Improved volumetric calculation with 3D CSEM

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Keywords

3D CSEM, resistivity, prospect evaluation, hydrocarbon volume, probability of success (PoS)

Summary

We present a workflow for improved volumetric calculation with 3D CSEM data. Volume estimation is critical to the evaluation of exploration ventures, but also one of the primary sources of uncertainty and failure in the exploration business. This is true in particular when significant minimum economic field sizes are required to make the venture economically successful. We explain how marine 3D CSEM can be used to update an existing volume distribution and reduce the volume uncertainty. The application of the workflow is demonstrated on a prospect in Norway, showing that our pre-drilling volume prediction is in very good agreement with the post-drilling evaluation by the operator. Although we focus on prospect evaluation in this abstract, the presented workflow can be applied equally to the appraisal of discoveries.

Introduction

When marine controlled-source electromagnetics (CSEM) was first introduced as an offshore hydrocarbon exploration method, it was primarily considered a risking tool impacting probability of success (PoS) evaluations. In recent years, the additional value of CSEM in volume assessment has been recognized (Baltar and Roth 2013, Escalera et al. 2013), which in combination with the PoS evaluation provides the ability to rank prospects more reliably in terms of their economic potential. The development of volume assessment methods has to a large part been driven by the introduction of wide-azimuth 3D CSEM acquisition providing quantitative 3D resistivity images of the subsurface.

Volumetric calculation is one of the fundamental components of the evaluation of exploration ventures and field size of discoveries. At the same time, it is one of the primary sources of uncertainty and failure in the exploration business. This is true in particular for exploration areas where significant minimum economic field sizes are required to make the venture economically successful.

The source of volume uncertainty lies primarily with the uncertainty linked to the areal extent and the net thickness of the accumulation. CSEM data, due to its inherent sensitivity to these two parameters, is especially well suited to reduce the total uncertainty in the volume estimation process (Baltar and Roth 2013).

In this abstract, we will describe the main principles of prospect evaluation with 3D CSEM, focusing on the volumetric calculation part, and present a case example demonstrating the ability to significantly reduce the risk in estimating field size.

Workflow

The economic evaluation of a prospect relies on the PoS and volumetric calculation. While seismic interpretation and DHI analysis provides valuable insight in the trapping, existence of a reservoir and likely presence of hydrocarbons, other success factors such as sealing, high saturation charge and volume typically remain very uncertain. CSEM is a complementary method that can fill these information gaps.

To embed 3D CSEM in an evaluation workflow, we recommend following the approach developed by Baltar and Barker (unpubl. results), which updates an existing prospect evaluation based on the CSEM observations instead of providing an independent CSEM evaluation. Key aspects to consider are:

- Use of Bayes theorem to update an existing PoS.
- Use of Monte Carlo simulation for the volume update.
- Accounting for CSEM sensitivity in both the PoS and volume update.
- Evaluation of interpretation pitfalls, i.e. probability of a non-hydrocarbon related resistor.
- Match between CSEM and seismic DHI observations.
- Calibration of the evaluation framework based on performance tracking.

In addition, quality and interpretability of the CSEM data entering the evaluation need to be considered, as is the case for seismic data.

The importance of CSEM sensitivity calculations in the evaluation cannot be overstated since the absence of a resistor in the CSEM data should not be misinterpreted as the absence of hydrocarbons but the absence of a resistive volume that is large enough and with sufficient contrast to be detectable by CSEM.

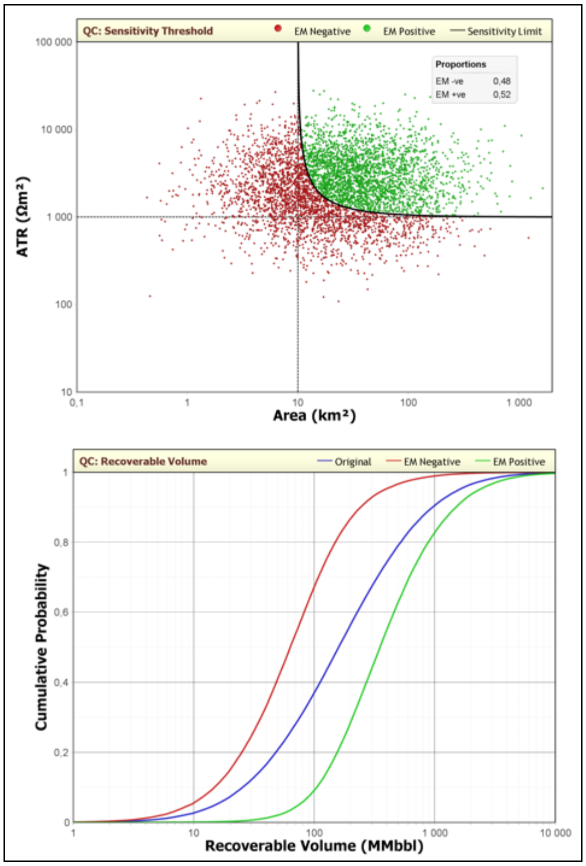

Figure 1: Sensitivity classification of reservoir realizations into "EM positive" and "EM negative" cases (top) and resulting update to the original/prior volume distribution (bottom). ATR describes the Anomalous Transverse Resistivity of the prospect defined as the product of *pay resistivity contrast* x *net pay*.

Similarly, the evaluation of possible interpretation pitfalls is critical, since there may be non-hydrocarbon related origins for high formation resistivity such as low porosity/compaction, fresh water, carbonates, calcite stringers etc.

In the following, an "EM positive" is defined as the case where a resistive anomaly is present in the 3D CSEM data as given by an unconstrained inversion result; an "EM negative" is the case where no resistive anomaly is detected at the prospect location.

Starting from an existing probabilistic volume assessment, given in terms of probability distributions for the reservoir parameters entering the volume calculation, a straightforward way to update the volume assessment is by running a Monte Carlo simulation and classifying the reservoir realizations into "EM positive" and "EM negative" based on CSEM sensitivity modeling. Doing so, updated volume distributions for these two cases can be generated, i.e. the original distribution is conditioned by the CSEM observation. See Figure 1.

Given an "EM positive", the volumetric calculation can be further constrained by deriving a Net Rock Volume (NRV) distribution from the imaged resistivity volume and combining this distribution with the remaining reservoir parameters (saturation, porosity, volume factor, recovery factor) from the original probabilistic volume assessment. The key concept in this "Constrained EM positive" volumetric calculation is to use the imaged resistivity volume to determine a surface attribute called Anomalous Transverse Resistance (ATR), defined as the product of *pay resistivity contrast* x *net pay*, and calculate the net pay from the attribute map using a Monte Carlo simulation approach. The method is illustrated in Figure 2 and fully described in Baltar and Roth (2013).

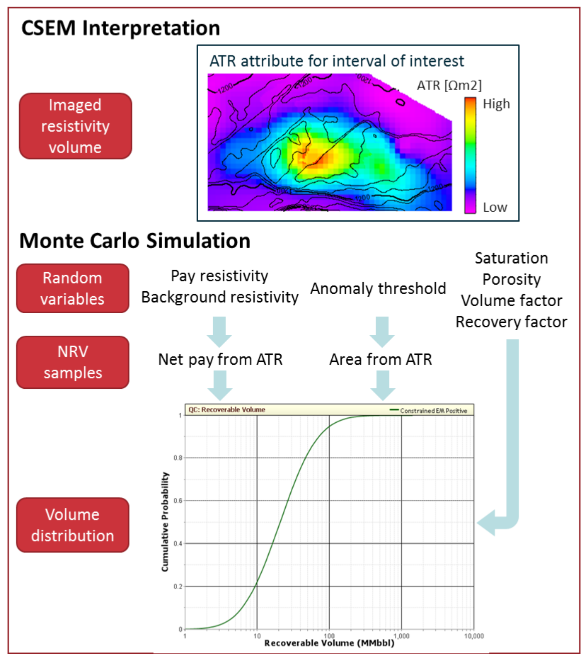

Figure 2: Illustration of the method for "Constrained EM positive" volumetric calculation.

Case example from Norway

We will demonstrate the volume assessment capability of 3D CSEM using an "EM positive" case from the Barents Sea in Norway. The Barents Sea is a large frontier area with a drilling history of more than 30 years. Although the drilling has demonstrated an active petroleum system, only very few economic discoveries have been made. The complex geological history including periods of deep burial, uplift and erosion leads to significant seal and reservoir risk, which motivates the use of CSEM in combination with seismic to increase exploration success.

The prospect we consider is called Pingvin and lies in the Bjørnøya Basin in the western Barents Sea. According to Fanavoll et al. (2014), a distinct shallow seismic amplitude anomaly can be observed close to the Base Tertiary horizon (Figure 3). The seismic amplitude exhibits a soft response indicating that it may represent presence of gas. Two flat spots provide indication of fluid contacts. The main uncertainty in the evaluation of this prospect is saturation and volume as it is well known that seismic data are also sensitive to the presence of very low saturation gas ("fizz gas"); see Figure 4. Prior to CSEM acquisition, two competing interpretations for the deeper contact were feasible, i.e. an oil water contact (OWC) or a paleo fluid contact (Figure 3).

We do not have access to the operator's pre-CSEM evaluation, and hence have developed a reference evaluation based on the following line of thought: 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. This yields the solid line NRV distribution in Figure 5.

Figure 6 shows the unconstrained inversion result of the 3D CSEM data generated prior to drilling. The result describes an "EM positive" case, however the resistivity anomaly only covers the up-dip part of the seismic amplitude anomaly. CSEM sensitivity modeling indicates high sensitivity at this target depth and hence high confidence in the CSEM result.

The CSEM result favors the interpretation of a paleo fluid contact and smaller volume. Re-evaluating the NRV based on the resistivity anomaly yields the dashed line NRV distribution in Figure 5. See Fanavoll et al. (2014) for details about this calculation. We note that while the CSEM result has increased the PoS for this prospect, the upside of the original volume distribution, linked to the deeper contact, has been ruled out. As a result, the probability of economic success was predicted as low by the CSEM contractor (EMGS) prior to drilling.

A wild cat was drilled just outside the resistivity anomaly and encountered a 15-metre gas column. The well drilled through the gas water contact (GWC), and probably through the transition zone with the main accumulation found up-dip and wedging out towards the GWC, which would explain the absence of a resistive anomaly at the well location. Volume estimates announced by the Norwegian Petroleum Directorate were in accordance with the NRV prediction from CSEM.

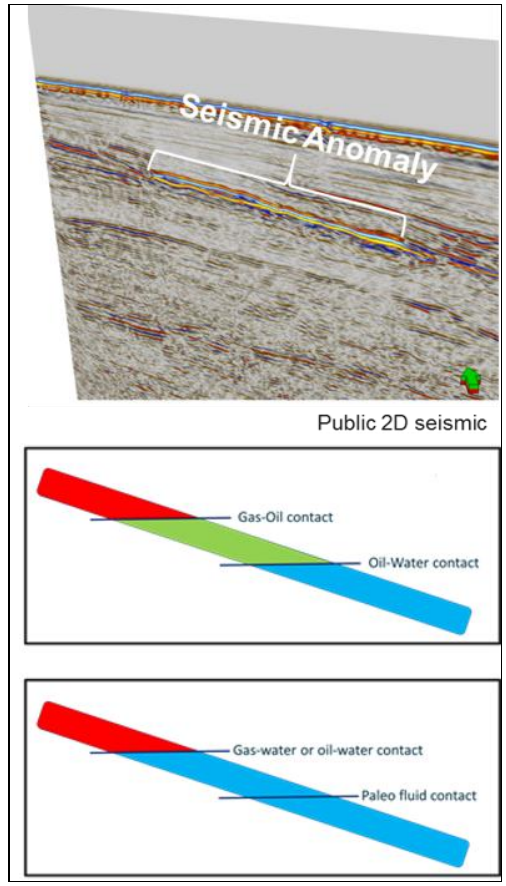

Figure 3: Seismic expression of the Pingvin prospect and possible contact interpretations.

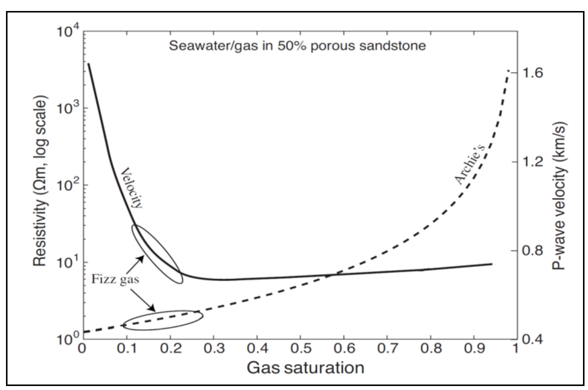

Figure 4: Resistivity (dashed) has good sensitivity to hydrocarbon saturation, while seismic velocity (solid) can typically only distinguish between presence and absence of hydrocarbons. From Constable (2010).

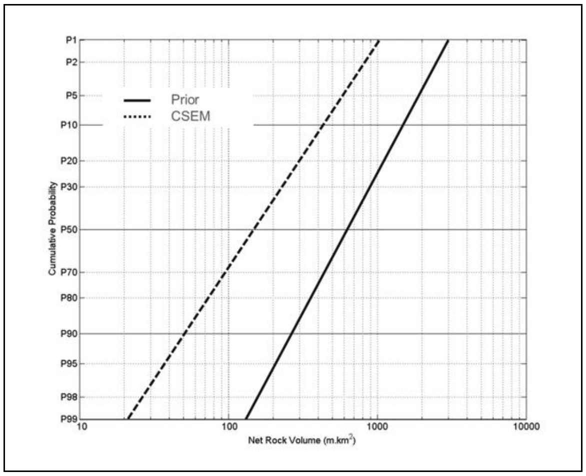

Figure 5: Prior and post-CSEM Net Rock Volume (NRV) distribution for the Pingvin prospect.

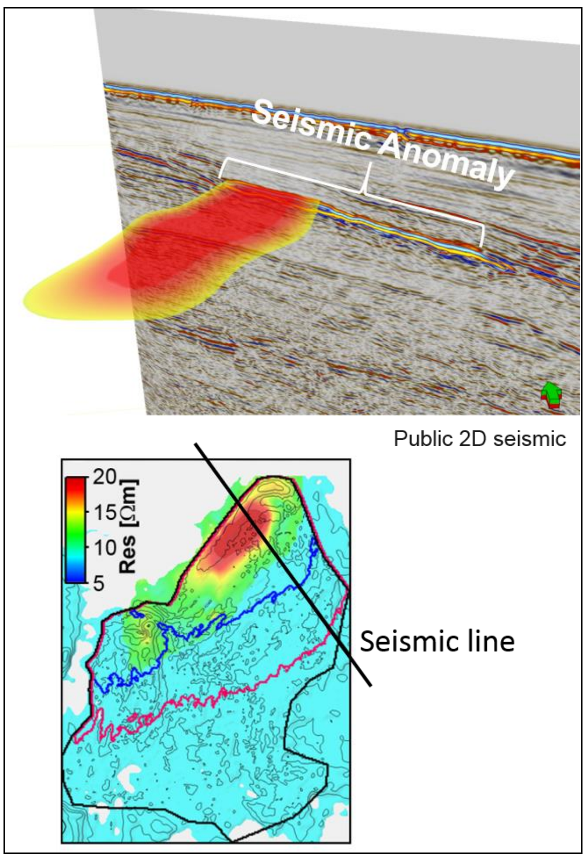

Figure 6: 3D CSEM inversion result of the Pingvin prospect co-visualized with the seismic line (top) and average vertical resistivity map displayed with contoured reservoir thickness from seismic (bottom). The black polygon defines the maximum prospect outline from seismic interpretation. Fanavoll et al. (2014)

Conclusion

CSEM allows for a significant reduction in the uncertainty in the volume estimation. This is due to the Net Rock Volume (NRV) being poorly constrained when only seismic is available, making the NRV a major uncertainty in the volume estimation process. CSEM sensitivity to the NRV allows for an improved understanding of this parameter, and hence significantly improves the overall quality of the volume prediction. The ability of CSEM to improve the volumetric calculation generates great value in exploration environments with large minimum economic field sizes. The presented workflow can be applied to prospects prior to drilling and appraisal of discoveries after a successful discovery well.

References

Baltar, D. and Roth, F., 2013, Reserves estimation methods for prospect evaluation with 3D CSEM data; First Break, 31 (6), 103–111.

Constable, S., 2010, Ten years of marine CSEM for hydrocarbon exploration, Geophysics, 75 (5), 75A67-75A81.

Escalera Alcocer, J.A., Vázquez García, M., Salazar Soto, H., Baltar, D., Ricoy Paramo, V., Gabrielsen, P.T. and Roth, F., 2013, Reducing uncertainty by integrating 3D CSEM in the Mexican deep-water exploration workflow. First Break, 31 (4), 75-79.

Fanavoll, S., Gabrielsen, P.T. and Ellingsrud, S., 2014, CSEM as a tool for better exploration decisions: Case studies from the Barents Sea, Norwegian Continental Shelf. Interpretation, 2 (3), SH55-SH66.

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