Characterization of thin beds through joint time-frequency analysis applied to a turbidite reservoir in Campos Basin, Brazil

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Summary

A new spectral decomposition based method is presented here. We propose to use the ridges of the joint time-frequency analysis, as a new way to detect, in each trace, the maximum instantaneous frequencies and their associated amplitudes, which were applied as a tool to detect seismic geomorphologic bodies. The technique was applied to a synthesized wedge model and also to a thin bed offshore turbidite reservoir in Campos Basin, Brazil.

Introduction

The seismic resolution improvement and the widespread 3D seismic data available in the last years made seismic geomorphology feasible as a new discipline. The basic assumption of seismic geomorphology is that depositional architecture could be recognized in the acoustic bodies. Thus, genetic reservoir elements, their spatial relationships and stratigraphic evolution could be obtained directly from seismic volume interpretation. Unlike traditional seismic interpretation, Seismic Geomorphology studies needs other tools to extract the maximum amount of information from the seismic data, such as time slices, horizon slices, and more recently spectral decomposition maps (Johann et al., 2003).

Considering the seismic signals as the sub-surface impulse responses, they can be interpreted as a low frequency representation of the sub-surface reflectivity. Specifically, seismic signals are characterized by transitions due to the acoustic impedance contrasts, and they can be synthesized by the convolution of the reflectivity function with a seismic wavelet. Therefore, the waveform at the strong reflection peaks is also influenced by the intermediate composition between the stratigraphycal units, and the typical low seismic resolution limits the pinch out identification. Figure 1 shows a synthesized wedge model, similar to the one used by Partyka et al. (1999), (Partyka, 2001), which illustrates the thin bed detection problem. When the thin bed detection is performed only in the time domain, it could lead to interpretation errors. In other words, significant portion of the reservoirs have thickness not well delimited in a direct way through the seismic mapping.

The frequency domain analysis using power spectrum techniques has been used in seismic interpretation, mainly for thin bed detections (Partyka et al.,1999), (Partyka, 2001), (Marfurt and Kirlin, 2001). However, the power spectrum does not reveal how the frequency content varies along the time and neither the seismic transition locations. On the other hand, joint time-frequency algorithms, such as the S transform, can be used to locate and to emphasize thin bed reservoir characteristics.

S transform as a tool for joint time-frequency analysis

It is well known that joint time-frequency contents of a seismic trace carry information about the properties of the subsurface (Steeghs and Drijkoningen, 2001) and could also be used for reservoir characterization (Matos et al., 2003), (Matos et al., 2004). Among the different time-frequency analysis techniques, the S transform (Stockwell et al., 1996) has a very good time-frequency localization properties that qualifies its use as a potential seismic attribute generator.

The S transform of a signal h(t) is defined as the Continuous Wavelet Transform (CWT), with a Morlet wavelet multiplied by a phase factor, as shown by the following equation (Stockwell et al., 1996):

$$S\left(\tau,f\right)=\int_{-\infty}^{\infty}h\left(t\right)\left\{\frac{\left|f\right|}{\sqrt{2\pi}}e^{\left[\frac{-f^{2}\left(\tau-t\right)^{2}}{2}\right]}e^{-2\pi jft}\right\}dt$$

In some ways, it is similar to the Short Time Fourier Transform (STFT), when the analyzing window is a Gaussian with length inversely proportional to the frequency and weight directly proportional to the frequency. The S transform is also invertible an easily discrete-time implemented (Stockwell et al., 1996).

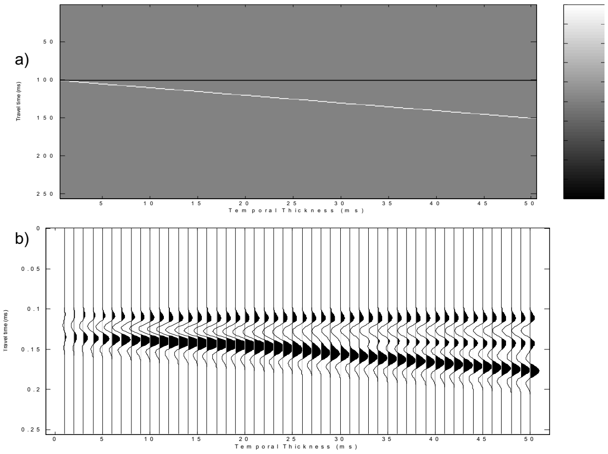

Figure1:Wedge reflectivity model filtered in the seismic band

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S transform applied to thin bed analysis

Figure 2a2 and 2b2 show the S transform absolute values of two different traces, shown in Figures 2a1 and 2b1, respectively. The horizontal axis represents the time along the trace and the vertical axis represents the instantaneous frequency. These joint time-frequency representations illustrate clearly the presence of at least two different instantaneous frequencies at any given time, which are detected through the ridges of the time-frequency representations (Mallat, 1999), and are illustrated in Figures 2a3 and 2b3, respectively. Figure 2 also shows, that the maximum instantaneous frequency in each instant of time is not related to the maximum instantaneous amplitudes. This fact suggests that the highest instantaneous frequency could be related to the stratigraphy, while the lowest instantaneous frequency could be associated to the seismic wavelet at each instant of time.

In this way, we propose to use the highest instantaneous frequency, detected through the ridges of the joint time-frequency transform, as an instantaneous attribute associated with its amplitude contribution. Figure 3 shows the filtered wedge model, the amplitude of the maximum instantaneous frequency and the maximum instantaneous frequency, obtained though the ridges of the S transform. It can be easily visualized the jointly time-frequency localization of the thin bed phenomena in the interval between 15 ms to 30 ms time thickness, approximately. The results shown in Figure 3 also suggest the use of the maximum instantaneous frequencies and their associated amplitudes as a time interval seismic attribute. These attributes are plotted in Figure 4 as a function of the wedge model time thickness, and actually they illustrate their usefulness as a tool to characterize thin beds. Figure 4 also confirms the expectation of the thin bed high frequency contents and its particular time-frequency behavior.

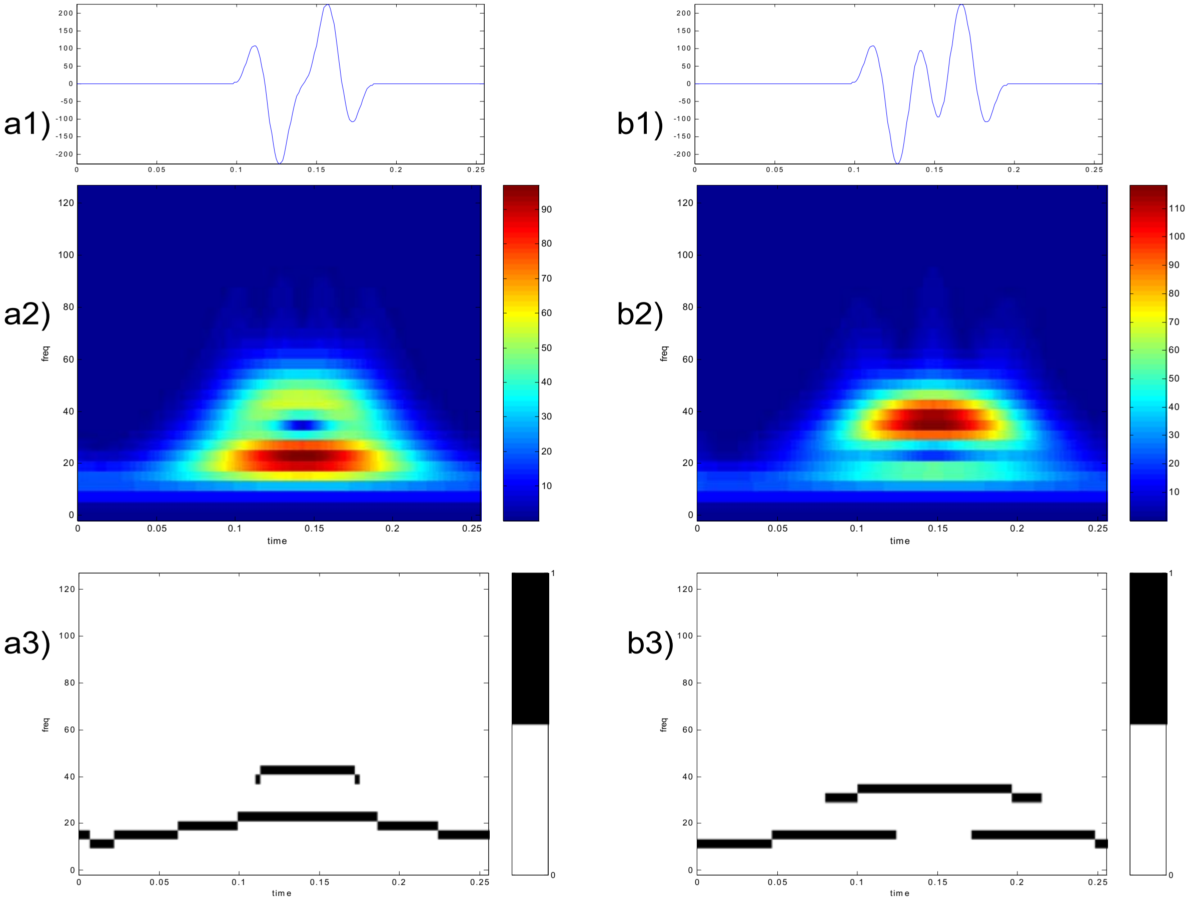

Figure 2: a1) Trace with 30 ms temporal thickness; a2) S transform of the trace a1; a3) Ridges of a2 showing two different instantaneous frequencies along the time; b1) Trace with 40 ms temporal thickness; b2) S transform of the trace b1; b3) Ridges of b2 showing two different instantaneous frequencies along the time.

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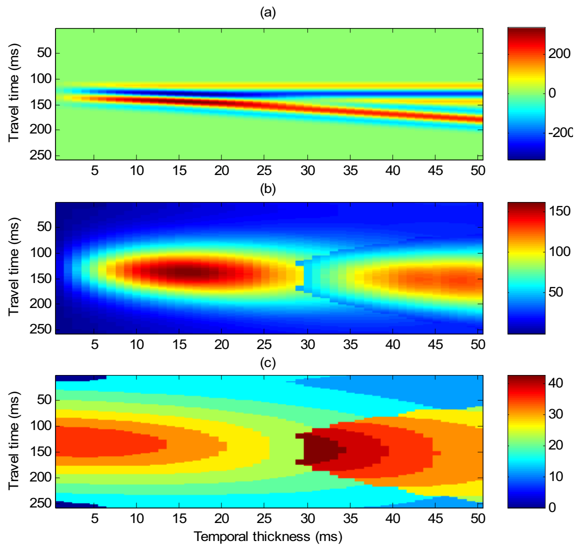

Figure 3: a) Filtered wedge model; b) The amplitude of the maximum instantaneous frequency obtained through the ridge of the S transform; c) The maximum instantaneous frequency.

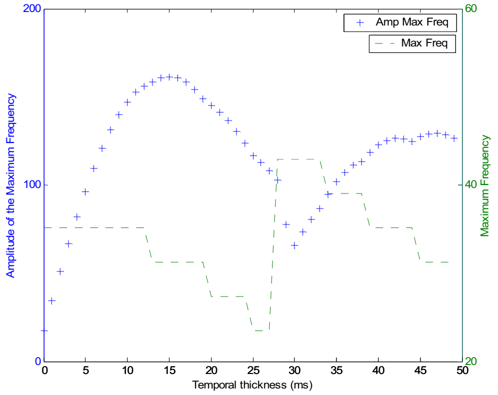

Figure 4: Time interval seismic attributes: the Maximum Instantaneous frequency and its associated maximum amplitude.

Results

The technique presented herein brought some improvements to the characterization of seismic geomorphology. The studied interval is represented by the reservoirs showing low amplitudes in Figure 5, which have been cut by Well-1. Note that there is a series of sand-rich intervals, and that the main sandstone bodies (lobes) present a backstepping pattern. In the maximum frequency amplitude section of Figure 6, channel features are very clear, as many channels feed frontal lobes, and others by pass the area, transferring sediments for mini-basins located downdip. In the lower part of the figure, the older channel that feeds the large frontal lobe to the east is clearly visible, even though it was covered by the backstepping younger lobe. Lobe positions are controlled by salt-related topography. The sinuous channels, seen in the upper (northern) part of the figure, are also topographically controlled.

Conclusions

Results obtained have shown that the proposed method can be a very good alternative way for the spectral decomposition and seismic geomorphology studies. Since the proposed attributes are generated by parameters extracted from a joint time-frequency analysis, its robustness suggests that changes in the analyzing window size could have little influence in it, which means that the present methodology is less sensitive to interpretation picking noises.

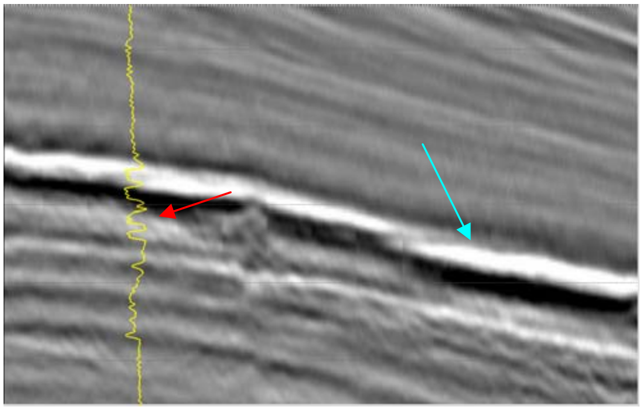

Figure 5: Longitudinal section from the turbudite reservoir. The canal sand facies recognized in the Well-1 density log (red arrow) is stratigraphicaly correlated to the lobe sands (blue arrow) but does not have a good seismic expression at this position.

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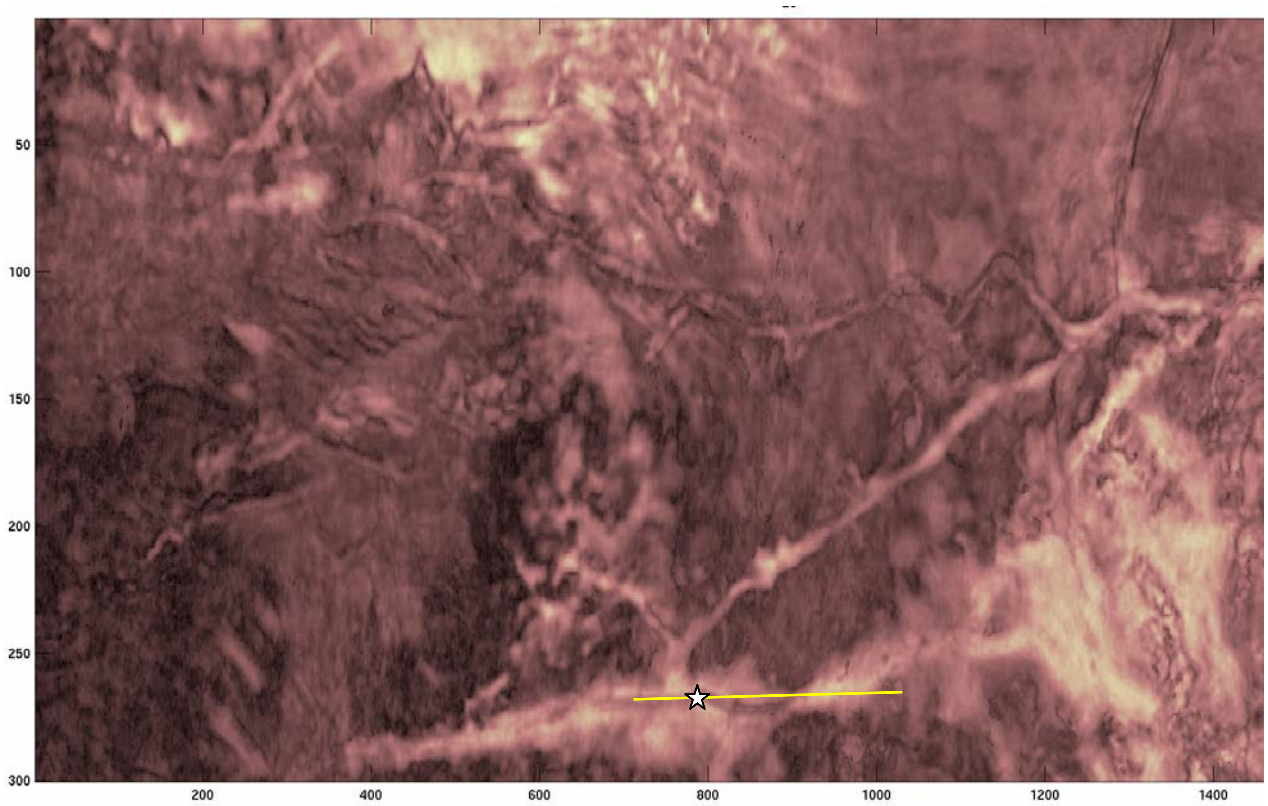

Figure 6: Maximum frequency amplitude section of the turbidite reservoir showing frontal lobes and their feeding channels. In some cases (star – which also marks the position of Well 1, referred to in the Figure 5); older channels occurring beneath the lobes are also visible. The section shown on Figure 5 refers to the yellow line in the present figure.

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