Introduction

Energy companies have been exploring in the Barents Sea for over 30 years. Regular license rounds and favourable financial terms encouraging exploration have led geophysical contractors to acquire large multi-client datasets in the Barents Sea. The key to linking geophysical responses seen in these data and the underlying rock and fluid properties is a robust understanding of the rock physics within reservoir intervals. In the last 5 years several large multi-client 3D CSEM (Controlled Source Electromagnetic) surveys have been added to the data available to Barents Sea explorers. CSEM is a relatively new tool in the exploration toolbox, and in the correct circumstances can provide higher sensitivity to hydrocarbon saturation than is possible to achieve with conventional seismic reflection data (MacGregor & Tomlinson, 2014). For the true value of these data to be realized, the interpretation must be placed within a regional resistivity context, calibrated where possible to well log data. The Barents Sea is geologically complex – stratigraphically, structurally, and historically (Gabrielsen *et al.*, 1990). One component of this complexity is the presence of strong anisotropy in measured and derived electrical resistivity (Fanavoll *et al.*, 2012).

In this study we aim to investigate the geological controls on electrical anisotropy, which will form the basis to build new predictive rock physics models that in turn will allow more accurate predictions of rock and fluid properties of the reservoirs in the Barents Sea. In order to achieve this we use a combination of well log data, CSEM survey data, and rock physics modelling techniques.

It is particularly important to develop an understanding of the causes of, and trends in, electrical anisotropy that can be significant in sedimentary structures. Disregarding resistivity anisotropy will lead to misleading CSEM survey feasibility studies, inaccurate CSEM data analysis, inaccurate estimations of hydrocarbon saturations and, consequently, erroneous interpretations (Ellis *et al.*, 2011).

Method

In order to achieve the goals of this study we have developed a three stage workflow.

Stage 1
In the first stage we build a comprehensive suite of conditioned well logs in the Barents Sea. Water resistivity, porosity, water saturation and mineral volumes throughout entire wellbore are estimated. Rock physics models are also used to conduct fluid substitution in each reservoir that the well encounters. Following this, a comparison between seismic and electrical properties at in-situ conditions is performed as a preparation for the reservoir modelling in the resistivity domain.

Stage 2
In the second stage we investigate electrical anisotropy levels in the subsurface. Using multi-azimuth CSEM data, the bulk background electrical anisotropy in major stratigraphic units can be directly estimated using a structurally constrained modelling approach with the horizontal resistivity tied to induction logs in the survey area. This analysis is done in areas where there is both CSEM and well log data.

Stage 3
The results of the first two phases provide an atlas of resistivity and anisotropy across the study region. This information is used to examine electrical anisotropy trends within major stratigraphic units across the region. The analysis is extended further by developing and calibrating electrical rock physics models and workflows that explain the observed trends.

Analysis in the Snøhvit region

Figure 1 shows a comparison between well induction data and the CSEM derived resistivity data for 6 wells in the Snøhvit region of the Barents Sea. Analysis of the wells in the Snøhvit area show high levels of electrical anisotropy. In general the greatest ratios are observed in the deepest section of the earth model. Values range from a minimum of around 2 to a maximum of 40, with the overburden units generally having ratios below 5.

Data from 3 shale formations (Torsk, Kolmule, and Kolje) in the overburden was used to investigate the resistivity and anisotropy trends. These formations were chosen because of their thicknesses. CSEM sensitivity depends not only on the resistivity of the formation but also on its thickness. Other formations were deemed to be too thin for reliable results. Well log data averages from each of the wells and each of the formations were compared to the corresponding CSEM derived horizontal and vertical resistivities (Figure 2). Linear trends were fitted to the cross plots and the coefficient of determination (R^2) was determined for various well log measurements (Table 1).

Results

Results show that horizontal resistivity did not trend significantly with any of the well data types. This can be seen in the extremely low R^2 values in Table 1. This is perhaps not unsurprising as CSEM is more sensitive to vertical resistivities than horizontal. Strong trends were seen between various well log measurements and vertical resistivity (Figure 2, Table 1). Surprisingly clay content showed a relatively low correlation with vertical resistivity and correspondingly low with anisotropy. Clay content, along with sediment layering and fracturing, is often given as one of the principal causes of anisotropy.

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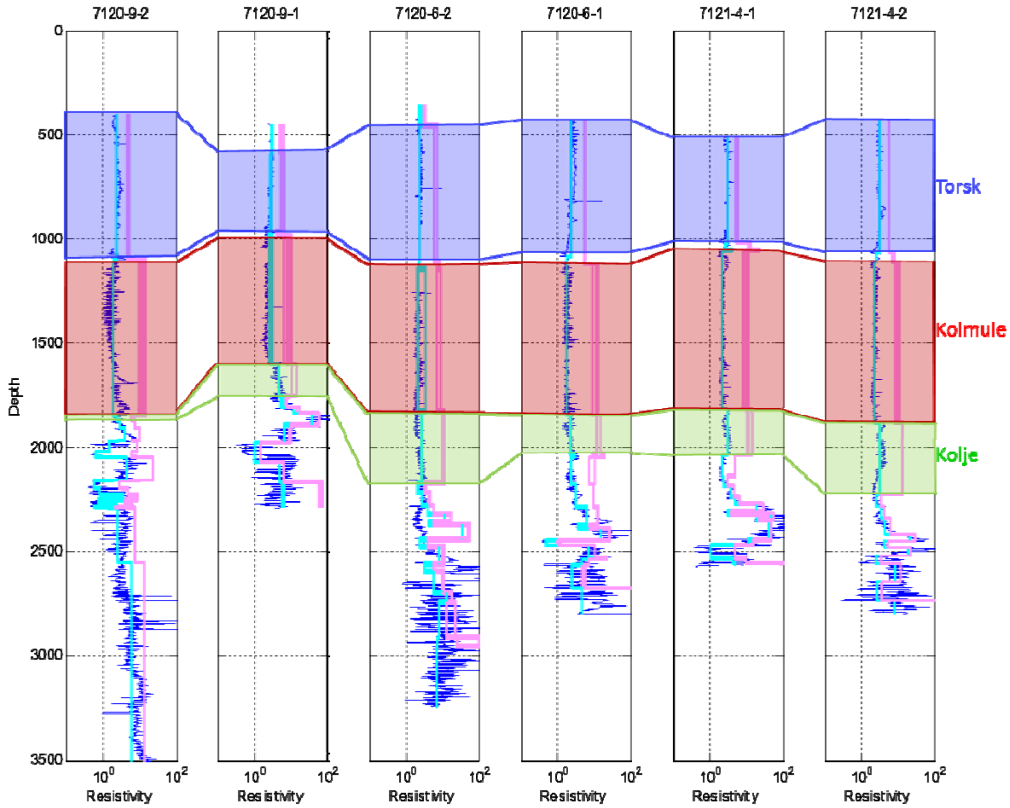

Figure 1. *Comparison of well log resistivity (blue line), CSEM derived horizontal resistivity (cyan line) and CSEM derived vertical resistivity (pink line) for six wells in the Snøhvit region. Formations used in the trend analysis are highlighted in blue, red and green.*

Well log data type	**Horizontal resistivity R^2**	**Vertical resistivity R^2**	**Anisotropy R^2**
Total porosity	0.08	0.89	0.38
Neutron porosity	0.00	0.12	0.18
Bulk Density	0.07	0.89	0.40
Clay Fraction	0.08	0.25	0.05
R_w	0.00	0.84	0.58
Depth	0.02	0.84	0.43
P-wave Velocity	0.08	0.87	0.35
S-wave Velocity	0.08	0.87	0.35
Acoustic Impedance	0.09	0.88	0.35
Poisson's Ratio	0.06	0.87	0.37

Table 1. *Linear trend R^2 values for cross plots of well data averages (total porosity, neutron porosity etc.) versus CSEM 1D forward model derived average resistivity values.*

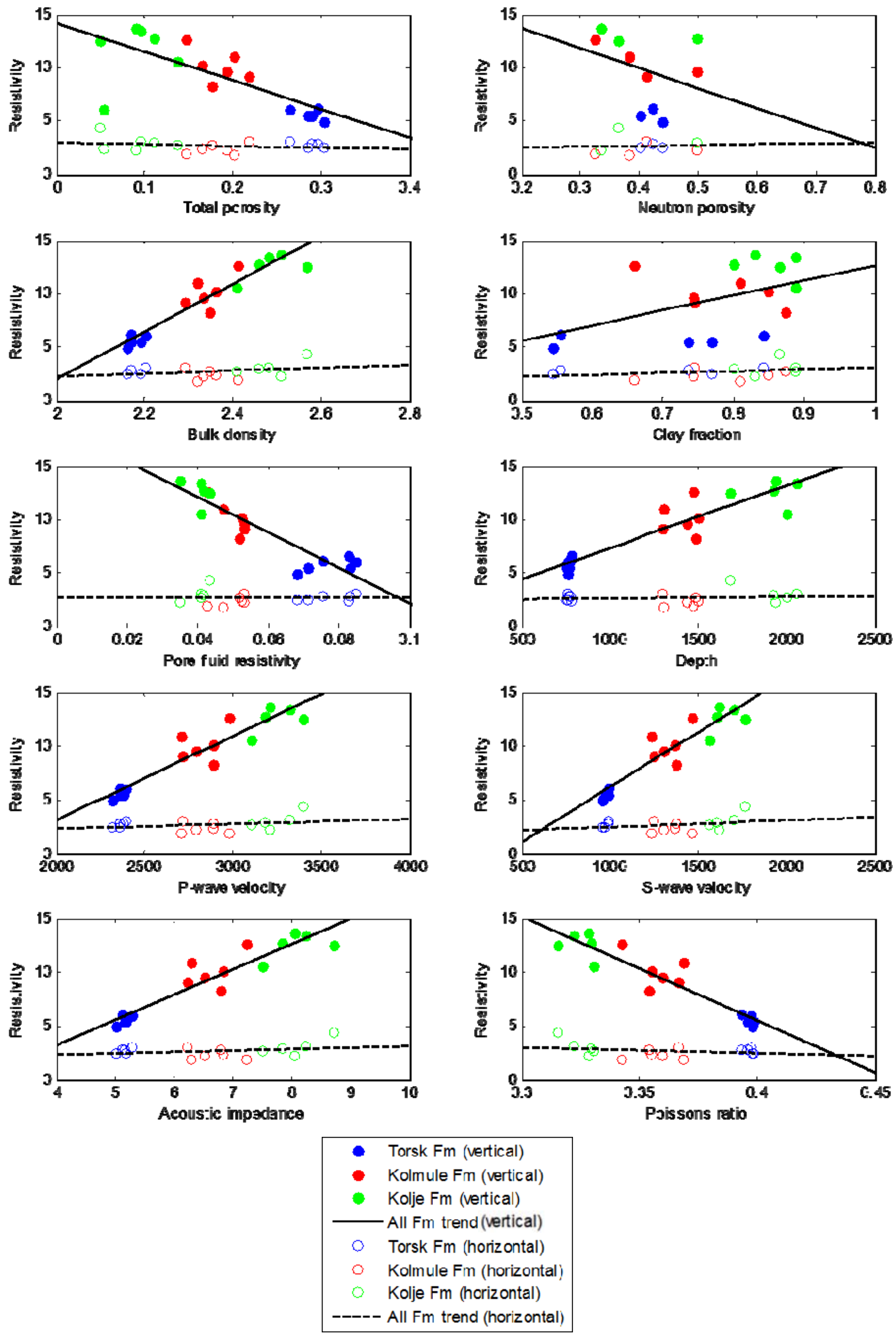

Figure 2. *Cross plots of vertical resistivity averages (solid circles) and horizontal resistivity averages (open circles) with well log data averages in the Torsk, Kolmule and Kolje formations from the Snøhvit area of the Barents Sea. Trend lines (solid black lines for the vertical resistivities and dashed black lines for the horizontal resistivities) calculated using a linear regression, R^2 values for each plot can be found in Table 1.*