Acquired Broadband Seismic and Its Value for an Interpreter and a Reservoir Geophysics

C. Reiser (Petroleum Geo-Services), Y. Balabekov* (Petroleum Geo-Services) & T. Bird (Petroleum Geo-Services)

SUMMARY

The seismic industry is constantly seeking of improving the contribution of seismic data to the upstream E&P workflow from seismic acquisition to reservoir modeling. In this paper, we review the experience we have in broadband seismic and illustrate how these benefits seismic interpreters and geoscientists involved in interpretation or quantitative seismic interpretation projects. One of the enduring objectives of the seismic industry has been the development of seismic solutions that are broader in term of frequency content, extending the range of both the low and high frequency sides without compromising one end or the other.

Petroleum Geo-Services (PGS) since now 2007 is using a dual-sensor streamer acquisition system which provides broader seismic frequency bandwidth without any compromise in pre-stack data quality or acquisition efficiency. Results over the last seven years have demonstrated the benefits of this system in processing, seismic interpretation and reservoir geophysics.

By presenting few case studies in different geographical and geological settings this paper seeks to 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.

Introduction

Deriving physical rock properties from seismic data offers great value to geoscientists. After all, it is rocks that operators are drilling, not acoustic signals. Seismic inversion (nowadays would have to be pre-stack) in a combination of rock physics is the most common workflow to derive rock or elastic properties from seismic data. A fundamental bias of all inversion methods is that a particular seismic data set can lead to a number of possible results. With narrow band seismic data there is a lack of information either on the high side and low side of the amplitude spectrum, so the geoscientists tend to constrain the number of possible solutions to reach the most reliable one or the one that they believe to be the correct one. Normally, they do this by injecting known or "a priori" information into the model, usually nearby well data or other geological values. As a consequence, the uncertainty of the results away from these constrains increases significantly. Using broadband seismic data, with its greater frequency content, substantially reduces the amount and potential bias of a priori data input. It thereby makes the inversion or any quantitative interpretation solution less dependent on what we already believe, and increases its usefulness in areas where a priori information may be scarce or uncertain.

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 (Reiser, 2012; Michel, 2012) 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.

Case studies

The benefits of broadband seismic to the geologist-interpreters and reservoir geophysicists will be illustrated by means of a selection of case studies. In the present article just 2 will be mentioned but additional ones will be presented during the workshop.

Added value for interpretation and elastic properties derivation

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 some 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.

The first case study looked at will be around the Grevling field located in the Norvegian North Sea (Figure 1) where we have over the same area a conventional seismic as well as a brand new dual-sensor MultiClient survey. On Figure 1, we can 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 try estimating trustworthy elastic properties as well as the lithology-fluid distribution over this area. The latter will be shown during the presentation.

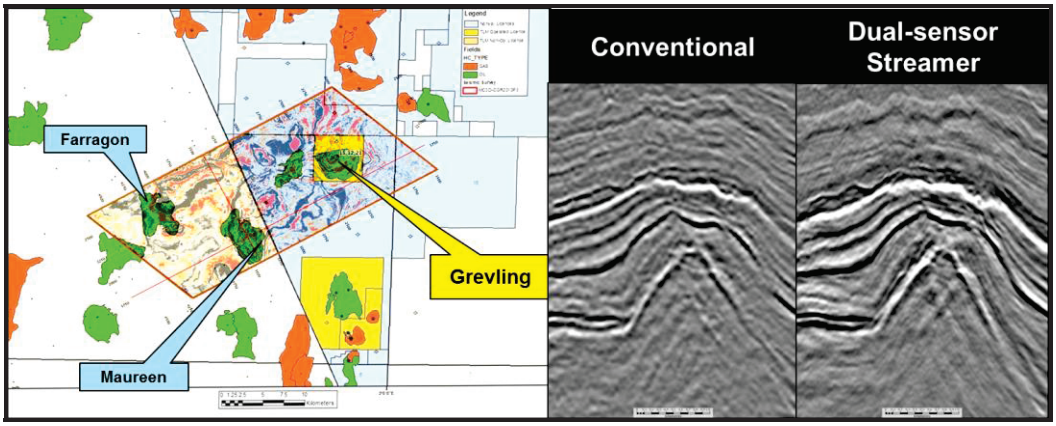

Figure 1: *The left hand-side represents the location of the MultiClient survey over few North Sea fields including the Faragon and Grievling fields. The right hand-side panel shows the comparison* between the conventional seismic and the dual-sensor seismic over the Upper Jurassic Grevling field. *The dual-sensor streamer seismic exhibits a significant increase bandwidth.*

A 3D pre-stack inversion was performed over the 2 datasets (Figure 2) targeting the middle Jurassic sands. Figure 2 shows the comparison between the pre-stack seismic inversion results for the conventional seismic and for broadband seismic (dual-sensor in the Figure 2). 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 is present over the area, a depth dependent rock physics analysis was performed and will be used only as a validation of the seismic driven elastic attributes derivation (Figure 2). It can be clearly seen that the elastic attributes derived using the broadband 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.

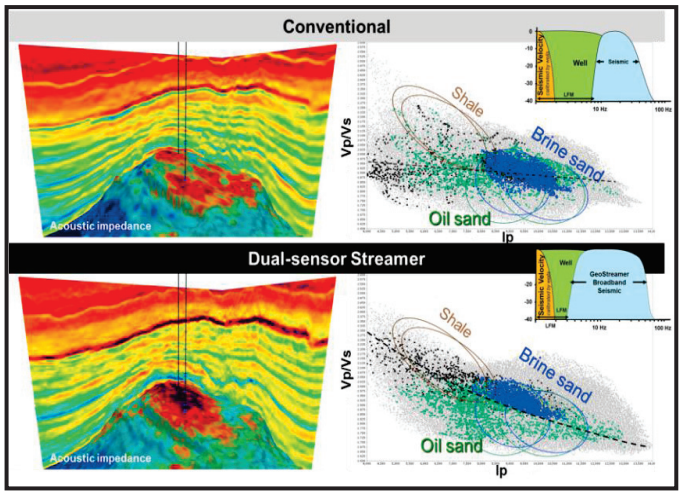

Figure 2: *The figure illustrates the results of the inversion over the conventional and the braodband datasets. Red color is low acoustic impedance and blue is high acoustic impedance. The results of the acoustic impedance derived from extended bandwidth seismic match very well with the structure in 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 with the broader bandwidth seismic acquired with dual-sensor streamer.*

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.

Added benefits in a deep-water context

An additional example closer to the workshop region will be presented using the BMS50/52 Phase 2 dataset. The BM-S-50/52 Phase 2 dataset is a MultiClient 3D seismic survey on trend and/or adjacent to some prolific discoveries in the northern Santos Basin, including Merluza, Lagosta, Cedro and Mexilhao. This survey, acquired in late 2012, bridges a gap in pre-existing 3D coverage in an area with light oil to condensate/gas prospectivity attracting substantial industry attention at various reservoir potential levels: post and sub-salt. The present survey is designed to help support a more complete understanding of the local and regional geological setting. The primary reservoirs in the aforementioned discoveries are deep marine turbidite sandstones within the Ilha Bela Mbr of the Itajai-Acu Fm. Over this dataset, we have performed a state-of-the-art pre-stack depth processing aimed at enabling clearer imaging focused on the pre-salt interval. A significant effort is made to build an accurate velocity model for the depth migration and the broader bandwidth seismic is helping in this regard.

Pre-stack analysis comparison with the adjacent modern conventional seismic dataset in this deep-water Santos Basin environment, the uplift is evident in terms of:

a) Improved penetration and imaging of deep targets, especially at the pre-salt level
b) Better signal to noise, especially of deeper sub-salt targets,
c) Broader seismic frequency bandwidth, especially at the low end.
d) Improved fidelity of pre-stack elastic attributes.

The 2012 dual-sensor broadband survey abuts a modern 2008 survey acquired with conventional solid streamer to the west (Figure 3). The surveys have a narrow overlap zone of 2km which allows a comparison of the two surveys, and allow the assertions of improved imaging and data quality arising from broadband data to be validated.

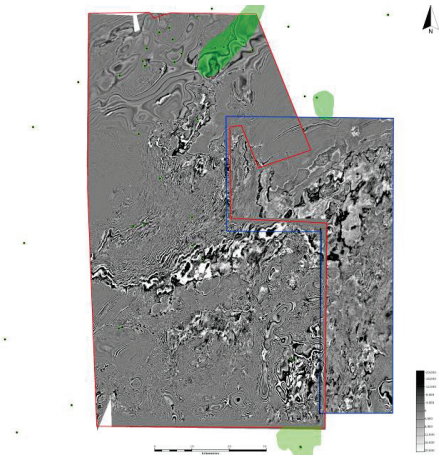

Figure 3: *Deep depth slices (6500m) intersecting the pre-salt section showing the conventional survey (left) and dual-sensor broadband survey (inverted L-shape, with blue outline on the right), with an overlap zone where comparative analysis was performed*

The amplitude spectra for a deep window (5.5-6.5 seconds) from this line are illustrated in Figure 4. The below figures clearly demonstrate that even analyzing deep in the section (around 5.5 to 6.5 sec), at the level of sub-salt targets, the range of the low frequencies is significantly extended with the dual-sensor data compared to the conventional data across all offset/angles without the detriment of losing any high frequencies.

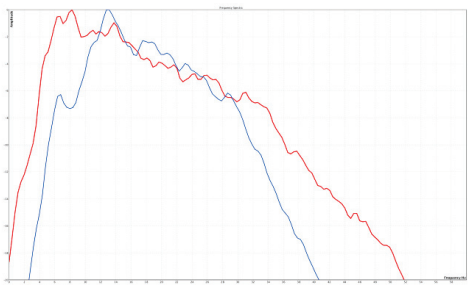

Figure 4*: Amplitude spectra in dB comparing the mid angle stacks for the conventional (blue) with broadband (red) for a deep window below base of salt.*

At the pre-salt interval, the dual-sensor data shows over an octave of additional low frequencies. It is the additional low frequencies and improved signal to noise penetrating deeper that enable better elastic attributes) to be derived in the sub-salt objectives.
For the conventional and broader bandwidth datasets, a relative pre-stack inversion has been performed. It can be observed that the relative acoustic impedance on the dual-sensor seismic data is significantly less noisy. In the pre-salt section, the inversion of the broadband data provides a clearer, less noisy structural image as well as cleaner definition of lithological variation within sub-salt layers. This provides more reliable information for reservoir characterization, mapping and correlation of geological events in the pre-rift, syn-rift and sag phases (figure 5).

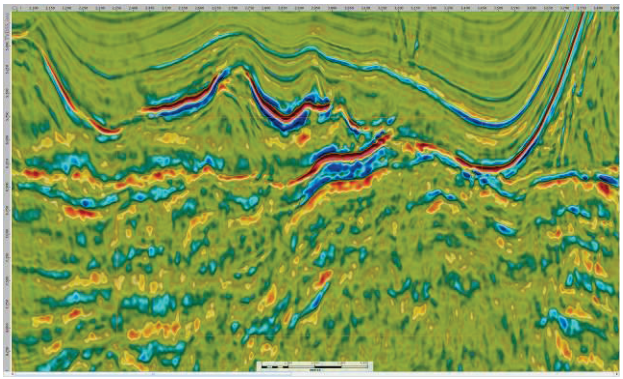

Figure 5: *Depth panel from relative acoustic impedance (from a pre-stack inversion workflow) of dual-sensor broadband data.*

Conclusions

These 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 acquisition system is also valid from exploration to appraisal / development making it an ideal seismic solution for the E&P asset life cycle. This paper highlight also 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 any well control making it a key element into the lead/prospect derisking process.

Acknowledgements

The authors would like to thank PGS for permission to publish this work and the many contributors within the PGS organization.

References:

Reiser, C., et al., 2012, Value of broadband seismic for interpretation, reservoir characterization and quantitative interpretation workflows, First Break, volume 30, September 2012.