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

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Summary

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. This presentation will focus on the reservoir characterization of a recently acquired and processed multi-azimuth multisensor survey in the prolific South Viking Graben, offshore Norway. This area has delivered a number of significant successes in multiple plays over the past decade. 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 dataset integrated with the many wells present in and around the area of interest. From the well data, a company multi-client interactive regional rock physics modelling product has been used, enabling a rapid assessment of the elastic properties variation as well as the pre-stack seismic responses with changes of reservoir condition. This case study will highlight how this new dataset integrated with regional well information can overcome some of the exploration and near-field exploration challenges. Even though the project work is still on-going, very promising results have been achieved for the evaluation of reservoirs and trapping styles of existing fields and discoveries as well as for the mapping of additional opportunities which would be of interest for any future near-field exploration activity.

Database

In the marine environment, a variety of seismic acquisition techniques have been developed through the years with the objective of obtaining the best description and understanding of target reservoirs, as well as characterizing the reservoir overburden, 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, O'Dowd et al., 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 coverage.

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 for making an informed decision.

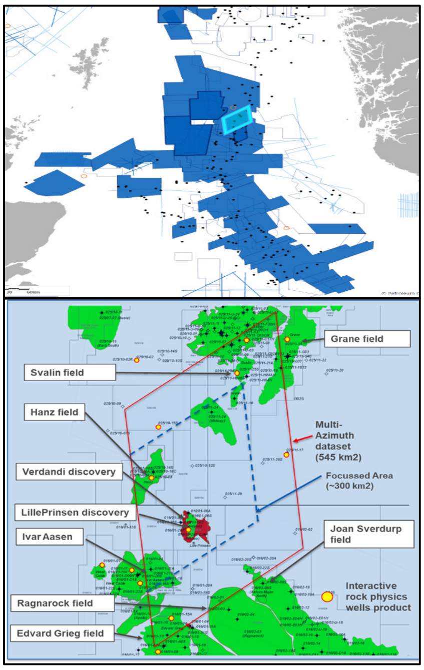

Figure 1. Top, Location of the 2019 multi-azimuth multisensor survey (highlighted in light blue) and its surrounding multi-client surveys in the UK-Norway North Sea. Bottom, the study area represents approx. 545 km2 with a focus area of around 300 km2 for more detailed analysis (blue dotted line). The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

The area of interest for this study is located in the South Viking Graben in offshore Norway (Figure 1). Major Norwegian fields are in this area, comprising several 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 the Lille Prinsen, drilled in 2018, which encountered various hydrocarbon intervals in the Eocene (Grid sand), Paleocene (Heimdal sand) and Permian (Zechstein Group).

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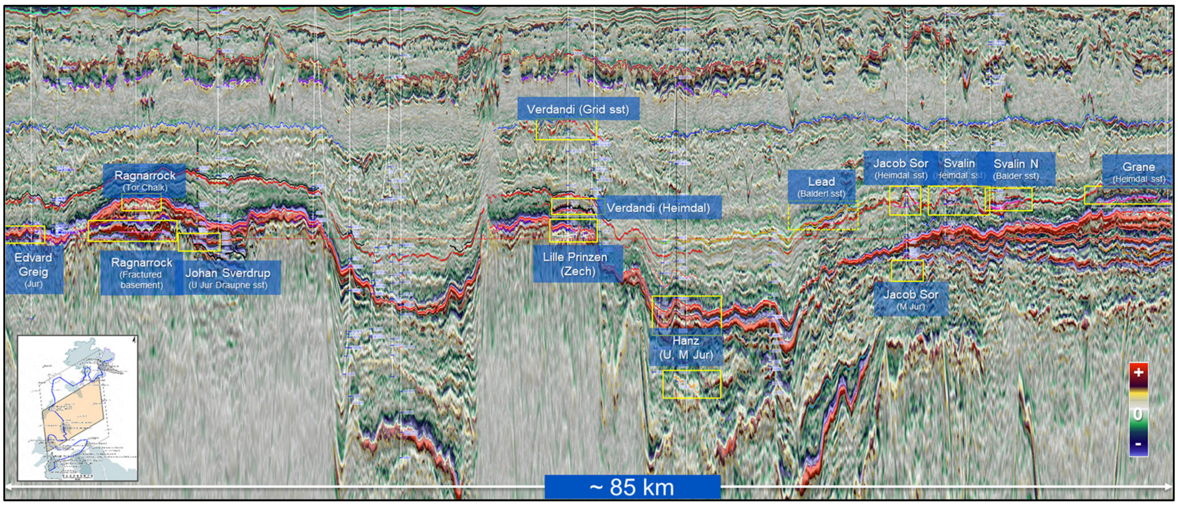

Figure 2. Regional full stack MAZ relative acoustic impedance random line going through the main fields, recent discoveries and their respective stratigraphic age where hydrocarbon interval has been encountered. The section also illustrates many features which degrade subsurface imaging such as injectites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

Even though, the North Sea is a mature basin, there is still significant potential and challenges remain over this region to optimize near-field exploration opportunities. Well-known challenges over this area are: shallow subsurface channels, shallow gas, Tertiary low velocity anomalies, 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 scatter the seismic signal and thus do not allow an accurate and reliable characterization of the numerous Tertiary to Paleozoic reservoir levels.

To overcome these diverse and complex challenges, an innovative multi-azimuth (MAZ) multisensor acquisition has been designed. MAZ as such, is not new and was implemented more than 10 years ago, for example, in the Nile Delta (Keggin et al., 2007 and 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 50-125 m offset range. More information about the acquisition design can be found in O'Dowd et al., 2019. The multisensor 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 survey 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

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 from 0 to 10 km and reflection FWI up to 15 Hz for the 0 to 6 km offset;
- 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 5 dimensional volume.

Analysis and main results.

Seismic interpretation has been conducted over the whole area based on this multi-azimuth broadband seismic calibrated with the available wells. For key wells, a regional interactive rock physics modelling product was further developed (11 wells for this area) and used to better

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understand the elastic properties response with the changes of the reservoir properties (e.g. VClay, Porosity) over the various intervals of interest. Rock physics modelling went through the following steps: data gathering, well-log data interpretation, conditioning, 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 later confirmed by the well to seismic tie.

Additionally, a Reservoir Oriented Processing (ResOP) was performed using all the 6 azimuths and angle stacks (4) with the 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 outcomes 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). The wavelet has indeed a very 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.

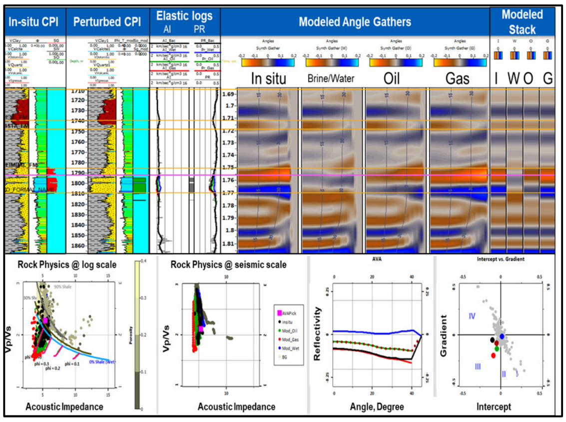

Figure 3. Montage view focusing on the Paleocene Heimdal sands view of the Lille Prinsen well (16/1-29S) showing the pre-stack seismic angle gather modeling response with a broadband wavelet (0-4-70-80Hz Ormsby parameters) corresponding to the MAZ seismic bandwidth and with different fluid scenarios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

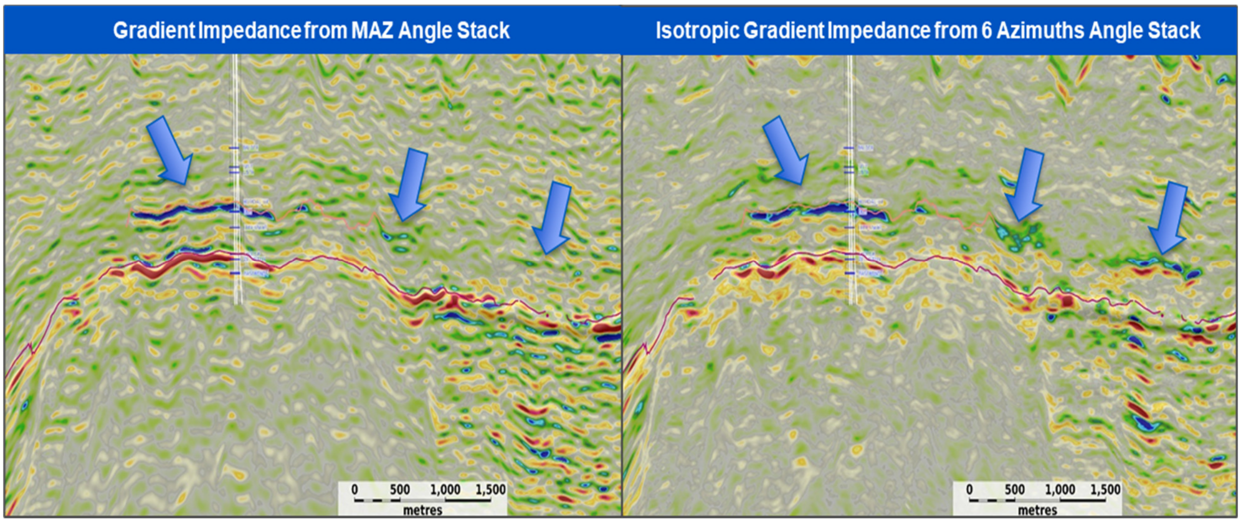

Figure 4. Figure showing the relative Gradient Impedance improvement from the MAZ angle stack to the estimation of the Isotropic Gradient (Rüger, 1998) using the 6 input azimuths and conditioned angle stacks. Some clear improvements (marked with the blue arrows) can be observed at the Heimdal sands level opening up some insights. It can be noticed that some low impedance downdip of the main structure (right hand-side image) that were not visible on the MAZ Gradient Impedance are clearly visible indicating some potential leads and more importantly some hydrocarbon potential.

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This seismic quality enables a very good to excellent well to seismic tie in the azimuths and associated angle stacks direction. The statistics are very encouraging with an average cross-correlation of 80-85% in all azimuthal / angle directions and for close to 10 wells. 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 substantially more stable gradient impedance (Figure 4) and now provides a clean, stable and continuous gradient / inversion results especially at the Heimdal sand level delineating the anomalies nicely. Subsequently, a relative pre-stack inversion per azimuth angle stacks has been carried out demonstrating e.g. that low Gradient Impedance or Vp/Vs anomalies estimated using the Isotropic AVA attributes (blue color on Figure 4) match very well with the Heimdal hydrocarbon interval at Lille Prinsen / Verdandi (wells 16/1-29S and 16/1-6S)

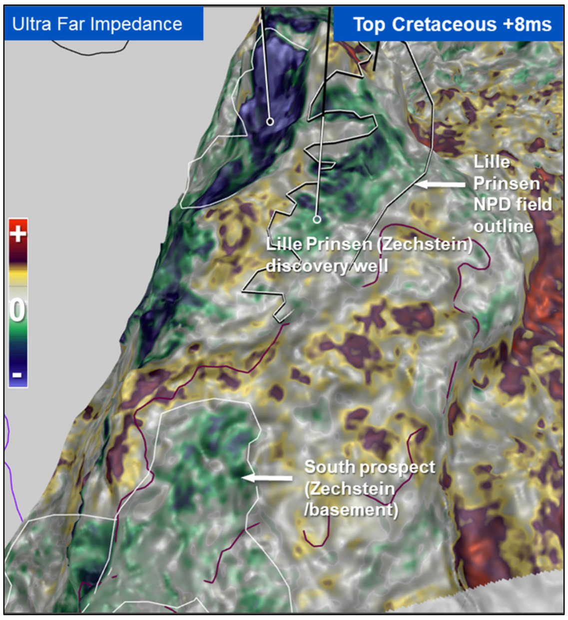

Figure 5. Ultra far relative impedance map extraction is well correlated to Vp/Vs, at the top Cretaceous over a 16ms window. Blue anomalies match very nicely with the Norwegian Petroleum Directorate (NPD) outline for the Lille Prinsen discovery at this level. A visible anomaly further north-west was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

Additionally, this multi-azimuth quantitative interpretation is providing some very interesting results for the deeper reservoirs. Few additional wells have been drilled following the Lille Prinsen discovery to examine the potential in the deeper stratigraphic interval such as the Jurassic sandstone and the Permian. Based on our elastic attributes extraction based on the pre-Cretaceous interpretation (Figure 5), there are some clear indications of hydrocarbon presence at the Upper Jurassic and Zechstein level. These anomalies are of reasonable size and could constitute some interesting near-field exploration potential.

Conclusions

This paper has demonstrated how an innovative acquisition set-up with a wide-towed sources (3) multi-azimuth (6) 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. 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.

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REFERENCES

Araman, A., and B. Paternoster, 2014, Seismic quality monitoring during processing: First Break, **32**, 69–78, doi: https://doi.org/10.3997/1365-2397.32.9.77966.

Keggin, J., M. Benson, W. Rietveld, T. Manning, P. Cook, and C. Page, 2007, Multi-azimuth 3D provides robust improvements in Nile Delta seismic imaging: First Break, **25**, 47–53, doi: https://doi.org/10.3997/1365-2397.2007008.

Marten, R, W. Rietveld, M. Benson, A. Khodeir, J. Keggin, and P. Cook, 2008, Utilizing multi-azimuth streamer data for reservoir characterization and uncertainty analysis in the Nile Delta: 70th EAGE Conference and Exhibition incorporating SPE EUROPEC, doi: https://doi.org/10.3997/2214-4609.20147598.

O'Dowd, D., M. Widmaier and C. Roalkvam, 2020, Redefining high resolution multi-azimuth towed streamer acquisition on the Norwegian Continental Shelf: 82nd EAGE Conference and Exhibition, Extended Abstracts, doi: https://doi.org/10.3997/2214-4609.202011886.

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

Rüger, A., 1998, Variation of P-wave reflectivity with offset and azimuth in anisotropic media: Geophysics, **63**, 935–947, doi: https://doi.org/10.1190/1.1444405.

Widmaier, M., D. O'Dowd, and C. Roalkvam, 2019, Redefining marine towed-streamer acquisition: First Break, **37**, 57–62, doi: https://doi.org/10.3997/1365-2397.2019035.

Widmaier, M., D. O'Dowd, and C. Roalkvam, 2020, Recent advances with wide-tow multi-sources in marine seismic streamer acquisition and imaging: First Break, **38**, 75–79, doi: https://doi.org/10.3997/1365-2397.fb2020093.

10.1190/segam2021-3583975.1