

Contribution to Prospect De-risking on the Veslemøy High, SW Barents Sea - An Offshore Vertical Source, Vertical Receiver CSEM Survey*

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Abstract

Integration of electromagnetic methods with seismic measurements has gained acceptance in the petroleum industry as a powerful tool for prospect de-risking. A time domain controlled-source electromagnetic (CSEM) method for marine hydrocarbon prospecting developed by the Norwegian company PetroMarker has been utilized in connection with the 21st License Concession Round application. The objective of this work was to evaluate a prospect defined by a small fault-bounded closure. This structure is located on the Veslemøy High, a prominent feature developed on a sheared margin setting in the SW Barents Sea. The stratigraphy beneath the high is not fully understood due to limited seismic resolution and lack of exploration wells. A geological model depicting a Jurassic or Cretaceous reservoir prospect at the top of the structure is proposed. In order to mitigate the risking factor prior to license application, a 2D EM survey was acquired over the target structure, with the prospect expected at ~2.5 km depth. The layout of the survey was designed to obtain optimal data coverage both above and outside the target.

This EM technique is characterized by vertical, stationary transmitters and receivers which operate at short offsets (typically ~1 km). The strong depth penetration and high lateral resolution of the method makes it particularly suitable in cases where target width and target burial depth are of comparable dimensions, like in the structure investigated herein. The results of the 8.5 km acquisition profile revealed a prominent resistivity anomaly at the NW end of the line, coincident with the position of the target structure.

Data inversion was performed using a 1D Marquardt-Levenberg inversion scheme incorporating anisotropy, using both unconstrained and constrained approaches. In both cases, the results confirm the presence of a resistor at the position of the target structure, consistent with pre-inversion apparent resistivity results.

From the exploration company's point of view, the contribution of this method in the de-risking workflow is considered as valuable because of the great potential showed in the detection of relatively small prospects. A more comprehensive evaluation of the method can be achieved after an eventual drilling of the prospect.

Introduction

Low-frequency electromagnetic (EM) prospecting methods have gained a lot of interest in recent years because of their capabilities to detect resistivity anomalies commonly associated with hydrocarbon accumulations. Whereas seismic methods provide detailed information about the geological structure but little information on the fluid content of the rocks, EM methods discriminate between conductive and non-conductive pore fluids, such as brine and hydrocarbons, respectively. EM methods thereby complement seismic measurements for petroleum exploration applications, and the integration of the two types of measurements often represents a powerful tool for de-risking prospects prior to drilling.

Over the last two decades, various controlled source electromagnetic (CSEM) methods have emerged (Edwards 2005). An offshore, time domain CSEM method* has recently been developed by the Norwegian petroleum exploration company PetroMarker (Holten et. al 2009). This method is characterized by vertical, stationary transmitters and receivers which operate at short offsets, typically ~1 km. The vertical electrical field measured by this method enables increased depth penetration, and the short offsets yield high lateral resolution.

In 2010, as part of the pre-licensing work for the 21st Concession Round, and with the purpose of helping de-risk an offshore prospect, the exploration company Concedo engaged PetroMarker in the acquisition of a CSEM survey over a mapped prospect within the Veslemøy High, on the SW Barents Sea. The processing and inversion of the data yielded encouraging results and are presented and discussed herein. The area of application was eventually awarded as PL607 with Concedo as partner.

Prospectivity on the Veslemøy High

The Veslemøy High is a prominent positive structure that developed along the dextrally shared portion of the SW Barents Sea margin. The deformation has been associated to the opening of the Norwegian-Greenland Sea during the Eocene (Faleide et al, 2008) and resulted in a NE-SW elongated structure of considerable dimensions ([Figure 1](#)). Resolving the stratigraphy beneath this structure still remains a challenge, mainly due to lack of exploration wells and poor seismic resolution over large parts of the area. Historically, there has been assigned a Lower Cretaceous age to the thick sedimentary succession in the upper part of the structure (Faleide et al, 1993), bringing the widespread, good reservoir quality sands of Middle Jurassic age down to depths beyond the range of prospectivity. In this situation, the main prospectivity

*The vertical transmitter-vertical receiver EM technology patented by PetroMarker under the name TEMP-VEL (Transient ElectroMagnetic Prospecting with Vertical Electrical Lines)

within the large structural closure of the Veslemøy High would depend on the presence of a Cretaceous play, not yet proved on this part of the Barents Sea. An alternative model is also observed, with the Middle Jurassic play present at the top of the structure. The latter interpretation may be supported by the presence of a gravity anomaly at the position of the high. A shallow Jurassic play would indeed reduce considerably the risk of reservoir presence at prospect depth. The prospective area that was chosen for this investigation forms a NW-SE elongated fault-bounded structure (Hårteigen Structure B) located on the NE part of the Veslemøy High ([Figure 2](#)). Regardless of the stratigraphic model chosen by the interpretation, the main target lies within the uppermost interval beneath the top of the structure, draped by a regional unconformity at Base Tertiary level.

Method and Results

In August 2010, PetroMarker acquired a CSEM survey across the Hårteigen Structure B, which consisted of a single line of 8.5 km of length along a NW-SE direction ([Figure 2](#)). The layout of the survey was designed to obtain optimal data coverage both above the target and from an adjacent “off-target” area to the SE. The locations of transmitters and receivers and the properties of the transmitted source signal were based on factors such as water depth, depth to target and seabed conditions. A total of six receiver positions and fifteen transmitter positions were utilized, with spacings of 1,700 m and 850 m respectively, giving primary offsets of 850 m and 1,200 m ([Figure 3](#)). These short offsets are possible because of the method’s ability to record near-field responses originating from localized spatial regions in the vicinity of each transmitter position. This enables high lateral resolution, including improved edge detection potential. According to Alumbaugh et al. (2010), the fundamental physics of conventional horizontal-dipole CSEM requires a potential target to be ‘wide enough’ in order to be detectable, i.e. the ratio of target width to target burial depth must be considerably larger than 1. In the case of the Hårteigen Structure B, the limited target width and the target burial depth (2 – 2.5 km) are of comparable dimensions. Therefore Alumbaugh’s study shows that the vertical-dipole method in this case is clearly more favourable, due to the increased sensitivity to the target.

After a thorough quality control of all acquired data where out-of-spec measurements were left out of the further analysis, EM responses associated with transmitter-receiver combinations from each of the two primary offsets were stacked and plotted together to build pseudo-profiles of normalized apparent resistivity with respect to a reference measurement ([Figure 4](#)).

One particular combination consisting of transmitter positions placed symmetrically around a receiver results in a less noisy pseudoprofile due to the averaging of the measurement and the reduced effects of transmitter tilt. All the pseudoprofiles reveal a general trend of high apparent resistivity values at the NW end of the line, decreasing drastically towards the SE ([Figure 4](#)). A weaker increase of apparent resistivity is also evident at the SE end of the line.

The data was inverted in 1D using a Marquardt-Levenberg inversion scheme, incorporating both anisotropy and induced polarization. Both unconstrained and constrained approaches were used to fit the initial model to the data. The initial model for the unconstrained approach consisted of seabed and a vertical transverse isotropic (VTI) subsurface where all layers were of 250 m thickness and with initial resistivities

of 2 Ωm . The resistivities of the geological layers were allowed to vary freely within the range 1 – 100 Ωm during the inversion. Resistivity values derived from available regional data showed a certain degree of anisotropy, 1.5 to 2.0, which was accounted for during the inversion.

The symmetrically stacked pseudoprofile of the apparent resistivity was used for the unconstrained inversion. The results from the unconstrained inversion are shown in [Figure 5](#), where several 1D inversion results at consecutive stacked-measurement common midpoint (CMP) positions along the EM acquisition line are stitched together to form a pseudo-profile. These results show a clear resistivity anomaly corresponding to the position of receivers 1 and 2, at a depth range of 2000-3000 m, consistent with the apparent resistivity results.

For the constrained inversion, an initial model was built based on seismically interpreted horizons and weakly constrained resistivity intervals. Individual depth constraints were derived for each CMP position and joined together to build an inversion pseudo-profile. The inversion was run having applied light resistivity constraints to the stratigraphic intervals similar to what was done in the unconstrained inversion, i.e. allowing the resistivity to vary freely within the range 1-100 Ωm . The results confirmed the presence of a resistor at receiver positions Rx1 and Rx2 ([Figure 6](#)). The depth of the anomaly fits reasonably well with the depth of the target in the Hårteigen prospect, as shown in [Figure 7](#), where a plot of the inversion results is overlapped to the corresponding seismic section. A weaker resistivity anomaly to the right end of the line could be carefully interpreted as a possible 3D effect from the neighbour horst SE of the main target structure.

Conclusions

PetroMarker's time domain EM method has been implemented as part of the exploration workflow to de-risk a prospect in a region of poor seismic resolution at target depth. The need for an integrated approach which included EM was strongly considered due to the uncertainty related to the presence of the reservoir interval. The inversion results reflect faithfully the expected on- and off-target locations along the section, showing a prominent EM anomaly, strikingly coincident with the position of the target structure. Concedo considers the contribution of this method as valuable in the de-risking workflow. In this case study, the inferred widespread nature of the reservoir formation favours an interpretation of the anomaly by other non-lithological causes like the presence of a hydrocarbon-filled reservoir. A more comprehensive evaluation of the method can be achieved after an eventual drilling of the prospect. In the future, when we have gained more experience, the method will be more important in the de-risking process.

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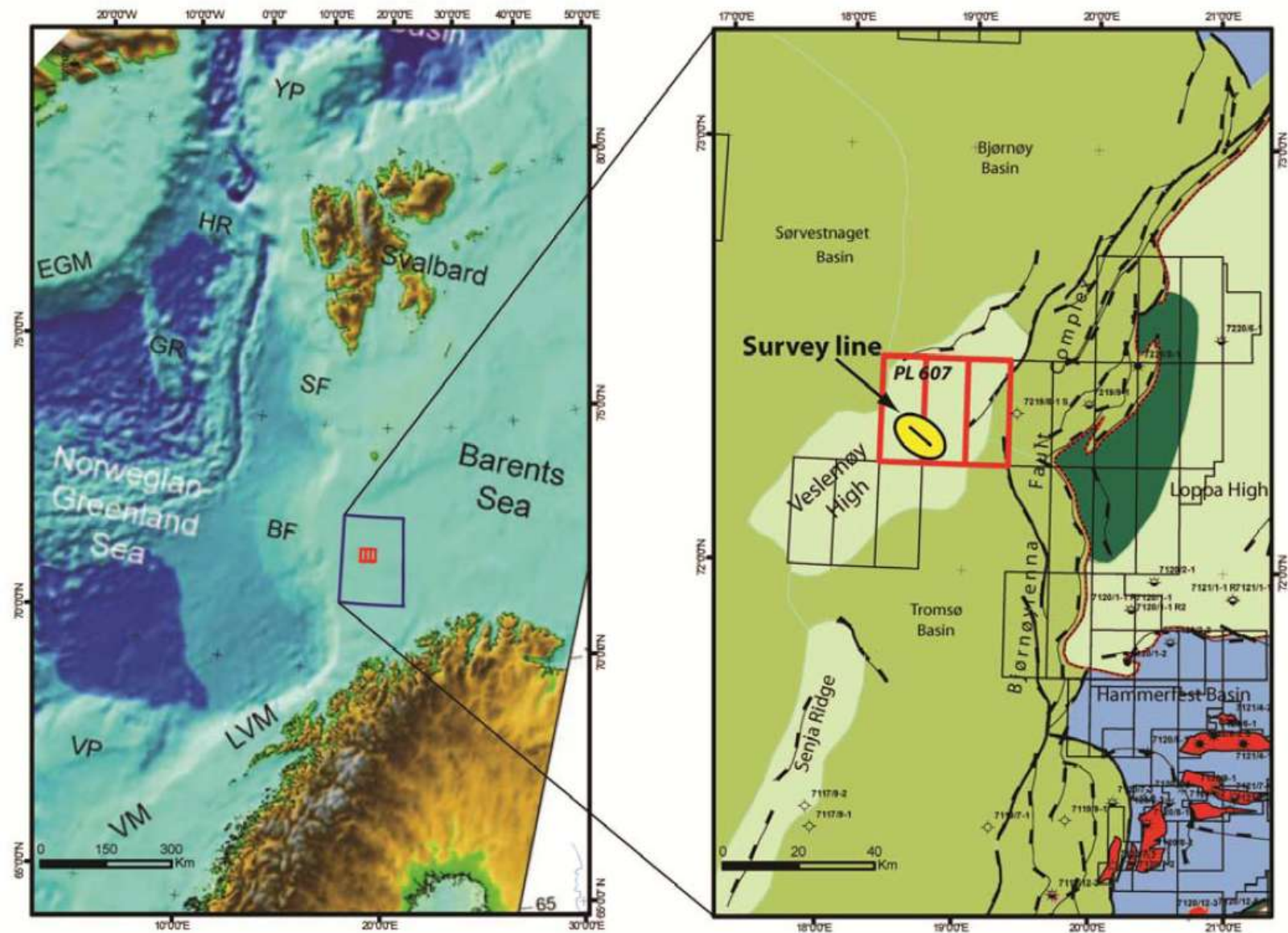


Figure 1. Location of the investigated area in the regional context of the SW Barents Sea (left) and major structural elements around the Veslemøy High area (right). The survey line (in yellow circle) is located within the recently awarded PL607 (outlined in red).

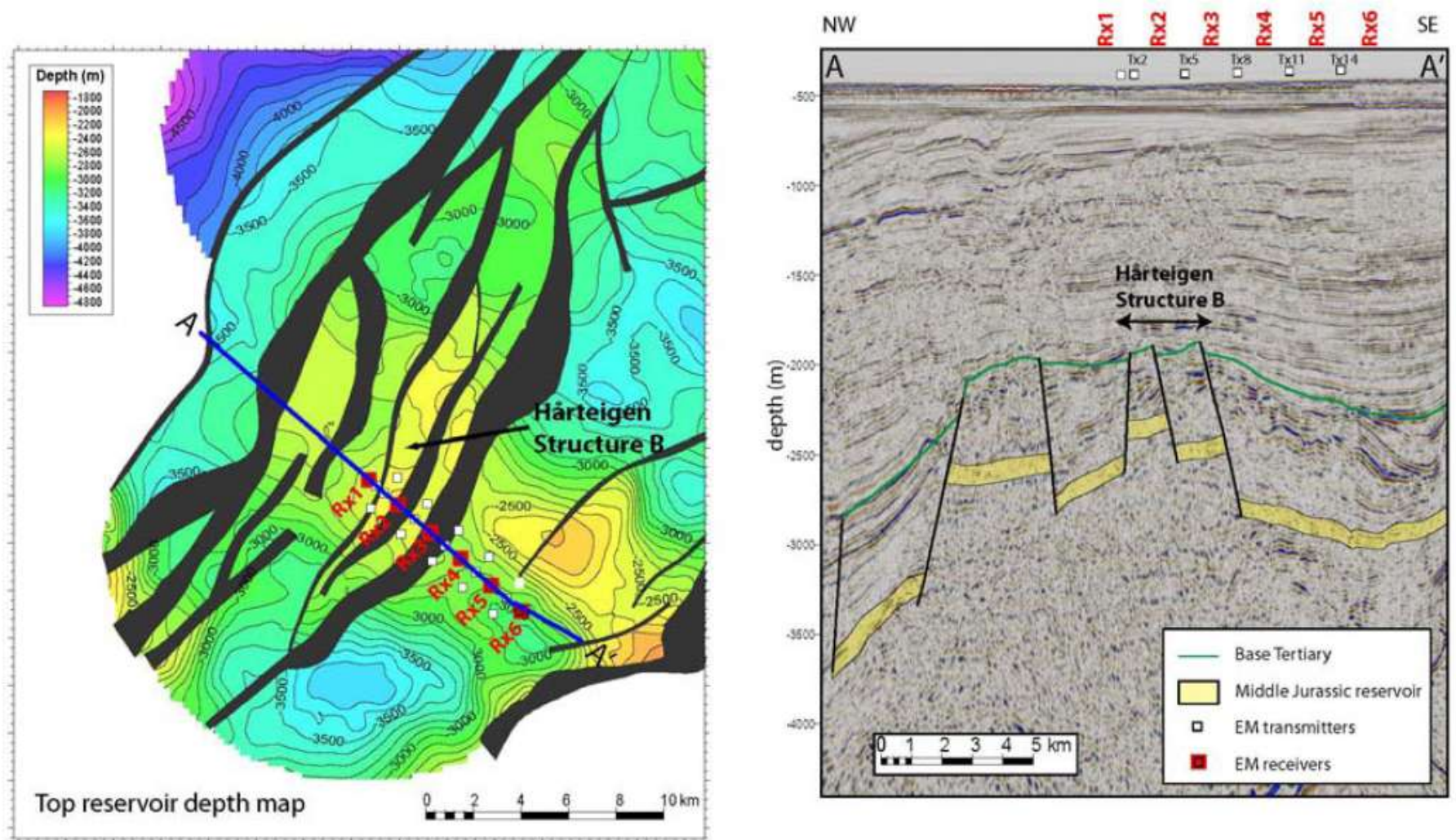


Figure 2. Structural top reservoir depth map for Middle Jurassic play model (left); seismic section along the acquired CSEM survey (right).

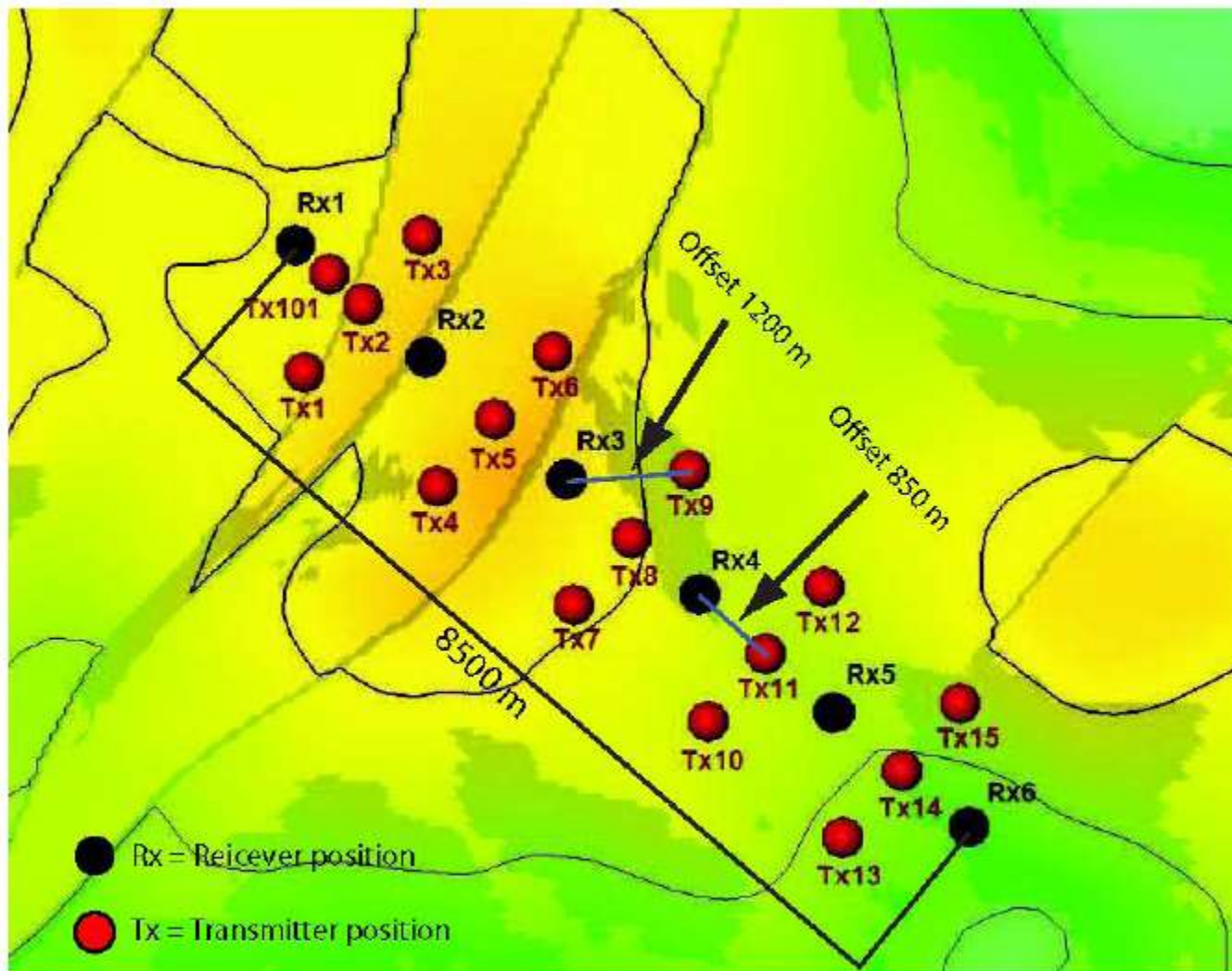


Figure 3. Survey layout detail showing the array of transmitter and receiver positions and the primary offsets.

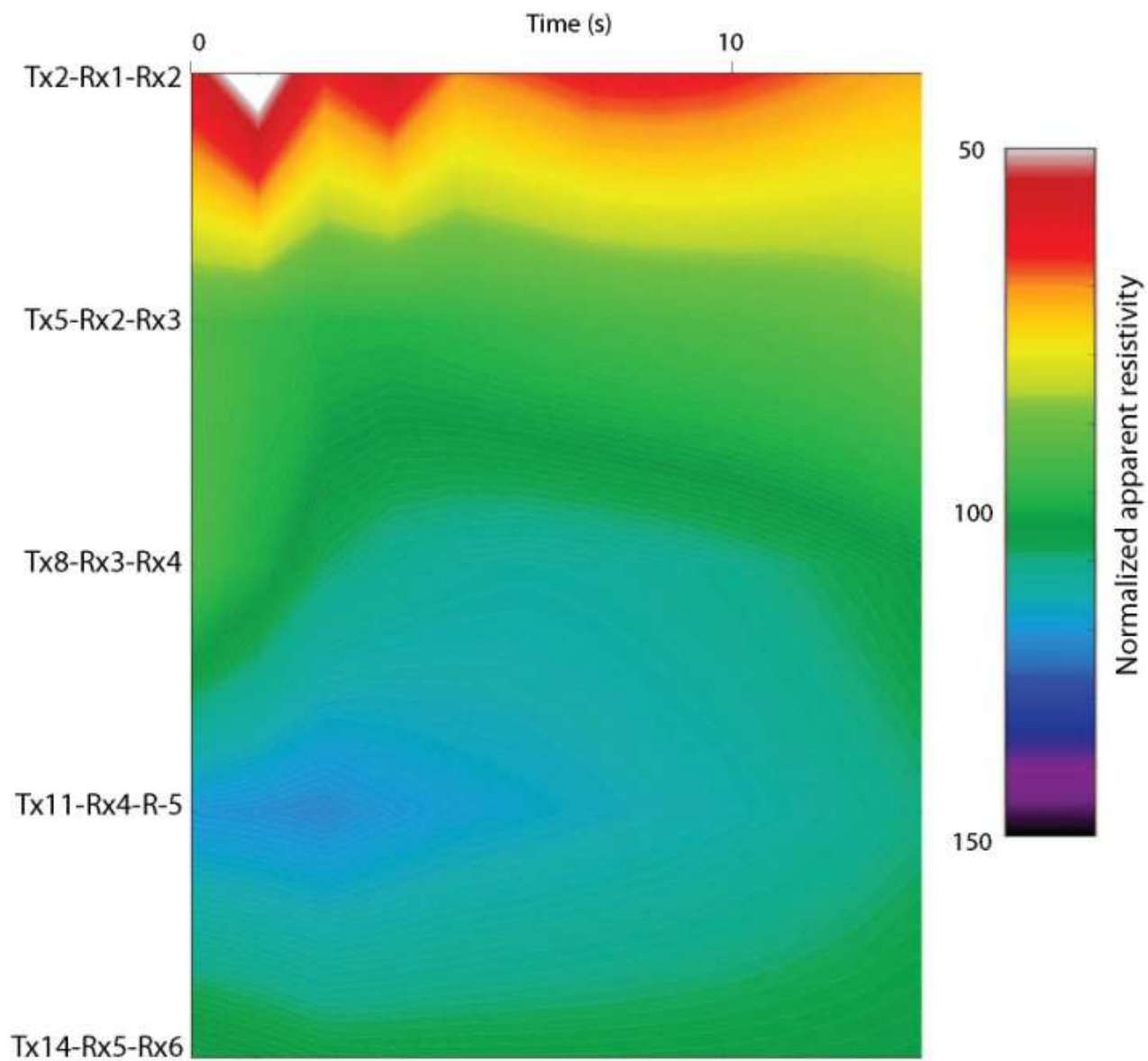


Figure 4. Pseudo-profile of normalized apparent resistivity with time for symmetrically stacked measurements. A strong anomaly is shown at receiver positions Rx1 and Rx2.

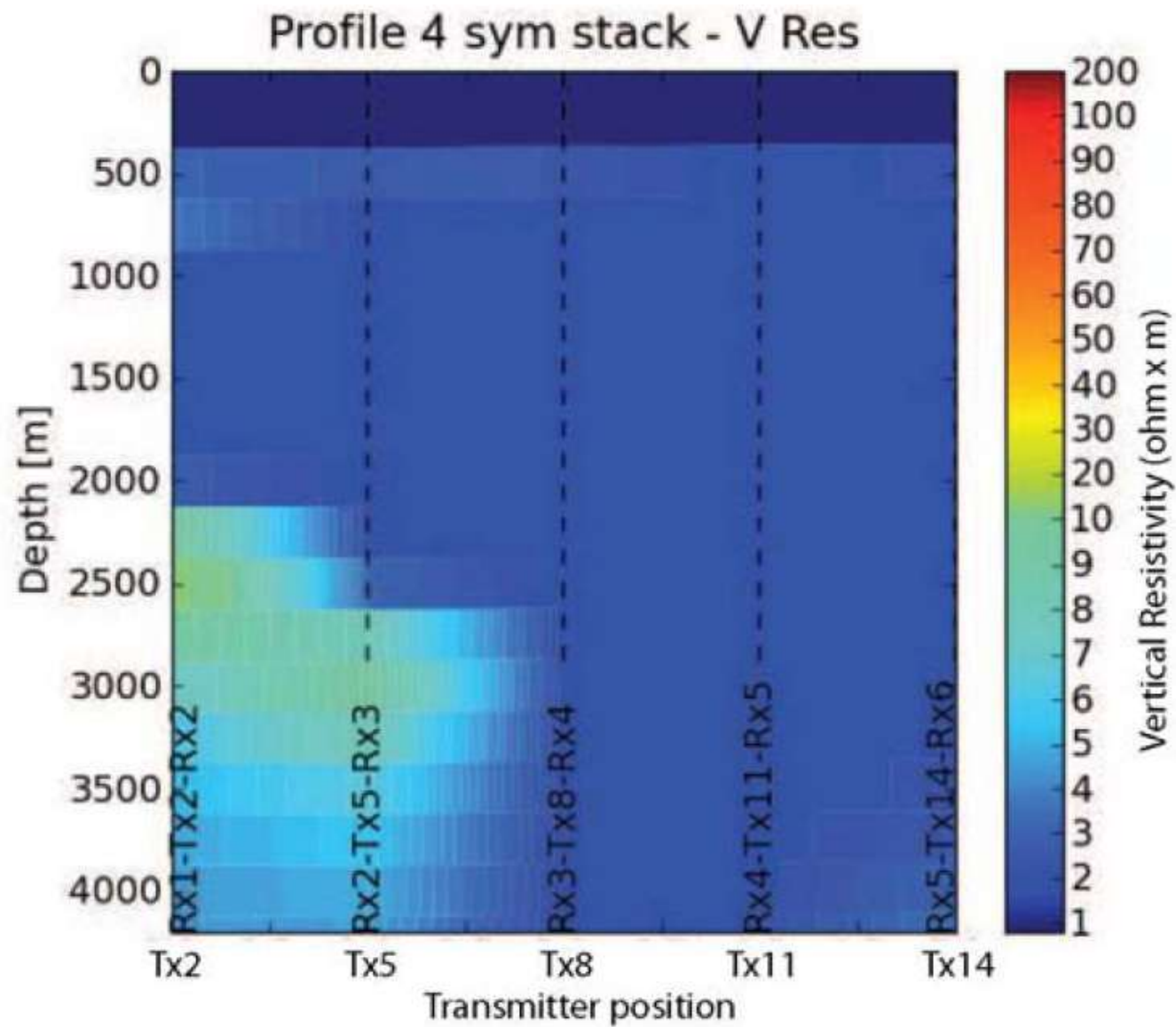


Figure 5. Results from the unconstrained inversion based on the symmetrically stacked pseudo-profile of apparent resistivity. A prominent anomaly is observed on the NW end of the survey (left side on figure).

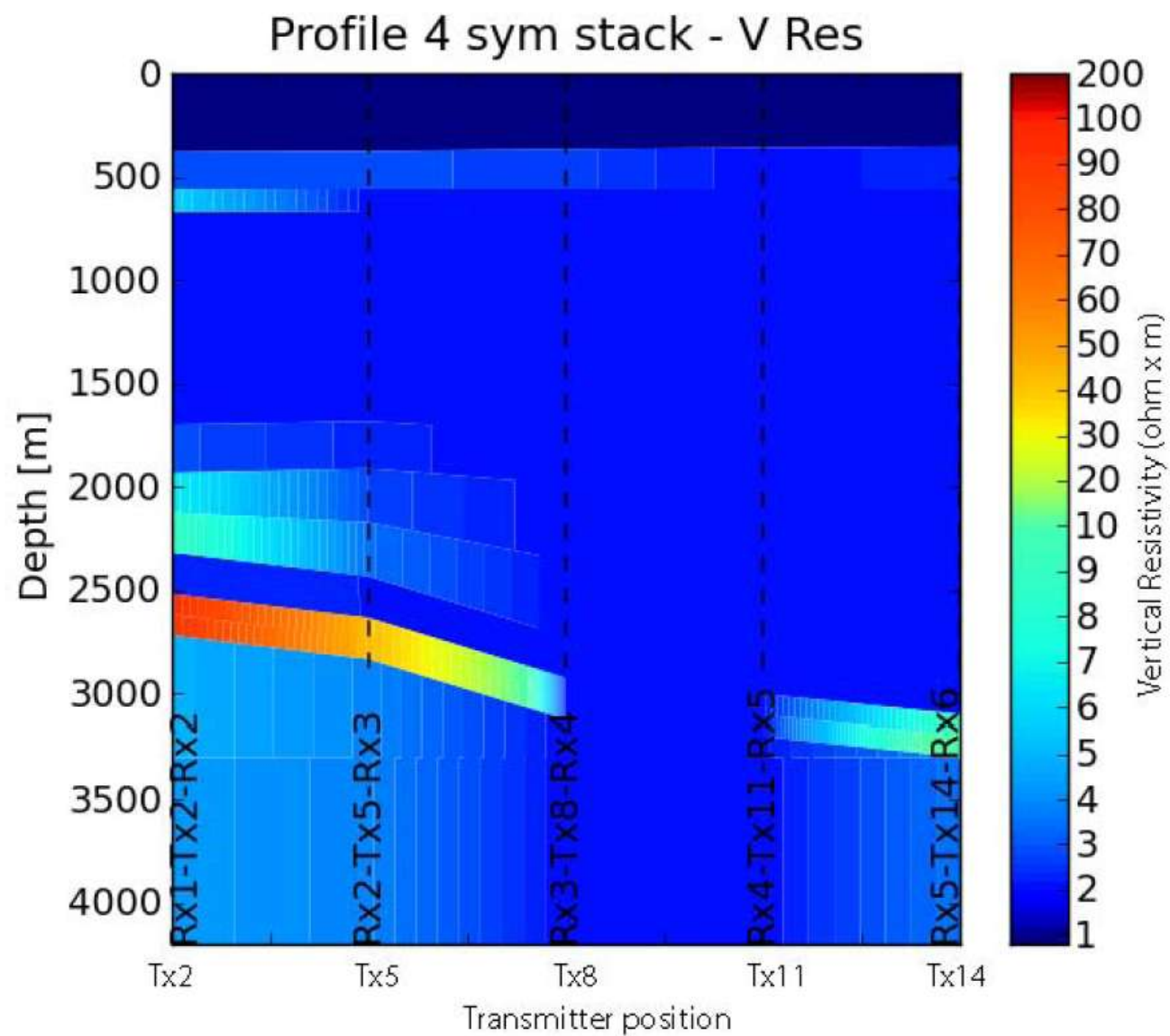


Figure 6. Constrained 1D inversion results, modelled with a 200 m thick reservoir.

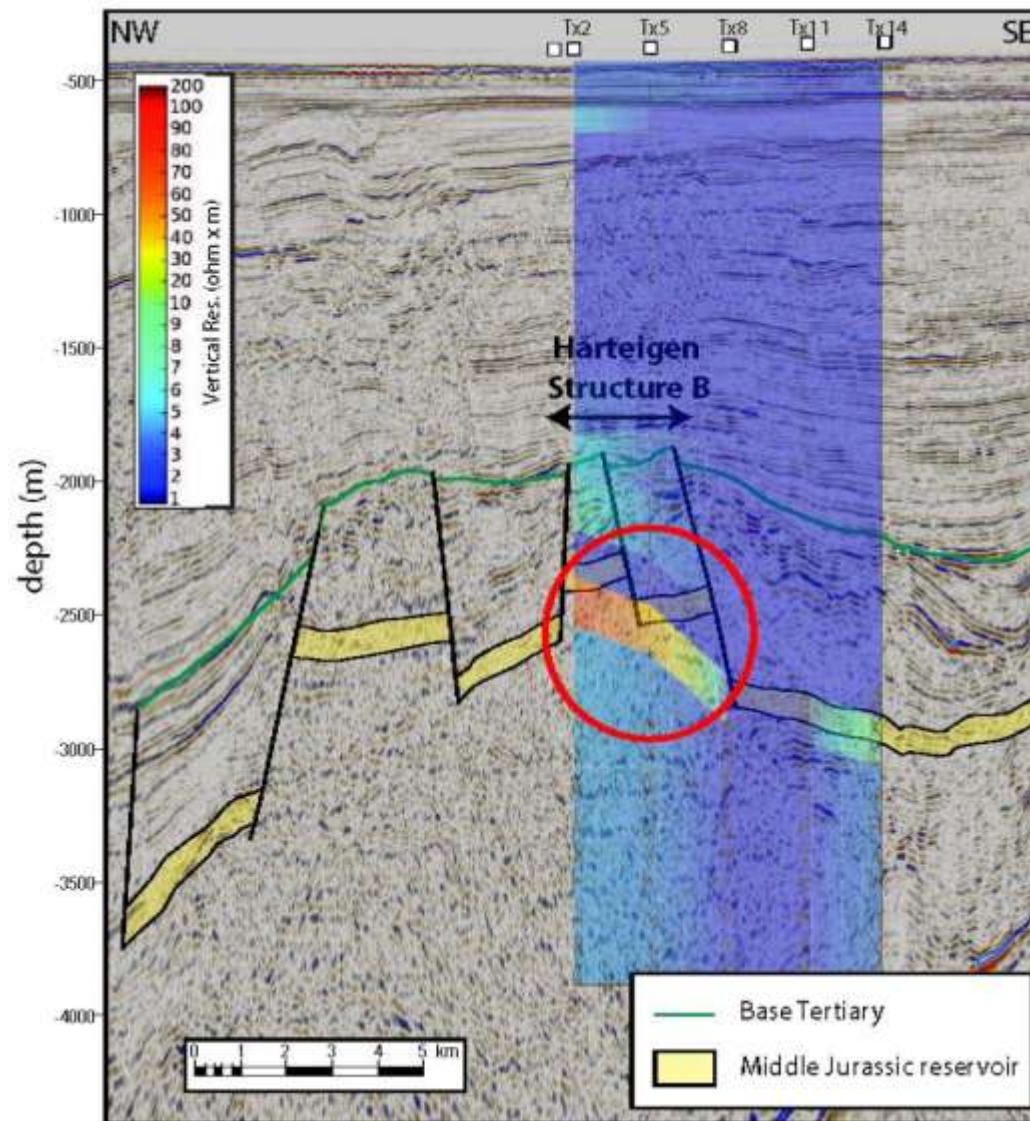


Figure 7. Constrained 1D inversion results modelled with a 200 m thick reservoir. The seismic section at the background shows the good coincidence of the major anomaly (outline in red circle) with the position of the target within the Hårteigen B Structure.