Detection of karstified features using volumetric segmentation techniques in a multi-azimuth seismic

Marcio Spinola*[1], Mitchel Xavier[1] and Luiz Eduardo Santos[2], [1]Halliburton, [2]Petrobras

Abstract

Karst geological features might be highly present in the pre-salt zone due to its intrinsic relationship with carbonate environment. So, the correct identification of its position and the correct interpretation of its geological characteristics are very important to guarantee that any kind of serious problems may not happen during the production phase, or at least to minimize the risk. Seismic data analysis plays an important role this type of study. Because of that, the number of multi-azimuth seismic campaigns have been increasing during the last years, which means more seismic data to analyze. After seismic processing and depth imaging stages, during the seismic interpretation workflow, it is possible to apply some special techniques that can contribute to a more reliable analysis of the karstified zones. In this work, after the seismic simulation of a multi-azimuth synthetic acquisition on a set of simulated karst geological objects introduced in the velocity model, work done in a research project in cooperation with involved companies, special interpretation techniques, such as spectral decomposition and geo-anomalies extraction were applied to eight synthetic seismic volumes related to a multi-azimuth seismic modeling. The final seismic volumes were generated by the application of RTM migration. The applied interpretation techniques delivered a satisfactory result in terms of identification of the karstified objects and its complicated geometries.

Introduction

The complexity of karst related features can represent a strong challenge during reservoir analysis and even during the production phase. Inside the karst geological environment, it is possible to find some very special type of geological configuration and geometries associated to dissolution of carbonate rocks like fractures, caves and dolines. The correct identification of these structures contributes to a better interpretation and to a more reliable reservoir characterization.

In order to perform a correct interpretation of the geological environment, it is almost mandatory to have good quality data and, also, a sufficient amount of data with as much as possible resolution, frequency content, and azimuth. In terms of seismic data, in the past, it was very common to have a seismic volume from a single seismic acquisition, i.e., from a narrow azimuth acquisition. In other words, the available seismic data was the result of only one seismic acquisition direction. But it is well known that it is possible to have different qualities of the seismic results depending on the acquisition direction. Because of this, multi-azimuth seismic acquisitions are becoming more and more frequent. Also, studies of illumination and seismic simulation in an exploratory phase, before the actual seismic survey field acquisition, are as well important for making sure that target of the geological plays is being correctly illuminated, and energy hitting reflector is evenly distributed so targets can be visualized, anisotropy identified, etc (SPINOLA et al, 2014).

The quality of the generated seismic volumes is directly related to the degree of accuracy of the velocity model and to the chosen migration algorithm, which is responsible for performing the depth imaging. Once with the seismic volumes, it is possible to apply several interpretation techniques to analyze the data such as spectral decomposition, seismic attributes generation, and geo-anomalies extraction.

Basically, seismic attribute (CHOPRA and MARFURT, 2005) is an information, or a quantity, calculated or extracted directly from seismic data. It is widely used to help in the interpretation process because it can reveal, for example, geological details that haven't been seen when analyzing the original seismic data. Spectral decomposition (CHOPRA and MARFURT, 2007) is a technique that has important applications in seismic interpretation, as it can often identify and delineate different types of geological bodies, such as channels, for example (USHIROBIRA et al, 2003). The study of geo-anomalies is very important for better characterization of the reservoir. When detected and correctly mapped, they help identify regions that may contain hydrocarbon accumulations and, likewise, can prevent problems related to geohazards.

The goal of this work is to analyze eight seismic volumes, generated by multi-azimuth seismic modeling and RTM migration (BAYSAL et al, 1983). The input for seismic modeling was a velocity model which contained karst features, i.e., caves and dolines. The karst structural model used to build the velocity model can be seen in Figure 1. Interpretation techniques such as spectral decomposition, seismic attribute generation, and geo-anomalies extraction were applied to try to have a better comprehension of data and to study the possible impacts of the karst features in terms of reservoir characterization.

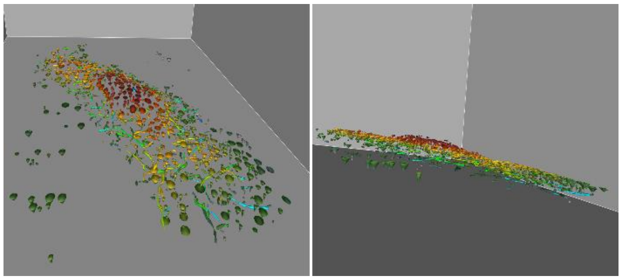

Figure 1: *Structural model based on a fractured and karstified reservoir.*

Method

The first step, as mentioned before, was to simulate eight 3D seismic acquisitions with different values of azimuth. The first azimuth value was defined as 0°. After that, a clockwise rotation was applied adding 45 degrees to obtain the next value of azimuth. The last value was equal to 315°. In Figure 2, it is possible to see all the azimuths. Tridimensional acoustic modeling (AMINZADEH et al. 1994) was applied to generate synthetic seismic data for each value of azimuth.

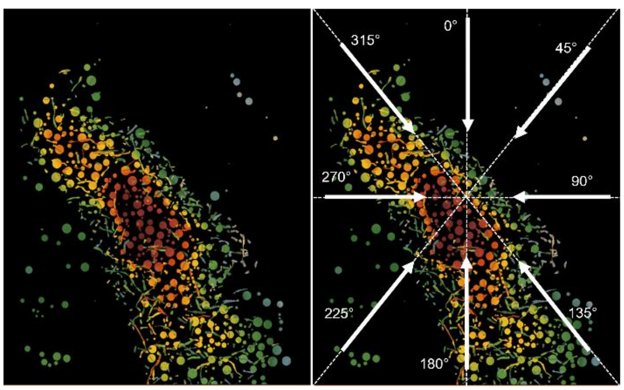

Figure 2: *Bidimensional view of the karst model (left) and all the seismic acquisition directions overlaid on it (right).*

After that, the synthetic seismic data was migrated, separately for each azimuth, using RTM migration, and the result was one seismic volume for each acquisition direction. All the eight generated seismic volumes can be seen in the Figure 3. In each volume, it is possible to identify structures related to the karst model present in Figure 1. These volumes were the main object of this analysis. They were the inputs for the subsequent results.

The spectral decomposition technique, based on PARTYKA (1999) and which uses the discrete Fourier transform (DFT), was applied to the seismic volumes of all azimuths. The DFT transforms the seismic data from time domain to the frequency domain, where, sometimes, it can be less difficult to identify complex structures. The calculation was performed in a window of 32 samples and centered in a specific horizon. The frequency range defined for the calculation was from 1 to 25 Hertz.

A geo-anomaly can be considered as a small region with clear geological differences if compared to the surrounding area. Such differences can be due to, for example, structural or compositional variations and the presence of hydrocarbons. For the detection of the 3D geo-anomalies, two types of volumes were used: the first type were the volumes from RTM migration. The second type were volumes of a seismic attribute known as reflection strength (TANER et al, 1979). Basically, the reflection strength attribute, also known as envelope amplitude, calculates the total energy of a given reflection and it can help to detect lithological variations that probably would be difficult to identify in the input seismic data (BARNES, 1991). The input for the reflection strength attribute calculation was also the RTM volumes.

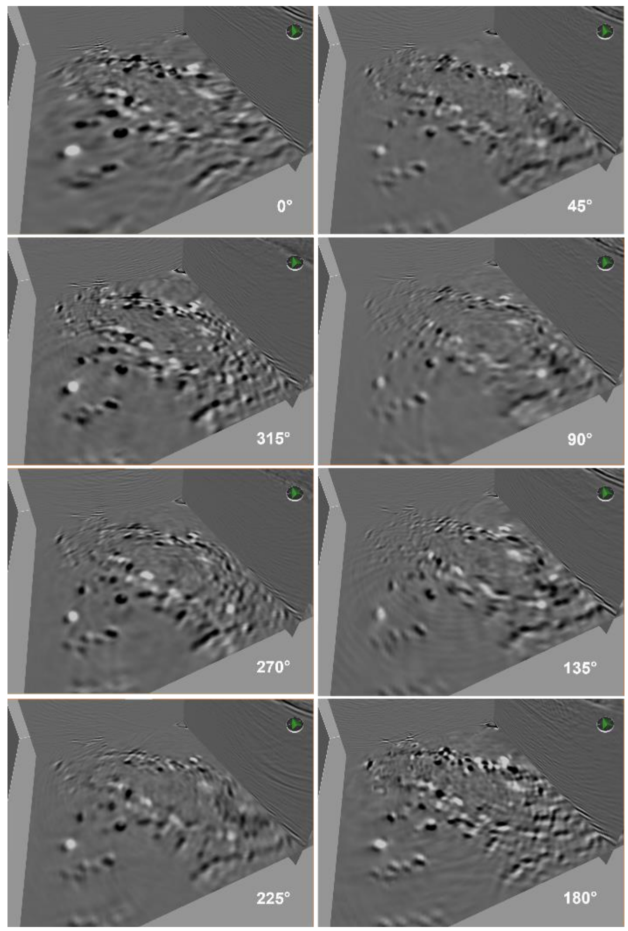

Figure 3: *Tridimensional view of the eight seismic volumes, one volume for each azimuth value. Depth slice is in the first plane.*

In Figure 3, it is possible to see differences in the seismic response depending on the analyzed azimuth value. In the next topic, it will be possible to verify that those differences can be more highlighted using the interpretation tools of the proposed method.

Results

The results of spectral decomposition can be seen in the Figure 4. It should be noted that the best results were found sometimes for frequency equal to 7 Hertz and sometimes for the frequency equal to 10 Hertz, depending on the azimuth value. The geological objects related to the karst model are relatively well identified in all azimuths, although some regions do not have enough resolution to identify dolines very close to each other and/or caves very close to each other or close to dolines. In regions with less agglomeration of structures, which generally only have dolines, structures are easily identified.

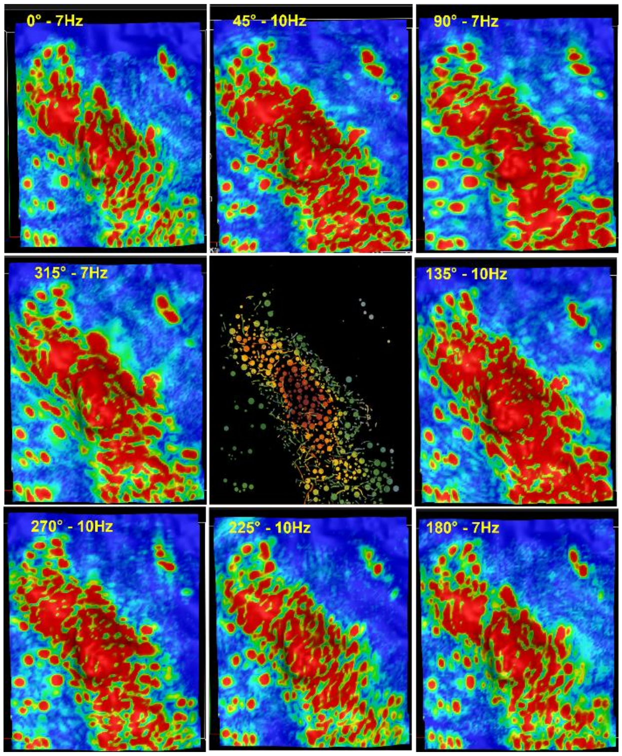

Figure 4: *Spectral decomposition applied to all volumes, in a bidimensional view. The structural karst model is in the middle of the figure, for comparison.*

As mentioned before, the identification of geo-anomalies was performed using two types of volumes. But firstly, an opacity effect was applied to the RTM volumes. This effect restricts the amplitude of visualization, allowing for better clarity. (Figure 5). After that, the geo-anomalies were extracted (Figure 6).

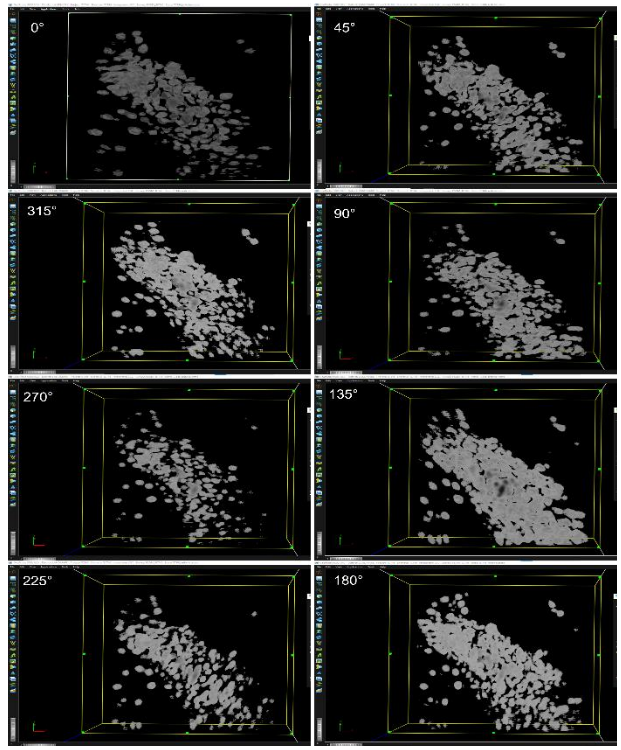

Figure 5: *RTM volumes with opacity applied.*

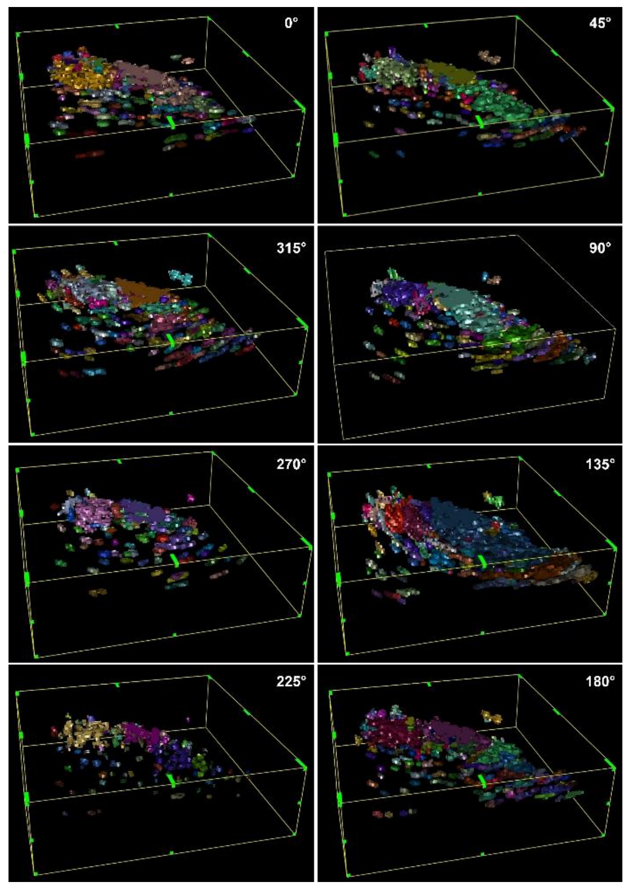

Figure 6: *Geo-anomalies extracted from RTM volumes.*

In general, the karst model structures are relatively well identified in all other azimuths. However, it is very clear that for some azimuth values, such as 270°, we identified fewer structures than for others. Because of resolution reasons, due to their dimensions being smaller when compared to the dolines, the caves end up being mixed with the dolines that are very close.

The results for geo-anomalies extraction related to the reflection strength volumes are shown in Figures 7 and 8. The same opacity effect applied to RTM volumes was applied to the reflection strength volumes.

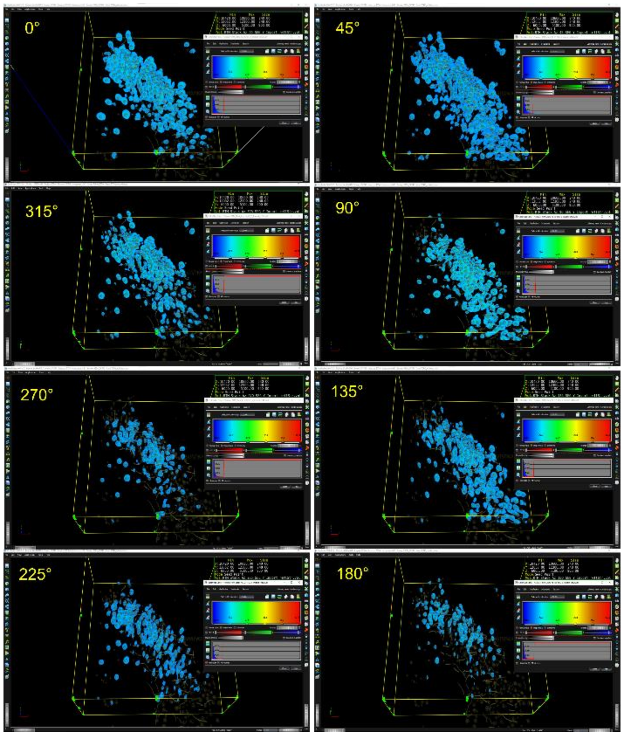

Figure 7: *Reflection strength volumes with opacity applied. The colormap in the images is just to indicate that the karst features are concentrated in the blue color zone, which means most negative values.*

We noticed that, in the same way as for the RTM seismic volumes, in general, it is possible to identify relatively well the structures of the karst model in all azimuths. However, in some azimuths, such as 180°, we identified few structures. Dolines continue to be better identified than caves.

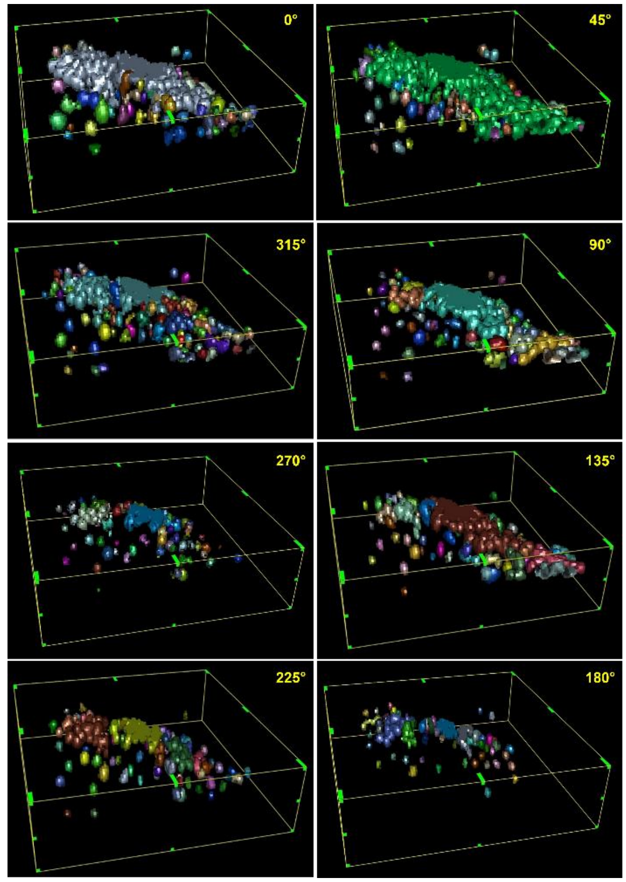

Figure 8: *Geo-anomalies extracted from reflection strength volumes.*

Conclusions

The correct interpretation of karstified features is very important because such type of structures can have an important impact in the reservoir behavior and, consequently, in the petroleum production. Multi-azimuth seismic significantly increases the interpretation power because it makes available a great amount of data from different directions which, normally, are complementary. A synthetic multi-azimuth seismic acquisition was carried out for eight different azimuths, based in a velocity model which contained karstified features in the reservoir zone. RTM migration was applied to perform the depth imaging. Spectral decomposition was applied to all seismic volumes. The technique proved to be efficient in mainly identifying dolines. Due to the structural complexity associated with the regions where the caves are located, they were more difficult to identify. Seismic volumes from RTM migration and reflection strength seismic attribute were used as input to geo-anomalies extraction. Anomalies related to dolines was easier to identify if compared to caves.

Acknowledgments

The authors would like to thank to ANP, Petrobras, and Halliburton for support during this work as well as our colleagues Carlos Seabra, Erwan Renaut and specially, we would like to thank posthumously, our colleague Caroline Cazarin for all her contribution, encouragement, and inspiring example.

References

AMINZADEH, F., BRAC, J., and KUNZ, T. 1994. SEG/EAGE 3-D Modeling Project: 2nd update. The Leading Edge, 13 (9): 949-952.

BARNES, A. E., 1991, Instantaneous frequency and amplitude at the envelope peak of a constant phase wavelet, Geophysics, v. 56, p. 1058-1060.

BAYSAL, E.; KOSLOFF, D. and SHERWOOD, J. W. C. 1983. Reverse Time Migration. Geophysics, V. 48, páginas 1514-1524.

CHOPRA, S. and MARFURT, K. J. 2005. Seismic attributes: a historical perspective. Geophysics 70:3–28.

CHOPRA, S. and MARFURT, K. J. 2007. Seismic Attributes for Prospect Identification and Reservoir Characterization. Society of Exploration Geophysics. ISBN 978-1-56080-141-2.

PARTYKA, G.; GRIDLEY, J. and LOPEZ, J. 1999. Interpretational Applications of Spectral Decomposition in Reservoir Characterization. The Leading Edge, 18, 353-360.

SPINOLA, M., CONCEIÇÃO E., CAMARGO G., WOLFE G. and BORGES, F. 2014. Applying Geostatistics to Evaluate Illumination Maps. VIII INGEPET, 2014, Nov 3-7, Peru.

TANER, M. T.; KOEHLER, F. AND SHERIFF, R. E. 1979. Complex seismic trace analysis. Geophysics, 44, 1041-1063.

USHIROBIRA, C. A.; CARVALHO, M. R. J. and SPINOLA, M. R. 2003. Aplicação da Decomposição Espectral em Reservatórios Carbonáticos da Plataforma Continental Brasileira. 8th International Congress of the Brazilian Geophysical Society. held in Rio de Janeiro, Brazil, 14-18 September.