Frequency Decomposition Methods Applied to Synthetic Models of the Hermod Submarine Fan System in the North Sea

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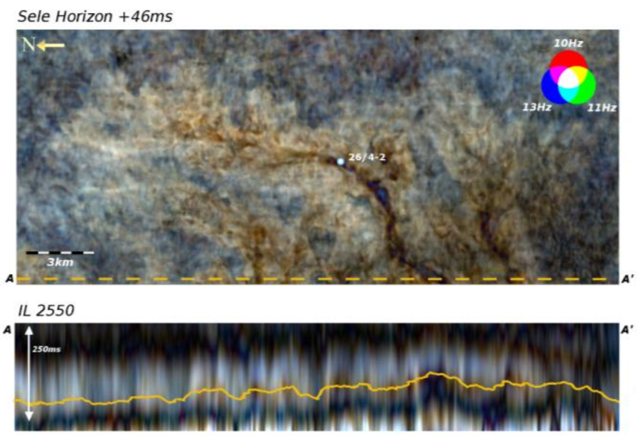
Introduction

The use of spectral decomposition has become common-place in the search for hydrocarbons since its introduction in the late 1990´s (Partyka *et. al.*, 1999). The most common method of displaying the output data from spectral decomposition is the RGB blend, where each output component is assigned a colour, usually red, green and blue. Although there are numerous literature examples of spectral decomposition having been applied successfully to image depositional geometries in the subsurface, there is still a lack of understanding of exactly what the colour changes in the RGB blend mean for the interpreter. In an attempt to close this knowledge gap Tomasso *et. al.* (2010) used the technique of spectral recomposition on outcrop examples in order to enable more accurate comparison of known outcrop geometries with those imaged in the subsurface.

In this paper, we will generate a complex 3D synthetic model of a known spectrally decomposed subsurface example and then re-apply spectral decomposition in order to understand; (1) the geological controls on colour changes within RGB blends, (2) what are the limits on vertical sensitivity in RGB colour blends, and (3) what are the relative advantages of each frequency decomposition method that can be applied.

The subsurface example used herein is an area of the Paleocene age Hermod Mbr. submarine fan system in the Viking Graben area of the northern North Sea. The eastern-most splay of this system has been investigated using the seismic response in cross-section, isochron maps and a 10, 11, 13Hz RGB blend, and has been interpreted as a frontal splay complex overlain by a leveed channel, with little erosion of the surrounding Sele Fm. shale. This dataset lends itself perfectly to the analysis performed here, since; (1) it has been comprehensively imaged using spectral decomposition (Bryn & Ackers, in press), (2) the sedimentology of the fan system is very well documented by several scholars (Hadler-Jacobsen *et. al.*, 2005), and (3) rock property information from several wells that have penetrated the system are available. Figure 1 shows an example RGB blend showing the geometry of this splay in comparison with side-scan sonar imaging of a modern submarine fan system from the Mississippi delta.



RGB colour blending of the Hermod Fm. using Constant Q Frequency decomposition, when viewed along a horizon, displays detailed geometries that are comparable to a modern day submarine fan.

This method of frequency decomposition has a poor vertical resolution which makes interpretation in section difficult.

Figure 1 *Comparison of RGB blend of Palaeocene Hermod Channel system and side-scan sonar imaging of a modern Mississippian submarine fan system (image from USGS).*

Comparison of frequency decomposition techniques applied to Hermod submarine fan system

Three methods of frequency decomposition are investigated here whereby the data are decomposed into three distinct frequency magnitude responses which are then colour blended. Constant bandwidth and constant Q are both band-pass methods of decomposition using a Gabor filter. For the constant bandwidth method the width of each frequency response remains constant around a central frequency. This technique is the lowest bandwidth method and because of this, the technique is most successful when individual responses have central frequencies that are close together, allowing for overlap in bandwidth and variation of colour in the blend. Constant Q is a variable bandwidth method, with bandwidth increasing with frequency so that the proportion of power to bandwidth remains constant between different responses. HD Frequency Decomposition (HDFD) 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 and different frequency responses blended together. The HDFD technique is the highest bandwidth method used here and the resulting HDFD blends are most successful when the central frequencies of the corresponding red, green and blue colour channels are distributed at intervals across the entire seismic spectrum. A comparison of the three different methods of frequency decomposition applied to the Hermod dataset is shown in Figure 2.

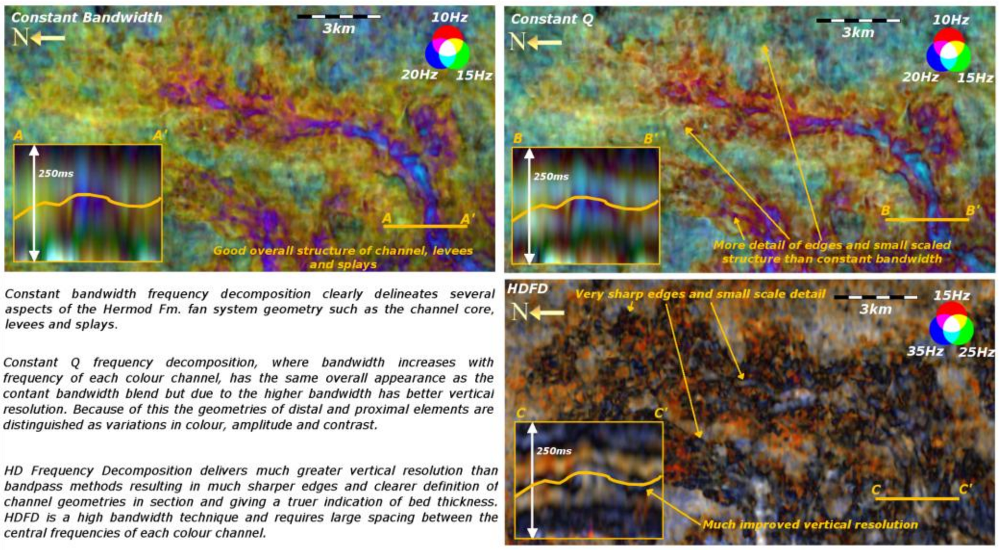


Figure 2 *Comparison of RGB blends of Hermod Mbr. submarine fan system generated using different frequency decomposition techniques and mapped onto a horizon 46ms below the top Sele reflector.*

Several key features are observed from the blends shown in Figure 2. All methods are successful in highlighting the edge of the fan system. Constant bandwidth and constant Q are particularly successful at highlighting the thickest part of the sequence at the channel core, which appears as the most 'colourful' part of the blend. Away from the channel centre, as the depositional system evolves into levees and splays, the blend brightens due to the amplitude of all the frequency magnitude responses increasing. Towards the most distal parts of the system, the bed thickness thins and the amplitude response decreases, resulting in a dimming of the blend. Also noticeable within thin layers is a 'sandwiching' effect, apparent a coloured layer caused by interference of the responses of the upper and lower reflector. The colour of this intermediate interference layer is seen to vary with thickness.

Although constant bandwidth and constant Q methods produce very similar results when the same central frequencies are blended, subtle difference are apparent. In particular constant Q decomposition resolves sharper edges due to the increased vertical sensitivity accompanying the increased bandwidth. The compromise made by increasing the vertical resolution through increased bandwidth is reduced localization of frequency. Therefore constant Q blends often do not isolate frequency as successfully as constant bandwidth and they can appear less colourful. The HD Frequency decomposition blend has the highest vertical resolution, and because of the high bandwidths of each response, reconstruction frequencies are chosen at bigger intervals prior to blending. This is necessary to produce a blend which displays a range in colour and contrast. The high vertical resolution means that the edges and small scale internal geometries of the fan system are successfully imaged.

Application of synthetic modelling to Hermod channel member

Synthetic modelling of seismic events using wedges to investigate tuning effects is well investigated (Widess, 1973) and more recent applications of spectral reconstruction applied to synthetic geological models have been carried out to show the effect of different geometries in single attribute reconstructed responses (Tomasso *et. al.,* 2010). Little published work is available synthetically reproducing the variations that are observed in frequency decomposition colour blends by modelling changes in geometry and/or rock properties and this section is aimed at addressing this issue.
Although observations have been made about the colour and contrast variations that occur with distance from the channel axis within RGB blends, there are two known and quantifiable variables that could be responsible for these variations; bed thickness and acoustic impedance. The sequence is thickest at the channel centre and the depositional model predicts that bed thickness reduces towards the periphery of the splays where it abruptly terminates. Accompanying this thickness change is an expected variation in acoustic impedance, whereby larger grain sands within the channel have high impedance and as the grain size reduces towards the edge of the fans, so does impedance. In order to investigate the predominant cause of the amplitude and colour variations, two synthetic models have been created exploring the effect of variable thickness and a combination of variable thickness and impedance.

The geometry of the sand fairway is defined by horizons picked near the top and base of the Sele Fm. and the thickness of the Hermod Mbr. was obtained by subtracting a constant shale thickness from the mapped isochron. Acoustic impedance values from well 26/4-2 are used to compute reflectivity at the top and base of the Hermod Mbr.. In the case of the variable thickness model, mean acoustic impedances are computed for the Sele Fm. (above Hermod), Hermod Mbr. and Lista Fm. (below Hermod). For the variable impedance model, the acoustic impedance profile for the Hermod Mbr. at the well is simplified and populated throughout the model. Synthetic Ricker wavelets are generated at the Sele and Lista horizons at varying frequencies. Frequencies between 5 and 40Hz at 5Hz intervals are summed to create a synthetic response which has similar bandwidth to the original data. The constant Q method of frequency decomposition is applied to both synthetic models using central frequencies that were sensitive to the variations in channel/splay geometry in the original data and these results are shown in Figure 3.

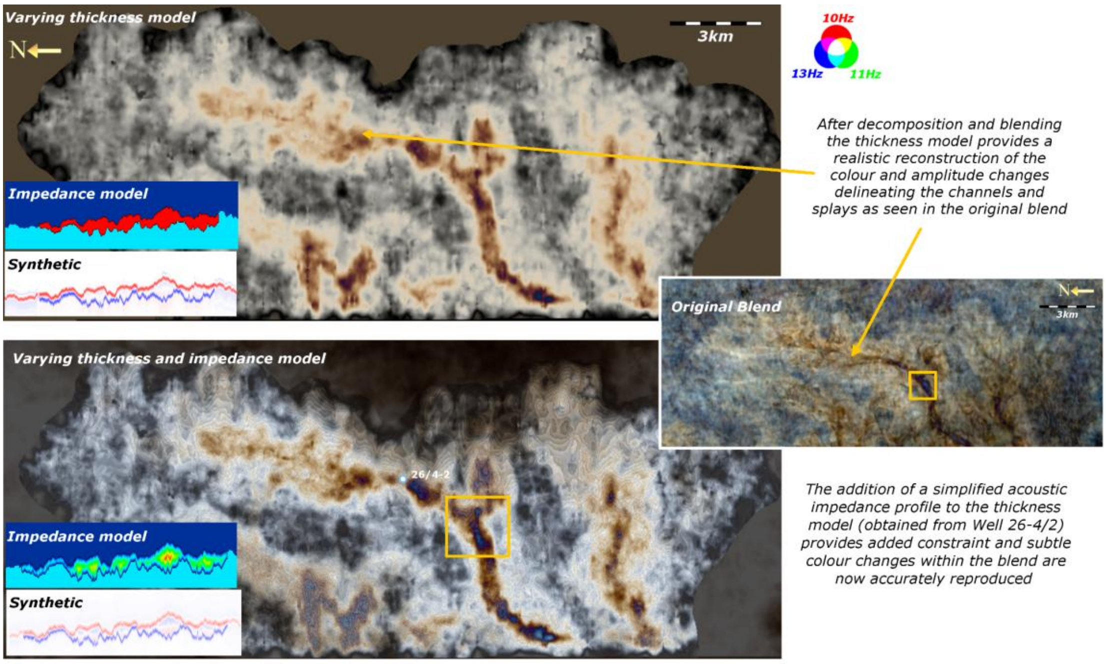


Figure 3 *a) Hermod synthetic thickness model. b) Hermod combined thickness/impedance model.*

Conclusions

A synthetic model of the Hermod Mbr. has been created, which when resolved using standard frequency decomposition, successfully reproduces aspects of the RGB blend generated on the original seismic data. This model combines sand thickness with acoustic impedance predicted from well data intersecting the package. The dominant effect on the colour blend is variation in bed thickness and the RGB blend of this model reproduces the overall structure observed in the original blend. To accurately reproduce subtle and localised changes in amplitude and contrast the inclusion of acoustic impedance data is useful. In general, large impedance contrasts are necessary to produce major contrasts within the blend, and because acoustic impedance changes are gradual with the Hermod Mbr., it has a lesser effect on the blend. The observations relating bed thickness and impedance changes to frequency decomposition colour blends have also been verified using thin bed and wedge models. Figure 4 relates the observations from the frequency decomposition colour blending of the Hermod Mbr. to variations in thickness and acoustic impedance.

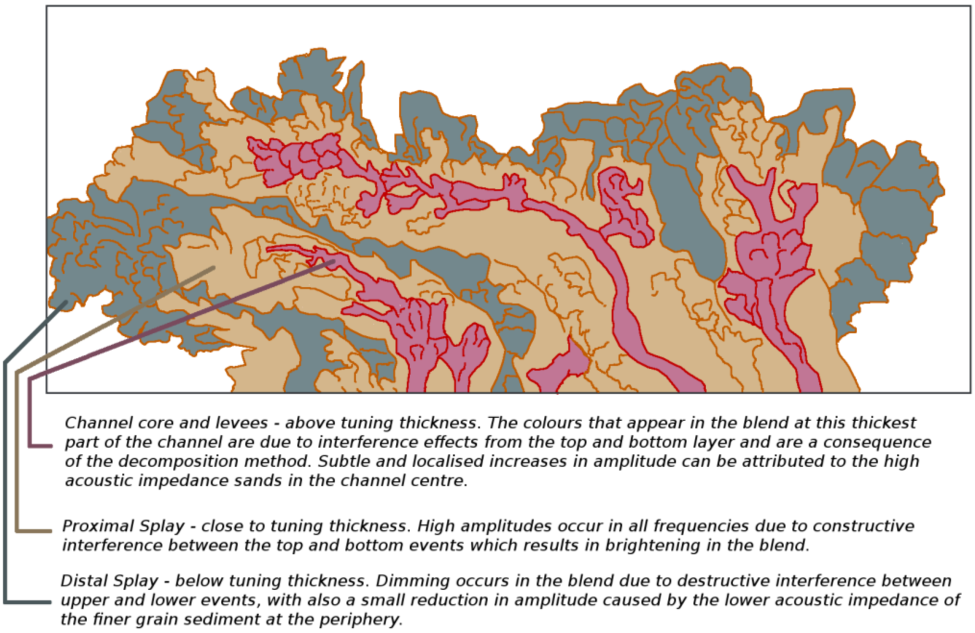


Figure 4 *Simplified explanation relating observations made from frequency decomposition colour blending of the Hermod Mbr. submarine fan system to variations in thickness and impedance.*

References

Bryn, B. & Ackers M.[in press] Unravelling the nature of deep-marine sandstones through the linkage of seismic geomorphologies to sedimentary facies – a North Sea case study. *IAS Spec. Pub.*, **47**

Hadler-Jacobsen, F., Jonannessen, E., Ashton, N., Henriksen, S., Johnson, S. & Kristensen, J. [2005] Submarine fan morphology and lithology distribution: a predictable function of sediment delivery, gross shelf-to-basin relief, slope gradient and basin topography. *Petroleum Geology Conference Series*, v. **6**, Geological Society, London, 1121-1145

Partyka, G., Gridley, J. & Lopez J. [1999] Interpretational applications of spectral decomposition in reservoir characterization. *The Leading Edge*, **18**, 353-360

Tomasso, M., Bouroullec, R. & Pyles, D. [2010] The use of spectral recomposition in tailored forward seismic modeling of outcrop analogs. *Geohorizons,* **94**(4), 457-474

Widess, M.B., [1973]. How thin is a thin bed? *Geophysics,* **38**(6), 1176-1180