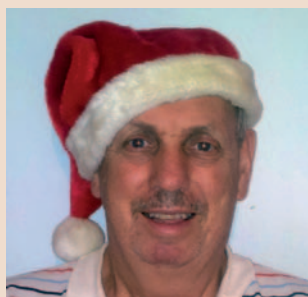# Seismic window

Michael Micenko
Associate Editor for Petroleum
micenko@bigpond.com

An introduction to spectral decomposition

Subtle traps and depositional features are often not obvious on normal seismic displays but can be enhanced by spectral decomposition, which always seems to produce great looking pictures. The technique has been in the interpreter's tool kit for some time now, and is used to transform normal seismic data into the frequency domain so that instead of one volume of data (amplitude) there is an unwieldy set of several to be analysed – one for each frequency component. Because of tuning each frequency component responds to a different bed thickness with high and low frequencies highlighting thin and thick beds respectively.

Historically a Fourier transform (FT) was used to calculate the frequency components, but this transform uses a constant window length regardless of frequency. To analyse a low frequency a longer window is used, and this leads to uncertainty in the origin of the high frequency response within the window. This trade off between frequency and temporal position has led to the use of other techniques such as the continuous wavelet transform (CWT). Although the CWT looks much more complex than the Fourier transform (Figure 1) it is essentially the same with the main difference being the CWT replaces the continuous cosine/sine wave with a finite length wavelet and a scaling term (regular readers may be shocked – I actually do know more than one formula!). The wavelet term (boxed in red) is more complicated because the length of the

Fourier Transform

$$\hat{f}(\xi) = \int_{-\infty}^{\infty} f(x)\,\boxed{e^{-2\pi i x \xi}}\,dx,$$

Continuous Wavelet Transform

$$X_w(a,b) = \frac{1}{|a|^{1/2}} \int_{-\infty}^{\infty} x(t)\,\boxed{\bar{\psi}\left(\frac{t-b}{a}\right)}\,dt$$

Figure 1. *The continuous wavelet transform (CWT) and Fourier transform are similar with both containing the input function and a wavelet description (red box). As frequency varies the CWT wavelet maintains its shape but varies in length while the Fourier transform uses continuous cosine/sine functions.*

analysis window changes with frequency while the wavelet's shape is maintained so that when higher frequencies are analysed a shorter wavelet is used.

Notice how the maximum amplitude (dark red) in Figure 2 is between 30 and 60 Hz for most of the time levels. This is because the frequency spectrum has a strong wavelet overprint on the tuning

information. In some implementations of spectral decomposition there is an option to normalise the data by setting the average amplitude (or maximum) to a constant value for each frequency. This whitening removes the wavelet overprint that is embedded in the data. The displays in Figure 2 have not been normalised so very low and very high frequencies have diminished amplitudes and the tuning effect may be masked.

Let's have a look at how spectral decomposition can be used to contour a prospect with an example from the Exmouth sub-basin of Western Australia.

The strong amplitude anomaly seen on the map view and seismic line of Figure 3 is possibly a gas accumulation, but other information is contained in the seismic data. By applying spectral decomposition it is possible to estimate the thickness of the gas column and calculate the rock volume of the anomalous structure. Figure 4 shows selected frequency components of the same data with the corresponding estimates of bed thickness as shown
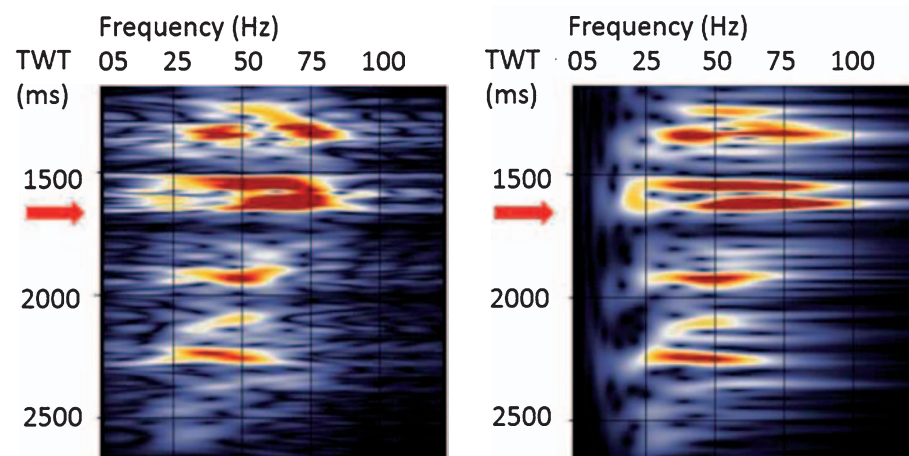

Figure 2. *Comparison of Fourier transform (FT) (left) and continuous wavelet transform (CWT) (right) using plots of frequency vs time for a single trace. These plots are a display of the frequency spectrum at every time sample in the trace. The FT (left) plot has less vertical resolution but more focussed frequencies than the CWT plot (right). The high amplitude reflector used in Figure 3 is indicated with the red arrow.*
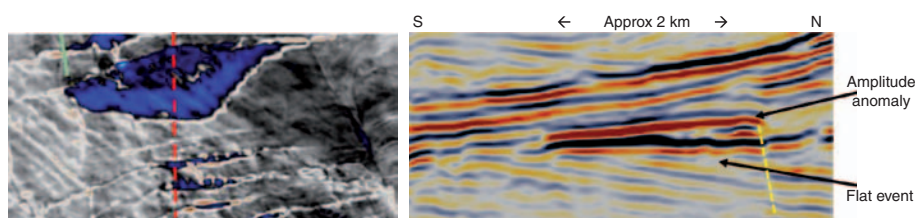
Figure 3. *Map of seismic amplitude anomaly (left) and a south to north seismic line (right) with high amplitude anomaly over a possible flat event. The amplitude anomaly is 6 km long and 2 km across.*
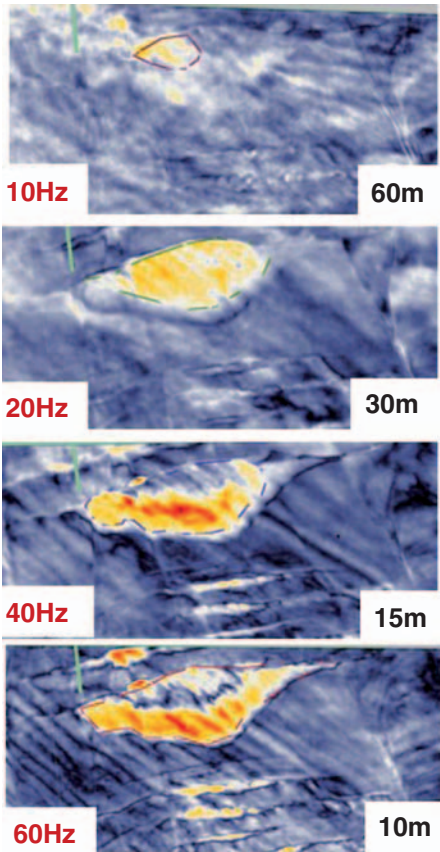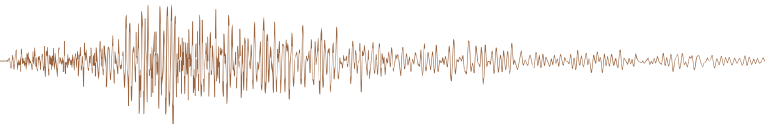
Figure 4. *Selected frequency slices of the amplitude anomaly of Figure 3. The anomaly expands outwards as frequency increases and thickness of the interpreted gas column decreases. These displays have not been normalised so the relative amplitude of the anomalies reflects the frequency spectrum of the wavelet in the data peak frequency is 30–40 Hz.*

Red 10Hz   Green 20Hz   Blue 40Hz
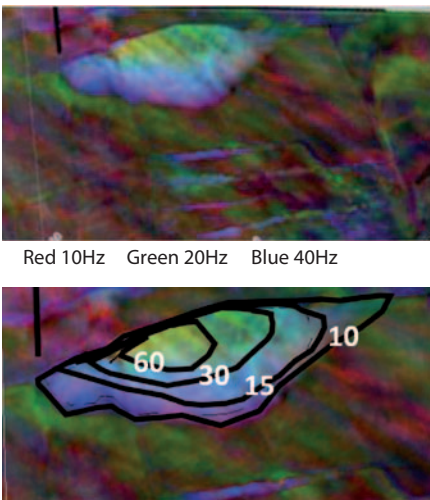
Figure 5. *Blended RGB display with and without contours based on spectral decomposition amplitude anomalies.*

in Table 1. The peak amplitudes are a tuning effect so, given the frequency and velocity, a thickness can be estimated for each component with high frequencies responding to thin beds and low frequencies responding to thick beds. By tracing the outline of an anomaly on a judicious selection of frequency slices a contour map of the anomaly can be built up (Figure 5) and a gross rock volume calculated.

Table 1.   Estimates of thickness

Thickness estimate (assuming a velocity of 2400m/s)				
Frequency (Hz)	10	20	40	60
Tuning thickness (m)	60	30	15	10

The number of data volumes produced makes analysis difficult, so the use of RGB colour blending can assist by allowing multiple (three) frequency components on the same display. To maximise the information contained in a colour blended display I have found it useful to select input frequencies an octave apart (e.g. 10, 20, 40 Hz or 15, 30, 60 Hz). Notice how the colour changes are somewhat conformable with the contours in Figure 5.

I encourage you to give Spectral Decomposition a go and if you have some good examples why not send them in.

Wishing you all a Merry Christmas!