An investigation into the dependence of frequency decomposition colour blend response on bed thickness and acoustic impedance: results from wedge and thin bed models applied to a North Sea channel system

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Introduction.

The use of frequency decomposition colour blending has become commonplace in the analysis of stratigraphic formations from 3D seismic data. Red-green-blue (RGB) colour blending is a particularly effective way of displaying multiple frequency decomposition responses, and the interference between different frequency bands can reveal startling detail within the colour blend and highlighting very subtle and sub seismic resolution. The colour and contrast apparent in the RGB blend is dependent on a number of variables related to the frequency and amplitude of the source signal, which in turn depends on the geometry and rock properties of the subsurface. Even though we can recognise specific geometries, structures and geological features within RGB blends, previously it has been difficult to predict exactly what colour and contrast variations relate to and here we attempt to address that problem.

The aim of this study is to generate a predicted frequency decomposition response for a number of simple geological models and relate these findings to observations from frequency decomposition of real 3D seismic data. Understanding the sensitivity of frequency decomposition to source frequency and change in thickness and impedance, will allow us to design frequency decomposition experiments with more efficiency and to analyse the results with greater effectiveness.

Methodology

The effect of interference of closely separated seismic wavelets was investigated in a seminal study by Ricker (1953). In the proceeding years the concept of interference and tuning thickness has been revisited with important contributions applied to using wedge models (Widess, 1973; Kallweit & Wood, 1982). The importance of spectral interference applied to the determination of bed thickness has also been described utilising decomposition methods (Partyka, *et al.* 1999).

Various models have been created to test simple geological scenarios. By using simplified models representing different geometries we are able to test how variations in simple factors affect the RGB response. Variation in rock properties are accommodated by modifying acoustic impedance within the models. Spectral interference caused by changes in bed thickness is investigated using wedge models. Single frequency zero-phase Ricker wavelets were used to approximate a seismic response at the boundaries of each model.

Three methods of frequency decomposition were investigated as part of this study; constant bandwidth, constant Q and HD frequency decomposition (HDFD). Constant bandwidth and constant Q are both bandpass filtering methods using a Gabor filter in the trace direction. For constant bandwidth decomposition each frequency band that is decomposed has an identical bandwidth, whereas for Constant Q the bandwidth of each frequency response increases with frequency such that the sum of peak energy and bandwidth remains constant between individual bands. HD frequency decomposition is a technique based on a matching pursuit algorithm whereby each seismic trace is decomposed into a number of individual wavelets, which when summed equate to the original trace. After decomposition into wavelets, a trace can be reconstructed at a given central frequency.

As part of our frequency decomposition workflow, 3 magnitude volumes are created at different central frequencies, but with overlapping bandwidth. Each frequency magnitude response is ascribed a different (red, green or blue) colour scheme and the volumes colour blended together. Where one frequency dominates so will that colour in the resultant RGB blend, where there is a strong and equal response from all decomposition frequencies the blend will appear white and where there is no resulting signal at any of the chosen frequencies the blend will appear black. The following models are designed to test how this variation in colour and contrast in the RGB blend is controlled by variations in the changing thickness / acoustic impedance.

Wedge Model

Wedge models are particularly useful for determining the expected seismic response where there is a variation in thickness. When applied to a geological situation they are particularly useful for modelling geometries where a stratigraphic layer thins or pinches out. In order to investigate this we created a simple wedge model with a constant impedance. The acoustic impedance of the sub layer was varied such that both peak-peak and peak –trough wedge models can be analysed.

The wedge model, synthetics and associated frequency decomposition RGB blends are shown in Figure 1. In this example a 15Hz event was created at the upper and lower boundary of the wedge. The interference of these two events as the wedge narrows has been described in detail elsewhere (e.g. Widess, 1973). Decomposition bands are chosen centred at frequencies 5Hz, 10Hz and 15Hz, with overlapping bandwidths, which when combined cover a range of frequencies sensitive to the source and to lower frequency interference between the upper and lower boundaries.

The resulting blends share several features. At the thickest part of the wedge there is no interference between neighbouring events and the reflectors are resolved as a uniform boundary of constant 'grey' colour. As the reflectors converge interference occurs, which manifests as a central colour within the RGB blend. Reducing thickness in the blend results in a pattern of colour, or interference spectra. This starts to occur most at a thickness much greater than the tuning thickness for this waveform (tuning thickness time for a Ricker wavelet, $T= 1/2.31f$, Kallweit & Wood, 1984). For the peak-trough model (high impedance wedge) the RGB response has a peak amplitude response at the tuning thickness. For the peak-peak model, interference patterns also occur, but the blend is brightest at the pinchout

and dimmest at the tuning point. The interference effect is seen to vary between frequency decomposition methods; constant bandwidth method shows the most separation of frequency, but has the lowest vertical resolution, whereas HDFD has the greatest vertical localisation but does not show the same frequency resolution through its RGB interference pattern. This trade off between frequency and temporal localisation is well understood within the field of time-frequency conversion, and understanding the relative advantages of each methodology within the context of RGB blending allows the best technique to be
chosen for a given interpretational objective.

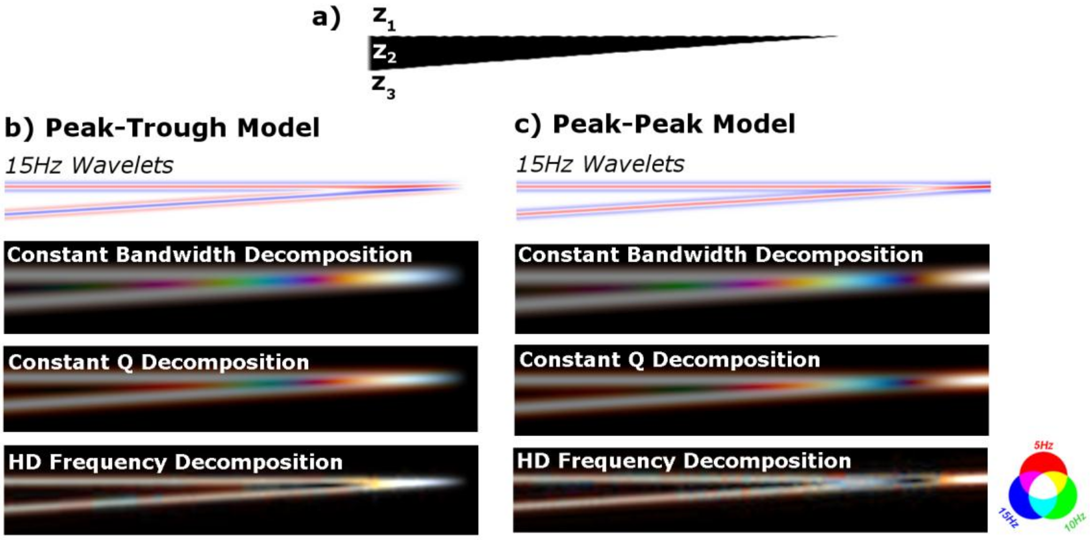

Figure 1: a) Three layer wedge model where acoustic impedance of the upper, mid and lower layers is denoted z_1, z_2 and z_3 respectively; for a peak-trough model $z_1 < z_2$ and $z_2 > z_3$, and for a peak-trough model $z_1 < z_2$ and $z_2 < z_3$. b) and c) show synthetic models using 15Hz Ricker wavelets and their resulting RGB blends using the three magnitude volumes.

Constant thickness, varying impedance model

Models have been generated to investigate the effect of a change in acoustic impedance on the interference patterns observed from RGB blends. Models have a thickness close to, but above the tuning thickness, so that some interference is observed. Figure 2 shows two constant thickness models where the impedance in the middle and lower layer is varied, and their RGB responses using the three frequency decomposition methods. In the first example (Figure 2a) the RGB response shows the same frequency decomposition RGB response, for trough-peak and peak-trough events and in this case varying the impedance of the intermediate layer simply changes amplitude. For the second example (Figure 2b) where the acoustic impedance of the underlying layer is varied the resulting RGB response is more interesting. Here it results in variation of both the colour and thickness of the intermediate interference layer resulting in an artificial wedge being imaged in RGB space. Because of this, being aware of situations where this kind of variation in rock properties can occur is very important in assessing the validity of any interpretation made from the frequency decomposition RGB blend. For each model shown a similar trade off between frequency and temporal resolution is observed between decomposition methods employed. In this example the only method to resolve the true geometry is HDFD.

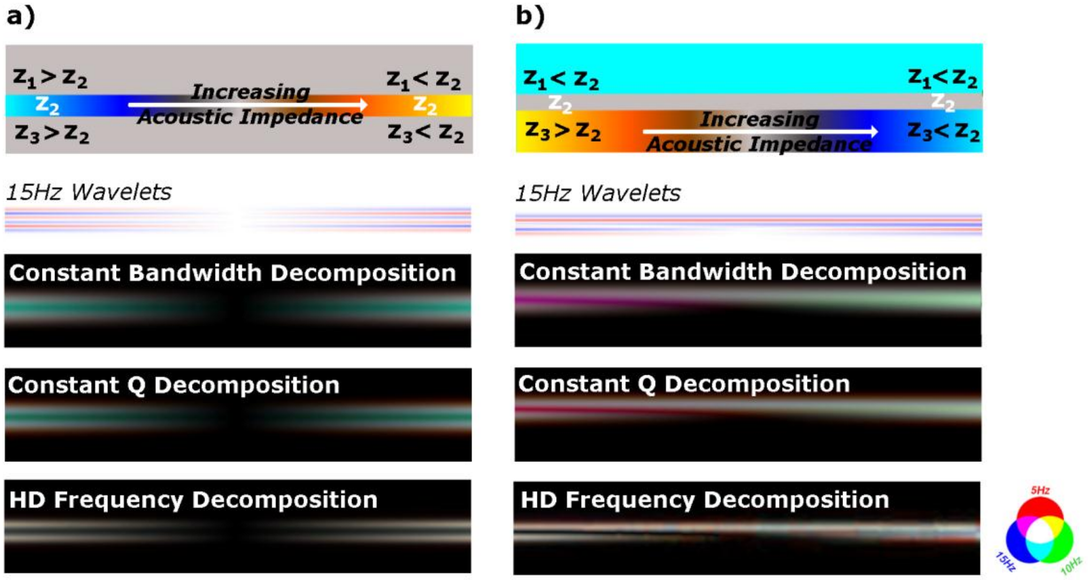

Figure 2: Impedance models, synthetic wave forms and RGB responses using different decomposition methods for a) constant thickness model with varying impedance central layer and b) constant thickness model with varying impedance lower layer.

Structural closures and flatspots

The third example (shown in Figure 3) shows the impedance model, synthetics and frequency decomposition RGB blends for the case of a structural closure, which contains a flat spot due to hydrocarbon accumulation. Firstly a single, low impedance gas leg is introduced. The resulting RGB response is a complex interference pattern composed of different frequency and amplitude response across the flat spot, due to interference of the gas contact with the layers above and below (Figure 3a). When an oil leg is introduced below the gas (Figure 3b) the interference response is complicated further and the two events are difficult to separate within RGB space. There are, however, distinguishing characteristics, particularly at the edges of the flat spots. Here the presence of the second flatspot is noticeable by a 'kick' and unique high frequency in the RGB blend, at the oil legs most peripheral extent.

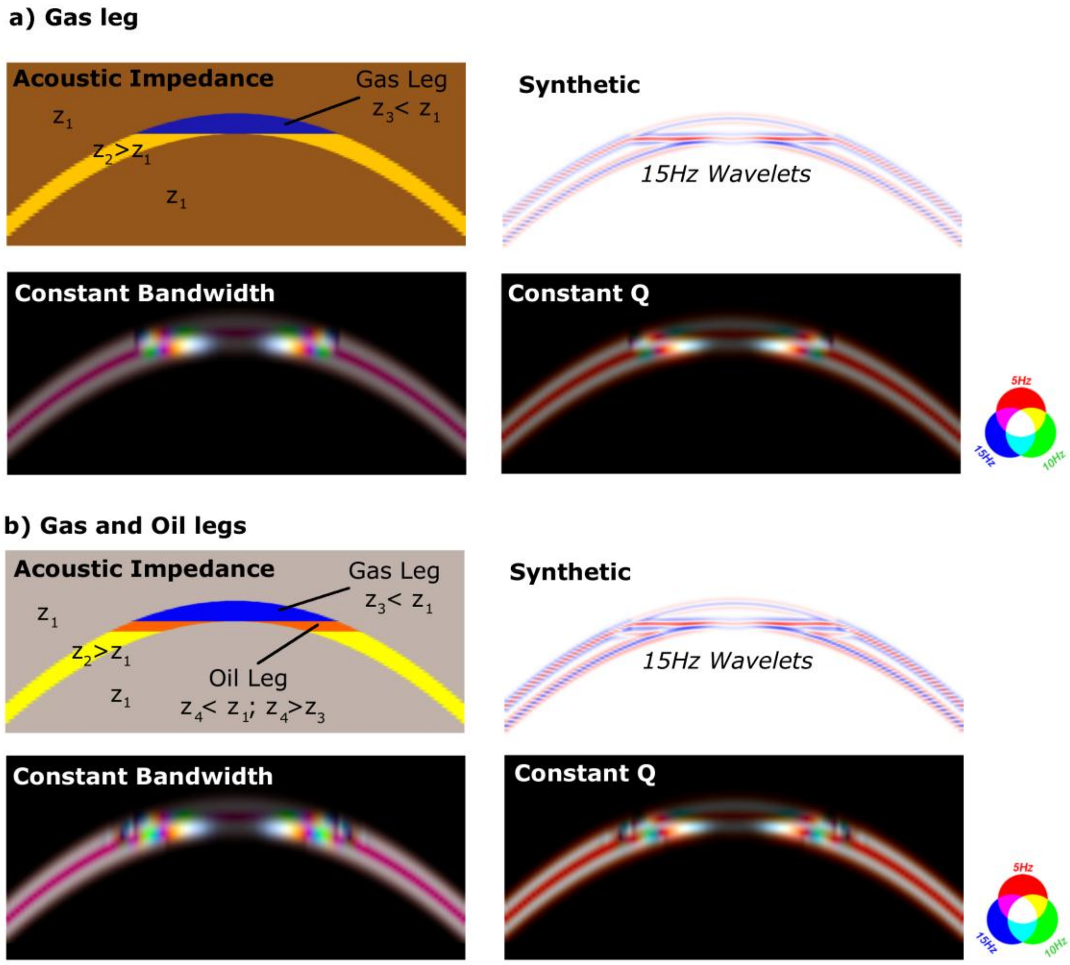

Figure 3: Impedance models, synthetic wave forms and RGB responses using different decomposition methods for structural closure models containing a) gas-water contact and b) gas-oil and oil-water contact.

Application to a real geological setting

In order to validate some of the observations we have made so far, the synthetic modelling approach has been applied to the Hermod Palaeocene fan system, Northern North Sea (McArdle *et al.* 2012; Figure 4). By generating simple synthetic models we can reconstruct the major elements of the RGB blends generated on real seismic data (Figure 4b). In this example it shows that thickness has an overriding control over what is seen in the RGB blend, with impedance changes making a secondary contribution. From this assertion a wedge model is created, using a synthetic Ricker wavelet of equivalent dominant frequency to the seismic data, and this is decomposed and blended using the same parameters and methodology as was used for the blend on the real seismic data (Figure 4c). The result is a RGB calibration wedge, which allows us to predict bed thickness from colour in RGB blend. This matches known sand thickness at a well location and throughout the synthetic model.

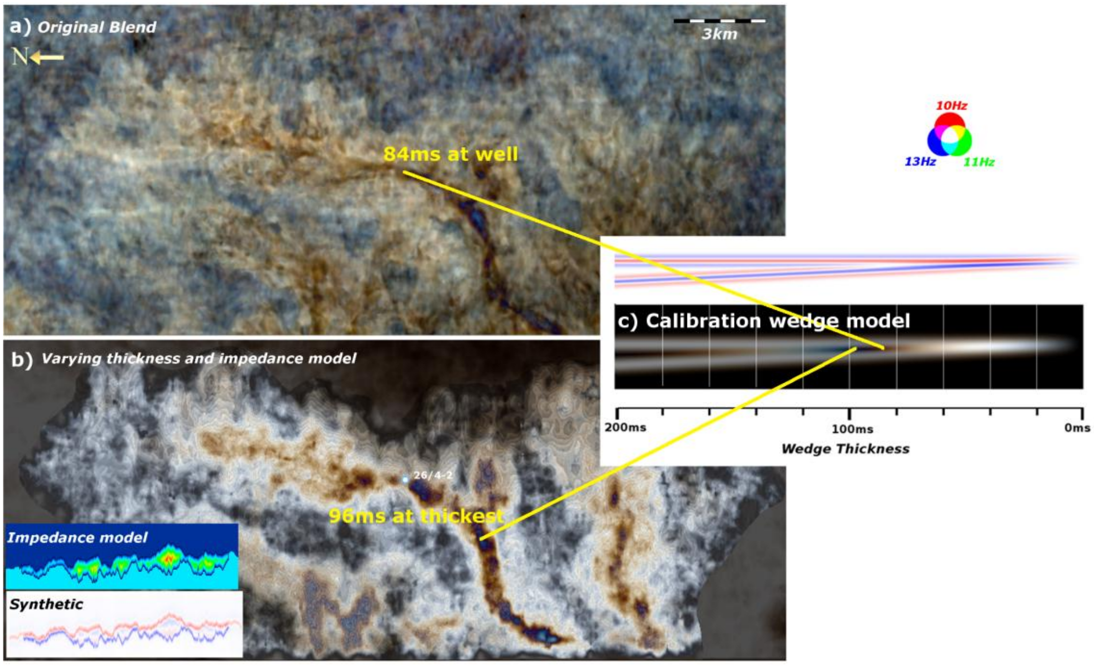

Figure 4: Frequency decomposition RGB blend showing Hermod fan system, generated on a) seismic data b) synthetic model and c) resulting RGB calibration wedge for these RGB blends.

Conclusions

The results of frequency decomposition applied to synthetic models presented here show the importance of understanding spectral interference effects when interpreting RGB blends. It is shown that thickness has an over-riding control on the spectral interference effects that manifest as colour with RGB blends. Changes due to impedance are lesser but can result in potentially anomalous interpretation. Of the three decomposition methods shown here, each has a relative advantage as frequency and temporal resolution is traded off. The Constant bandwidth method has highest frequency resolution giving the most pronounced interference spectra, whereas HDFD gives much higher definition and vertical isolation of events. Where a good knowledge of the geometry and sonic properties of the system is available (though existing interpretation and well logs) calibration models can be used to quantitatively analyse RGB variations and relate them back to thickness variation. We envisage that this style of forward modelling as a tool for the analysis of frequency decomposition RGB blends will become more commonplace as industry demands 'more than pictures' from these workflows.

References

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