Reservoir Properties Estimation Using MAZ Towed Multisensor Streamer Seismic: A Norwegian Case Study

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Summary

This paper will focus on a data driven approach for reservoir properties estimation of a recently acquired and processed multi-azimuth multisensor survey in the prolific South Viking Graben, Norway. This case study will review the main benefits over various stratigraphic interval such as the Tertiary and the deeper Jurassic.

For instance, on the Jurassic interval, the implemented technologies and methodologies will be performed without the need of building a low frequency model necessary to achieve absolute reservoir properties and applied on the under-explored Vana sub-basin.

This case study will highlight the combination of innovative acquisition, quantitative interpretation, and seismic morphology interpretation that delivered enhanced imaging and understanding of the Tertiary-Jurassic interval and also an improved assessment of the volume size of some exploration leads/opportunities.

Introduction

The Viking Graben in the North Sea has delivered a significant number of successes across multiple plays ranging from the shallow Tertiary to the deep Permian and is still an area of intense exploration, near-field exploration and field development. However, accurate imaging, identifying, mapping and evaluating each target with seismic technology has required a step change in the robustness with the objective to estimate and predict elastic and reservoir properties more accurately and reliably. Additionally, for an explorer or operator, these techniques should be cost efficient. To address these challenges, various seismic acquisition techniques have been deployed recently in this mature region, for example Dunlop et al. (2020) reported Ocean Bottom Node (OBN) surveys acquired over two seasons and a multi-azimuth (MAZ) towed streamer configuration acquisition was presented by Widmaier et al. (2020).

In this, we aim to build on the previous case study with a similar MAZ dataset to the south (Reiser et al., 2021), but going a step further by estimating reservoir properties, such as volume of shale (Vsh) and porosity. This will be driven using only the seismic data information, i.e., removing the necessary need to build a low frequency model to achieve absolute reservoir properties.

We will first describe the overall dataset used for this case study, show the main workflow implemented and report observations, and draw conclusions and suggest a way forward.

Area of Interest (AOI) and database

The area of interest (AOI) is located in the South Viking Graben (Figure 1) on the Norwegian side over the Utsira High and the adjacent Vana Basin.
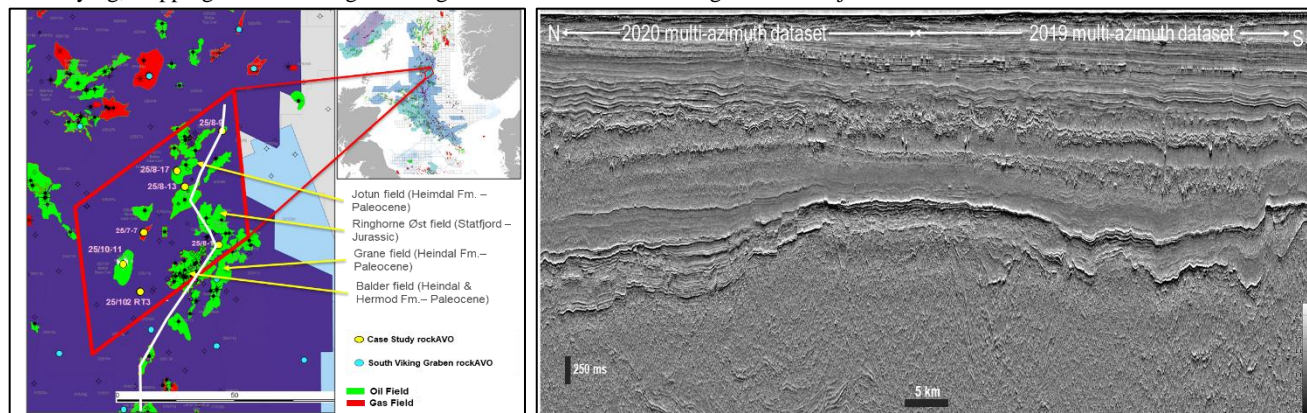

Figure 1. Left: Location of the 2020 multi-azimuth survey (red polygon) and its surrounding multi-client surveys in the UK-Norway North Sea. The PGS 2019 multi-azimuth dataset is located in the south of the red polygon (Reiser *et al.*, 2021). The 2020 dataset study area represents around 1200 km². This figure shows the various fields present and the wells (yellow dots) used for the interactive rock physics modelling analysis. Right: This panel represent the MAZ full stack seismic 3D relief random line (white line on the basemap) crossing some of the fields/discoveries and across the two multi-azimuth datasets (2019 and 2020).

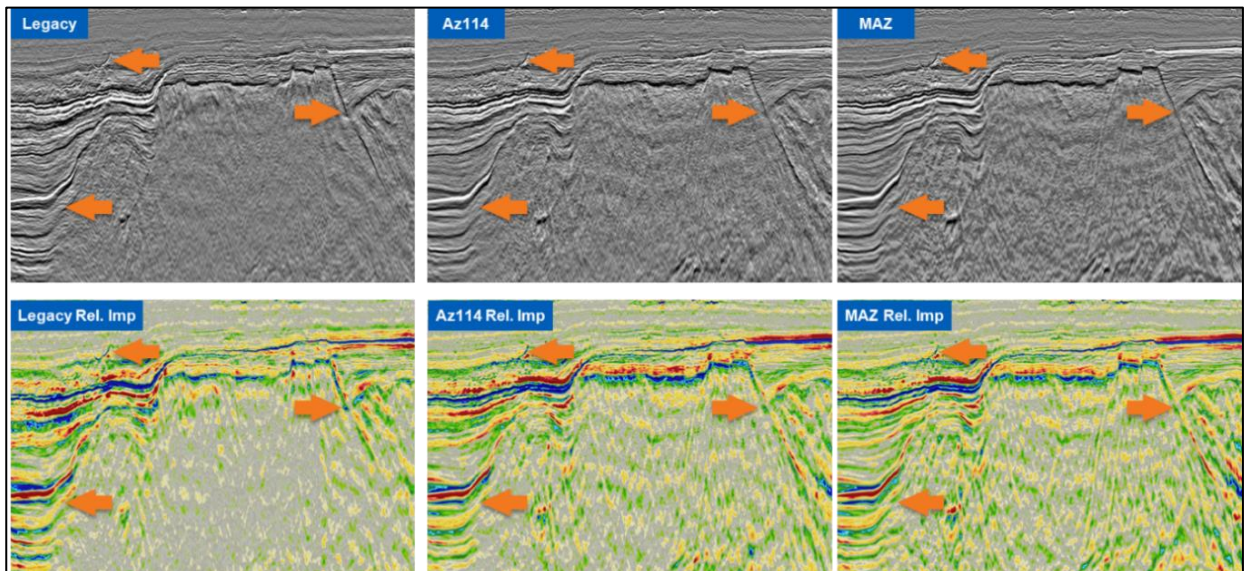# Reservoir Properties Estimation Using MAZ Towed Multisensor Streamer Seismic: A Norwegian Case Study

Figure 2. Top row represents the full stack amplitude seismic with the legacy (left), the azimuth 114 (middle panel) and the MAZ (right) data. The bottom row represents the results of the relative acoustic impedance (no low frequency model) of the three different input seismic. A series of image/inversion improvements can be seen comparing legacy to reprocessed narrow azimuth 114 and to the multi-azimuth dataset. Enhancement can be observed from the shallowest part of the section to the deepest part with clearer faults definition in the Utsira High (right) and towards the Vana Basin (left), with better delineation of the deepest and shallowest events.

The main fields over the AOI (Figure 1) are: the Balder field discovered in 1967 producing from the Heimdal and Hermod Formations (Paleocene age) as well as some injected sands, the Ringhorne field part of the Balder complex produces from the Hugin (late Jurassic), Ty (early Paleocene) and Hermod Formation (Late Paleocene), the Grane field on the eastern part of the survey produces from the Heimdal Formation (Paleocene) with very good reservoir quality, and the Jotun field, further north in the survey was producing (currently shut down) from the Heimdal Formation. Few discoveries have been made in the deeper Vana basin part of the survey: the 25/10-11 well drilled in 2011 targeting the early Jurassic interval encountered some minor oil and gas in this interval, the Busta prospect (25/7-7) and 25/7-2 drilled by ConocoPhillips targeting the Jurassic Intra-Draupne formation encountered some gas condensate and light oil. Overall, the Vana Basin is under-explored and will be the main focus of this case study.

The MAZ survey has the same configuration as the 2019 survey (O'Dowd et al., 2020) with minor differences: two new deep-tow azimuths of 12 streamers by 6 km by 93.75 m, including two 10 km long streamers for an improved Full Waveform Inversion (FWI), and a wide-towed triple source with 250 m separation between outer source arrays for more reliable near offsets coverage in the 50-125m range. The streamer spread has been towed with a nominal tow depth of 25 m and between 28-30 m depth for the long tails,

respectively, in order to provide an improved signal to noise ratio along with enhanced low frequency recordings. This seismic acquisition has the benefits of providing richer azimuth/offset information and illumination at all depths. The additional acquisition azimuths (two in the 174^0 and 234^0 direction) are complementary to the completely reprocessed 2011 narrow-azimuth multi-client broadband data (114^0), creating a homogenous multi-azimuth dataset.

In terms of the processing and imaging sequence, a state-of-the-art pre-processing sequence from raw field data to demultiple ensured a seamless merge of all the azimuths into a single 5D dataset prior to Kirchhoff Pre-Stack Depth Migration (KPSDM). The Titled Transverse Isotropy (TTI) velocity model was obtained through a comprehensive Velocity Model Building (VMB) flow where Full Waveform Inversion (FWI) using refractions and reflections in a MAZ setting was key in resolving both shallow and deep velocity anomalies such as shallow channels, high velocity injectites and chalk / basement layers.

Figure 2 illustrates the uplift obtained from high-grading existing data (legacy 2011 or azimuth 114^0) with complementary new acquisition and more advanced imaging workflows. The improvements are observed from shallow to deep, in higher contrast, continuity, and resolution of reflectors, and as well as clear improvements in the

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interpretability, definition of the faults and structural elements.

One of the challenges in the AOI is the presence of an over-pressure zone in the Jurassic interval in the Vana Basin causing a drop in seismic velocity (Figure 3) to around 2.6-2.7 km/s at around 4.4km depth. Well, 25/7-02 recorded some abnormal pore pressure in the Jurassic section. No wells in the deeper part of the basin have been drilled nor "sampled" this over-pressured zone for the elastic attribute calibration.
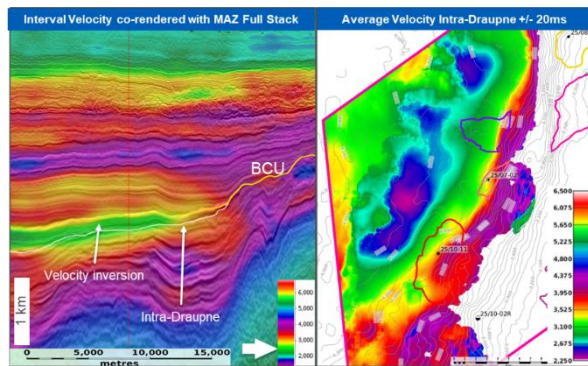

Figure 3. Velocity section co-rendered with the MAZ full stack seismic (left) and map display of the average velocity around a Jurassic Intra-Draupne formation horizon (right). A distinct velocity inversion can be seen on the in the central part of the Vana Basin.

Data driven quantitative interpretation workflow and results

Based on the above observations, and with the objective to extract reservoir properties such as volume of sand and porosity, instead of estimating absolute elastic attributes, it was decided to use only the seismic amplitudes. The properties will thus not have any direct input from the seismic velocity, which is usually used for the low frequency model building. The over-pressured area and associated very low seismic velocity would have biased significantly the estimation of reservoir properties (Figure 4).

Subsequently, a multi-attribute rotation scheme was implemented to derive the reservoir properties. The multi-attribute rotation scheme (M.A.R.S.) is a methodology that uses a numerical solution to estimate a transform to predict petrophysical properties from elastic attributes (Alvarez et al., 2015). This is achieved by estimating a new attribute in the direction of maximum change of a target property in an n-dimensional Euclidean space defined by a number of elastic attributes, and subsequent scaling of this attribute to

the target unit properties. The first step is to compute the transform from well-log-derived elastic attributes to the reservoir properties, which is then applied to seismically derived elastic attributes. Such transforms were used to estimate reservoir properties, porosity and volume of shale (Figure 5) based on the derived elastic properties (relative acoustic impedance and Vp/Vs).

M.A.R.S. methodology has been implemented on the legacy and the new multi-azimuth datasets with the exact same workflow i.e., relative pre-stack seismic inversion following by the above reservoir properties transform. It is possible to map and detect untested porous sands located in the Vana Basin based on the above attribute (Figure 5). These sand geobodies could correspond to ponded sands associated with deep-water mass transport deposits (MTD) systems (e.g., Cardona et al., 2020) which accumulated in a distal position (suggesting good grain sorting) roughly parallel to the Utsira High slope.

These bodies represent reasonable sized porous sand accumulations that may be attractive exploration targets. With these results clear differences can be observed between using the legacy narrow azimuth dataset (Figure 5 left) and the recently acquired and processed multi-azimuth (Figure 5, right). The overall volume using the multi-azimuth dataset appears smaller but potentially more accurate than using a partial view of the subsurface, thus reducing the uncertainty in the volume estimation.

Conclusions

This paper has demonstrated that new opportunities can be found for near-field exploration in a mature basin such as the Norwegian south Viking Graben. A combination of an innovative acquisition, an entirely seismic driven reservoir properties estimation, and seismic morphology interpretation delivered an enhanced imaging and understanding of the Jurassic interval. This overall workflow for the characterization and understanding of the subsurface allows an improved assessment of the volume of these opportunities and constitute therefore a very powerful risking and uncertainty assessment tool.

Acknowledgements

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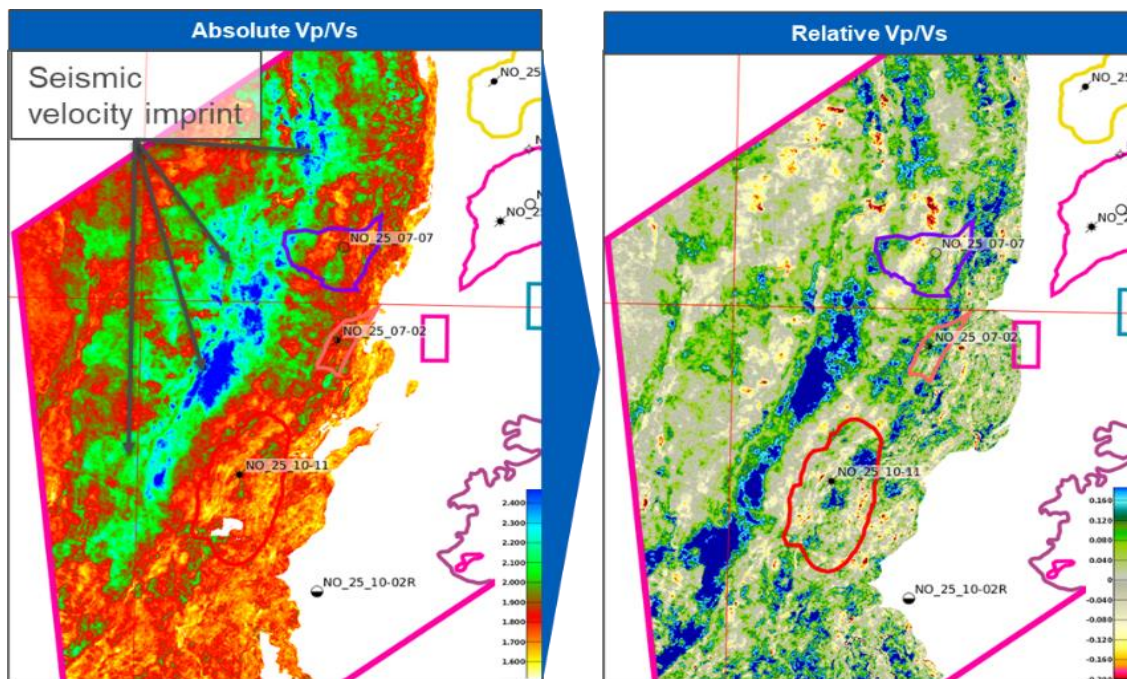
Figure 4. Seismic velocity imprint on the absolute Vp/Vs extraction can be clearly observed (left) at the Upper Jurassic level (around the intra-Draupne interval) as opposed to the seismically derived relative Vp/Vs (right)
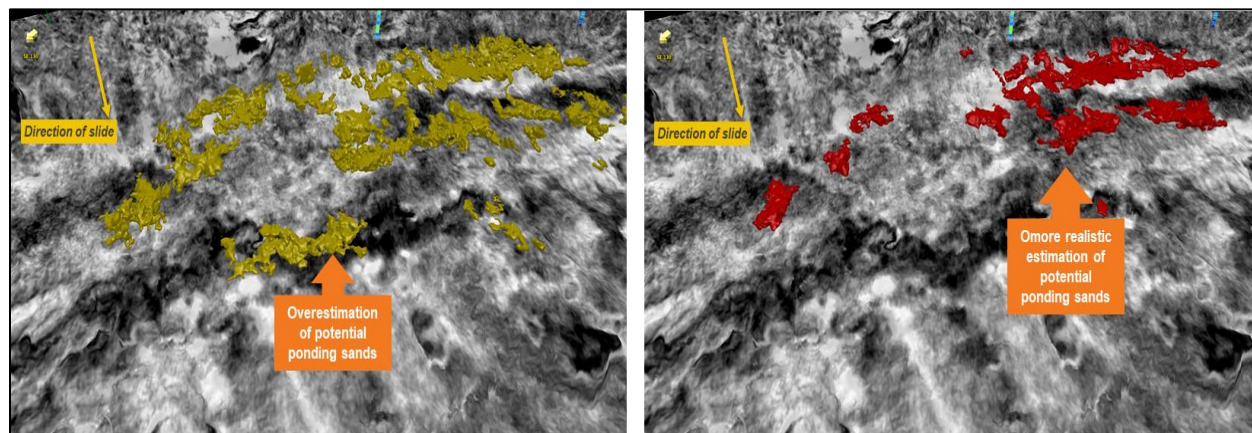

Figure 5. Effective porosity estimation using the reservoir property transform based on data driven elastic attributes. The above results show the detected geobodies using a cut-off on the volume of shale (below 0.3) and with a porosity above 12%. These geobodies represent the most porous sands. On the left is the result of the porosity estimation using the legacy narrow azimuth dataset and, on the right, using the newly acquired and processed multi-azimuth dataset. Clear differences exist between the two extractions, estimations. The legacy porosity estimation is overall noisier, less coherent compared to the multi-azimuth dataset leading potentially to an over-estimation of the volume of porous sands.

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