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Resolution and imaging of complex reservoirs - the value of broadband seismic via dual-sensor streamer acquisition.

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Summary

The seismic industry is constantly seeking ways of improving the contribution of seismic data to the upstream E&P workflow from seismic acquisition to reservoir modeling. We review recent developments in broadband seismic and illustrate how these benefit seismic interpreters and geoscientists involved in reservoir characterization or quantitative interpretation projects. Petroleum Geo-Services (PGS) launched in 2007 a dualsensor streamer acquisition system developed with the objective of providing broader seismic frequency bandwidth without any compromise in pre-stack data quality or acquisition efficiency. Results over the last five years have demonstrated the benefits of this system in processing, seismic interpretation and reservoir geophysics. Case studies from different geological settings illustrate the benefits to end-user practitioners in seismic interpretation and seismic reservoir characterization across a range of E&P asset development phases from exploration to appraisal and field development/optimization.

Keywords*: Interpretation, inversion, QI (quantitative interpretation), broadband, dual-sensor, de-ghosting.*

Introduction

The holy grail of reservoir geoscientists seeking to optimize the locations of costly wells is to be able to discern the physical properties of rock formations in the earth before drilling. Until now seismic images have fallen short of delivering this goal. A serious limitation to seismic bandwidth has always been the ghost reflections from the sea surface that occurs both at the source and the receiver. PGS developed in 2007 (Tenghamn et al. 2007) a dual-sensor streamer enabling the acquisition, measurement of the wavefield (up and downgoing wavefield). This acquisition system has enabled a significant extension of seismic bandwidth at both the low and high ends of the frequency spectrum and has been used extensively in 2D and 3D mode over many regions and basins across the world. This increase in bandwidth was achieved by removing the sea-surface ghost at the receiver end by wavefield separation, and more recently by removing the source ghost with a time and depth distributed source (Parkes et al. 2011).

The simultaneous extension of both low and high frequencies has a major positive impact on seismic interpretation and quantitative seismic interpretation or reservoir properties derivation: 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. This broadening of the seismic bandwidth has some benefits for the seismic imaging (Kelly et al. 2009) and especially for the full waveform inversion algorithms as more low wavenumber are available.

The benefits provided by broadband seismic can be demonstrated by means of some modeling and synthetic example and then with case studies. 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 25ms thickness and each layer pinching out to 0ms. This model was then convolved with various wavelets having bandwidths from 10-40Hz up to 2.5-200Hz producing corresponding synthetic responses. Those seismic synthetic responses were then band-limited/“inverted” into relative impedance responses. As observed the bandwidth extension (2.5-200Hz) provides an impedance response close to the

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original acoustic impedance model: resolving thin layers (the high frequency part of the spectra), returning the absolute value of impedance (the low frequency part) 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, with the contribution of the low frequency extension, a relative inversion of the seismic data should provide a good estimate of the absolute elastic properties without a compromise.

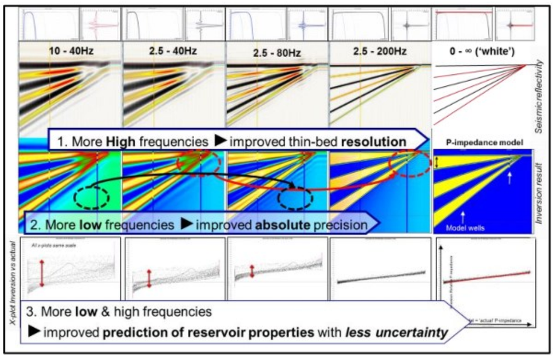

Figure 1: Wedge model showing seismic responses for wavelets of different bandwidth. The 3 top right images illustrate the seismic responses for the various wavelets and the 3 bottom images illustrate the impedance inversions based on the modelled seismic. The color palette for the impedance sections are the same.

Case Studies – Added Value for Interpretation and Elastic Properties Derivation

Recently new seismic data with a dual-sensor streamer and time-depth distributed source was acquired offshore Norway over the Møre Marginal High (Figure 2). The regional geology is dominated by some deep Cretaceous sediments, some Eocene basalt/volcanics and slump structures as explained by Faerseth et al., 2008. Those geological elements are clearly visible on the seismic section presented. From this seismic image, the various sequence units can be clearly identified. The seismic quality and bandwidth (2.5 to more than 175Hz) reveal geology never seen before in this region. Interpreters now have the possibility to see the earth, the geology with a significantly reduced filter on it allowing them to identify clearly the various stratigraphic sequences and geological units. In addition, a pre-stack seismic inversion was performed over this dataset revealing some extraordinary uplift in term of reservoir properties understanding and few examples will be presented. Thus, from an interpretation perspective, dual-sensor seismic allows us to see the geology in unprecedented detail and realism, with far less artifacts generated by the ghosting operators.

As the conventional seismic is band-limited, as a minimum the missing frequencies on the low side necessary for the estimation of the absolute properties, need to be provided by a combination of the seismic velocity and the well information. This a priori information, depending of the energy amount, could introduce a significant bias into the seismic inversion process, which has been the drawback and constant battle into the quantitative interpretation process for so many years now. As the dual-sensor seismic is particularly rich on the low side of the spectra without a compromise on the high side, the need of a strong low frequency data from an a priori model or well information is considerably reduced. The latter will be demonstrated by few case studies demonstrating the significant reduction of a low frequency model for the seismic inversion allowing an increase reliability of the elastic properties estimation away from the well. This increase reliability into the seismic inversion results will provide operators reliable reservoir properties for drilling decision and hence significant prospect / target derisking as the reservoir properties derived will be reliable away from the calibration points, the wells.

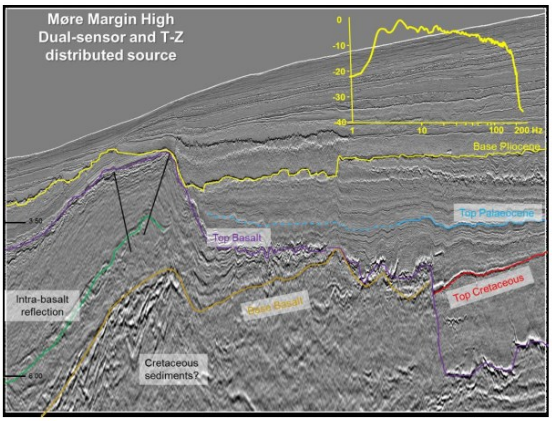

Figure 2: the figure represents a portion of a seismic line (Møre Marginal High, Norway) acquired with a dual –sensor streamer and depth-time distributed source-arrays. The amplitude (log scale) has been computed in the Pliocene interval and shows a frequency bandwith from 2.5/3Hz up to 180 Hz. Previously not seen, intra-basalt reflections are now visible with this new dataset with also a good signal to noise ratio.

The first case study concerns the Grevling field located in the Norvegian North Sea (Figure 3) where conventional seismic as well as a new dual-sensor MultiClient survey exist. In Figure 3, we observe a significant improvement of the seismic image with the dual-sensor. This datasets exhibits an increase of the low frequency and not at the detriment of the high frequency component. The Grevling is a relatively deep middle Jurassic age (the Hugin and Sleipner formation) and hence present some challenge for the elastic attributes extraction. The main objective of this project was to estimate elastic properties as well as the lithology-fluid distribution.

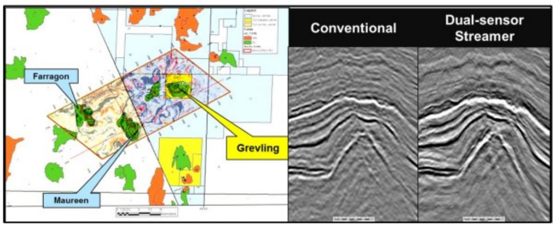

Figure 3: The left hand-side represents the location of the MultiClient survey over few North Sea fields including the Faragon and Grievling fields. The right hand-side panel shows the comparison between the conventional seismic and the dual-sensor seismic over the Upper Jurassic Grevling field. The dual-sensor streamer seismic exhibits a significant increase bandwidth.

A 3D pre-stack inversion was performed over the 2 datasets (Figure 4) targeting the middle Jurassic sands. Figure 4 shows the comparison between the seismic inversion results for the conventional seismic and for the dual-sensor streamer survey (right hand-side of the Figure 4). The seismic inversion was performed without any well for the low frequency model building. The low frequency model was built using only the seismic velocity multiplied by a constant mimicking a relative acoustic and shear impedance model. Hence, all the elastic properties estimated with the pre-stack simultaneous inversion were derived only with the seismic information. As some wells information are present over the area, a depth dependent rock physics analysis was performed and will be used as validation of the seismic driven elastic attributes derivation (Figure 4). We can see clearly that the elastic attributes derived using the dual-sensor seismic match well the rock physics model trend and again the elastic attributes have not been derived using a well calibrated low frequency model and all is coming from the seismic. A Bayesian lithology fluid classification exercise highlights the value of such seismic in the derisking process and even for the reserve estimate. By performing a pre-stack simultaneous relative inversion and adding the low frequency seismic velocity information, we have achieved significant benefits in: the ability to use pre-stack inversion in a prospectivity workflow without building a time consuming and tedious low frequency model of questionable accuracy, for an understanding of the reservoir distribution and identification of possible leads / prospects.

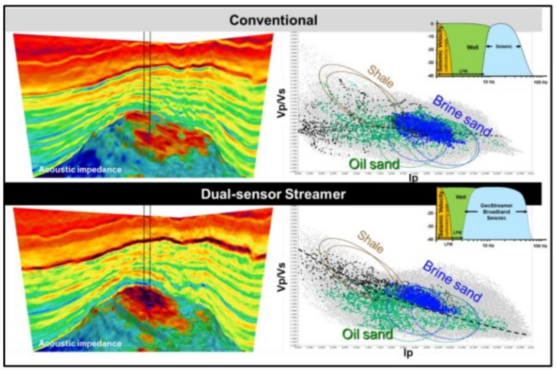

Figure 4: The figure illustrates the results of the inversion over the conventional and the dual -sensor datasets. Red color is low acoustic impedance and blue is high acoustic impedance. The results of the dual-sensor acoustic impedance match very well with the structure in comparison of the conventional seismic results. Also, when the seismic driven elastic attributes are projected to the rock physics template, the match between the rock physics and the elastic attributes is very good using the dual-sensor streamer results.

Conclusions

These few case studies demonstrate that towed dual-sensor streamer seismic benefits not only the operations and seismic processing aspects, but also the “downstream” part of the G&G workflow cycle: interpretation and quantitative seismic interpretation. This system is also valid from exploration to appraisal / development making it an ideal seismic solution for the E&P asset life cycle. This paper also highlight that the extended seismic bandwidth on both the low and high side reduces significantly our dependency on a strong a-priori information (low frequency model) by keeping-improving the resolution and increases noticeably our elastic properties predictability away from the well control making it a key element into the prospect derisking process.

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