MULTI-AZIMUTH QUANTITATIVE INTERPRETATION: A CASE STUDY FROM THE SOUTH VIKING GRABEN, NORWAY

C. Reiser[1], T. Bird[2]

[1] PGS; [2] Formerly of PGS

Summary

This paper will focus on the reservoir characterization / quantitative seismic interpretation of a recently acquired and processed multi-azimuth multi-sensor survey in the prolific South Viking Graben, Norway. This area has delivered a number of significant successes in multiple plays over the past decade. The study emphasizes application of multi-azimuth derived elastic attributes from various stratigraphic intervals ranging from the Tertiary down to the Permian reservoirs. This case study will highlight how this new dataset integrated with regional well information has overcome some of the exploration and near-field exploration challenges. Very promising results were delivered in terms of the evaluation of reservoirs and trapping styles of existing fields and discoveries as well as mapping of additional opportunities.

Multi-Azimuth Quantitative Interpretation: A Case Study from the South Viking Graben, Norway

Introduction

Extracting the most reliable, high quality elastic and reservoir properties from seismic in an effective manner has always been the quest for every geoscientist trying to build a reservoir model or to estimate the petroleum resources.
In the Viking Graben (North Sea), the presence of various geological features above and around the hydrocarbon reservoirs significantly degrades seismic imaging and consequently seismic characterization of reservoir and overburden properties. Thus, a seismic solution needs to be developed and implemented. In this paper, we will showcase the results of an analysis performed in the South Viking Graben, North Sea, based on a recently acquired (2019) and processed 3D marine multi-azimuth multi-sensor streamer seismic survey (Oukili et al., 2020). This survey was designed to overcome these imaging challenges and to provide a viable, cost reducing and efficient MAZ (Multi-Azimuth) acquisition alternative. This new dataset was acquired in addition to an existing single exploration survey resulting in a 3 azimuthal direction seismic dataset.
We will focus our analysis on the quantitative interpretation of the various stratigraphic intervals ranging from the Tertiary to the Permian reservoir levels using this multi-azimuth dataset integrated with the many wells present in and around the area of interest. For the latter, we will be using an interactive rock physics modelling product (rockAVO), enabling a quick assessment of the variation and sensitivity of elastic properties as well as the pre-stack seismic responses with changes of reservoir properties. This aims to allow a more reliable reservoir understanding and quantitative interpretation.

Database

In the marine environment a variety of seismic acquisition techniques have been devised through the years with the objective of obtaining the best description and understanding of target reservoirs, as well as characterizing the reservoir over and underburden and lateral non-reservoir sections. These range from well-known, conventional narrow azimuth towed streamer seismic acquisition, extending to multi-azimuth through wide / full azimuth seismic streamer acquisition as well as ocean bottom nodes or cables. All these acquisition techniques can be combined with various set-up configurations on both the streamer side and the source side (Widmaier et al., 2019 and 2020). All of these approaches, have some advantages and disadvantages. One of the main disadvantage of the traditional narrow azimuth seismic acquisition is the limited azimuth distribution which reduces the reliability of the full reservoir characterization in terms of azimuthal anisotropy and illumination. An additional parameter to consider for determining the solution to implement is the timing that E&P operators have, as the seismic acquisition configuration can be adapted and tailored to address as much as possible the frequency and turnaround time required.

The North Sea is a mature basin, yet still significant potential and challenges remain over this region to optimize near-field exploration opportunities. Some challenges over this area are: shallow subsurface channels, shallow gas, Tertiary low velocity anomalies and high velocity sand injectites or so-called V-brights, Paleogene polygonal faults and a high impedance rugose Late Cretaceous Chalk interval (Figure 2). All these geological features distort, obscure, attenuate, dim, and/or refract the seismic signal and thus do not allow an accurate and reliable characterization of the numerous Tertiary to Paleozoic reservoir levels.

The area of interest for this study is the South Viking Graben in Norway (Figure 1 and 2). Major Norwegian fields are located in this area, comprising a number of stratigraphic intervals: Eocene – Balder sands, Paleocene – Heimdal sands (Grane, Svalin), Upper Jurassic – Draupne (Hanz field), Late Triassic to Mid. Jurassic (Ivar Aasen), Late Triassic to Early Cretaceous sandstone (Edvarg Grieg), Upper Jurassic intra-Draupne sandstone (Johan Sverdrup). More recent discoveries include Lille Prinsen, drilled in 2018, which encountered various hydrocarbon intervals in the Eocene (Grid sand), Paleocene (Heimdal sand) and Permian (Zechstein Group).
To overcome these diverse and complex challenges, an innovative MAZ multi-sensor acquisition has been designed. MAZ as such, is not new and was implemented more than 10 years ago, for example, in

the Nile Delta (Marten et al., 2008) to overcome some local challenges and use the data for reservoir characterization.

In this case study, the innovative MAZ survey has two new deep-tow azimuths and used a 12 × 6 km × 85 m high-density streamer spread, including two 10 km long streamer for an improved Full Waveform Inversion (FWI), and a wide-towed triple source with 225 m separation between outer source arrays allowing reliable near offsets coverage in the 50-125m range. More information about the acquisition design can be found in O'Dowd et al., 2019. The multi-sensor seismic streamers have been towed between 25 and 28 m depth for an improved signal to noise ratio and enhanced low frequency recording. This seismic acquisition has the benefits of providing richer azimuth/offset information and illumination below and above the various intervals of interest. These additional azimuths are complementary to the existing narrow-azimuth 2011 multi-client broadband data.

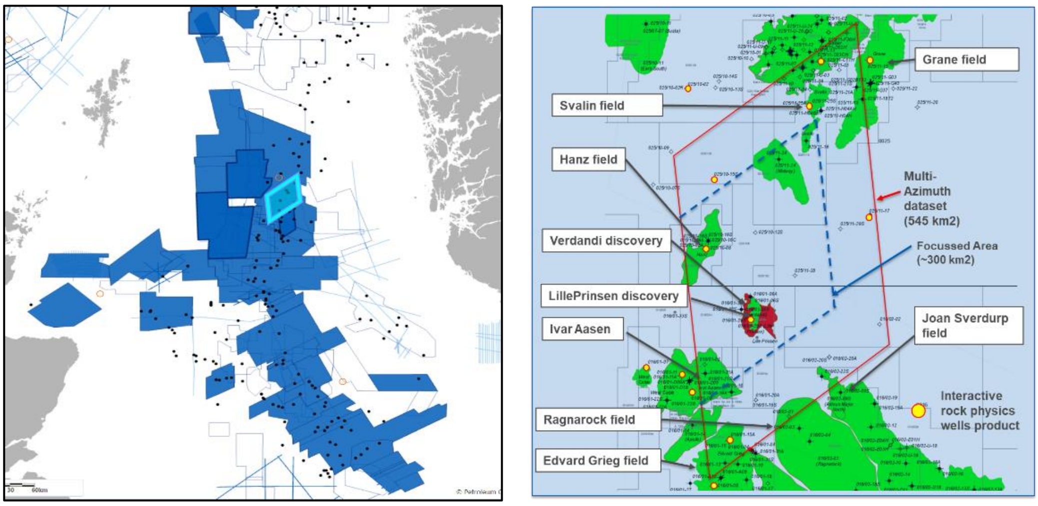

Figure 1. *Left, Location of the 2019 multi-azimuth survey (highlighted in light blue) and its surrounding multi-client surveys in the UK-Norway North Sea. Right, the study area represents approx. 545 km2 with a focus area of around 300 km2 for more detailed analysis (blue dotted line). The right figure shows the various fields present as well as some discoveries (Verdandi and Lille Prinsen) in addition to the wells where an interactive rock physics modelling product is available (yellow dots).*

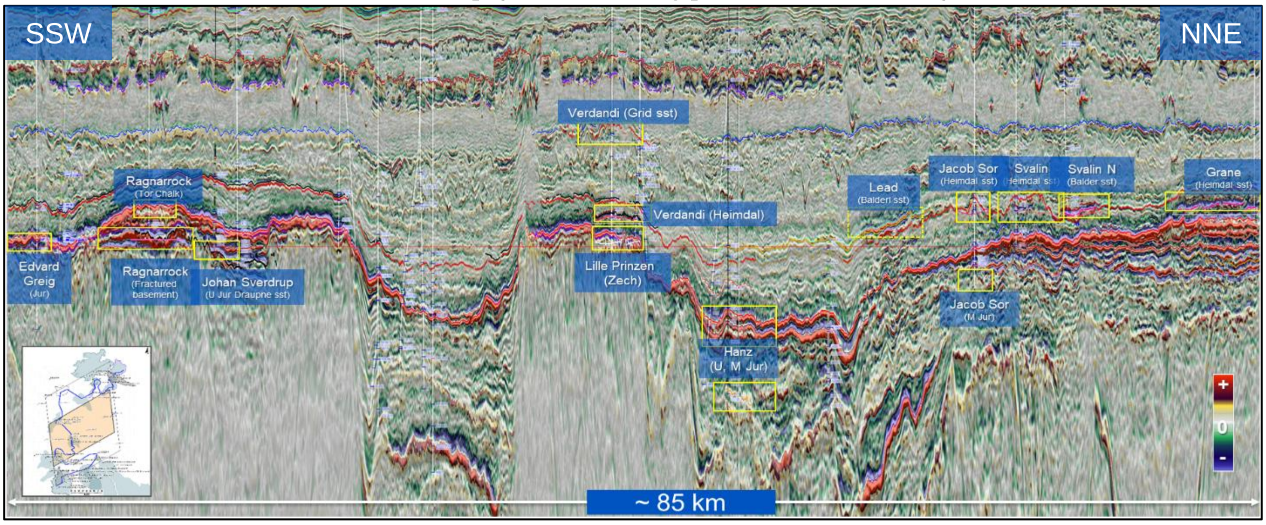

Figure 2. *Regional relative acoustic impedance random line derived from the full stack multi-azimuth going through the main fields, recent discoveries and their respective stratigraphic age where hydrocarbon interval has been encountered. The section also illustrates many features which degrade subsurface imaging such as injectites and irregular, high impedance Chalk.*

The MAZ dataset went through a complex and rigorous pre-stack depth migration sequence with the main processing steps summarized below (Oukili et al., 2020):

- Comprehensive demultiple sequence addressing the short and long period multiples integrating 3D SRME (Surface Related Multiple Elimination) and SWIM (Separated Wavefield Imaging);
- Full Waveform Inversion based on refraction information up to 12 Hz, using the long tail streamers from 0 to 10 km and reflection FWI up to 15 Hz for the 0 to 6 km offset streamers;

- As the azimuth distribution and offset diversity is rich up to 2 km offset and up to 40 degrees of incidence angle down to the Chalk interval, 6 azimuthal sectors have been generated for this survey with 3 azimuths corresponding to the vessel acquisition direction and 3 additional ones in between. All these datasets were regularized and migrated as one 5D multi-azimuth volume.

Analysis and main results.

Seismic interpretation has been conducted over the whole area based on this multi-azimuth broadband seismic calibrated with the publicly available wells. For key wells, an interactive rock physics modelling product (PGS multi-client product, rockAVO) was further developed (11 wells for this area) and used to better understand the elastic properties response with the changes of the reservoir properties (e.g. VClay, Porosity) of the various intervals of interest. Rock physics modelling went through the following steps: data gathering, well-log data interpretation, conditioning, and modeling using the geophysical well-log analysis, rock-physics diagnostics, and rock-physics modeling workflows. The expected AVA response for the main reservoirs are: Class II / IIp AVO for the Tertiary Heimdal sands with hydrocarbons (well Lille Prinsen, 16/1-29S), and Class I/II for the Upper Jurassic Draupne sands (Hanz, 25/10-8) and for the Permian Zechstein carbonate over Lille Prinsen side-track (16/1-29ST2) for instance (Figure 3). These AVA response were latter on confirmed by the well to seismic tie.

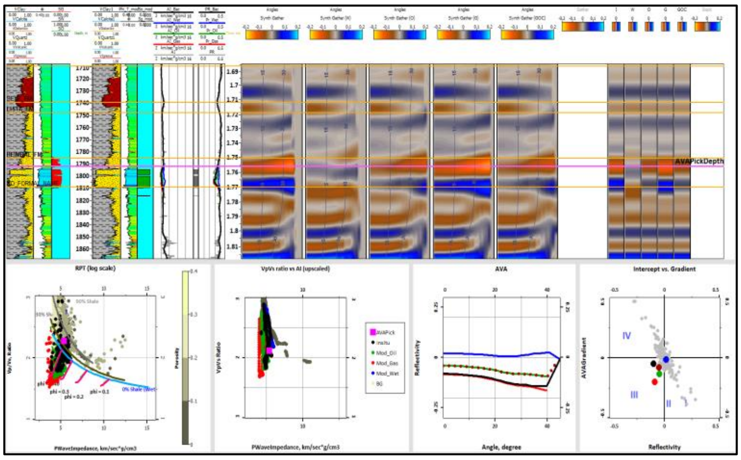

Figure 3. *Montage view focusing on the Paleocene Heimdal sands view of the Lille Prinsen well (16/1-29S) showing the pre-stack seismic angle gather modeling response with a broadband wavelet (0-4-70-80Hz Ormsby parameters) and with different fluid scenarios. Seismic panels from left to right: in-situ, brine, oil, gas. The pink dot on the bottom cross-plots corresponds to the AVA response at top of the reservoir interval (1792m).*

Additionally, Reservoir Oriented Processing (ResOP) was performed using all the 6 azimuths and angle stacks (4) with a focus on the main reservoirs and including: spectral harmonization, denoise, low frequency enhancement, multi-angle-azimuth time misalignment correction and estimation of the isotropic / anisotropic gradient and intercept (Rüger, 1998). One of the main outcome of this targeted seismic data conditioning has been a distinctive broadband wavelet (3/4Hz to 80 Hz bandwidth in the Eocene/Paleocene interval) with very low side-lobes energy and presenting all the broadband wavelet characteristics (pre-stack and per azimuth): high peak to through ratio, low ratio between the side-lobe and the zero-crossing, and as a result a high bandwidth index following Araman et al., 2014.
Furthermore, this seismic quality enables a very good to excellent well to seismic tie with the azimuths and associated angle stacks. The statistics are very encouraging with a cross-correlation in the angle & azimuth domain on average at 80-85% in all azimuthal / angle directions. The AVO class observed at the various reservoir levels from the well (e.g. Figure 3), have been confirmed with this MAZ dataset.

The improved data quality has enabled a significantly more stable gradient impedance (Figure 4 with the 2 left hand-side images) and provides now a very clean, stable and continuous gradient and inversion results especially at the Heimdal sand level delineating nicely the anomalies. Subsequently, a relative pre-stack inversion per azimuth angle stacks has been carried out demonstrating e.g. that low Vp/Vs anomalies estimated using the Isotropic AVA attributes (red color on Figure 4) match very well with the Heimdal hydrocarbon interval at Lille Prinsen / Verdandi (wells 16/1-29S and 16/1-6S) as well as providing some clear hydrocarbon indications in the deeper Upper Jurassic and Zechstein level (Figure 5).

Conclusions

This paper has demonstrated how an innovative acquisition set-up with a wide-towed sources (3) multi-azimuth broadband seismic dataset has overcome the main exploration challenges in the prolific southern Viking Graben and delivered an improved understanding and characterization of the various reservoirs present, as well as illustrating additional opportunities nearby (Figure 5). This also shows that the integrated approach of the acquisition, imaging and reservoir characterization delivers promising results at a very effective, efficient cost. With these available datasets, we have been able to map the various existing fields and discoveries known in the area at all the stratigraphic levels as well as highlighting some clear leads and opportunities suitable for near-field exploration using an integrated quantitative interpretation workflow. More work is on-going and will be presented in due course.

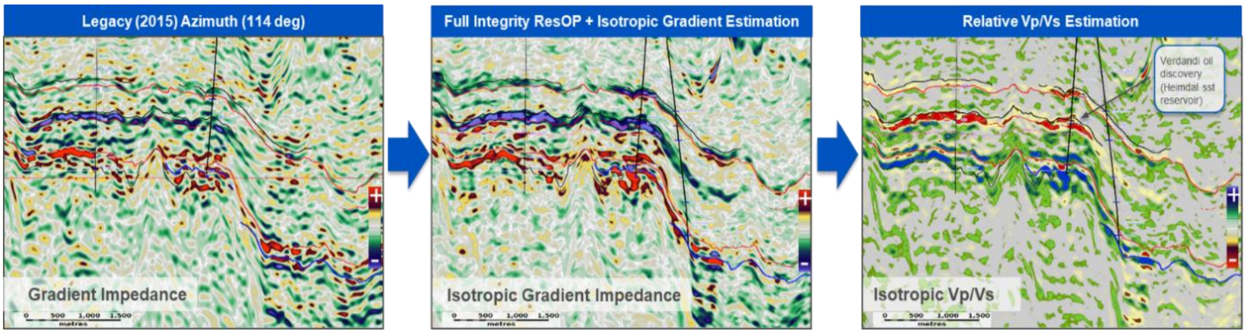

Figure 4. *Figure showing the Gradient Impedance (GI) improvement from the narrow azimuth legacy dataset (left) and after the reservoir focused dataset (middle) and finally (right) the relative Vp/Vs based on the estimation of the isotropic gradient and intercept using the Rüger (1998) equation, from the 6 input azimuths and conditioned angle stacks.*

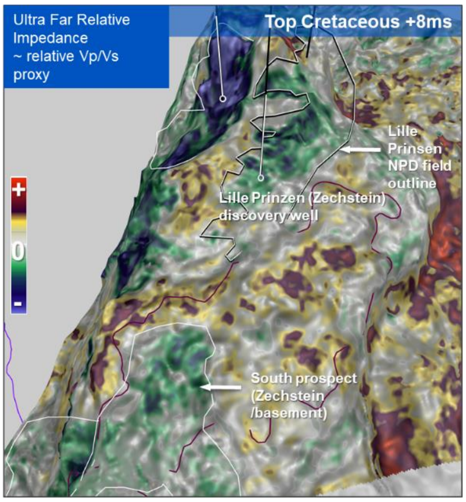

Figure 5. *Ultra far relative impedance map extraction is well correlated to Vp/Vs, at the top Cretaceous over a 16ms window. Blue anomalies match very well with the Norwegian Petroleum Directorate (NPD) outline for the Lille Prinsen discovery at this level. A visible anomaly further north-west was tested successfully by a recent appraisal well. Additional opportunities exist to the south of Lille Prinsen as well as downflank*

Acknowledgements

We thank PGS for the permission to present this work. Furthermore, we thank Lucile Goswami, and Eric Muller for valuable discussions and support.

References

Araman, A., and B. Paternoster, 2014, Seismic quality monitoring during processing: First Break, 32, 69–78

Marten, R, Rietveld, W, Benson M, Khodeir A, Keggin J., and Cook P., [2008] Utilizing Multi-azimuth Streamer Data for Reservoir Characterization and Uncertainty Analysis in the Nile Delta, Conference Proceedings, 70th EAGE Conference and Exhibition incorporating SPE EUROPEC 2008

Oukili J, Limonta L, Budner M, Mueller E, Kultom-Karlsen T. [2020] Revealing new opportunities with a cost-effective towed streamer MAZ solution in the South Viking Graben, Norway, First Break, 38, 95-101, DOI: 10.3997/1365-2397.fb2020085

Rüger, A., 1998, Variation of P-wave reflectivity with offset and azimuth in anisotropic media, Geophysics, Vol. 63, No. 3, 935-947

Widmaier, M., O'Dowd, D. and Roalkvam, C. [2019] Redefining marine towed-streamer acquisition. First Break, 37(11), 57-62

Widmaier, M., O'Dowd, D. and Roalkvam, C. [2020] Recent advances with wide-tow multi-sources in marine seismic streamer acquisition and imaging. First Break, 38 (12), 75-79