Electrical anisotropy drivers in the Snøhvit region of the Barents Sea

Michelle Ellis, Lucy MacGregor, Rolf Ackermann, Paola Newton, Robert Keirstead, Alberto Rusic, Slim Bouchrara, Amanda Geck Alvarez, Yijie Zhou and Hung-Wen Tseng.*
RSI

Summary

In this study we use Controlled Source Electromagnetic (CSEM) data, well log data and rock physics to investigate electrical anisotropy drivers in the Snøhvit area of the Barents Sea. Results show that for the shale dominated sediments electrical anisotropy varies systematically with porosity, depth and elastic properties. However there is little systematic trend with clay content.

Introduction

CSEM can be used to provide higher sensitivity to hydrocarbon saturation than is possible to achieve with conventional seismic reflection data (MacGregor & Tomlinson, 2014). In CSEM's infancy anisotropy was ignored, however, 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). In order to improve our interpretation of CSEM data we need to understand what drives the anisotropy for a given rock type. The aim of rock physics is to understand the relationship between geophysical observations and the underlying physical properties of the rock (Mavko *et al.*, 2009). Physical properties include properties such as porosity, mineral composition, pore-fluid composition and sediment microstructure. By using rock physics we can start to understand the controls on electrical resistivity and anisotropy in a given area. The aim of this project is to determine the controls on electrical anisotropy in the Snohvit area of the Barents Sea and forms part of a wider study of Barents Sea electrical properties (Bouchrara *et al*, 2015). The Barents Sea was chosen as a study area because of the current interest in the area and the rich dataset which included well logs and CSEM surveys (Figure 1). Also the Barents Sea is geologically complex – stratigraphically, structurally, and historically (Gabrielsen *et al.*, 1990). One component of this complexity is the presence of strong

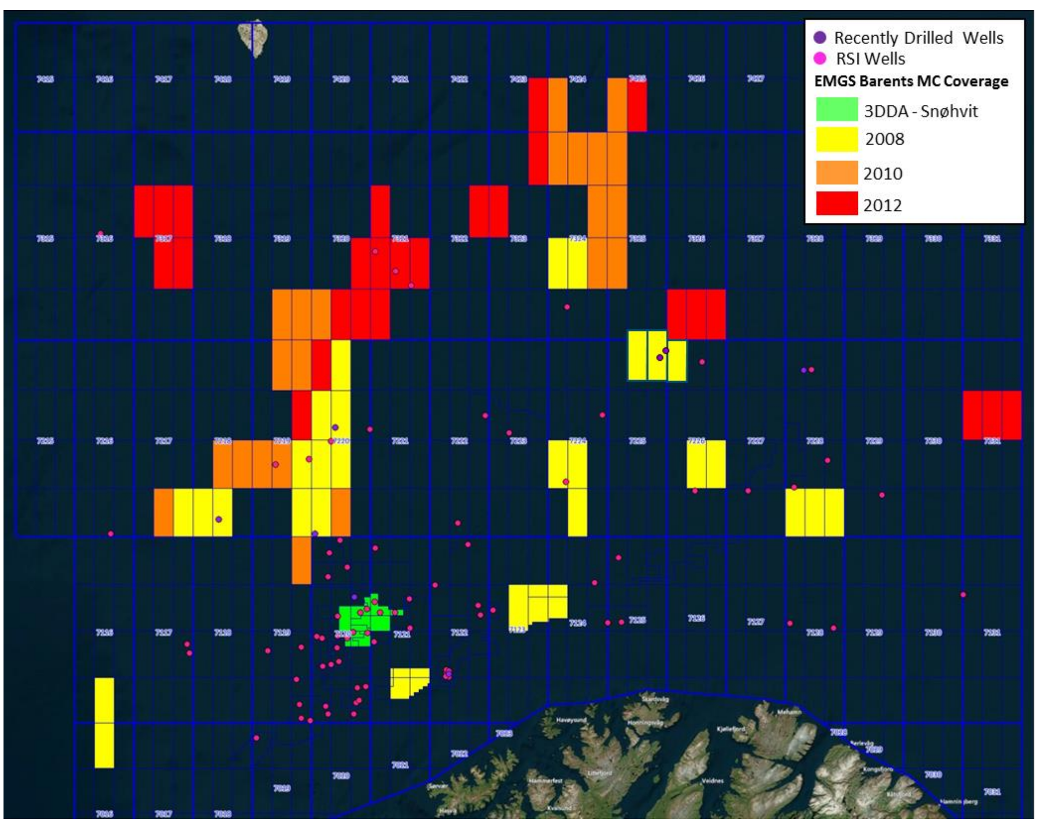

Figure 1: Map showing locations of all the exploration wells drilled in the Barents Sea (pink and purple dots) and EMGS's CSEM survey locations.

anisotropy in measured and derived electrical resistivity (Fanavoll *et al.*, 2012).

The Snohvit Area

The Snohvit area is a gas field located in the Hammerfest basin of the Barents Sea. The main reservoir is the Sto formation which is a sandstone rock with varying amounts of porosity. The overburden sediment consists of thick laterally continuous shales (Torsk, Kolmule and Kolje formations). The area is heavily faulted with both E-W and N-S trending faults which act as part of the trapping mechanism for the reservoir.

Method

In order to achieve the goals of the project we compared electrical resistivity and anisotropy derived from CSEM data with well log data from the overburden sediments of the Snøhvit region of the Barents Sea (Figure 1).

Stage 1 - Well log conditioning
In the first stage we build a comprehensive suite of conditioned well logs in the study area. 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. This builds a consistent database across the area which can be used to compare to the CSEM data.

Stage 2 – CSEM modelling
The CSEM data can be used to determine the vertical and horizontal resistivity at the well sites using a 1D

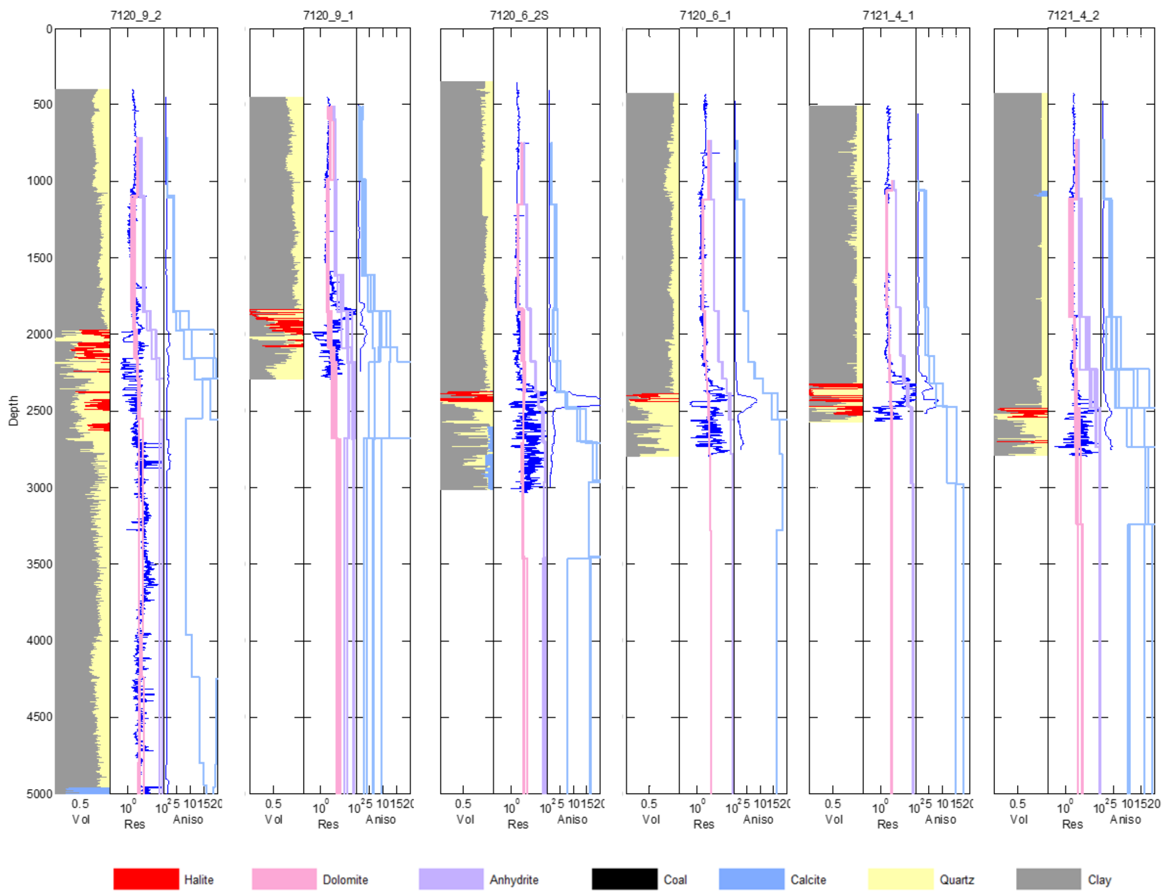

Figure 2: Six Snøhvit wells. Left – sedimentary column with reservoir highed in red. Middle – well log resistivity (thin blue line), CSEM derived horizontal resistivty (pink) and CSEM derived verstical resistivity (purple). Right – anisotropy due to thin layering (dark blue) and CSEM derived anisotropy (light blue).

DOI http://dx.doi.org/10.1190/segam2015-5919757.1

stratigraphically constrained approach (Bouchrara *et at* 2015).. A set of receivers was inverted separately around each well in the Snøhvit area of the Barents Sea to give multiple resistivity profiles (Figure 2). This gives us anisotropy profiles which could be compared to well log data to see possible trends. Averaging each of the profiles from each of the receivers gives us a single resistivity and anisotropy measurement per formation. This allows us to compare different formations separately and consistently.

Stage 3 – Trend analysis

Well log data was processed by averaging the well log data in each formation. Resistivity was averaged using a harmonic mean, elastic measurements were averaged using a Backus average, and all other measurements were averaged using an arithmetic mean. The properties averaged were acoustic impedance, neutron porosity, total porosity, effective porosity, Poisson's Ratio, resistivity, density, clay volume, depth P-wave velocity and S-wave velocity. These results were then compared to the CSEM resistivity and anisotropy results in each formation. In this analysis only formations with a thickness greater than 100 m at depths above 2500 m were included, to ensure good CSEM sensitivity to electrical parameters. In general the formations included in the analysis were the overburden shales.

Results

Figure 3 shows a subset of the trend results for the Snøhvit region and table 1 shows a summary of the correlation coeffecients (R^2) for all the different physical properties and anisotropy trends (strong trends are highlighted in green). All stratigraphic units meeting the depth and thickness criteria above are included, and so the variation represents bulk trends in the complete background section.

Results show that horizontal resistivity does not vary systematically with any of the well data types investigated when bulk properties across several stratigraphic units are considered. However the horizontal resistivities from the wells match those derived from the CSEM data well providing confidence in the results. Strong trends were seen between various well log measurements and vertical resistivity (Figure 3, Table 1). Porosity, unsurprisingly, correlates well with resistivity, but it also appears to correlate with anisotropy. As the porosity decreases the anisotropy increases. Also the elastic properties, such as p-wave velocity, also correlate strongly with the resistivity and anisotropy. Although this relationship is not causal, it indicates that there may be an underlying control affecting both parameters.

Surprisingly clay content showed a relatively low correlation with vertical resistivity and correspondingly with anisotropy. Clay content, along with sediment layering and fracturing, is often given as one of the principal causes of anisotropy. This lack of correlation may be the result of the bulk scale and multiple stratigraphic units being considered in this analysis. Also the range of clay volume values is small in this area making trends difficult to obverse.

Acknowledgments

The authors would like to thanks the sponsors of the ERA consortium project for funding and donating data to this project. The CSEM data used in the project was provided by EMGS.

Well log data type	Horizontal resistivity R^2	Vertical resistivity R^2	Anisotropy R^2
Total porosity	0.00	0.80	0.76
Neutron porosity	0.51	0.06	0.17
Bulk Density	0.07	0.70	0.73
Clay Fraction	0.14	0.24	0.20
Depth	0.12	0.77	0.74
P-wave Velocity	0.00	0.77	0.75
S-wave Velocity	0.06	0.80	0.78
Acoustic Impedance	0.08	0.78	0.78
Poisson’s Ratio	0.10	0.79	0.80

Table 1: Trend Correlation (R^2) values for from well data averages (total porosity, neutron porosity etc.) versus CSEM 1D inverse model derived average resistivity values. Green highlights indicate strong trends (R^2 >0.75).

DOI http://dx.doi.org/10.1190/segam2015-5919757.1

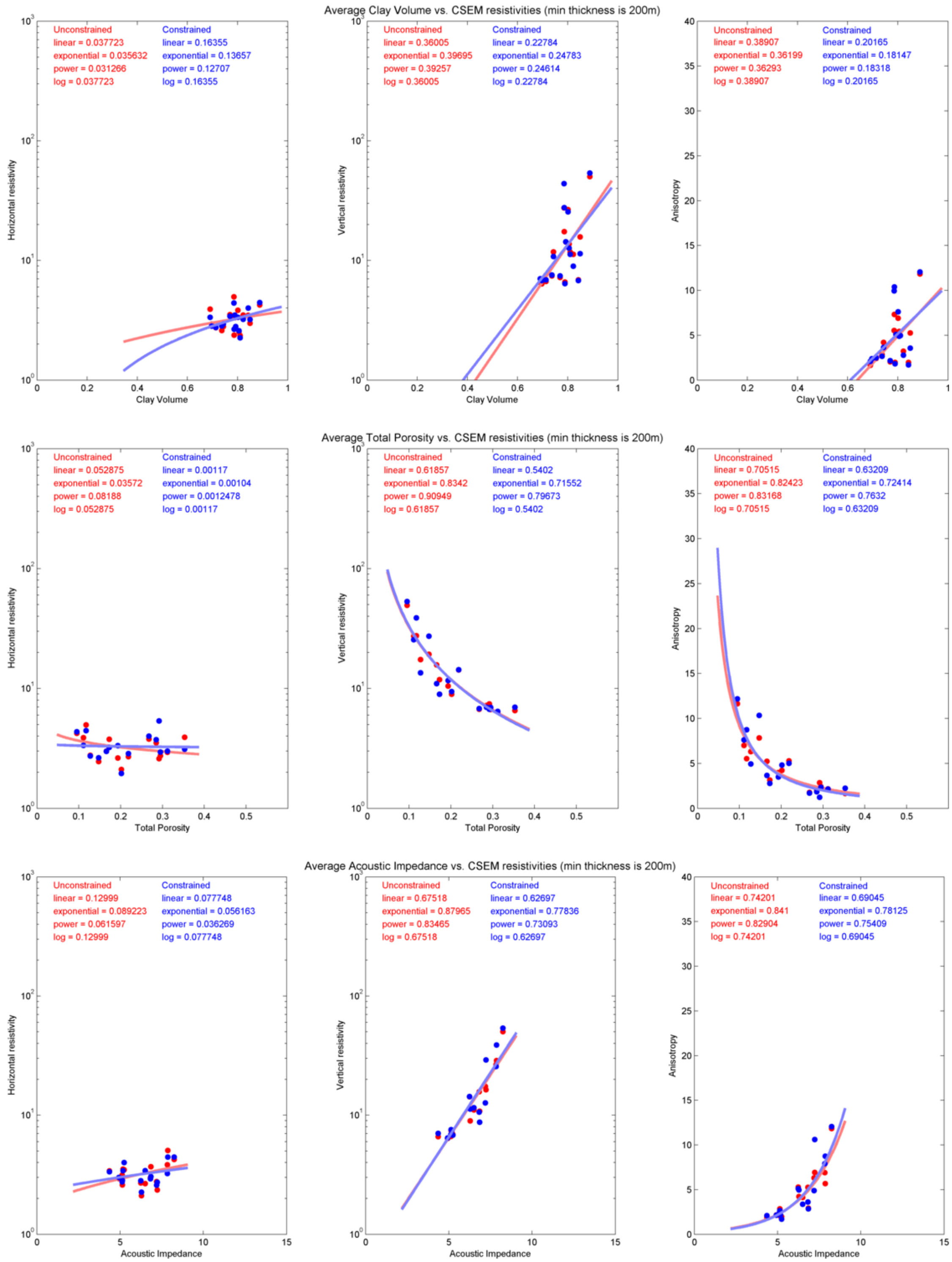

Figure 2: Comparison of unconstrained (red) inversion data and constrained inversion (blue) data for the Snøhvit overburden sediments. Trends lines shown are the best fit trend. Middle Left – porosity vs. horizontal resistivity, Middle Center - porosity vs. vertical resistivity, Middle Right – porosity vs. anisotropy. Bottom Left – acoustic impedance vs. horizontal resistivity, Bottom Center – acoustic impedance vs. vertical resistivity, Bottom Right – acoustic impedance vs. anisotropy.

DOI http://dx.doi.org/10.1190/segam2015-5919757.1

EDITED REFERENCES

Note: This reference list is a copyedited version of the reference list submitted by the author. Reference lists for the 2015 SEG Technical Program Expanded Abstracts have been copyedited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Bouchrara, S., L. MacGregor, A. Alvarez, M. Ellis, R. Ackermann, R. Keirstead, A. Rusic, Y. Zhou, and H.-W. Tseng, 2005, CSEM-based anisotropy trends in the Barents Sea: Presented at the 85th Annual Meeting, SEG.

Ellis, M., F. Ruiz, S. Nanduri, R. Keirstead, I. Azizov, M. Frenkel, and L. MacGregor, 2011, Importance of anisotropic rock physics modeling in integrated seismic and CSEM interpretation: First Break, **29**, no. 6, 87–95.

Fanavoll, S., S. Ellingsrud, P. T. Gabrielsen, R. Tharimela, and D. Ridyard, 2012, Exploration with the use of EM data in the Barents Sea: The potential and the challenges: First Break, **30**, no. 4, 89–96.

Gabrielsen, R.H., Faerseth, R.B., Jensen, L.N., Kalheim, J.E. & Riis, F., 1990, Structural elements of the Norwegian continental shelf, Part1: The Barents Sea Region, NPD-Bulletin, no. 6.

MacGregor, L., and J. Tomlinson, 2014, Marine controlled-source electromagnetic methods in the hydrocarbon industry: A tutorial on method and practice: Interpretation, **2**, no. 3, SH13–SH32. http://dx.doi.org/10.1190/INT-2013-0163.1.

Mavko, G., T. Mukerji, and J. Dvorkin, 2009, The rock physics handbook: Tools for seismic analysis in porous media: Cambridge University Press. http://dx.doi.org/10.1017/CBO9780511626753.