Application of seismic attributes in enhancing thin beds: An Example from North Sea

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Summary:
Many potential reservoirs are found to consist of thin stratigraphic intervals which prove to be a challenging task to be interpreted from a seismic section. These thin stratigraphic intervals are considered to be potential hydrocarbon bearing zones. The analysis of the 3D seismic data set of the F3 block located in the north-eastern part of the Dutch sector of the North Sea, shows the presence of such intervals. These thin beds are analysed using spectral decomposition technique and comparative results of different algorithms used in this technique have confirmed their presence. The blending of monochromatic colours brought out their presence in a much more enhanced way.

1. Introduction:

A thin bed is defined as one whose thickness is less than λ/8, where λ is the dominant wavelength that is computed using the velocity of the bed (Widess, 1973). In other words, a thin bed is a stratigraphic unit that has a thickness much less than the dominant wavelength of the seismic wavelet that illuminates the bed. Seismic resolution is an important aspect in deciphering the stratigraphic details. In order to extract information about features such as thin beds, a good vertical resolution is necessary. When a seismic wave propagates into the subsurface the frequency content tends to decrease with depth. Due to attenuation, the higher frequencies, which image the thin beds, get masked. We have utilized the technique called spectral decomposition to identify thin beds in this work.

Spectral Decomposition technique shows the characteristic expression of thin beds in the frequency domain. This technique decomposes the seismic signals into narrow frequency sub-bands which when examined into a spatial context, reveal interference that occurs across the available bandwidth of the signal. In this study, the seismic data is decomposed into discrete frequency volumes using Short Time Fourier Transform (STFT) and Continuous Wavelet Transform (CWT) techniques. In STFT, a window of a fixed frequency resolution is preselected, which slides along the time axis to give a 2-D representation of the signal. In order to overcome the problem of preselection, the CWT is utilized that does not require the process of preselection of a window. The CWT convolves the input data with a set of functions generated by the translations and dilations of the “mother wavelet” (Mexican Hat, Gaussian and Morlet) (Goyal et al. 2014).

In this paper we have presented a comparative study of both STFT and CWT techniques and proved that CWT is a better technique.

2. Geological Setting:

The North Sea basin is an epicontinental basin consisting of several horsts and grabens produced due to several episodes of rifting in its geological history. It is presumed to be a part of the North-West European Basin during the Late Cenozoic Era (Vinken, 1988; Ziegler, 1990; Evans et al., 2003; Kuhlmann et al., 2006). The basin was open into the Atlantic on the north-west reach (Bijlsma, 1981; Glennie, 1990; Ziegler, 1990) and was separated by the London-Brabant–Massif on the south.

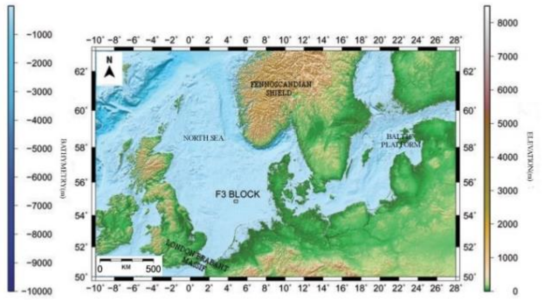


Figure 1: Geological Map of the study area (developed in GMT)

The study area (Fig 1) lies in the southern North Sea Basin in the Netherlands offshore sector. The North Sea had a huge prograding deposition of Cenozoic sediments spanning to nearly 3 km of which nearly half of the deposition took place in the Neogene period (Kuhlmann et al. 2006). Late Cenozoic sedimentation dominantly consisted of an extensive fluvial system that eroded and carried the Fennoscandian and Baltic Shield sediments. This extensive fluvial system has been named as Eridanos Drainage System. It prograded into the sea forming large scale delta called the Eridanos Delta which shows a maximum thickness of 1500m (Bishop-Kay, 1993) resulting due to simultaneous Neogene upliftment of Fennoscandian Shield and basin subsidence (Overeem et al., 2001). The lower reach of the delta is marked by the most prominent unconformity in the basin called the Mid-Miocene Unconformity. Progradation is identified by the sediments downlapping above the MMU (Overeem et al., 2001).The system is composed mainly of two active channels that are relatively straight with no branching indicating steep gradients and wave action which indicates a wave-dominated delta regime. The subsidence history of the basin shows spatial non-uniformity (Jordt et al., 1995) with higher subsidence rate at the basin centre and lower rates of subsidence or uplift at the flanks (Cloetingh et al., 1992). During the later parts of Neogene the shallowing of the basin took place resulting in lower depositional rate.

3. Data Base:

The present study is based on the data obtained from a 3D seismic survey carried out in the F3 block of the Dutch sector which covers an approximate area of 384 sq. km. This data is publicly made available by dGB Earth Sciences. This seismic data is a Post-Stack Time Migrated volume which comprises of 650 inlines and 950 crosslines with a line spacing of 25m in both inline and crossline direction (Fig 2). The sampling rate is 4ms with a total data length of around 1.8 seconds.

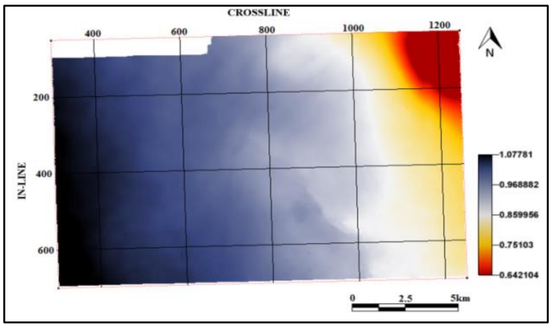


Fig 2: Base Map of F3 Block. The amplitude values are indicates ranging from red (minimum) to blue (maximum)

3. Methodology and analysis:

The workflow which has been followed and used for the characterization of thin beds is as follows:

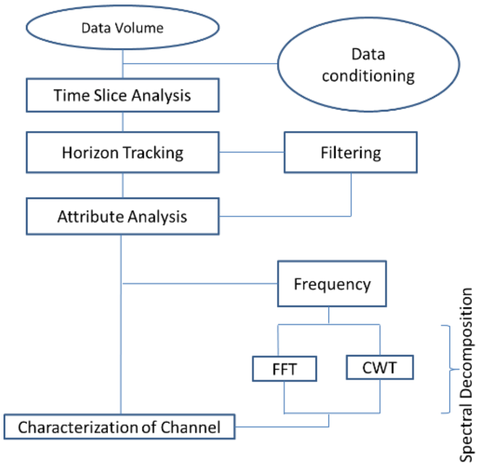
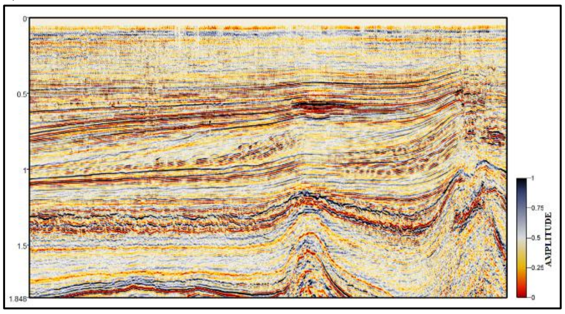


Figure 3: Work Flow

Seismic interpretation is carried out using OpendTect v5.0.7. Before using the seismic data for further analysis, the data is optimally conditioned in order to remove noise and thereby increase its signal-to-noise ratio (SNR). The conditioning of data is done by preparing steering cube using an FFT algorithm and thus preserve the dip and azimuth information of the seismic reflectors (Tingdahl 1999; Tingdahl et al., 2001). Afterwards, Dip-Steered Median Filter is applied over the entire cube and the Dip-Steered Median Filtered (DSMF) data (Fig 4) is obtained.

a)



b)

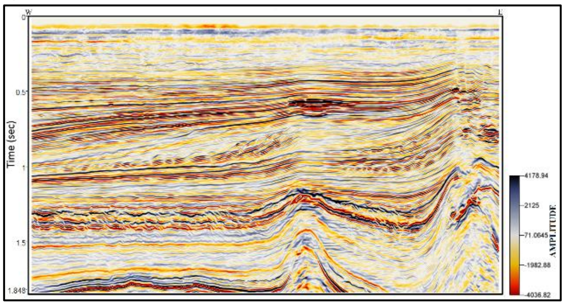
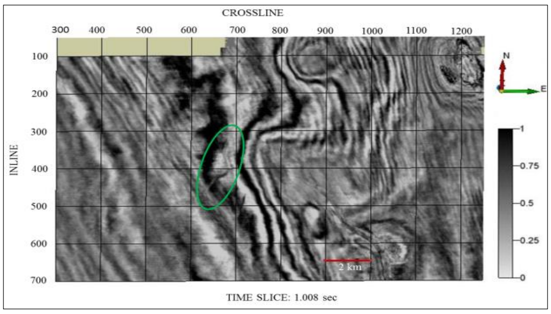


Fig 4: (a) Display of seismic (inline 666) before DSMF and (b) after DSMF

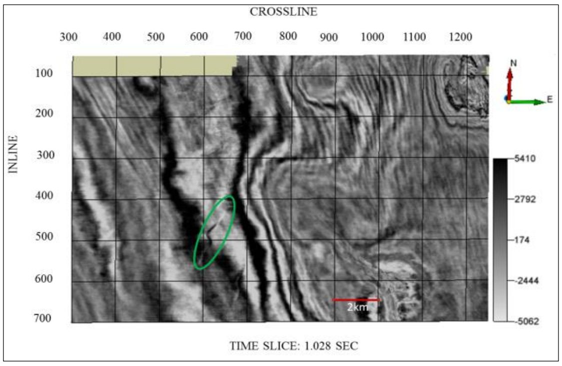
After optimal conditioning of the data, the geological features in different time slices from 1.008 to 1.064 seconds, are analysed. The time slices displayed in grey scale from light to dark colour represents lower to higher amplitude values. At about 1.008 seconds (Fig 5a), a pattern having NNE-SSW trend is observed which is suspected to be a channel like feature. At about 1.028 seconds (Fig 5b), a growth in the pattern is noticed towards the SW part of the area. The feature continues to extend towards the southern part in the 1.036 second slice (Fig 5c). However, at 1.056 seconds (Fig 5d), only a small part of the feature is observed towards the south which is not discernible at 1.064 seconds (Fig 5e). From this analysis, we draw a conclusion that a channel exists between 1.008 to 1.064 seconds which shows maximum prominence at 1.028 and 1.036 seconds.

After time slice analysis, the horizon top is picked at every 10th inline and crossline. To remove any miss-picks, the horizon is filtered using a median filtering technique with a 3X3 step out.

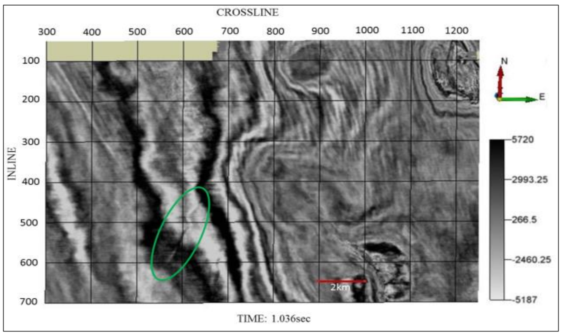
5a)



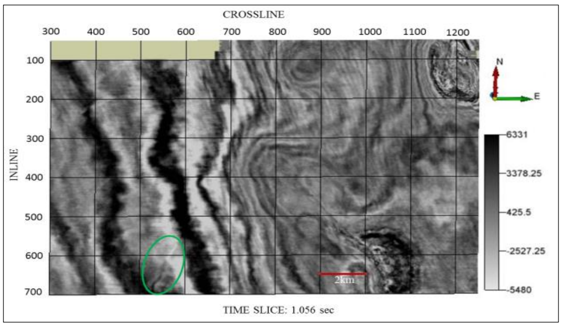
5b)



5c)



5d)



5e)

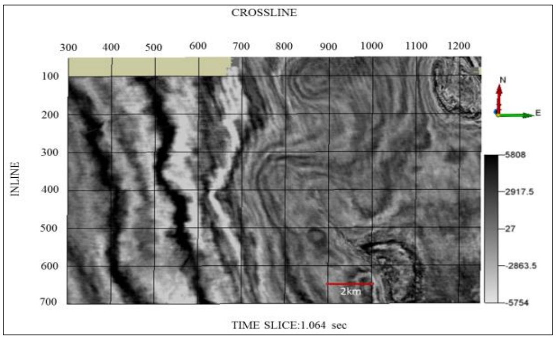


Fig 5: Time Slices: a) 1.008 secs, b) 1.028 secs, c) 1.036 secs and d) 1.056 secs (Green oval shape indicates the channel-like linear feature). e) The feature is not resolvable at 1.064 sec.

4. Attribute Analysis:

Seismic attributes have nowadays become an important tool in seismic interpretation techniques. The interpretation of structural and stratigraphic features has thereby improved.

For delineating subtle features like faults and stratigraphic features like channels and analysing the amplitude spectra of the seismic data, spectral decomposition tool proves to be a better technique within the seismic data. The output of this decomposition is referred to as a tuning cube which is thoroughly investigated for identifying the tuning frequency that best resolves these geological features. After analysis of the amplitude spectrum of the seismic data, spectral decomposition technique is applied. This spectrum (Fig 6) helps to identify different frequency zones like low frequency zone (10Hz to 20Hz), mid frequency zone (25Hz to 40 Hz) and high frequency zone (45Hz to 60 Hz) which are used for decomposing the seismic data volume.

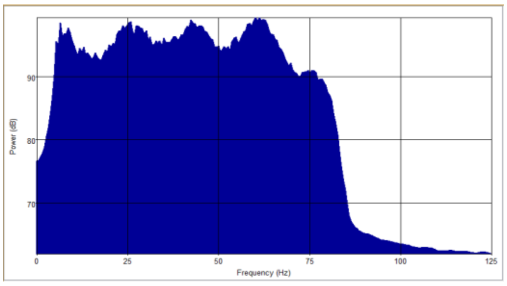


Fig 6: Amplitude spectrum of the original data volume

For carrying out decomposition, first of all, we test both the STFT and CWT techniques (Fig 7) over the low, mid and high frequency zones. It is observed that the CWT technique improved the resolution of the channel mapping in whole frequency range. It is to be noted that to obtain better result by the CWT technique, it is essential to use a perfect mother wavelet which would help in better imaging these features. Thus, we test three different wavelets viz. Morlet, Gaussian & Mexican Hat (Fig 8). It is observed that the Mexican hat operator provides a better resolution as compared to the other two wavelets. Hence, this confirms that Mexican Hat is the perfect mother wavelet for the current data set.

Through this decomposition, we observe that some parts of the channel are getting resolved at low frequencies, some at mid frequencies and rest at higher frequencies. However, at 35 Hz frequency a better image of the channel is observed. It is this frequency at which the channel geometry is well resolved and hence is called as the tuning frequency. Since different parts of the channel are resolved at different frequencies, the channel geometry is obtained in its full form when these frequency volumes are stacked together. Hence, a stacked frequency volume is prepared by summing up of 25Hz frequency (low frequency), 35Hz frequency (mid frequency) and 60 Hz frequency (high frequency) volumes (Fig 9).

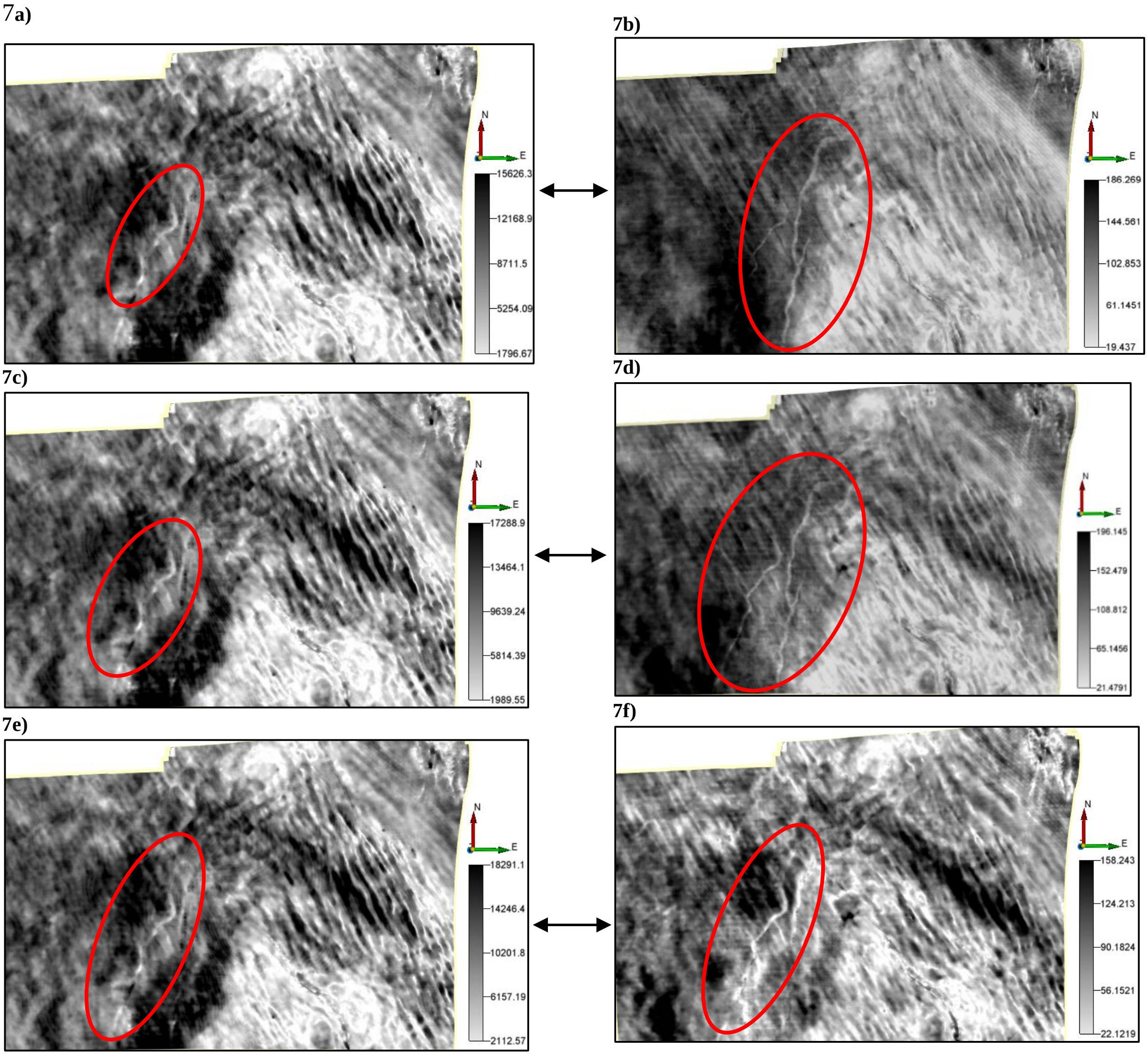


Fig 7: Comparison between STFT and CWT. a) 25Hz STFT and b) 25Hz CWT; c) 35Hz STFT and d) 35Hz CWT; e) 60Hz STFT and f) 60Hz CWT. (Channel-like feature shown in red coloured oval circles). Amplitude scale increases with colour intensity).

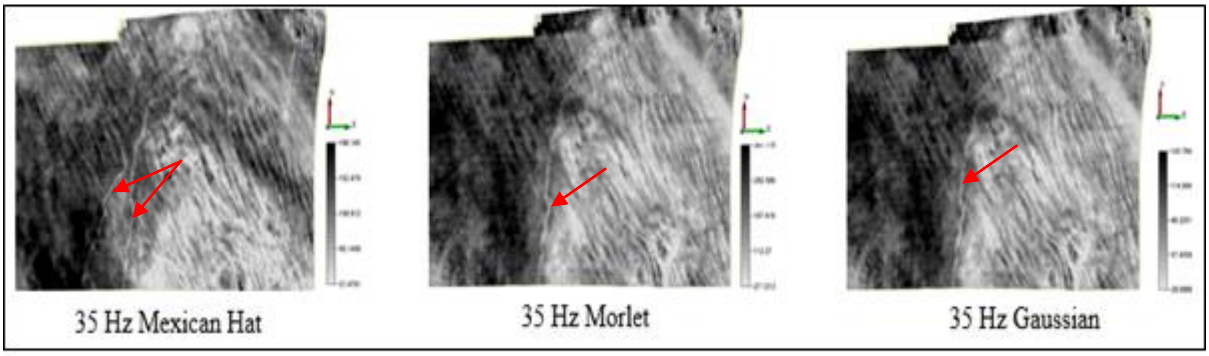


Fig 8: Comparison between the three mother wavelets at 35Hz frequency. The Mexican Hat resolves two channels (red arrows) with respect to Morlet and Gaussian wavelets.

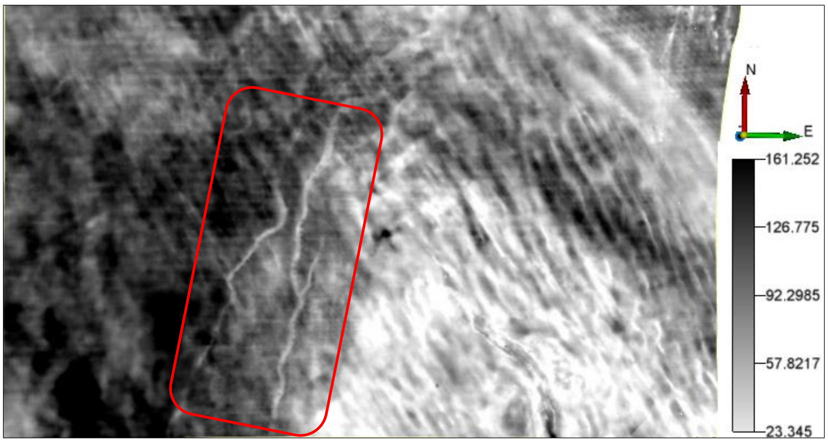


Fig 9: Stacked frequency volume of frequencies 25Hz, 35Hz and 60Hz. (Red box shows the linear channel)

5. RGB Blending:

A coloured display of the acquired stacked frequency volume proves to be a much more powerful tool for visualizing the inferred channel. A colour blending of the primary colours i.e. red, green and blue also known as the RGB blend display is carried out (Fig. 10). In case of a composite RGB display, each input attribute volume is mapped individually to the red, green and blue monochromatic components of the RGB space. The intensity of each primary colour represents the intensity of the attribute in that channel, which is distinguishable clearly. This shows that the RGB blending tool is very comfortable, even to the naked eye, to visualize the geological features.

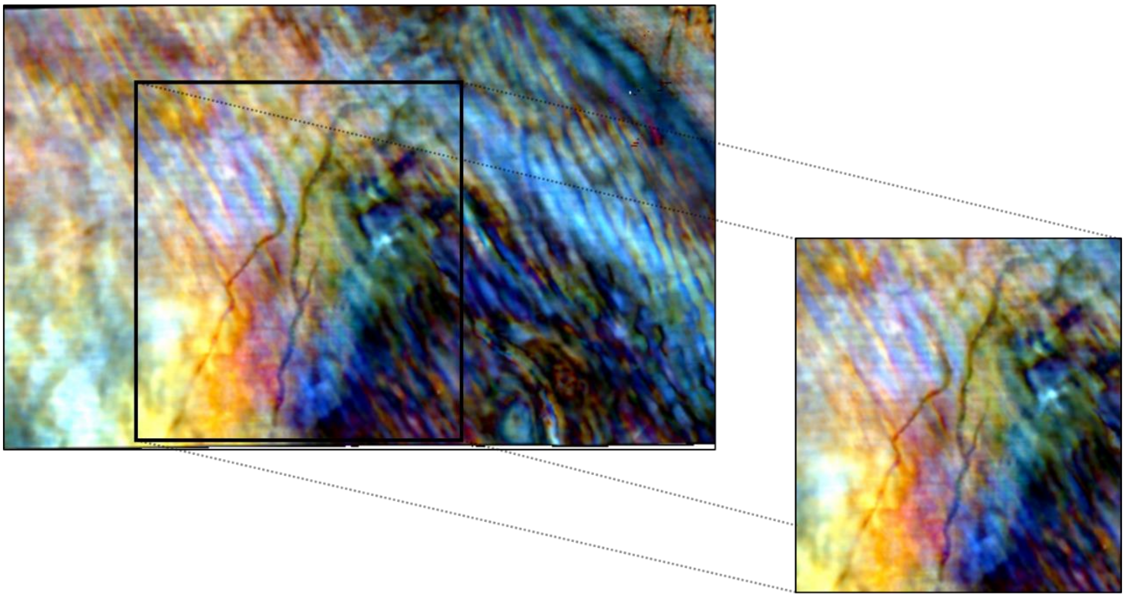


Fig 10: RGB Colour blending Of frequencies 25Hz (Red Colour), 35Hz (Green Colour) and 55Hz (Blue Colour). The channel is zoomed in the separate image.

Conclusion:

From this study we infer that the time slice analysis helps to visualize the presence of the channel between 1008 to 1064 millisecond which, in-turn, enables to identify a reflector close to this feature. While carrying out the spectral decomposition technique over the horizon picked close to this geological feature, it is observed that the CWT algorithm is able to enhance this geological feature in a much better way than that of the STFT algorithm. The decomposition technique also helps in identifying the channel geometry (almost linear) and its orientation towards NNE-SSW. The process of blending the monochromatic colours brings out the presence of this feature in its full form.

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8. Acknowledgement:

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