Demonstrating the Full Potential of Controlled-Source Electromagnetic Surveying (CSEM) Technology for Hydrocarbon Exploration: A Case Study of a Deep Gas Discovery from the Upper Cretaceous of the Norwegian Sea*

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Abstract

Whilst 2D and 3D seismic methods are now widely accepted and considered as proven technology for hydrocarbon exploration and reservoir characterization, the use of controlled-source electromagnetic (CSEM or EM) surveying is still in its infancy and is often met with **skepticism** by geologists, geophysicists, and managers. This is at least partly due to the existence of a number of negative case studies that are frequently cited as evidence for the technology being unreliable. The Luva gas discovery in the Norwegian Sea is one such example. It has gained a reputation as being a significant gas discovery that shows only a very small and enigmatic EM response, in spite of a proven hydrocarbon column in excess of 150 metres thick. This "false-negative" response could easily have led to the discovery being missed by a company that was using CSEM to guide "drill-or-drop" decisions. Recent advances in acquisition technology, processing algorithms, and the development of advanced workflows for integrated processing of EM and seismic data have greatly improved the power of CSEM technology. In this case study we present the workflow and results from a recent reprocessing of the Luva dataset, which has not only explained the reasons for the apparent false-negative response, but also revealed a clearly visible EM anomaly that can be correlated with seismic DHIs. This study illustrates that many CSEM data sets that have previously been dismissed as being "unresolvable" may yet yield valuable information, and it demonstrates that the oil-industry still has a long way to go before mastering CSEM technology.

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Demonstrating The Full Potential of Controlled-Source Electromagnetic Surveying (CSEM) Technology for Hydrocarbon Exploration:

A Case Study of a Deep Gas Discovery From The Upper Cretaceous of The Norwegian Sea

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Talk Outline

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- Overview of controlled-source electromagnetic surveying
  - Basic processing
  - Inversion
  - Integrated processing

- Real data case study from the Norwegian sea
  - Basic processing results
  - Iterative processing using forward modelling
  - Integrated processing results

- Integrating new technology into the exploration workflow

What is CSEM?

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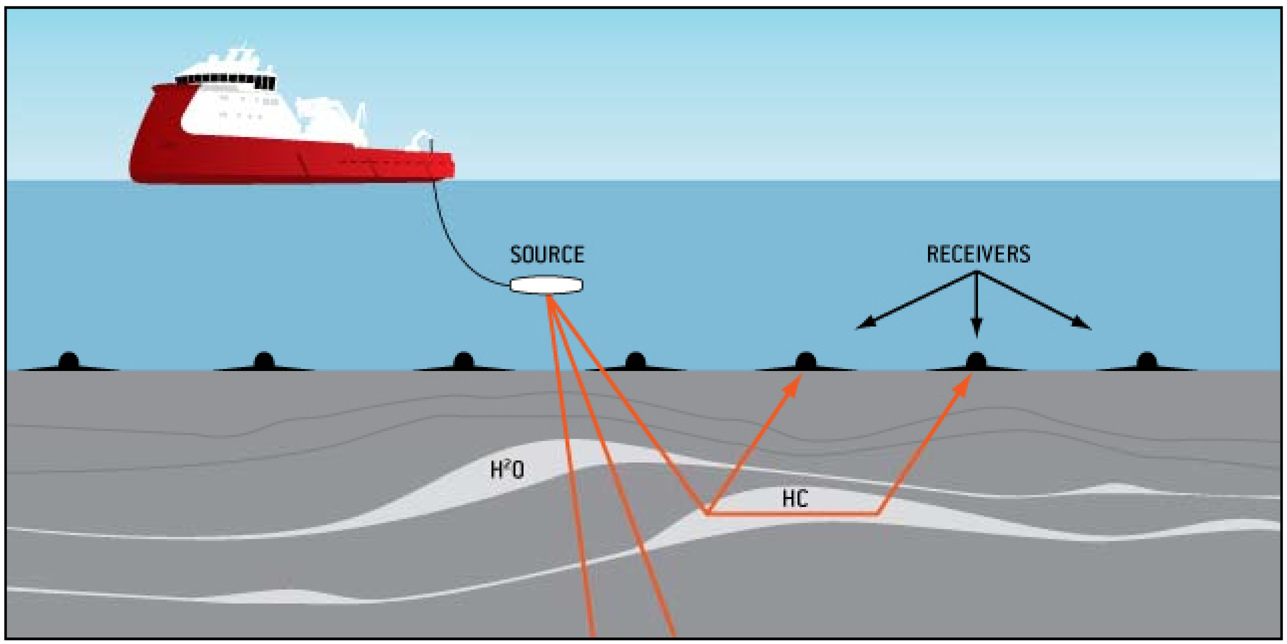
- Controlled-source electromagnetic (CSEM) data in an offshore setting:
  - Loosely analogous to seismic in terms of theory and acquisition; uses electromagnetic, rather than acoustic energy and an array of sea floor receivers instead of streamers
  - Hydrocarbon-bearing sediments are more resistive than water bearing sediments



Basic processing

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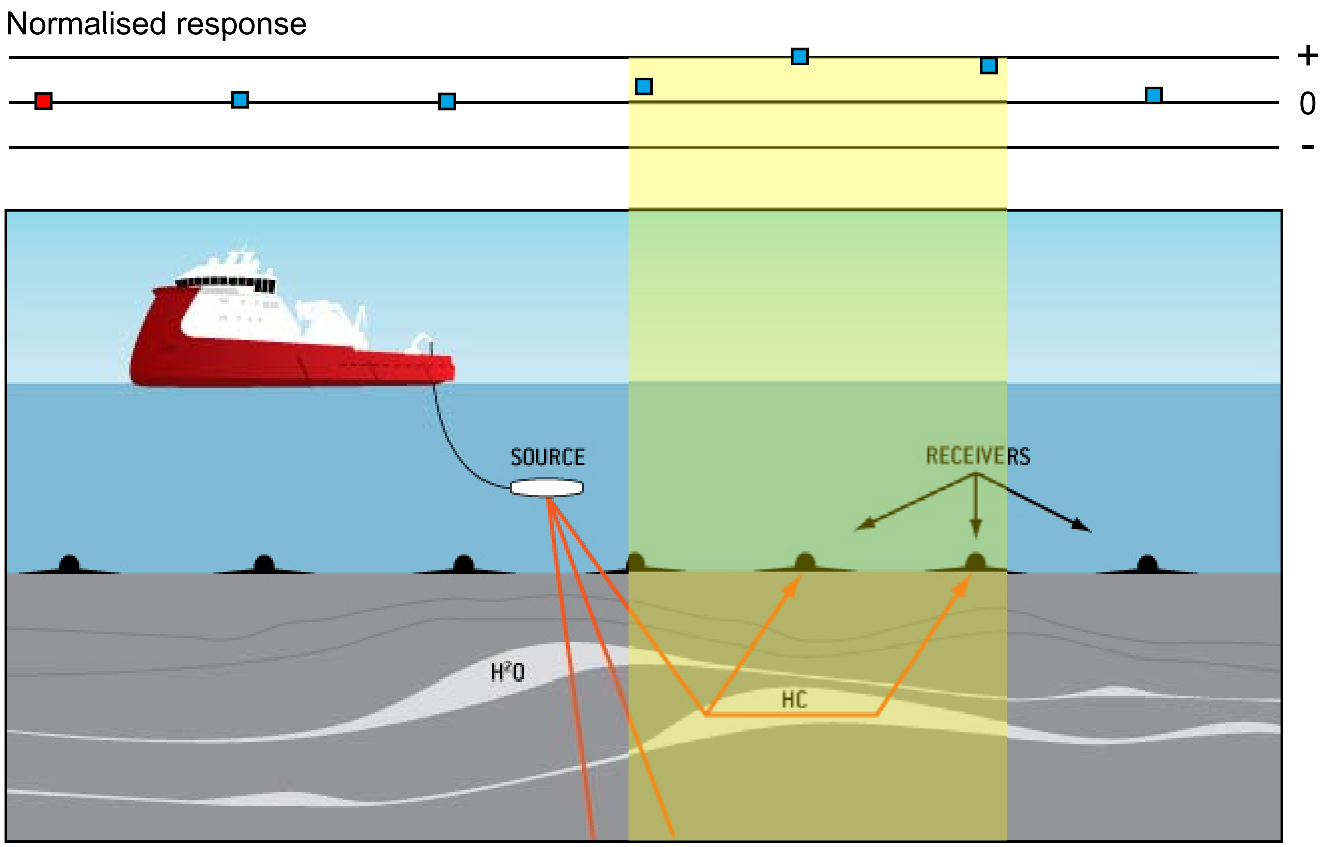
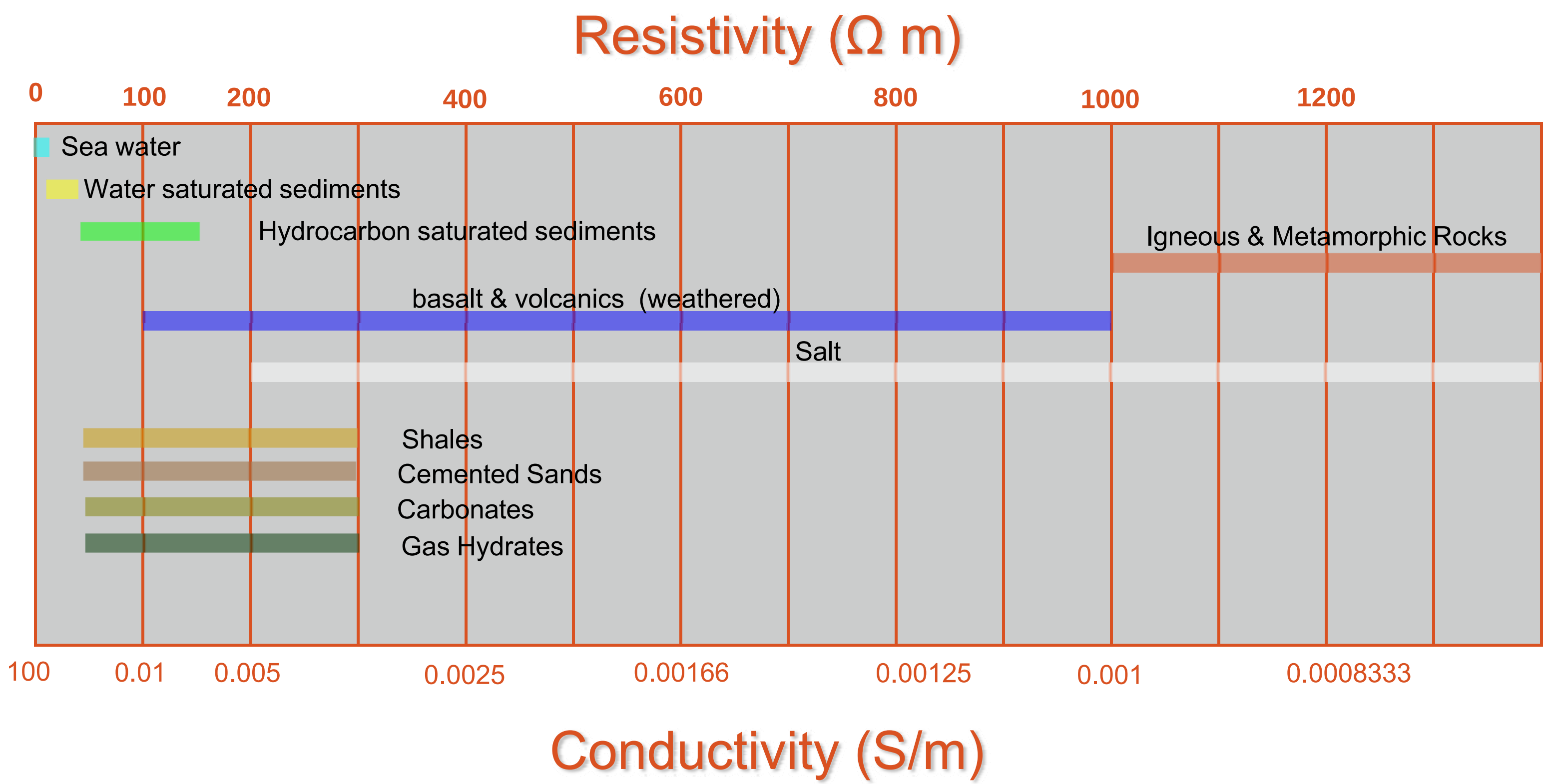
- Normalisation of responses against a receiver away from survey target



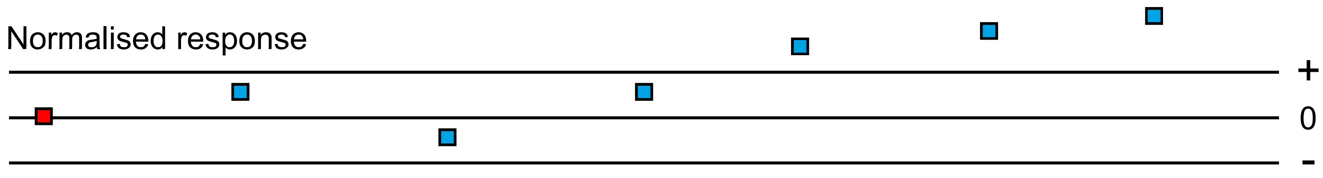
Geological complexity

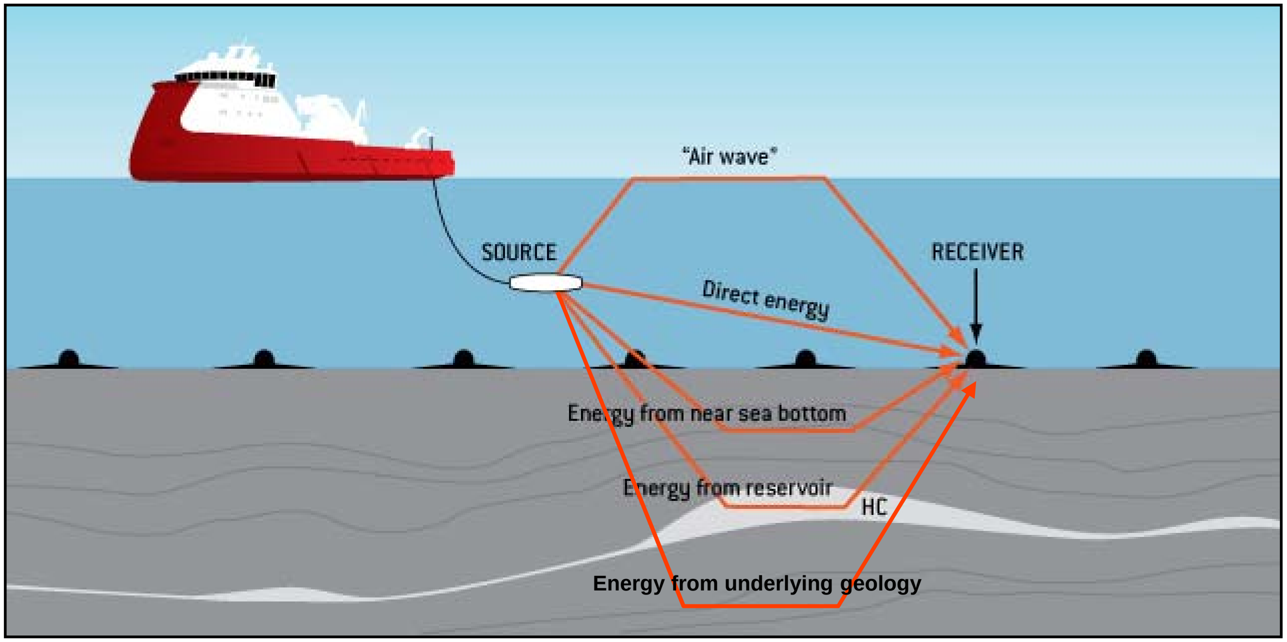
- Different lithologies have a wide spectrum of resistivity values, in some cases an order of magnitude greater than that associated with hydrocarbon-filled sediments...



Geological complexity

- Geological complexity and ”airwave” can hide signal from hydrocarbons





Inversion

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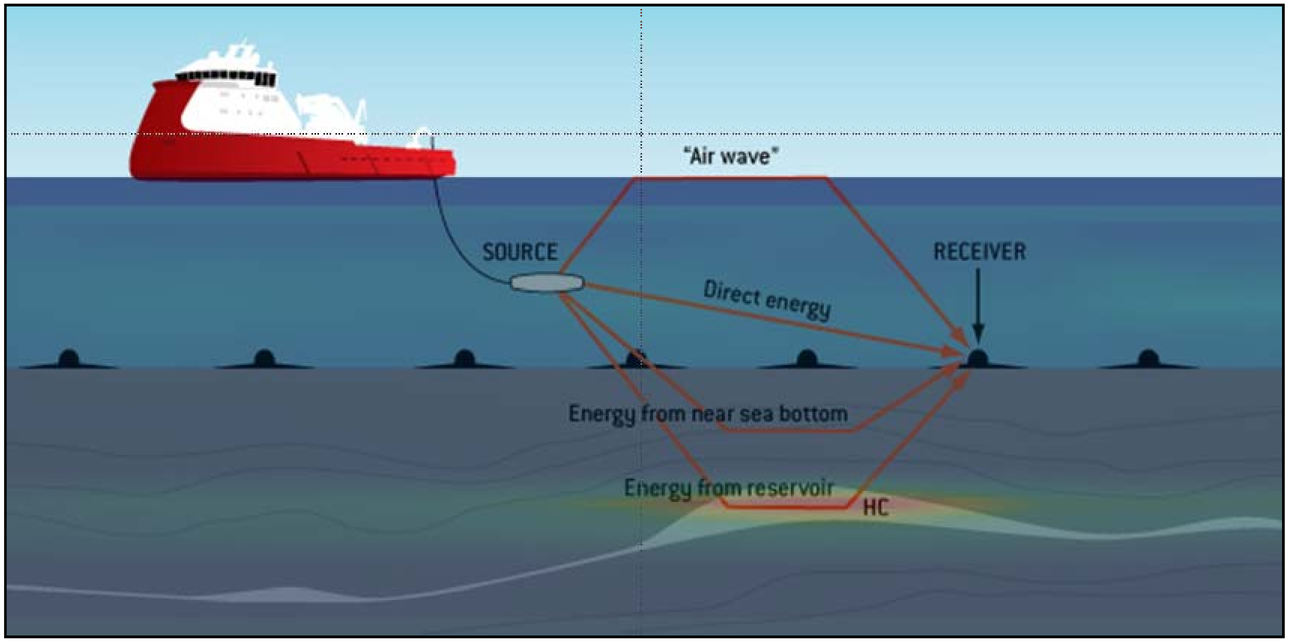
- A more advanced approach to processing CSEM data involves inversion of the data (the opposite to forward modelling)
- Results are non-unique solutions, but they show possible subsurface scenarios that could account for the results achieved



Inversion

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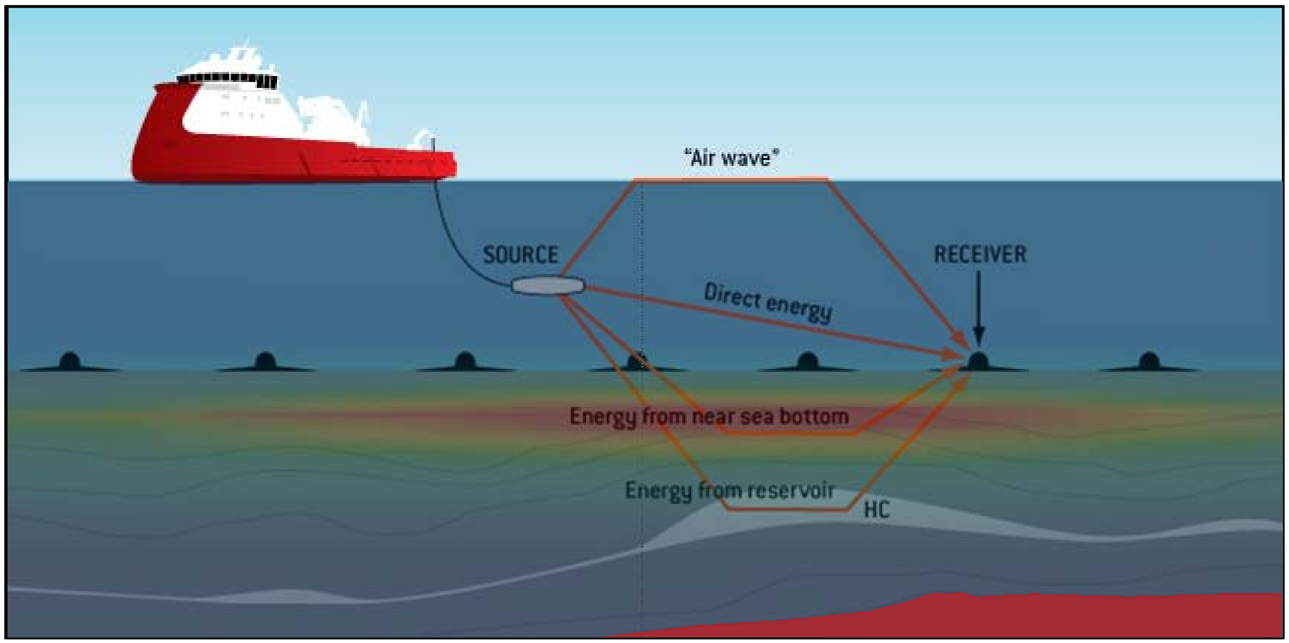
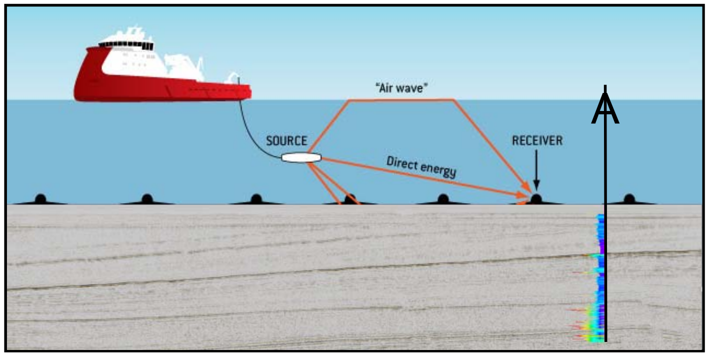
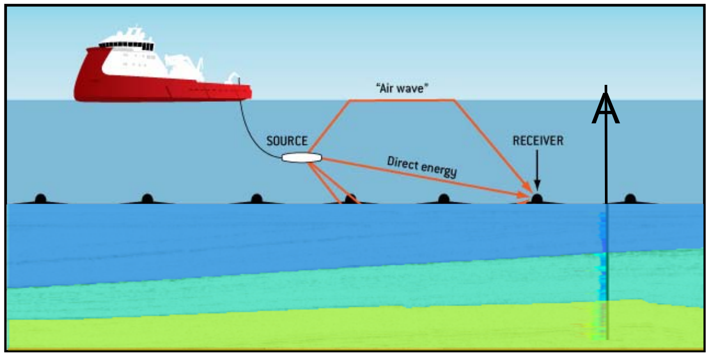
- A more advanced approach to processing CSEM data involves inversion of the data (the opposite to forward modelling)
- Geological complexity, especially resistive lithologies can complicate the process and mask the signal from hydrocarbons

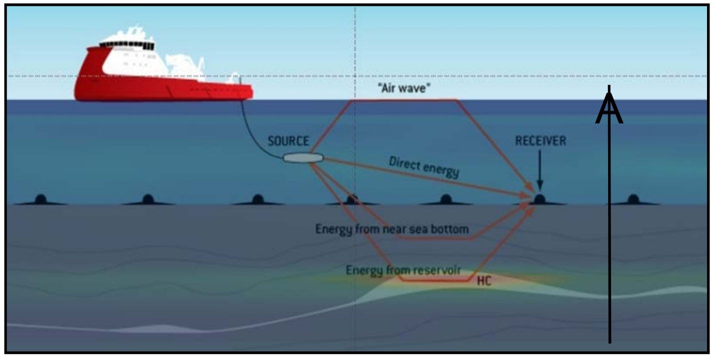


Integrated processing

- In many cases, it may be necessary to incorporate geological information into the processing of CSEM data:
  - Well logs provide information on resistivity in the subsurface
  - Seismic and depositional models used to predict lateral resistivity distribution
  - Subsurface resistivity model used to constrain or guide the inversion process







Luva Case Study

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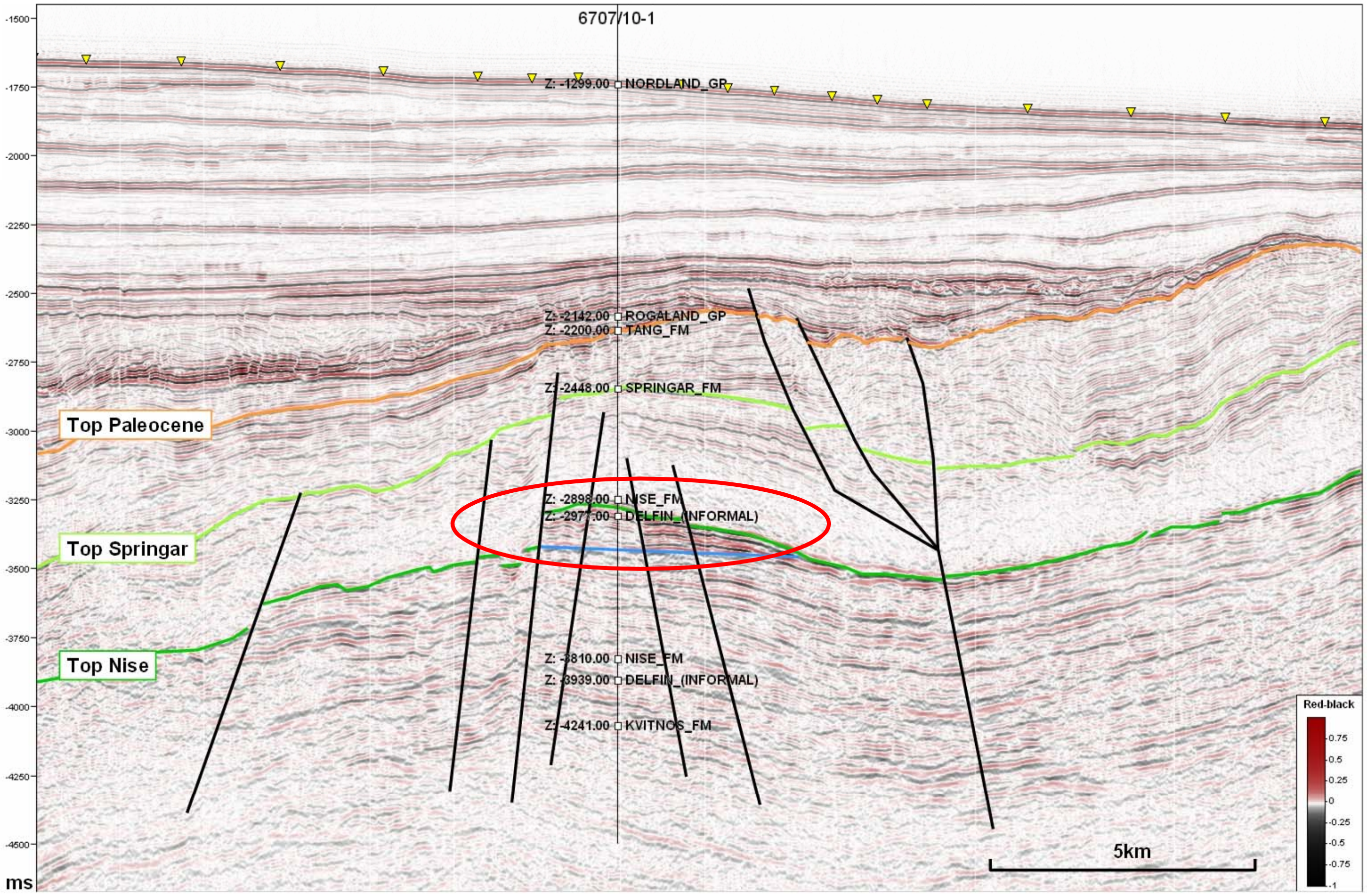
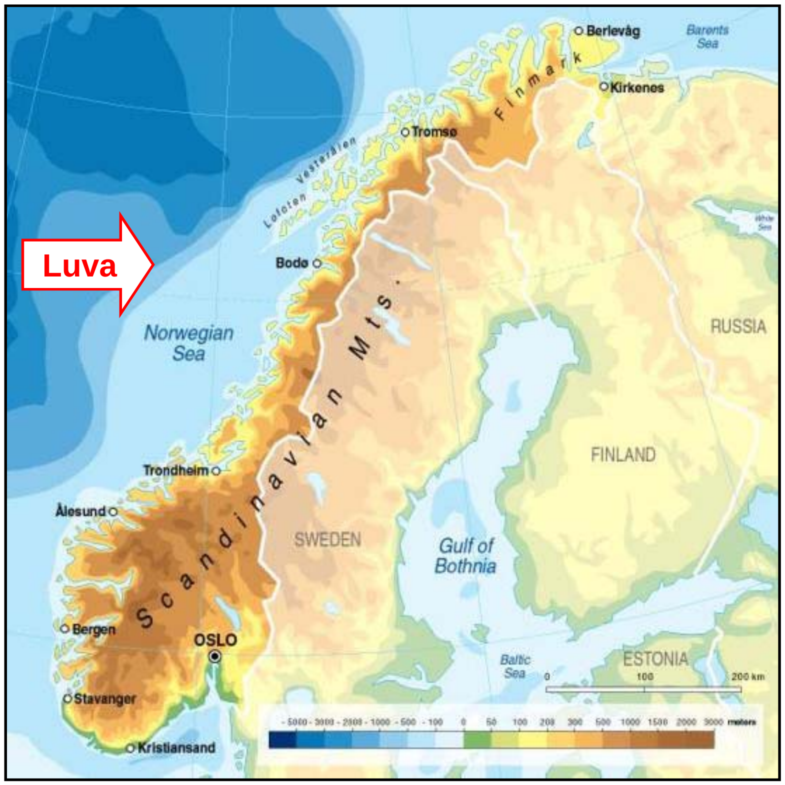
- Nise Fm consists of a thick succession of unconfined deepwater sheet sands
- Overlain by Upper Cretaceous / Paleocene shales and Paleocene sands



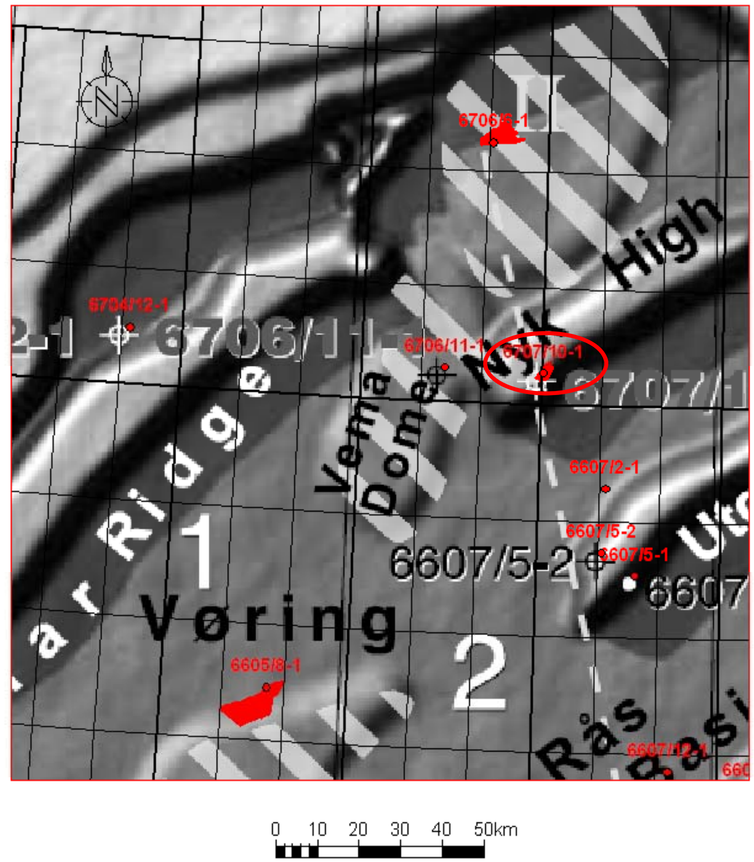
Luva Case Study

- Luva gas discovery in the Vøring Basin drilled by BP in 1997
- Upper Cretaceous Nise Fm @ 1700m SSB + 1200m water depth



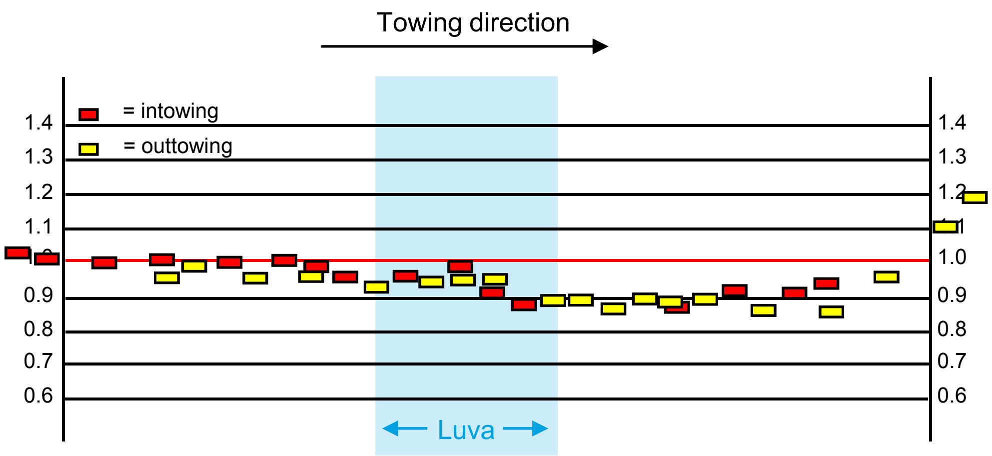
http://maps.grida.no/go/graphic/norway_topography_and_bathymetry
Philippe Rekacewicz, UNEP/GRID-Arendal

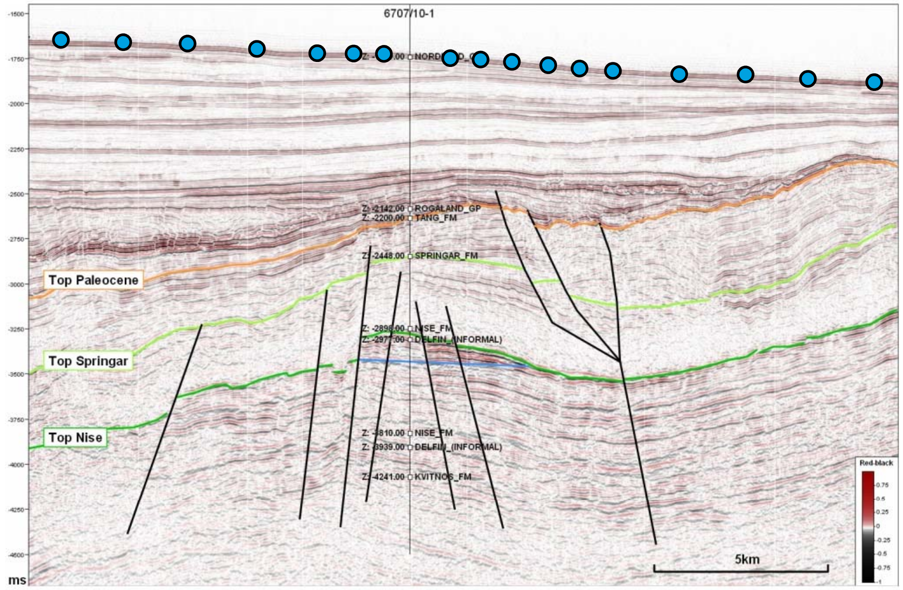
Modified from Fugelli & Olsen, 2005



Basic processing

- CSEM data acquired over the discovery in 2004 in order to test technology
- Appeared to be well suited:
  - Deep water setting (> 1000m)
  - Relatively shallow (1.7km SSB)
  - Thick gas column (>150m)
  - Lack of resistive lithologies
- Results were disappointing:
  - Normalised plot proved to be inconclusive to negative
  - Considered to demonstrate failure of the technology





Basic inversion

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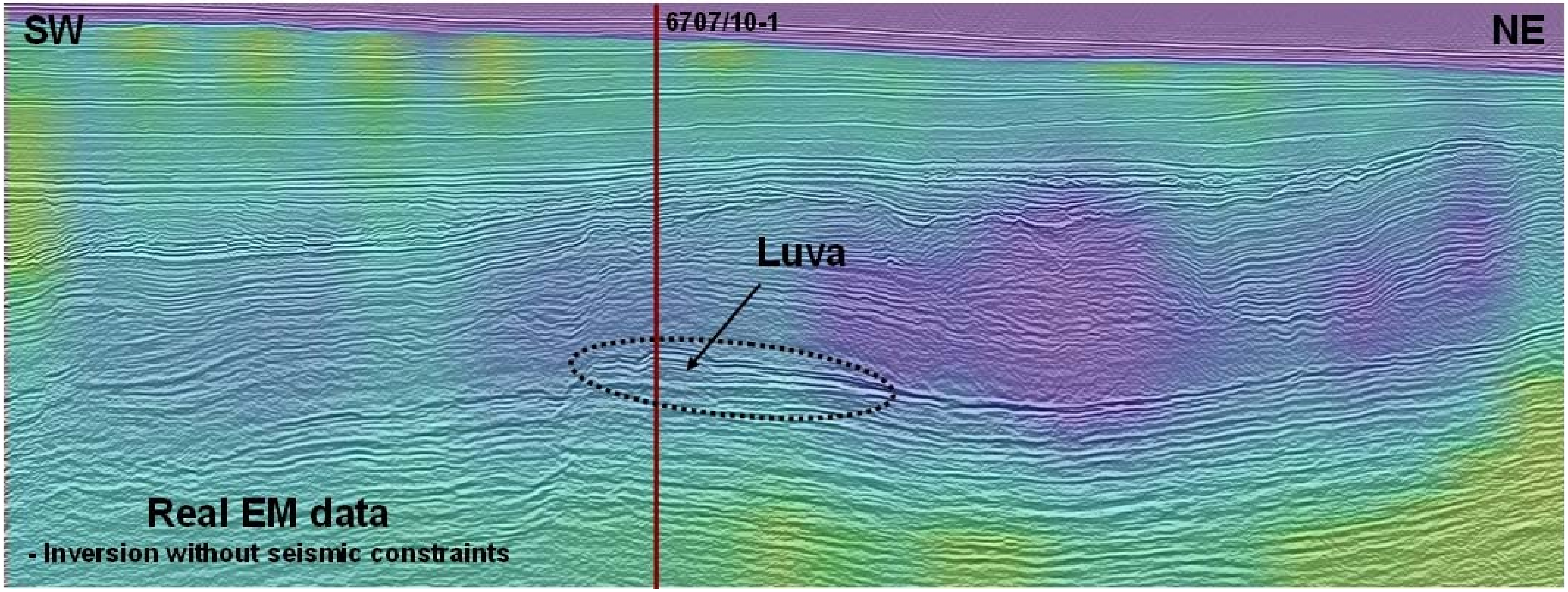
- Luva CSEM dataset was reprocessed during 2007 in order to test advances in processing capabilities and integrated workflows
- Basic inversion processing of the data also yielded a negative result with no obvious anomaly detected
- Different approach to the dataset needed



Understanding the data

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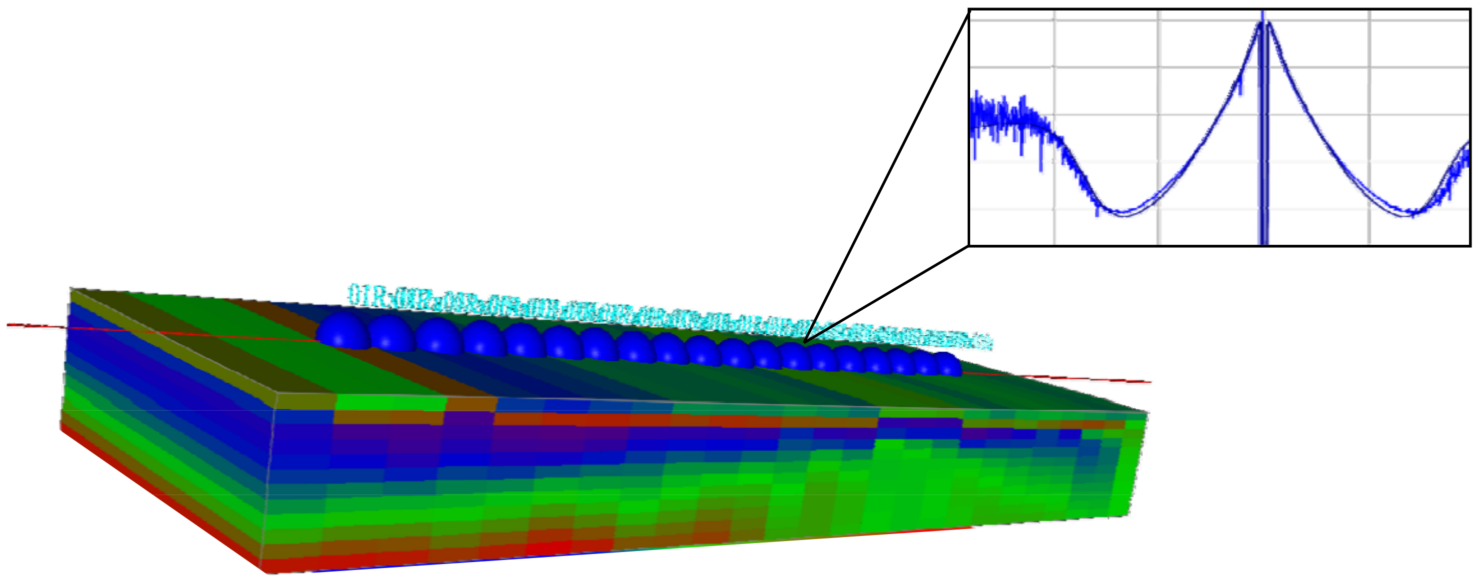
- Forward modelling using realistic synthetic data can be used to investigate the reasons for the apparent ”failure” of the technology
  - A geological model based on well and seismic data is used to model the expected response at each receiver / source position in the survey
  - Forward modelling is carried out both with and without the reservoir in order to determine how strong a signal is likely to return to the receivers



Understanding the data

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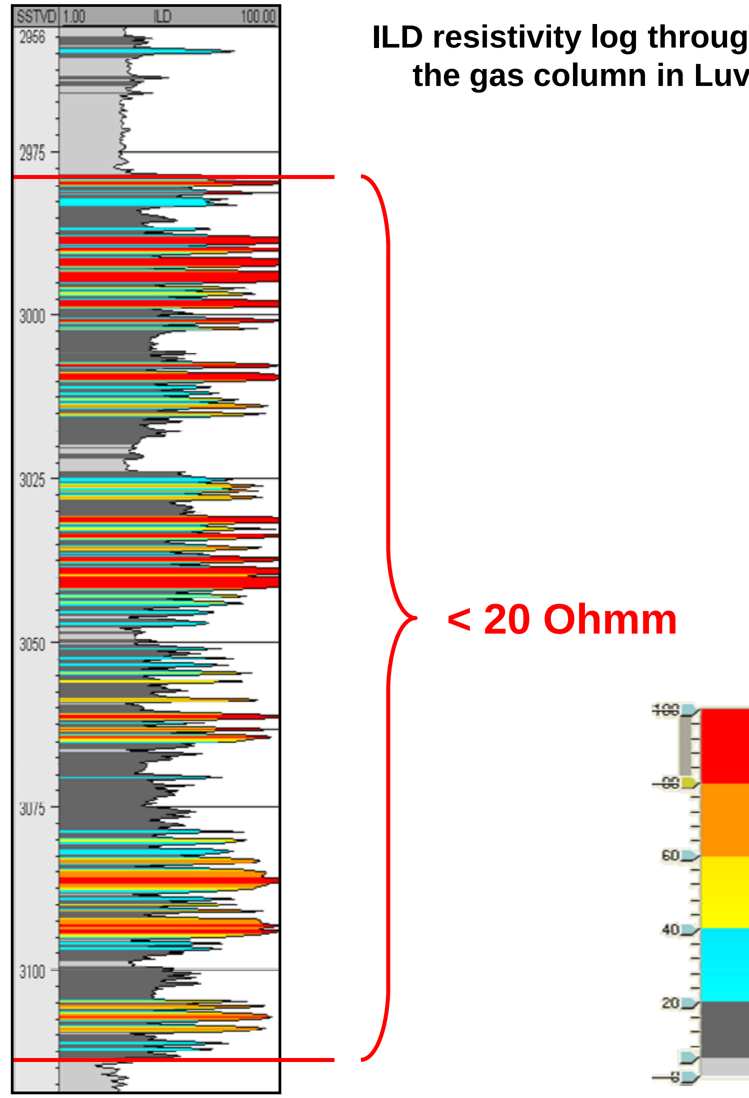
- Forward modelling showed that the expected difference between the signal with and without the gas reservoir was < 10%
- This is at or below the noise threshold and explains why the discovery was not detected using basic CSEM processing
- One of the main reasons for the weak signal is that the average resistivity within the gas column is less than 20 Ohmm
- Results in a low resistivity contrast between the reservoir and the background geology

ILD resistivity log through the gas column in Luva



Iterative approach

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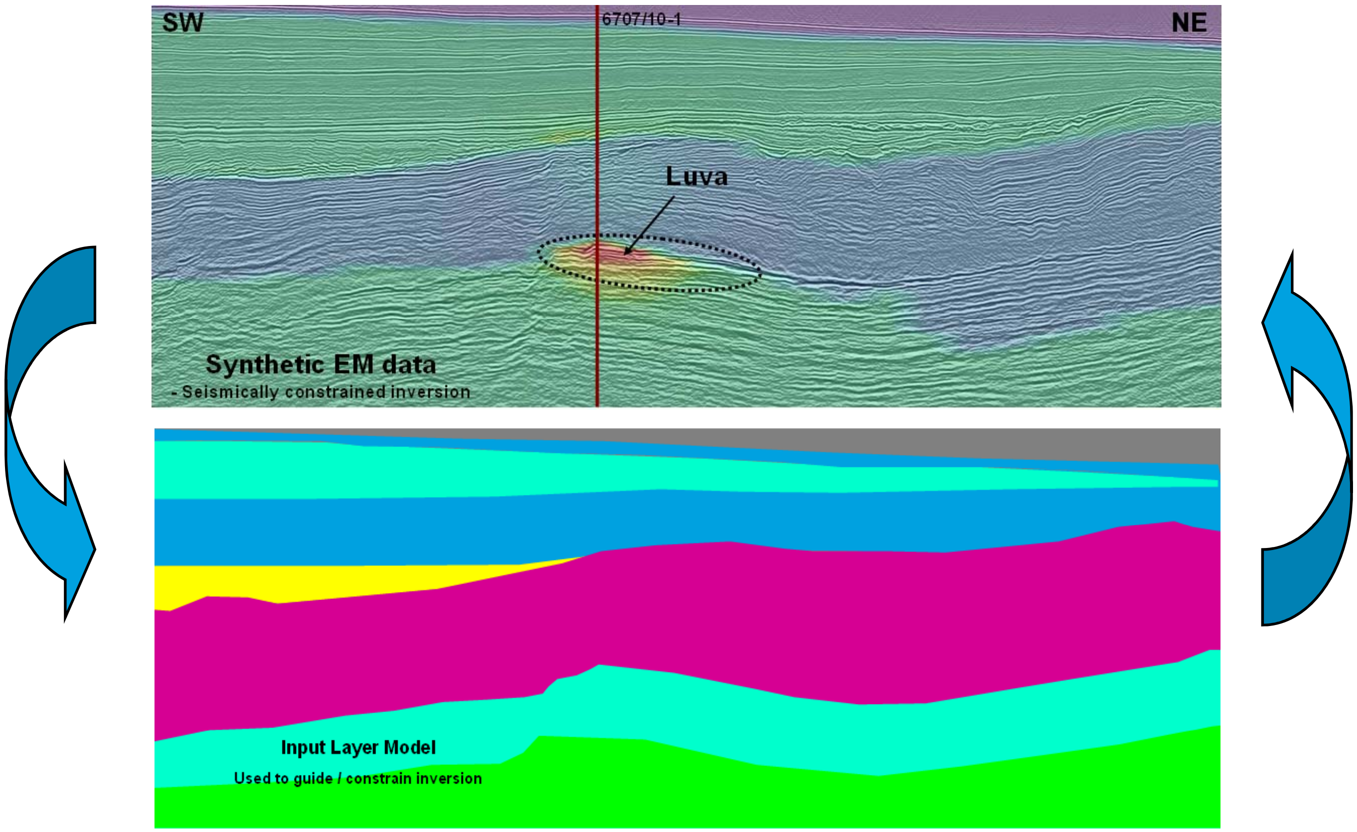
- Iteratively processing the synthetic data with a range of different values in the background layer model enables us to identify the optimal processing parameters that allow the reservoir to be resolved:



Constrained inversion

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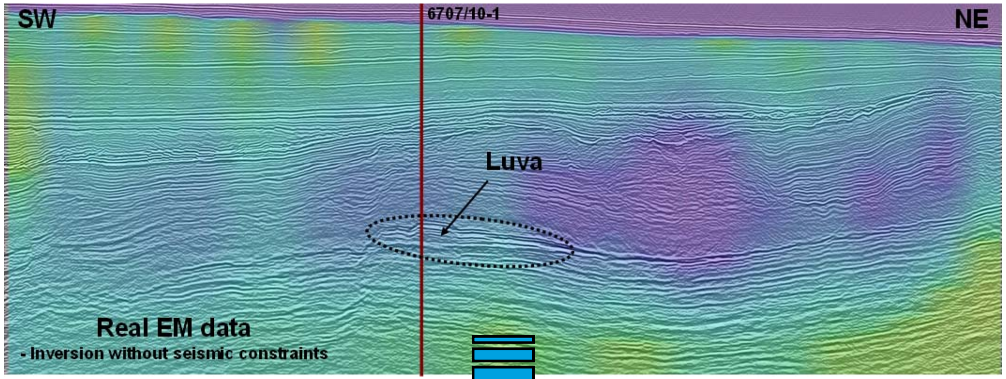
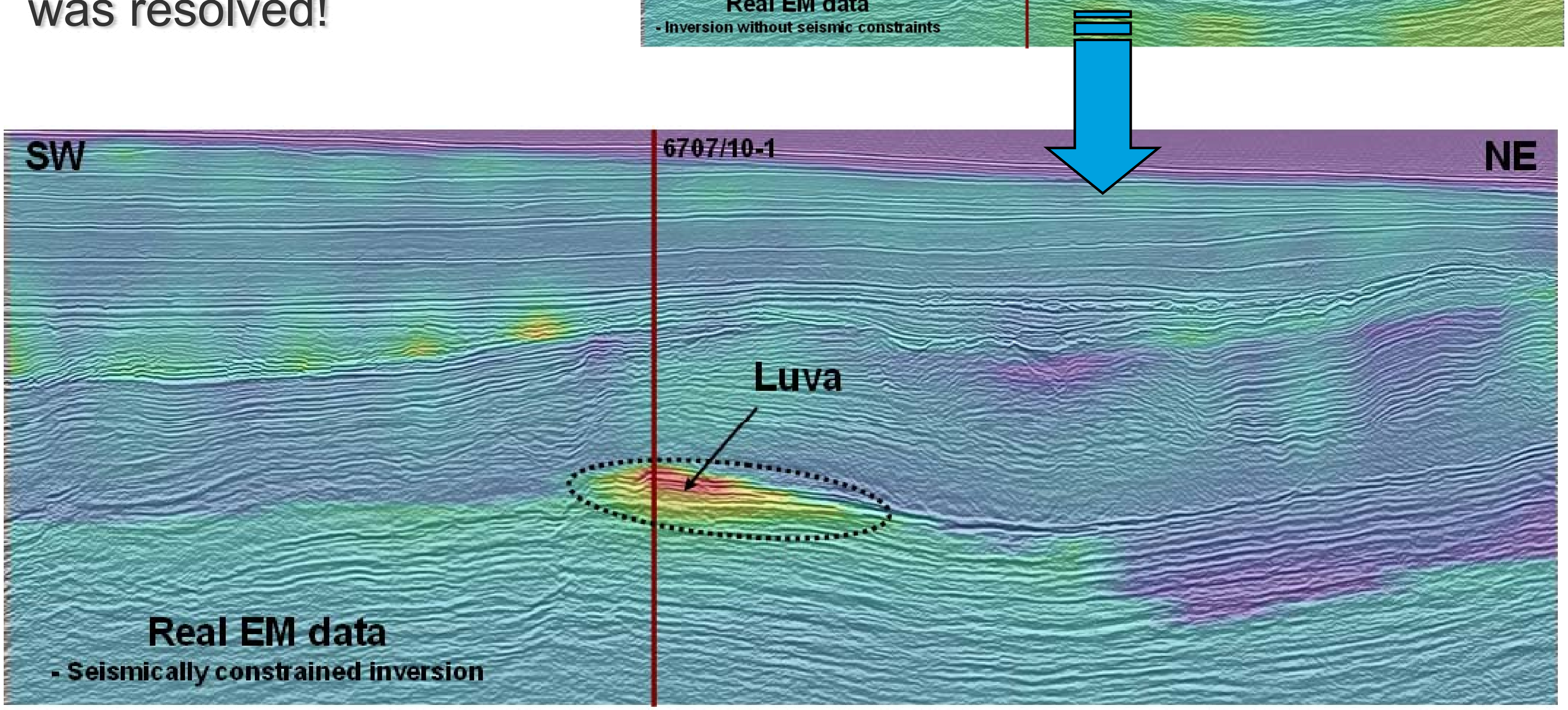
- When the real data was reprocessed using the ”correct” layer model to guide the inversion process, the discovery was resolved!





Summary

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- The Luva case study demonstrates that CSEM has the potential to be a powerful offshore hydrocarbon exploration tool...
- Integration and iteration are the key to success
- Also demonstrates some of the pitfalls that can be encountered when bringing new technologies into the exploration workflow:
- Had Luva been an undrilled prospect being tested with CSEM, it may well have been missed based on the original processing results
- New technologies often carry a heavy burden of expectation that can lead to them being prematurely rejected when ”failures” occur

Integration of new technology

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- Exploration will always carry an element of risk – regardless of how good new (or existing) technologies are!
- Nevertheless, technology (such as CSEM) can significantly modify the chances of exploration success when appropriately applied:

Conventional exploration

~20% chance of success

CSEM led exploration

>50% chance of success?

Acknowledgements

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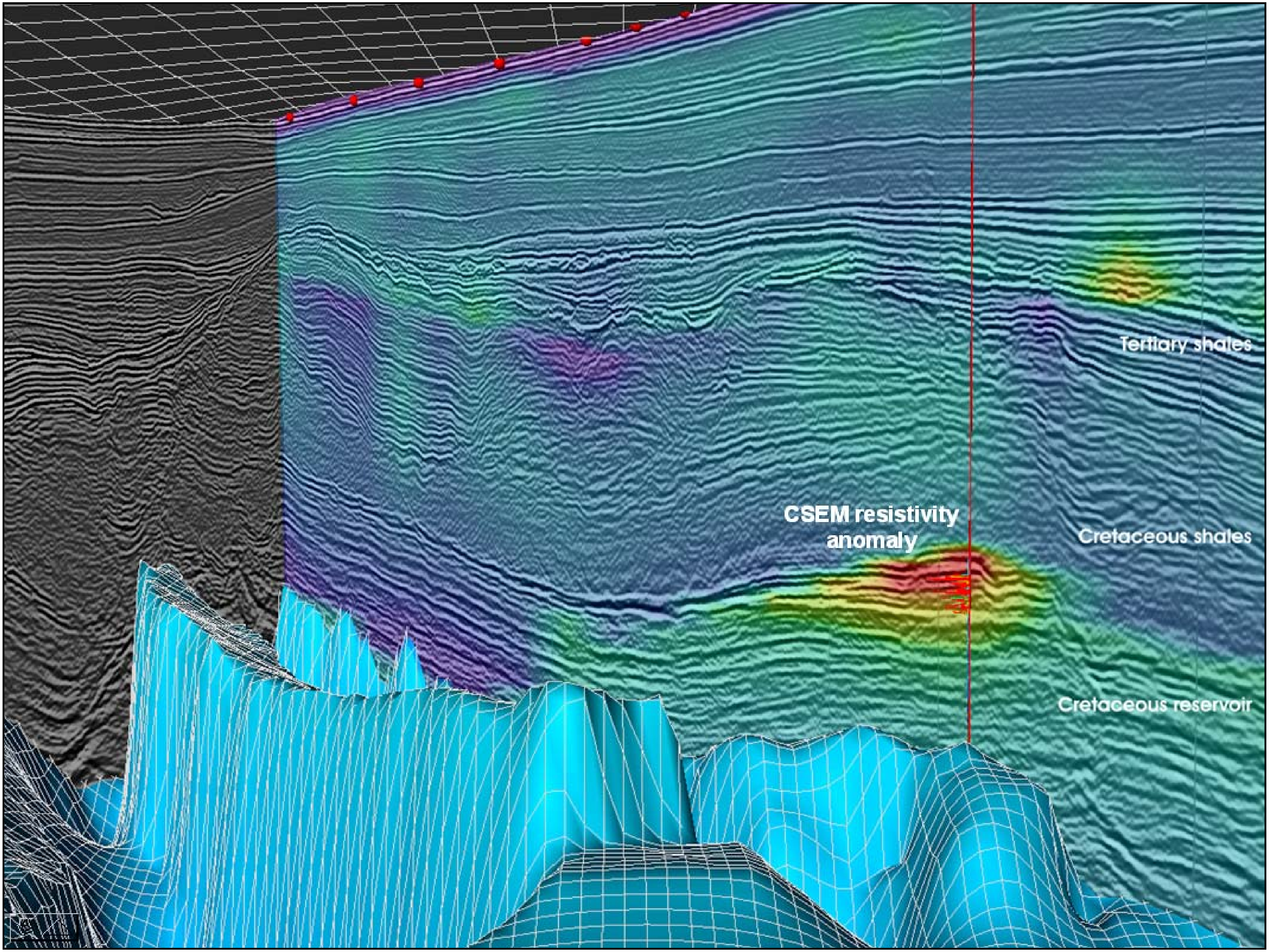
- Released seismic data from DISKOS
- Released well data from Norwegian Petroleum Directorate

- Luva case study published in GEO ExPro, September 2007
- Edited version published in Harts E&P, March 2008


Tertiary shales
CSEM resistivity
anomaly
Cretaceous shales
Cretaceous reservoir

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