Abstract
Ideally, geoscientists would like to have quantitative information about rock properties, along with information about fluid content of potential reservoirs relatively directly from the seismic as this information is available as oppose to the well data. Historically, seismic images have stopped short of delivering this, as the seismic bandwidth was limited due to the conventional streamer design and acquisition method.

The ability to predict reservoir properties away from the well using seismic information is a key element in quantitative interpretation. Quantitative seismic interpretation combines various types of data: well, seismic and seismic interpretation or geological prior information. Thus, this workflow is integrated and the quality and accuracy of each individual constituent is of great importance to the accurately estimate the volume of hydrocarbon in place in a particular reservoir interval.

Seismic plays a key role in this, and if the seismic data contains very strong low frequency information and the seismic image is of high quality/resolution, it is possible to directly estimate the absolute impedance at each point within a seismic volume.

Over the last few years, new acquisition methods and technologies exist aiming to provide a broader seismic bandwidth: streamer towed shallow at the front and going deeper at the mid of the streamer, towed acquisition with some streamers at shallow and deeper depth, and the dual-sensor towed streamer.

These new broadband seismic data volumes are bringing the seismic a step closer to the reservoir and this is what we will try to demonstrate in this presentation. We will have the latest look at some of the newest and most exciting improvements in reliably unraveling the rock properties from the 3D seismic data.

Introduction
The ultimate goal of the oil and gas company geoscientists seeking to find the best places to drill an exploration or production well is to be able to characterize the physical properties of rock formations in the earth before the drilling. Ideally, they would like to have quantitative information regarding key rock properties such as lithology, porosity, clay content, and net-to-gross, along with information regarding fluid types, saturations and pore pressures of potential reservoirs. Historically, seismic images have stopped short of delivering this, as the seismic bandwidth was limited due to the conventional streamer design and acquisition method. The conventional streamer acquisition (with a single type of sensor (hydrophone), and conventional towing depth) fails in most cases to fulfill the geoscientist requirement: broader bandwidth with as much low and high frequencies extension as possible.

In this paper, we look at some of the latest and most exciting improvements in reliably unraveling the rock and fluid properties from the extended bandwidth 3D seismic.

The industry is moving towards maximizing the recovery rate of the hydrocarbons already discovered. The time of easy oil is behind us. Therefore, there is an urgent need to accurately characterize very complex reservoirs, as well as being able to resolve very thin remaining hydrocarbon columns. In order to achieve an improved seismic reservoir characterization and better reservoir properties prediction away from the well, high quality broadband seismic is needed. Well data offers high
resolution vertically but does not provide lateral information, whereas the seismic has the opposite characteristic: densely spaced traces with “limited” vertical resolution.

Quantitative interpretation or seismic reservoir characterization is the workflow combining various types of data: well, seismic and seismic interpretation or geological prior information. Thus, this workflow is very integrated and the quality and accuracy of each individual constituent is of great importance to accurately estimate the volume of hydrocarbon in place in a particular reservoir interval with the main aim to optimize the drilling location based on the 3D seismic.

Over the last few years, new acquisition methods and technologies have been introduced aiming to provide a broader seismic bandwidth: variable inline streamer tow depth, acquisition with some streamers at different constant depths, and the dual-sensor towed streamer

This first dual-sensor (combination of hydrophone and vertical velocity sensor) towed streamer was developed by PGS (Tenghamn et al. 2007 and Carlson et al. 2007). The combination of the two sensors enables an effective removal of the sea-surface ghost by wavefield separation, allowing us to capture the full bandwidth of the upcoming wavefield.

The simultaneous extension of both low and high frequencies has a major positive impact on seismic quantitative interpretation: the low side of the spectrum contributes in particular but not only (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.

In this paper, we illustrate by means of two case studies the benefits of the dual sensor technology in the pre-stack domain for lithology – fluid prediction.

Case studies

North Viking Graben – qualitative and quantitative lithology / fluid discrimination

In 2009, the first ever North Sea 3D dual-sensor towed streamer surveys were acquired in three different areas of the Norwegian sector of the Central and Northern North Sea. Since the dual-sensor towed streamer technique was utilized in close proximity to conventional seismic surveys, some comparisons were possible as illustrated in Figure 1. This dataset is currently under reprocessing since a new nearby dataset has been acquired and thus a merged phase with the 2009 dataset is on-going. The new results will be presented.

Prospects and fields of greatly varying age and depth of burial were imaged with a superior data quality at all levels. Targets described in this case study vary from very shallow Neogene channel systems through producing Paleocene sands to the Jurassic level, with the main focus on the Tertiary section

Following this comparison, two studies were carried out: an enhanced qualitative AVA analysis of the dataset followed by a more quantitative workflow.

Firstly, on the extended qualitative approach, an implementation of the workflow presented by Thompson et al., 2010 was performed. The workflow of interest here is on the AVA stack rotation. The AVA stack rotation presents the following differences compared to other AVO techniques, such as the well known Extended Elastic Impedance (EEI) attribute (Whitcombe et al., 2002): use of the rock physics and relative pre-stack simultaneous inversion for an optimum rotation angle (Figure 2) for lithology and fluid discrimination or maximum separation between those two (if the rock physics allow it).
Results of this workflow will be presented demonstrating that in the present case of the North Viking Graben dataset, a combination of the extended seismic frequency bandwidth with the dual-sensor streamer and the AVA stack rotation, allow (in the relative sense) a lithology – fluid discrimination in a very clear and obvious manner without well calibration.

Secondly, on this dataset, a pre-stack seismic inversion workflow was conducted. As, on this dataset a modern conventional seismic was not available and in order to assess the impact of the low frequency on elastic attributes extraction, the seismic (dual-sensor streamer acquisition) was filtered on the low frequency side (10Hz low pass filter). The results of the inversion are presented on Figure 3a and 3b and illustrate the benefit of having extended low frequency content when extracting elastic properties.

The low frequency model used for this pre-stack simultaneous inversion was up to 10Hz in the first case and up to 5Hz in the second case (Figure 3b). A low frequency model at 5Hz is very low in comparison with what is done in the industry nowadays with conventional streamers where usually a 10-12Hz low frequency model is included into the absolute inversion. In the latter, an octave is gained on the amount of a-priori information injected into the inversion scheme. The example demonstrates that the acoustic impedance estimated through a pre-stack simultaneous inversion at Well B is nearly identical whether the well is included as a priori information in the model or not. This observation shows that our ability to predict the reservoir properties away from calibration wells is much improved due to the extended low frequency bandwidth offered by the dual-sensor streamer.

This case study has demonstrated that the broader seismic frequency bandwidth, and especially the extension at the low frequency side of the seismic amplitude spectrum, represents a key step forward in the reservoir property estimation away from the well and more importantly in the lithology - fluid prediction, as the need of a priori information is significantly reduced compared with a conventional streamer. Thus, the inversion and litho - fluid prediction using this unique acquisition system has proven to depend less upon the incorporation of well data as a background model and therefore enhance the prediction of the reservoir properties away from the wells. The process is now mainly seismic driven as opposed to previously being model driven.
North-West Australian shelf: the Carnarvon basin

The seismic line used for this case study is located in a very well known gas province of the North West Shelf of Australia. The stratigraphic sequence concerned is the Permo-Triassic sediments overlain by Jurassic to Cenozoic syn- and post-rift successions (Longley et al., 2003). Over this area, a seismic line was acquired with conventional and dual-sensor streamer technology. The two datasets were submitted to a pre-stack simultaneous inversion workflow and the results are presented in Figure 4.

It should be stressed that both simultaneous inversions were carried out using exactly the same low frequency model and inversion parameters with only the wavelet being different. Therefore the only differences between the two datasets are simply due to the type of towed streamer. The dual-sensor seismic inversion results exhibit a clearer definition of the individual geological layers and the fluid contact.

To further extend the analysis between the two datasets, a cross-plot was done over the area enclosed by the red rectangle in Figure 4. This area includes the gas reservoir and should therefore have an unambiguous elastic attribute response, with the gas having both lower acoustic impedance and lower Vp/Vs-ratio as seen in Figure 5. The cross-plot demonstrates clearly the better stability and lower noise in the pre-stack domain of the elastic reservoir properties, especially in the Vp/Vs-ratio using the dual-sensor streamer acquisition system compared to the conventional data.

Very recently (2011), the combination of the dual-sensor streamer with a specific source design (Parkes et al. 2011) is providing a full ghost-free marine seismic acquisition solution by removing the source and the receiver ghosts. At the time of writing, the data are not yet available to illustrate the impact of a fully de-ghosted acquisition system but will be presented.

Conclusions

With these two examples, we have demonstrated that the dual-sensor technology provides significant advantages in important reservoir characterisation aspects. Reservoir delineation and geobodies detection are improved thanks to an increased signal to noise ratio and broader bandwidth. The extended bandwidth, especially at the low frequency side of the spectrum, represents a key improvement in the lithology-fluid prediction and also in seismic reservoir property estimation. The need for a-priori information is considerably reduced by relying more on the data and less on a low frequency background model compared with a conventional seismic streamer which should notably improve the number of successful wells.
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