic sections in which the reflectors are flat, the reflection point will be located directly below the midpoint. However, if the reflectors have a dipping component the point will be moved in the opposite direction of the dip course (considering the case of a dip component along the acquisition line) or out of the plane of the section in the presence of a cross-dip. Migration, therefore, is the process that shifts the reflectors from the midpoint to their correct positions in subsurface at the right time. It also corrects the effects caused by diffraction due to faults or point reflectors (Telford et al., 1990). For migration it was used the Kirchhoff algorithm in time domain. Four cutoff frequencies were tested: 50, 60, 70 and 80 Hz. This choice took into account the frequency spectrum of the seismic data after the application of the f-k filter. Of these, the migration up to 70 Hz was chosen to proceed with the processing because it displayed a better reposition of the reflectors. From this output, another quality control was performed to identify noisy traces still strong in the section and 'migration smiles'. Additionally, a top mute was applied above the seafloor to remove the effects of the water column. Figure 7 shows the seismic section obtained after the application of procedure 1.

Procedure 2

The processing order for the pre-stack migration is identical to post-stacking up to the noise attenuation step (f-k analysis). After this correction, it is not necessary to conduct NMO and DMO corrections, since the Kirchhoff algorithm for Pre-Stack Time Migration (PSTM) already includes such corrections. However, it is still necessary to mute traces that have undergone strong stretches; otherwise the data will present undesired noises in the staked section. Only then, the data is stacked.

Again, the migration up to 70 Hz was chosen to continue the processing. The quality control was responsible for muting the upper part of the section, above the seafloor, and for the removal of noisy traces. Figure 8 shows the seismic section obtained after the application of procedure 2.

Instead of CMP gathers, the PSTM uses individual seismic traces gathered in common offset groups. These groups are migrated and then rearranged into CMP gathers in order to be stacked. Due to this, the PSTM requires a longer computational time because it uses a larger quantity of traces, when compared to post-stack migration.

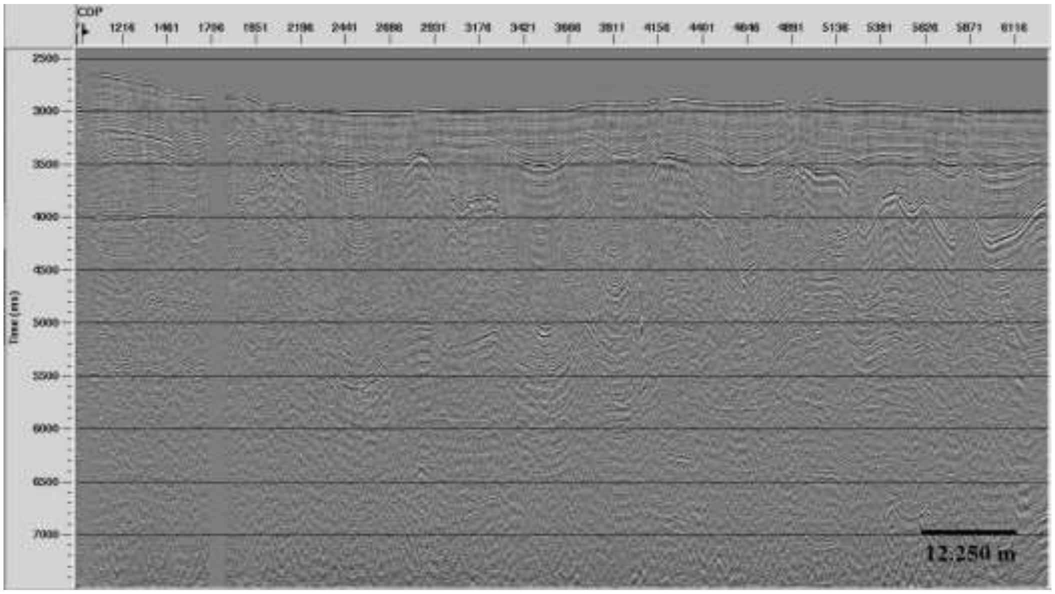

Figure 7: Seismic section obtained after procedure 1 (post-stack migration).

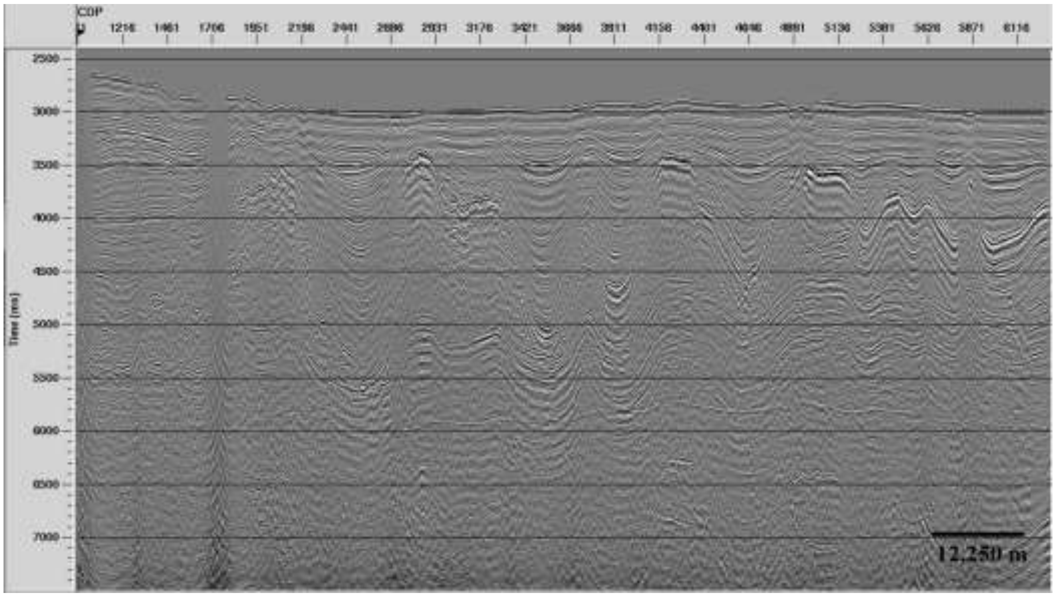

Figure 8: Seismic section obtained after procedure 2 (pre-stack migration)

Results

Based on the results obtained for each procedure, the seismic sections were compared in order to evaluate which migration type, pre or post-stack, provided the best seismic response. Pre-stack migration (procedure 2) generated the image with the best seismic character in the delimitation of the reflectors, it was much less noisy than the post-stack migration and it improved the temporal resolution of the seismic section more effectively. For this reason, the pre-stack migration section was chosen as the best output.

To complete the processing, filters and gains were applied. First, it was used the f-x decon filter to reduce the effects of random noises; then, an AGC gain to enhance the amplitude of the traces; and finally a bandpass filter (8-10-55-60) to remove undesired frequency contents. These tools improved the final image's quality. Figure 9 shows the stacked section of the raw data after the parameterization of the geometry to compare with the final section after the application of the conventional processing flow, figure 10.

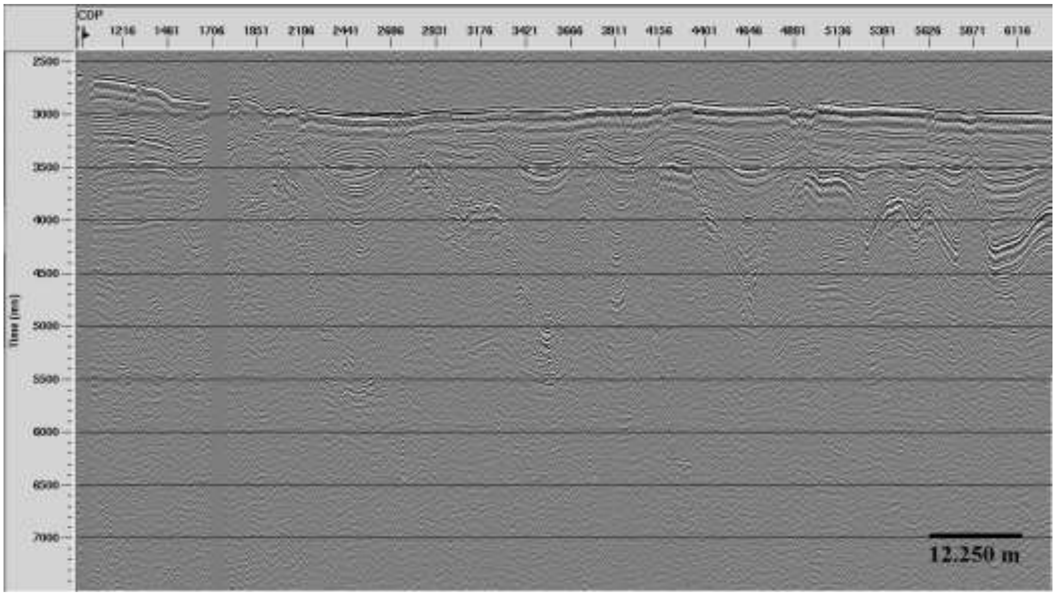

Figure 9: Stacked seismic section of the data loaded with geometry. Observe the initial aspect of the section to compare with the final section.

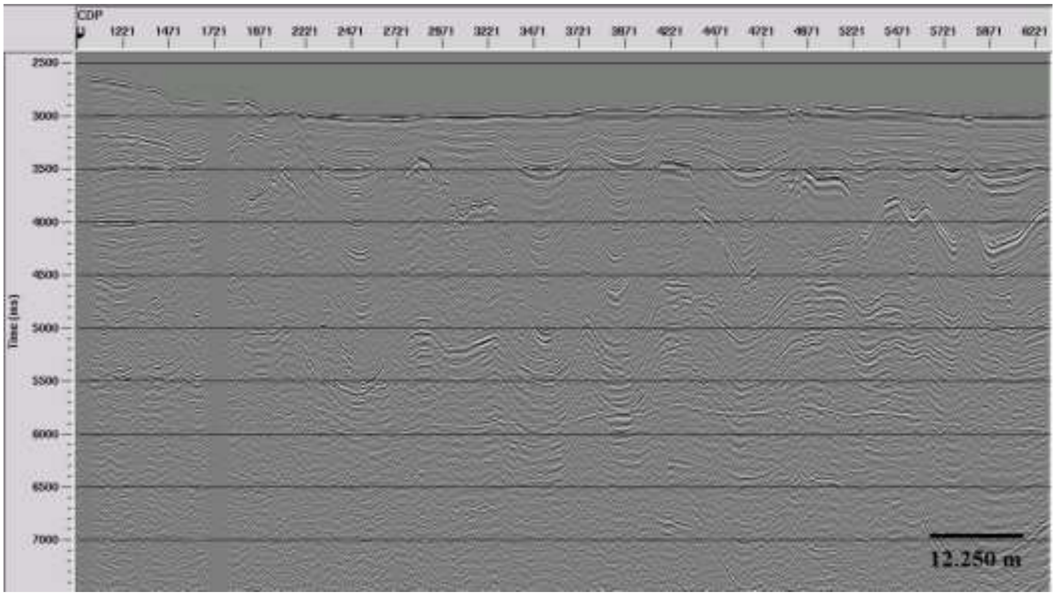

Figure 10: Final seismic section.

Conclusions

After the end of the processing, it is evident that the conventional processing flow used was efficient, as it was able to produce a quality image, capable of being representative of the region's geological outline.

The first stages of the flow showed satisfactory results to their purposes, significantly improving the quality of the image. Although they were not able to remove the first order seafloor multiple reflections in a pleasing way, the f-k filter managed to attenuate them. This occurred due to a very low signal-to-noise ratio. The seismic survey responsible for the data acquisition had been designed to serve a project, which aimed to map a shallow seafloor hence there is an extremely low signal-to-noise ratio, especially for longer times due to the fact that the survey had not been parameterized for such. Thus, it is still possible to observe seafloor multiples even in the final sections, especially in the pre-stack migrated section.

Regarding the migrations, the pre-stack migration showed better results than the post-stack migration, producing a seismic image with better attributes, lower noise and greater temporal resolution. Nonetheless, after the application of filters and gains, both migrations produced seismic sections capable of being properly well interpreted.

Therefore, it is understandable that seismic data processing is a thorough geophysical tool and, while the flow worked to yield a good final seismic section, it should not be followed in every single seismic line. Improvements and implementation of other steps are extremely welcomed in order to attend the interpreters' needs and close the gap between the final section and the geological outline.

Acknowledgments

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