False negatives and positives in the interpretation of EM data

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Summary

When acquiring EM data, there is always a risk that the EM results are not fully in accordance with the results of a subsequently drilled well. These cases are commonly denoted as 'false negatives', a discovery which is not detected by EM, and 'false positives', a dry well drilled at the location of an EM anomaly. In the statistical database comprising 87 wells where EM data is available, 11 wells fall into each of these categories. It is quite natural that such cases cause skepticism in the industry, especially in the part where knowledge and skills in the use of EM data is low.
However, when looking into the facts behind these cases, it can be shown that there is no evidence that significant discoveries can be left behind after use of EM data. Regarding the false positive examples, it is evident that the risk of drilling a dry well is still present, even when there is a significant EM anomaly.
In conclusion, the full value of EM, as with any other geophysical method, can only be obtained by an improved understanding of the nature of the measurements, through thorough geological work and integration with other geophysical information and through understanding of the uncertainties which allows the method being part of the decision process.

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, Hesthammer et al. 2005, Smit et al. 2006).
However, the adoption of the technology has been slower than initially anticipated, and the value of the new information is subject to discussion. In a recent paper (Hesthammer et al. 2010), it is demonstrated that use of CSEM data has the potential of significantly increasing the discovery rate for new wells. The database for this work consisted of 86 wells of which some are drilled before an EM survey (calibration) and some after, including both dry wells and discoveries. An earlier paper (Johansen et al. 2008) evaluating around 50 wells concludes that it is in fact possible in more than 90% of the cases to explain the EM results in light of what is encountered by the well.
In this paper we will focus on the most disputed cases; where the EM results apparently do not reflect the drilling result, often denoted as 'False Negatives' and 'False Positives'. In the above mentioned database, there are 9 'False Negatives', and 11 'False Positives' (Table 1 and Table 2).

Definitions

As demonstrated in the earlier paper by Hesthammer et al., 2010, a normalized EM response (the response of a receiver divided by a reference) of more than 15% over a prospect is a reasonable threshold value to differentiate a prospect with a significant resistive anomaly from non-significant background related resistivity variations. Following this simplistic approach of CSEM data evaluation we adopt the following definitions:
False Negative: The EM data show a normalized response less than 1.15, while the well is rated as a discovery
False Positive: The EM data show a normalized response higher than 1.15, while the well is rated as dry
Discovery: A well that encounters moveable hydrocarbons, regardless of volume or economic value

Database

Out of the total database of 87 wells, 11 wells fall in the 'False Negative' category, while 11 wells fall into the 'False Positive' category (Table 1 and -2). For the false negatives, there was made an effort to categorize the discoveries into commercial and non-commercial discoveries, as this will influence the evaluation of the results.

#	Area	Year of survey	Year of well	WD	Burial Depth	NAR
1	Africa	2005		300	1400	1
2	Africa	2006	2006	300	1000	1.1
3	Africa	2007		1300	1500	1.1
4	Africa	2004	2005	2500	1300	1
5	Asia	2006		1700	1500	1
6	Norway	2003	1997	1250	1800	1.1
7	Norway	2004/2008	2008	300	600	1.05
8	Norway	2004/2008	2008	300	600	1.1
9	Norway	2005	2008	270	1100	1
10	Norway	2003	2003	1200	1300	1
11	Norway	2009		375	1	1.05

Table 1 List of discoveries with Normalized Anomalous Response (NAR) less than 1.15

#	Area	Year of survey	Year of well	WD	Burial Depth	NAR
1	India	2006	2006	1200	1600	1.3
2	India	2007	2008	2000	2000	1.5
3	India	2006	2007	2300	1200	4
4	Malaysia	2006	2006	1500	600	1.2
5	Malaysia	2009	Pre-survey	90	1300	1.25
6	Malaysia	2006	2007	1350	950	1.3
7	Norway	2006	2009	300	1300	1.3
8	Norway	2005	2006	300	1100	1.7
9	Norway	2003	2006	1700	1000	2
19	Norway	2005	1986	300	700	3.5
11	Philippines	2006	2008	150	800	2.9

Table 2 List of dry wells with Normalized Anomalous Response (NAR) larger than 1.15

Results

When treating EM data, it is utterly important to include geologic knowledge in order to understand and interpret the results. This is also valid in the planning phase, when a proper pre-study can help avoiding running surveys over non-feasible targets. When doing a thorough study of the 'False Negative' examples, they tend to fall into two categories: non- commercial and non-feasible cases, the latter in general due to limited size. In most cases the non-feasible cases can be sorted out in a feasibility study, if this is (can be) carried out properly. "Non-commercial" means that the discovery was smaller than expected or hoped. CSEM data carry information about the commerciality of a hydrocarbon filled prospect, since the electric resistivity response is related to the volume of the target and its saturation level. It is therefore possible that a CSEM survey sensitive to the maximum size of a potential discovery is t not necessarily sensitive to its minimum size. Similarly CSEM will often be unable to distinguish a water saturated reservoir from e.g. a low gas saturated reservoir. It should therefore be expected that discovery wells will be drilled over prospects which have no EM response or small response which complicates interpretation. In that sense CSEM is less suitable in differentiating between dry and non-commercial discovery wells, as it is question of not only the presence of the resistive fluid phase, but also its volume. This may turn out to be an advantage as CSEM is complimentary to seismic in that respect.

The disputed cases are often of this type: a well is announced a discovery, but the EM data did not show any significant responses. The explanation is that either the Earth model used in the feasibility study was unrepresentative, or the volumes encountered are smaller than anticipated. The latter, although sometimes hard to accept, is an acceptable result from a technical point of view, as the value of the information is often higher than the survey cost, and the survey data in fact explains the result of the well. The former is technically more serious, as the value of the information is lower, and the data set cannot be relied on for a business decision. Even with improved feasibility studies, it is not always possible to eliminate the risk of an indecisive survey.

For the ‘False Positive’ cases, the picture is more complex. Most often these occur due to misinterpretation of a complex background, e.g. there are other than hydrocarbon resistors in place. Processing-wise, they are often easier than the false-negatives, since there is an anomalous response to work with, but they can be very misleading showing significant anomalies. In order to solve these cases, a high degree of geologic understanding is necessary; scenarios not containing hydrocarbons must be considered and evaluated. Even then, in some cases, the target has to be tested by drilling due to the uncertainty in the interpretation.

Examples

In 2007, a well was drilled on the Norwegian continental shelf, which was reported to be a discovery. Rumors said that there was a hydrocarbon column of several hundred meters. However, an EM line run over the prospect prior to drilling did not show significant responses over the prospect, leading to the assumption that “EM doesn’t work” in the area. Two years after drilling, the well data was made public and the discovery turned out to be a series of thin (1-2 m) layers totaling 10-12 m over the entire column of 700 meters. Later, the discovery was declared non-commercial as a standalone by the operator. A 3D CSEM survey run over the discovery in 2008 supported the original evaluation of a non-significant EM response (Figure 1). Inversion of CSEM data was not available when the pre-well dataset was evaluated, but subsequent inversion of the modern 3D data indeed demonstrates the ability to identify the minor amounts of hydrocarbons present. This represents the evolution of data and processing quality from 2006 to 2009.

On an EM survey in India, there was observed a huge response along the survey line (Figure 2). However, seismic data indicated that there was no clear connection between mapped targets and the location of the anomaly. Subsequent post-survey modeling revealed that this could be caused by a high resistive carbonate layer (Engenes et al., 2008). Drilling of the anomaly confirmed the modeled result. Even though false positives can be sorted out pre drilling as shown in this example, there may be arguments for drilling the target nevertheless.

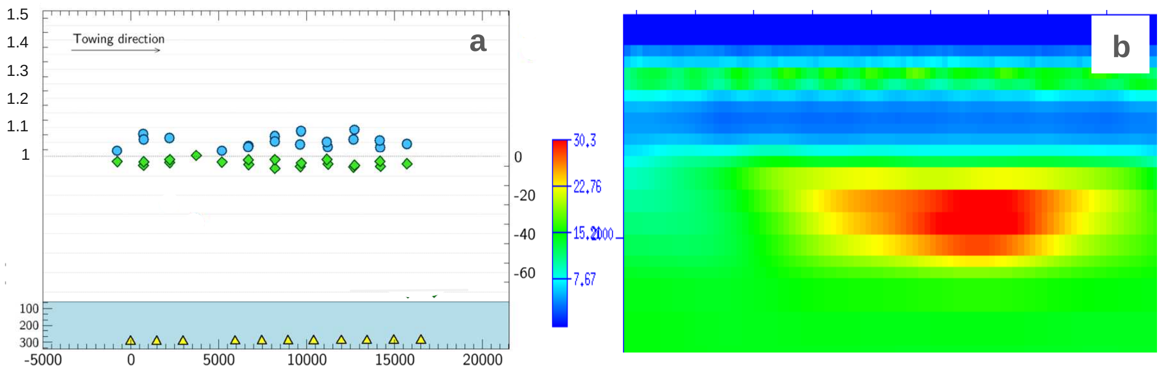

Figure 1: a) Normalised Magnitude response along a line over a discovery in Norwegian waters. Only very small responses are seen, even with the high frequency (3 Hz) used in this example. Blue circles are Normalised Magnitude, green diamonds are Phase Difference. On the inversion image (b), the anomaly is clearly seen, even though very low saturations or reservoir thicknesses are needed in order to detect the anomaly.

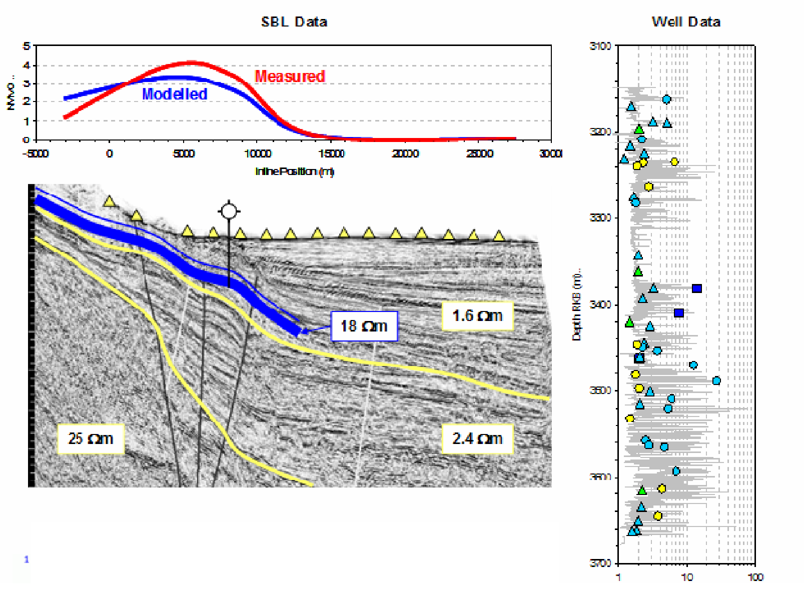

Figure 2: Measured and modelled response along an EM line in India. Due to an apparent mismatch between the observed anomaly and mapped targets, the line was modelled with a shallow, high resistive carbonate layer, which gave a comparable result to the observed anomaly. Subsequent drilling confirmed this model (from: Engenes et al., 2008).

Conclusions

After thorough analysis of the ''False Negative' and 'False Positive' cases, the following conclusions can be drawn:

- There is no evidence that large hydrocarbon volumes can be overlooked by CSEM measurements
- The application of CSEM over small hydrocarbon volumes can be correctly decided through proper feasibility studies
- Geologic control is essential in order to understand responses caused by the background geology and avoid false positive interpretations
- CSEM as any geophysical method, it will always be limited by the interpreter's ability to arrive at a representative model. Data must be thoroughly analyzed and fully understood in order to take out the full potential.
- The uncertainties related to the CSEM data should be treated as any other geophysical data uncertainty and evaluated in the decision process.

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.

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