# Prospectivity evaluation with 3D CSEM

**Daniel Baltar[1*] and Neville D. Barker[1] describe a method to update a prospect's existing evaluation with 3D Controlled Source Electromagnetic (CSEM) data.**

Evaluation of the prospectivity potential of hydrocarbon exploration ventures is a process of integration. Information provided by different technologies needs to be integrated into a single evaluation. This paper details a method for embedding the additional information provided by 3D Controlled Source Electromagnetic (CSEM) surveys into existing (or independently generated) prospect evaluations. Workflows are designed to leverage the primary value of the CSEM information in exploration (sensitivity to hydrocarbon volume), while minimizing the disruption and potential increase in risk associated with the adoption of a new technology. This is achieved through a focus on maintaining the independence of information sources and visibility of measurement uncertainties, along with adoption of standard performance-tracking methodologies.

Previously-described workflows for embedding CSEM information in a prospect evaluation process (e.g., Buland et al., 2011; Baltar and Roth, 2013) focus either on updates to the Probability of Success (PoS), or volume assessment. In contrast, we show that the nature of the information provided by CSEM is more suited to a coupled reassessment of both risk and volumes. This generates a more robust update not prone to the shortcomings associated with existing stand-alone approaches.

Workflows are illustrated with the use of realistic synthetic examples; a published prediction using the methodology is also reviewed in light of recent drilling results. When applied systematically across a CSEM-sensitive portfolio, the new information provided by 3D CSEM has the effect of polarising existing evaluations, making CSEM a valuable tool in exploration venture evaluation.

## Assessment format

As an example, we consider existing volume assessments derived from six parameters, represented by probability distributions: area, net thickness, porosity, hydrocarbon saturation, recovery factor and formation volume factor.

The updating of PoS with CSEM information is a process suited to the Bayesian approach, which indicates the change in a prior evaluation when new information is added (Buland et al., 2011). Given the volumetric component of CSEM detection, it is preferable that PoS is defined relative to the predicted volumes. Here, we consider PoS to be the probability of finding an amount of hydrocarbons between the P99 (1st percentile) and P01 (99th percentile) of the volume distribution.

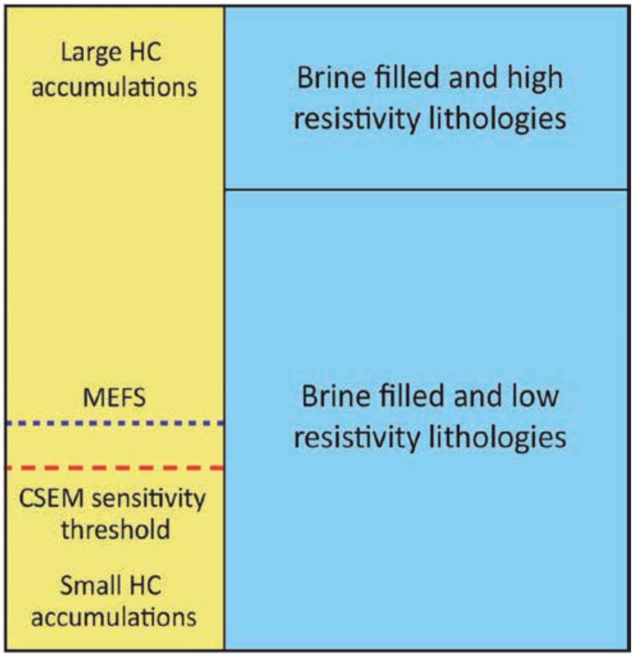


***Figure 1** Graphic representation of a prospect evaluation without the inclusion of CSEM information. Blue region: brine outcomes (some with high resistivity; some with low resistivity). Yellow region: hydrocarbon (HC) outcomes, ranging from small to large accumulations. The Minimum Economic Field Size (MEFS) and CSEM sensitivity threshold to hydrocarbon outcomes are simplified as dashed volume lines. From this arrangement, PoS corresponds to the area of the yellow region divided by the total area; the Probability of Economic Success, Pe = PoS * P(Recoverable volume > MEFS) is the area of the yellow region above the MEFS line, again relative to the total area.*

Schematically, we can represent this initial evaluation as in Figure 1.

## CSEM-embedding workflows

Three related workflows are described:

1. The 'EM Negative' workflow is used to assess the range of the original volume distribution and PoS that is consistent with a negative CSEM survey outcome (the case where no resistive anomaly is identified to be associated with the prospect)
2. The 'EM Positive' workflow is used to assess the total range of the original volume distribution and PoS that

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is consistent with a positive CSEM survey outcome (the case where a resistive anomaly is identified to be associated with the prospect).

For a schematic representation of these two workflows see Figure 2(a). Both of the above are tightly linked to the assessment of CSEM data sensitivity. During survey planning, they can be used to assess the value of the CSEM information for the targeted prospect.

3. The 'Constrained EM Positive' workflow is used to assess the volume distribution, and corresponding PoS, that are compatible with a specific CSEM-identified resistor.

The resistor in workflow 3 is typically a subset of the total EM Positive range, as illustrated in Figure 2(b). This workflow, along with the EM Negative workflow in the case of non-detection, are therefore the preferred choice once results are available from the CSEM survey.

## CSEM sensitivity

The ability of CSEM to detect a hydrocarbon accumulation depends not only on the presence of hydrocarbons in the reservoir, but also on the size of the accumulation, and the surrounding resistivity structure. More specifically, the dominant parameters that determine the strength of the CSEM response are the Anomalous Transverse Resistance (ATR = $\Delta Z \Delta R$, Figure 3) and the area of the accumulation.

CSEM sensitivity can be assessed with appropriate synthetic modelling, combined with an understanding of environmental factors, and equipment and imaging performance characteristics (Mittet and Morten, 2012 and applied e.g. in Barker et al., 2012). For the purposes of evaluating a specific prospect, the key sensitivity assessment is a cross-plot of ATR and target area, as illustrated in Figure 4. Detectability is established using a sensitivity threshold, which divides the ATR and target area domain into detectable and undetectable regions. Factors not included in this assessment which affect the ability to reliably recover or interpret a target resistor include dataset quality, and background complexity and uncertainty. In Figure 4, these can be thought of as affecting the level of sensitivity below which we would not expect a resistor to be reliably identified from the data. Performance tracking can be used to improve our estimates of this threshold level.

## Updating volumetric assessments with information from 3D CSEM data

For volumetric updates, we broadly follow the approach detailed in Baltar and Roth, 2013, combining this with the more advanced CSEM sensitivity assessment detailed above. Given an existing probabilistic volume evaluation, only background and charged reservoir resistivity distributions, along with CSEM-sensitive criteria, need to be added. A Monte Carlo simulation is carried out, where each realisation is classified as either detectable or undetectable by CSEM. In this way, two updated volume assessments are generated, corresponding either to the cases where we would expect an appropriate resistor to be identified in the CSEM data (EM Positive), or the cases where no such resistor could be identified (EM Negative).

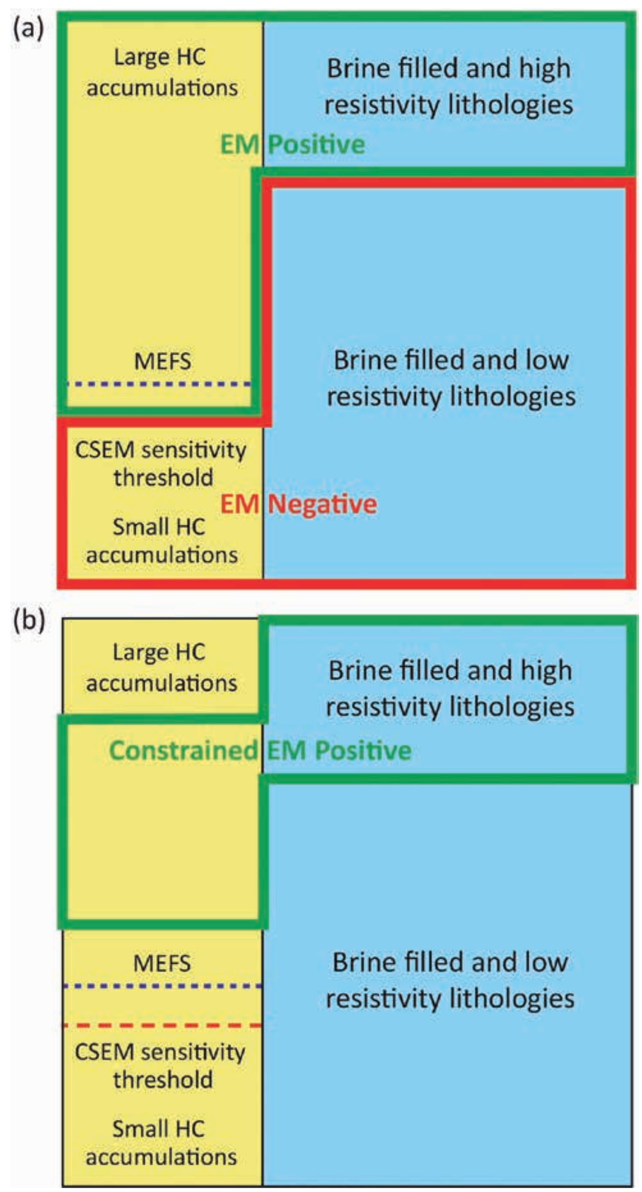


*Figure 2 Graphic representation of the partitioning of the evaluation from Figure 1, after application of CSEM-embedding workflows. (a) An EM Positive or Negative result indicates our new solution space is either inside the green or red boxes respectively. The new PoS is the area with HC relative to the new solution space area; the new volume distribution corresponds to the hydrocarbon accumulation scenarios inside the corresponding solution space. (b) The new solution space constrained by one specific EM Positive outcome sits inside the green box. Within this box, the new PoS is the area with HC relative to the new solution space area, and the new volume distribution is the one created from the hydrocarbon accumulations inside the green box.*

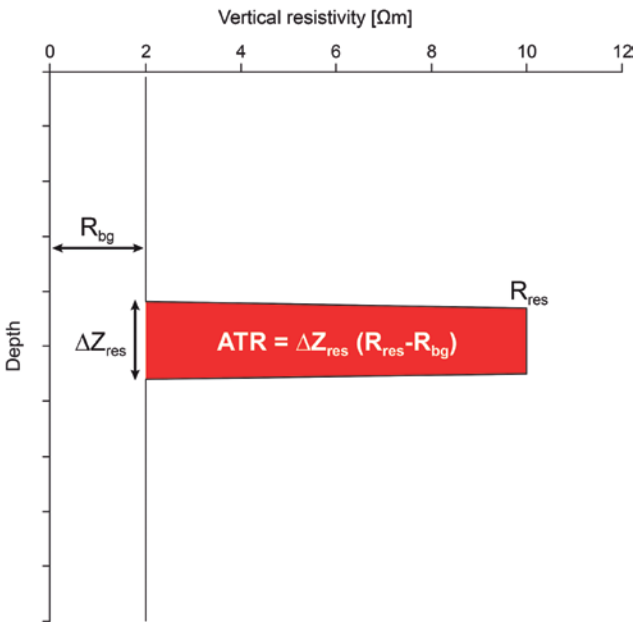


*Figure 3 CSEM sensitivity to thin resistive layers is, to a good approximation, a function of the Anomalous Transverse Resistance (ATR) within the resistive layer.*

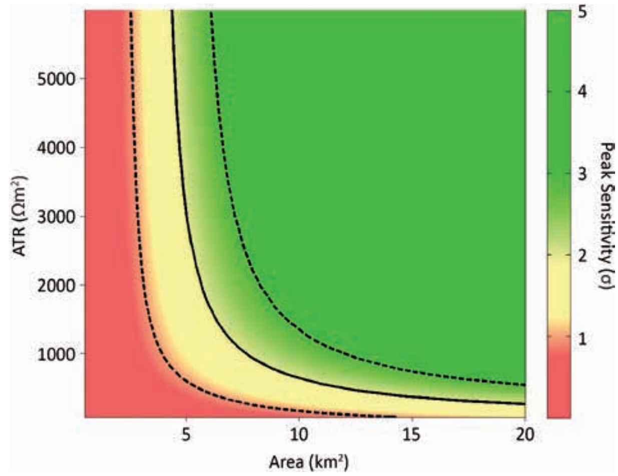


*Figure 4 CSEM sensitivity assessment as a function of the potential ATR and area ranges for a specific prospect. The solid contour corresponds to a performance-tracked estimate of the threshold of sensitivity to the target (we would expect scenarios above and to the right of this contour to be identified from the CSEM survey; scenarios below and to the left would be below detection). Additional factors not considered directly in the sensitivity calculation serve to modify this threshold sensitivity level as appropriate (dashed contour line examples).*

With a specific EM Positive outcome, Baltar and Roth, 2013 describe how the characteristics of the identified resistor can be used to directly constrain the volume estimation, by the substitution of a new EM-derived net rock volume distribution (NRVem); we follow this approach in the Constrained EM Positive workflow.

## Bayes' theorem applied to EM

According to Bayes' theorem, given an existing (prior) probability of finding hydrocarbons, P(HC) = PoS, and a certain CSEM outcome, EM, the new probability of finding hydrocarbons, P(HC|EM), can be calculated by applying:

$$P(HC \mid EM) = \frac{P(HC)}{P(HC) + R(1 - P(HC))}. \quad (1)$$

In order to evaluate P(HC|EM), the likelihood ratio, R, of each of the two possible EM outcomes is needed. The R for EM Positive (Rp) and EM Negative (Rn) outcomes are:

$$Rp = \frac{P(EMp \mid nHC)}{P(EMp \mid HC)} \quad (2)$$

$$Rn = \frac{P(EMn \mid nHC)}{P(EMn \mid HC)}, \quad (3)$$

where EMp is an EM positive case, EMn is an EM negative case, HC denotes the case where hydrocarbons exist in the reservoir, and nHC the case where no hydrocarbons exist.

## Evaluation of EM response probability in the absence of hydrocarbons

We can evaluate P(EMp|nHC) and P(EMn|nHC) together, since they are complementary: P(EMn|nHC) + P(EMp|nHC) = 1. P(EMp|nHC) is the probability of obtaining an EM positive outcome in the absence of hydrocarbons, an important interpretation pitfall to be considered when using resistivity data for hydrocarbon detection. Buland et al., 2011, from their experience estimate this probability to be 0.2 for a typical and realistic prospect; this case-specific probability will primarily depend on the geologic setting.

Typical sources of high resistivity in a sedimentary basin, aside from hydrocarbons, are low porosity rocks and fresh water; hence information on the age of the rocks, burial history, depositional environment, sediment provenance, availability of cements, and any other information that might help to understand the likelihood of low-porosity or fresh water lithologies, will help in assessing this probability. Since low-porosity lithologies are very often characterised by high impedances, seismic data and seismic velocities are a valuable piece of information in order to evaluate the probability of a false positive due to low porosities (Figure 5). Fresh water reservoirs, however, often exhibit no clear seismic signature; hence we will need to rely on other geological information to better characterise the probability of occurrence of this source of resistivity.

## Evaluation of EM response probability in the presence of hydrocarbons

We can also evaluate P(EMp|HC) and P(EMn|HC) together as complementaries. The probability of imaging a resistor in

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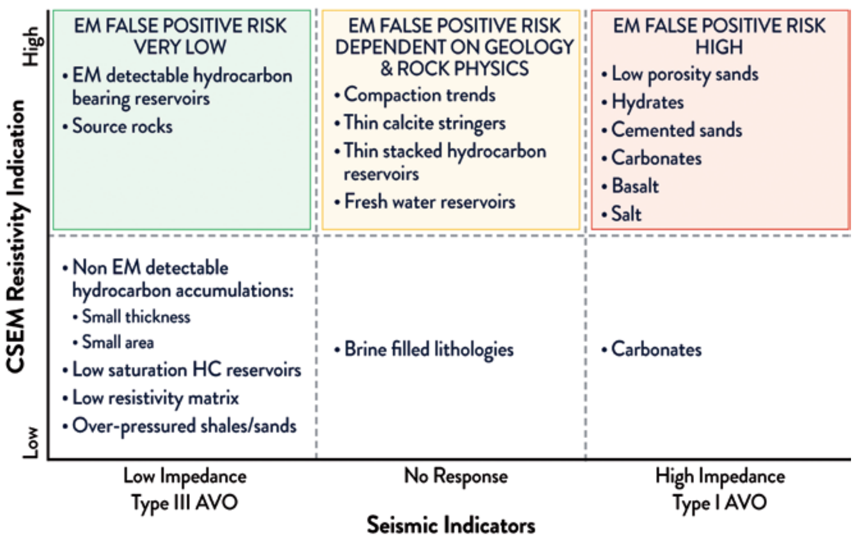


***Figure 5*** *Various geological scenarios as a function of their typical relative electrical and acoustic characteristics. A joint analysis is a useful de-risker for the 'false-positives' possible from both resistivity DHI and seismic DHI in isolation.*

the CSEM data in the case where hydrocarbons are present depends on the sensitivity to the target, as detailed previously and in Figure 4. In practice, P(EMp|HC) and P(EMn|HC) are evaluated in different ways, depending on which of the volumetric workflows is followed.

For the EM Positive and EM Negative workflows, P(EMp|HC) can be calculated directly from the outcome of the Monte Carlo simulation described in Baltar and Roth, 2013, and corresponds to the ratio of detectable volume cases to the total number of Monte Carlo iterations, N. P(EMn|HC) can be calculated as the ratio of non-detectable volume cases to N, or 1-P(EMp|HC).

For the Constrained EM Positive workflow, P(EMp|HC) no longer relates to the entire range of potential positive outcomes, but is specific to the positive survey outcome obtained. Its value, the proportion of the prior NRV that could produce a CSEM anomaly similar to the one actually measured, can be estimated from the overlap between the prior NRV and NRVem distributions:

P(EMp|HC) = Percentile of prior NRV at P01(NRVem) - Percentile of prior NRV at P99(NRVem).

For example, assume that the prior NRV P99 and P01 values are 80 m.km$^2$ and 9000 m.km$^2$ respectively, and the corresponding NRVem values are 500 m.km$^2$ and 9000 m.km$^2$, then it follows that there is approximately a 70% (P99 NRVem = P70 NRV, and P01 NRVem = P01 NRV) chance of having an NRV that generates a resistive anomaly consistent with the 3D CSEM data (shown graphically in Figure 6).

Coupling of P(EMp|HC) to volumes in this way has three key benefits over stand-alone risk and volume assessments, which help to reduce the risk of inappropriate use of the new information:

1. Likelihood ratio estimates in EM Positive and Negative workflows depend upon the data sensitivity: high sensitivity to a scenario (whether positive or negative), increases the data's R in that scenario, and vice versa.
2. Very precise NRVem estimates (narrow P10-P90 range relative to the prior) require correspondingly high confidence in the information, or PoS to that outcome will be penalised.
3. Confidence in NRVem ranges, partially (or wholly) outside the prior's range, is partially (or wholly) penalised as being inconsistent with the original evaluation. By reducing (zeroing) PoS in such cases, the interpreter is forced to re-evaluate prospect risk factors to this new volume range.

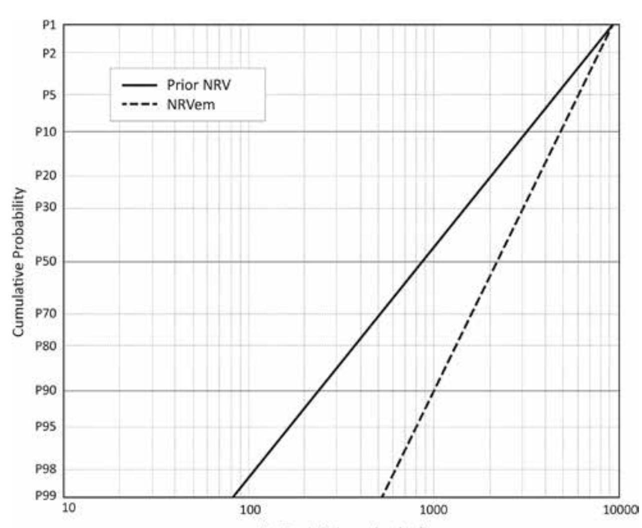


***Figure 6*** *A CSEM-derived NRV distribution (NRVem) compared to the originally assessed distribution. A cumulative log probability graph is used here to more clearly illustrate the evaluation of P(EMp|HC), being the proportion of the prior volumes included in the new CSEM assessment.*

## Illustrative example

Consider a realistic frontier exploration scenario in 1500 m water depth, with a prospect at 3500 m below sea surface. The PoS has been estimated at 30%; the prospect's volume estimation parameters are listed in Table 1, leading to a volume distribution curve of the blue line in Figure 7. Assuming a minimum economic field size (MEFS) of 100 MMbbl, the probability of economic success for this prospect, Pe = PoS * P(Recoverable volume > MEFS), will be: Pe = 0.3 * 0.65 = 0.2.

3D CSEM data acquisition is planned over a large area, including this prospect. We will now calculate how the prospect evaluation changes in terms of PoS, volumes, and Pe, depending on whether a resistor is seen or not seen in the CSEM data.

We assume that the background vertical resistivity is estimated from the data as somewhere between 1 and 1.5 Ωm. Analog, depth, pressure, and temperature evaluations allow us to estimate the hydrocarbon-charged vertical reservoir resistivity to be somewhere between 25 Ωm and 125 Ωm (a broad range, which takes into account both the rock and fluid property uncertainties). Based on these properties, the CSEM target sensitivity is calculated to be as Figure 4, with the threshold sensitivity for detection estimated as 2 (the solid contour on Figure 4), once data quality and resistivity complexity are taken into account.

## EM Negative scenario

In the case where the EM data show no resistive anomaly we can follow the EM Negative workflow. The geology is relatively benign in its electrical properties and we observe sub-horizontal bedding and little lateral variation in background structure over the survey area. False positives are therefore unlikely. However, we decide to remain conservative about the risk, given the frontier nature of the area. Hence we use a false positive risk, P(EMp|nHC), of 0.3, and thus P(EMn|nHC)=0.7. Now we evaluate P(EMn|HC) from the volumetric Monte Carlo simulation, where 100,000 iterations yield 33,000 non-detectable cases (not illustrated), hence P(EMn|HC)=0.33. Using Equation 3 we compute Rn, and finally apply Bayes' theorem from Equation 1 to calculate the updated probability of finding hydrocarbons to be 0.17.

The updated evaluation comprises the updated probability of success and the updated volume estimation generated in the Monte Carlo simulation. Referring to Figure 7, the changed probability of economic success due to the EM Negative outcome is then Pe = 0.17 * 0.20 = 0.03.

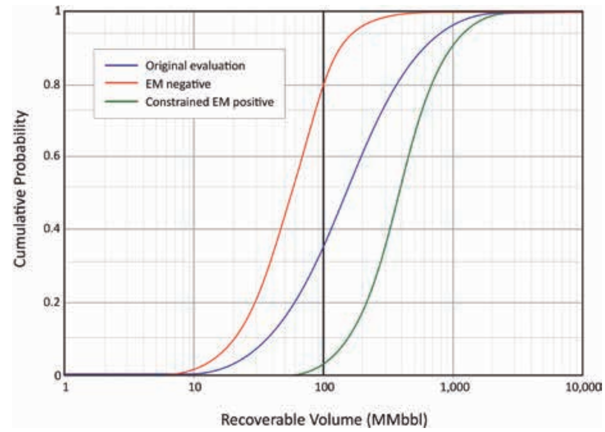


***Figure 7*** *Recoverable volume assessments from the illustrative example detailed in the text. The minimum economic field size (MEFS) is shown by the solid vertical line.*

## Constrained EM Positive scenario

Now consider that 3D CSEM results over the prospect indicate a resistor where expected. Following the Constrained EM Positive workflow, we use the properties of the recovered resistor to directly constrain the NRV. An NRVem probability distribution is obtained: the same as shown in Figure 6.

False positive risk was estimated to be 0.3 in the EM Negative example. A good correlation is now seen between seismic amplitudes that represent a low impedance, and the distribution of high resistivities. This allows for a reduction in the likelihood of a false positive, which we now estimate as P(EMp|nHC)=0.2.

P(EMp|HC) is calculated from the two NRV distributions. In this case, P99 of the NRVem distribution corresponds approximately to the P70 of the prior NRV, allowing us to estimate that approximately 70% of the prior NRV could produce a similar EM Positive response to the one measured in the CSEM inversion; hence, we estimate P(EMp|HC) = 0.7.

Using the updated values from the above discussion, and Equation 2, we can calculate an Rp for the constrained EM positive scenario and again apply Bayes' theorem to calculate the updated PoS to be 0.6. By replacing the prior NRV with the NRVem, an updated recoverable volume distribution is

| | P90 | P10 |
|---|---|---|
| Area (km$^2$) | 5 | 50 |
| Net Thickness (m) | 30 | 100 |
| Porosity (fraction) | 0.18 | 0.25 |
| Hydrocarbon saturation (fraction) | 0.5 | 0.7 |
| Recovery factor (fraction) | 0.2 | 0.4 |
| Formation volume factor (fraction) | 1.2 | 1.4 |

***Table 1*** *Lognormally distributed volume parameters for the illustrative prospect example.*

calculated as Figure 7, and the new probability of economic success will be: Pe = 0.6 * 0.97 = 0.58.

## Results discussion

The evaluations for each scenario are summarised in Table 2 and graphically in Figure 8. The differences in the probability of economic success resulting from different 3D CSEM survey outcomes illustrate how powerful, and polarising, these data can be if used properly. The absence of a resistor implies lower chance of success and/or lower volume potential. In this example, the EM Negative result has led to a drastic drop in the probability of economic success, mainly as a result of the high minimum economic field size in combination with the reduction in the upside potential that the negative result implies. The presence of a resistor allows for the identification of high-potential features, in this case nearly tripling the chance of finding an economic accumulation.

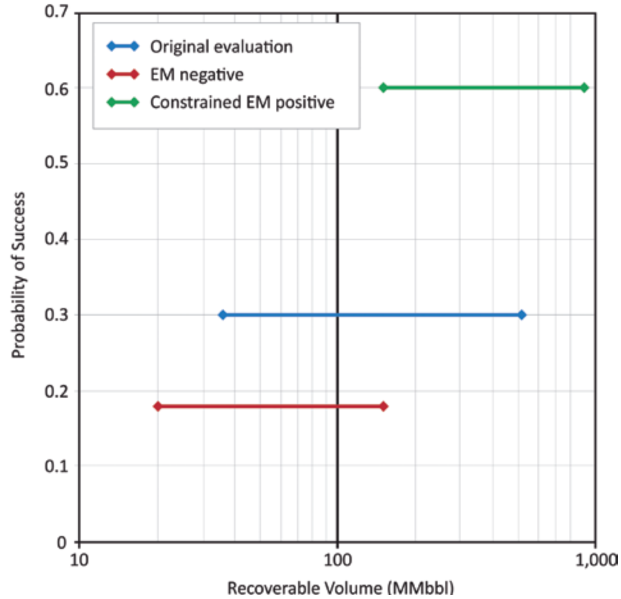


***Figure 8*** *An illustration of the example evaluation updates described in the text. The minimum economic field size (MEFS) is shown by the solid vertical line. Coloured lines represent the volume range between P90 and P10. The different potential outcomes from the use of the CSEM information would help polarise this prospect's evaluation.*

## Real-life Constrained EM Positive example: Pingvin

Fanavoll et al. (2014), used the NRV workflow from Baltar and Roth (2013), to generate a pre-drill net rock volume prediction from a CSEM anomaly associated with an existing prospect in the Barents Sea (Figure 9). The Pingvin prospect was located in production licence 713, approximately 65 km northwest of the 7220/8-1 Johan Castberg oil and gas discovery and 300 km northwest of Hammerfest. Subsequently, the operator, Statoil Petroleum AS, tested the prospect with wildcat well 7319/12-1 and encountered gas in the reservoir interval, announcing drilling results and preliminary volume estimates (NPD Drilling Announcement, 2014). We use this case to illustrate the practical application of the Constrained EM Positive workflow.

## Prior evaluation

To consider the impact of CSEM in the evaluation of this prospect, and given that we do not have access to Statoil's pre-CSEM evaluation, we must first generate a reasonable prior.

In Fanavoll et al., we can observe two clear flat spots, naturally interpreted as GOC and OWC. Taking into account that prior to drilling this was a frontier setting and an unproven play, the probability of success must be low. On the other hand, the seismic indicators were good (flat spots and bright spots). We therefore conclude PoS would have been at the high end of the unproven play range, and use a value of 0.33. We assess the area from available information: the area inside the first flat spot will be used as P90 and the area inside the second flat spot will be used as P10, thus P90 = 20 km², P10 = 60 km². For the thickness we use the same source of information, leading to P90 = 10 m, P10 = 35 m, and an NRV distribution as Table 3.

All other parameters (porosity, hydrocarbon saturation, recovery factor and formation volume factor) will be considered unaffected by the new CSEM information and will therefore be set aside for the rest of the example.

## Fit of CSEM to prior

This CSEM case is a clear positive response, therefore the positive likelihood ratio, Rp, (comprising P(EMp|HC) and P(EMp|nHC)), needs to be assessed. P(EMp|HC) can be calculated by the ratio between the prior NRV and NRVem. The calculation performed in Fanavoll et al. yields the NRVem probability distribution listed in Table 3. We graphically compare the overlap between both NRV distributions in Figure 10. P01 of the NRVem corresponds approximately to P25 of the prior NRV. Therefore, we estimate P(EMp|HC) = 0.75.

| | Prior to EM data | Updated analysis using EM data | |
|---|---|---|---|
| | | *EM Negative* | *Constrained EM Positive* |
| Probability of Success (PoS) | 30 % | 18 % | 60 % |
| P(Recoverable Volume > MEFS) | 65 % | 21 % | 97 % |
| Probability of Economic Success (Pe) | 20 % | 4 % | 58 % |

***Table 2*** *Summary of prior- and post-CSEM risk evaluations for the illustrative example.*

Now we estimate the false positive risk. The excellent fit between the area distribution of CSEM and seismic DHI places this case in the upper-left corner of Figure 5, leading us to conclude that P(EMp|nHC) is quite low. The limited number of similar cases (one example would be 'Case A' in Escalera et al., 2013) limits our ability to narrow-down this number in a statistically sound way, so we use Buland et al's reference P(EMp|nHC) = 0.2, and reduce it to account for the fit to seismic DHI information, estimating P(EMp|nHC) as 0.1.

Computing Rp from Equation 2, and applying Bayes' theorem in Equation 1 gives an updated probability of success of 0.79.

These results are summarised in Table 4. It can be seen that, compared to the prior, the CSEM data, and its good fit to seismic DHI information, are pointing to a higher likelihood of finding hydrocarbons in the reservoir, but severely limiting the upper side of the NRV distribution. The announced discovery (NPD Drilling Announcement, 2014) comprised a gas column of 'about 15 m', and 'Preliminary estimates place the size of the discovery at between 5-20 billion standard cubic metres of recoverable gas'. Using reasonable estimates for the reservoir properties (area, saturation, recovery factor, and expansion factor), it can be shown that CSEM-predicted volume range is in line with the reported discovered volumes.

## Performance tracking

As with other components of the evaluation process, prediction performance tracking is key to the balanced use of the CSEM information. Some statistical look-backs have been published

| | P90 | P50 | P10 |
|---|---|---|---|
| NRV (m.km$^2$) | 280 | 600 | 1300 |
| NRVem (m.km$^2$) | 50 | 150 | 450 |

***Table 3** A reasonable prior (before CSEM) NRV distribution for the Pingvin prospect, along with an NRVem distribution calculated directly from the CSEM results by Fanavoll et al. (2014).*

(e.g., Buland et al., 2012; Hesthammer et al., 2010). While they are a useful starting point for the application of the workflows described here, care should be taken when directly applying numbers obtained from one interpretation workflow to another.

## Impact on a portfolio, and large-scale application of CSEM

While described here in terms of a single prospect, the greatest value has been obtained from the 3D CSEM data when the information is available at the portfolio scale and early in the exploration process: the CSEM information can be used to identify new exploration leads in known plays, aid in the development of new play concepts, or upgrade untested concepts (e.g., Escalera et al., 2013; Fanavoll et al., 2014). Within an existing CSEM-sensitive portfolio, the typical behaviours of individual prospects are summarised in Figure 11. These changes naturally lead to greater portfolio polarisation, and the potential for significant changes in exploration decision making.

## Conclusions

Workflows have been presented for embedding CSEM information into existing risk and volume assessments. The potential changes in the evaluation are significant, and in line with experience from recent application of this maturing technology.

While the adoption of a new technology inevitably comes at a cost (associated with the development and use of new evaluation tools, workflows and training of personnel, as well as the data cost itself), the workflows presented here have been designed to leverage the primary strengths of the CSEM measurement, while keeping to a minimum the disruption and potential increase in risk associated with the adoption process. This has been achieved through:

1. A focus on updating existing evaluations, rather than proposing more fundamental changes to evaluation components;
2. The use of largely unconstrained 3D CSEM inversion results as input, rather than more complex joint imaging

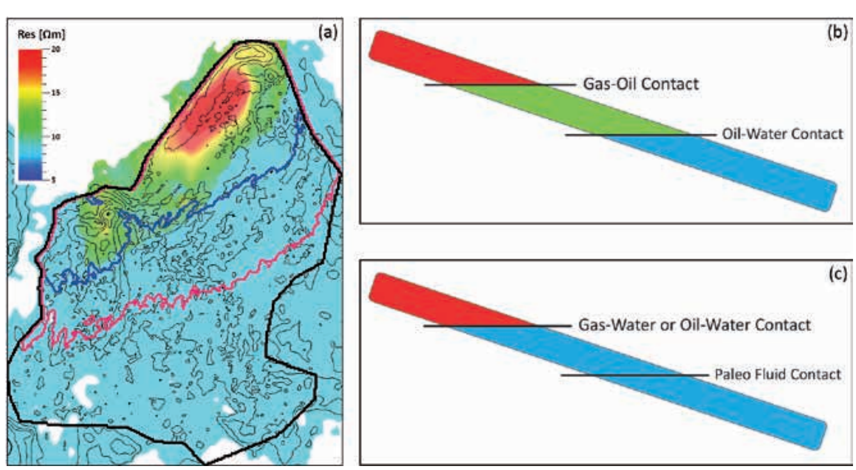


***Figure 9** (a) Pingvin prospect average resistivity map from CSEM inversion displayed with contoured reservoir thickness. Minimum (blue), medium (red), and maximum (black) scenarios based on seismic data are given by the three polygons. Reproduced from Fanavoll et al. (2014), Figure 7(b). (b) and (c): two competing interpretations of the double flat spot identified in seismic data. In scenario (b), the prospect is fully charged; the flat spots corresponding to gas-oil and oil-water contacts. In scenario (c), the prospect is only charged to the uppermost flat spot. CSEM information provides compelling evidence in support of scenario (c), as turned out to be the case.*

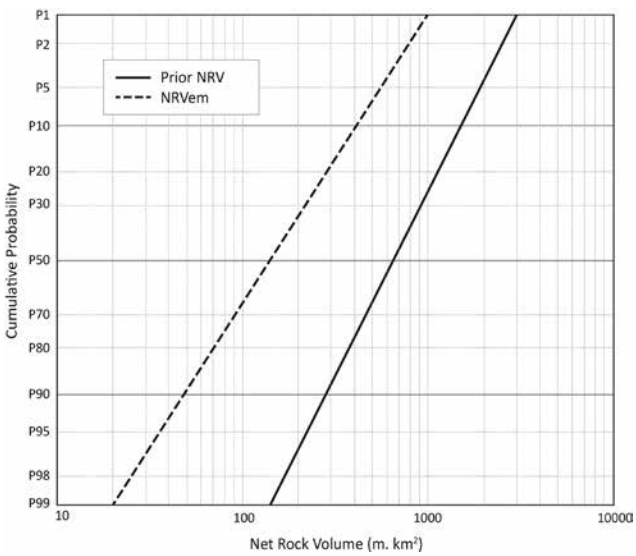


***Figure 10*** *The CSEM-derived NRV distribution (NRVem) from Fanavoll et al., compared to a reasonable NRV prior estimate for the Pingvin prospect, Barents Sea.*

| | Prior to EM data | Updated analysis using EM data: *Constrained EM Positive* |
|---|---|---|
| Probability of Success (PoS) | 33 % | 79 % |

***Table 4*** *Pingvin prospect: summary of realistic prior- and post-CSEM risk evaluations.*

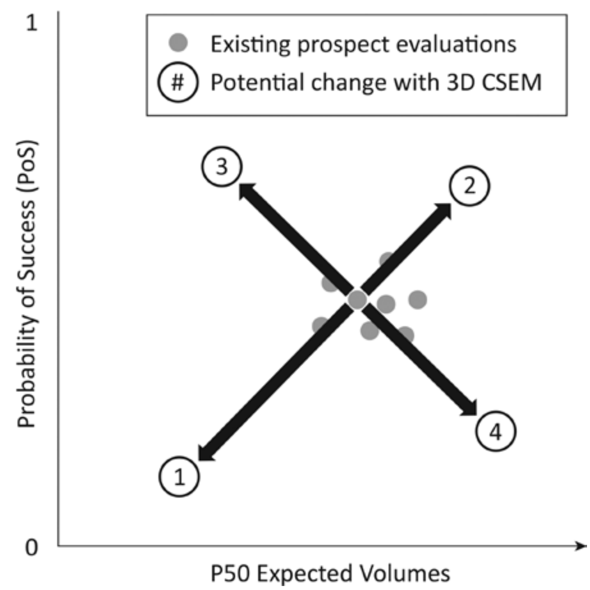


***Figure 11*** *A summary of the typical end-member outcomes seen after the addition of information from 3D CSEM to an existing prospect portfolio. (1) EM Negative. Reduction in expected volumes to below the level of EM sensitivity, removing potential upside, and corresponding reduction in PoS. (2) Large Resistor. When consistent with prior, the large resistor increases both potential volumes and PoS, especially in the presence of other supporting evidence from seismic or absence of false positive potential. (3) Very Small Resistor. Again, consistent with the prior, the small resistor has increased the PoS, but removed the upside, potentially pushing the expected volumes to sub-commercial levels. (4) Unexpectedly Large Resistor. Increase in volumes, but potential decrease in PoS if volumes are largely incompatible with prior (increased risk of false positive). Increased potential may, or may not, outweigh increased risk.*

products. This provides a more independent information source, from which in practice it is easier to estimate uncertainties and minimise interpreter bias;

3. Adoption of industry-standard performance tracking methodologies. In the early stages of the adoption, the logical approach is to start with a conservative estimate for the R parameters, making larger evaluation updates as experience with, and confidence in, the information increases.

Within the same CSEM technology application, we see potential for future improvements in evaluation of the recovery factor (reservoir resistivity is linked to reservoir permeability), the fluid phase (lighter fluid phases tend to show higher saturation due to viscosity and pressure-related effects, therefore they should show higher resistivities), rock porosity, and hydrocarbon saturation. All of these refinements are more easily developed and applied once a core CSEM-embedding framework, such as the one presented in this paper, is in place.

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