Enhancing seismic interpretation by pseudo-3D seismic volume generation from 2D Sub-Bottom Profiling (SBP) data: a case study from Santos Basin, Brazil.

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Abstract

Sub-Bottom Profiling (SBP) data is commonly used in oil & gas industry to support geohazard studies, for example. Since these projects regularly have several lines, seismic interpretation then becomes very cumbersome. Additionally, such seismic data presents specific parameterization to highlight shallow features, e.g., sampling rate in microseconds and CMP (Common Mid-Point) distance in centimeters scale (about 0.5 m spacing). In this scenario, regular interpretation process is very challenging and any improvements in the workflow can help interpreters when working with these data. Due to the SBP parameters, a traditional approach to generate a pseudo-3D seismic volume can result in large datasets, with high computational cost. A geostatistical approach, following two different philosophies, is then presented to overcome these setbacks. The results are compared in the sense of providing interpreters with agility and robustness during interpretation of SBP data from Santos Basin, Brazil.

Introduction

High-frequency seismic data, or Sub-Bottom Profiling (SBP), represents 2D seismic reflection data acquired by transductors working with in a frequency range from 1 to 12 KHz (Lurton, 2002). The information obtained from SBP are of vital importance for submarine engineering projects once they provide high-resolution geological information of the shallow layers close the ocean bottom. Focusing on seismic interpretation, the 2D lines from SBP surveys are commonly loaded in separated files on the interpretation packages, reaching sometimes a total of more than thousand lines. This amount of data imposes some issues regarding data management and handling, contributing to increase the time spent in the interpretation phase, and making it difficult to quality control the interpretation products.

The case study is related to the generation of a pseudo-3D seismic volume from high-resolution 2D seismic lines. In total, the project has 55 lines, with 53 lines following a NW-SE trend, and 2 lines in the orthogonal direction (Figure 1). Blue square is highlighting the area enclosed by the lines used to generate the seismic volume (26 lines). The choice for the area to create the cube is led by the fact that the orthogonal line (reference or tie line) is crossing just few lines in the survey. The reference line (bold line) is utilized for mistie corrections of NW-SE lines inside the blue square. Acquisition geometry exhibits a line spacing ranging from 140 m to 160 m, approximately. CMP distance is about 0.5 m and the sampling rate is 46 microseconds, and 225 ms total recording. Thus, there is a direction (CMP or NW-SE) with high density of information, and the orthogonal direction (inline or NE-SW) with more spaced information. This, undoubtedly, confers some bias in the volume generation process. The challenge is generating the pseudo-3D seismic volume while honoring the data from the input seismic lines and keeping the consistency between the interpolation across the lines. To accomplish that, it is presented a methodology where a geostatistical procedure (Krige, 1951 and Matheron, 1963) is used to control the interpolation between the lines.

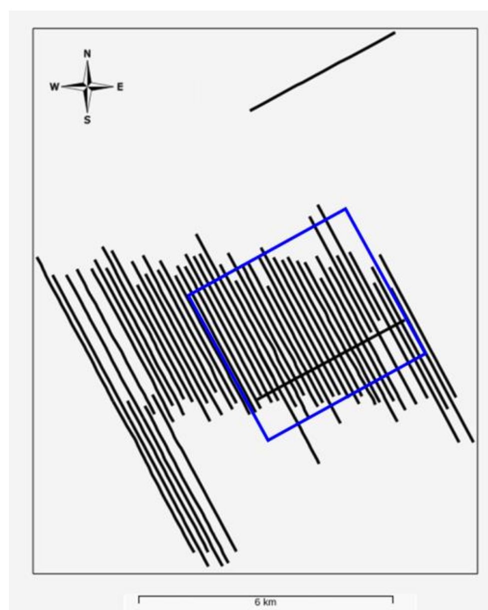

Figure 1 – Map showing all lines in the survey (reference line is in a bold style in the orthogonal direction), and the ones selected to generate the seismic volume (blue square). The lines are located at the Santos offshore basin, Brazil.

Method

The workflow followed in this case study is presented in Figure 2. Five main procedures have been applied to the input data to start from SBP 2D seismic data to reach a pseudo-3D seismic volume.

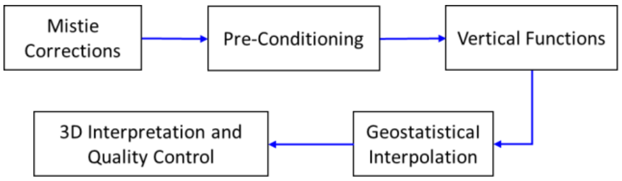

Figure 2 – Workflow showing the procedures to generate the 3D volume.

Before mistie corrections, is recommended an inspection of the data to guarantee all lines have the same seismic amplitude range. It is commonly done in the processing stage, but when working with 2D surveys, it is not unusual to work with different vintages and different processing schemes. In this case, the processing was done for all lines and they present a common signature like in Figure 3. In the map in Figure 3, one can see the location of the line (bold line) inside the blue square.

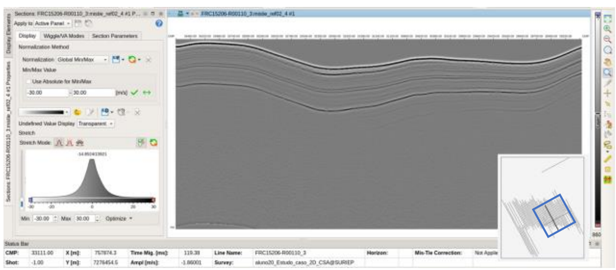

Figure 3 – A line example showing the seismic amplitude variation.

Mistie Corrections

Mistie corrections (Gibson, 1941 and Bishop and Nunns, 1994) represent the adjustments regarding seismic datum, to guarantee all lines are presenting the seismic response due to the same seismic reference. The adjustments are introduced for each line, and are related to vertical shift, phase rotation and amplitude scaling factor identified in each tie point (crossing point) from the lines with the reference line (bold line from Figure 1). The vertical shift and phase rotation regard to the time shift between survey and reference lines, while amplitude scaling corrects for small distortions since all lines have the same amplitude range. All lines crossing the reference line are corrected by a global least square approach bringing them to the same seismic datum. Figure 4 presents the same line before (above) and after (below) mistie corrections, showing the continuity of reflections from survey and reference lines.

Pre-conditioning

Pre-conditioning refers to the application of filters to enhance seismic amplitude events. Focusing on the 3D seismic interpretation using 3D auto-trackers, a fairly distribution of amplitudes is a plus to help on the automated process. So, a spectral balancing has been applied to the data just to enhance for low and very high frequencies. The attribute tends to sharp subtle events and make them easy to track once the volume is created.

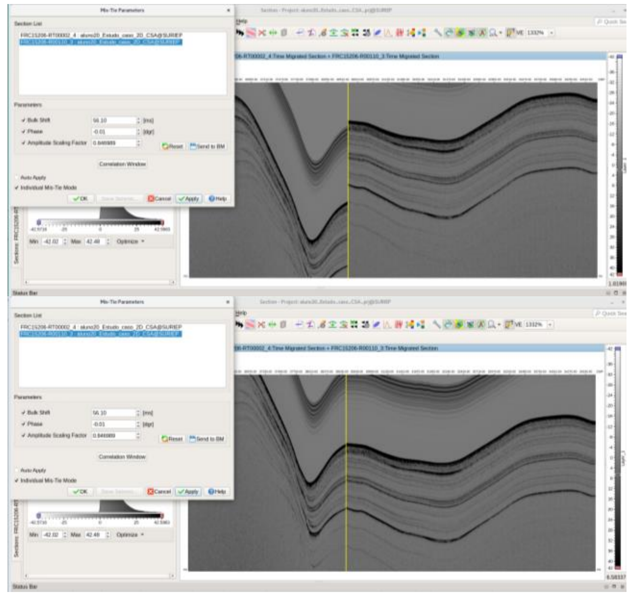

Figure 4 – Seismic line before (above) and after (below) mistie correction.

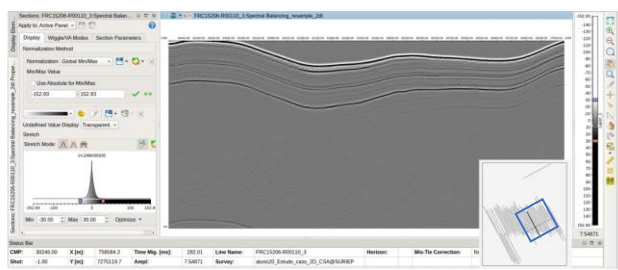

Figure 5 **–** Spectral balancing attribute applied to data from Figure 3 to sharp and enhance seismic reflections.

Vertical Functions

Next step in the workflow is the extraction of 2D vertical functions from seismic lines. Vertical functions are vectors storing the amplitudes from each seismic line. The extraction can be done in specific positions, and sampling can be controlled. By working with vertical functions, it is possible to select a sub-set of the data, still honoring the original set, but reducing the amount of data. In this case study the vertical functions were extracted at every 20 CMP's (regarding to original distance of about 0.5 m) and keeping the original sampling rate of 46 microseconds. To exhibit the comparison between original seismic data and the respective vertical function, the Figure 6 presents both data along the same line. As one can see, the reflections are maintained, and the structure is preserved. The use of such vertical functions as mentioned, can reduce computational cost while preserving the data quality.

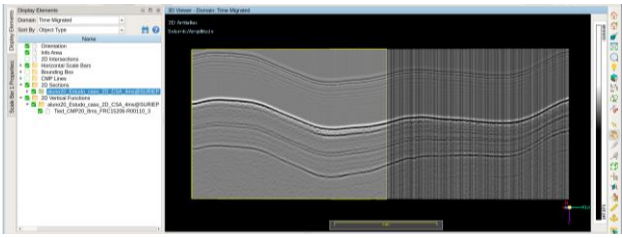

Figure 6 – Comparison between seismic line (left) and vertical function (right) extracted from the same line. The continuity of reflection is guaranteed to keep structure unchanged.

Geostatistical Interpolation

The geostatistical interpolation is realized from the extracted vertical functions. The lines (and vertical functions) selected to generate the seismic volume are the ones displayed inside blue square in Figure 1. There are some alternatives to control how interpolation will run along vertical functions. It is possible interpolating the functions in the following ways: i) horizontal direction (or with no structure); ii) following a pre-determined structure. If the structured option (model-based) is chosen, it is possible to build a layered model using constant intervals or providing surfaces. In this case study, both methods have been derived to give an impression about both techniques.

The simplest way to interpolate the vertical functions is the non-structured option, where the samples are interpolated following no trend. The interpolation runs in the horizontal direction, from 0 to 225 ms (total recording). Sub-layer thickness and averaging interval were set to a double of sampling rate, i.e. 92 microseconds, semivariogram type as exponential and semivariogram range as 200 m. The result volume of the non-structured geostatistical interpolation is shown in Figure 7. The inline direction of the volume is parallel to the 2D line direction (green arrow in the orientation axes), and the crossline direction is the orthogonal direction (blue arrow in the orientation axes) where geostatistical interpolation acts. When analyzing the volume, it is evident that interpolation tends to fill the gaps between lines providing a continuity from one line to the next. However, horizontal plane (slice view) doesn't give much information. It is because of horizontal interpolation is not capturing the correct trend of the layers.

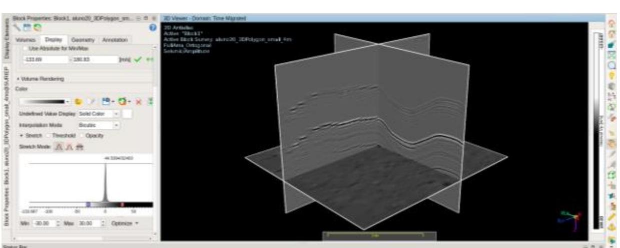

Figure 7 – Seismic volume generated from horizontal interpolation of vertical functions.

The second way to run geostatistical interpolation is following the model-based method. To control the interpolation, it is necessary to define a model layer structure within which the 3D microstructure kriging will run to perform the calculations. Two 2D horizons were interpreted (h1 and h2) in the seismic section/lines to build a simple layered structure (Figure 8). Therefore, 3 reference layers were created; the first, from the datum 0 ms to h1 (first reference horizon); the second, from h1 to h2 (second reference horizon); and the third, from h2 to the end of the model, in about 225 ms. The layer topology is set for each layer, i.e., the sub-layers are estimated and rearranged according to it. Different types of layer topology can be used; parallel to top, parallel to bottom, and proportional, for instance. The proportional topology was preferred to display the results. Once the structure is defined, the sets of vertical functions are submitted to interpolation. The semivariogram type and range are the same as the non-structured method, i.e., exponential and 200 m, respectively. The sub-layer thickness and averaging interval parameters are also the same, 92 microseconds for both.

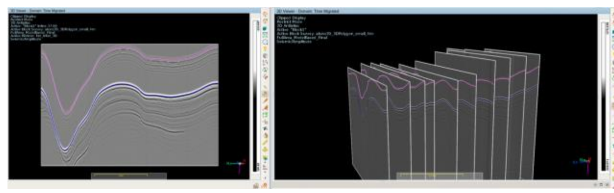

Figure 8 – Layer structure definition using two interpreted 2D horizons. Front (left) and perspective views (right).

The result volume of the model-based geostatistical interpolation can be seen in Figure 9. When comparing Figure 9 with Figure 7, it is evident that the model-based method presents a higher geological consistency as it better displays the continuity of the layers. In the crossline direction (blue arrow direction), the layers are more coherent with trend and shape easily identified. In the slice direction, the continuity and orientation of the reflections are now evident, in comparison to Figure 7. The results clearly show that geostatistical interpolation following a pre-defined structure should be preferred to the non-structure method.

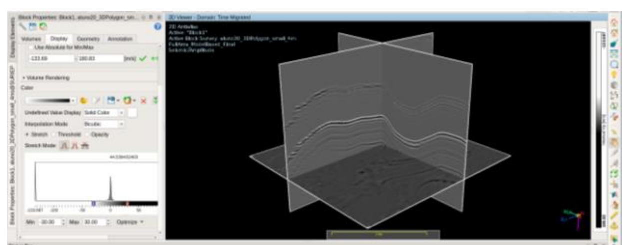

Figure 9 – Seismic volume generated from model-based interpolation of vertical functions. Clearly there is an improving in the continuity of the layers compared to Figure 7.

3D Interpretation and quality control

With both volumes generated from each geostatistical procedure, it is quite evident that the model-based method presents the better results. This volume was used to perform 3D interpretations and validate results in comparison to 2D previous approaches. The point here is to gain agility and robustness when working with pseudo-3D volumes in comparison to regular 2D workflow. To validate the results, an arbitrary and free criterion was chosen, only as a reference and capable to control the quality of the results. The criterion is the comparison between 2D interpreted (gridded) horizons to the 3D horizons generated by auto-tracking tools. The final shape and time consumed to create the horizons were the information considered in the comparison.

First, the two horizons h1 and h2, interpreted in the seismic lines, have been gridded using ordinary kriging to generate two surfaces. Then, with model-based volume, the 3D version of horizons h1 and h2 have been built using automatic tracking using an auto-tracker tool following the shape of adjacent seismic traces as a guide. Figure 10 shows the 3D horizons generated by auto-tracking. It is clear the smoother shape of the horizons generated directly from the 3D data. It is due to the soft variation of layers in model-based volume.

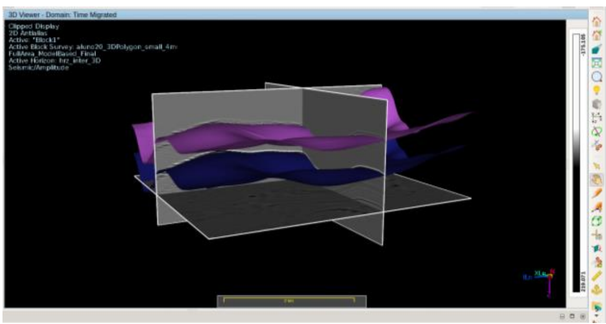

Figure 10 – 3D horizons generated by auto-tracking tools from model-based volume from Figure 9.

Both horizons h2, 2D interpolated (top left) and 3D auto-tracked (top right), and the residual difference between them (below center), are shown in Figure 11. The color table presents positive values downwards (blue) and negative values upwards (red). The residual map then presents higher values close to regions with no data, i.e., where the lines are not covering the whole area. The black square represents the volume area (same blue square in Figure 1). There are still some residuals along the line's direction representing the impacts of pursuing a 2D or 3D approach, however these mismatches ranged from 4.6 to 6.5 ms. Finally, the interpolation of seismic values (to generate 3D horizons) and the interpolation of time values (to generate 2D horizons) tend to be different in principle, which can explain subtle residual in the center of the volume area (green values). The residual for this green zone ranges from 1.83 to 2.76 ms.

Regarding time consuming, both techniques are not so costly. However, evidently this point is widely dependent of the number of lines treated in each study. For this case study, the average time per line to interpret the horizon was about 4 to 5 minutes. For a sub-set of 26 lines used in this case study, it gives a total between 104 to 130 minutes, plus about 3 minutes to interpolate the 2D horizons and create its gridded version. On the other hand, the 3D approach, comprising the steps; extracting vertical functions, geostatistical interpolation, and 3D auto-tracking, reaches about 30 to 40% (40 to 50 minutes) of the time consumed with 2D approach. It represents undoubtedly a considerable gain for the interpreters, allowing them to expend much more time in QC'ing the results and adjusting where needed. Finally, the times described here can obviously change from machine to machine due to hardware and network (if working in virtual environments) specifications.

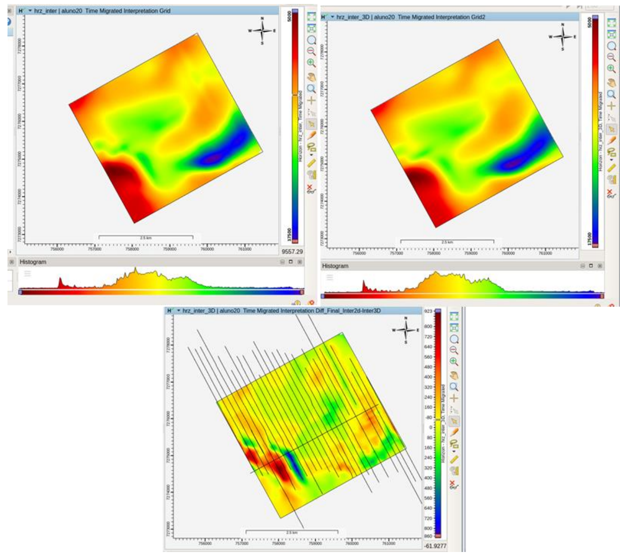

Figure 11 – Comparison between horizon h2 generated by 2D interpolation (top left), by 3D auto-tracking (top right), and the residual difference between both (below center).

Conclusion

This case study is dedicated to highlighting the steps in the workflow to create a seismic cube from 2D SBP seismic data. The described processes here represent just a possible workflow, not covering all possibilities. The idea of comparing approaches is just to reach the best-in-class solutions to handle such type of data. Therefore, the methods presented here do not exhaust the alternatives and updates are suggested.

At the end of the workflow, two seismic volumes were created, one by simple horizontal interpolation of vertical functions and another by model-based interpolation, where a layering structure is given to control the calculations. The second option presented best results with a clear continuity of the layers, including highlighting some reflections where they were not visible with the first volume approach. The model-based option was then selected to be considered for 3D automatic horizon generation. The horizon surfaces, obtained from interpolation of 2D interpretation horizons in the seismic lines and from 3D automatic tracking using model-based interpolated volume, were compared regarding shape and time spent in the process. The model-based volume plus 3D auto-tracking procedure produced a very good result, with minor residuals according to Figure 11. The time spent in the whole process was about 40% of regular time for 2D approach, representing a robust and agile way to treat this type of data.

Despite variations in the workflow, it represents indeed an advance in handling SBP data, especially for big projects with dozens and hundreds of lines

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