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Value creation using electromagnetic imaging

Recent advances in controlled source EM have created new business opportunities by changing the risk equation in offshore exploration drilling.

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In recent years, electromagnetic (EM) imaging has emerged as a promising technology to reduce exploration risk in marine environments. Major oil companies such as ExxonMobil, Statoil and Shell have been highly visible as early adopters. Forward-thinking national oil companies such as Pemex, Petrobras and Petronas have also used EM methods to improve exploration success rates. EM imaging is also attracting a lot of interest in areas of environmental sensitivity, where permits to acquire seismic data are not always easy to obtain. This article will take a closer look at how the EM method can be used to increase the expected value of an oil company's portfolio.

THE EM IMAGING METHOD

Hydrocarbon reservoirs typically exhibit higher electromagnetic resistivity than their surroundings. Controlled-source electromagnetic (CSEM) technology and associated EM imaging have been used for almost 10 years to measure subsurface resistivity related to marine hydrocarbon exploration.[1,2] Of course, an indication of high resistivity is not sufficient to ensure the presence of oil or gas. There are many other geological features that can display high resistivity, including salt, volcanics, carbonates and fresh water. Consequently, CSEM data must be interpreted only as part of an integrated effort to determine the most probable subsurface model based on analyses of all available data including EM data, seismic data, well data and regional geologic knowledge. Carefully integrated interpretation can significantly increase the probability of correct identification of the pore fluid: oil, gas or water.

Figure 1 shows an example from West Africa where five prospects (red, blue, yellow, orange and green) have been mapped from seismic data. The depositional environment is that of deepwater fan systems, and all prospects represent stratigraphic traps. Without any additional information, it is not possible to tell if any of the prospects are associated with hydrocarbons, and the chance of drilling a discovery well is relatively low due to the high risk typically associated with stratigraphic traps. However, subsequent acquisition of CSEM data and integrated analysis suggested that two of the seismically mapped channel systems contain hydrocarbons. The interpretation was later confirmed by a discovery well that targeted the red prospect, proving up gas reserves likely to exceed 1 Tcf.

Figure 2 shows another case example from West Africa. In this case, a structural trap associated with a deep marine prospect had been identified from seismic data. A structural trap is commonly associated with less risk than stratigraphic traps. However, subsequent integrated analysis of both seismic and CSEM data revealed no anomalous resistivity response at the location of the target. Since the target is located well within the EM window with respect to depth and size, the lack of a significant response suggests that there are not significant amounts of hydrocarbons present.[3] This interpretation was proven correct by the later drilling of a dry exploration well.

EM technology, like seismic, is an imperfect tool, but the statistics are impressive. EM data have been shown to be highly accurate in identifying subsurface resistivity variations,[1,4] and although interpretation errors must be considered, the commercial exploration drilling success rate is 50–70% for exploration wells drilled on prospects with a significant EM anomaly, compared to 5–14% for wells drilled on prospects without a significant EM anomaly.[3,4] Advances in data acquisition and imaging methods, together with

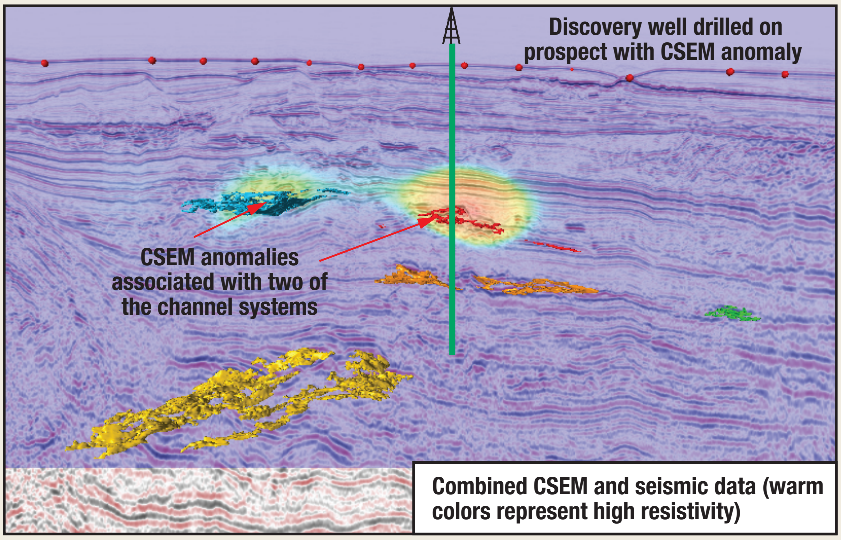

Fig. 1. Integrated analysis of CSEM data suggested that two of the seismically mapped channel systems (red and blue) contained hydrocarbons. The interpretation was later confirmed by the drilling of a discovery well.

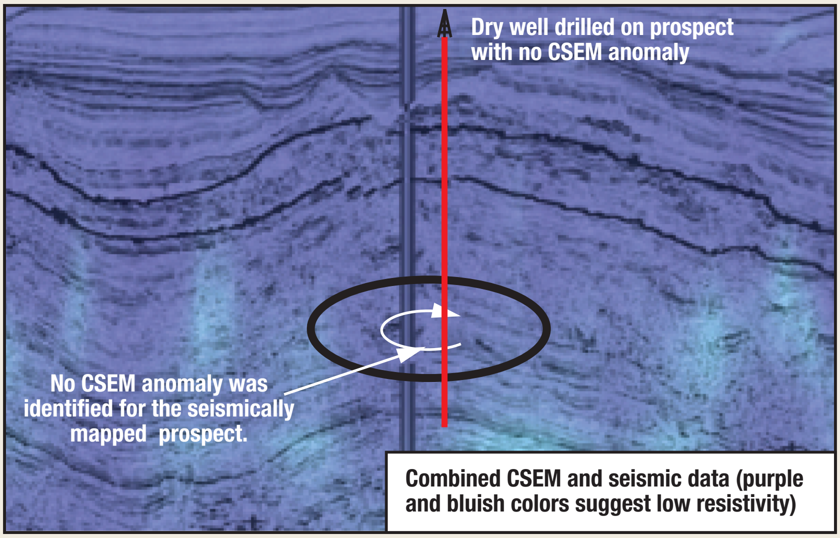

Fig. 2. A well was drilled through a prospect in spite of a CSEM survey that showed no significant resistivity at the location. The well encountered no hydrocarbons.

improving integrated analysis methods, can be expected to further reduce the rate of occurrence of false positives and false negatives due to noise and artifacts. It should be noted that false positives are usually the result of non-hydrocarbon-related subsurface resistive anomalies, but false negatives are now quite rare for prospects tested in EM-suitable settings.

EXPECTED VALUE: COIN FLIP

Expected value is a well-known concept allowing the application of statistics to make effective business decisions. Imagine a game where a coin is flipped, and you receive $10 if the result is heads, and $2 if the result is tails. There is a 50% chance of winning $10, and a 50% chance to win $2. The expected value of each coin flip is the sum of all the probability-weighted outcomes, or:

(50% x $10) + (50% x $2)
= $5 + $1 = $6

Thus, if the price to play the game is less than $6, it would be a good business decision to take part. If more than $6, it would be best not to play. Note that in the real world, as the numbers get bigger, concepts such as cost of capital and risk tolerance become significant factors. For simplicity, in the analysis that follows, we will ignore these complications.

It is also interesting to note that for any one instance of the game, the "expected value" does not need to be a possible outcome. It is only when applied to a large portfolio of games that the overall portfolio performance will tend to look increasingly like the expected value.

Expected value without 3D EM. Drilling a well often has some similar statistical probabilities to a coin flip. Imagine a prospect similar to those shown earlier. The potential volume of hydrocarbons (with associated uncertainties) within a mapped reservoir can be estimated from the analyses of seismic data and nearby well data. The final element in estimating the value of success is to assign a value for each barrel of recoverable oil. For a small prospect, this might be as little as $200 million. The value of failure is simply the cost of the dry hole. Let's assume a dry hole cost of $40 million.

Sadly, the probability of geologic success (P_g) is often much lower than a coin flip. In some parts of the Gulf of Mexico, where low saturation gas often produces strong seismic amplitude anomalies, P_g can be as low as 15%. So what is the expected value of this prospect if we drill?

Expected value
= (P_g x value of success)
+ ((1 – P_g) x cost of failure))
= (15% x ($200M – $40M))
+ (85% x (–$40M))
= $24M – $32M = –$8M

This prospect has a negative expected value. The correct business decision is not to drill this prospect (an expected value of $0).

Expected value with 3D EM. There are two clear potential benefits of applying EM technology. One is to avoid drilling dry wells (on prospects without any EM anomaly). Another is to drill discoveries (on prospects with an EM anomaly). Both will, of course, be associated with uncertainties, as EM data do not represent perfect information. One risk is that a well is not drilled (because no EM anomaly is observed) although there are hydrocarbons within the mapped prospect (a false negative). Another risk is that a dry well is drilled on a prospect that displays an EM anomaly (a false positive).

Assuming that hydrocarbons are present, an EM anomaly may be observed (true positive) or not (false negative). Similarly, assuming that hydrocarbons are not present, an EM anomaly may be observed (false positive) or not (true negative). Of course, prior to drilling, the answer remains unknown, and the analyses must address the uncertainties associated with the interpretation. One way of approaching this is to apply Bayes' theorem and quantify the (positive) reliability for true positive and false negative and the (negative) reliability for false positive and true negative. In the following, we will assume that these two reliabilities have the same value. (Software tools are available to explore different values for the reliabilities.)

Let's assume the survey costs $2 million. If we use 3D EM, the value of success is reduced by the cost of the EM survey, and the cost of failure is increased by the cost of the EM survey. We will assume both a positive and negative reliability R of 75% (50% reliability equals a coin flip and 100% reliability equals perfect information; i.e., the answer is known). This 75% reliability assumption is quite conservative considering the empirical results so far from the investigation of 50 exploration wells drilled on prospects where EM data have been acquired.[3–5]

Assuming that a well is drilled if (and only if) we see a resistive anomaly in our EM data, we now have four possible outcomes to consider, as represented in Table 1.

Plugging in all the numbers from the table, we now have an expected value of:

(11.25% x $158M)
+ (3.75% x –$2M)
+ (63.75% x –$2M)
+ (21.25% x –$42M)
= $7.5M (with EM)

So, even though EM data represent imperfect information (as all geophysical data do), the application of EM in this particular case reduces risk sufficiently to make an initially non-commercial prospect worthy of further work. This is because the EM data and associated analyses can be expected to change the probability of success for the relevant prospect, and thus change the risked value and risked cost. For a portfolio containing many such prospects, significant value can be created by the systematic application of EM.

As mentioned earlier, a more rigorous analysis would consider cost of capital and risk tolerance. There are also other aspects that should be considered. For one, there may be some value even in a dry hole, particularly in frontier basins. Logs acquired may be used to build additional regional geologic understanding. Furthermore, EM surveys can provide useful quantitative information to delineate the reservoir and improve the estimation of fluid type and saturation. Thus, additional value may be created by more accurate knowledge of the value of reserves obtained through integrated analysis of the EM data. Finally, for large fields, the more accurate knowledge of the distribution of fluids provided by 3D EM could lead to a more efficient appraisal drilling program.

EM IN A PORTFOLIO SETTING

Most oil companies maintain a portfolio of drilling candidates and high-grade the opportunities, drilling the prospects with the highest expected value first, if possible. Figure 3a shows a portfolio risked in the traditional manner (initial chance of success, P_g, established through evaluation of key risk parameters such as presence of reservoir, trap, source, seal and migration), with the prospects having the highest probability of success being the most likely to be drilled. This strategy may be modulated based on the expected reserves. In Fig. 3b, EM is applied to the same portfolio, resulting in an asymmetric bimodal distribution with a small group of high-probability prospects and a larger group of low-probability prospects. By adopting a strategy of drilling only the EM positives in the portfolio, current empirical data suggest that the drilling success rate can be increased significantly.[3–5]

In Fig. 3, a portfolio of 35 prospects is presented. Assuming that all prospects exhibit the same economics described above (which would, of course, be a strong oversimplification), an investment of $70 million in 3D EM should result in two to three additional discoveries having a total value of $400 million to $600 million in additional recoverable reserves.

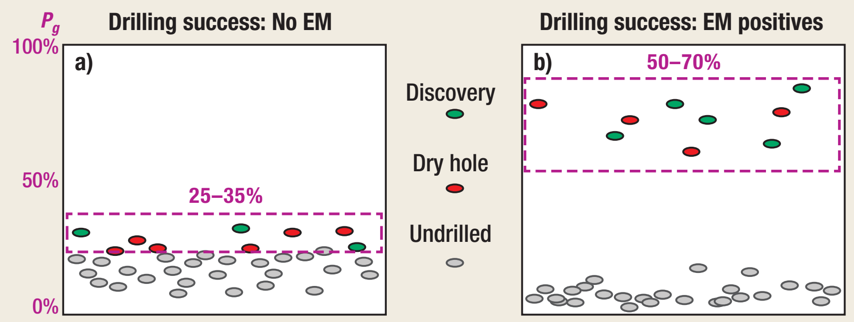

Fig. 3. Systematic application of EM reduces (but does not eliminate) prospect risk, creating significant portfolio value. The y-axis displays chance of success while the x-axis represents size of prospect.

TABLE 1. Possible value outcomes of an EM survey

Hydrocarbons	EM anomaly	EM result	Probability	Value
Exist	Yes	True positive	$P_g \times R$	Reserves – (Well + EM)
Exist	No	False negative	$P_g \times (1 - R)$	–EM
Do not exist	No	True negative	$(1 - P_g) \times R$	–EM
Do not exist	Yes	False positive	$(1 - P_g) \times (1 - R)$	– (Well + EM)

CONCLUSIONS

A study of 86 wells has demonstrated that prospects showing a significant resistive anomaly are roughly twice as likely to contain hydrocarbons, when compared to prospects that do not exhibit a significant resistive anomaly.[4] Furthermore, discoveries associated with a significant resistivity anomaly are several times more likely to be commercial than discoveries without an associated significant EM anomaly.[3]

A recent paper concluded, based on an internal Statoil evaluation, that “conservative estimates of the economical value of CSEM data can be more than 10 times above the typical costs for a CSEM survey.”[5] However, EM will not be effective in all geologic settings, and should only be applied in areas where it is likely to be reliable. In these areas, the best business decisions are made when EM data is interpreted in the context of all available subsurface data.

The careful, systematic application of EM using rigorous risk evaluation methods can enhance portfolio value significantly. The CSEM technology can increase exploration efficiency by allowing more prospects to be evaluated for less money and by ensuring that the best prospects are drilled first.

EM is a relatively new technology for marine exploration, and much work remains to be done in the development of workflows to make the best use of the data in business decisions. Furthermore, as the technology improves over the coming years, workflows will need to adapt continuously to extract the greatest possible value from EM data. **WO**

LITERATURE CITED

1 Johansen, S. et al., “How EM survey analysis validates current technology, processing and interpretation methodology,” *First Break*, June 2008, pp. 83–88.
2 Boulaenko, B. et al., “Marine CSEM technology: The Luva case,” *Houston Geological Society Bulletin*, December 2007, pp. 23–43.
3 Fanavoll, S., Hesthammer, J., Danielsen, J. and A. Stefatos, “Controlled source electromagnetic technology and hydrocarbon exploration efficiency,” *First Break*, May 2010, pp. 61–69.
4 Hesthammer, J., Fanavoll, S., Stefatos, A., Danielsen, J. E. and M. Boulaenko, “CSEM performance in light of well results,” *The Leading Edge*, January 2010, pp. 258–264.
5 Buland, A., Loseth, L. O. and T. Rosten, “The value of CSEM data in exploration,” Paper C006 presented at the 72nd EAGE Conference and Exhibition incorporating SPE EUROPEC, Barcelona, June 14–17, 2010.

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Dave Ridyard earned a degree in applied physics in 1980 from Durham University in the UK. He then joined Geophysical Service Inc., where he worked with 3D marine seismic. In 1989 he founded QC Tools to deliver quality control solutions to the seismic exploration industry. The company was sold to Input/Output (now ION) in 1994. He left Input/Output to join EMGS Americas, based in Houston, in late 2005, and currently serves as President.

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