EM anomaly detection under a high resistive, anisotropic overburden: Inversion study from the Nucula discovery, Barents Sea

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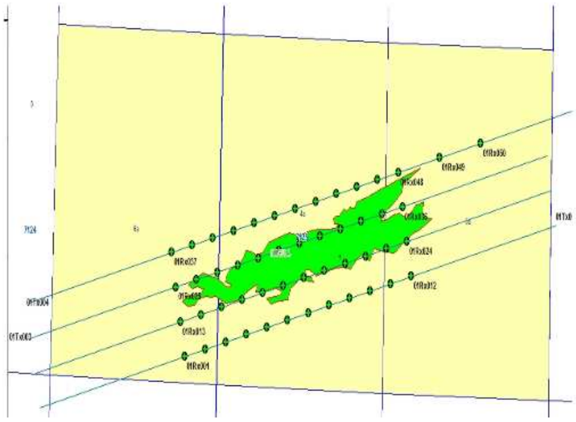
Summary: We show that with good quality, far offset, controlled source electromagnetic (CSEM) data at high frequencies, it is possible to detect resistive anomalies below an anisotropic, high resistive overburden.

Background: The Nucula prospect in the Barents Sea represents a challenging case study for the CSEM technology. As often found in the Barents Sea, the overburden of the Nucula field is highly anisotropic. This anisotropy must be taken into account for a proper estimation of the resistivity distribution underneath. An additional complication at the Nucula discovery is a relatively thick, high resistive layer belonging to the Cretaceous Kviting formation in the overburden. This layer is found in several representative well logs from the Hammerfest basin. A thick high resistive layer will strongly influence the CSEM data, and may dominate responses from resistivity anomalies underneath. These two factors, anisotropy and a thick high resistive layer in the overburden, make the evaluation of possible hydrocarbon induced resistivity anomalies challenging for the Nucula discovery.

EMGS carried out a 3D grid survey over the Nucula prospect in late 2008. Using the acquired knowledge about anisotropy and high-resistive background, a source waveform with high frequency content (f=1, 3, 5 and 7 Hz) was used. We show below that from these data, it is possible to detect resistive anomalies below the anisotropic, high resistive overburden at Nucula.



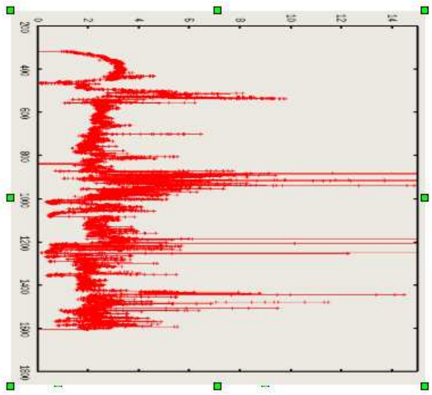


*Figure 1: **Left:** Nucula prospect (green) and 3D grid survey layout. From bottom to top, acquisition line 1, 2, 3, and 4. **Right:** Well log from the 2007 discovery well on line 2 showing the horizontal resistivity versus depth (vertical axis). Note the nearly 100m thick high resistive layer belonging to the Cretaceous Kviting formation in the overburden at around 500m depth.*

Method: We have estimated the resistivity distribution at the Nucula field by inverting in-line data from acquisition lines 2 and 4 (see Figs. 1 and 2) using an anisotropic 2.5D inversion algorithm. This is a pixel based inversion tool, i.e. each point of the resistivity model can be inverted for individually. The 2.5D assumption is that the earth is invariant transversal to the source tow-line, i.e. only variations in the resistivity distribution along the line and in depth are taken into account. Regularization which favours a horizontally layered model is used to stabilize the ill-posed inverse problem. To reduce the effect of the air wave, we muted all offsets above 10 km for f=1 Hz and 6.5 km for f=3 Hz. A more detailed description of the method will be published elsewhere.

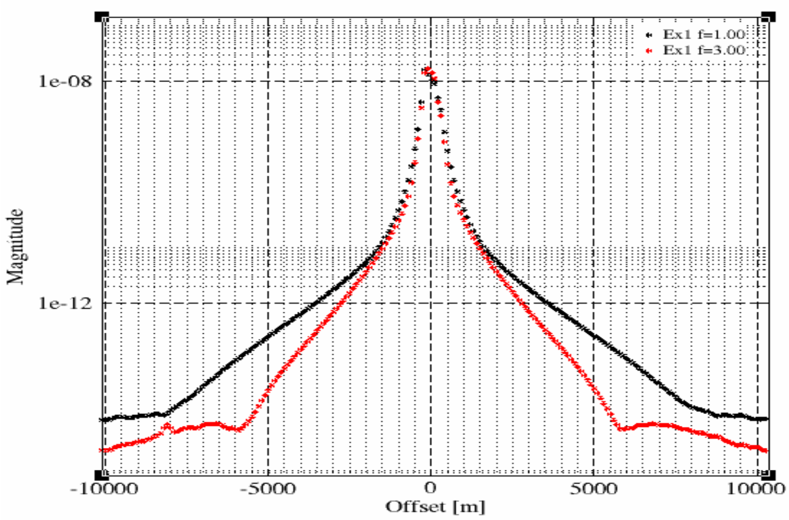


Figure 2: A representative data sample from the 3D grid survey. Magnitude of the in-line electric field versus offset for a single receiver at two frequencies 1 and 3Hz. The data quality is consistent over nearly 7 decades for offsets -10000m to 10000m.

Results: The resulting vertical resistivity models for lines 2 and 4 are shown in Figure 3. We see that the vertical resistivity model for both acquisition lines contain a high-resistive layer in the overburden. This high-resistive layer strongly influences the total electromagnetic response and may thereby mask the response of possible smaller resistivity anomalies below. However, due to the good quality of the high frequency data at far offset, see Figure 2, it was still possible to detect a resistivity anomaly below the overburden. It is precisely those high frequency, far offset data that contain responses of anomalies below the overburden.

The anisotropic 2.5D inversion result in Figure 3 also shows that the vertical resistivity model for line 2 contains a laterally bounded, resistive anomaly of up to 35 Ωm beneath the overburden. The resistive anomaly is located close to the position of the discovery well. The vertical resistivity model for line 4 does not show a similar resistive anomaly, see Figure 3. This line is outside the Nucula prospect, see Fig. 1. Although the anomaly is required to explain the CSEM data, we note that the background resistivity outside the anomaly at the same depth is around 8-10 Ωm. From Archie's law we see that it is the ratio of the resistivity of the anomaly and the background that is important for estimating the hydrocarbon saturation, not the absolute resistivity of the anomaly. In this case, this ratio is no greater than around 4, which leads us to classify the resistivity anomaly as weak. A more thorough petrophysical analysis is required to attempt to quantify reserves from the CSEM data, which is beyond the scope of this paper. It is interesting to note that standard processed attribute data (Normalised Magnitudes and Phase) do not show any large anomalies over the survey area. This can indicate that much of the resistivity seen by the inversion is indeed part of the background, and not caused by thick, high resistive hydrocarbon reservoirs.

Let the anisotropy be defined as vertical resistivity divided by horizontal resistivity. We find the first layer between the sea floor and the top high resistive layer to be isotropic. The overburden, however, is highly anisotropic.

The data misfit for the resistivity models shown is very low, below 5% on the average. Thus, the resistivity models shown in Fig. 3 provide a good explanation of the acquired data.

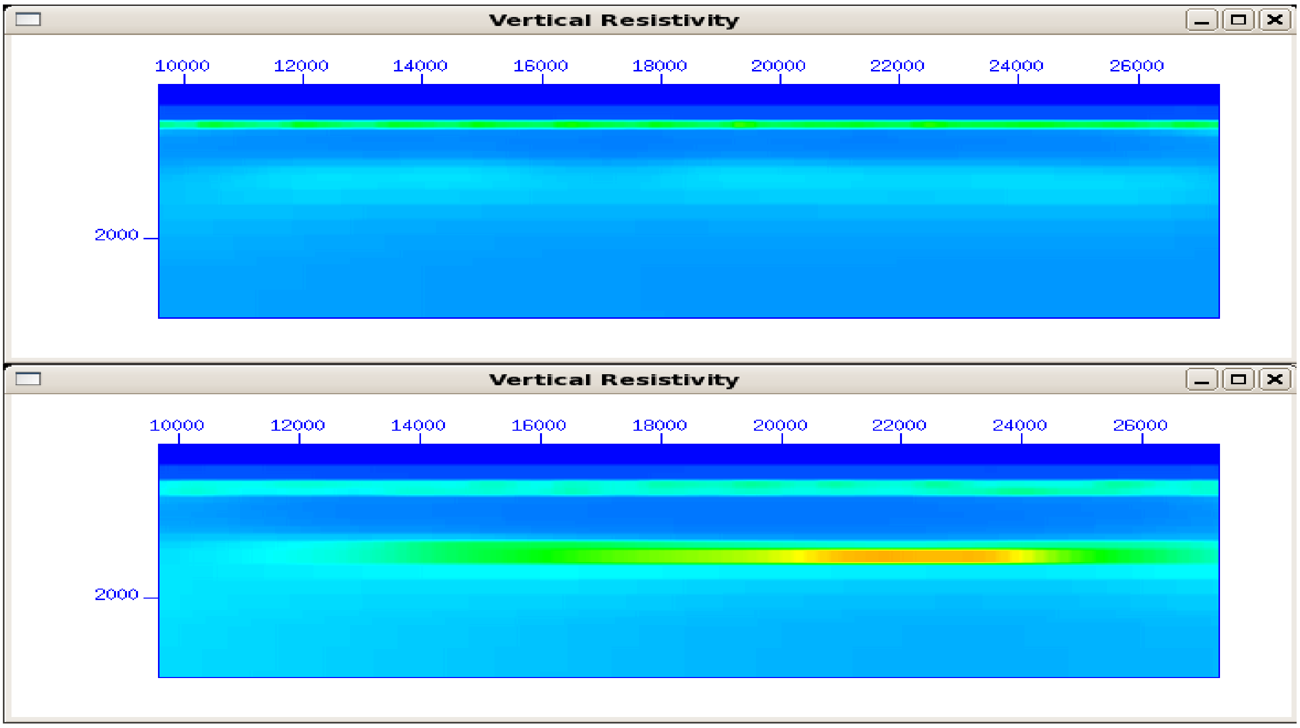


Figure 3: Vertical resistivity models for acquisition line 2 (bottom) and line 4 (top), red/blue color denotes high/low resistivity. Note the resistive anomaly at line 2, which is not found at line 4. Note also the high resistive layer in the overburden.

To check for the consistency of the resistive distributions shown, we have carried out several runs using different starting models, regularization parameters, frequency contents and offset mutes. All the inversion results support qualitatively the models shown although the precise amplitude of the resistivities and the layer depths may vary somewhat from run to run.

Conclusion: We have shown that using state-of-the-art CSEM with high frequency, long offset data, it is possible to detect resistive anomalies below an anisotropic, high resistive overburden. The position of the resistive anomaly found is consistent with the prospect and discovery well. Thus, with correct source frequencies and good quality long offset data, the CSEM may be used to evaluate the Nucula discovery.

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