Impact of Broadband Seismic on Quantitative Interpretation Workflows*

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Abstract

New acquisition methods and technologies have been made available to interpreters and quantitative interpretation specialists with the aim of providing broader seismic frequency bandwidth. Various systems do exist at the moment in the market place, and the one referred to in this paper is based on the dual-sensor towed streamer. This seismic acquisition system was introduced in 2007, and recently further developments have been made with a time and depth distributed source finally allowing the removal of both the source and the receiver ghosts in a single seismic acquisition solution.

In this paper, we review some of the overall benefits offered by the broadband seismic from the end users point of view; seismic interpreters as well as reservoir geophysicist or quantitative interpretation specialist knowing that all of them are benefiting significantly from an extended bandwidth and improved signal to noise (S/N) across all the frequencies. The benefits are presented by means of a few case studies in different geological settings as well as at various stages of the Exploration and Production asset life.

Introduction

Geoscientist would like to have seismic data that fulfill a few criteria: ability to identify and delineate prospects based on amplitude and/or attributes response (post and pre-stack); to describe the internal structure of the reservoir; to depth convert the seismic; and to characterize or quantify key reservoir properties such as porosity and the probability of successfully separating lithology-fluid facies, and all this in 3D using all the dimensions of the seismic (pre-stack 3D and 4D). Hence, the need for seismic to image the subsurface accurately in general and the reservoirs in particular is of significant interest.

A serious limitation to seismic has always been the ghost reflections from the sea surface that occurs both at the source and the receiver side which degrade the seismic image affecting interpretation and quantitative interpretation workflows. In 2007, Petroleum Geo-Services introduced the dual-sensor streamer (Carlson et al., 2007), allowing the receiver ghost to be removed by separating the up- and down-going

wavefield with the two sensors (pressure and vertical particle velocity) collocated in the streamer. This revolutionary acquisition system has now been available for a few years facilitating an extended bandwidth at both the low and high ends of the frequency spectrum.

Recently, the de-ghosting has also been developed for the source side. The new source design is allowing the removal of the source ghost by having a time and depth distributed source (Parkes and Hegna, 2011). This elimination of both the source and receiver ghosts increases significantly the seismic bandwidth (Reiser et al., 2012).

The broader bandwidth should have a significant impact on seismic interpretation and quantitative seismic interpretation: the low side of the spectrum contributes in particular but not exclusively (Engelmark and Reiser, 2010) to the improved derivation of the absolute elastic properties such as acoustic and shear impedance, whereas the high side of the spectrum improves the seismic resolution and hence the detection of thin reservoir layers. The low side extension of the bandwidth also offers significant advantage for the depth penetration and seismic imaging; more specifically for the full waveform inversion (Kelly et al., 2009) which could form the basis for the low frequency model in the quantitative interpretation workflow.

The benefits provided by broadband seismic can be demonstrated by means of some modeling and then with case studies in various geological settings: from frontier to more mature areas without well control and with much reduced well control. The 2D wedge-model shown in Figure 1 provides more insight into the benefits of broadband seismic data. The wedge model was designed with 3 layers of sand tapering from 25 ms thickness and each layer pinching out to 0 ms. This model was then convolved with various wavelets having bandwidths from 20-40 Hz up to 2.5-200 Hz producing corresponding synthetic responses. The seismic synthetic responses were then band-limited/"inverted" into relative impedance responses. As observed the bandwidth extension (2.5-200 Hz) provides an impedance response close to the original acoustic impedance model: resolving thin layers (the high frequency part of the spectra), returning the absolute value of impedance (the low frequency part which is clearly highlighted with the model response difference between 20-40 Hz and 2.5-40 Hz) and an increasingly clear delineation of the top and base of each individual layer based on the contribution of the low and high frequencies. Thus, the high frequency is crucial for vertical resolution and the low frequency is very important for depth penetration and low frequency model building. The low frequency extension will reduce the need for complex background models to convert relative properties to absolute properties for parameters such as P-impedance and Vp/Vs (Reiser et al., 2011). Thus, with the contribution of the low frequency extension, a relative inversion of the seismic data should provide a very good estimate of the absolute elastic properties.

The high end of the bandwidth extension can be seen in Figure 2, which illustrates the extended bandwidth at the wavelet level from a real dataset. The wavelets were extracted at the water bottom and show that with a conventional acquisition (left hand-side) the peak of the wavelet is relative broad and present significant amount of side lobes, whereas the wavelet from the broadband seismic (receiver and source ghosts removed) presents almost no side lobes and a very narrow peak with the ability to image very thin layers that were not possible to image before with conventional seismic, with the presence of the two ghosts in the seismic image.

Case Studies

The benefits of broadband seismic to the interpreters and to the reservoir geophysicists are now illustrated by means of a few case studies. The case studies are subdivided into the various relevant benefits such as: interpretability and elastic properties estimation.

Interpretability

Recently seismic data with a dual-sensor streamer and a time-depth distributed source was acquired offshore Norway over the Møre Marginal High (Figure 3). The regional geology is dominated by some deep Cretaceous sediments, some Eocene basalt/volcanics and slump structures as explained by Faerseth et al., 2008. From this seismic image, the various sequence units can be clearly identified, as well as the internal geological structure. The seismic quality and bandwidth (2.5 to more than 175 Hz) reveal geology that had never been seen before in this region.

With a seismic image so rich in frequencies (low and high side) the benefits just for interpretation are significant and allow the seismic interpreter to evaluate the geology more directly. Instead of interpreting a seismic image contaminated with side lobes and exhibiting a lack of resolution, this type of seismic image quality appears to reveal the earth response close to an outcrop view in appearance.

Thus, from an interpretation perspective, broadband seismic allows us to see the geology in unprecedented detail and realism, with significantly less artifacts generated by the ghosting operators.

Of even greater interest would be to carry out a seismic inversion of the data, and this is what has been performed over the entire 2D line. We will be presenting some examples of the pre-stack inversion results (Figure 4) over some key areas demonstrating the benefits in terms of increased resolution and low frequency content. The wedge model presented in Figure 1 can be observed in this real dataset with a resolution limit of 3 ms for the wedge model demonstrating again the importance of the extended bandwidth on the high side of the frequency spectrum.

Extraction of Elastic Properties

As the broadband seismic is particularly rich on the low side of the spectra, the need to add low frequency data from an a-priori model or well information should be considerably reduced and this is what we are trying to present with the results in Figure 5. This figure shows a 3D pre-stack relative inversion from a 3D dual-sensor streamer dataset in the Norwegian sector of the Central and Northern North Sea representing close to 4,000 km² of data. The target reservoir interval is a very shallow Neogene channel system through producing Paleocene sands down to the Jurassic level, with the main focus on the Tertiary section. The seismic inversion was performed without any well derived low frequency model. In order to get an idea of the absolute properties, the seismic stacking velocity or the residual normal move out velocity was used and added to the relative acoustic impedance. Figure 5 illustrates the relatively good agreement between the acoustic impedance at a blind well and the "absolute" acoustic impedance derived by using seismic information only (broadband seismic and seismic velocity).

By performing a pre-stack simultaneous relative inversion and adding the low frequency seismic velocity information, we have achieved significant benefits in our ability to use pre-stack inversion in a prospectivity workflow without building a well-based time consuming and tedious low frequency model of questionable accuracy, to understand the lithology/fluid distribution and identification of possible leads/prospects. This increase notably the reliability of the seismic inversion away from the well as well as being able to "predict" elastic response in 3D and being used by interpreters for delineating their prospects with inversion products based on seismic data only.

In the case of estimating absolute elastic properties, and following up the work done and presented last year in the Carnarvon Basin in North-West Australian Shelf and in the North Sea (Reiser et al., 2011), results will be presented over a few case studies in the North Sea of a pre-stack inversion followed by a lithology fluid prediction (Figure 6); more specifically over the Frigg Field (Eocene age and deep water marine environment). Comparison between the conventional and the broadband seismic will be done in the presentation.

The results demonstrate some of the benefits for the end user: improved delineation of the various geological features as well as improved delineation of the residual gas fields in the area.

Conclusions

The examples shown demonstrate that broadband seismic benefits not only the operations and seismic processing aspects, but also the more "downstream" part of the G&G cycle: interpretation and quantitative seismic interpretation. They also highlight that the extended seismic bandwidth on both the low and high side reduces our dependency on a-priori information and noticeably increases our predictability of elastic properties away from the well control. The latter plays an important role in the well leads/prospects de-risking and evaluation. Broad bandwidth seismic without receiver and source ghosts opens the possibility of interpreting and analyzing the true earth response with significantly less filtering and interference effects. Thus, the potential benefit of the broadband seismic in the asset life is across the board: in the beginning at the exploration stage and later more downstream with the lithology and fluid prediction in the appraisal and development stage.

Acknowledgements

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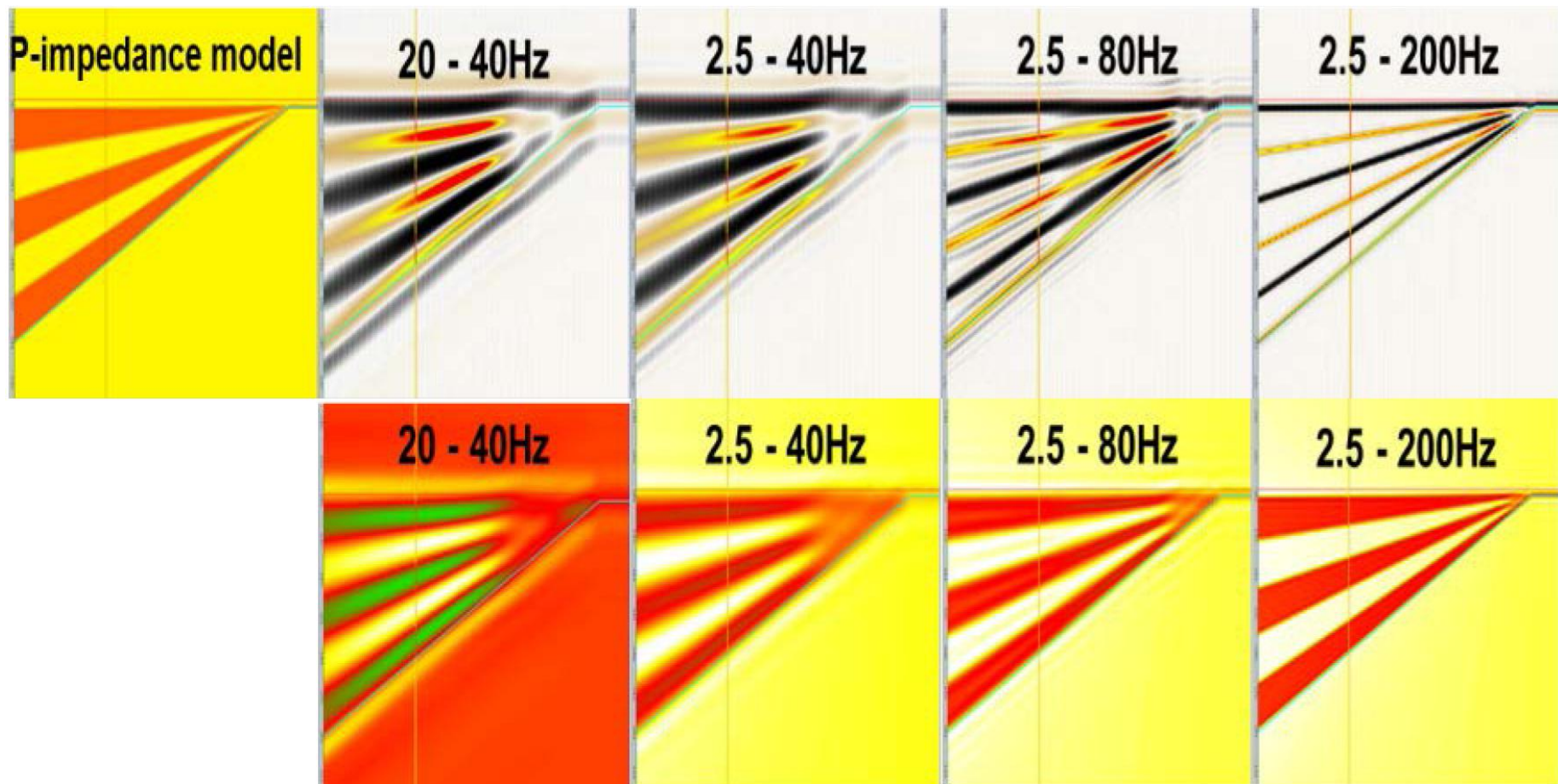
Figure 1. Wedge model showing seismic responses for wavelets of different bandwidth. The 4 top images illustrate the seismic responses for the various wavelets and the 4 bottom images illustrate the impedance inversions based on the modeled seismic. The color palette for the impedance sections is identical.
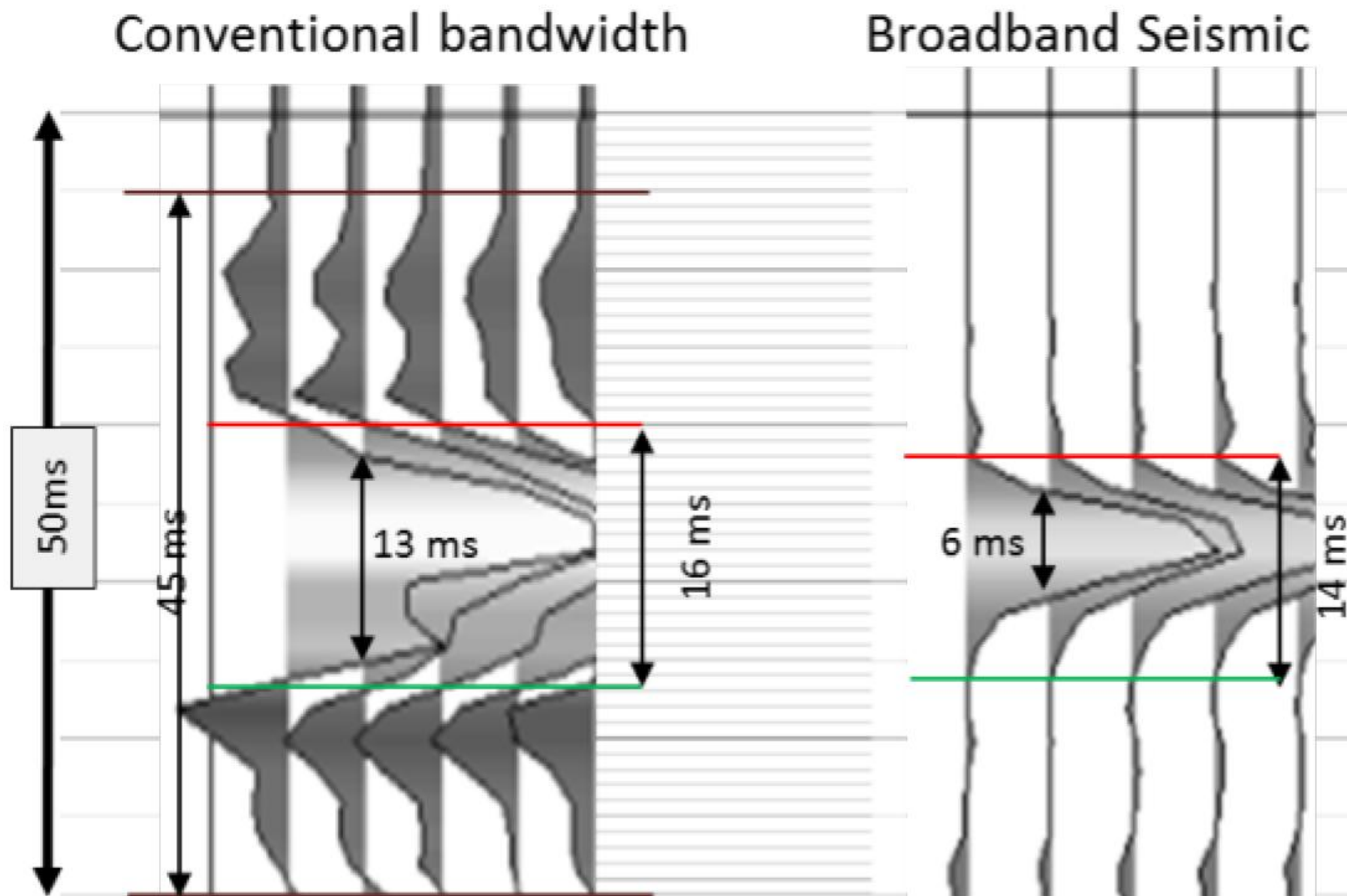
Figure 2. Extracted wavelets at the water bottom from a conventional (left hand-side) and broadband ghost- free acquisition (right hand-side).
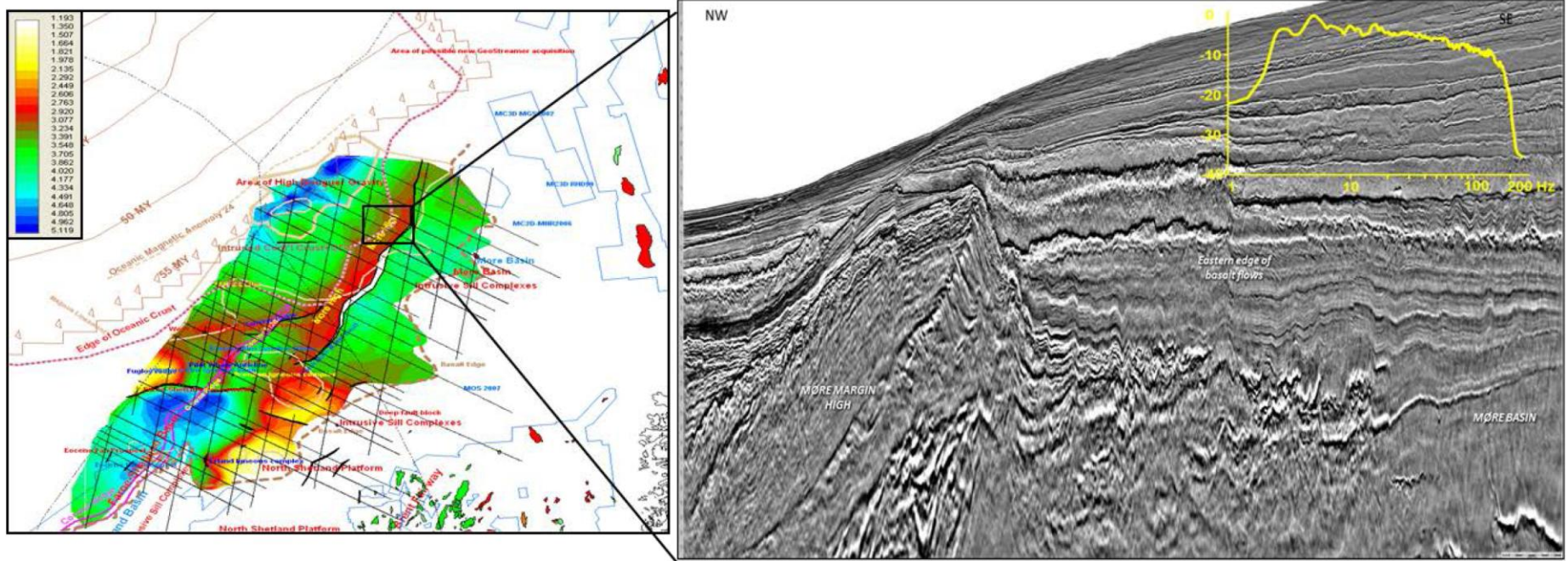
Figure 3. Example of a 2D seismic line over the Møre Margin High (Norway) in the Faroes Shetland Basin acquired with a ghost-free acquisition system (dual-sensor towed streamer and time & depth distributed source).
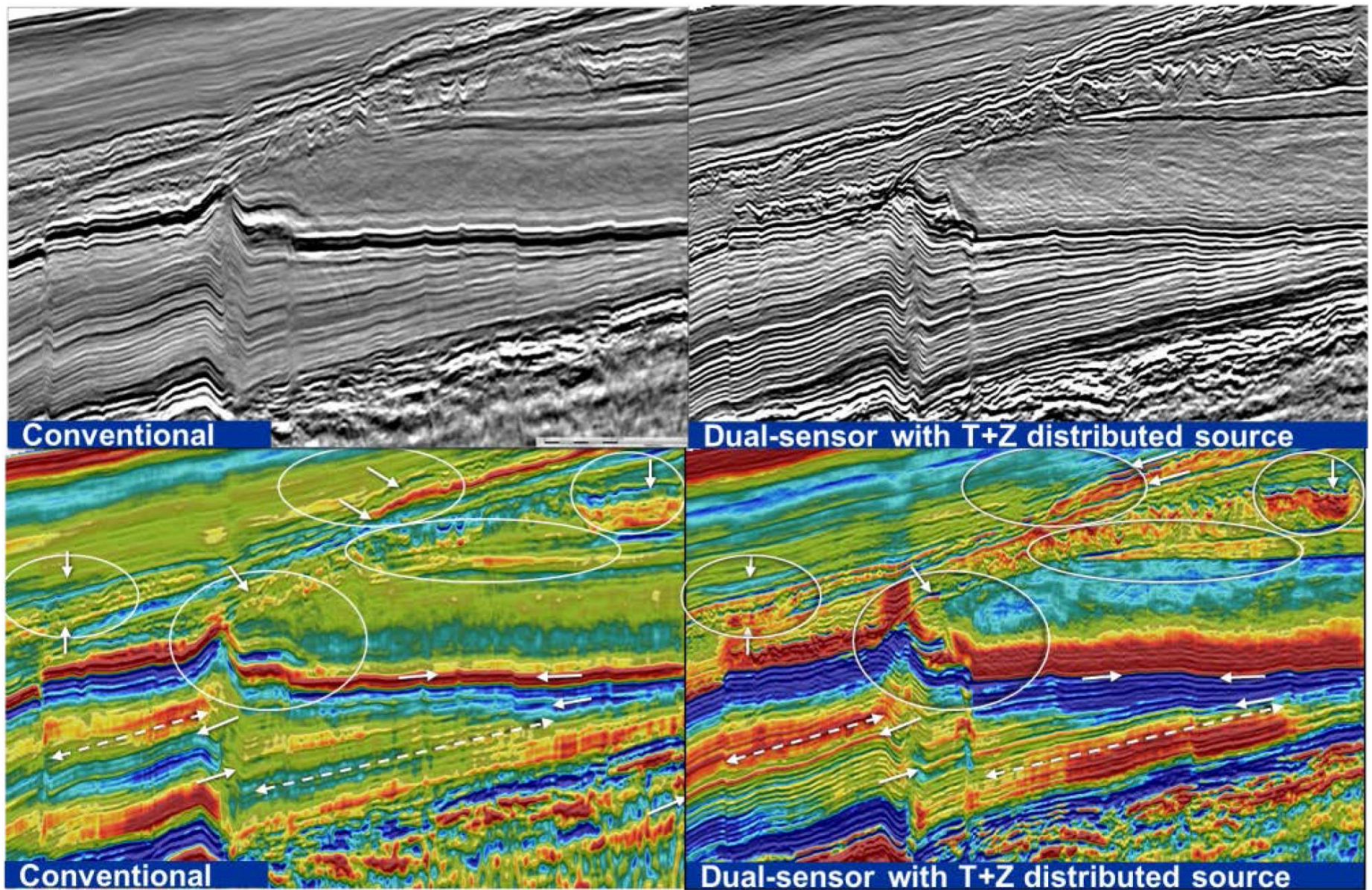
Figure 4. Zoom over the Møre Margin High (Norway) 2D seismic line presenting the conventional seismic response and the one acquired with a ghost-free acquisition (dual-sensor towed streamer and time & depth distributed source) system (right hand-side) and their respective relative acoustic impedance responses.
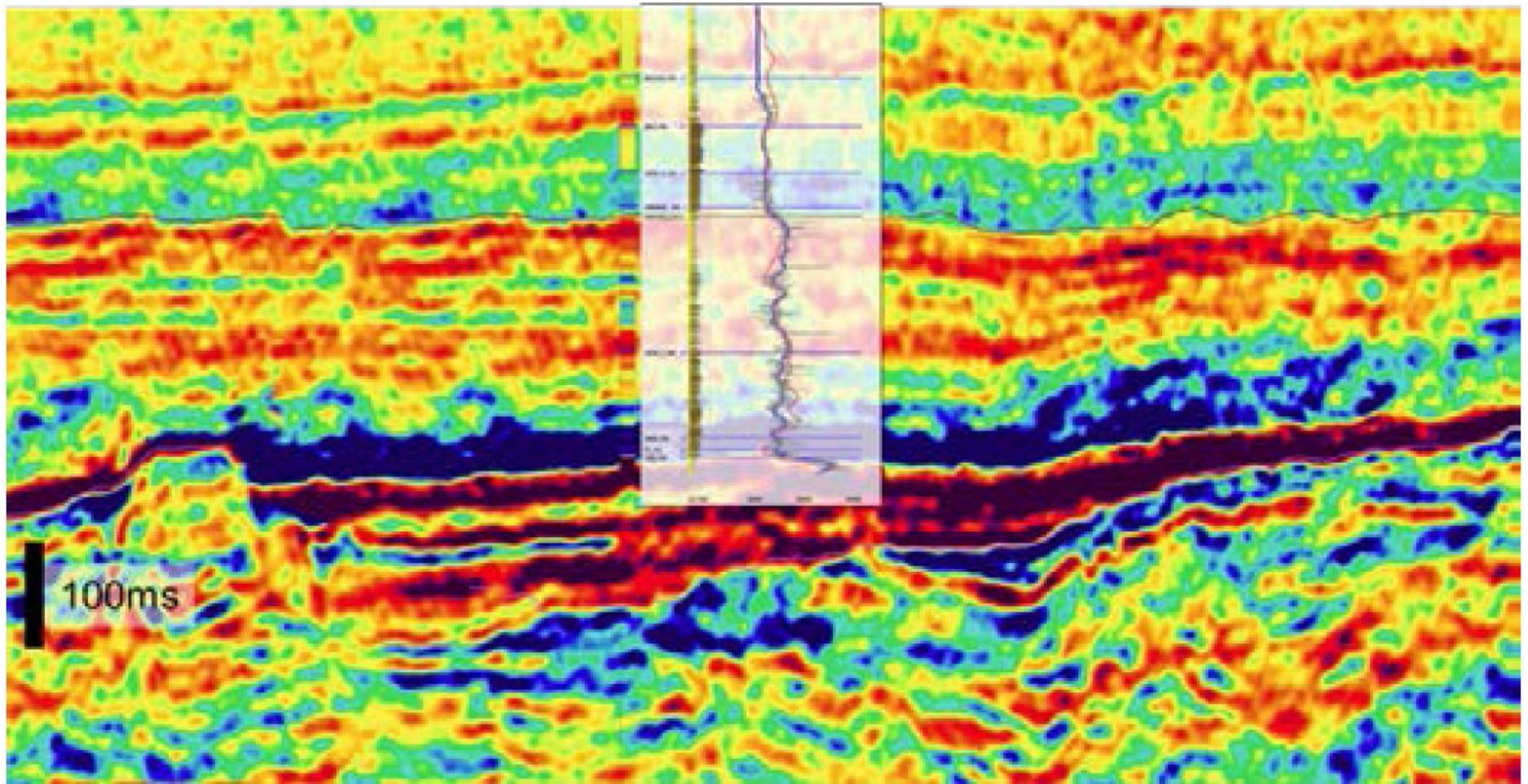
Figure 5. The Relative Acoustic Impedance compared to one well used as a blind well validation. Red trace is the results of the relative inversion and blue trace is the well log filtered in the seismic bandwidth.
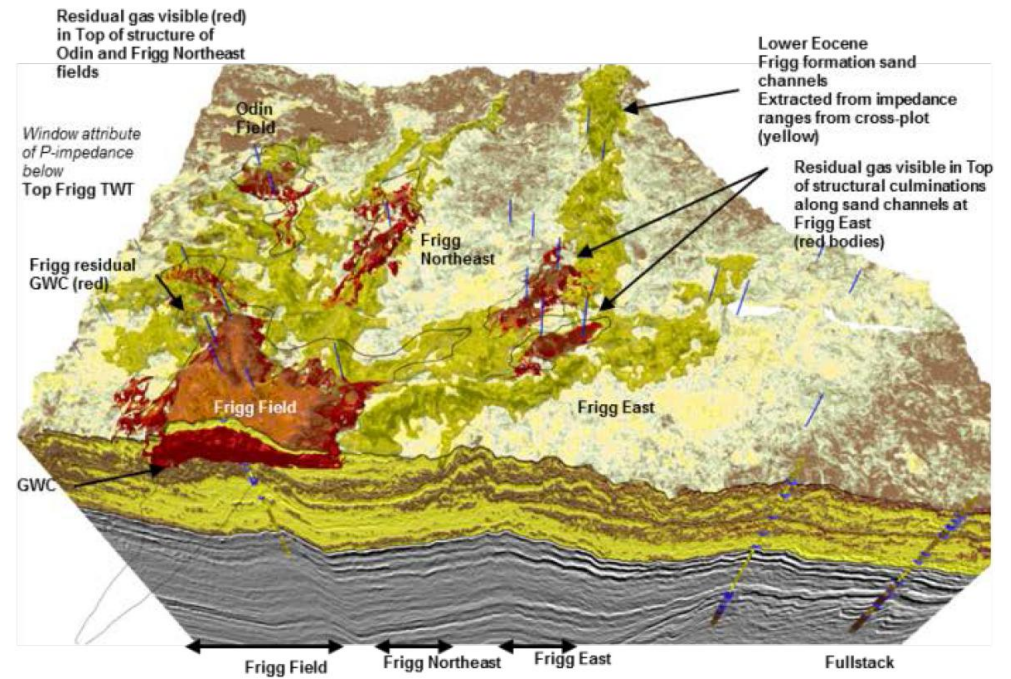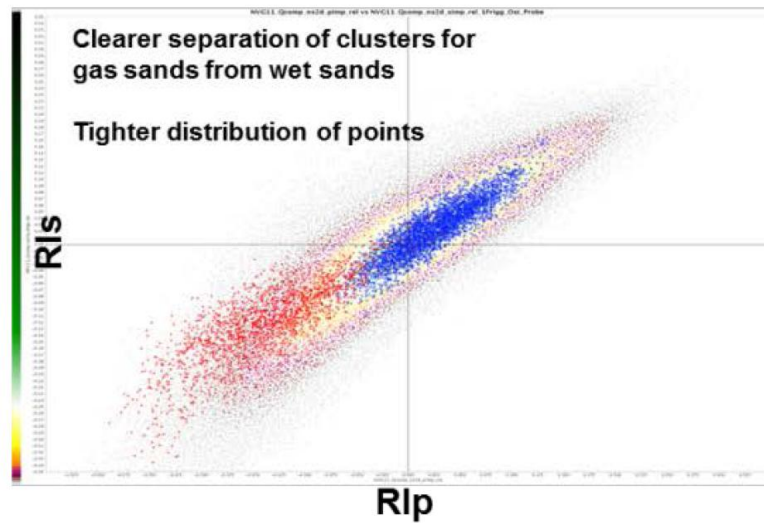
Figure 6. The left hand-side image represents the result of the classification in the acoustic and shear impedance domain. The blue points represent the brine sands and the red points represent the gas sand. The 3D broadband seismic was classified (right hand-side image) in term of lithology and fluid and the results are presented showing a clear delineation of the Gas Water contact as well as mapping the residual gas and channel bodies.