The performance of CSEM as a de-risking tool in oil and gas exploration

Jonny Hesthammer, Rocksource ASA & Department of Earth Science, University of Bergen, Aristofanis Stefatos, Rocksource ASA, Stein Fanavoll and Jens Danielsen, EMGS ASA.*

Introduction

During the past several years there has been an increasing focus on the use of CSEM technology for hydrocarbon exploration in marine environments (Eidesmo et al. 2002; Ellingsrud *et al*. 2002; Røsten *et al*. 2003; Hesthammer *et al*. 2005; Choo *et al*. 2006; Smit *et al*. 2006; Boulaenko *et al*. 2007; Stefatos *et al.* 2009; Hesthammer *et al*. 2010).

The impact of any new technology on exploration success can be very difficult to assess since most data are held as proprietary by the lease or licence owners. Marine controlled source electromagnetic (CSEM) data for use in hydrocarbon exploration have been acquired for nearly 10 years and more data are now available to attempt understanding the impact of this technology on drilling success rates. This study is an objective observation of statistical results of 86 wells that have been drilled on prospects and fields that contain marine CSEM data. As there are numerous parameters not known to the authors, the study constrains the focus to provide information on observed results.

The database

By mid-2009, a database consisting of more than 400 marine CSEM surveys was made available to the authors. From the combined data set, 86 wells are currently available for statistical analyses. The database contains 36 calibration surveys across existing wells. As such, 50 wells are exploration wells that have been drilled after the acquisition of marine CSEM data.

The marine CSEM database contains wells from (in alphabetical order) the Barents Sea (9 of which 2 are calibration surveys), Brazil (1 calibration survey), Ghana (1), Gulf of Mexico (7 calibration surveys), India (12, of which 2 are calibration surveys), Malaysia (3), Mediterranean (5, of which 2 are calibration surveys), North Sea (5, of which 4 are calibration surveys), Norwegian Sea (15, of which 7 are calibration surveys), Offshore Sarawak (1 calibration survey), South-China Sea (11, of which 4 are calibration surveys), Sulu Sea (1) and West-Africa (15, of which 6 are calibration surveys). A calibration survey is defined as a CSEM survey acquired across an existing discovery or dry well. These data are valuable in terms of evaluating if a normalised anomalous response can be observed over a proven discovery or dry well, but have to be disregarded for statistical evaluation of discovery rates. The distribution of surveys around the world within different basins and geological settings strengthens the validity of the statistical analysis on a global scale.

Analyses

There has been no effort to interpret any data apart from identifying a simple, observable normalised anomalous amplitude response of the electric field at the fundamental frequency. This is done to ensure consistency when comparing the different data sets, and to have a minimum of bias in the analyses. A normalised anomalous response considers the resistivity response of something anomalously resistive in the subsurface with respect to the background resistivity (Figure 1). This is simply done by identifying a receiver outside the target region which is assumed to represent the general background resistivity. This receiver is referred to as a reference receiver. During an acquisition, the source will be towed above the receivers, emitting electromagnetic energy by alternating the current between two electrodes. The current alternating frequency and signature can be varied to provide a fundamental frequency as well as numerous harmonics to the fundamental frequency of varying strengths. In this study, only the amplitude variations of the electric field for the fundamental frequency are considered for analyses. Although this is a highly simplistic approach, the purpose is to be as objective as possible when comparing results. More detailed analyses are indeed both possible and preferred, but will be the topic of future publications.

For each CSEM line, a reference receiver and an offset between the source and the reference receiver is chosen. Next, all other receivers are normalised against the reference receiver for the chosen offset and frequency and displayed in a normalised amplitude response plot (also called Normalised Magnitude versus Offset, NMVO, plot). This allows for identification of areas with an anomalous response compared to the general background trend, of which the maximum variation is referred to as the normalised anomalous amplitude response (NAR). The term NAR is used relatively loosely in this paper with the purpose of establishing a simple mean to analyse the data. A normalised response value of 1 indicates that the chosen receiver has exactly the same electric field magnitude for the chosen offset as the reference receiver. A value of 1.5 indicates that the observed receiver has a normalised response 50% higher than the reference receiver. This indicates the presence of something in the subsurface with higher resistivity than observed at the reference receiver. This could potentially be a hydrocarbon-filled reservoir or something else resistive (cemented sandstone, volcanics, organic-rich shale, carbonates, salt and more). It may also be related to aspects such as survey geometry effects, airwave effects, bathymetry effects and more.

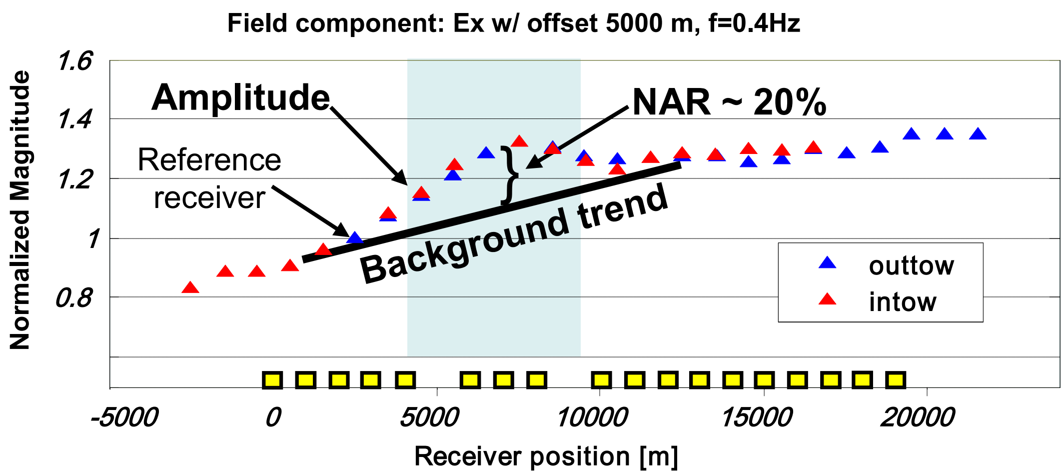

Figure 1 An example of a normalised amplitude response plot from the Barents Sea. This example shows a maximum normalised anomalous response (NAR) of around 20%.

Experience shows that when the NAR becomes less than 15%, it is commonly difficult to differentiate a clear subsurface anomaly due to lateral and vertical variations in the resistivity of non-hydrocarbon bearing subsurface formations. In this study, a NAR cut-off value of 15% has been used to separate prospects with a significant CSEM anomaly from those without a significant anomaly. Although this is again a simplified approach, it serves the purpose for this particular study by keeping the analyses at an objective level rather than the introduction of subjective interpretations.

The available database contains information of released well results drilled by a number of different oil companies. A well is considered a discovery if movable hydrocarbons were encountered in the well (with the exception of three wells which encountered only very minor amounts of hydrocarbons and which are referred to as dry in this study). No information is available on the initial chance of success (initial Pg) based on standard geological and geophysical analyses. Nor is any information available on the reasoning for drilling decision or location relative to observations from the CSEM data. As such, it is quite possible, and likely, that observations from CSEM data did not change the drilling decision or location for some wells due to existing drilling commitments and other factors. Any drilling decision that incorporated CSEM data would likely have been based on interpretation reports provided by service providers as well as the knowledge of the CSEM technology within the different oil companies. The extent of this knowledge is not known. As a result, only the most basic and conservative observations are presented in this paper to avoid any conflicting discussions.

Results

Of the 86 wells with associated CSEM data, 36 are calibration surveys collected to test the technology. Of the 22 calibration surveys acquired over existing discoveries, 19 (86%) show a NAR value above 15%. Of the 14 calibration surveys acquired over prospects that are proven dry, 13 (93%) show a NAR value less than 15%.

Perhaps of greater interest is the evaluation of success rates for wells that were drilled after the acquisition of CSEM data. Figure 2 shows the main results found through the evaluation of the current database. Of the total 86 wells drilled, 50 are listed as discoveries. When disregarding all calibration surveys, 28 out of 50 wells are discoveries. When considering wells drilled on prospects with a NAR above 15% (referred to as prospects with a significant CSEM anomaly in this study), 21 out of 30 wells are discoveries. For wells drilled on prospects with a NAR below 15% (prospects without a significant CSEM anomaly), 7 out of 20 wells are discoveries (commerciality is not known).

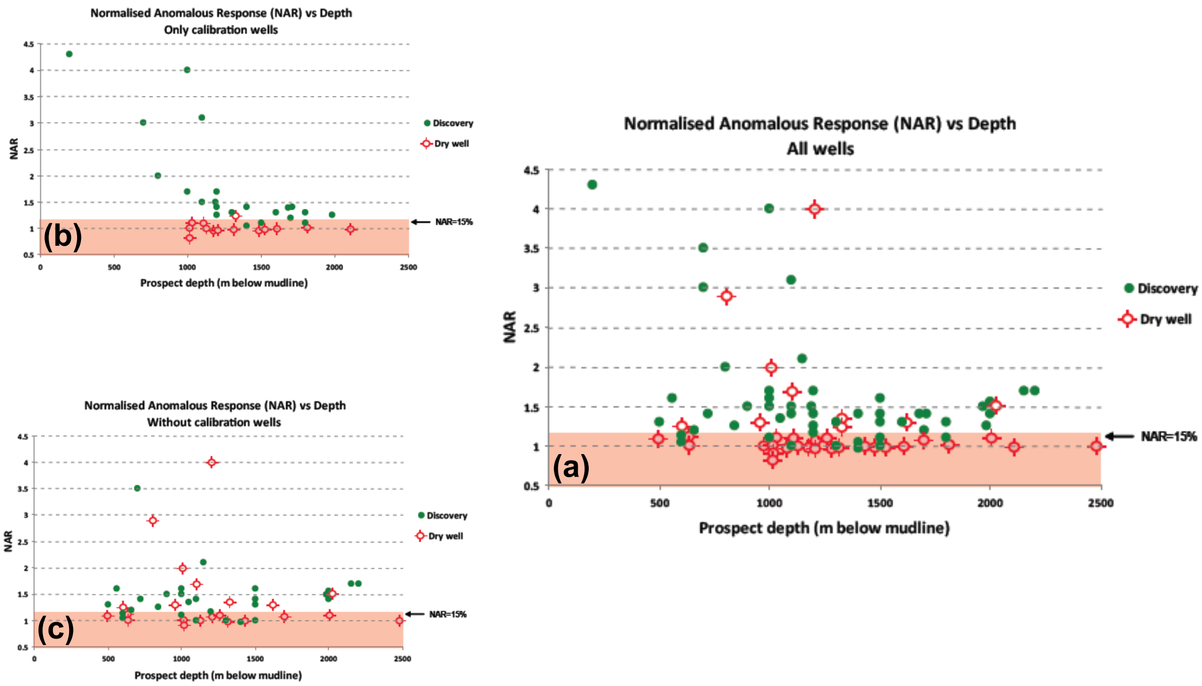

Figure 2 *The empirical data used in the current study. The observed normalised anomalous amplitude response (NAR) is plotted against the depth to prospect (below mud line).* ***(a)*** *Plot of all 86 wells* <u>*including*</u> *the 36 calibration wells.* ***(b)*** *Plot of all 36 calibration wells.* ***(c)*** *Plot of all 50 wells* <u>*excluding*</u> *the calibration wells.*

When disregarding all calibration wells, this provides an overall success rate (in terms of technical success regardless of commerciality) of 56%. For wells drilled on prospects with a significant CSEM anomaly the success rate increases to 70%, whereas it drops to 35% for wells drilled on prospects without a significant CSEM anomaly. Some of the prospects with an observed NAR below 15% may still have clear and localized CSEM anomalies above mapped prospects, while others clearly do not as numerous wells are actually drilled on prospects with no observable NAR.

When excluding all calibration wells from the study and only considering areas with at least 8 wells available for analyses, India with 10 wells shows a success rate of 50% when all prospects are included in the analyses. If only prospects with NAR values above 15% are included, the success rate is 63% (5 discoveries). Data from the West-Africa (9 wells) show an average success rate of 44% when including all prospects, but the success rate increases to 100% when only prospects with NAR values above 15% are included (3 discoveries). In the Norwegian Sea (8 wells), the overall success rate for all wells is 25% with a success rate of 40% for wells drilled on prospects with NAR values above 15% (2 discoveries).

As many as 20 of the 50 exploration wells were drilled on prospects showing a normalised anomalous response in the CSEM data equal to or less than 10%. Half (10) of these 20 wells were drilled in a location where none or even negative normalised anomalous responses were observed for the fundamental frequency. Of these 10 wells, 4 were discoveries. All 4 where classified by Johansen et al. (2008) as "hydrocarbon discoveries modelled sub-detection" which means that well data revealed hydrocarbon-filled reservoirs with properties shown by modelling to be unfavourable (too small, too deep or with too little resistivity contrast) for detection by the CSEM method.

Conclusion

The most important finding in this study is that the average success rate for wells drilled on prospects with a significant CSEM anomaly (NAR above 15%) is twice the average success rate for wells drilled on prospects without a significant CSEM anomaly (NAR less than 15%). It seems a fair conclusion that the incorporation of CSEM data into the oil company's work flow can significantly help de-risk prospects in CSEM suitable settings. The true technical potential of the technology, as illustrated by the calibration wells is even higher than the success rates achieved today on exploration wells. This study clearly illustrates that the CSEM technology does not eliminate risk, but has the potential to significantly reduce risk when applied correctly. As such, the CSEM technology serves as an important risk reduction tool in a portfolio setting where each prospect is analyzed as extensively as possible using an integrated approach where all available data are utilized.

Acknowledgement

We would like to thank all oil companies that provided the necessary information to establish this extensive database and allowing the results to be published for the benefit of the general oil and gas industry. We are furthermore grateful for contributions from and stimulating discussions with a number of employees within EMGS ASA and Rocksource ASA.

EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2010 SEG Technical Program Expanded Abstracts have been copy edited 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

Boulaenko, B., J. Hesthammer, A. Vereshagin, P. Gelting, R. Davies, and T. Wedberg, 2007, Marine CSEM technology – The Luva case: Houston Geological Society Bulletin, 23-43.

Choo, C. K., M. Rosenquist, E. Rollett, and A. Kamal, Abd.A. Ghaffar, J. Voon, and H.F. Wong, 2006, Detecting hydrocarbon reservoir with Sea bed LoggingTM in deepwater Sabah, Malaysia: SEG Technical Program Expanded Abstracts, 714-718.

Eidesmo, T., S. Ellingsrud, L. MacGregor, S. Constable, M. C. Sinha, S. Johansen, F. N. Kong, and H. Westerdahl, 2002, Sea Bed Logging (SBL), a new method for remote and direct identification of hydrocarbon filled layers in deepwater areas: First Break, **20**, 144–152.

Ellingsrud, S., M. C. Sinha, S. Constable, T. Eidesmo, L. MacGregor, and S. Johansen, 2002, The Meter Reader—Remote sensing of hydrocarbon layers by sea bed logging (SBL): Results from a cruise offshore West-Africa: The Leading Edge, **21**, 972–982. doi:10.1190/1.1518433

Hesthammer, J., and M. Boulaenko, 2005, The offshore EM challenge: First Break, **23**, 59–66.

Hesthammer, J., S. Fanavoll, A. Stefatos, J. E. Danielsen, and M. Boulaenko, 2010, CSEM performance in light of well results: The Leading Edge, **29**, no. 1, 258–264.

Johansen, S., K. Brauti, S. Fanavoll, H. E. F. Amundsen, T. A. Wicklund, J. Danielsen, P. Gabrielsen, L. Lorentz, M. Frenkel, B. Dubois, O. Christensen, K. Elshaug, and S. A. Karlsen, 2008, How EM survey analysis validates current technology, processing and interpretation methodology: First Break, **26**, 83–88.

Røsten, T., S. E. Johnstad, S. Ellingsrud, H. E. F. Amundsen, S. Johansen, and I. Brevik, 2003, A Sea Bed Logging (SBL) calibration survey over the Ormen Lange gas field: 65th Conference and Exhibition, EAGE, P058.

Smit, D., S. Saleh, J. Voon, M. Costello, and J. Moser, 2006, Recent Controlled Source EM Results Show Positive Impact on Exploration at Shell: New Orleans 2006 Annual International Meeting, SEG, Expanded Absrtacts.

Stefatos, A., M. Boulaenko, and J. Hesthammer, 2009, Marine CSEM technology performance in hydrocarbon exploration - limitations or opportunities?: First Break, **27**, 65–71.