The application of data conditioning, frequency decomposition and DHI from RGB colour blending in the Gohta discovery (Barents Sea, Norway)

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Abstract

Geological Expression workflows, involving data conditioning and frequency decomposition can be used to detect subtle changes within the seismic signal, increase the confidence on the seismic interpretation and de-risk exploration and appraisal wells. This paper looks at the application of these workflows to the Permian carbonates in the Gohta discovery (Barents Sea, Norway) and how the results can help to increase the confidence on the proposed appraisal program.

As a preparation for the rest of the workflow, the data was conditioned using post-stack techniques. The first step involved noise cancellation of the seismic data using structurally oriented and edge-preserving algorithms. An area of poor quality data due to shallow gas clouds was identified to the south of the Gohta Structure. In this area, a stronger noise attenuation workflow followed by an amplitude normalisation was applied to increase the reflector continuity. Both noise cancellations were then combined and this noise cancelled dataset was used as an input for the spectral enhancement. Two different spectral enhancements were tested using different methods; one involved the enhancement of the low frequencies using a low-pass high-cut filter, and the other one involved an enhancement of both the low and the high frequencies, aiming for a white spectrum.

Frequency decomposition and RGB blending were applied on both enhanced datasets, using two different methods: one involving a window-based Fast Fourier Transform, and the other one involving an adaptive matching pursuit algorithm. The bright colours observed in the blends were interpreted as an indicator of the presence of oil and gas, while colour changes were interpreted as changes in reservoir thickness, lithology or fluid content.

The results of this work supported the presence hydrocarbons on the proposed location of the Gohta Appraisal well (7120/1-4 S), which was drilled in 2014 and encountered gas but the testing in the oil zone was inconclusive because of the technical problem of isolating gas flow from the oil zone, proving the validity of this technique as a DHI.

Geological setting

The Gohta Discovery is located in PL 492 (Norway) on the south western edge of the Loppa High, on the Polhøg Sub platform, bordering the Hammerfest and Tromsø basins.

The Barents Sea is a proven hydrocarbon province with several gas and oil fields. It is characterized by repeated rift phases that postdate the Caledonian Orogeny, forming deep basins of Paleozoic to Tertiary age. One or more episodes of general uplift of the Barents Sea, east of a hinge line west of the Stappen – Loppa Highs have taken place in post-Paleocene times. The Goliath Field, 100 Km to the South East, is presently in the development phase. Two other discoveries (Havis and Skrugard) have recently been made north of the Gohta Discovery, being the most recent additions to the exploration models in the up-lifted setting.

The Gohta discovery well (7120/1-3), drilled by the operator Lundin in 2013, discovered oil and gas in the Røye Formation of Permian age, with possible hydrocarbon migration from the basin immediately to the North West. A drill stem test was performed, showing very good production rates and confirming the presence of an open reservoir system. The trap is defined as a 4-way dip closure, with a reservoir consisting of Permian porous karstified carbonates of the Tempelfjorden Group. The pay zone consists of a 25 m gas column and 75 m of oil (Figure 1).
In the down flank well 7120/1-1, the carbonate has had limited sub aerial exposure and is mainly tight. Up-dip from this well the truncation and sub-cropping exposure has been extensive, and porous carbonates due to karstification and dolomitisation were encountered in 7120/1-3 well. Mixed spiculitic/dolomitic zone has been also observed in the cores of Røye Formation.

In 2014, the Gohta appraisal well 7120/1-4 S was drilled to the Upper Røye Formation in the northern part of the Gohta Structure where a bright colour blend response had been identified in the area using the workflow proposed in this paper. The conglomeratic/brecciated carbonate of 10m thickness at Top Permian reservoir was tested and produced 700,000 Sm³ gas / day. The testing in the oil zone was inconclusive because of a technical issue that made difficult isolating the gas from the oil flow.

A 3D seismic dataset was acquired in 2011 by the operator, Lundin, and was processed to PSTM. It is a zero-phase European-polarity dataset (i.e. the increase in acoustic impedance at the seabed is represented by blue trough). Three wells are located in the survey, 7120/1-1 and 7120/1-3 (Gohta discovery well) and 7120/1-4 S (Gohta appraisal well). Generally there is good well to seismic tie as shown in figure 2.
Figure 2. Arbitrary line showing the seismic-well tie and correlation between the Gohta discovery well (7120/1-3) and well (7120/1-1) just out of the reservoir closure.

Geological Expression workflow

In order to identify the extents of the reservoir and its internal variations, a Geological Expression workflow (Henderson, 2012) was applied to the data. As shown in the chart (Figure 3), the workflow involved several steps of data conditioning to improve both the signal-to-noise ratio and the frequency content of the dataset; then different methods of frequency decomposition to identify the subtle changes within the seismic signal which can be related to changes in reservoir thickness, fluid contents or lithological changes.

![Geological Expression workflow chart](image-url)

Figure 3. Geological Expression workflow chart.
Noise cancellation

Noise cancellation was applied as a first step to condition the data and ensure the data quality is optimised as much as it can be in the post-stack domain. Two different noise cancellation workflows were applied for two different areas within the region of interest. For the areas with good seismic imaging (i.e. not affected by the gas cloud), the workflow involved the application of a structurally oriented and edge-preserving finite impulse median hybrid filter targeting coherent noise, followed by a tensor diffusion algorithm targeting random noise. This combination of filters resulted in an increase in the signal-to-noise ratio, improving the continuity of the seismic reflectors while preserving the fault breaks.

For the areas where seismic signal is degraded due to the presence of the shallow gas cloud, a stronger noise cancellation using a mean filter was applied. Both noise cancellations were combined using a chaos-based mask volume, and then the amplitudes were normalised by estimating the amount of amplitude reduction produced by the gas cloud, and applying an amplitude scaling factor using the chaos-based mask. To describe workflow, the first step was to generate the envelope attribute of the noise cancelled volume and then to calculate the square root of the envelope volume. Then the chaos attribute volume was generated to enhance the amplitude of the noisy chaos area affected by presence of shallow gas observed on seismic data. Another volume was generated by dividing the chaos volume by square root of the envelop volume and multiplying it by scale factor of 10, from this volume we note the maximum value to be used for next calculations for amplitude balancing. Although different scale factors 10, 20 and 40 were tested but the scale factor of 10 produced the reasonable amplitude balance of chaos area and normal seismic area. Eventually the final balanced amplitude was generated after following a few mathematical expressions to balance the highest value of the boosted volume of the low amplitude noisy area of with the high amplitude area of the normal seismic. In this process the lower amplitude zone in the chaos area is better imaged while still maintaining the imaging potential of the higher amplitude.

The results of the noise cancellation and amplitude normalisation show overall an improvement in the reflector continuity and an increase in the signal-to-noise ratio (Figure 4). The areas initially affected by the gas cloud effects, show higher amplitudes and increased reflector continuity, allowing a more accurate horizon interpretation to be made across the gas cloud. However, the reflectivity is still dominantly chaotic, and due to the fact that we are artificially boosting the amplitudes, it can be considered an area of uncertainty for any further interpretation.

Conventional spectral enhancement

This technique aims to balance the contribution of frequencies within the data, producing a “white spectrum”, where all the frequencies contribute equally to the signal power. This leads to a better vertical resolution as a result of the increased bandwidth and higher mean frequency of the output volume. To archive the optimum results in the Gohta dataset, both the low and the high end of the spectrum were boosted. The spectral enhancement was carried out by decomposing the signal in a number of band-pass filters using a modified Fast Fourier Transform (FFT), and then the band-passes were recombined using some weighting factors to generate the target spectrum (Figure 5).
Figure 5. The spectral enhancement workflow involves a spectral decomposition to generate a number of band-pass filters (left), which then are combined to produce a “white spectrum” (right).

The application of spectral enhancement resulted on a better vertical resolution of the data and a more detailed image of the reservoir area. As Figure 6 shows the comparison of original XL 3546 (a) and after the noise reduction and conventional spectral enhancement (b) a pre-requisite before colour blending.

Figure 6. XL 3546 showing (a) the original data and (b) the noise cancelled/spectral enhanced data.

Low-frequency enhancement

Several authors (Goloshubin et al., 2002; Burnett & Castagna, 2003; Castagna et al., 2003; Bahal et al., 2007; Yu et al., 2011) have used low frequency effects as a predictive method for identifying and mapping hydrocarbon reservoirs by applying frequency dependent processing.

Bahal et al. (2007) proposed a low-frequency enhancement of seismic data which involves the application of an amplitude boost in the low frequency range of data, generating an output with an enhanced low-frequency component but still preserving the full bandwidth of the data spectrum. The output low-frequency enhanced data will highlight low-frequency amplitude anomalies potentially indicating hydrocarbon presence.

The method involved the analysis of an amplitude spectrum for the time window of interest for several seismic lines. After analysing the spectrum, a low-pass and high frequency cut filter was designed on the frequency domain and applied over the entire seismic volume. The amplitude envelope of the filtered seismic volume was then calculated and used to multiply the input data, producing the final enhanced data. By doing this multiplication, the low frequency reflectors were enhanced and the high frequency reflectors were still preserved (Figures 7 and 8).
In our study, the time window used was 2.5 s and the low-pass high-cut filter covered a frequency range of 4 Hz to 10 Hz.

Figure 7. (a) The average amplitude spectrum of original data, (b) the average spectrum of the low-frequency enhanced data, (c) Low-frequency enhanced spectrum highlighted on both spectra overlaid.

Figure 8. XL 3635 showing (a) the input data and the calculated spectrum, (b) the low-pass high-cut filtered data, (c) the envelope volume calculated on the filtered data, (d) the final output volume after multiplying the filtered envelope by the input data.
Figure 9 shows the comparison of a time slice through the gas cap in the original seismic section and the low-frequency enhanced section. The dynamic range in the low-frequency enhanced data was broadened as a result of the enhancement. The low frequency enhancement highlighted the reflectors within the reservoir, which after the enhancement show much higher amplitudes than the surrounding reflectors outside of the reservoir. These observations can be linked to the presence of hydrocarbons, as they absorb the high frequencies and produce a low frequency response as seen on the enhanced volume.

![Figure 9. Comparison of time-slices at 1792 ms through original data (left) and low-frequency enhanced data (right). The time-slice goes through the Gohta gas cap.](image)

Figure 10 shows an amplitude extraction of the low-frequency enhanced seismic data along a horizon slice at the Top Permian Reservoir. The high amplitude area is generally located within the OWC polygon. The high amplitude anomaly may be interpreted as related to the presence of the gas-bearing carbonate conglomerates at the top section of Permian carbonates encountered in 7120/1-4 well. The possibility of the presence of non-reservoir conglomeratic section out of the HC closure cannot be ruled out.
Figure 10. Amplitude map of the low-frequency enhanced data at Top Permian reservoir. The red outline shows the projected gas-oil contact and the green outline the projected oil-water contact.

**Frequency Decomposition and RGB blending**

Frequency decomposition has become a common tool in the oil industry, since it was introduced in the 1990s (Partyka et al., 1999). RGB blending combines information from three input volumes (in this case three magnitude volumes with different dominant frequencies) into a single output blended volume, and can be used both for looking at stratigraphic and structural features (Henderson et al., 2007).

The workflow was tested using both the conventionally spectral enhanced data and the low-frequency enhanced data as input volumes. Different frequency decomposition algorithms were tried on the datasets, including the Constant Q method (analogous to a Constant Wavelet Transform or CWT) and the HDFD method (based on a modified matching pursuit algorithm).

The Constant Q method is a variable bandwidth method, with bandwidth increasing with frequency so that the proportion of power to bandwidth remains constant between different band-passes (McArdle and Ackers, 2012; Cooke et al, 2014).

Using the conventionally enhanced dataset as an input, the Constant Q method was applied to generate three magnitude volumes for dominant frequencies of 10 Hz, 14 Hz and 22 Hz. These volumes were blended in an RGB colour scheme, so that the 10 Hz volume was assigned to the red colour, the 14 Hz volume to the green colour and the 22 Hz volume to the blue colour. These frequencies were selected based on an assessment of which combination was giving a better looking output blend.
As Figure 11 shows, the colour blend tends to show bright responses (i.e. high amplitudes) in the areas within the reservoir, while the response is significantly darker outside of the Gohta structure. Changes in colour within the reservoir can be a result of changes in thickness, fluid content or reservoir proprieties. The southern area of the reservoir, which was initially obscured by the gas cloud, shows a chaotic response on the blend, but still has a brighter response than the surrounding areas outside the reservoir, supporting the current gas-oil contact interpretation.

![Figure 11](image1.png)

Figure 11. Time-slices through the gas cap (left) and oil leg (right), showing Constant Q RGB blends generated on the conventional spectral enhanced dataset.

A similar workflow was applied using the low-frequency enhanced dataset as the input. The three magnitude volumes were generated for dominant frequencies of 7 Hz, 13 Hz and 20 Hz. Again, these frequencies were selected based on a qualitative assessment of which combination was producing a better looking blend. In this case, the amplitude contrast (i.e. brightness contrast) between the reservoir and the surroundings was even more evident (Figure 12).
One of the drawbacks of the filter-based frequency decomposition techniques, such as FFT or CWT, is that the vertical resolution of the original seismic data is not preserved due to vertical smearing. High Definition Frequency Decomposition (HDFD) is a technique based on a modified matching pursuit algorithm which preserves seismic resolution. With the HDFD method, each seismic trace is decomposed into a number of individual wavelets whose sum equates to the original trace. After decomposition into wavelet responses, a trace can be reconstructed at any given frequency (McArdle and Ackers, 2012). The ability to decompose and recompose wavelets on a trace gives an end result with minimal vertical smearing allowing for the best vertical resolution.

The HDFD was tested both using the conventionally enhanced volume and the low-frequency enhanced volume as input volumes. In both cases the three magnitude volumes were generated for dominant frequencies of 20 Hz, 30 Hz and 40 Hz. Then the 20 Hz magnitude volume was assigned to the red colour, the 30 Hz magnitude volume was assigned to the green colour and the 40 Hz magnitude volume was assigned to the blue colour. As figures 13 and 14 show, the results of the HDFD colour blends show a clear brightness difference between the areas within the reservoir and outside the reservoir, which could be linked to the presence of hydrocarbons.

Figure 12. Time-slices through the gas cap (left) and oil leg (right), showing Constant Q RGB blends generated on the low-frequency enhanced dataset.
Figure 13. Time-slices through the gas cap (left) and oil leg (right), showing HDFD RGB blends generated on the conventional spectral enhanced dataset.

Figure 14. Time-slices through the gas cap (left) and oil leg (right), showing HDFD RGB blends generated on the low-frequency enhanced dataset.
Conclusions

Data conditioning, including both noise cancellation and spectral enhancement, optimised the input data to be used for further interpretation and frequency studies. The noise cancellation increased the signal-to-noise ratio while preserving the subtle edges and fault breaks, and the spectral enhancement brought a white spectrum to the data improving the vertical resolution. A stronger noise cancellation filter was applied in the areas affected by amplitude reduction due to the presence of a shallow gas cloud. The amplitude in these areas was corrected using an adaptive amplitude normalisation workflow, which adjusted the amplitudes that were attenuated because of the gas cloud, recovering a similar amplitude range to the surrounding un-affected areas.

The Frequency decomposition workflow analysed the subtle frequency variations in the seismic signal which were interpreted as changes in reservoir thickness, lithology or fluid content. This technique has been used mainly as a qualitative approach for identifying those reservoir variations. The brighter RGB blend colours observed within the reservoir were interpreted as an indicator of the presence of hydrocarbons.

Different approaches of frequency decomposition and colour blending techniques were tested in the dataset, and all of them showed a brighter colour response within the reservoir, which could be an effect of the presence of hydrocarbons.

The first results of this work supported the presence hydrocarbons on the proposed location of the Gohta Appraisal well (7120/1-4 S), which was drilled in Q2 2014 and encountered at least gas but the presence of the oil could not be confirmed, still proving the validity of this technique as a hydrocarbon indicator. The test of the gas zone was positive, whereas the results from the oil zone are non-conclusive. A new appraisal well will be planned to test the presence of oil at a different location of Gohta structure.

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