Spectral Decomposition Reveals Geological Hidden Features in the Amplitude Maps from a Deep Water Reservoir in the Campos Basin

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Abstract

Results and applications of the spectral decomposition based on the Discrete Fourier Transform (Bracewell, 1986 e Gridley e Partyka, 1997) are presented in this article. An emphasis on the statistics and quantitative aspects obtained from frequency slices of the 3D tuning cube are addressed. Fourier transform is characterized by a linear transform, frequently used to solve mathematical problems representing natural phenomena in a different domain where the solution couldn't be found or was not completely resolved. This work attempts to show an application of spectral decomposition in deep water Campos Basin project, in the presence of channel-lobes turbidite play. Faults are also present and are potential boundaries for the hydrocarbon flow.

Introduction

Many methods have been applied to seismic data in the reservoir characterization domain in order to produce images that can reduce the uncertainties associated to the geologic interpretation process, litho-stratigraphic interpretation and fluid contents.

Spectral decomposition has been frequently used by the geophysical community in seismic processing workflow, such as; spectral analysis, filtering, signal analysis, etc. Only recently has spectral decomposition been used for the interpretation of seismic data (Partyka et all, 1998; 1999; Bahorich et all, 2001).

This work attempts to present the spectral decomposition as a qualitative and quantitative tool to indicate geological discontinuities and images of the thickness variability, with a focus on the statistical aspects of the frequency slices.

The technology used in this work was originally developed by researches from Amoco (Partyka and Gridley, 1997), and later by BP and Apache in partnership with Halliburton/Landmark.

In Petrobras's research project "New Technologies Applied to Reservoir Characterization of Thin Turbidites Reservoirs", PRAVAP 19 - Advanced Oil Recovery Program, there is a special interest in the use of this technology in order to obtain an estimation of the thickness especially in the presence of stratigraphic pinch-outs that may be causing tuning effect in some reservoirs. These geological situations represent important oil volumes in the main reservoirs of the company.

This method was recently developed to represent the tuning effect as an important characteristic of spectrum to be revealed and not as an effect to be removed by traditional procedures of seismic processing.

From the interpreters perspective the richness of this method is the capacity to reveal seismic stratigraphy and seismic structural features that cannot be seen in full-band width dominant frequency (time or depth domain).

Today most seismic interpreters usually work with amplitude anomalies based on dominant frequency. With the method presented here we emphasize the added value of working with the discrete components of seismic bandwidth. Each frequency component is available to help to understand and interpret subtle seismic structural behavior and new details of the stratigraphic framework of the oil field.

Spectral Decomposition - Methodology

The method of spectral decomposition through Discrete Fourier Transform (DFT) presented in this work is based on a phase independent, qualitative and quantitative approach of spectral decomposition (Partyka, 1999).

Seismic reflections, particularly from thin bed reservoirs, have characteristic expressions in the frequency domain. These features on a map view of the amplitude spectrum were obtained from the tuning volume representing the time tuning thickness of the geological beds.

The workflow consisted of choosing an interval of interest in time domain (3D slab containing sequence of interest) that was flattened and then through DTF, transformed into frequency domain (Figure 1a - c). In order to compare different frequencies, a spectral balancing of amplitudes was performed (Figure 1 d).

Animating through the spectral decomposition images allows interpreters to detect subtle differences and lateral discontinuities not obvious in standard displays and caused by the tuning effect of geological beds (thickness changes) or heterogeneity (Figure 1e).

Figure 5 shows the spectral decomposition methodology in a pinch-out synthetic model. Note that each axis represents a different variable: (a) frequency content of seismic data; (b) vertical axis represents frequency domain for the surface shown and time domain for seismic data; (c) time thickness of the wedge model increasing direction. The surface represents the first spectral peak event associated with bed tuning. Deeper the surface is thinner the layer that can be measured. Note that thinner time thickness is associated with higher frequencies in the tuning cube.

Data Segmentation – Tuning Cube Parameters

The time window length and spatial position were the most sensitive parameters tested with this dataset. Since the two reference horizons did not conform well to each other, we chose the two-window option as the best. The frequency range from 0 to 80 Hz tuning cube was chosen from an earlier spectral analysis where mostly noise was found above 80 Hz. This time window position gives the sharpest overall image but combines geology from several sand layers. Calibration with well logs is needed to find out if these images reveal gross interval thickness or separate lobes.

Data Analysis and Interpretation

Interpretation can be performed through animation of the cube in Z direction, namely, frequency slices. Techniques commonly used in volume visualization can be applied, for instance, optical stacking where different frequency slices can be merged. An example is illustrated in the Figure 2 where frequencies from 5Hz to 10 Hz were combined.

In this case, for each frequency the same opacity function (transparency) was applied to each frequency map and then each one was summed or stacked optically. This makes sense only on a map view. The main idea is to extract from the seismic frequency images some geological features.

Figure 3 shows the histogram of amplitude of a component frequency (5Hz). Note the frequency slices are normalized by the median value of the distribution. Normalization is necessary in order to compare the amplitude anomalies from different discrete frequencies.

We also performed a seismic-facies color code analysis based on quartiles of the distribution of tuning anomalies (Figure 4) from 5 Hz to 80Hz in intervals of 5Hz. Figure 4 shows a map representing the distribution of quartiles: minimum values to first quartile (black); first quartile to median (blue); median to 3rd quartile (orange) and 3rd quartile to maximum (red).

Application

This method is being applied in different Petrobras deep water oil fields including onshore and offshore cases, such as Campos, Espirito Santo, Reconcavo and Potiguar Basins.

The figures in this article represent images from an offshore deep-water oilfield in the Campos basin.

Summary and Conclusions

Spectral decomposition is an endeavor to reduce the impact of misinterpreted seismic caused by the tuning effect and/or the lack of some geological features due to seismic filtering. It provides an opportunity for a different approach to the geological interpretation of seismic information. Images obtained exhibit more geological fidelity than those produced using conventional amplitude maps.

Frequently, depending on the filtering used during seismic processing, images with geological features can be interpreted up to 1/4th above the dominant frequency. With spectral decomposition, especially if the signal random noise ratio is good enough, higher frequency slices can contain useful geological information.

In deep water field development, the seismic interpretation of the continuity of geological bodies is crucial for optimizing the position of producer and injector wells. If some geological features of geological discontinuities between the producer and injector wells were hidden by the standard seismic amplitude images, the risk of reduced production and/or injectivity rate would increase. As a consequence, the economic impact of the project would be damaged.

Besides the discrete frequency components available for seismic interpretation, this method also allows a set of new attributes associated with each frequency. These new attributes could be used as input for seismic pattern recognition to identify the seismic facies of the reservoirs under geological characterization.

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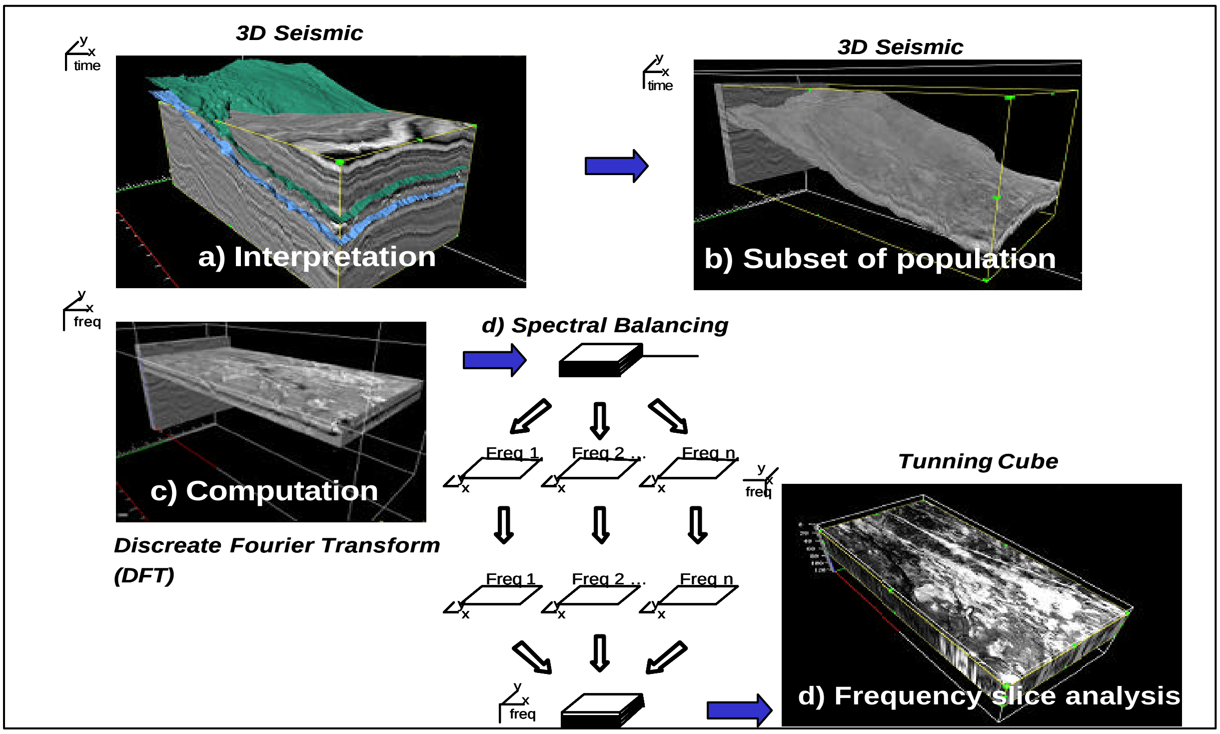


Figure 1. Diagram of the spectral decomposition methodology: (a, b) following horizon interpretation, a sub-volume of the entire population of 3D seismic data is selected (stratigraphic sequence) and this sub- volume is flattened; (c, d) subsequently by the application of DFT a spectral balance is performed so that different frequencies slices can be compared; (e) the results of this processing is a tuning cube in which constant z values represent amplitude maps produced by the tuning of seismic-stratigraphic and seismic-structural features. The interpretation can be performed through animation of the constant slices in the Z direction, namely in frequency slices.

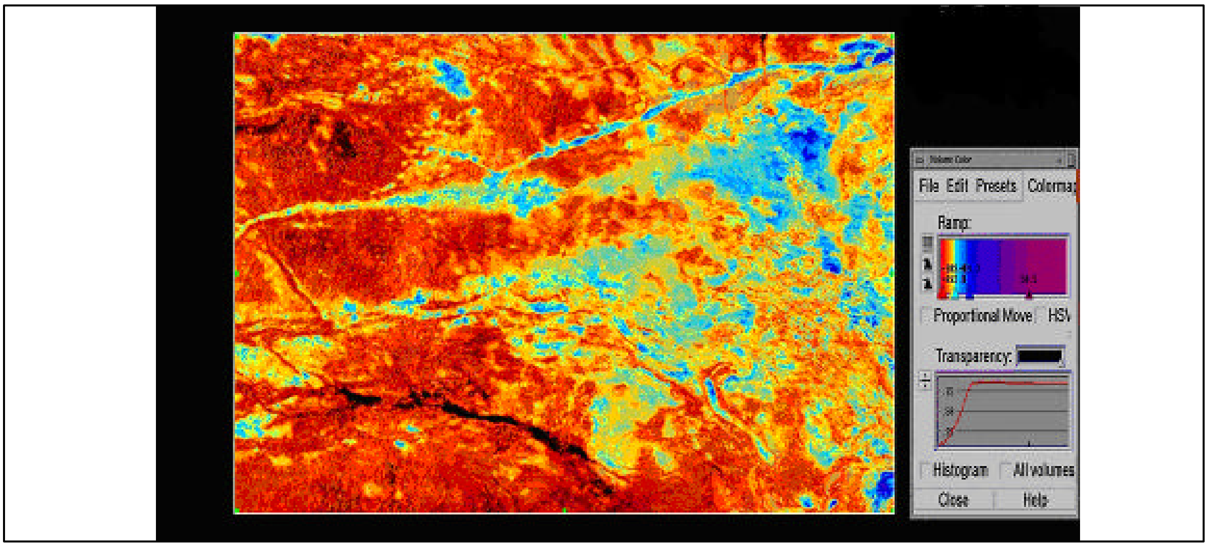
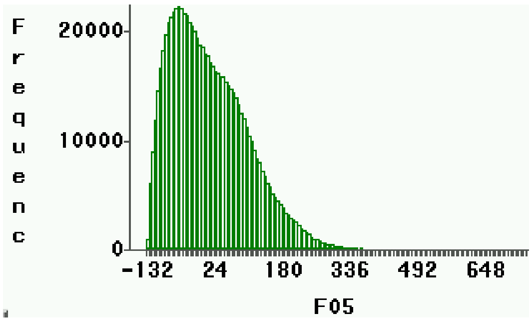


Figure 2 - Merging Frequency Slices – Applying 3D visualization technology, this figure represents an optical stacking, of difference frequency slices. ie, for each frequency the same opacity function was applied and summation of these images produced. In this case a summation of amplitudes from 5 to 80 Hz.



Moments			
N	781507.000	Sum Wgts	781507.000
Mean	15.4398	Sum	12066308.5
Std Dev	92.4236	Variance	8542.1135
Skewness	0.9803	Kurtosis	1.5627
USS	6.862E+09	CSS	6.676E+09
CV	598.6061	Std Mean	0.1045

Quantiles			
100% Max	741.1971	99.0%	278.0194
75% Q3	72.4927	97.5%	224.1134
50% Med	0	95.0%	183.9589
25% Q1	-57.0114	90.0%	139.1460
0% Min	-127.9939	10.0%	-90.0016

Figure 3 - a) histogram curve for 5 Hz. b) each frequency slice is normalized according to its median amplitude - note that Q2 iqual to zero. Normalizing the tuning cube (Partyka 1999).

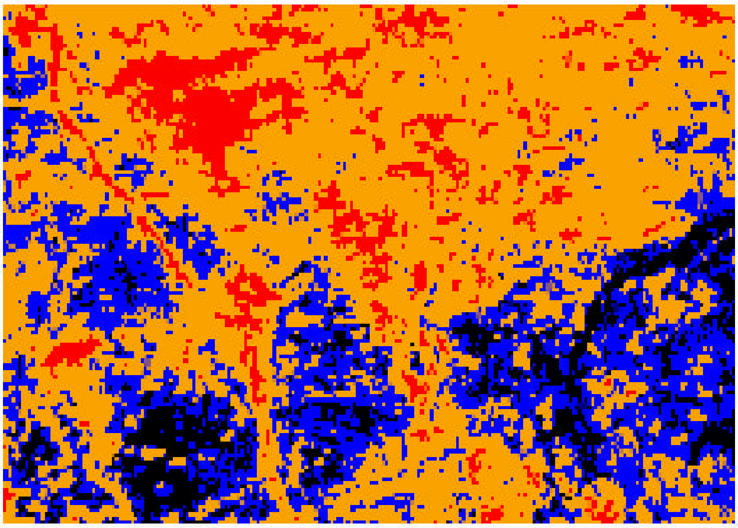


Figure 4. Distribution analysis of 5 Hz frequency slice: Maps of quartiles: minimum values to first quartile (black); first quartile to median (blue); median to 3rd quartile (orange) and 3rd quartile to maximum (red). Red means interference produced for thicker parts and black low or no interference.

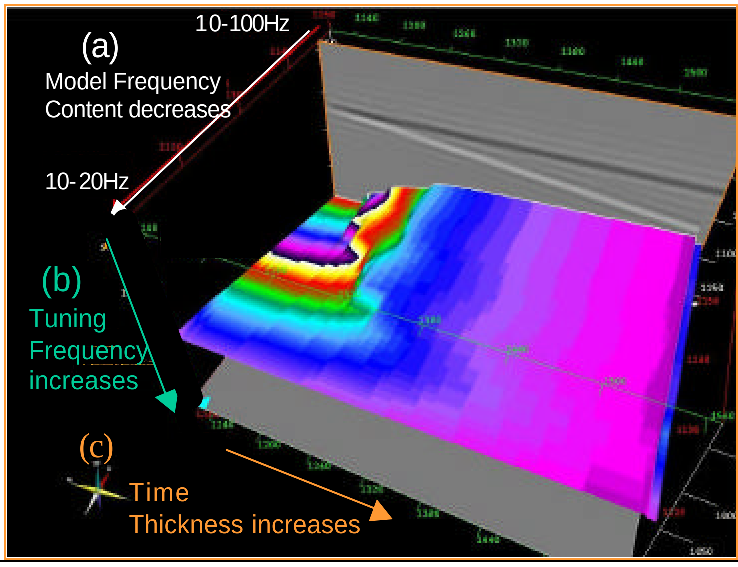


Figure 5. Spectral decomposition methodology in a pinch-out synthetic model: the deeper the surface the thinner the layer that can be measured.