B019

High Frequencies Attenuation and Low Frequency Shadows in Seismic Data Caused by Gas Chimneys, Onshore Ecuador

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SUMMARY

Hydrocarbon reservoirs can be sources or sinks for migrating gas, hence gas chimneys have an inherent correlation with HC reservoirs. If frequency effects show a strong correlation between reservoirs and gas chimneys, observing attenuation zones above reservoirs can be considered an equivalent indicator. Loss of seismic data quality is usually the main characteristic of gas chimneys but it is hoped that in the future we can use high frequency observations with CWT as an alternative method to detect gas clouds correlating with reservoirs, even in cases where there is no apparent loss of data quality.

In this case study, using spectral decomposition techniques, zones of high frequency attenuation can be observed in seismic data above onshore sandstone oil reservoirs in Ecuador. This attenuation correlates directly with gas chimneys seen in the seismic volume. The amount of attenuation is dependent on the vertical extent of chimneys. Low frequency shadows of reflectors at reservoir depth can also be observed and correlated laterally with the extent of shallower gas chimney zones directly above. Intrinsic attenuation of seismic waves through gas chimneys is proposed as a likely cause of these frequency effects.

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Introduction

As a seismic wave propagates through the earth its amplitude decreases for a variety of reasons which include geometric spreading, energy partitioning at interfaces, scattering, tuning effects due to the stratigraphy and anelastic (intrinsic) attenuation. Preferential attenuation of higher frequencies which changes the spectral content of the seismic wavelet is caused by tuning effects, scattering and intrinsic attenuation (Sherriff and Geldart, 1995, Clark, R. A. 2007).

The gas chimneys observed in the dataset are characterized as gas cloud type chimneys (Heggland, R., 2005) and are mostly found above the confirmed oil fields in 2D and 3D seismic data. Gas cloud chimneys are associated with partial seal failure, which results in the partial or complete loss of the gas cap, but generally the oil fraction of the accumulation is retained by the seal. The escaped gas will spread in the overlying rock by means of buoyancy and will result in a large volume with low gas saturations. The gas chimneys appear in the seismic volume as vertical zones of lower seismic data quality and bed continuity. In the Ecuador data the gas chimneys in the seismic were highlighted through a neural network technique as described in Ligtenberg, (2003), see figure 1. Attributes that the NN uses to isolate the gas chimneys are: verticality, coherency, local average frequency, windowed rms-amplitude and a "chaos" attribute.

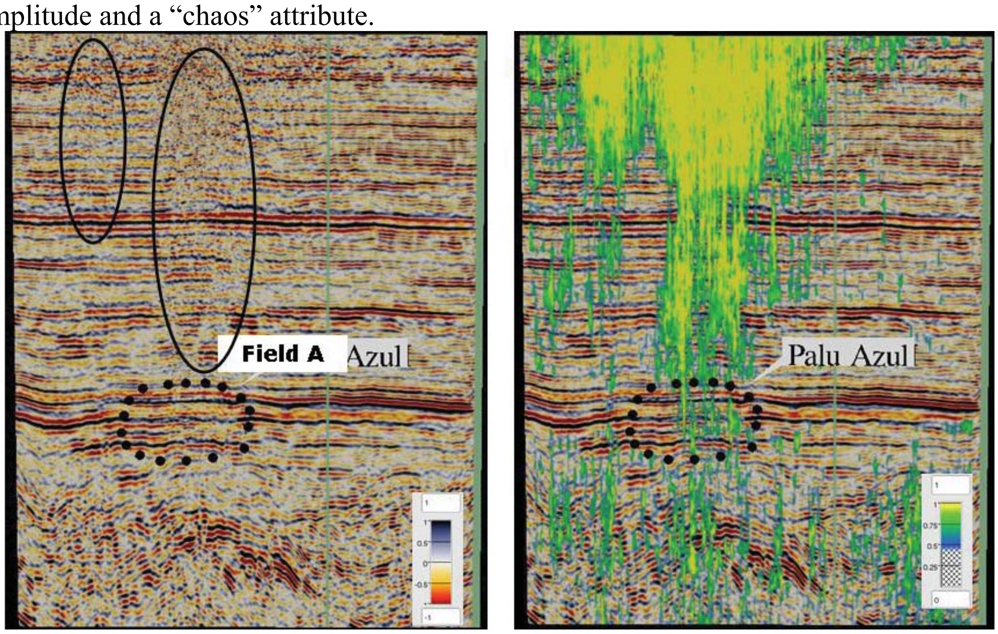

Figure 1:Left: full stack seismic with zones of data quality degradation interpreted as gas chimneys encircled. Right: the results of the NN gas chimney detection overlain on the seismic display.

Spectral decomposition is a common denominator for several techniques that map a seismic trace into time-frequency space. This mapping is a local operator on the seismic trace, thus the frequency spectrum found at a certain time is representative of the seismic frequencies found in a local window around this time. Consequently the spectrum will represent a combination of local geology, through the frequency expression of interfering reflections and will represent the overburden through the accumulated frequency effects of the wave transmission. There exist several techniques for spectral decomposition. We use the continuous wavelet transform (CWT), a technique with favorable qualities to preserve both time and frequency resolution. The principles of the different spectral decomposition techniques can be found in Partyka, et al, 1999 and Chakraborty and Okaya, 1995.

Data examples

We applied CWT to the full stack volume of the Ecuador survey. In the analysis of the high frequency volumes (30+ Hz) we observe strong attenuation of amplitudes in the shallow section approximately correlating with the location of the deeper reservoirs. Closer observation shows that the attenuation of the high frequencies coincidences with the zones of gas chimneys extending directly from the reservoir formation (see figure 2). Gas saturation is known to cause a high degree of intrinsic attenuation but the often small reservoir thicknesses mean that attenuation effects occurring within the reservoir can be very subtle. Because of their vertical geometry, much greater travel paths are possible through gas chimneys. Despite the low gas saturation, these long travel paths allow for significant intrinsic attenuation to cause observable frequency effects.

Also we observe the occurrence of enhanced amplitude levels of low frequencies associated with the spatial locations of the reservoirs. However the anomalies do also occur above the reservoir and are again closely related to the occurrence of chimneys, see figure 2. Low frequency shadows are described by many authors, for example Wang, Y., 2007 and Castagna, et al, 2003. Low frequency shadows cannot be explained by intrinsic attenuation alone since the amplitude of the low frequency bands actually increases compared with the reference. Multiple mechanisms have been proposed by, among others, Ebrom, D., 1996 and Korneev, V. A, et al, 2004. While Ebrom lists chimneys below the reservoir as a possible mechanism, none of the authors consider chimneys above the reservoir.

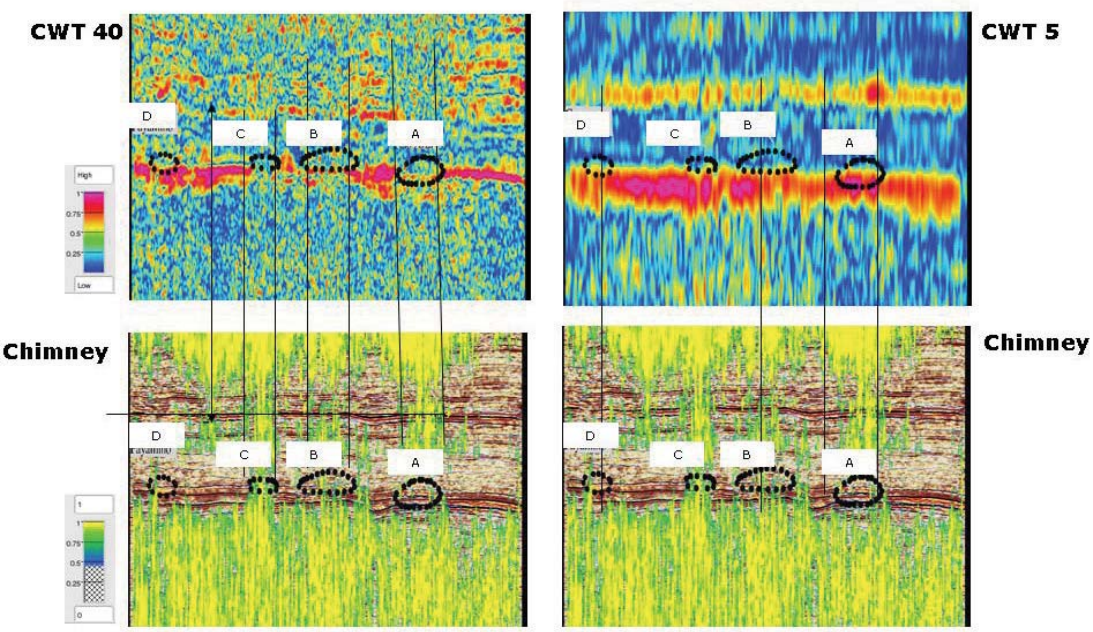

Figure 2: Left: Showing CWT 40hz (top) and gas chimneys (bottom). The higher frequencies are attenuated where gas chimneys are present. Right: CWT 5hz (top) and gas chimneys (bottom). A low frequency shadow effect is visible under the gas chimneys.

While the previous examples are taken from a 2D line along 4 confirmed oil fields, the same observations can be made in the 3D survey covering the same area. Figure 3 shows the correlation of gas chimney and attenuation in CWT 40Hz above a producing oil field. Figure 4 shows CTW 10hz, 20hz and 40hz sections side by side. Low frequency shadows are visible in the CWT 10hz at and below the location of the gas chimney. The CWT 20hz is more or less continuous through the gas chimney with some hints of attenuation in the middle of the chimney. CWT 40hz is strongly attenuated in and below the area of the gas chimney. In figures 5 we show the average amplitude of the CWT 40Hz at a shallow and a deep level next to the extent of the gas cloud at a much shallower level. While there is no good correlation with the reservoir, there is an excellent match between the outline of the shallow gas cloud and the outline of the attenuated area. The correlation between low frequency shadow and chimney in the 3D is weaker, possibly an indication that low frequency shadows are processing artifacts, enhanced in 2D processing.

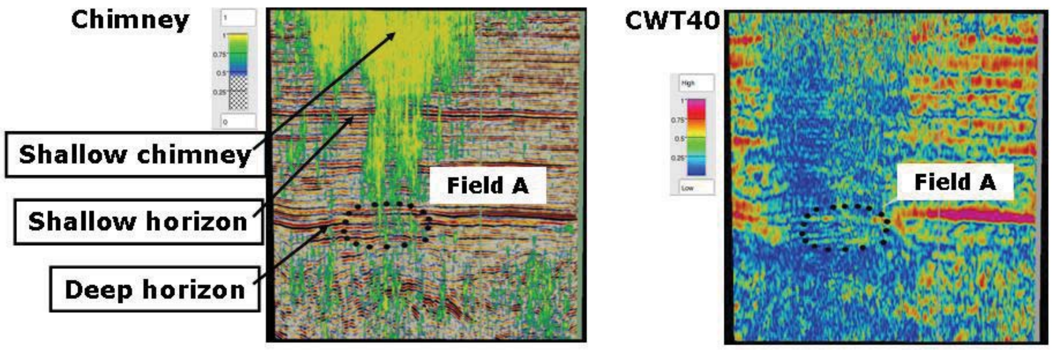

Figure 3: Left gas chimney, right CWT 40Hz in 3D-seismic data. Note the high frequency attenuation at and below the gas chimney.

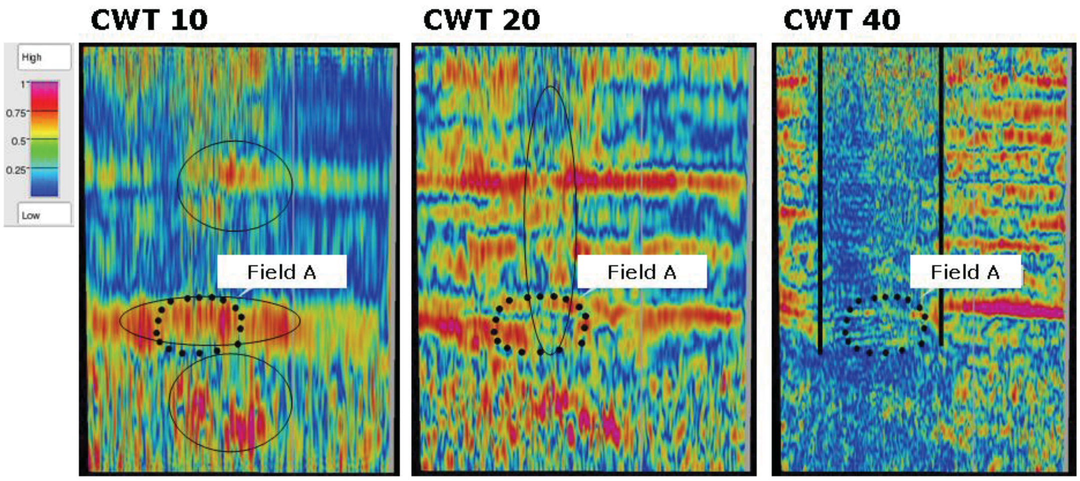

Figure 4: CWT 10hz, CWT 20hz and CWT 40hz side by side. Note that while the high frequencies are attenuated by the gas chimney, lower frequencies (notable CWT 10hz) are enhanced at and below the location of the gas-chimney.

Conclusions and future research

Hydrocarbon reservoirs can be sources or sinks for migrating gas, hence gas chimneys have an inherent correlation with HC reservoirs. If frequency effects show a strong correlation between reservoirs and gas chimneys, observing attenuation zones above reservoirs can be considered an equivalent indicator. Loss of seismic data quality is usually the main characteristic of gas chimneys but it is hoped that in the future we can use high frequency observations with CWT as an alternative method to detect gas clouds correlating with reservoirs, even in cases where there is no apparent loss of data quality. From the data it is also suspected that gas chimneys might be an important but previously overlooked cause for low frequency shadows in seismic surveys. Another important conclusion is that when using spectral decomposition for purposes as thickness estimation, geomorphologic & seismic facies analysis or DHI the effect of gas-chimneys should be considered to avoid misinterpretations. Currently similar effects are being investigated in other datasets.

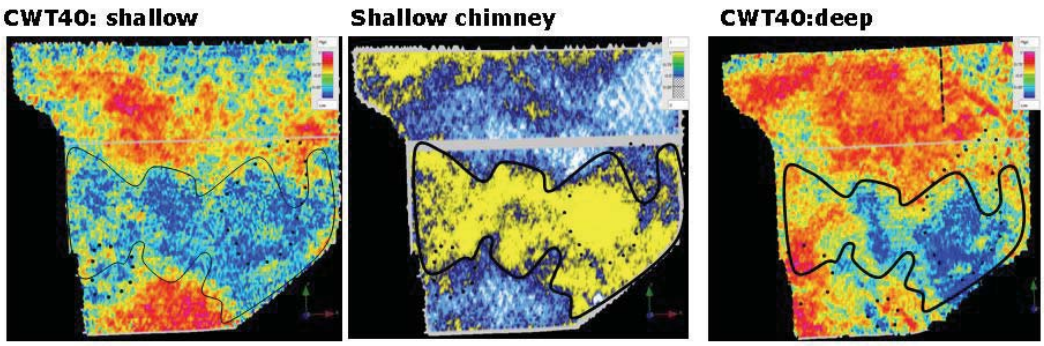

Figure 5: Comparison between the horizon slides through the gas chimney at shallow level (middle), CWT40hz at shallow level (left) and CWT 40hz at the deeper reservoir level (right) showing the correlation between gas chimneys and extend and amount of attenuation in the CWT 40hz.

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