

Advanced Processing and Inversion of Two AEM Datasets for 3D Geological Modeling: The Case Study of Spiritwood Valley Aquifer*

Vincenzo Sapia¹, Andrea Viezzoli², Greg Oldenborger³, and Flemming Jørgensen⁴

Search and Discovery Article #80434 (2014)

Posted December 29, 2014

*Adapted from extended abstract prepared in conjunction with presentation at CSPG/CSEG/CWLS GeoConvention 2013, (Integration: Geoscience engineering Partnership) Calgary TELUS Convention Centre & ERCB Core Research Centre, Calgary, AB, Canada, 6-12 May 2013, AAPG/CSPG©2014

¹INGV, Rome, Italy (Vincenzo.sapia@ingv.it)

²Aarhus Geophysics, Aarhus, Denmark

³Geological Survey of Canada, Ottawa, Canada

⁴Geological Survey of Denmark and Greenland, Denmark

Abstract

In this short paper, we present results obtained from advanced processing and inversion of AEM data related to AeroTem and VTEM surveys over the same area, Spiritwood Valley, Manitoba. We present an example of integration of ancillary seismic data into the AEM inversion. In particular, the depth to different layers as interpreted from seismic are added to the inversion to constrain the resistivity model. Furthermore, we compare inversion results with other available ground based geophysical data, focusing on electrical resistivity data collected across seismic lines in order to provide some constraints on the AEM resistivity model. Finally, we outline how these results will be applied to generate an integrated 3D geological model for a quantitative description of the Spiritwood aquifer system.

Introduction

At the conference, we will focus mainly on the results obtained from AeroTem III and “Full Waveform” VTEM survey flown over the Spiritwood Valley Aquifer in Manitoba ([Figure 1](#)). In 2010, the Geological Survey of Canada conducted an airborne electromagnetic (AeroTem III) survey over a 1,062 km² area along the Spiritwood Valley. During Fall 2011, Geotech conducted a helicopter-borne geophysical survey over the Spiritwood Valley. It is well known in literature how airborne geophysics can be used to significantly improve geological and hydrogeological knowledge on a regional scale. The Spiritwood Valley is a Canada-USA trans-border buried valley aquifer that runs approximately NW - SE and extends 500 km from Manitoba, across North Dakota and into South Dakota. In addition to the seismic, other ground-based data exist in the survey area and make it possible to provide some additional information on subsurface resistivity values. Over 10 line-km of electrical resistivity data and resistivity downhole logs were collected and supply a simplified electrical model relative to the geological layers. Then, incorporating different physical parameters originating from several sources into one inversion can directly result in a resistivity model that is consistent with all data sets.

Theory and/or Method

The aim of data processing is to prepare data for the inversion. For AEM data, this includes altitude corrections, filtering and discarding of distorted or noisy data contaminated by culture. The data are then averaged spatially increasing signal to noise levels without compromising lateral resolution. Models are constrained spatially to reflect the lateral homogeneity expected from the geology (vertical and horizontal layer resistivity, boundary thickness or depth). Before data inversion, late time noise assessment has been performed to maximize resolution at depth and to remove effects due to the raw data leveling from flight to flight. Despite primary field compensation and leveling, self-system response is still observable for some time gates (i.e. primary field bias). In order to add a-priori information to the AEM data, and to have it migrate throughout the dataset, we use the framework of the Spatially Constrained Inversion (Viezzoli et al., 2008). The a-priori information is entered into the SCI formulations as an extra data set, by taking into account location, values, uncertainty, and expected lateral variability. Spatial constraints spread the a-priori information to the location of neighboring AEM soundings. For our purposes, the a-priori information consists of depth of the conductive bedrock and other relevant reflectors derived from seismic data.

Examples

The main Spiritwood Valley is readily apparent as a moderate conductivity feature set amongst a conductive background interpreted to be the response of the shale bedrock. In the centre of the main valley, a resistive linear feature has been interpreted as an inset valley within the Spiritwood (Oldenborger et al., 2012). The survey area has been flown from AeroTem III system and provides a wide dataset with respect to VTEM data that cover few lines to the north, the center and the south part of the area. The inset of [Figure 1](#) is a result of the two SCI for both system dataset over the north subset of the whole area. In general, models show consistent agreement in terms of detections of the main resistivity structures, such as the conductive bedrock.

Despite the early-time limitation of AeroTem system and the fact that it is not designed for peak response over resistive materials such as those found in this survey area, the AeroTem dataset provides rich information content in terms of lithological detail, identification and bedrock morphology. As expected by the presence of earlier time gates, models obtained from VTEM data provide a better resolution in terms of shallower geological layers and resistive bodies that fill the channel.

Using all the gates from the original VTEM data for inversion resulted in unrealistic features (too conductive), and poor matching with geoelectrical results, in the very near surface part (e.g., 0-30 m bgl) of the models. This probably points towards the presence of residual primary field in the data. Better agreement with ancillary information could be achieved by increasing noise level on the first few gates (gates one to eight) and by adding a priori to the inversion. In alternative, we deleted the first two gates and applied a time shift to all the other gates, of 21 μ s. This procedure, which brought the first usable gate to 10 μ s from beginning of ramp down, gave excellent agreement between the VTEM models and the electrical tomography (and seismic) and known geology as showed in [Figure 2c](#).

[Figure 2](#) shows the comparison between electrical tomography data with AEM inversion results. Both AEM resistivity models reproduce with excellent detail the resistive structures that come up with the electrical profile. The features attributable with sand and gravel bodies filling the main buried valley is well defined in the obtained resistivity model; moreover it is evident how inversion result of VTEM data seems to better

resolve shallower geological layer (glacially deposited silt and clay) and show much more detail in the upper portion as a result of advanced processing and modeling of the improved early time VTEM system.

Figure 3 (top) shows the obtained resistivity model (AeroTem) without a-priori. In general, the AEM result shows good agreement with the seismic information in terms of depth of the conductive bedrock. In the results presented here, the a-priori information is entered into the inversion as two different parameters: 1) a grid of the elevation for the bedrock surface (i.e. shale) derived from the seismic data, and 2) a resistivity value (derived from histogram analysis of the relative frequency of model values) with an associated standard deviation for the bedrock layer for which the depth are given. These values are used to constrain the SCI inversion as a-priori data. Since the seismic data were acquired along roads, much of the surrounding data have been removed because of coupling effects. In order to constrain the 1D model around the seismic lines the grid related to the seismic data depth has been interpolated to a distance of 250 m. The use of a-priori from seismic reflection data allowed the conductive basement layer to be more homogeneous and continuous providing a more structural geological result. Notice how the data residual remains low with the a-priori, proving that the latter is not in conflict with the measured AEM data (**Figure 3** bottom). At the conference, we will also show the effect of constraining layers associated to other reflectors.

Conclusions and Future Work

The Spiritwood AEM data show significant geological structures and clearly indicate a complex valley morphology that can be used to significantly improve geological and hydrogeological knowledge on a regional scale. With regards to AeroTem data, most of the features observed in the SCI model are recovered without any a-priori information. However, adding a-priori information to the inversion in form of elevation to layers from seismic measurements can help increase resolution across a model of otherwise poorly determined parameters as well as return a better or more credible result in terms of expected geological setting. Advanced processing and accurate inversion consisting on correct description of the system transfer function, remove all the couplings, etc. results to a reliable resistivity model that reflect expected geology and provides interesting details in terms of detection of new structures, define several complex morphologies that appear to be difficult to resolve by the use of ground geophysical measurements only.

At the conference, we will show some preliminary results of 3D geological modeling of the survey area. A general conceptual geological model which is primarily descriptive (also based on a review of former work and existing literature) and imaged in conceptual cross-sections will be shown. 3D resistivity grids based on AEM data are useful for a detailed geological interpretation. Since AeroTem data reveals a complex glacial setting with several crosscutting buried valleys of several generations, the challenge is to resolve this heterogeneity in a proper geological model following a step-by-step modeling approach. One way to do this is by “voxel” modeling with appropriate voxel discretization in xyz directions resulting in 3D voxel grids. In this way we’ll generate, first, a 3D stratigraphical model in which the geological structures and the stratigraphical boundaries are subdivided according to their geological origin, then a 3D lithofacies model in which each voxels are identified with an attribute for each different lithofacies.

Focusing on water wells data we found that the use of water wells information in addition to geophysical data is clearly complicated since the first often provide inaccurate information in terms of poorly described stratigraphy and due to the fact that their location is not correctly

recorded. Therefore, it makes them unusable and not comparable with the other available dataset in order to generate a reliable geological model.

Acknowledgements

We thank Geotech for allowing us to use and to publish their data. Seismic data were processed and provided by A.J.-M. Pugin of the GSC.

References Cited

Oldenborger, G.A., A.J.-M. Pugin, and S.E. Pullan, 2012, Airborne time-domain electromagnetics, electrical resistivity and seismic reflection for regional three-dimensional mapping and characterization of the Spiritwood Valley Aquifer, Manitoba, Canada: Near Surface Geophysics, v. 11/1, p. 63-74.

Viezzoli A., A.V. Christiansen, E. Auken, and K. Sorensen, 2008, Quasi-3D modelling of airborne TEM data by spatially constrained inversion: Geophysics, v. 73/3, p. F105-F113.

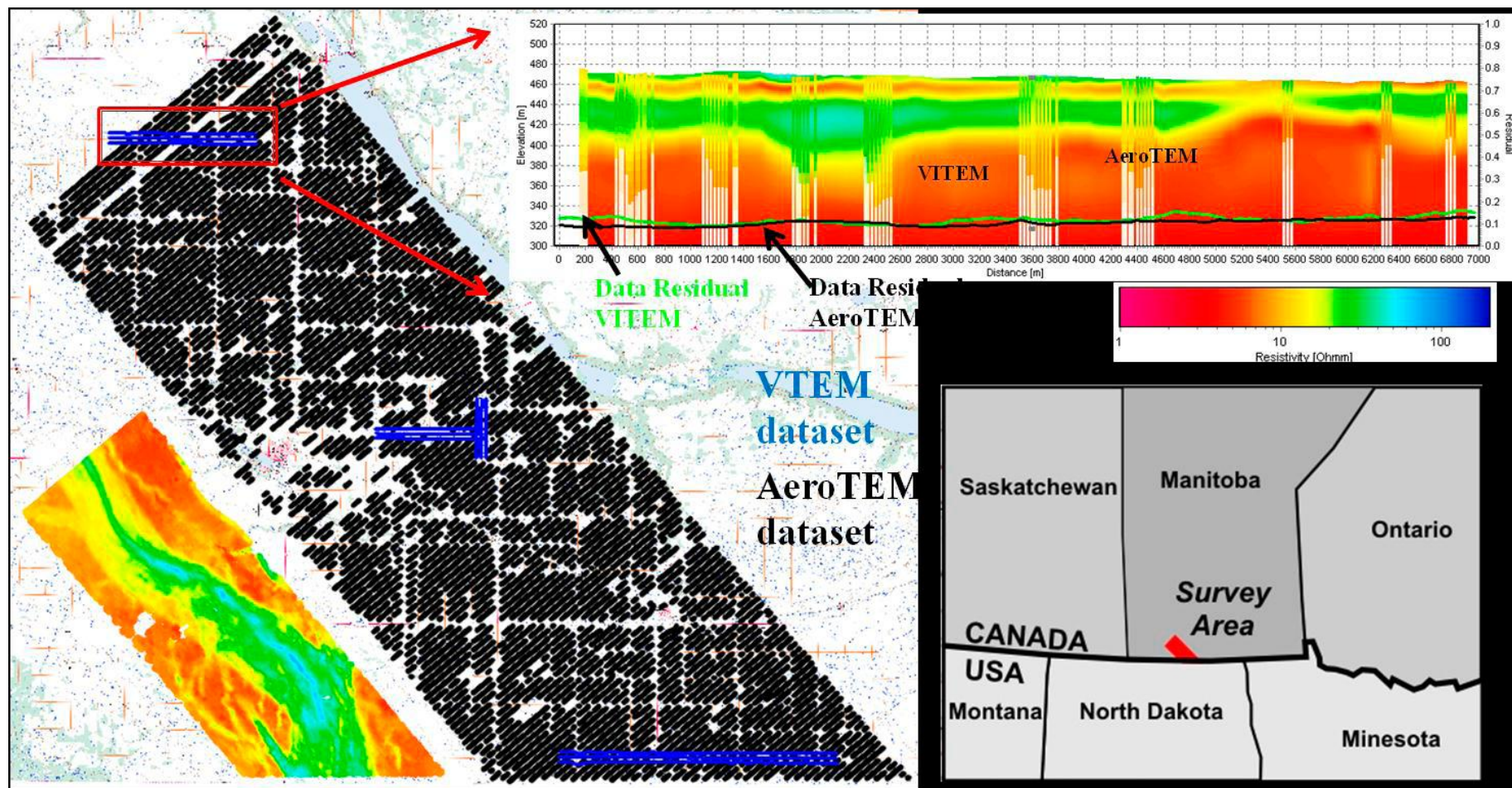


Figure 1. Spiritwood Valley survey. The black dots indicate the AeroTem survey and the blue dots the VTEM survey. The inset images show respectively a profile along the collected flight lines with a comparison between AeroTem and VTEM inversion results and a detail of the location of the survey area.

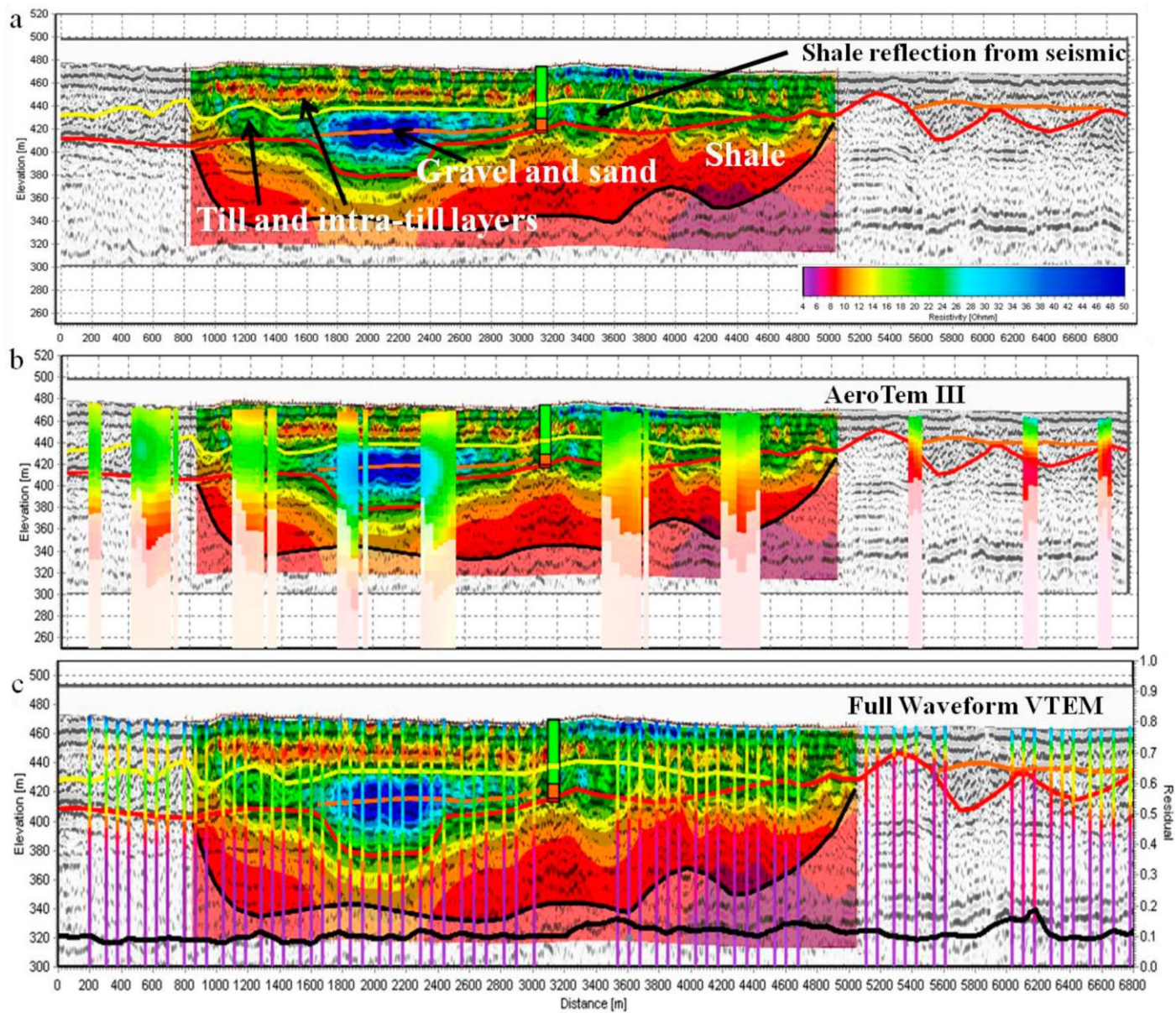


Figure 2. a) Electrical resistivity tomography profile along one of the seismic lines collected in the survey area. Resistivity values provide several geological layers; b) and c) show respectively, AeroTem and VTEM inversion results. The obtained AEM resistivity model show up a very good agreement with respect to electrical resistivity data and seismic reflectors.

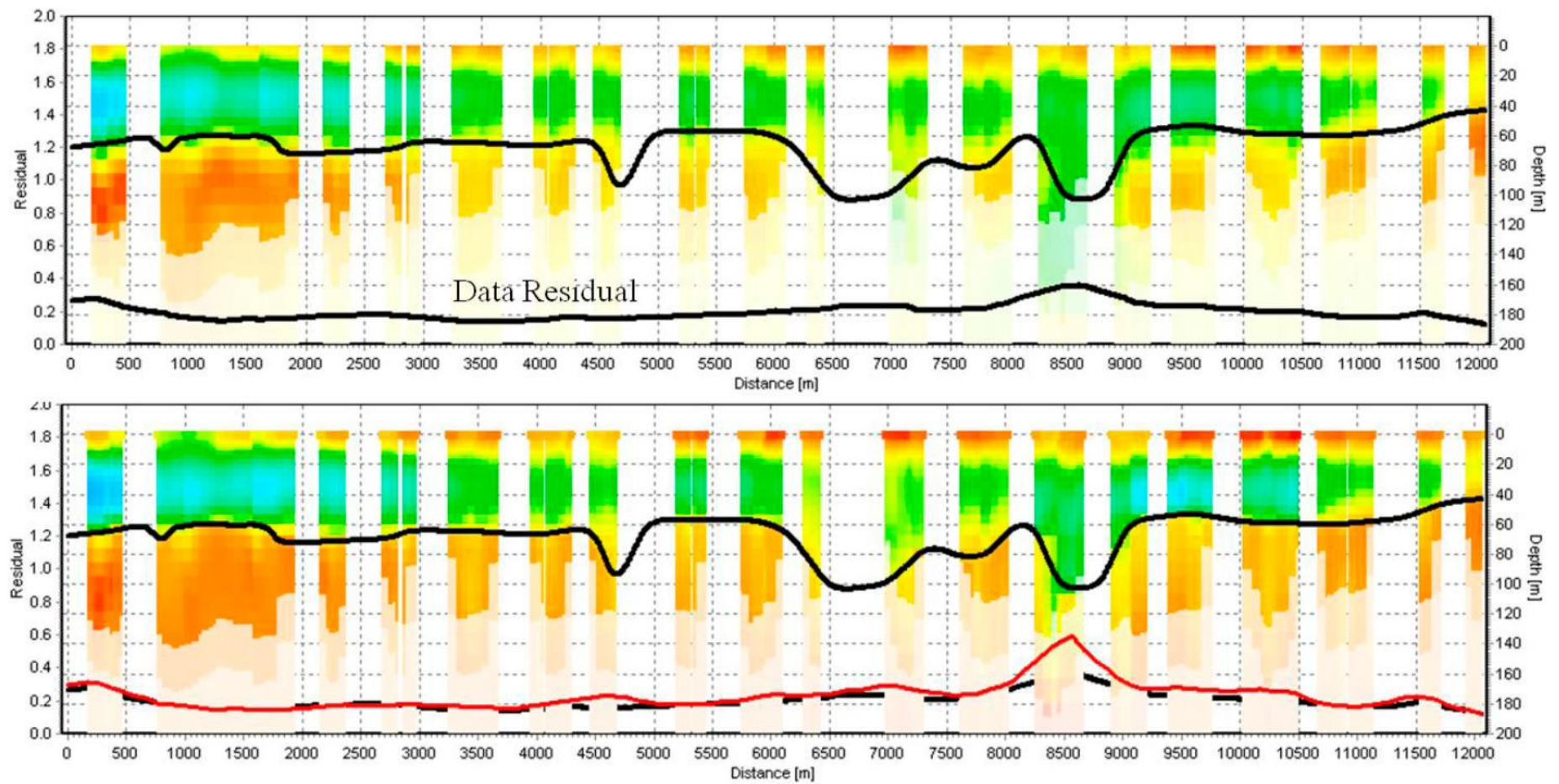


Figure 3. The effect of adding the a-priori, i.e. seismic determined depth to conductive shale bedrock (solid line) to inversion of AeroTem data. Top no a-priori, bottom with a-priori.