1D and 2D Inversion of the Magnetotelluric Data for Brine Bearing Structures Investigation

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Abstract

A detailed standard Magnetotelluric (MT) study was conducted to recognize brine bearing layers in depths of less than 1200 m in northeast of Iran close to southeastern shore of Caspian sea. Long and medium period natural-field MT method has proved very useful for subsurface mapping purpose by determining the resistivity of the near surface structure.

MT data were analyzed and modeled using a 1D inversion scheme. Then corresponding data on eight profiles were inverted using 2D inversion schemes. To have the best possible interpretation all possible modes (TE-, TM-, TE+TM- and DET-data) were examined.

Down to 2 km, the resistivity model obtained from the MT data is consistent with the geological information from a 1200 m borehole in the area. Analysis of the MT data-set suggests signatures of salt water reservoirs in the area which are distinguished potentially positive to contain Iodine. Due to the very conductive nature of the sediments regardless of all difficulties in the interpretation stage because of the lack of a considerable resistivity contrast we could recognize the more conductive zones in the less conductive host as layers of saline water.

Key words: conductivity, Iodine, magnetotelluric, 1D and 2D inversion, resistivity.

1. Introduction

Conductive structures are ideal targets for Magnetotelluric method when located in a considerably resistive host. They produce strong variations in underground electrical resistivity. In cases where the electrical resistivity of the target is not substantially different from that of it would be quite difficult to reach a promising result. Despite this limitation, we could get some useful results in our study.

Dashli-Boroon area is located in Golestan province in northeastern part of Iran right at the border with Turkmenistan. Geologically it is a part of Kopeh-Dagh sedimentary basin. Kopeh-Dagh has been formed by the last orogeny phase of Alpine and the erosion followed. Topography relief is very smooth and basically it is a flat plain consisting loesses occurring naturally between the Elburz mountain range and the desert of Turkmenistan. Quaternary sediments including clay and evaporates and particularly salt are impenetrable.

An MT survey was carried out using GMS05 (Metronix, Germany) and MTU2000 (Uppsala University, Sweden) systems in February 2007. MT data were collected at 60 sites in a network of 2 by 2 km meshes along eight EW profiles (Fig. 1).

For data processing a code from Smirnov (2003) was used. 1D and 2D inversions are conducted to resolve the conductive structures. 1D inversion of the determinant (DET) data using a code from Pedersen (2004) as well as the 2D inversion of TE-, TM-, TE+TM- and DET-mode data using a code from Siripunvaraporn and Egbert (2000) were performed.

A supplementary goal of this work is to evaluate the possibility of using surface MT measurements on the very conductive sediments to monitor the underground salt water bearing layers or bodies. Our concern which is followed in the current paper, only in the frame of one- and two- dimensional (1D and 2D) interpretation, is to emphasis on the characteristics of the extremely conductive structures which are supposed to bear Iodine in economic meanings. Based upon the MT results some sites were proposed for detail exploration by excavating deep exploration boreholes. As results the resistivity sections show a clear picture of the resistivity changes both laterally and with depth.

2. MT data acquisition

In February 2007, an MT survey was carried out at 60 sites in Dashli-Boroon area. All MT-sites are marked on the location map of Fig. 1. The magnetic declination in the area is less than 4^o i.e. in the range of error of the array setup so that the geographic north is approximately the same as the magnetic north. The MT sites were projected onto eight EW lines for later 2D modeling. A regular grid mesh of 2 km was organized for the sites due to easy transportation in the plain. The study area has a topographic relief of about maximum ±10 m which can be disregarded when using 2D inversion scheme compared with the 2 km depth of investigation.

In this study, data within a period range of 0.001-1000 s were analyzed. MT data were processed using a modern robust technique to obtain complete impedance tensor. The vertical magnetic components from various sites are not available due to an unknown source of noise which contaminated the data, therefore, we missed induction arrows which would be used to confirm the dimensionality analysis of the data. Overnight MT recording for minimum 12 hours per site have been arranged. Long time data collection was necessary to recover the proper signals from noise using statistical approaches. The problem with the unexpected noise could be dealt only by removing the noisy stacks manually since remote reference systems were not used for data acquisition.

3. MT data processing

MT data were processed as single sites using a robust routine from Smirnov (2003). The final results of processing for data from most sites were of a reasonable quality. For some sites very bad electric field data were gathered in either *x* or *y* direction most probably due to the currents directed from some power-lines in the area. Only one main component of the impedance was used for further analysis for such sites.

4. Dimensionality of the subsurface structures in the region

General morphology of the quaternary deposits shows no tendency to judge about the dimensionality. From the data itself Swift's skew (Swift, 1967) were estimated in order to analyze the dimensionality of the data. Swift's skew, defined as the ratio of the on- and off-diagonal impedance elements, approaches zero when the medium is 1D or 2D. In the case of our data, Swift's skews shown in Fig. 2 are generally less than 0.2, which shows a good indicator for almost 1D or 2D structures.

The regional strike of the survey area was calculated by applying a routine from Smirnov (2003). Relatively stable regional strike estimates defined a principle direction of about 90^{o} from magnetic north at most of the sites at period range 10 to 100 s. This would correspond to both NS and EW strike directions. Since we do not have the tipper data due to the noisy vertical component of the magnetic field we cannot approve the either strike direction, therefore we would take the determinant data in the inversion stage.

In the following section, results of 1D inversion of the determinant data and 2D inversion of the determinant data, TE-, TM-mode data and joint inversion of TE- and TM-mode data are described.

5. Near-surface distortions in EM induction

The static shift of MT apparent resistivity sounding curves is a classic example of the galvanic effect. MT sounding curves are shifted upward when measuring directly over surficial resistive bodies and they are depressed over conductive patches. The physical principles governing electromagnetic (EM) distortions due to near-surface inhomogenities have been understood for several decades and several methods appeared to correct these distortions. Two of these methods are: use of invariant response parameters like the determinant data (Pedersen and Engels, 2005) and curve shifting (Jiracek, 1990).

We did try to conduct DC-Electrical sounding in the region with no success due to extremely strong EM coupling which arose because of very highly conductive surface layer. That is why we used only the determinant data to proceed with the inversion.

6. Inversion

Depending on the dimensionality of the field structure defined by the geology, tectonics and MT data 1D, 2D and 3D modeling can be applied on the data. Models explain the data if their responses fit the measured data within their errors. Generally, the better the fit between measured and predicted data, the better the model resolution.

1D as well as 2D inversion of the determinant (DET) data were performed using a code from Pedersen (2004) and a code from Siripunvaraporn and Egbert (2000), respectively. The data were calculated as apparent resistivities and phases. To avoid of probable unrealistic small errors on the data for the 2D approximation an error floor of 5% on the apparent resistivity was defined.

MT data were collected in the period range 0.001 – 1000 which by taking into account that the average resistivity of the area is extremely low we consider a maximum depth penetration of about 2 km for our models.

6.1. One dimensional inversion

1D inversion of the determinant data (*DET*) was performed. The determinant provides a useful average of the impedance for all current directions. Furthermore it is unique and independent of the strike direction. Regardless of the true dimensionality 1D inversion of MT data and, in particular, inversion of rotationally invariant data like the determinants, provides an overview of the subsurface conductivity in a feasible sense. Based on the results of 1D inversion, a reasonable starting model and strategy can be constructed for higher order inversions of 2D or 3D. An examples of 1D modeling together with the data and calculated model responses is shown in Fig. 3.

6.2. Two dimensional inversion

Data along eight profiles were corrected were taken for 2D inversion purpose. Apparent resistivity and phase data exhibit fairly different characteristics in TE- and TM-mode and 2D modeling would therefore be expected to provide a more reasonable approximation of the true subsurface structure. Moreover, the results of the data analysis with respect to the dimensionality and the surface and deep geology of the area indicate that a 2D inversion of the MT data is required. 2D inversions of the determinant data (*DET*) profiles are performed in using the code of Siripunvaraporn and Egbert (2000).

Starting with a half-space or a priori model as the initial model, for all models, convergence to a possible minimum RMS misfit was achieved after limited numbers of iterations. Root mean squared (RMS) of data misfit normalized by data error is used to control the data-fit. The resulting models using the determinant data, data-fit and residuals along profiles E2 and E3 are shown in Figs. 4 and 5. The residuals are simply the arithmetic difference between the observed and calculated data. In some cases there is a large misfit which most probably is due to 3D structures, since outliers in the residuals are seen quite frequently.

A shallow conductor is identified as a horizontal layer in all resistivity sections at depth about 300 m. Sites 4 and 6 along the profile E2 and sites 3 and 6 along profile E3 show conductive bodies in larger depths. Data, model responses and residuals are plotted as a function of station in corresponding figures. For an easy comparison resistivity sections along all profiles are shown in Fig. 6.

7. Conclusions

1D and 2D modelling of the MT data at various sites and along profiles revealed remarkable signatures of the conductivity structures down to the depth of 2 km. Our MT investigation resolved the area very conductive which could be expected considering the common geology of the area. By depth we discovered even higher conductivities which somehow prove the idea of salt water bearing layers possibly containing Iodine minerals. Two very conductive layers are resolved in depth from 300 m to 400 m and from 800 m. The bottom of the second conductor could not be estimated accurately due to the problem of limitation on the penetration depth.

8. Acknowledgement

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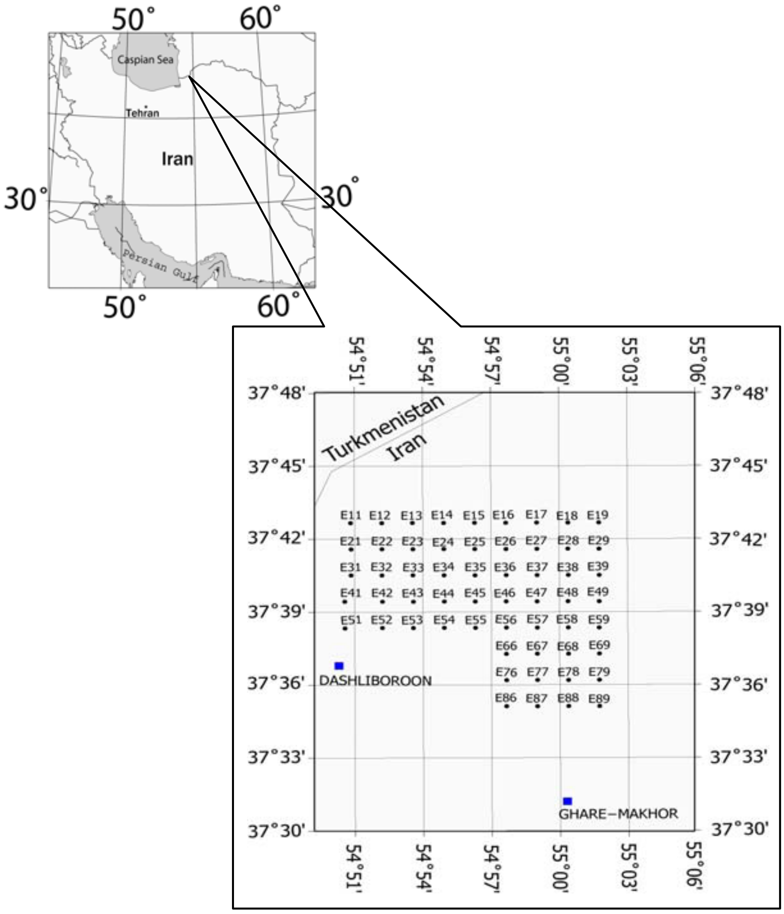
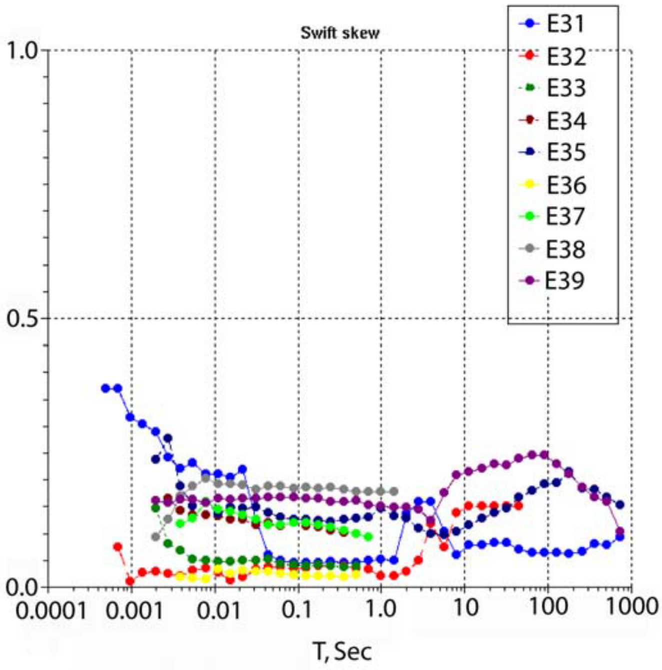
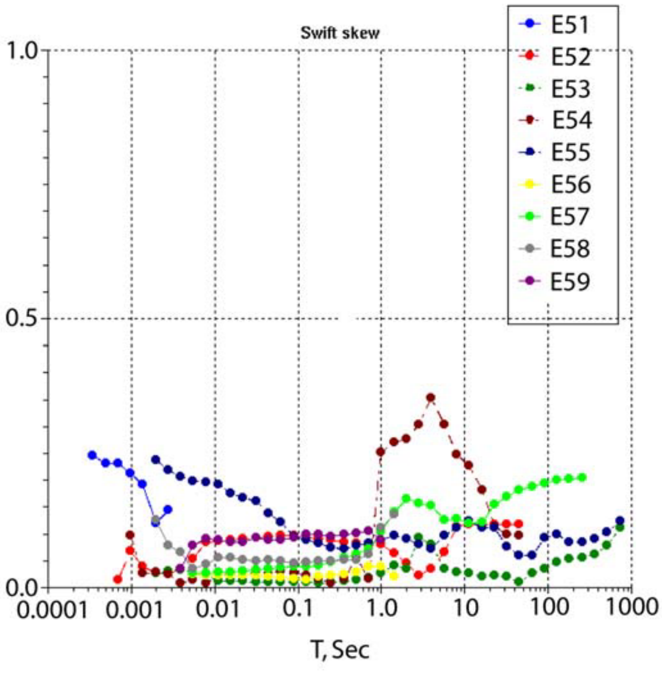


Fig. 1. A sketch of the MT-sites in Dashli-Boroon, north of Iran.



(a)



(b)

Fig. 2. Swift's skew values for all sites along profiles 3 (a) and 5 (b).

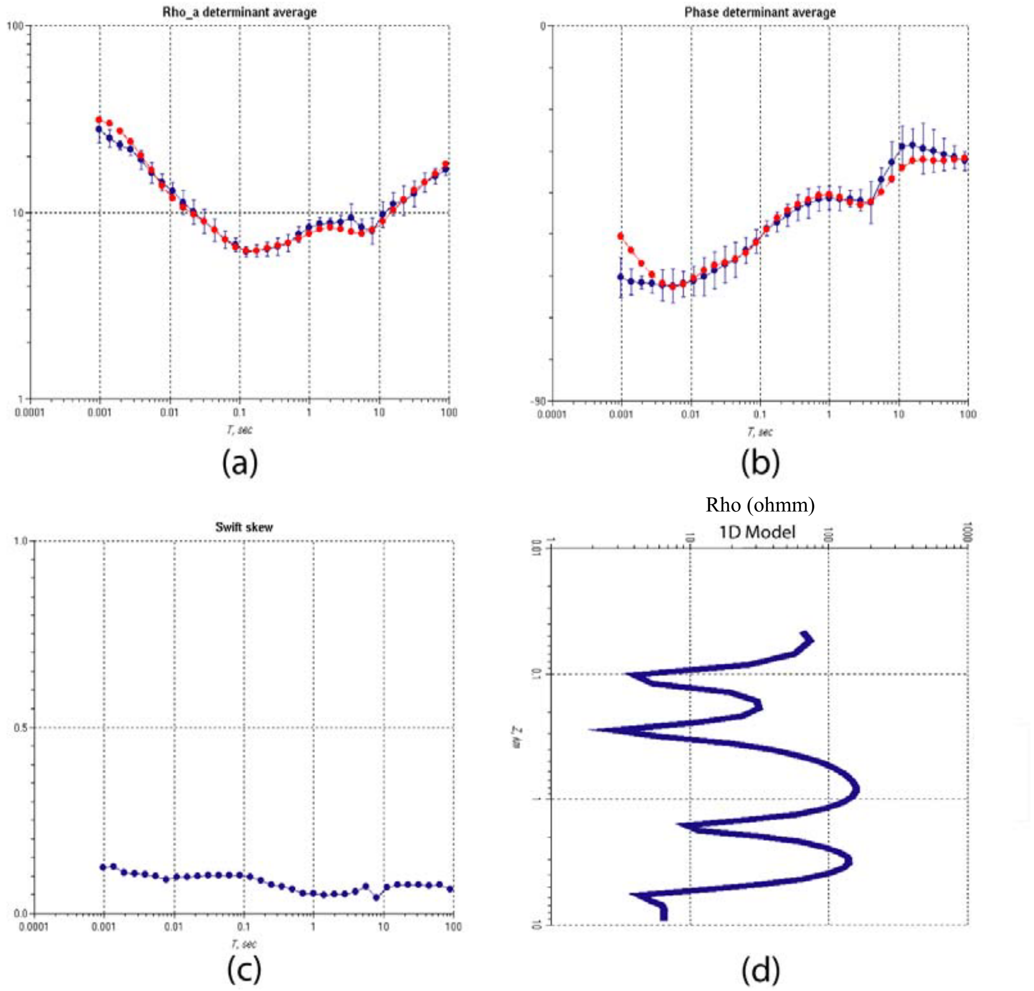


Fig. 3. Data-fit and the model for 1D inversion of the data from site E12, a) Apparent resistivity, b) Phase, c) Swift's skew, d) 1D model.

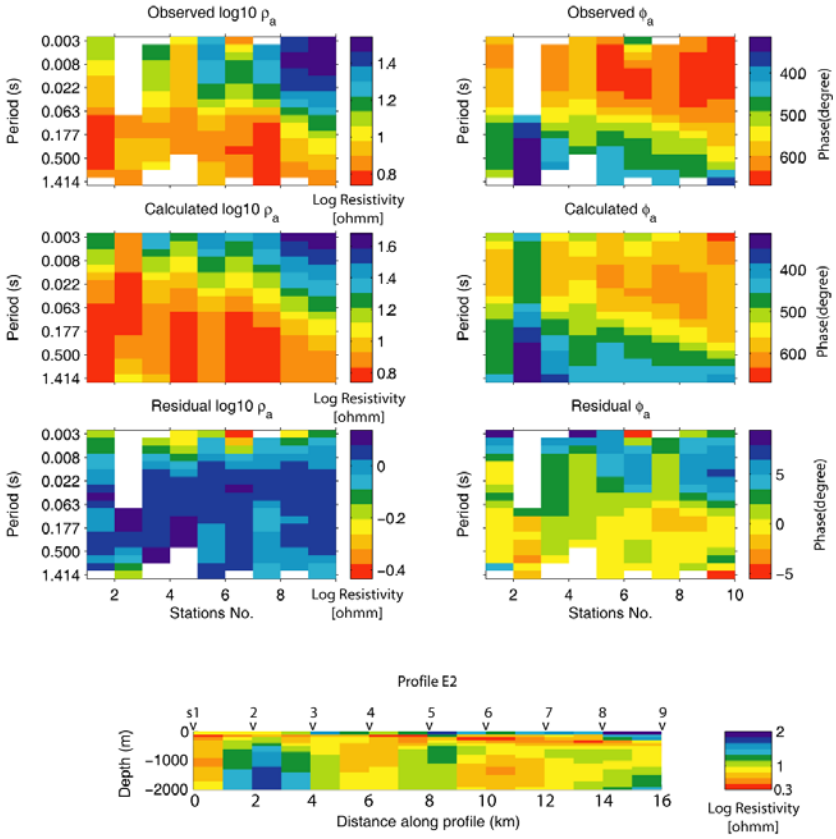


Fig. 4. Data, model responses, residuals and the model of 2D inversion for data along profile E2.

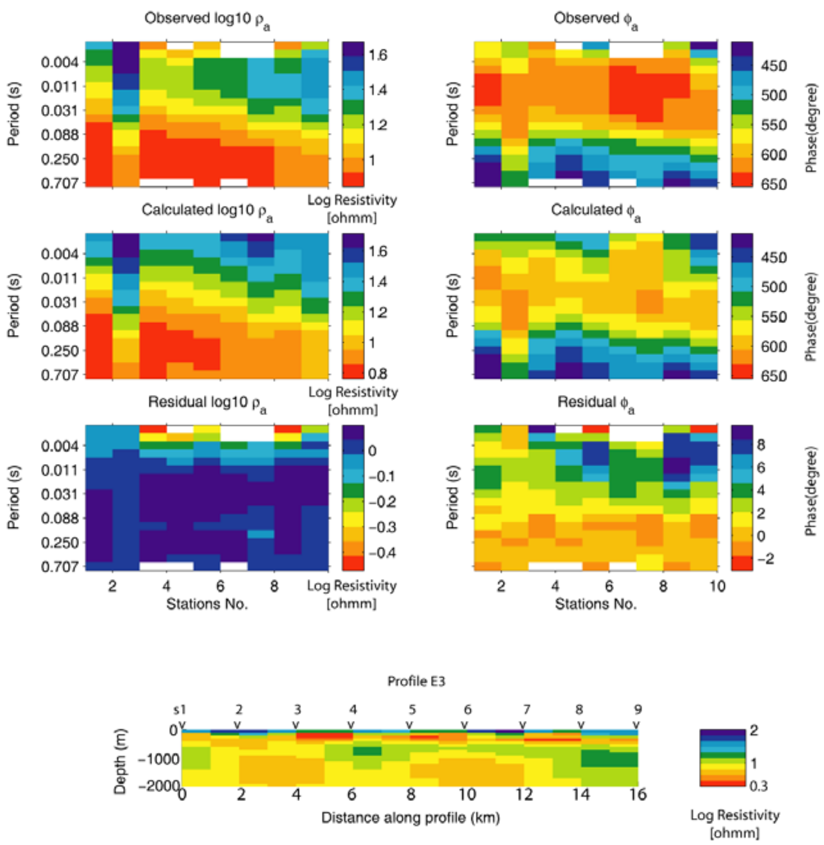


Fig. 5. Data, model responses, residuals and the model of 2D inversion for data along profile E3.

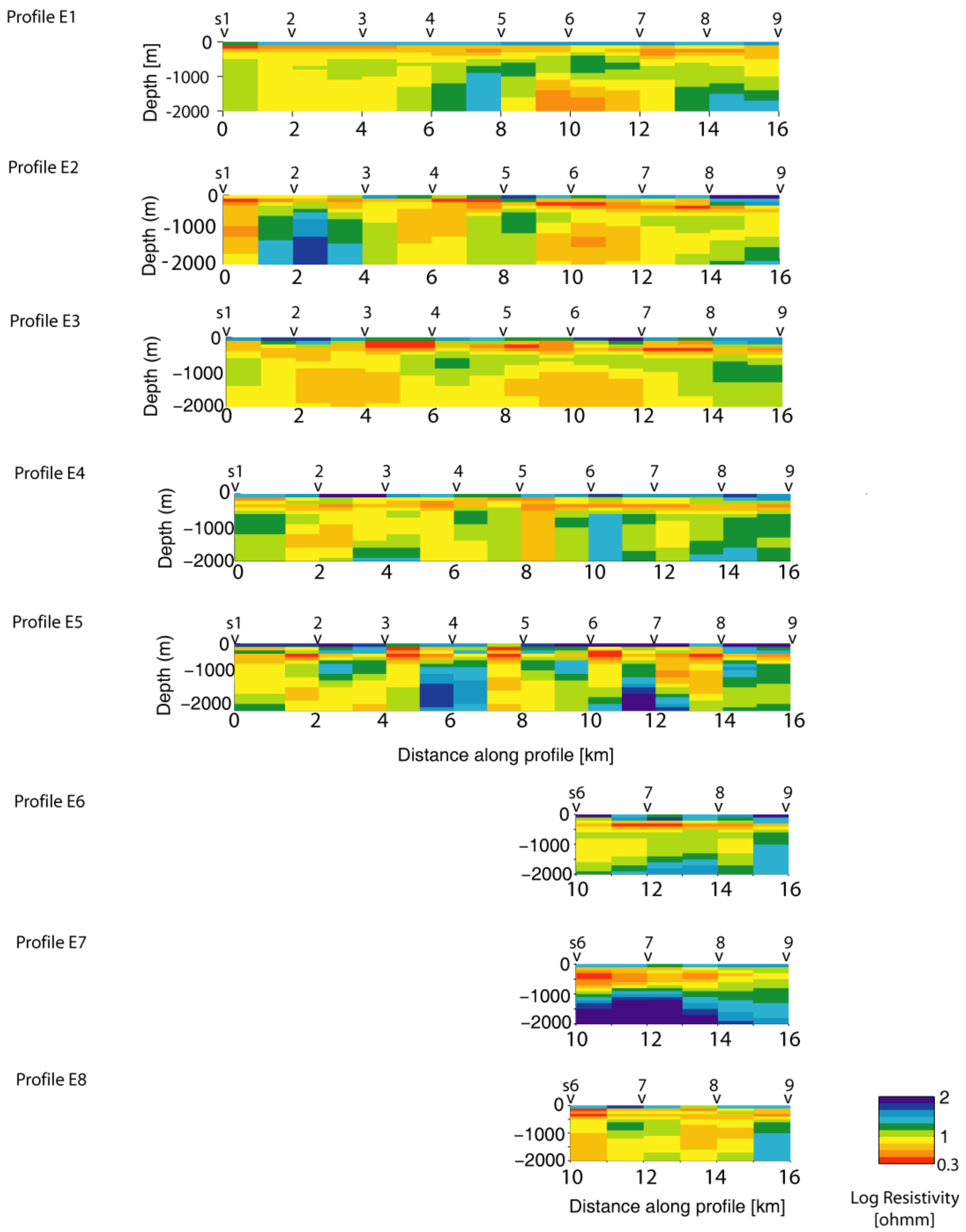


Fig. 6. 2D models along all 8 profiles for an easy comparison.