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# USE OF NOVEL GEOPHYSICAL TECHNIQUES TO REDUCE EXPLORATION RISK

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## 1. Abstract

There has been a significant development of geophysical techniques within data acquisition, processing and interpretation/analysis in recent years. Although the technology is important in itself, we demonstrate that only through integration with proper geological understanding the technology can help us in reducing exploration risk. The AVO technique is in widespread use. Understanding seismic responses within varying depositional sand units and different fluid fill, requires knowledge of the rock physics of both the reservoir rocks and encasing shales. In many deepwater areas, we have seen a tight link between rock physics depth trends and the seismic response from brine and hydrocarbon-filled turbidite sands. Spectral decomposition and rgb-blending allow us to produce first class images of depositional systems in order to decrease the overall reservoir risk. In structurally complex areas, advanced seismic acquisition and processing/imaging techniques are important for an optimum image of the subsurface and thereby reducing the trap risk. Through the acquisition of controlled-source electromagnetic (EM) data we can estimate the resistivity structure of the subsurface. EM data can reduce risk on prediction of reservoir fluid type given a good geological model.

## 2. Introduction

Making oil discoveries is becoming more and more demanding worldwide. Exploration (play/prospect) risk constitutes of risk on trap, reservoir and source. For successful exploration it is detrimental to reduce the risk and at the same time reduce the volumetric uncertainty. It is demonstrated how the exploration risk can be reduced through the use of novel geophysical techniques combined with good local geological knowledge.

## 3. AVO and Rock Physics

Seismic data contain information about lithology (mineralogy and porosity) and pore fluids (fluid type and saturation). AVO is widely used in the industry in combination with rock physics in trying to capture this information. The link between the two is essential for making valid assumptions.

We try to make the link as tight as possible by using standardised plots for both well and seismic analysis. Typically, we plot acoustic impedance (AI) and NEAR (or intercept) offset data on the x-axis. On the y-axis we plot Vp/Vs and FAR-NEAR (or gradient) offset data. In this way we try to compare apples with apples. For standard well analysis we call the Vp/Vs versus AI plots for Rock Physics Templates (RPT) (Ødegaard and Avseth, 2004). Trend lines from rock physics models (Avseth et al., 2005) that are valid for various lithologies and pressure / temperature settings, can be added onto the RPT plot. By doing so, catalogues for worldwide basin characteristics can be generated and applied throughout the company. Figure 1 shows effects of lithology and pore fluid variations exemplified in a RPT.

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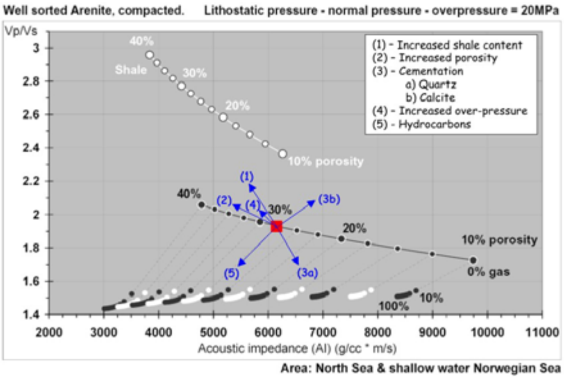


Figure 1. Typical Rock Physics Template illustrating effects of lithology and pore fluid variations on the Vp/Vs and AI cross-plot (Modified from Ødegaard and Avseth, 2004).

Once a good rock physics model is established in an area, generalised models versus depth for various lithologies and fluid types can be plotted on top of well data for comparison. From the plot, cross-over depths between shales and sands and, consequently, expected AVO classes at varying depths can be established.

From several deep water passive margin sedimentary systems, we have seen a very tight link between the established rock physics model, expected AVO classes and seismic behaviour on NEAR and FAR offset data. As an example of a Class 2 AVO behaviour, we would expect the NEAR offset to be dim and FAR offset to brighten with hydrocarbon fill at a given burial depth. This is what we observe on the seicmic data (Figure 2).

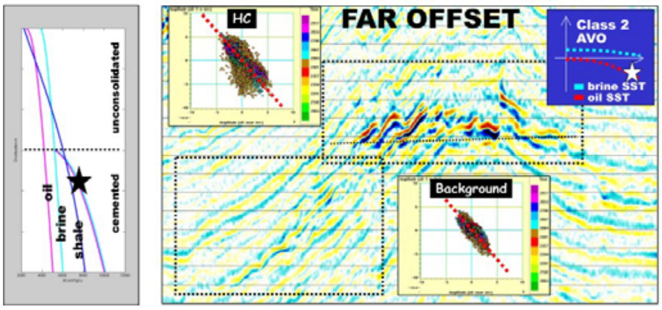


Figure 2. Link between rock physics depth trends AVO classes and seismic response.

## 4. Spectral Decomposition / RGB Blending

Spectral decomposition of seismic data of good quality gives opportunities for revealing geological features or subtle changes in depositional systems. The technique is simply a multi-volume Red-Green-Blue (RGB) blending of different frequency cubes.

A seismic cube is firstly decomposed into discrete frequencies with a small frequency range. The second stage is having an arena where the cubes could be mixed or blended together. The lowest frequency cube is assigned to red, medium to green and the high frequencies to the blue colour spectrum. This cube blending technique is illustrated in Figure 3. Where all the cubes are overlapping in frequencies, a white colour is achieved. Where a given frequency is outside the spectrum covered by the seismic cubes, a black colour will appear. Applying this technique to a seismic data set, detailed images of geological systems may appear that are often more detailed compared to standard attribute mapping techniques.

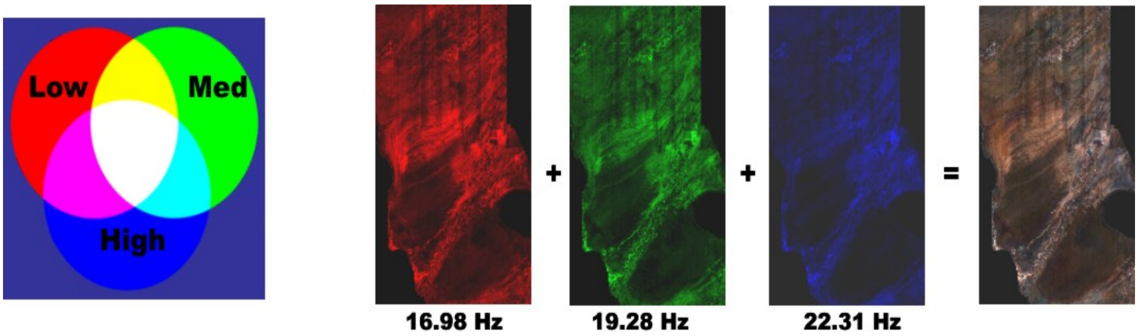


Figure 3. Each colour represents a seismic decomposed seismic cube. Red colour is assigned to the low, Green to medium and Blue to the high frequencies. Where the cubes overlap in frequency range, the colour will be white. On a real seismic data set, the different channels combine to give a realistic, almost satellite-like, image of the turbidites.

We have seen that RGB blending of seismic volumes can help us decrease the overall reservoir risk in the following aspects:

- Understanding development of turbidite systems from base to top by making instantaneous slices throughout the complex.
- Different facies may be revealed due to thickness variations from e.g. channel to levee facies of a turbidite system.
- Overlapping channel complexes can be better discriminated compared to standard attribute mapping.
- Spectral decomposition using the blending technique can ideally also be used for mapping varying thickness across a geological feature.

Figure 4 shows two turbidite complexes that are overlapping within a relatively small time window (50ms). From attribute mapping these are difficult to discriminate in the overlap area. RGB blending gives an improved visual impression of the complexes and helps building up a more sound geological story for the development through time.

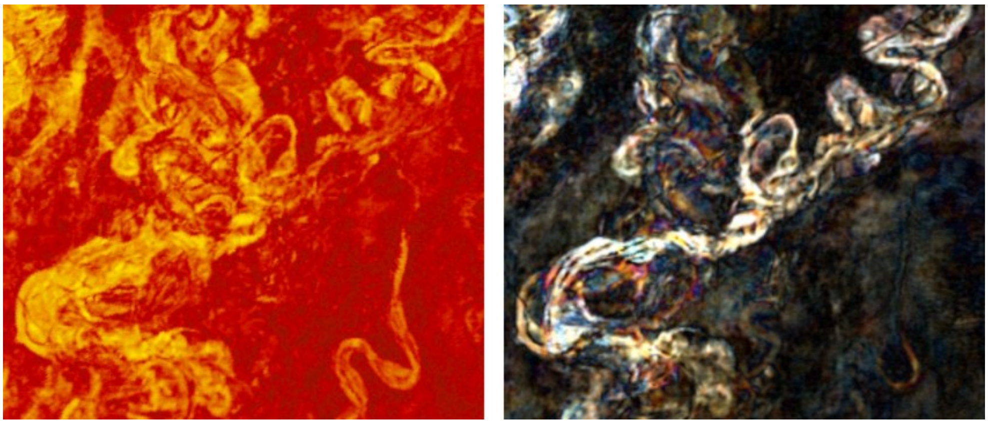

Figure 4. RGB blending (right) shows an improved definition of the two overlapping turbidite systems compared to standard attribute maps (left).

## 5. Mapping Techniques

For interpreters, the hunt for the subtle trap is a challenge that may become easier with instantaneous 3D view update of the seismic interpretation. The best way of scrutinizing and fully understand an interpretation is within a 3D viewer. Artificial light sources and fault enhancement techniques can e.g. reveal low relief features.

But, as always, the only way at revealing the subtle features is by detailed and accurate interpretation work required for optimizing the 3D view. In modern interpretation packages, more flexibility is put into the color manipulation for enhancing small contrasts. In addition, attribute draping and combination of several attribute maps with transparency functionality give improved possibilities for extracting geological features in the seismic data.

In the example shown in Figure 5, a detailed interpretation combined with attribute mapping at several layers helped building up a viable geological story in an area where limited well information was available. The effect of combing the RMS amplitude map with the variance map and displaying it in 3D together with a carefully chosen artificial light source, gives quite an improved image of the geological setting for the possible patch reefs compared to a 2D image without illumination.

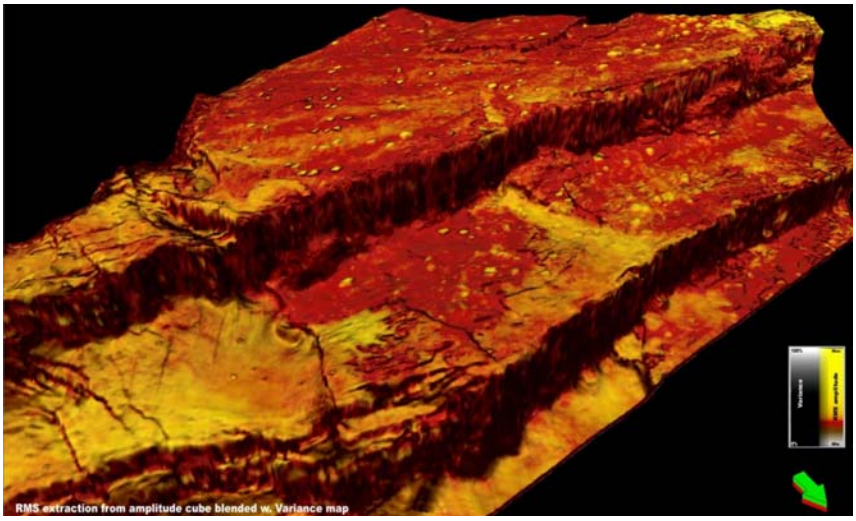


Figure 5. By combining RMS amplitude and variance maps onto a consistent structural interpretation and viewing it in 3D, possible patch reefs are visualised.

## 6. Image Quality

In many areas the exploration risk is closely related to the image quality of the subsurface. Use of pre-stack depth migration is becoming a standard tool for areas with large scale velocity contrasts, like salt basins or thrust zones. Here, the rapid development of advanced velocity model building tools and migration algorithms has led to significant improvements in data quality. As the inversion/imaging process is non-unique, the use of advanced methods must go hand-in-hand with significant geological input from the exploration teams. In many areas the image is distorted due to more subtle velocity contrasts in the overburden and we experience that tomographic techniques (layer and grid) that generally work well, seem to fail when the geometrical dimensions of the anomalies become very small.

When even advanced processing techniques do not give an adequate image, more sophisticated acquisition techniques than conventional 2D/3D are required. It is well known that single-azimuth 3D streamer geometries may fail beneath salt bodies with steep dip due to limited illumination, and surveys with a wider range of offset/azimuth distributions must be considered. One example from the North Sea is where shallow cemented sands with velocities around 5000-6000 m/s disturb the imaging at the target level, both by the scattering from the anomalies and the velocity effect. These sands are randomly distributed and are believed to range from 1-25 meters in thickness and can vary from 25-500 meters in lateral coverage. A wide range of techniques have been adopted to overcome this problem. From simple residual statics techniques to joint prestack wave equation depth migration of two perpendicular conventional streamer surveys. Even if it is difficult to interpret all the anomalies, attempts have been made to incorporate these anomalies in the velocity model. Improvements have been accomplished but not to such an extent that it really solved the problems. A modeling study was performed to evaluate if other acquisition geometries could improve the image where focus was on obtaining a good offset coverage in at least 9 azimuth sectors. The study showed that the preferred solution was to acquire full azimuth data to undershoot the anomalies and thereby stacking out their influence (Figure 6).

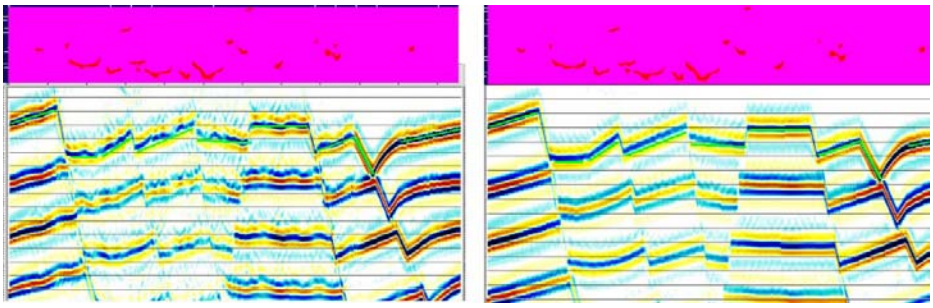

Figure 6. Pre-stack depth migrated synthetic data for a model with shallow high-velocity anomalies (in red colour) for single azimuth data (left) and full azimuth data (right).

A 3D OBS survey with orthogonal source and receiver lines densely separated was acquired with preliminary processing finished spring 2006. The results are in line with the modeling study, the effect of the shallow anomalies has vanished on the target level giving a superior image of the structure (Figure 7).

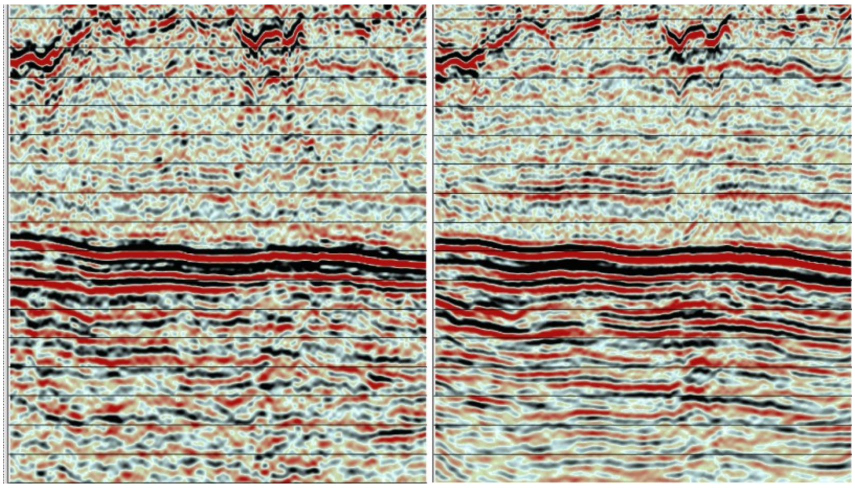

Figure 7. Preliminary pre-stack time migrated real data, single azimuth data (left) and full azimuth OBC data (right)

## 7. The Controlled-source Electromagnetic Method (EM)

The controlled-source electromagnetic method has been introduced as a new tool for hydrocarbon exploration, being able to identify zones of high resistivity in the subsurface. The method is elegant in that it potentially is capable of detecting hydrocarbon zones directly, and that it can discriminate well with respect to hydrocarbon saturation. This is an issue where AVO often fails. However, there are some pitfalls in using the EM method in that hydrocarbon reservoirs are not the only high resistivity layers in the subsurface. Salt, carbonate (cemented) rocks, volcanics all have high resistivity, while low resistivity zones due to high salinity formation water or ooze layers all contribute to “false“ anomalies. It is therefore important to integrate detailed geological knowledge of the area in the survey planning and data analysis for EM projects.

To further understand the potential and limitations of the EM method it is important to acquire data over known hydrocarbon accumulations. An example is over the Troll field, where not only the electric component but also the magnetc component gives data that match the well-known subsurface model very well (Figure 8).

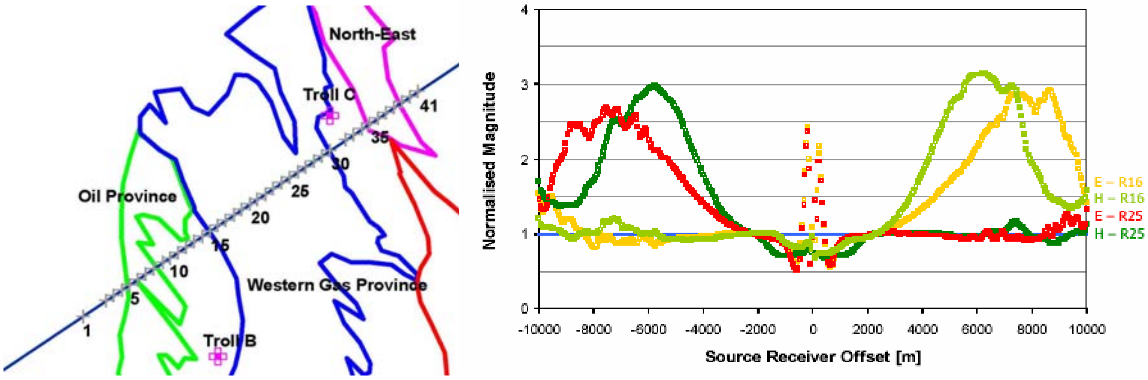


Figure 8. Troll EM survey layout and normalized electric and magnetic magnitudes for receivers R16 and R25 for both in- and out-towing (0.25 Hz). Reference receiver is R41 out-towing. (Johnstad et al., 2005).

The EM method for hydrocarbon detection is proven in deep water prospects. However, application of the method in water depths less than 300 m has been problematic since energy travelling through the air will have a severe impact on the recorded signals and can dominate the response. An EM survey over the Grane Field at 120m water depth has demonstrated that with careful choice of acquisition parameters it is possible to collect data with little or no airwave contamination (Farrelly et al., 2005). The development of EM migration and inversion techniques will further contribute to reduced risk on prediction of reservoir fluid type given a good geological model.

## 8. Summary

The development of geophysical techniques within data acquisition, processing and interpretation/analysis over the recent years has shown a significant potential in reducing exploration risk. It is vital that these techniques are all integrated and not the least integrated with local geological knowledge.

## 9. Acknowledgement

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