Essays on SBP imaging

Eduardo Filpo, Fernando Collo, Gilberto Lima e Claudio Duarte, Petrobras.

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Abstract

Sub-Bottom Profiling (SBP) consist of a set of high-resolution seismic records with frequency content in the range of kilohertz, and it have been a widely used tool in oil production projects, mainly for subsea devices installation.

For subsea projects, SBP provides information that, in general, is not given by conventional 3D seismic, such as detailed stratigraphy of the layers close to the seabed, precise positioning of faults, presence of anthropic structures, etc.

Petrobras has a significant collection of SBP data from several technology generations, processed by the service companies during the acquisition phase. The main motivation of this work is the development of a pre-processing procedure for SBP datasets, in a such way that they can be processed and interpreted with conventional tools available in internal systems.

The first experiments for imaging SBP data carried out at Petrobras using in-house tools are presented. Two different approaches were investigated: introduction of 3D geometry in a set of 2D lines and the regularization with redatuming by means the cascading application of migration and demigration algorithms.

Due the behavior of the amplitude spectra of SBP data, we decide to develop imaging algorithms without the use of anti-aliasing filters. Instead of that we avoid operator aliasing by interpolating the recorded data by means of non-uniform basis splines. The results show the feasibility of transforming the acquired data with non-uniform spacing and variable source-receiver depth, into a regular and uniform zero-offset data with constant source-receiver depth.

Introduction

Acoustic profiling systems are commonly classified according to the method that the sound energy is produced, i.e., piezoelectric, boomer, spark, air gun, etc. The various sources provide different degrees of resolution and penetration, which are related to the spectral differences of the generated acoustic energy.

Within this context, SBP equipment can be classified as tools for reflection seismic, which operate with acoustic signals in the frequency range between 3.5 kHz to 12 kHz using a transducer source of piezoelectric type.

Due to the high frequency content, the SBP's acoustic signal does not penetrate so much into the ground, reaching a maximum of a hundred meters inside muddy and homogeneous lithologies. As a compensation to the low penetration, the SBP has a very high resolution in time. As the resolution is related to the inverse of the dominant frequency, which is in the range of kilohertz, SBP is the ideal tool for soil investigation in the areas of subsea projects for oil production.

Along the last twenty years, SBP technology has advanced a lot, in special the acquisition platform due to the use of autonomous underwater vehicles (AUV). The main advantage of the acquisition from an AUV is the short distance between the vehicle and the seabed, which mitigates energy losses and improves de signal-noise ratio (SNR).

Another important advance in the SBP technology is the introduction of the chirp pulse (Compressed High Intensity Radar Pulse). The chirp pulse has the advantage of amplifying energy by increasing the length of the pulse, typically from 10 to 50 milliseconds, as consequence there is a relevant increase of SNR. This happened in the industry around the end of the nineties and modified the seismic quality information in a very positive way (Lurton, X., 2002).

Another important point is the improvement in the acoustic directivity obtained by means of news piezoelectric transducer array designs, for both projectors and receivers. This improvement considerably contributes for the SNR increase.

In relation to acquisition geometry, SBP data consists of a set of zero-offset records with source-receiver pairs distributed in a vertical plane, which contains the planned acquisition line. The depth of these pairs is controlled by both, the topography of the seabed and the presence of obstacles on this surface. With AUV the recorded data has an irregular spatial distribution, as the depth and the speed are variable. The nominal depth of the source-receiver pair is defined by a pressure sensor.

Figure 1 shows a typical SBP section acquired in the Santos basin, being this section used in this work to illustrate the application of the developed algorithms. Table 1 contains the main acquisition parameters used in the survey of the selected SBP line, and the pulse used in this survey was of the chirp type.

Methodology

Using only conventional procedures for in-house 3D seismic data processing at PETROBRAS, we create a routine to manipulate the headers of 2D lines from an SBP data survey, in order to allow such data to be treated as if they were 3D. The flowchart of this routine is shown in Figure 2. The ability of viewing a whole 2D survey promoted a great performance improvement in the SBP interpretation work. In addition, this change facilitates the image quality control in the processing of raw data. Finally, it is important emphasizing that before this modification, Interpretation used to be carried out line by line without any image quality control.

In another initiative, data regularization is addressed as an imaging problem. The aim is to develop a tool for carrying out the regularization in a single step through the application of local operators in the time domain (Silva, 2013). Such operators can be obtained through the cascade application of migration and demigration algorithms, both subjected to suffer from aliasing operator effects when the spatial distribution of traces is not adequate. In this work, the regularization with redatuming is carried out in two steps:

1) Kirchhoff migration in the Cartesian system considering irregular acquisition geometry with non-uniform distance between records.
2) Kirchhoff demigration in the Cartesian system to a fixed datum (constant depth) with uniform distribution of traces.

In the implementation of a Kirchhoff-type algorithm, the problem of operator aliasing can be avoided in two different ways: through the application of an anti-aliasing filter, or spatially interpolating input data. The anti-aliasing filter is a high-cut filter with a variable cut-off frequency, which varies according to the dip of the event sampled by the operator at each point.

The choice of the most appropriate strategy depends on the spectral characteristics of the recorded data and the geometry of acquisition. The strategy based on the application of an anti-aliasing filter is computationally more efficient and presents satisfactory results when the spatial sampling interval is small enough to ensure correct imaging of low-angle events. Another aspect important to consider in choosing of the filtering strategy is that the input data should have a rich frequency content, especially at lower range.

Typically, SBP data does not satisfy either condition. Figure 3 corresponds to the amplitude spectrum computed in the window defined by trace numbers from 1800 up to 2800, and times between 2,660 and 2,685 seconds in the section presented in Figure 1. Observe that up to 1 kHz there are no significant amplitude and that the maximum observed frequency is close to 10 kHz. To correctly migrate this kind of data with an aperture of 15 degrees preserving this maximum frequency, a spatial sampling interval of 15 cm is required, while the average distance between source-receiver pairs in a typical SBP survey it is greater than 50 cm. For these reasons, it was decided to use the strategy of implementing a migration algorithm making use of interpolated data without applying any anti-aliasing filter.

To perform the SBP data interpolation in the migration algorithm, it was used a library for non-uniform basis splines with variable degree, being used grade one for the spatial dimension and grade three for time. The implementation of this library followed the script described by Piegl and Tiller (1996).

The first version of the implemented migration algorithm was as simple as possible for irregular geometry data with receiver source pair at variable depth using non-uniform data interpolation, it is an algorithm for Kirchhoff migration in depth, considering constant velocity and constant weight function. The same premises are used in demigration, in which case the problem is simpler because the input data is regular and is properly sampled.

Examples

Figure 4 shows the result of the migration of the input section presented in Figure 1, using the following parameters: velocity of 1497 m/s, aperture angle of 45 degrees and interval between interpolated traces of 10 cm.

It is worth to emphasize that migration of SBP data is not the usual procedure. In general, we work with only the application of static corrections in envelope sections. To compare the migrated image with something close to the usual, a pseudo depth section was generated by applying static corrections on input data and then converting the result to depth (Figure 5).

When we compare Figures 4 and 5 in the scale in which they are, it is not possible to observe significant differences between the migrated and the converted section. Figures 6 and 7, show in detail the migrated and converted sections, respectively. They cover the region between the positions of 975,0 and 1100,0 meters and the depths of 2012,0 and 2027,0 meters.

Comparing Figures 6 and 7, the feature that most attracts attention is the presence of two diffractors located at positions 1016 and 1070 meters. The energy on the rightmost diffractor is fully collapsed in the migrated section, while the of the leftmost diffractor is partially collapsed, indicating that the trajectories involved in the generation of this diffraction must be outside the acquisition plane. This type of observation is not evident when we only look at the converted image. Others relevant aspects are the differences in dipping reflectors position, the better continuity and resolution of reflectors in the migrated section.

Results

The aim is to regularize and change the datum the SBP data, which is achieved after the demigration of the migrated section. It is important to emphasize that this aim cannot be achieved through a simple static correction, since this process only correctly works for events with vertical trajectories. Reflections of dipping horizons or diffractions do not have their trajectories correctly treated by static correction.

Figures 8 and 9, show a 10-millisecond window between positions 1050 and 1090 meters of two demigrated sections with datum at depths 1990 and 1994 meters. Note that in addition to the fact that events are observed in longer times in the demigrated section with a shallower datum, there are evident differences in observed diffractions. There are significant time differences in the trajectories due to datum changing, causing the diffraction hyperboles to appear with different curvatures for the different datum depths.

Conclusions

The results show that it is possible to regularize sections of SBP data changing the reference datum, through the cascade application of migration and demigration processes. The migration was implemented using non-uniform basis spline with variable degree for data interpolation.

The regularization with redatuming of SBP data is a required step for further processing. After that, it is possible to apply all conventional tools for seismic processing on this reconfigured SBP data.

The results show that the proposed migration algorithm improves the image resolution and the interpretation of SBP data using these sections can be greatly benefited.

Acknowledgments

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References

Lurton, X., 2002, An Introduction to Underwater Acoustics: principles and applications, second edition, Chichester, UK, Springer.

Piegl, L. and Tiller, W., 1996, The NURBS Book**,** second Edition. Berlin: Springer.

Silva, E.F.F., 2013, Data regularization using local operators: Expanded Abstracts of the 13th International Congress of the Brazilian Geophysical Society.

Number of pings	Ping rate (pings per second)	Average survey speed (knots)
3452	4.7	3.98
Frequency sweep range (kHz)	Bandwidth (kHz)	Pulse length (ms)
1-10	9	20

Table 1: Acquisition parameters of the selected SBP line.

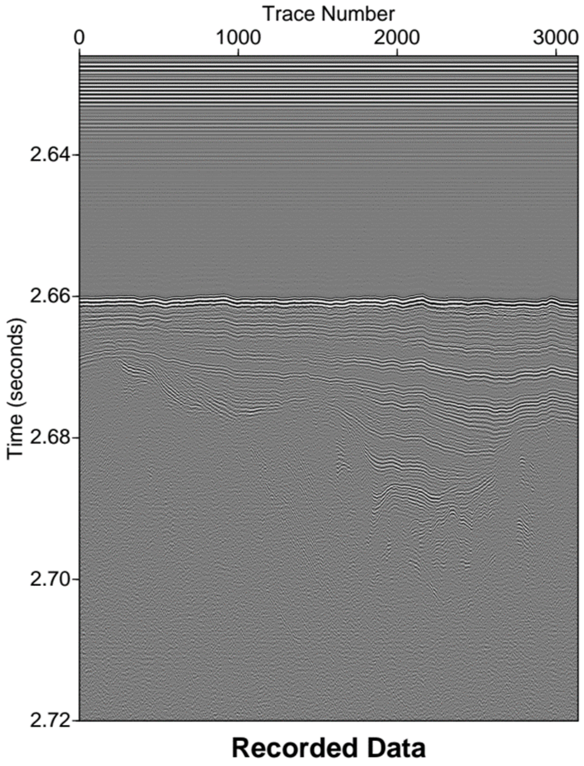

Figure 1: Selected SBP section after automatic control gain (AGC) application.

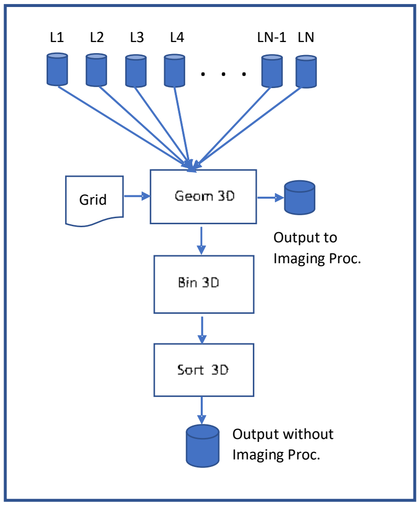

Figure 2: Flowchart of the processing tool to transform 2D lines into 3D volumes.

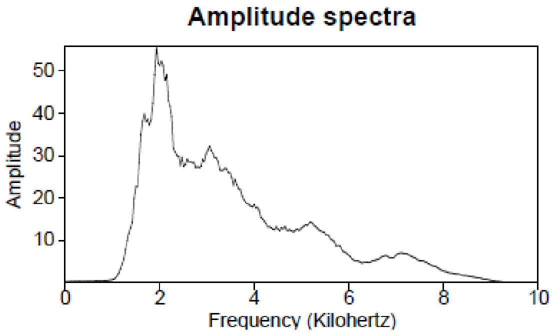

Figure 3: Amplitude spectrum.

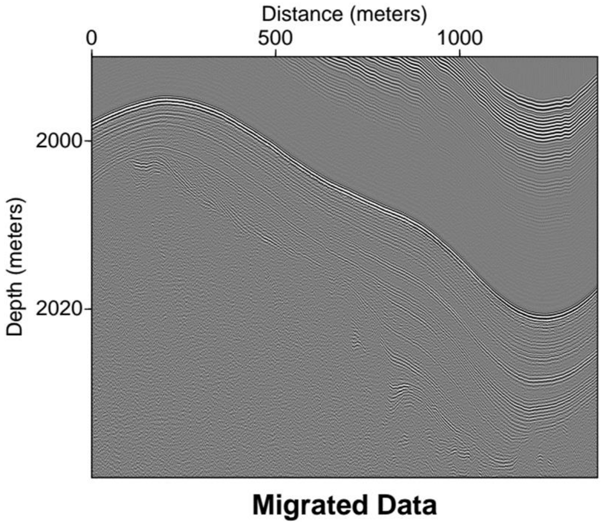

Figure 4: Migrated section.

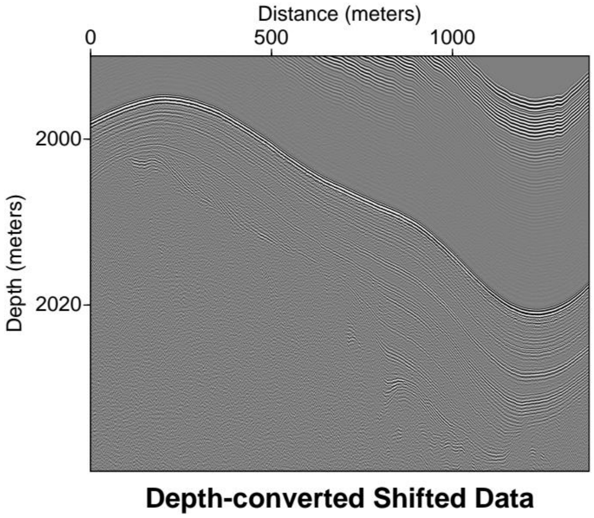

Figure 5: Pseudo depth section: input data after static correction and vertical time-to-depth conversion.

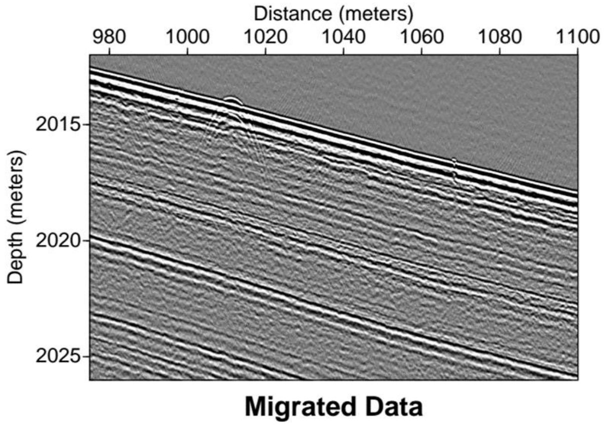

Figure 6: Migrated section in detail.

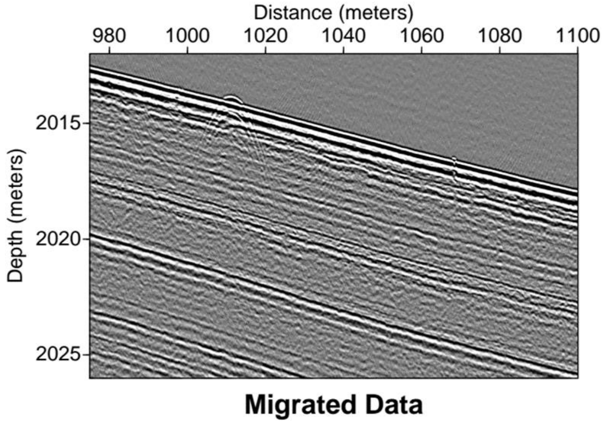

Figure 6: Migrated section in detail.

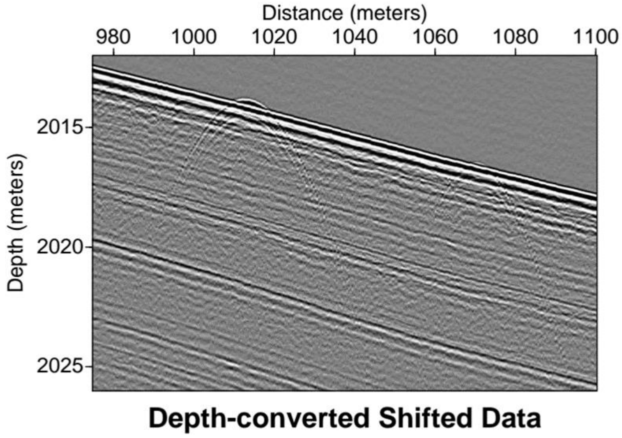

Figure 7: Pseudo depth section in detail.

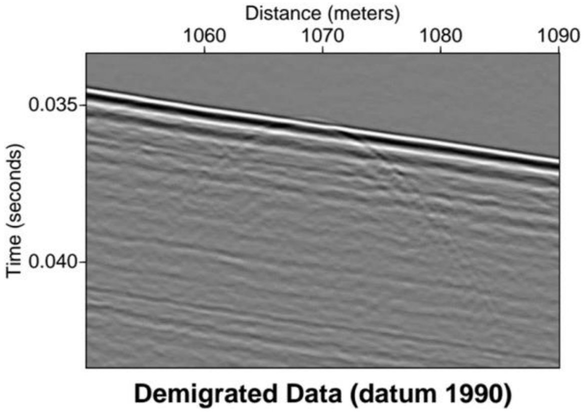

Figure 8: Detail of the demigrated section with datum at a depth of 1990 meters.

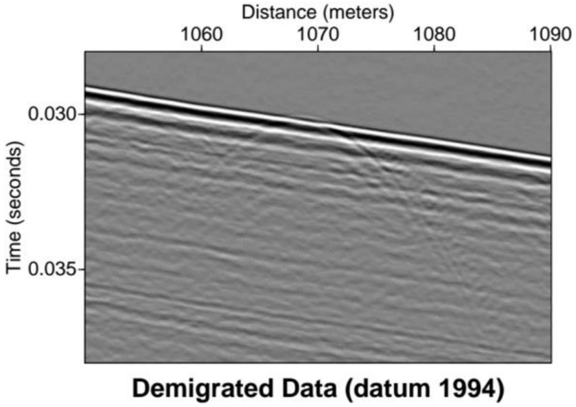

Figure 9: Detail of the demigrated section with a datum at a depth of 1994 meters.