SBGf41499

Facies Recognition using Wavelet Based Fractal Analysis on Compressed Seismic Data

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Abstract

We present in this paper a method to analyze seismic data in the compressed domain which measures the changes in the variance of the wavelet coefficients as a function of the scale of the transformation. After applying this method to resistivity logs, acoustic impedance logs, and 3D seismic data around a Eocene, clastic reservoir, we show the wavelet coefficients themselves contain relevant information about the subsurface that can be used for seismic based facies classification without having to through the reconstruction process.

INTRODUCTION

During the last six years, there have been significant advances in the use of the discrete wavelet transform to compress seismic data (Bossman and Reiter, 1993) (Donoho and Ergas, 1995) (Reiter and Heller, 1994). Compression ratios above 100:1 have been obtained without loosing significant geophysical information. Most efforts in quantifying such losses have been focused in comparing original vs. reconstructed data in a variety of ways which range from visual comparisons to detailed statistical measures (Ergas, 1996) However, little effort have been made, as far as we know, in examining whether the wavelet coefficients from which the data are reconstructed contain by themselves relevant information about the subsurface without having to go through the reconstruction process.

We show in this paper a method borrowed from the biomedical literature (Akay, 1997) wavelet based fractal analysis, that can be used to analyze the information contained in the wavelet coefficients themselves. We first test the method with resistivity logs recorded in two wells that penetrate shally and sandy environments respectively, and obtain the variation of the variance of the coefficients with scale shows distinctive behaviors depending of the dominant lithology around the each well. Then, we repeat the process with acoustic impedance logs from the same pair of wells and 3D seismic data that covered a larger area, and obtain responses that can be used also for facies classification. This result suggests it may not be necessary to reconstruct the data to obtain information about the subsurface, from seismic attributes for instance, since such information may be already contained in the wavelet coefficients in the compressed domain.

WAVELET BASED FRACTAL ANALYSIS (WBFA)

The wavelet transform is a very useful tool in the analysis of nonstationary signals due to their ability to resolve features at various scales. In particular, on the of the most promising application has been the analysis of the variance of a physical process across different scales.

In a interesting and novel approach Akay (1997) used the technique of Wavelet Based Fractal Analysis (WBFA) for the computation of the fractal dimension of heart-sound waveforms. Akay's analysis consisted in the calculation of the variance of the wavelets coefficients (the detailed signals) and plotted versus scale on a log-log plot. At each scale, the detailed signals are assumed to be stationary. Regions of linearity in this kind of plot correspond to a power-law process over a particular region of frequencies, with the exponent of the power law process being related to the slope of the line (Percival and Guttorp,1994).

Figure 1 shows Akay's original analysis performed on heart-sound waveforms showing the effect of the coronary artery disease. The normal heart sound waveform contain less high frequency energy than the abnormal one. WBFA performed on both signals reveals larger variances at all scales for the abnormal heart-waveform. Moreover, the variation of the variance with scale follows different power-laws for each case which, according to Akay, suggests the possibility of devising electronic instruments capable of helping physicians detect coronary ischemia in its early stage. Akay's results suggests also the possibility of using WBFA to classify geophysical signals (well logs and seismic traces) depending of the geological features being sampled. Next section explores this idea in detail.

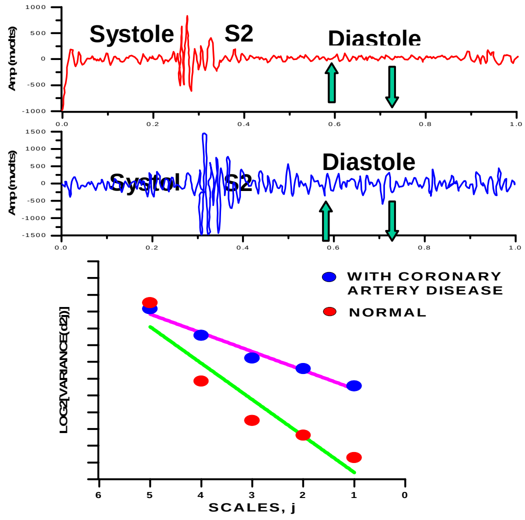

Fig. 1: WBFA (bottom figure) of heart -sound waveform of normal human subject (top figure) and a subject with multiple coronary oclusions (middle figure). The analysis was performed on the quietest part of the signal,contained between the arrows (taken from Akay [1997]).

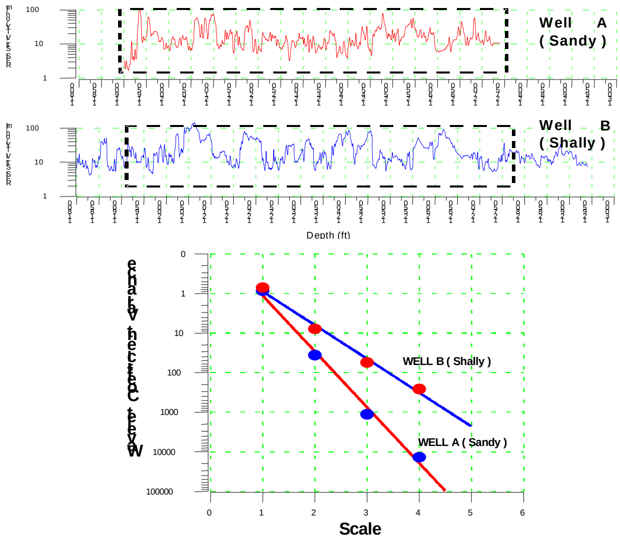

Fig. 2: WBFA (bottom figure) of the resistivity logs of wells A and B

FIELD DATA EXAMPLE

The data set we used to test the applicability of Akay's ideas to classify geophysical data consisted of two resistivity logs from two different wells (A and B), two sonic logs, two density logs, and a 3D seismic cube recorded with the aim of characterizing a clastic, Eocene reservoir in Lake Maracaibo, Venezuela, located at a depth of 12 300 feet. Wells A and B are located in areas that penetrate sandy and shally environments respectively.

WBFA of resistivity logs

We performed WBFA on the two resistivity logs. After doing a wavelet decomposition, we computed the variance of the coefficients at every label and plotted the result against its corresponding scale. Higher scales correspond to greater stretching in the analyzing wavelet and therefore, lower resolution.
After testing the decomposition with Daubechies and biorthogonal wavelets, we selected biorthogonal wavelets since they provided better separation of the WBFA regression lines. Figure 2 shows the result. We observe distinctive separation between the slopes calculated from each log, which means this method (WBFA) has the potential of being used as the basis for facies identification in this area. Resistivity logs from wells with properties between these two end members can be classified with this method.

As we said before, increasing the scale of the wavelet transform implies in general more stretching in the analyzing wavelets and therefore, less resolution in the result. At such higher scales, the analyzing wavelets contain frequencies typical of the surface seismic frequency band. When we extend the WBFA of the resistivity logs to such higher scales, we observe a variation in the rate of change of the variance with scale at the fifth level, as Figure 3 shows.

This methodology can be used to relate the averaging processes of the subsurface properties between surface seismic and well log scale (which follow different power laws), to improve the estimation of reservoir properties based on the combination of seismic data and well logs, and to analyze large bandwidth data which may contain information of unrelated averages of the subsurface properties (with different power laws), as Figure 3 shows.

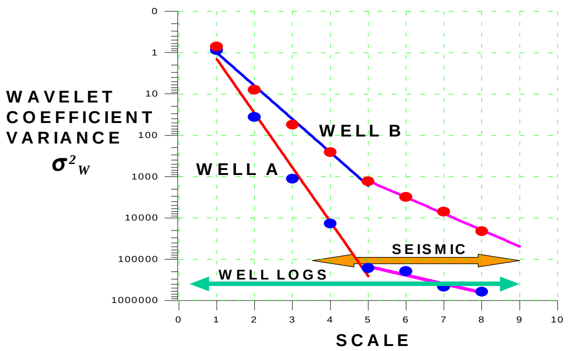

Fig. 3: WBFA of the resistivity log using ten scales. Notice two differents power laws in the behavior of the variance for high resolution (well logs) and low resolution (sur-face siesmic) regimes.

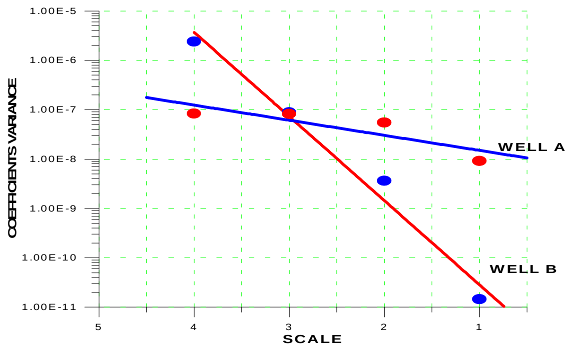

Fig. 4: WBFA applied to the reflectivity series generated for wells A and B.

WBFA of synthetic seismic traces

We checked whether the reflectivity series of each well responded differently to the WBFA depending on the dominant lithology of the target around each well. Figure 4 shows the result, which indicates it is still possible to recognize different lithologic characteristics using the reflectivity series in this area.

To generalize this result to surface seismic frequencies, we performed WBFA on synthetic seismic traces obtained after convolving the reflectivity series with a set of eight Ricker wavelets with central frequencies ranging from 20 to 256 Hz. We computed the slope and intercept of the line that best fitted the variance of the wavelets coefficients vs. scale for each synthetic trace. Figure 5 shows the results. For large frequencies, we obtain differences in slope and intercept between wells A and B. Differences in slope decrease as the central frequency decreases until lines become parallel at 20 Hz. Differences in intercept remain for all frequencies.

Results of Figure 5 indicate the methodology of classification of compressed surface seismic data based on slope and intercept that result after WBFA will be more robust as the frequency increases. For low frequencies, only differences in intercept will be significant.

When generating synthetic data, we also generated random, acoustic impedance logs (not shown). The results of the WBFA on such random logs did not exhibit the straight line behavior shown in Figures 2 and 4 that we obtained when analyzing the real resistivity and impedance logs. The behavior of the log-log plots for the random, synthetic well logs was erratic.

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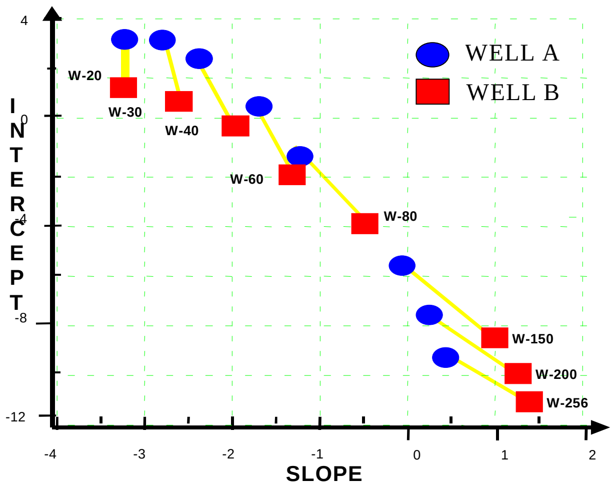

Fig. 5: WBFA intercept - slope graph showing the separation between two facies for different levels of seismic resolution.Central frecuency of the synthetic traces range from 20 to 256 Hz.

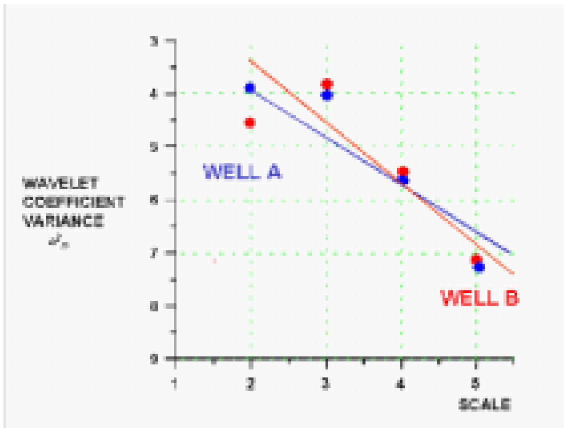

Fig. 6: WBFA for the traces closests to wells A and B.

WBFA of compressed, 3D seismic data

To map the extension of different facies in the reservoir, we used the WBFA slope-intercept methodology to classify the 3D seismic data in a time window around the zone of interest. According to the results of Figure 5, we did not expect to see large differences in the slope of the lines after performing WBFA for traces around each well, since the frequency content of the 3D seismic data we used in this study varied only between 15 and 35 Hz. The result of the WBFA for the closest traces to wells A and B shown in Figure 6 confirmed this hypothesis: both lines are almost parallel and the separation is not as clear as when using well logs. However, when we performed the analysis for the 25 traces closest to each well, we obtained that slope and intercept of the different straight lines clustered in almost disjoint sets (Figure 7), which means the differences in the signals that WBFA reveals, even though subtle, are consistent and independent of random noise. This result is significant and suggests the WBFA slope-intercept scheme could be a valuable tool for facies identification using compressed seismic data

Figure 8a shows a coherency slice (Bednar, 1998) around the zone of interest. Notice the presence of a channel crossing the area. The result of classifying each trace of the 3D seismic data around the zone of interest using the WBFA slope-intercept methodology is shown in Figure 8b. The channel indicated in the coherency slice turns out to be, as expected, filled with sand. White areas in the map of Figure 8b could not be classified as either shale or sand.

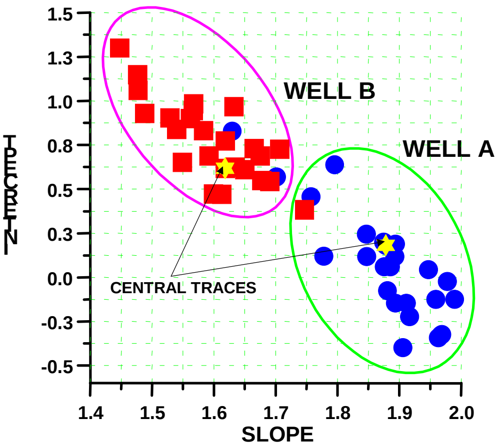

Fig. 5: WBFA slope-intercept result for the 25 traces closest to each well .

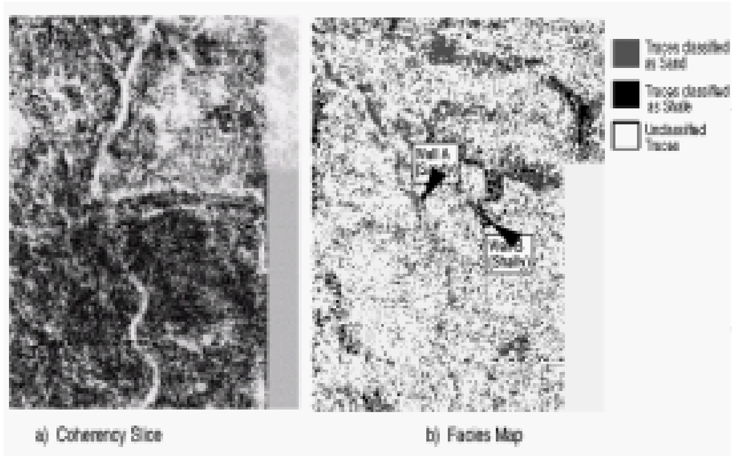

Fig. 8: facies classification map using WBFA.

CONCLUSIONS

We have presented a methodology, wavelet based fractal analysis (WBFA), to analyze the variance of the wavelet coefficients of compressed seismic traces at different scales. When applied to well logs, the method is able to to discriminate properties of signals recored in areas with different shale and sand content. Even though the discriminating power of the method diminish for low frequency seismic data, useful results can still be obtained when applied to the problem of facies recognition using compressed data.

In this particular study, we found that two parameters that result from the WBFA, slope and intercept, were enough to classify the different facies. In other cases, slope and intercept may not be sufficient and we may need to use the variance of each scale of the wavelet transform without assuming a straight line model.

The results of this study suggest it may not be necessary to reconstruct the compressed data to obtain useful information about subsurface properties from the seismic data.

ACKNOWLEDGMENTS

We thank PDVSA-Intevep for permission to publish this work.

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