CSEM's Influence on Exploration Decisions & Seismic: Examples From the Barents Sea

by By Stein Fanavoll, EMGS

Stein Fanavoll
Exploration Advisor
EMGS

While the Barents Sea has long been a source of frustration for E&P operators with only one field in production and one under development after 30 years of exploration, there has recently been more optimism with oil discoveries in Skrugard, Alta and Wisting.

Historically, exploration wells in the Barents Sea have been drilled on the basis of seismic data and geologic structures. Since 2008, however, EMGS has begun acquiring 3D controlled-source electromagnetic (CSEM) data to provide additional geophysical information in the last three licensing rounds. Over 40,000 km2 of multi-client data has been acquired to date and is being used as an interpretation tool alongside seismic.

This article will provide an update on 3D CSEM activity in the Barents Sea and through using case studies examples, will demonstrate: i) How 3D CSEM supports play models and generates valuable information on a license application phase as well as in drilling decisions; and ii) How 3D CSEM provides crucial input to prospect ranking and drill-or-drop decisions.

CSEM – Method, Survey Design & Inversion Methodology

Electrical resistivity of the subsurface is a physical property that strongly correlates with the fluid content and saturation of hydrocarbon reservoirs. 3D Controlled Source Electromagnetic (CSEM) data maps resistive anomalies in the subsurface, where the larger the resistive body, the greater the response.

All multi-client 3D CSEM data acquired in the Barents Sea is 3D wide-azimuth data and is acquired through grids of receivers (all with multi-component electric and magnetic sensors) along with a 3 km receiver and line distance.

In the case examples, the 3D CSEM data was inverted into 3D earth resistivity models.

CSEM in the Barents Sea

Most of the wells in the Barents Sea are concentrated in the Hammerfest Basin, the Loppa High, Hoop area and the Polheim Subplatform. Here, the geology is variable, ranging from Tertiary basins in the west, Jurassic basins (e.g., Hammerfest Basin) in the middle part, and Triassic and Permian platforms (e.g., Bjarmeland Platform and Finnmark Platform, respectively) in the east.

Major uncertainties remain, however, in regard to the prospectivity of some areas. This is mainly related to the reservoir quality of Triassic reservoirs and high seal risk. New ideas and technologies are therefore needed to increase future success rates.

Between 2008 and 2013, EMGS built up a substantial 3D EM multi-client library, as shown in Figure 1 where the red rectangles illustrate acquired blocks and the case study examples are shown – 1 and 2.

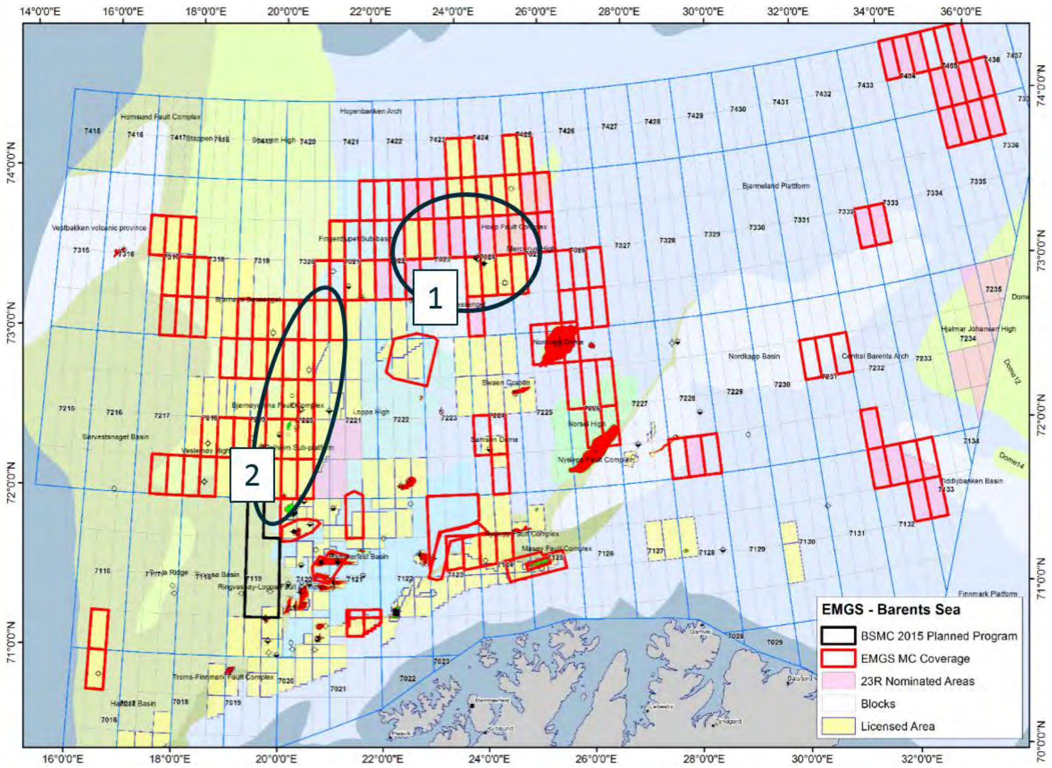

Figure 1. An overview of EM acquisition in the Barents Sea. The case study examples are shown 1-2; red rectangles indicate blocks where CSEM was acquired

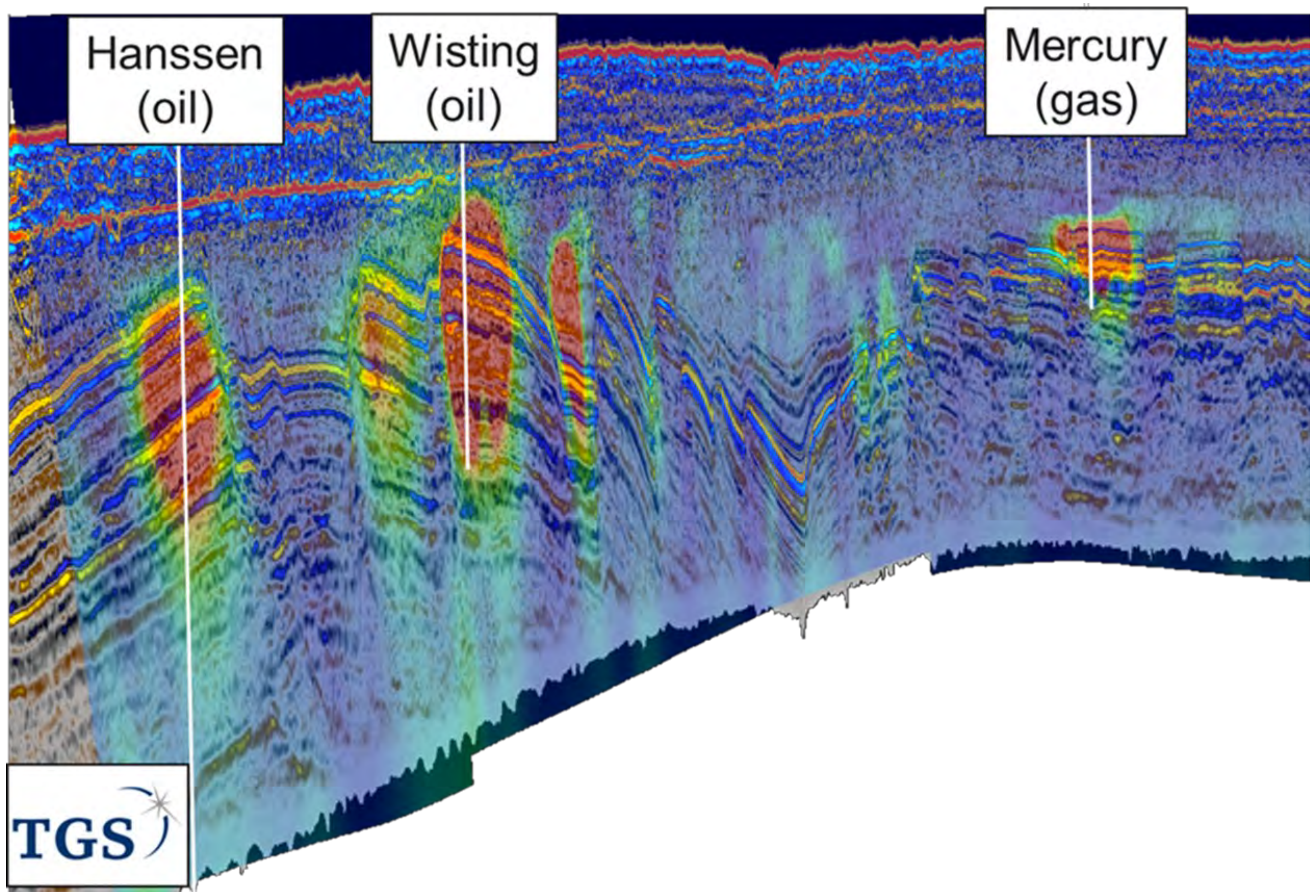

Figure 2. The Wisting, Hanssen and Mercury Discoveries where the white lines indicate wells and where the very high resistive anomalies represent hydrocarbons and show an excellent conformity to structure

Case Study 1: The Hoop Area

One key discovery in the Hoop is the Wisting prospect in Lower Jurassic reservoir rocks. In September 2013, the Austrian oil company OMV announced an oil discovery in license PL537 on the Wisting prospect with an oil column of 50–60 m and potentially recoverable reserves of 60–130 MMboe. The following year a new oil discovery - Hanssen - was announced in the same license. In the neighboring license there was a gas discovery, Mercury, the same year.

All discoveries are associated with a significant EM anomaly as can be seen in Figure 2. The illustration shows a 3D CSEM inversion overlaying high resolution seismic for the Hanssen, Wisting and Mercury wells – all of which

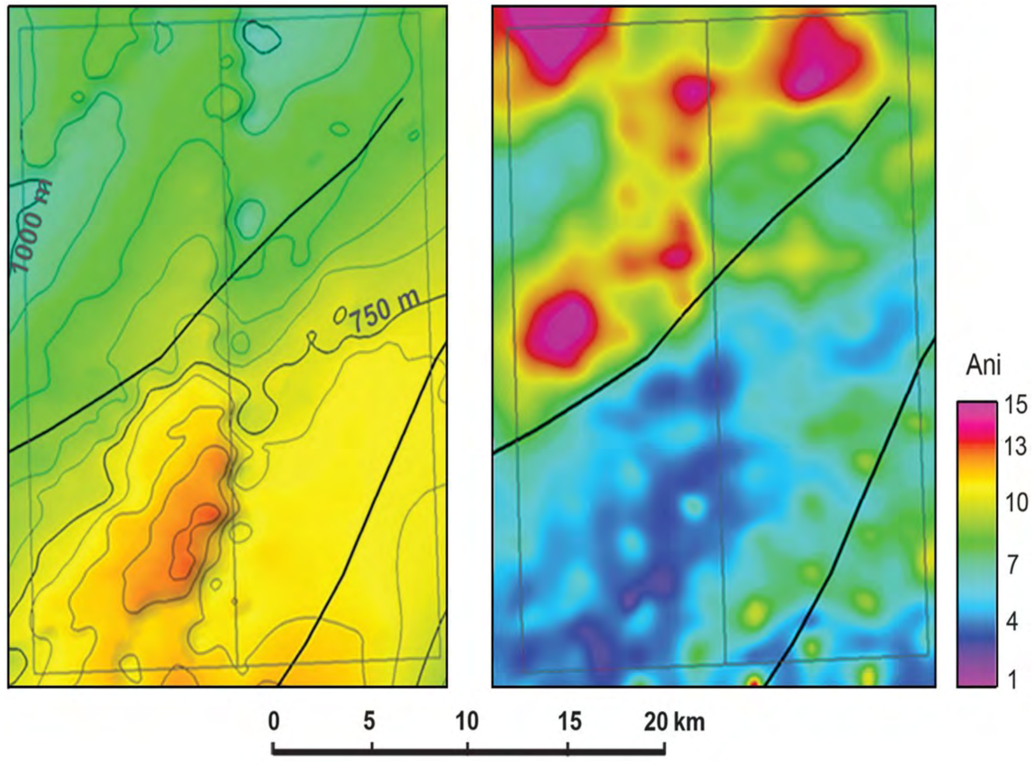

Figure 3. A structure map and CSEM Results two blocks Northwest of the Wisting Discovery. The depth structure map (left) indicates a large, shallow structural closure (contour interval 50 m), whereas the CSEM anisotropy anomaly map (right) shows resistive anomalies in the northern part

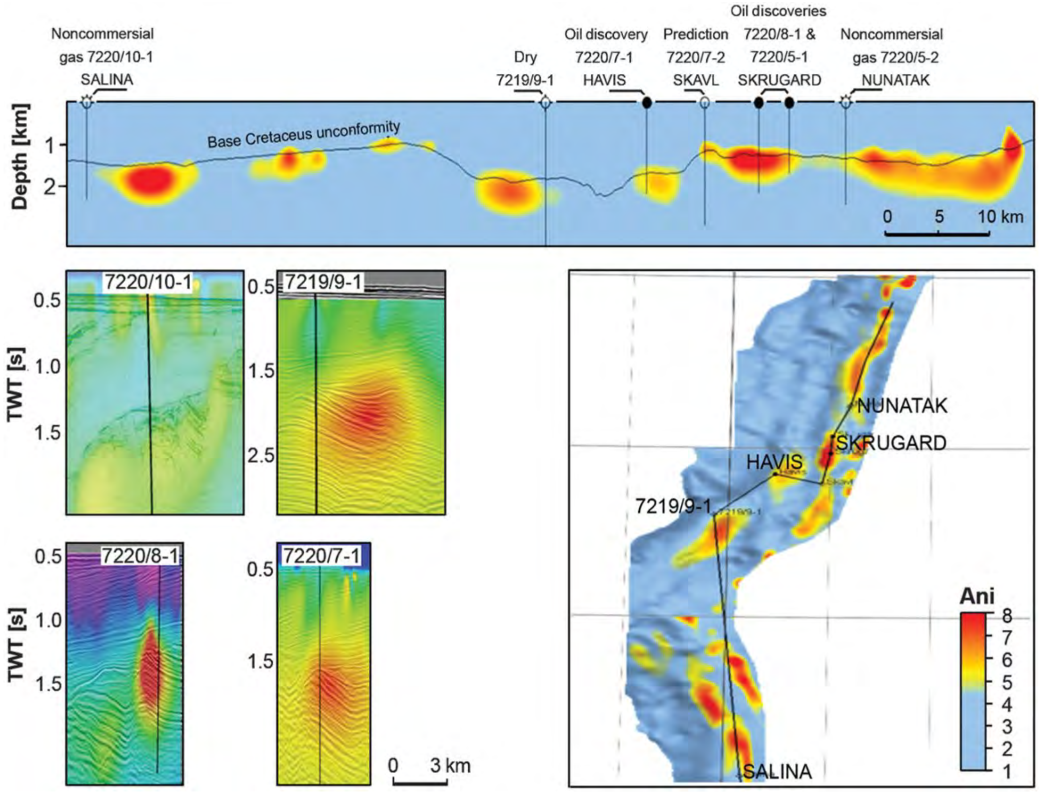

Figure 4. Seven wells where CSEM provided a correct prediction for the Lower to Middle Jurassic and Lower Cretaceous plays along the Bjørnøyrenna Fault Complex

were successful. The high resistivity (highlighted in red) indicates hydrocarbon charged reservoirs.

However, there are also examples where seismic amplitude anomalies are not associated with high resistivity, severely limiting the possible outcome of such a target.

Different Play Models Requiring Further Investigation

These discoveries also open up additional oil discoveries in the area with the CSEM data revealing large anomalies for further investigation.

Some have argued recently, for example, the case for an increased focus on a different depositional environment in the upper Triassic *(Kjølhamar, 2012)*. This idea is supported by the inversion results from the CSEM data, where CSEM anomalies are present in the area where these Triassic reservoirs are assumed to be present *(Fanavoll et al., 2013)*. This also raises fundamental questions as to which play models should be pursued: the resistive Triassic target or the Jurassic target even though there might be a mismatch between seismic and CSEM?

When studying the map for two of the blocks in the area (see Figure 3), it can be seen that there is little correlation between the shallow Jurassic structure and CSEM anomalies. This suggests that if the anomalies are caused by hydrocarbons, the traps will partly need stratigraphic closure and/or fault seal. In addition, these resistive anomalies seem to represent a deeper source for resistivity than the Wisting Discovery.

Making the right decisions between Triassic and Jurassic targets will be of enormous value to the industry, especially as the same question applies for many of the other Hoop area licenses. An integrated approach that includes CSEM, seismic AVO and inversion, well results, and other geologic information will be crucial in achieving this.

Case Study 2: The Polheim Subplatform and Bjørnøyrenna Fault Complex - Looking for Analogs

The Polheim subplatform and the Bjørnøyrenna fault complex separate the Loppa High to the east from the Bjørnøya Basin to the west. Skrugard and Havis were discovered on the Polheim subplatform in 2011 and 2012.

Figure 4 shows seven wells in the area where CSEM provided a correct prediction for the Lower to Middle Jurassic and Lower Cretaceous plays along the Bjørnøyrenna Fault Complex.

Three of the wells are significant discoveries (Havis 7220/7-1, Skrugard 7220/8-1, and 7220/5-1). Skavl (7220/7-2) also revealed oil and gas predicted by CSEM, although it was a small discovery. Together these discoveries form the Johan Castberg field development.

Three wells are non-commercial or dry (7219/9-1, Salina 7220/10-1, and Nunatak 7220/5-2), demonstrating CSEM's ability to distinguish between commercial and non-commercial hydrocarbon bearing reservoirs. Recently, two more wells have been drilled on the Polheim Subplatform: the Kramsnø (7220/4-1) and Drivis (7220/7-3). Both wells reported small amounts of hydrocarbons below the sensitivity range of the CSEM technology.

Figure 5 shows three leads on the Polheim subplatform along the Bjørnøyrenna Fault Complex where multi-client 3D CSEM and 2D seismic data are integrated. Two of the leads are interpreted to be analogs with the Lower to Middle Jurassic reservoirs penetrated by the wells (Figure 5a and 5b). The third lead is located east of well 7219/9-1 (Figures 4 and 5c) and is interpreted to be associated with the Lower Cretaceous–Upper Jurassic section.

Through the integration of geophysical, seismic and CSEM data (see figure 5a), an interpretation of the deltaic Lower to Middle Jurassic sand is shown in yellow and Lower Cretaceous fans are shown in green.

Structural closure is identified for the deltaic sand whereas the Lower Cretaceous fans need a combined structural-stratigraphic trap. CSEM data (anomalous vertical resistivity) overlays the seismic data to the right in Figure 5a. This CSEM attribute emphasizes anomalous resistivity values and is calculated by subtracting a background resistivity model from the vertical resistivity model obtained from inversion *(Gabrielsen et al., 2013).*

In Figure 5b, a possible flat spot is identified on 2D seismic data in a rotated fault block. The flat spot is interpreted to be in the Middle Jurassic. The CSEM

attribute apparent anisotropy overlays the seismic data to the right. Apparent anisotropy is calculated by dividing the inverted vertical resistivity model by the horizontal resistivity model.

This attribute emphasizes thin resistors because thin resistors are only imaged in the vertical resistivity model and not in the horizontal resistivity model in an unconstrained inversion *(Alcocer et al., 2013; Gabrielsen et al., 2013)*. The apparent anisotropy shows an anomaly located in the same position as the flat spot on the seismic.

The last example is within Upper Jurassic to Lower Cretaceous syn-rift sediments southeast of the dry well 7219/9-1 (Figures 4 and 5c). Sand is predicted to be present in the syn-rift sediments by seismic inversion *(Carstens, 2009 and Gabrielsen, 1994)* and a vertical resistivity anomaly is identified to be located in these syn-rift sediments (Figures 4 and 5c right). The depth of this resistive anomaly is uncertain.

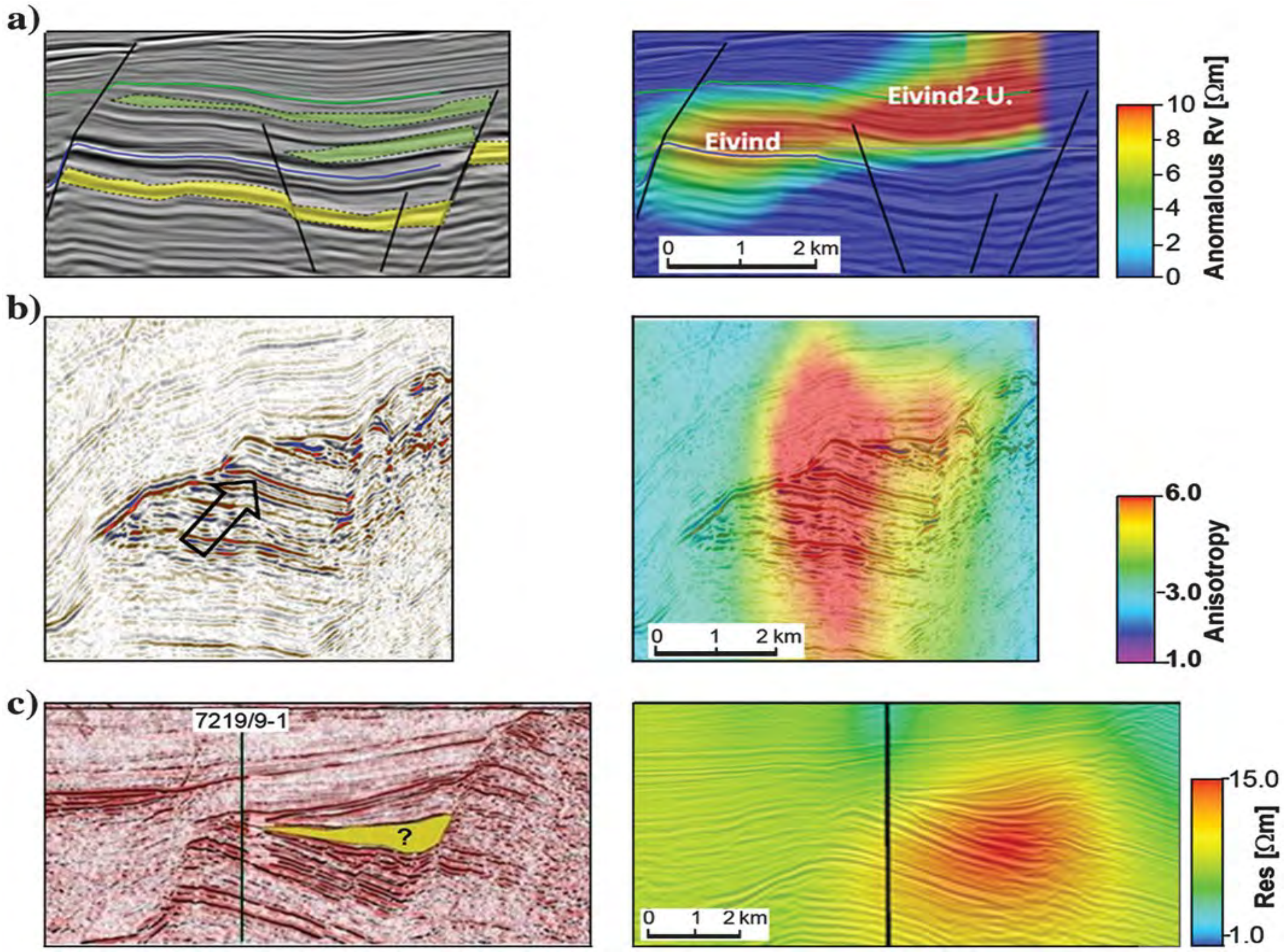

Figure 5 - Three leads on the Polheim subplatform along the Bjørnøyrenna Fault Complex where multi-client 3D CSEM and 2D seismic data are integrated

The two first leads in Figure 5 also show resistive anomalies in Lower to

Middle Jurassic sands located in a rotated fault block. One of them also shows indications of a flat spot on the 2D seismic data. These leads are interesting because they can be regarded as analogs to the Havis and Skrugard discoveries.

The result of combining CSEM with marine seismic is the identification of a number of new leads and vital information for prospect ranking and drill-or-drop decisions.

Conclusion

While exploration history in the Barents Sea cannot be considered successful to date, the emergence of CSEM data as a complimentary tool to seismic raises reasons for optimism, especially as there are large unexplored areas (in the range of 100,000 km2).

With the coverage of 3D multi-client CSEM data allowing for the calibration of more than 20 wells - some drilled before and some after CSEM acquisition - for all these wells CSEM accurately predicted the outcome of drilling. This knowledge can in turn be used to better de-risk new prospects.

Based on this convincing track record to date in the Barents Sea, CSEM data when interpreted alongside other geophysical and geologic information can have a crucial influence on exploration decisions - where to and where not to drill, license applications, prospect ranking, drill-drop decisions, and farm-in–farm-out decisions

Acknowledgments

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Some examples are also taken from the joint project between EMGS and MultiClient Geophysical ASA for seismic and CSEM integration and cooperation between EMGS and TGS.

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