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Spectral Decomposition of Seismic Reflection Data to Detect Gas Related Frequency Anomalies

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SUMMARY

A study was conducted into the use of spectral decomposition algorithms for the purpose of direct hydrocarbon detection through frequency anomalies in a geologically and seismically challenging area. A shallow water North Sea seismic data set in an area with well-known geology, with good well control for both water and hydrocarbon bearing formations was used as test set in this study. The correlations found between attribute responses and well results can be used to de-risk leads and prospects. The study included synthetic modeling with two objectives: assessing the relative performance of different spectral decomposition algorithms, and obtaining indications on algorithm sensitivity, especially for changes in rock properties such as porosity and saturation. Subsequently the most promising spectral decomposition algorithms were applied to the real seismic dataset. The results of this step were cross-validated with the synthetic study and interpreted using the geological information in the area as constraints.

Introduction

A study was conducted into the use of spectral decomposition algorithms for the purpose of direct hydrocarbon detection through frequency anomalies in a geologically and seismically challenging area. A shallow water North Sea seismic data set in an area with well-known geology, with good well control for both water and hydrocarbon bearing formations was used as test set in this study. The correlations found between attribute responses and known well results can be used to de-risk leads and prospects. The study included synthetic modeling with two objectives: assessing the relative performance of different spectral decomposition algorithms, and obtaining indications on algorithm sensitivity, especially for changes in rock properties such as porosity and saturation. Subsequently the most promising spectral decomposition algorithms were applied to the real seismic dataset. The results of this step were cross-validated with the synthetic study and interpreted using the geological information in the area as constraints.

Geology and seismic dataset

The survey area, located in the Southern North Sea, contains gas producing reservoirs in a late Permian carbonate formation and several early Triassic sandstone intervals located in up-thrown fault blocks. The carbonate has a regionally constant thickness of around 30 meter; reservoir quality depends on presence of secondary porosity. The sandstone reservoir intervals are inter-bedded with claystones over a thickness of about 260m and reservoir quality depends on permeability and mineralization. Figure 1a presents a typical section through such a up-thrown block, figures 1b and 1c present this same section on 7.5 and 40 Hz spectral sections respectively.

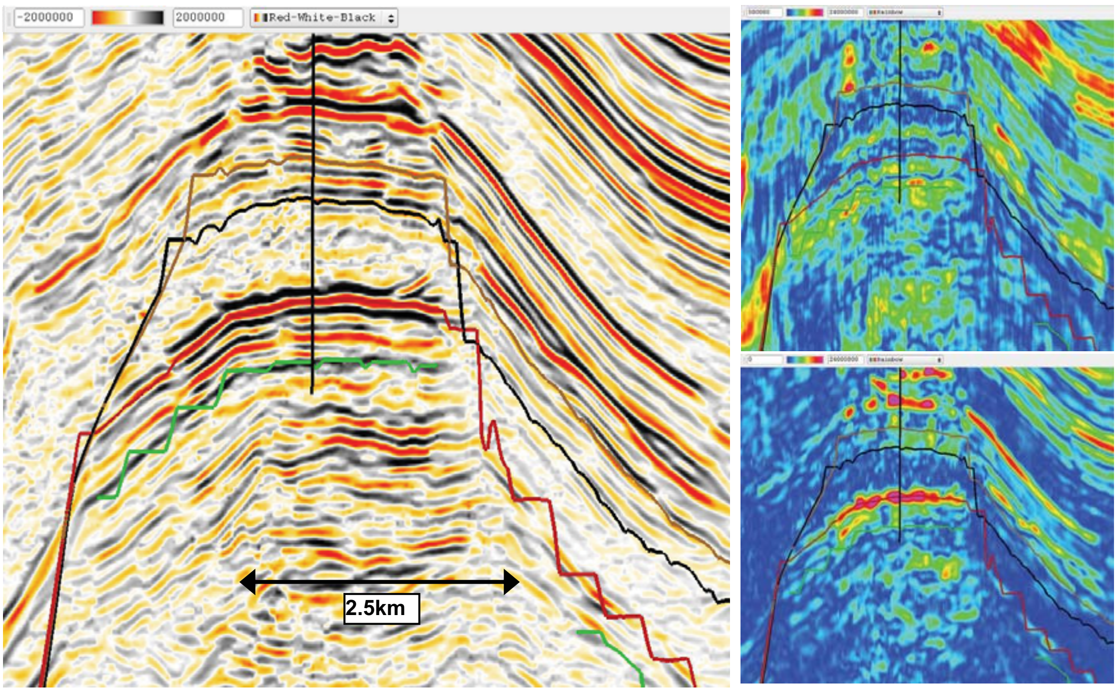

Figure 1: Typical broadband seismic section through a drilled horst-structure (a, left) and corresponding spectrally decomposed sections at 7.5Hz (b, upper right) and 40 Hz (c, lower right). Different spectral behavior of the units is clearly visible.

High-resolution 3D seismic data were acquired in 2005 with 6 km long cables; which were processed through Kirchhoff pre-stack time migration. Parameters for acquisition and processing had been optimized to image both medium-depth Triassic clastic and deep Permian carbonate and clastic targets, as well as steeply dipping strata. Large-scale regional faulting, forming a horst-and-graben system, posed significant challenges in imaging.

Frequency anomalies as direct hydro-carbon indicators

In recent years the development of spectral decomposition methods has made it possible to examine seismic data at individual frequencies. Using such techniques, geoscientists have described anomalous effects at low and high frequencies which are claimed to be related to the presence of hydrocarbons in the subsurface. These include low frequency shadows beneath gas reservoirs and attenuation of higher frequencies in gas reservoirs and gas migration pathways.

Anomalous effects at high and low frequencies have been observed at different locations in the world (Australia, Gulf of Mexico, Russia; see for examples Castagna et al, 2003 and Goloshubin et al, 2006) and have been attributed to the presence of hydrocarbons in the subsurface. These include low frequency shadows (LFS) below and high frequency attenuation within gas reservoirs and gas migration pathways. Although a number of different mechanism for the cause of low frequency shadows have been proposed, no definitive theory has been provided yet (see Castagna et al, 2003 and Ebrom, 1996). In this study we aim to classify our observations in 3 classes to aid systematical analysis of the spectral decomposition data and to try, at least in part, to match each observational category with separate set of physical processes causing the observations.

-1- High Frequency Attenuation (HFA): lack of high frequency band in seismic reflections below reservoir quality formations. Possible indictor of (fizz) gas charge in the reservoir formation. (Li and Han, 2005)
-2- Low Frequency Anomaly (LFA): Boost of the low frequency band in the reflection signature of a reservoir. Similar observations have been linked to oil mobility (Goloshubin et al, 2006)
-3- Low Frequency Shadows (LFS): Boost of the low frequency band below seismic reflections below reservoir-quality formations. This phenomena has been linked to HC content in multiple cases studies (Castagna et al 2003).

Spectral decomposition algorithms and forward modeling study

In this study several spectral decomposition algorithms were assessed. These were the Short Time Fourier Transform (STFT, which is a FFT implementation), the Continuous Wavelet Transform (CWT). See for further explanation and comparison of spectral decomposition methods Chakroborty and Okaya, 1995 and Castagna and Sun, 2006.

Using a synthetic seismic data volume with known frequency content, the performance of the STFT and CWT algorithms were compared. The STFT algorithm was adjusted from its conventional form such that the time-window for data extraction was inversely related to the output frequency. This allowed a better time resolution for the higher frequencies. It was found that when frequency dependent time windows are employed, the STFT has better resolution than the CWT, particularly at low frequencies. Figure 2 presents the results for the low frequency modeling, where the STFT with a 136ms window gives the best resolution (figure 2b). CWT performance is highly dependent on the analyzing wavelet. In this case the Mexican Hat (figure 2d) is a better match to the signal than the Morlet (fig 2a) as it yields much better resolution. It was thus concluded that CWT performance is highly dependent on the choice of mother wavelet. In Figure 3, the high-frequency results are illustrated: all three methods give good resolution, though the FFT (fig 2b) is the best choice for a wide frequency range (a 26ms window was used for the 40Hz FFT). These observations were also confirmed to be true for real seismic data.

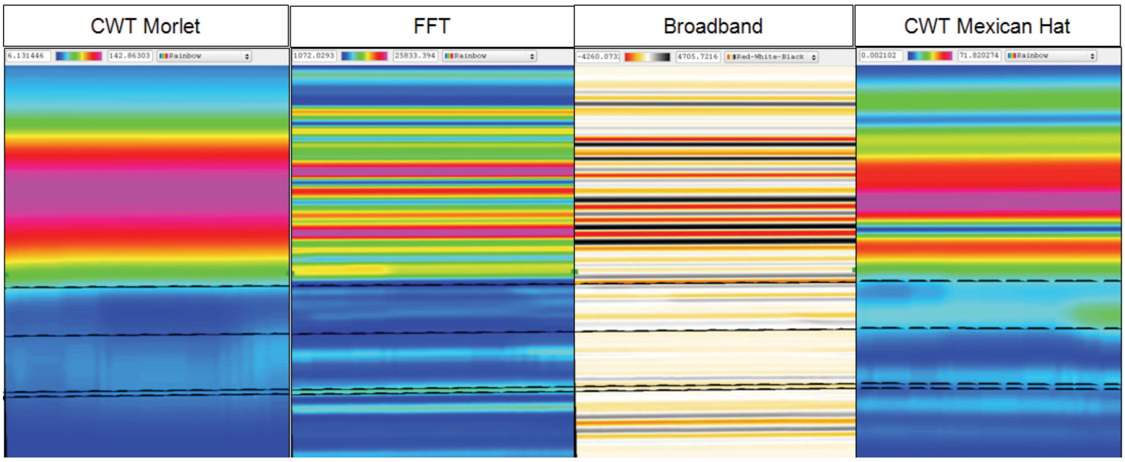

Figure 2: 7.5Hz spectral decomposition of synthetic seismic data using (from left to right) CWT with Morlet wavelet (a), FFT (short-time FT) (b), the original broadband synthetic data (c) and CWT with Mexican Hat wavelet (d).

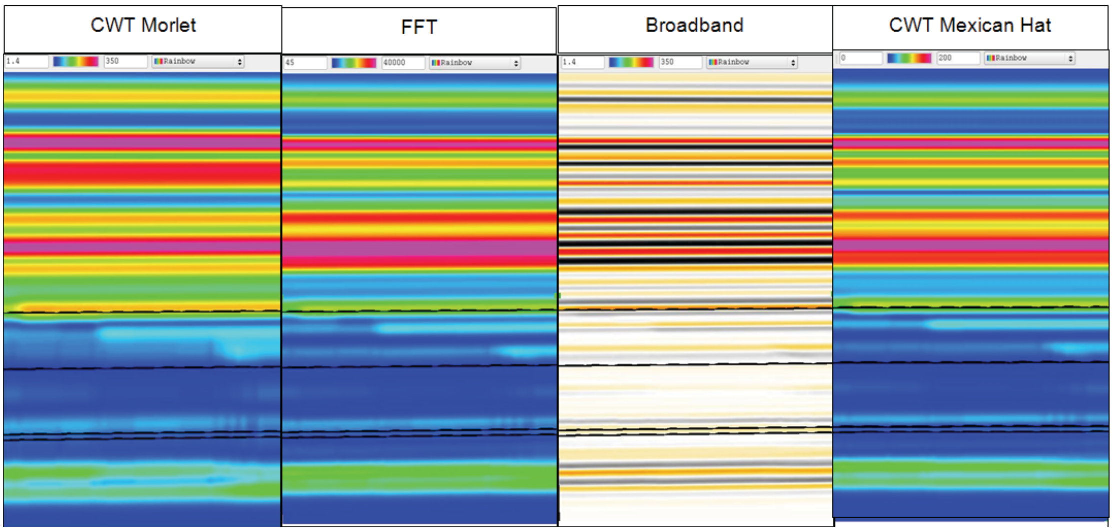

Figure 3. High frequency (40Hz) spectral decomposition of synthetic seismic data using (from left to right) CWT with Morlet wavelet (a), FFT (short-time FT) (b), the original broadband synthetic data (c) and CWT with Mexican Hat wavelet (d).

Interpretation of seismic data

Using STFT spectral decomposition, an assessment of frequency effects was carried out on a southern North Sea seismic volume. Observations were made and compared around a number of drilled wells on the various target intervals. Regions thought to be gas migration pathways were also included in the study. First of all, very distinctive different low and high-frequent behavior of the various target formations was observed. If a low frequent section (fig 1b) is compared with its high-frequency one (fig 1c), the interval indicated with the red horizon clearly stands out. Secondly, clear indications of low frequency anomalies beneath gas reservoirs (figure 4a) and high frequency dim spots at reservoir level were observed. Anomalous attenuation of higher frequencies was seen in regions with increased probability of being gas migration pathways such as large regional faults (figures 4b and 4c), but not in the gas reservoirs themselves. It was not possible to establish if the observed frequency anomalies were directly caused by the presence of gas, since large scale faults and steeply dipping beds may have affected the frequency content of the seismic data. Also contributing to the uncertainty were the presence of gas accumulations at multiple levels, still limited well control and a lack of independent evidence for gas migration pathways.

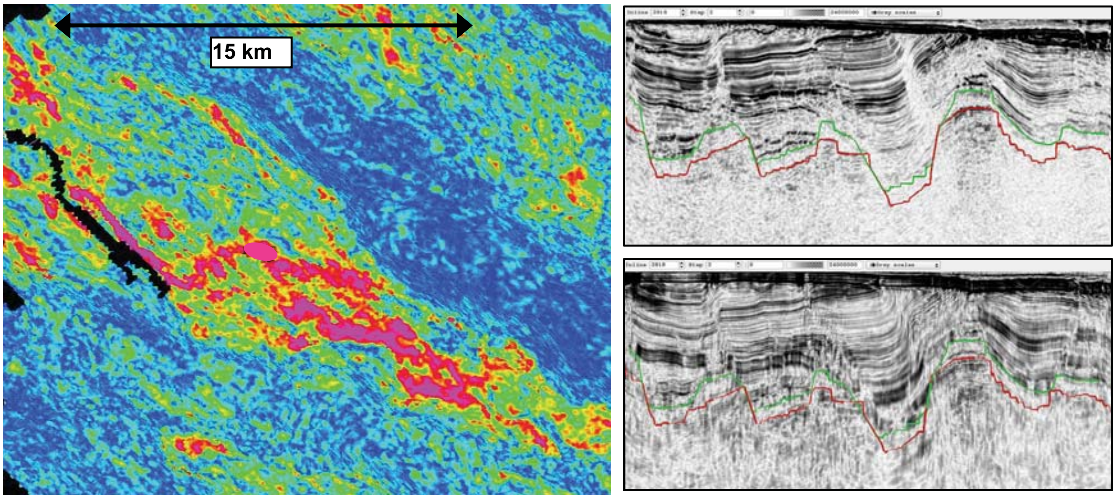

Figure 4a (left): low frequency horizon slice 150ms beneath a known gas accumulation. There is a rough correlation between the high amplitude low frequency anomaly and the extent of gas field.
Figure 4b (upper right) and 4c (lower right): frequency sections at 40 and 7.5 Hz respectively; note the differences in imaging around the regional horst-and-graben faults.

Conclusions and future work

The results of this study contain some very promising observations, but were not consistent enough to use in a predictive fashion for prospect de-risking using a simple "more anomaly is better prospect" interpretation model. Possible factors that contribute to the difficulty in understanding the behavior of spectral decomposition are 1) the challenges in seismic data quality (large horst-graben structures make consistent seismic imaging difficult and will cause amplitude and frequency differences) 2) the rock property regime (moderate to low porosities and low and potentially variable permeabilities) that would reduce the magnitude of frequency effects. Follow-up research is planned that includes a multi-attribute study and closer integration between geophysical, petrophysical and geological expert knowledge.

Acknowledgements

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