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Intra-Chalk Porosity Variations in Norway-Danish Central Graben: Integrated Mapping Using Broadband Elastic Attributes

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Summary

Understanding the influence of porosity on elastic properties through rock physics analysis is essential in seismic reservoir characterisation and key in the context of the chalk play. It is known that acoustic impedance is strongly correlated with porosity in carbonates but also that the chalk properties can vary widely creating intra-chalk layers of varying reservoir quality. This integrated study shows how reliable broadband relative elastic attributes tie at the wells and are able to map lateral and vertical changes of porosity within the Chalk interval in the Norwegian and Danish North Sea Central Graben.

Introduction

Chalk lithologies represent an important petroleum reservoir in the North Sea Central Graben, which spans the Norwegian, Danish and UK sectors. The Upper Cretaceous (Cenomanian to Maastrichtian) to early Paleocene (Danian) interval here is dominated by Chalk deposits that form a prolific hydrocarbon fairway with major fields including Ekofisk-Eldfisk, Valhall, Dan-Halfdan, Tyra and Gorm. The Chalk play has recognised reserves approaching 10 billion barrels of liquids and almost 5 billion boe of gas. The plays complexity lies in the combination of structural trapping, variations in timing of hydrocarbon migration and sedimentology, deposition and re-working and deformation history that can result in a wide range of reservoir facies and associated porosities (20% to over 50%), and permeability's (1 mD to 1000 mD) (Megson, 1992) affecting the economic value or interest in a potential field.

Whilst the elastic properties and seismic response of clastic reservoirs are relatively well understood, quantitative interpretation for chalk reservoirs and seismic reservoir characterization using elastic attributes is more challenging and requires careful rock physics analysis and calibration at wells combined with high quality broad bandwidth seismic data.

In an integrated study of the Norwegian Chalk fields using 7,600 km^2 of modern dual-sensor broadband towed-streamer seismic data from the core of a contiguous depth migrated dataset of over 21,500 km^2 were calibrated with detailed well ties and integrated into analysis of pre-stack relative elastic attribute volumes.

Rock physics analysis

A representative sample of key wells with suitable coverage in the North Sea Central Graben were integrated in a regional rock physics analysis performed across borders (UK-Norway). Figure 1 (left hand-side) illustrates the vertical thickness variability of the chalk various units (D1 and D2) and sets the expectations on the vertical resolution for the inversion process. Effective porosity, saturation and composite logs helped the interpretation of the elastic properties of the intra-chalk layers to build the elastic properties cross-plot on Figure 1 (right hand-side). Neutron logs were used as a proxy for porosity estimation when no CPI (Computed Processed Interpretation) was available. The analysis confirms that P-impedance decreases with an increase of porosity.

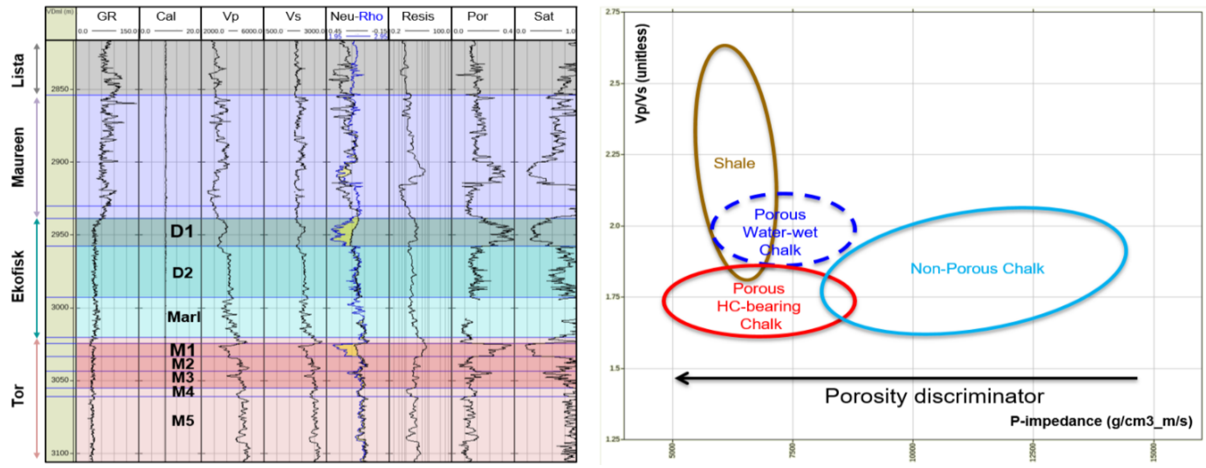

Figure 1: *Left: example of vertical heterogeneity of the chalk interval. D1 in the Ekofisk Formation and M1 in the Tor Formation show an increase of porosity (second track from the right) compared to the other sub-layers. Right: Summary scheme of rock physics analysis in the P-impedance vs. Vp/Vs domain performed on ten wells. Porous chalk is expected to be lower P-impedance than non-porous chalk, irrespective of the fluid.*

The rock physics characterization applied in this study may also help shed light on recent chalk exploration wells that were dry despite having good preserved porosity and low acoustic impedance within the chalk target intervals (Figure 1, dark blue ellipse) (as observed, for instance, in a previous published study by Gennaro and Wonham, 2014). Early hydrocarbon fill is a well-established mechanism for preserving porosity, however it does not always follow that high porosity intervals will be hydrocarbon-charged. Recent studies have suggested that some remobilized chalk features can be hydro-dynamically isolated and preserve porosity through over-pressure (Oxnevad and Taylor, 1999). Such results underline that challenges remain in estimating the fluid distribution in carbonates (Herbert et al., 2013).

Calibrating porosity estimation from relative P-impedance volume with the wells

A P-impedance volume was computed from this newly depth migrated broadband data from which the rich low frequency content allowed pre-stack inversion with confidence and reliability from 5Hz (Ozdemir, H. 2009; ten Kroode et al., 2012 Reiser et al., 2012; Whaley et al., 2013). Figure 2 illustrates the correlation of low P-impedance intra-chalk layers (red) with the elastic logs computed from the wells and also with the neutron porosity log. Thus, the relative acoustic impedance estimated from this dataset has a vertical resolution (thanks to the reliable high frequency present in the broadband data up to 45Hz at the target) allowing us to detect and characterize the various chalk units.

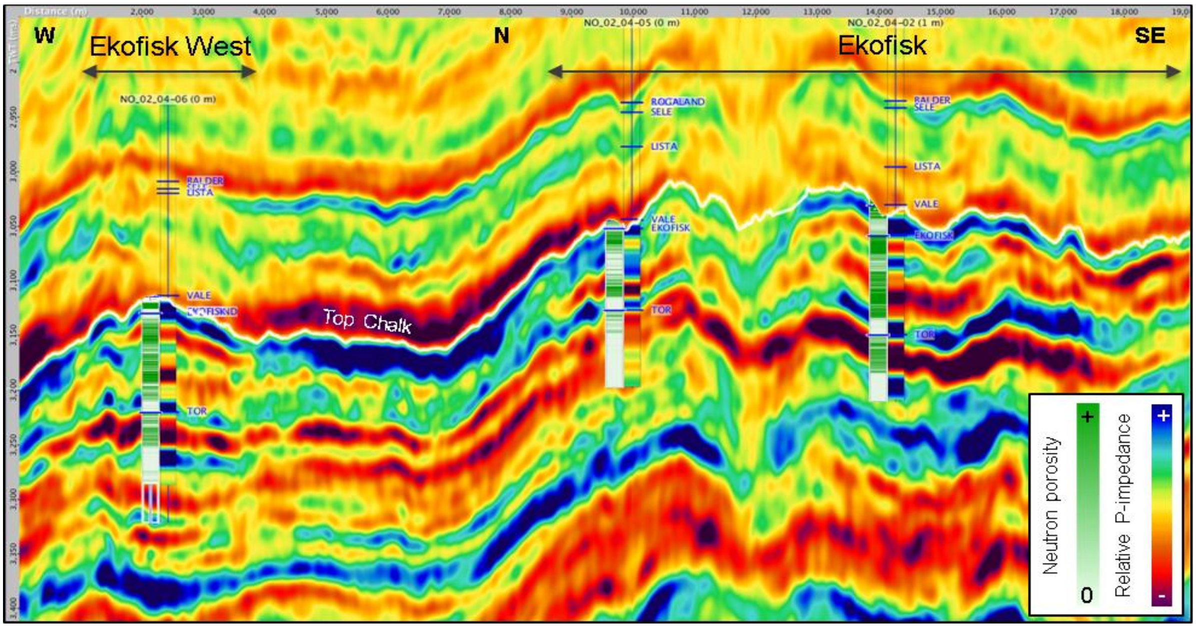

Figure 2: *Pre-stack relative P-impedance volume shows good match with elastic log computed at three well locations around Ekofisk and Ekofisk West fields. Porous chalk layers are expected to be low P-impedance (red) from the rock physics analysis and correlate with high values of neutron porosity log (dark green).*

3D mapping of porosity changes in the Ekofisk fields area

Five intra-chalk horizons (1: oldest, to 5: youngest) were semi-automatically picked within the first 100ms of the Ekofisk Formation. Relative P-impedance amplitudes were then extracted along each horizon and results in the vicinity of the Ekofisk field are displayed in Figure 3.

Horizons 1, 3 and 5 lie on the non-porous chalk layers whereas horizons 2 and 4 follow the most porous intra-Ekofisk layers. High porosity zones (red) are well defined inside the field outlines

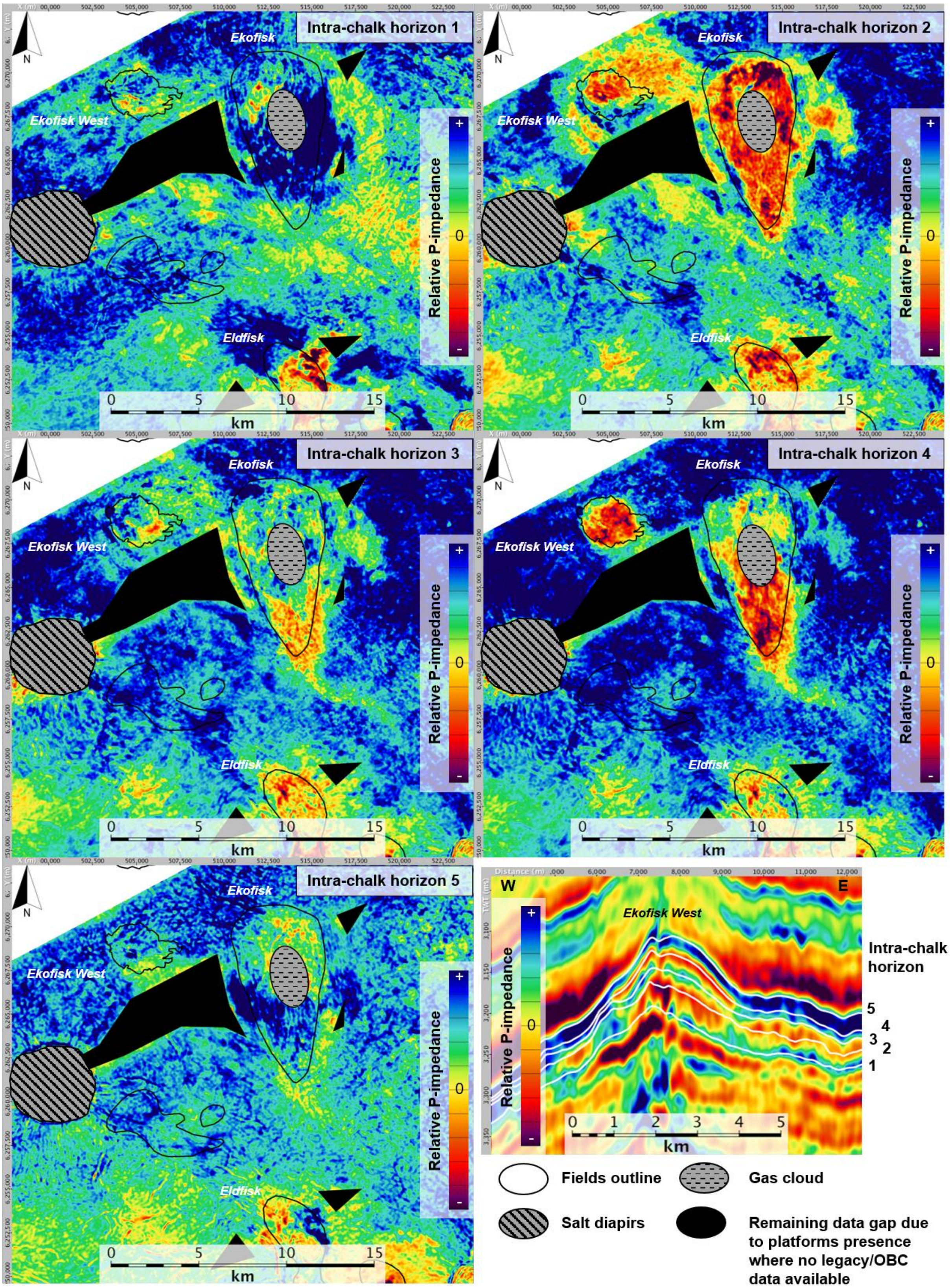

***Figure 3**: Amplitude extraction of broadband relative P-impedance performed on five intra-Ekofisk horizons. Abrupt changes of chalk porosity vertically and spatially are well imaged due to broadband dual-sensor streamer seismic data. Very good match of low P-impedance (high porosity – red) with field outlines.*

Conclusions

This study illustrates the high resolution 3D mapping of the porosity variations within the Chalk interval in the Central Graben thanks to the reliable broadband P-impedance volume and regional rock physics analysis integration.

Neutron porosity logs were used as direct porosity indicator in Chalk. Low P-impedance values from the seismic inversion attributes and at the wells correlate with high neutron porosity values. Relative P-impedance proves to be a good indicator of porosity in the Chalk interval. The rock physics analysis has been crucial to understand the expected relative behavior of the different intra-chalk layers.

Broadband dual-sensor towed seismic data was input to the pre-stack inversion workflow and was effective in reliably differentiating the intra-chalk layering away from the wells.

In addition to the good match of high porosity chalk observed at established hydrocarbon discoveries and fields, the rock physics results give encouragement that broadband seismic data with robust elastic attributes has the potential to distinguish hydrocarbon-filled porous chalk from water-wet anomalies.

Acknowledgments

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