

Application of an Innovative AEM System for Mapping Hazards and Water Resources in Oil and Gas Fields*

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Abstract

Mira Geoscience has collaborated with SkyTEM Canada Inc. to produce this case study using public Airborne Electromagnetic (AEM) data collected by Geoscience BC in partnership with members of the Horn River Basin Producers Group. The objective of the AEM survey at the outset was to delineate possible sources of near surface groundwater thought to be contained in quaternary paleochannels. Modeling and interpretation of the data has resulted in imaging of subsurface resistivity features thought to represent these paleochannels. Throughout the course of the project, other applications of the dataset have become apparent during the interpretive process. These applications include: detection of shallow gas and structures that may confine gas in the near surface (clay caps), explanation of artesian water in hole d-66-f and prediction of further artesian water flow throughout the property, and detection of near surface coarse materials for engineering applications such as road and drill pad construction. The case study illustrates the interpretive power of combining AEM models with seismic interpretation as well as the advantages that low noise and high-resolution multi moment airborne electromagnetic data acquisition systems and advanced EM processing bring to the interpretive process

Introduction

Approximately 2400 line km of SkyTEM Airborne Electromagnetic (AEM) data were flown over the Horn River basin in April 2011. The data was collected over the four blocks shown in [Figure 1](#). The data in block 3, considered in this study, are publically available on the Geoscience BC website and the survey is described in Anglin, 2012. The SkyTEM AEM system was selected for this study because of its global success mapping groundwater resources. It is a unique time-domain electromagnetic (TDEM) system that offers a multi-moment transmitter capable of concurrently resolving both near surface and features at depth and low noise characteristics that make possible the detection of subtle contrasts critical for mapping aquifers. The survey was flown with the objective of using AEM data and models to better understand the near surface groundwater resources in the Horn River Basin. During the course of interpretation, due to the high quality of the data and resulting resistivity models, other important discoveries and applications were developed from and for the AEM dataset.

Theory and/or Method

Quaternary age paleochannels exist in the Horn River Basin and may present an important source of water for industrial development. Nearby, in northwestern Alberta's High Level and Rainbow Lake areas, Quaternary paleochannels are known to contain significant shallow gas deposits, which are both a resource and a possible hazard when drilling for deeper resources. Understanding the structure of the quaternary age sediments overlying consolidated bedrock is of considerable importance for operators in the Horn River Basin.

The SkyTEM 304 was employed for this project. All SkyTEM systems have a rigid frame and are capable of transmitting with a dual-moment (Sørensen and Auken, 2004). In contrast to conventional TDEM systems, SkyTEM systems have the receiver coil positioned slightly behind the transmitter wire in a 'null' position, where the intensity of the primary field is minimized. SkyTEM, initially designed for groundwater mapping and now employed for resource exploration and geotechnical engineering solutions, employs two transmitter moments with different currents and different numbers of transmitter wire turns. The low current or low moment (LM) mode, with a moment of 3,000 NIA, is used to record early-time gates, which constrain near-surface information, while the high current or high moment (HM) mode, with a moment of 120,000 NIA, improves the signal-to-noise ratio at late time gates. The SkyTEM304 system flown for this study has a transmitter area of 314m², and is intermediate between the SkyTEM 101 system, used for near-surface applications, and the SkyTEM 512, designed for deeper investigations. The SkyTEM 304 system records time gates from 3 μ s to 7 ms. The correction of early-time data for the residual primary field is done in more recent SkyTEM surveys, and permits the use of data as early as 2-3 μ s, thus improving near-surface resolution (Schamper et al. 2013). All SkyTEM systems are equipped with several devices enabling complete modeling of the movement of the system in the air facilitating excellent high-resolution images of the subsurface. (Auken et al. 2009).

AEM inversion is a quantitative method that produces a resistivity model of the earth consistent with the airborne observations and capable of stably resolving considerable subsurface detail. The program EM1DTM was used to simultaneously invert both high and low moment SkyTEM data for the vertical resistivity structure of the earth. The program EM1DTM is one of the most flexible EM inversion programs currently available, providing the ability to statistically deal with data outliers using L1 measures of data misfit and to recover L2 'smooth' or L1 'blocky' or any intermediate models as required. Mira Geoscience provides EM inversion processing using specialized techniques and experienced processors resulting in reliable, interpretable models of subsurface resistivity. An example of SkyTEM EM profile data and the inverted resistivity model result is provided in [Figure 2](#).

Examples

The Case study area is an excellent example for a number of reasons. First, a well, d-66-f, is located on the flight line shown in [Figure 2](#). The well has resistivity logged in the hole that allows for a comparison between modeled results and the measured resistivity. This comparison is provided in [Figure 3](#) where simplified geology is shown adjacent to the deep resistivity log and the resistivity profile extracted from the AEM resistivity model along the well path. The comparison shows that, while the AEM resistivity model does not capture all of the fine detail available in the resistivity log, the model reproduced the key resistivity variation observed in the hole.

A 3D seismic survey was also carried out in the study area and, from this survey, a bedrock surface from seismic refraction has been supplied along with the weathering layer from seismic statics for comparison to the resistivity model. The comparison of the two seismic surfaces is shown with an interpretation of the AEM resistivity model in section [Figure 4](#). The figure shows that weathering layer from statics appears to track a thin variable resistivity layer in the AEM resistivity model. This is thought to represent near surface recent till and muskeg.

Below the weathering layer, the AEM resistivity model shows considerable and significant detail. A thin, continuous conductive layer (red) is imaged throughout the property at a depth ranging from 15-25m as shown in [Figure 4](#). This layer is thought to represent a thin lacustrine clay horizon, which has the potential to be an aquitard. Below this clay cap, over most of the property, a relatively resistive and variable thickness layer is imaged below (green). Below this layer the model resistivity drops to relatively low values ($< 10 \Omega\text{m}$) before the depth of investigation of the system is reached. The layers below the clay cap are interpreted to represent resistive water charged quaternary paleochannels overlying a conductive basal quaternary clay fill. The shapes of the interpreted sand channels are very similar to the seismic refraction image of the consolidated bedrock as shown in [Figure 5](#) (which largely occurs at a depth below the depth of investigation of the AEM survey). Both the AEM resistivity model and the bedrock from seismic refraction image the dendritic pattern of the river valley system.

From the AEM resistivity model the sand channel's resistivity and thicknesses can be estimated. [Figure 6](#) shows the resistivity-thickness product in the quaternary channel as an indication of the potential for contained water. Areas with greater resistivity-thickness are likely to result in more productive water wells from the Quaternary sediments.

Well d-66-f experienced artesian water flow from the quaternary. Based on this information and, given that the clay cap confining the aquifer below has been imaged as a continuous layer throughout the property, we are able to predict the artesian flow on the property, as shown in [Figure 6](#). Given a pressure reading at the well head, the interpretation could be extended to provide artesian water pressure over the entire property using the geometry of the confining layer and the location of the reservoir.

A complete geological interpretation of the quaternary can be assembled from the combined seismic and AEM data and the interpretation is provided in [Figure 7](#). This geological configuration is highly reminiscent of the geology observed in the nearby Rainbow Lake and High Level area where lacustrine clay caps in the quaternary trap significant accumulations of shallow gas in underlying quaternary paleochannels. Napier et al, 2005 showed significant shallow gas accumulations in this setting appear as comparatively high resistivity zones within the quaternary with AEM resistivity model values ranging from $200 \Omega\text{m}$ to more than $1000 \Omega\text{m}$ in some areas. No resistivities greater than $50 \Omega\text{m}$ were observed within the channels identified in this study, indicating that it is unlikely that the channels are gas-charged anywhere within the property.

Conclusions

A multi moment AEM system (SkyTEM) along with a carefully applied EM inversion modeling workflow is capable of providing both near surface resolution (aggregates, engineering materials) as well as the ability to map targets at depth (sand channels, clay caps) and does a good job of discriminating lateral resistivity contrasts and layering. Furthermore, subsequent to this work, SkyTEM has developed much more powerful systems capable of achieving greater depths of investigation without comprising the level of detail. This makes the combination of

SkyTEM and EM inversion even more effective than shown in this study. This study has demonstrated a good correlation between inversion models of SkyTEM airborne TDEM data, well logs and seismic data. A 3D integrated interpretation of AEM inversion models provides complimentary information to the seismic dataset and allows a complete interpretation of the quaternary sequence, which is not possible with seismic alone. The interpretation shows similarities to previous work by Napier et al (2005) in nearby NW Alberta showing that AEM can/should be considered as a tool for detecting, mapping and discriminating between water and gas filled quaternary channels. The 3D interpretation provides a number of verifiable predictions: prediction for the location of ground water resources, prediction for the location of artesian water flow from the quaternary, prediction for the presence (absence) of shallow gas on the property, and a prediction for locations of near surface coarse materials for engineering applications.

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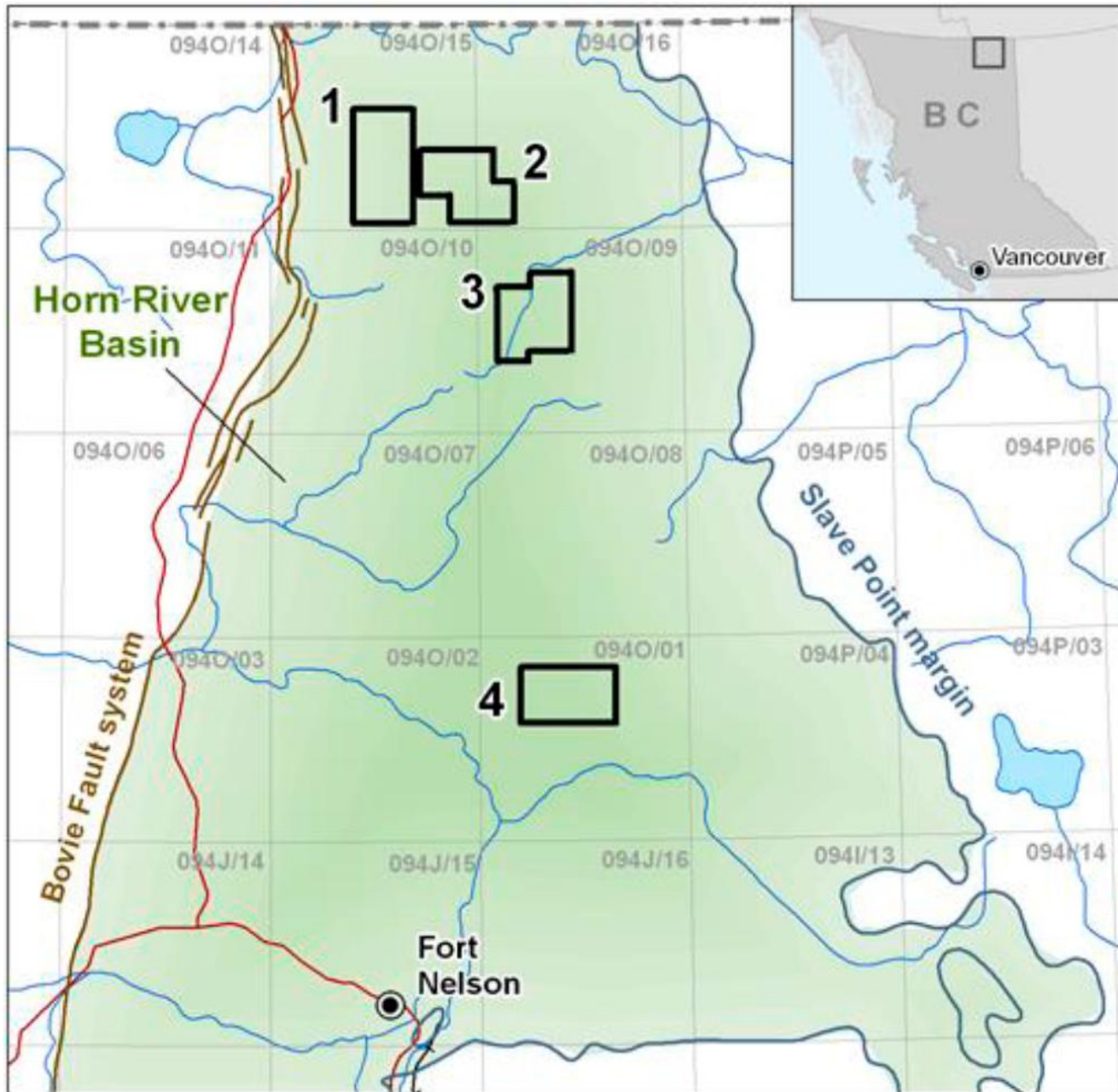


Figure 1. Location of AEM study area. The data considered here were acquired in block 3.

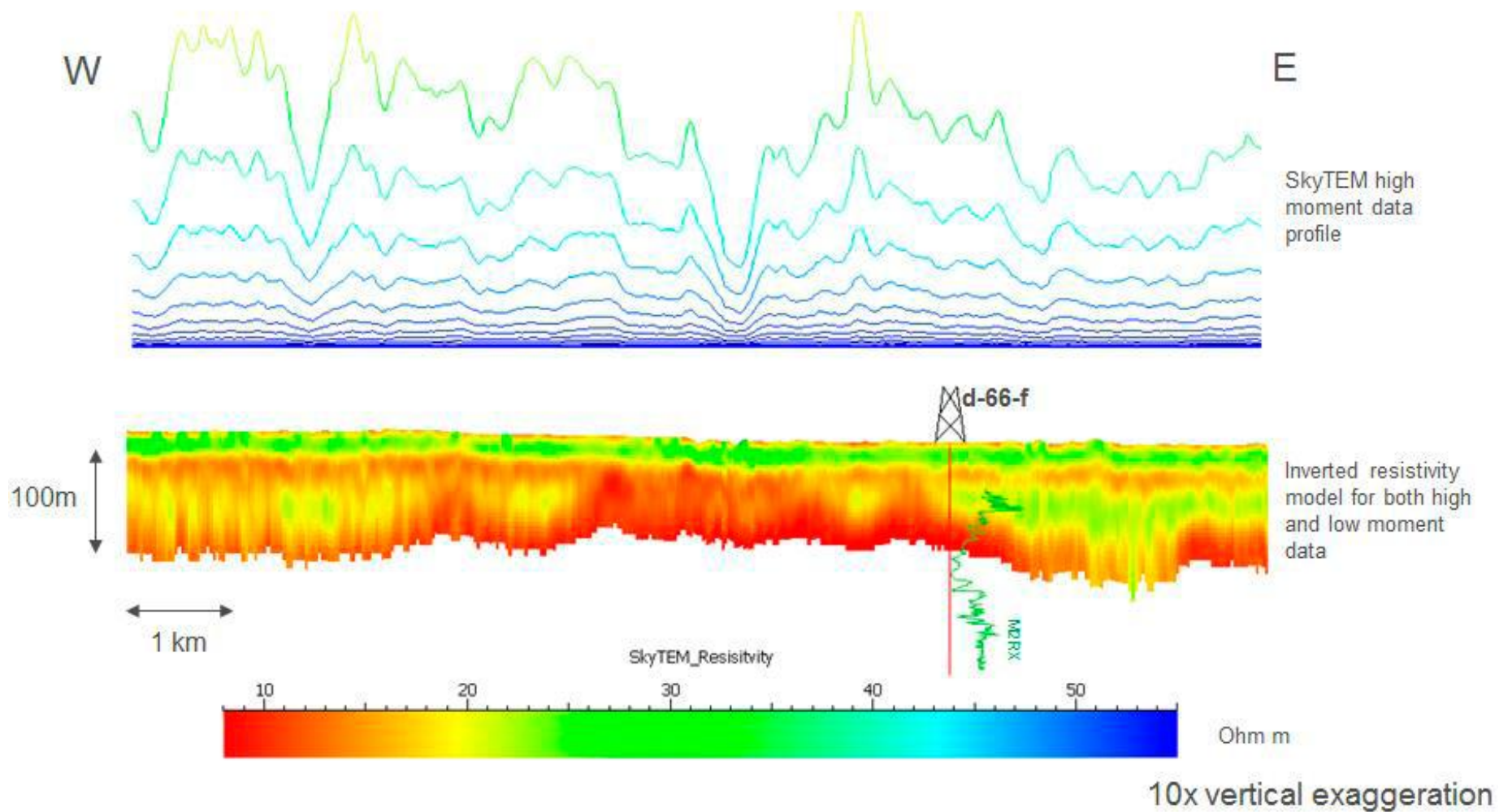


Figure 2. SkyTEM high moment EM profile data (above) and inversion model below. The location of the well d-66-f is shown with the deep resistivity profile M2RX in green.

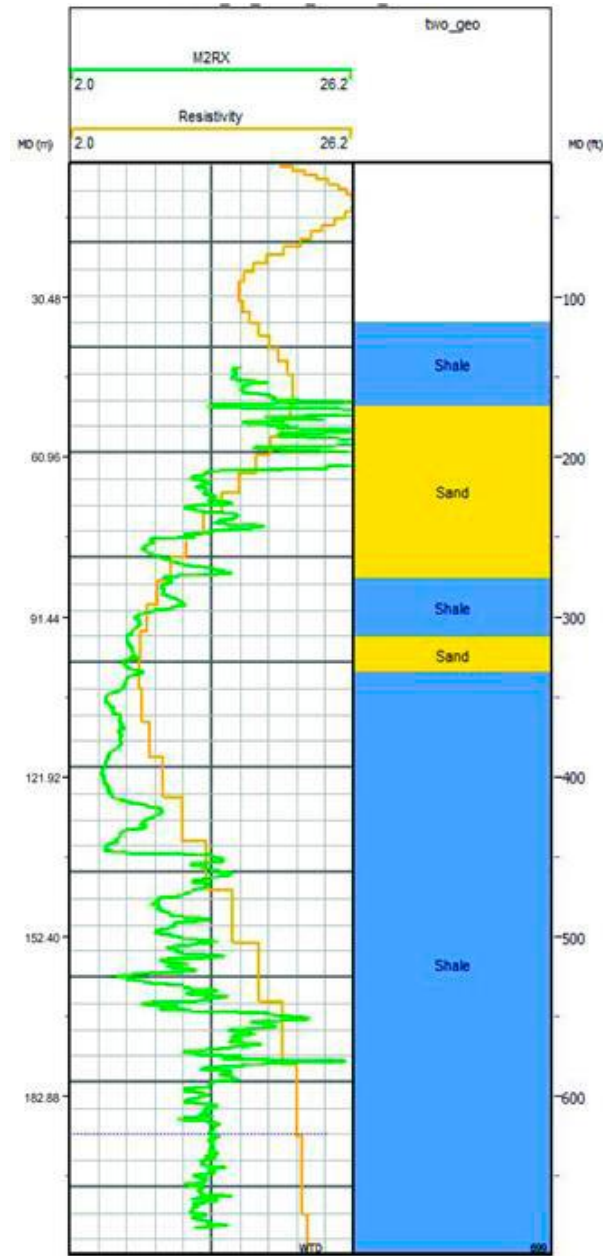


Figure 3. Right: simplified geology log. Left: M2RX deep resistivity log (green) and the SkyTEM inverted resistivity model profile extracted along the well path (yellow).

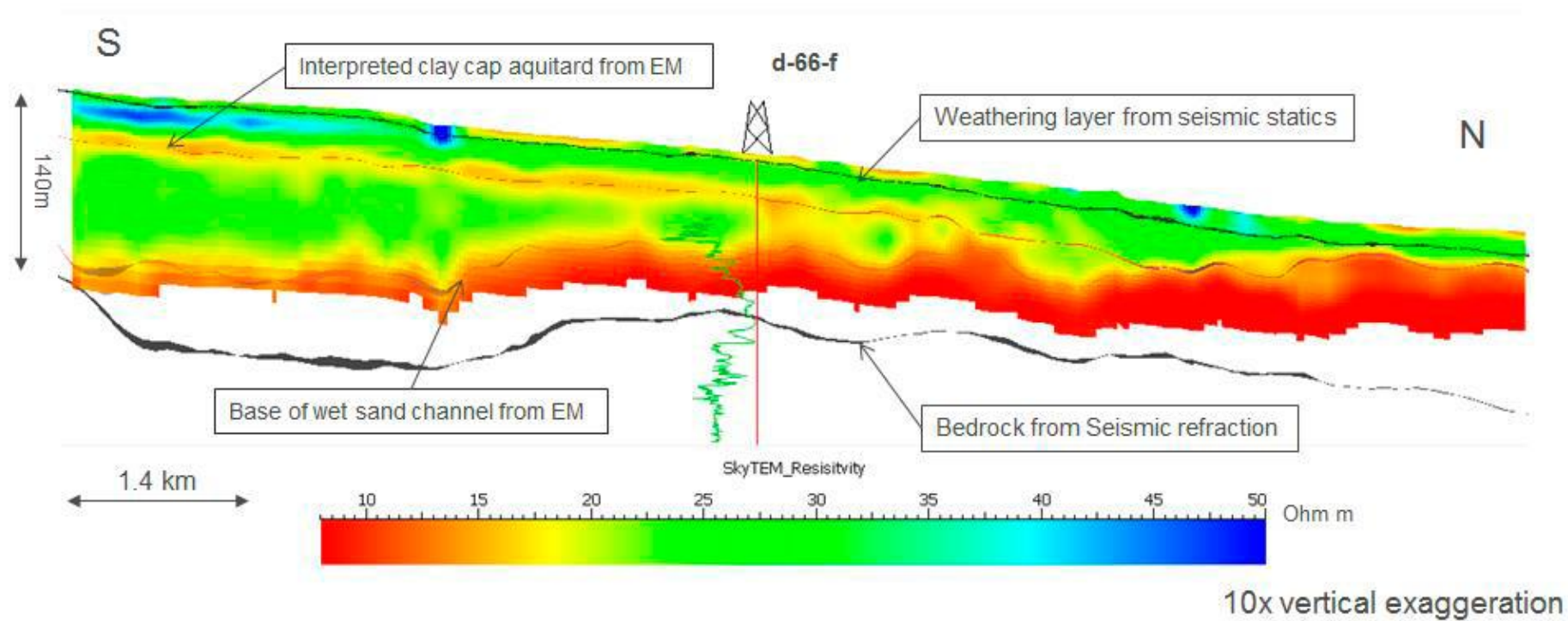


Figure 4. North-South section showing an integrated interpretation of SkyTEM inverted resistivity model and seismic data.

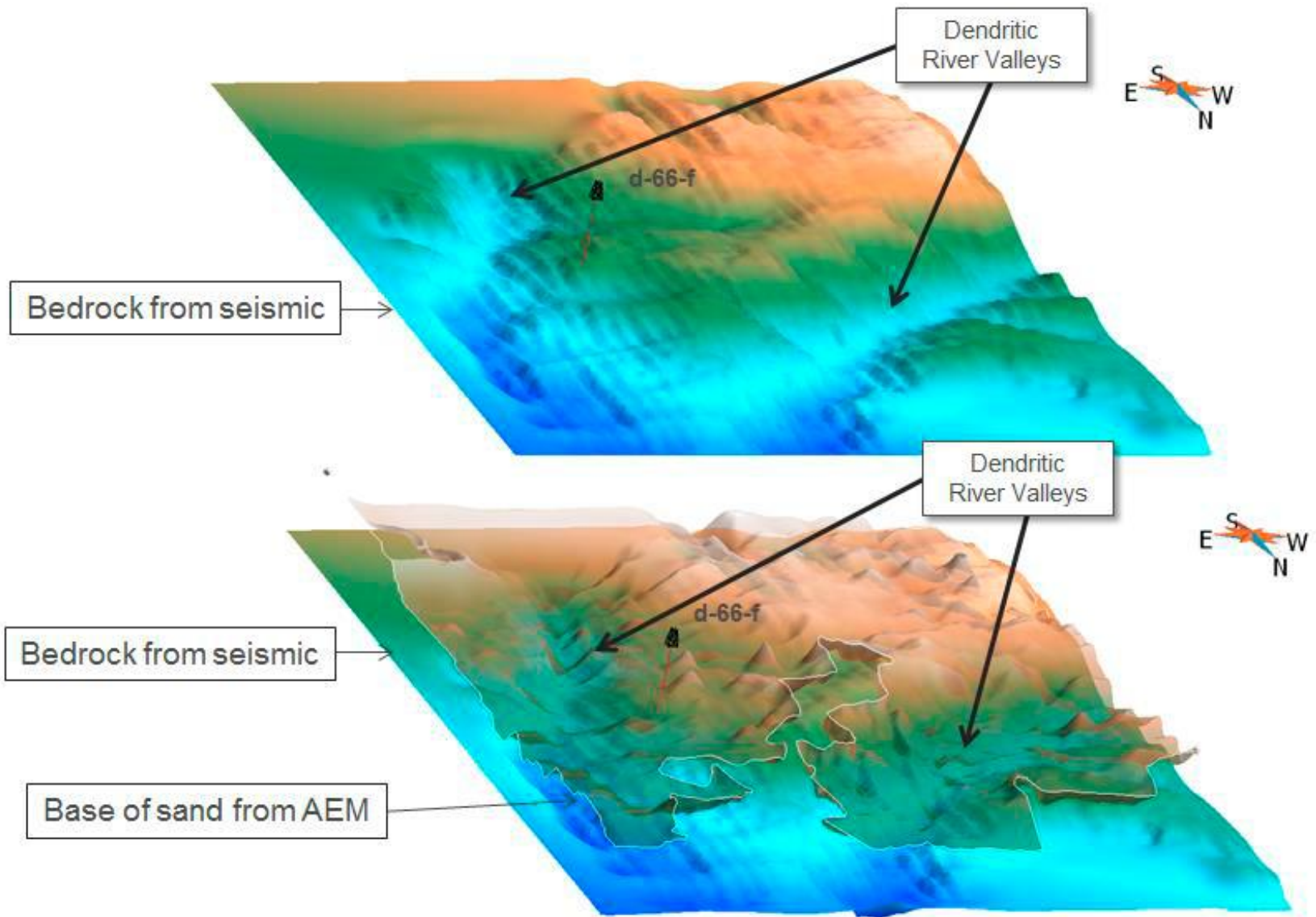


Figure 5. Comparison to 3D seismic bedrock surface to AEM base of sand interpretation. Perspective view from above and from the NE. Above: bedrock from seismic. Below: interpreted base of wet sand from resistivity shown with bedrock from seismic.

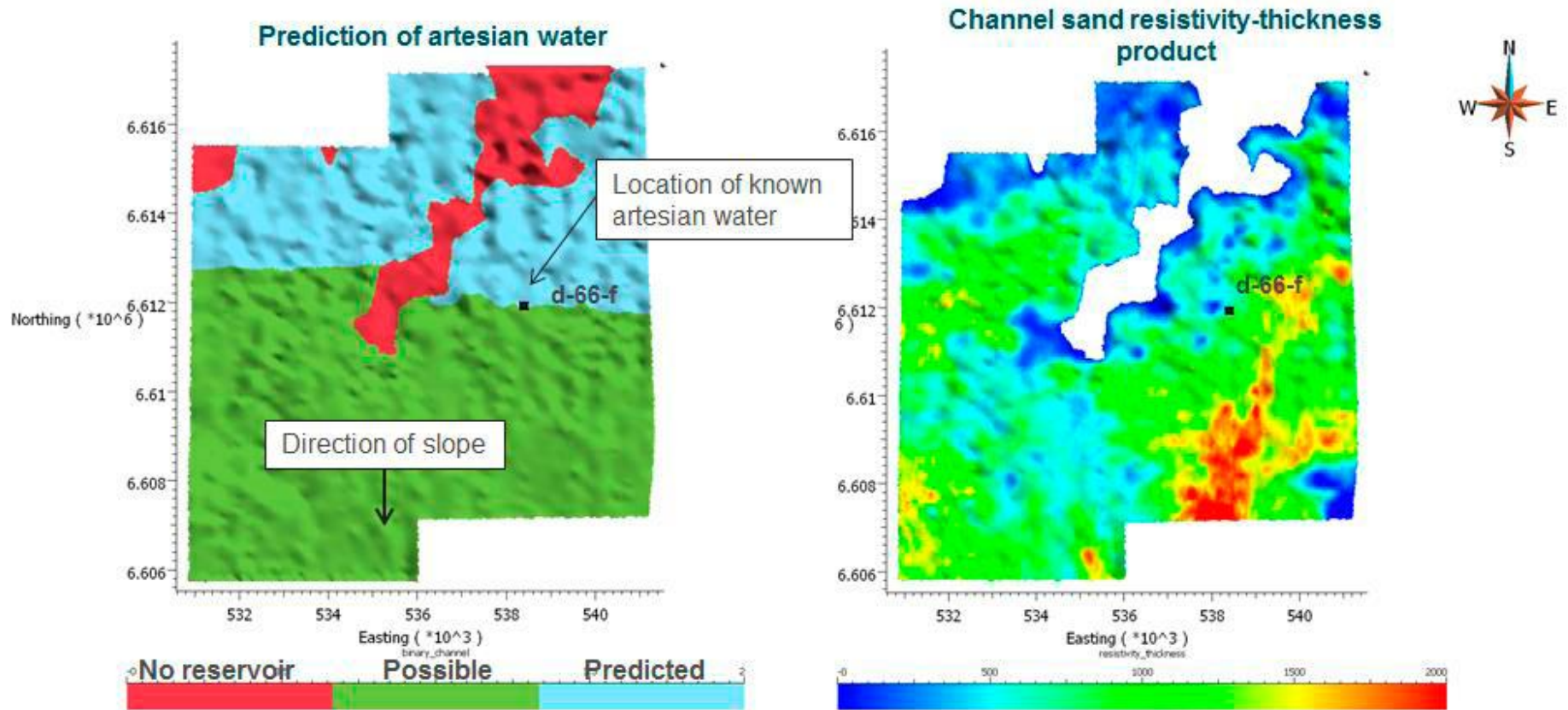


Figure 6. Left: Prediction for location of artesian water flow from the Quaternary. Right: Resistivity-Thickness of interpreted Quaternary sand channel as an indication of contained water.

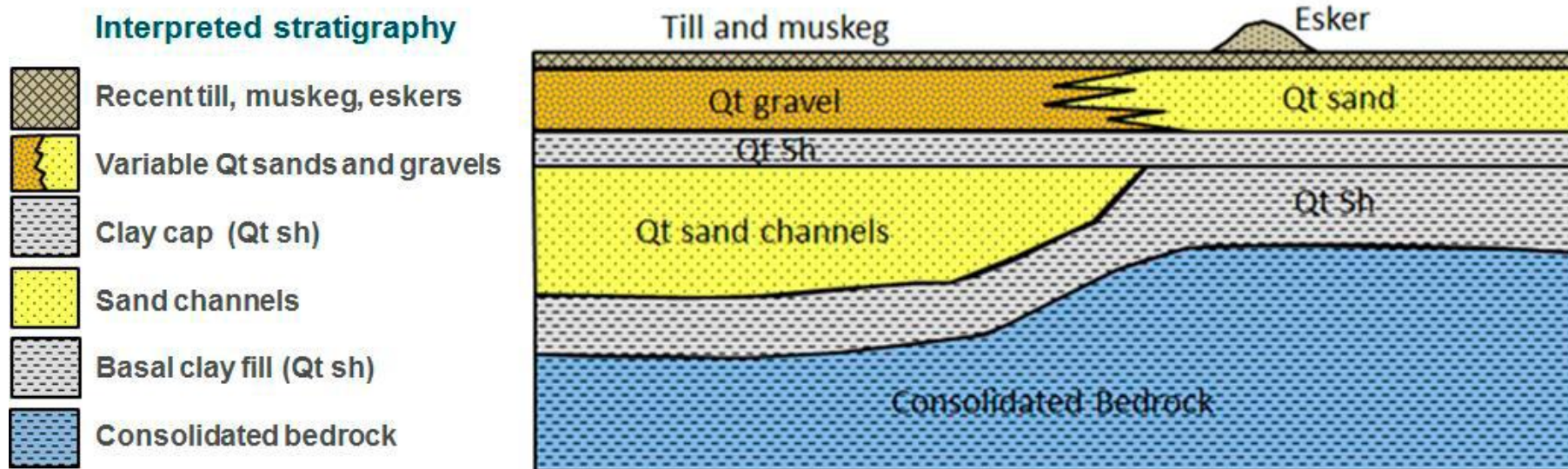


Figure 7. Property wide interpreted stratigraphy of the Quaternary.