MATURE PALEOCENE SOUTH VIKING GRABEN PLAY DERISKED WITH MULTI-AZIMUTH SEISMIC DATA, A NORWEGIAN CASE STUDY

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Summary

Integration of 3D seismic reflectivity data and well logs in AVO studies have led the way in the characterization of the Paleocene deposits in the mature South Viking Graben. However, there are limitations in these techniques, in some instances highly anisotropic facies, such as volcanic tuffs, might show a similar response to well-known reservoir sands. To overcome this issue, we present an innovative workflow that integrates isotropic information derived from the recently acquired multi-azimuth multisensor survey into AVO workflows. Results are promising, as the seismic isotropic information increases our ability discriminating volcanics from clastics, revealing the internal geometry of the deep-water fan system, and opportunities in this mature area.

Mature Paleocene South Viking Graben play derisked with Multi-Azimuth Seismic data, a Norwegian case study

Introduction

A great deal of the success of the Viking Graben as a hydrocarbon province is attributed to the deep-water Paleocene sandstones, in particular the Hermod Formation, and traditional AVO techniques integrating well and narrow-azimuth seismic data are often used to track these prolific reservoirs. However, during the time of deposition of these sandstones, the volcanic activity in the area led to the formation of volcanic tuffs. This facies can produce, in some instances, a response similar to sandstone deposits in elastic logs and on seismic data sets that do not take into account the isotropic component of the seismic reflection. This is problematic, as tuffs might be misinterpreted as potential reservoirs or even mask the geomorphology of the sand deposits, increasing the uncertainty in the prospect de-risking process. In order to overcome this issue, we have integrated information from seven wells from an interactive rock physics regional study (rockAVO) and isotropic information coming from wide-azimuth seismic data to better understand the distribution of the Hermod Fm. over the Southern part of the Viking Graben.

Method and Theory

For this study a Multi-Azimuth (MAZ) multi-sensor survey, was available. MAZ is an innovative acquisition that overcomes geological challenges that can distort, obscure, attenuate, dim, and/or scatter the seismic signal, enabling a robust characterisation of the seismic data compared with traditional narrow azimuth data. This solution has been implemented with great success in other areas such as the Nile Delta (Keggin et al., 2007) and also within the Viking Graben for quantitative interpretation (Reiser and Mueller, 2021).

This 1170 sq. km MAZ survey is located in the in Norwegian side of the South Viking Graben (Figure 1) and has been acquired using wide tow sources and used 14 × 6 km × 93.75 m high-density streamer spread. The acquisition included two 10 km long streamer for an improved Full Waveform Inversion (FWI) and a wide-towed triple source with 125 m separation between outer source arrays allowing reliable near offsets coverage. The multi-sensor seismic streamers have been towed at 25 m depth for an improved signal to noise ratio and enhanced low frequency recording. This acquisition configuration provides a richer azimuth/offset information and better illumination of the geological features.

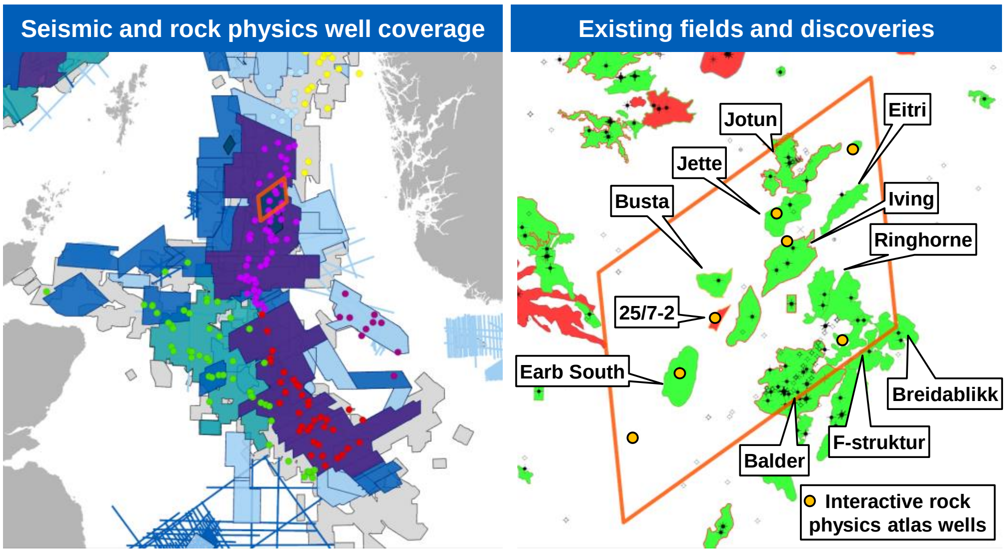

Figure 1 *Left: location of the multi-azimuth multisensor survey (orange polygon) acquired in 2020 and the neighbouring multi-client seismic in the UK and Norwegian side of the North Sea. Right: study area (red polygon), the various fields and discoveries covering different stratigraphic ages and interactive rock physics (rockAVO) wells used in the study (orange dots).*

The results from processing are two different sets of seismic data, one set of partial angle stacks without any azimuthal sectorization, hereafter labelled MAZ6 angle stacks, and another data set where partial angle stacks have been generated for each of the six azimuthal directions, hereafter labelled as Full-Azimuth stacks (FAZ).

Both sets of partial angle stacks have been conditioned using a Reservoir Oriented Processing (ResOP) workflow. The conditioning included random noise attenuation, amplitude spectral harmonisation and time mis-alignment correction. Once all seismic data has been conditioned, intercept and gradient have been estimated using a two-term approximation (Shuey, 1985) shown in equation 1 from the MAZ6 data set.

$$\boldsymbol{R(\alpha)} = \boldsymbol{A} + \boldsymbol{B} \times \boldsymbol{sin^2(\alpha)} \quad \text{(Eq. 1)}$$

Where, A is the intercept and B the gradient. Then, this intercept and gradient volumes were used to estimate relative Ip and Vp/Vs scaled to band-limited well logs (top image in figure 2). In the case of the FAZ dataset, the equation (Rüger,1998) below was applied:

$$R(\alpha, \Phi) = A \times \left[B_{iso} + B_{ani} cos^2 \times \left(\Phi - \Phi_{ref}\right)\right] \times sin^2(\alpha) \quad \text{(Eq. 2)}$$

Where, A is the intercept, B_{iso} the isotropic part of the gradient and B_{ani} its anisotropic part. Φ_{ref} is the reference azimuth. The isotropic gradient and intercept from equation 2 where then used in the workflow to derive relative Ip and isotropic relative Vp/Vs calibrated to well logs.

Examples

The arbitrary line running North to South in figure 2 shows the results of the two different relative Vp/Vs seismic sections and the match at the well location, the colour bar between the seismic section and the band-limited well logs are synchronised. At the top, the relative Vp/Vs section derived from MAZ6 stacks exhibits a soft event (low relative Vp/Vs), that appears quite continuous across the section. This reflector has been used to interpret a horizon across the entire survey (black dashed line). At well 25/8-1, this event corresponds to oil charged sandstones of Hermod Fm. (dark green arrow), while the same soft event at well 25/8-13 (orange arrow) is consistent with the presence of volcanic tuffs. This is discouraging, as it implies that stacking information from all azimuths (thus removing any relevant information that the azimuthal sectorization can provide) to generate partial angle stacks, is insufficient to separate the elastic response of the Hermod Fm. from the volcanic tuffs.

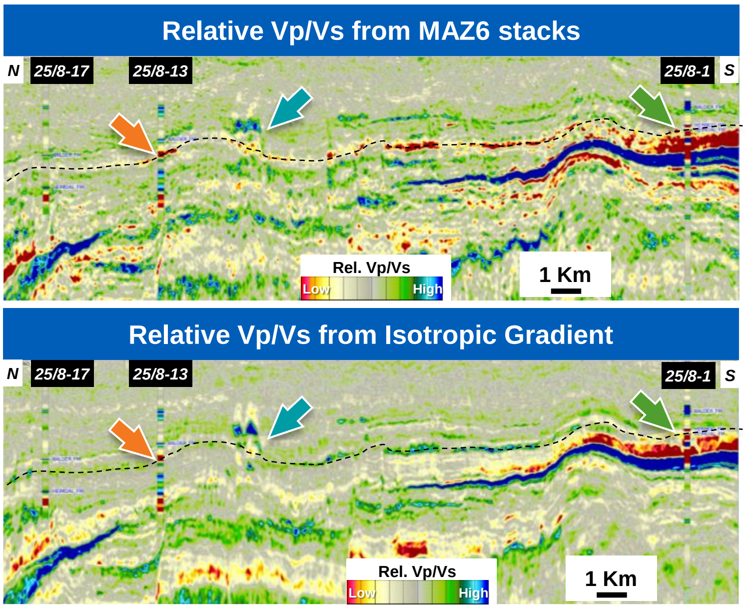

Figure 2 *Top: relative Vp/Vs, volcanic tuffs in well 25/8-13 (orange arrow) are a soft event (red colour) and is similar to the hydrocarbon charged sandstones of Hermod Fm. (dark green arrow). Bottom: isotropic relative Vp/Vs; volcanic tuffs show a soft but very dim response (high anisotropy), while the response of Hermod Fm. is still a soft event. Band-pass Vp/Vs well logs are displayed along the well trajectory and the colour bar has been synchronised to the seismic. A recent injectite discovery in the area (turquoise arrows) is better delineated in the isotropic relative Vp/Vs section.*

The isotropic relative Vp/Vs section, bottom section in figure 2, however shows a different story:

- The soft event from the section above doesn't appear as strong and continuous
- The tuffs in well 25/8-13 show a very dim response (orange arrow),
- Hermod Fm. oil sands remain a soft event on 25/8-1 (dark green arrow) and they seem slightly offset from the original interpretation performed on the section at the top
- Finally, there is a flip in the polarity of the reflector in the middle of the section

When looking at the response on an amplitude extraction maps (figure 3), it is clear that the relative Vp/Vs from MAZ6 stacks has a strong soft response across most of the survey, and it is not possible to observe any geological feature that could be associated to deep-water sandstone deposits. However, the amplitude map generated using the isotropic relative Vp/Vs (top right figure 3) clearly delineates the submarine channel system, with the feeder channel coming in from the North, and the fan with multiple distributary channels extending towards the South of the seismic survey, into the Balder field, as well as into the unexplored South-West section of the survey.

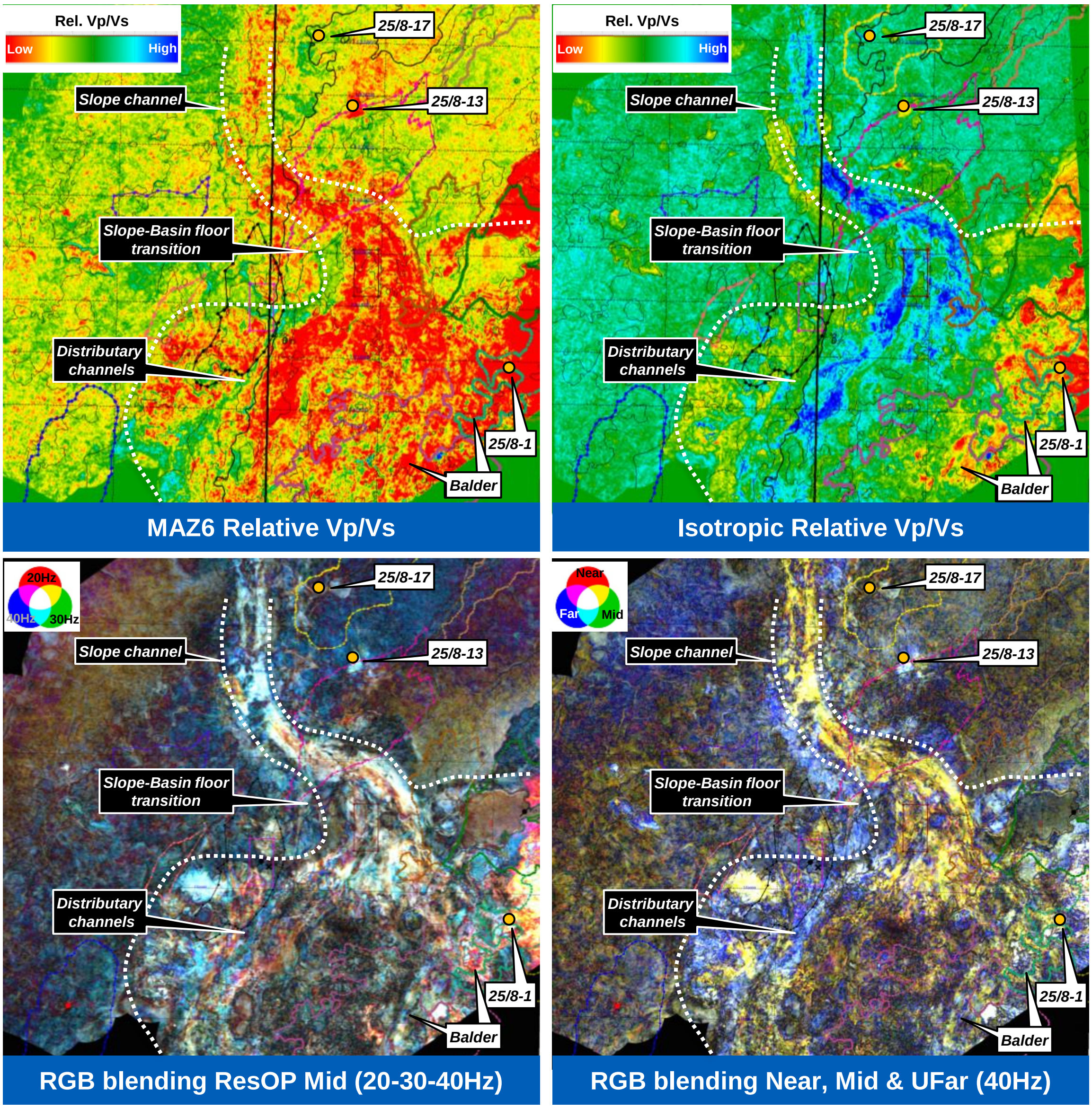

Figure 3 *Upper left: Relative Vp/Vs amplitude extraction from MAZ6 stacks. Upper right: Relative Vp/Vs based on the isotropic gradient and intercept. Bottom left: RGB blend results from MAZ6 mid stack of three frequencies (20-30-40 Hz). Bottom right: near, mid and ultra-far MAZ6 RGB blending results; the three stacks have been blended using 40 Hz frequency. Amplitude extractions on all maps have been done at the top of the horizon shown as a black dashed line in figure 2.*

With the aim of further characterising the submarine fan system revealed by the isotropic relative Vp/Vs, two different RGB blending approaches have been used: a frequency blending using the MAZ6 mid stack at frequencies 20, 30 and 40 Hz, for revealing the internal geometry of the submarine fan; and another technique involving the blending of the near, mid and ultra-far MAZ6 stacks using a single frequency channel at 40 Hz, that can help revealing amplitude anomalies associated to the hydrocarbon presence. Results from the frequency RGB blending (bottom left, figure 3) confirms the geomorphology of the submarine fan system revealed by the isotropic relative Vp/Vs, while the blending of the different partial angle stacks (bottom right, figure 3) correlates well with hydrocarbon presence in known fields in the area, while highlighting leads and opportunities over the survey.

Conclusions

This paper has demonstrated how the integration of the multi-azimuth broadband seismic data in AVA analyses can help in discriminating the response of volcanic tuffs facies from deep-water marine sandstone facies at the Paleocene level in the prolific South Viking Graben. We have shown that the derived isotropic relative Vp/Vs volume is a powerful tool that provides better insights of the distribution of the sands in the area compared to the relative Vp/Vs from MAZ6 data. Finally, with this available dataset, it is possible to highlight opportunities for infrastructure lead exploration (ILX) in the area.

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