Magnetotelluric signature and well log data interpretation of Santos Basin, Brazi.

Vinicius R. Pinto[1], Sérgio L. Fontes[1], Emin U. Ulugergerli [2]; 1 - Observatório Nacional/MCT, Brazil; 2 - Çanakkale Onsekiz Mart University, Turkey

This paper was prepared for presentation at the 11th International Congress of the Brazilian Geophysical Society, held in Salvador, Brazil, August 24-28, 2009.

Abstract

In this work, we investigate the resistivity distribution of the subsurface on Santos Basin in southeast coast of Brazil. We utilize marine magnetotelluric data and geophysical well log to construct a resistivity model. 91 stations along the 3 profiles (P01, P02 and P03) covered 270 km. Frequency range is from 10 Hz to 0.0003 Hz approximately. The borehole data consists in 4 ILD logs located in the region of the magnetotelluric profiles. We show a 2D model obtained by integration of the data of profile P02 and other 2D model of the P01 profile based only in magnetotelluric data. In both models the basement was delimited clearly in position and depth and some resistive bodies were delimited in the central and southeast portion of the profile.

Introduction

Recent oil discoveries have drawn attention to marine exploration. On the contrast of high velocity masking of upper geological units such as salt, basalt and carbonates, the high contrast of the electrical resistivity between, e.g, the salt and the surrounding sediments provides an opportunity to test the applicability of the marine magnetotelluric (MMT) method in oil exploration studies (Constable et al., 1998; Sandberg et al., 2008). The Santos Basin is an offshore basin located in southeast coast of brazilian territory, covering an area of about 350.000 km^2 in front of the states of Rio de Janeiro and São Paulo. The basin has the same origin and geological evolution of adjacent Campos Basin that obtain a high production rate of oil and gas. It's reasonable to think that the Santos Basin represents an interesting target to petroleum exploration. Therefore the region have been investigated for several authors (Souza, 2006; Chang, 2008). We study the region using Marine Magnetotellurics (MMT) and well log (ILD - Induction Logging Deep) data. The magnetotelluric survey generates a whole of 3 profiles and 91 stations but we analyzed only the lines P01 and P02 with 18 and 56 stations respectively. These two profiles across the salt bodies province located in front of Campos and Santos Basin. The orientation of these profiles was based in a magnetic anomaly map (Figure 1) that exhibits a approximately NE-SW structural trend (Fontes et al., 2009). A seismic section of the area (Figure 2) shows the presence of many units but presents uncertainties in mapping the depth of the basement. A resistivity model can help to improve the resolution or even to assist in the reprocessing of seismic section. One fact deserves attention: the scale of section is exaggerated in the horizontal direction (offset) because the length is about of 160 km while the length in the vertical direction is only 10 km.

We assumed the two-dimensionality condition for the region of study based in this map. The measurements were realized since low depth waters (50 m) reaching a depth maximum of about 1500 m. We utilize the data of 4 well logs that exists along of the region of the profile. The logs are namely sps2, sps7, sps36a and sps42 and the 3 first are distant of the magnetotelluric profile about of 200 m but this value may be considered negligible when compared with the extension of the profile (Figure 3). The sps42 log is exactling in the place of station 45 of profile. The others logs (sps2, sps7 and sps36a) were considered as alocated on line in the place of stations 24, 32 and 50 respectively. The model was calculated using a routine developed by Rodi and Mackie (2001) wich finds regularized solutions based on Tikhonov Regularization (Tikhonov and Arsenin, 1977) to the two-dimensional inverse problem for MT data using the method of nonlinear conjugate gradients. We perform a joint interpretation based on this two types of data. The main aim of the Santos Basin MMT survey is to improve depth imaging. The research objective is to significantly enhance the interpretation of basement depth and salt bodies in the basin. Here, we report on the result of a preliminary evaluation of the MMT data.

Metodology

The geophysical well logging is a important method on hydrocarbon exploration and reservoir characterization because represents a low cost tool that can provide valuable informations about of reservoir properties. In this work we use ILD log data to obtain some informations about the resistivity of the rocks in several depths. The resistivity logs are used commonly to realize geological correlation but this was not possible because the data of the logs were not in the same depths. Figure 4 shows the data of the 4 logs used to construct the model. These data were used to supply a kind of information *a priori* to calculate the magnetotelluric model.

From the data logs we analyze and estabilish values for the resistivity of the rocks in different depths and introduce this information in the model to perform the inversions. These resistivity values and the conductive water layer value were locked during the iterations and these informations were the geophysical bonds utilized in this work. The geoelectrical model of P02 line is shown in figure 5a and it presents some importants characteristics. We utilize a range of resistivities from 0.1 Ω.m representing the seawater to 250 Ω.m. This decision was taken to evidence the resistivity contrasts as salt-sediments or basement-sediments. We compared our results with a model from the paralel line P01 (Figure 5b) to make possible identify the lateral continuity of the structures. This model of the line P01 was obtained using only the magnetotelluric data and 2D-inversion.

The Inverse Problem

The inverse problem can be written as

$$\vec{d} = F(\vec{m}) + \vec{e} \quad (1)$$

where $\vec{d}$ is a observation vector, F is a foward modeling function, $\vec{m}$ is a parameters vector and $\vec{e}$ is a misfit vector. Solve the inverse problem is solve the equation 1 inside the precision of the misfit vector. The inversions were computed using the algorithm nonlinear conjugate gradients that finds regularized solutions that explain the magnetotelluric data inside of a misfit. The technique consists in minimize the objective function

$$\psi(\vec{m}) = (\vec{d} - F(\vec{m}))^T V^{-1} (\vec{d} - F(\vec{m})) + \lambda \vec{m}^T \vec{L}^T \vec{Lm} \quad (2)$$

where $\vec{V}$ is a positive matrix, $\vec{L}$ and $\vec{Lm}$ are second-difference matrices and λ is a positive number called regularization parameter. This parameter controls the tradeoff between fitting the data and adhering to the model constraint. Larger values causes smoother models however worse data fit are obtained. This is a parameter that must be find in several inversions not existing a default value to be used in any inversion.

The models presented here were obtained using the WinGLink interpretation package consisting of a 2D inversion code of Rodi and Mackie. The maximum number of iterations was set to 30 for each session. The software required some additional inputs. The first one was smoothing factor, tau (regularization parameter), which was taken as 20 for the first 30 inversion steps then reduced in succeeding sessions. Therefore, inversion was, at first, allowed to find a general pattern then forced to delineate the details by sing lower tau (10) values in the later steps. Error floors for all data were kept at 5% as is the default of the code. All available frequencies were used in the inversion. Only TM mode apparent resistivity and phase of impedance data was inverted because this mode answers better to the lateral variations of resistivity.

The inversions are computed from foward model constructed using finite difference equations. The algorithm inverts for a user-defined 2D mesh of resistivity blocks and incorporating topography. The model generated from inversions is represented by a mesh of 28 by 61 cells. Evidently each station of profile is represented by one column in the model.

Summary and Conclusions

The Santos basin in Brazil have received considerable attention. The regional magnetic anomaly map shows a clear NE-SW structural trend in the area of study. The result of 2D-inversion of the MMT data across this trend provides an important practical validation of the MMT method in the deep marine environment of Santos basin. This study has shown that MMT is capable of producing a reliable geoelectrical model for offshore hydrocarbon exploration in Brazil. The both models agree in relation to the basement position and depth. The basement depth is estimated to be at about of 1000 m to 2000 m and extending itself for approximately 80 km.

These data are result of a multi-institutional effort that gave origin to magnetotelluric survey and they are being used to realize several studies (Pinto, 2009). Some preliminary results were presented on III Symposium of Brazilian Geophysical Society realized in october 2008 (Pinto et al., 2008). Many others sutdies and results are for coming.

Acknowledgments

We would like to thank PETROBRAS, CAPES and Observatório Nacional for financial support to realize this work.

References

Chang, H. K., et al., 2008. Sistemas petrolíferos e modelos de acumulação de hidrocarbonetos na Bacia de Santos. Revista Brasileira de Geociências, vol. 38, no. 2 (suplemento): p. 29-42.

Hoversten, G. M., et al., 1998. Marine magnetotellurics for petroleum exploration, part II: Numerical analysis of subsalt resolution. Geophysics, 63, no. 3, 826-840.

Fontes, S. L., et al., 2009. Marine magnetotelluric (MMT) mapping of basement and salt bodies in the Santos Basin of Brazil. First Break, EAGE Publications. **Accepted to publication**.

Pinto, V. R., et al., 2008. O método magnetotelúrico marinho aplicado às situações pré-sal na Bacia de Santos. III Symposium of Geophysical Brazilian Society, Belém-Pará, Brasil.

Pinto, V. R., 2009. O Método Magnetotelúrico Marinho (MMT) na Exploração de Hidrocarbonetos. Msc. Thesis, Observatório Nacional/MCT, Rio de Janeiro, Brasil.

Rodi, W. & Mackie, R. L., 2001. Nonlinear conjugate gradients algorithm for 2D magnetotelluric inversion. Geophysics, vol. 66, no. 1, p. 174-187.

Sandberg, S. K., X. Wu and T. Roper, 2008. Salt mapping in the Gulf of Mexico using marine magnetotellurics. First Break, 26, 91-94.

Souza, S. B., 2006. Feições regionais da porção emersa do Alto do Cabo Frio e sua continuação para para as Bacias de Campos e Santos. Msc. Thesis, Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brasil.

Tikhonov, A. N. and Arsenin, V. Y., 1977. Solutions of ill posed problems. W. H. Winston, California, USA, 258 pp.

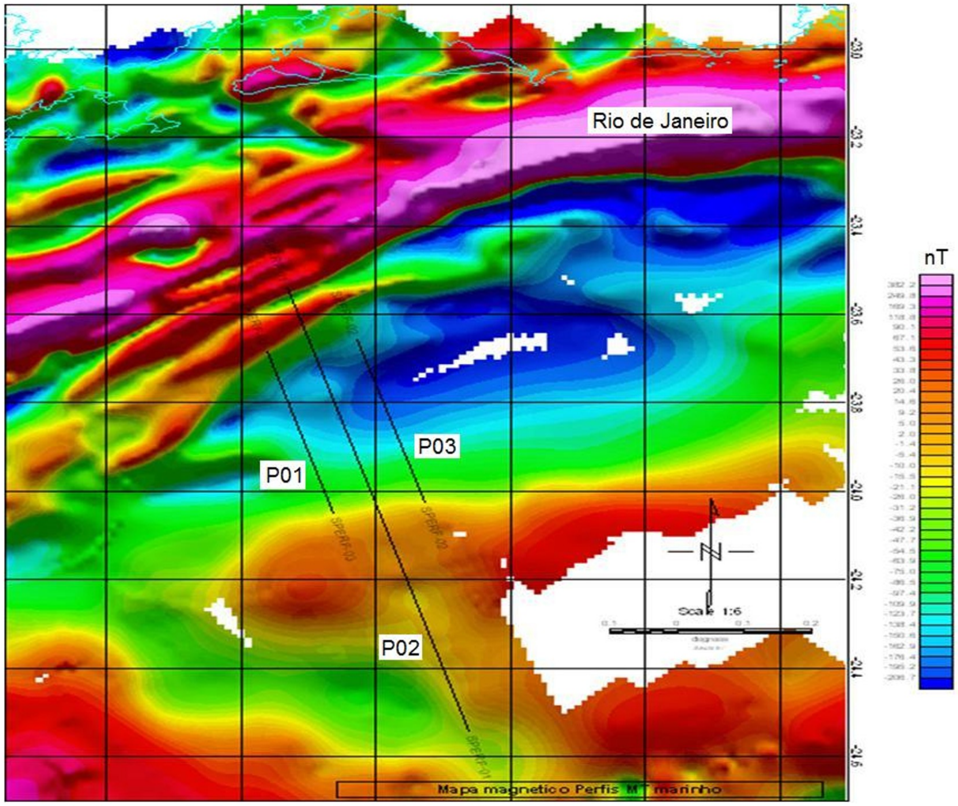

Figure 1: Localization map of Campos and Santos Basins in front of the states of the Rio de Janeiro and São Paulo (a) and magnetic anomaly map of Santos Basin showing the 3 profiles P01, P02 and P03 (b).

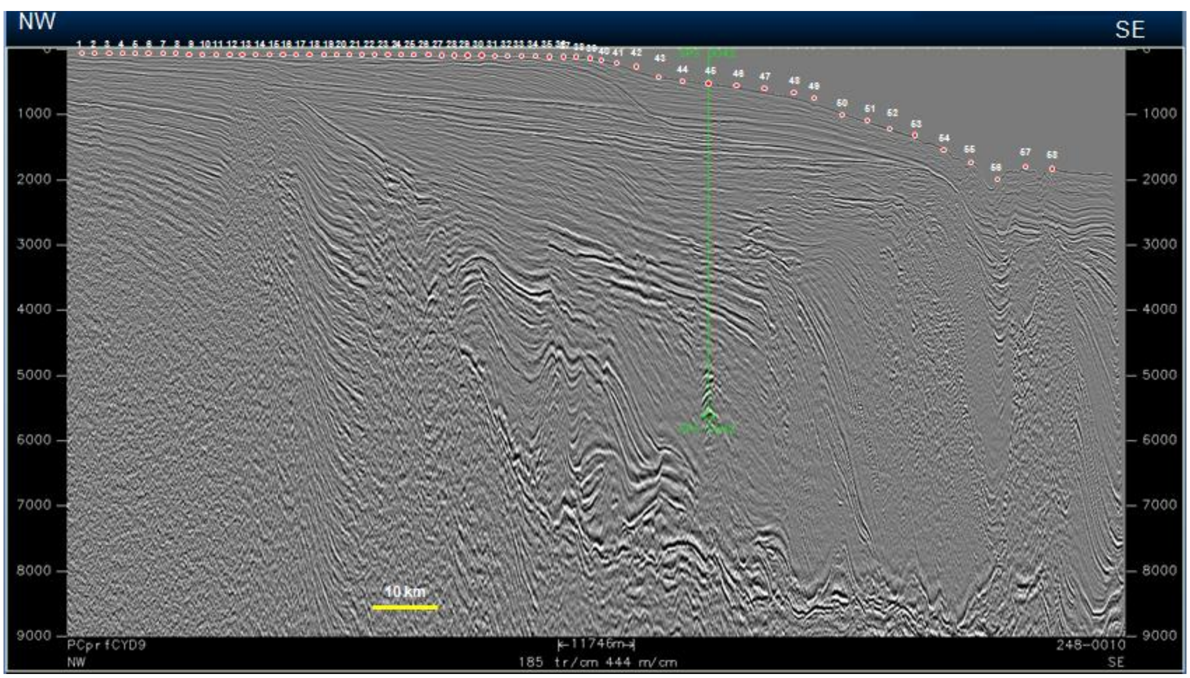

Figure 2: Seismic section of the region of the magnetotelluric profile in Santos Basin. Note the scale (yellow trace) representing 10 km while in the vertical direction this size is different.

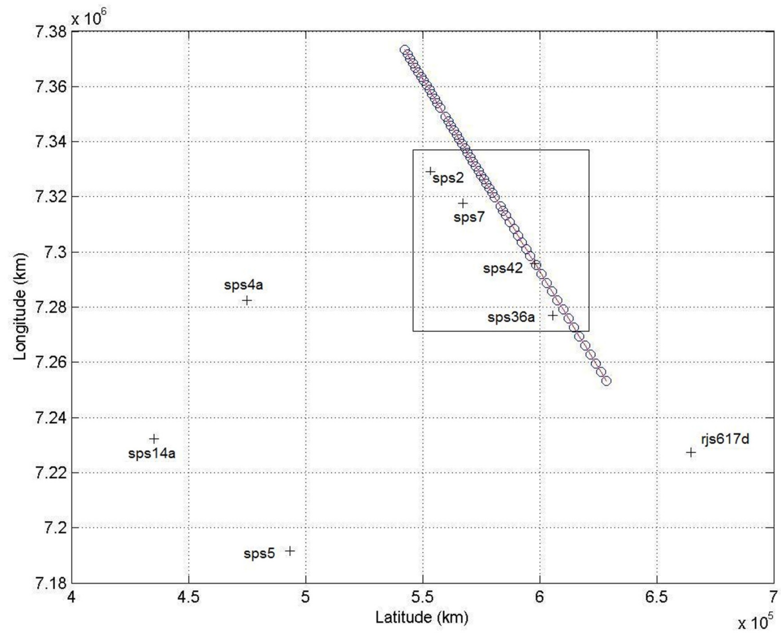

Figure 3: Perimeter of study showing the profile and the well logs of the area, the circles are the magnetotelluric stations and the crosses are the logs. Inside the square are the 4 logs analyzed in this work and out are some others logs.

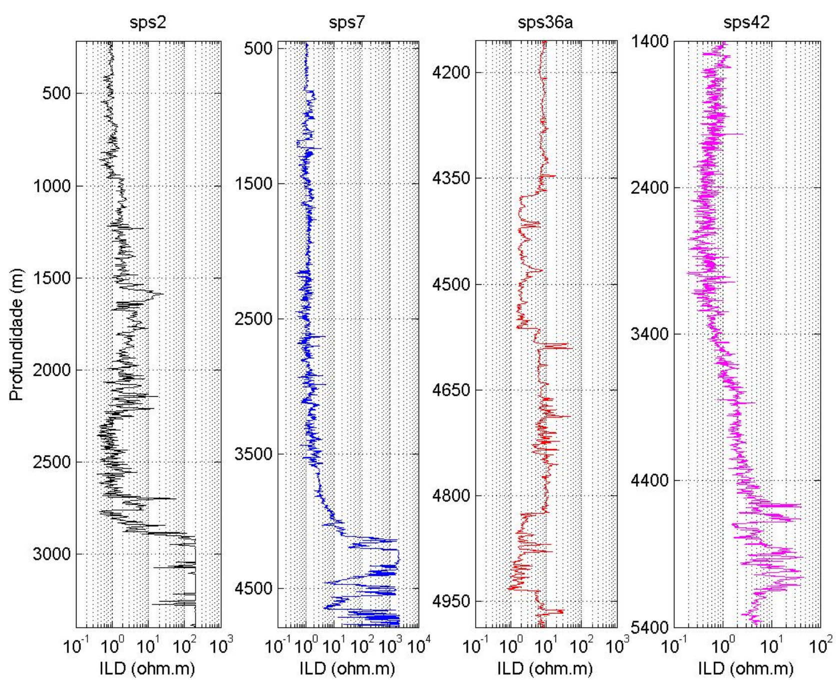

Figure 4: Well logging data used as initial information to help to calculate the resistivity model. Note that the depths are not equals, this fact confuses a possible geological correlation.

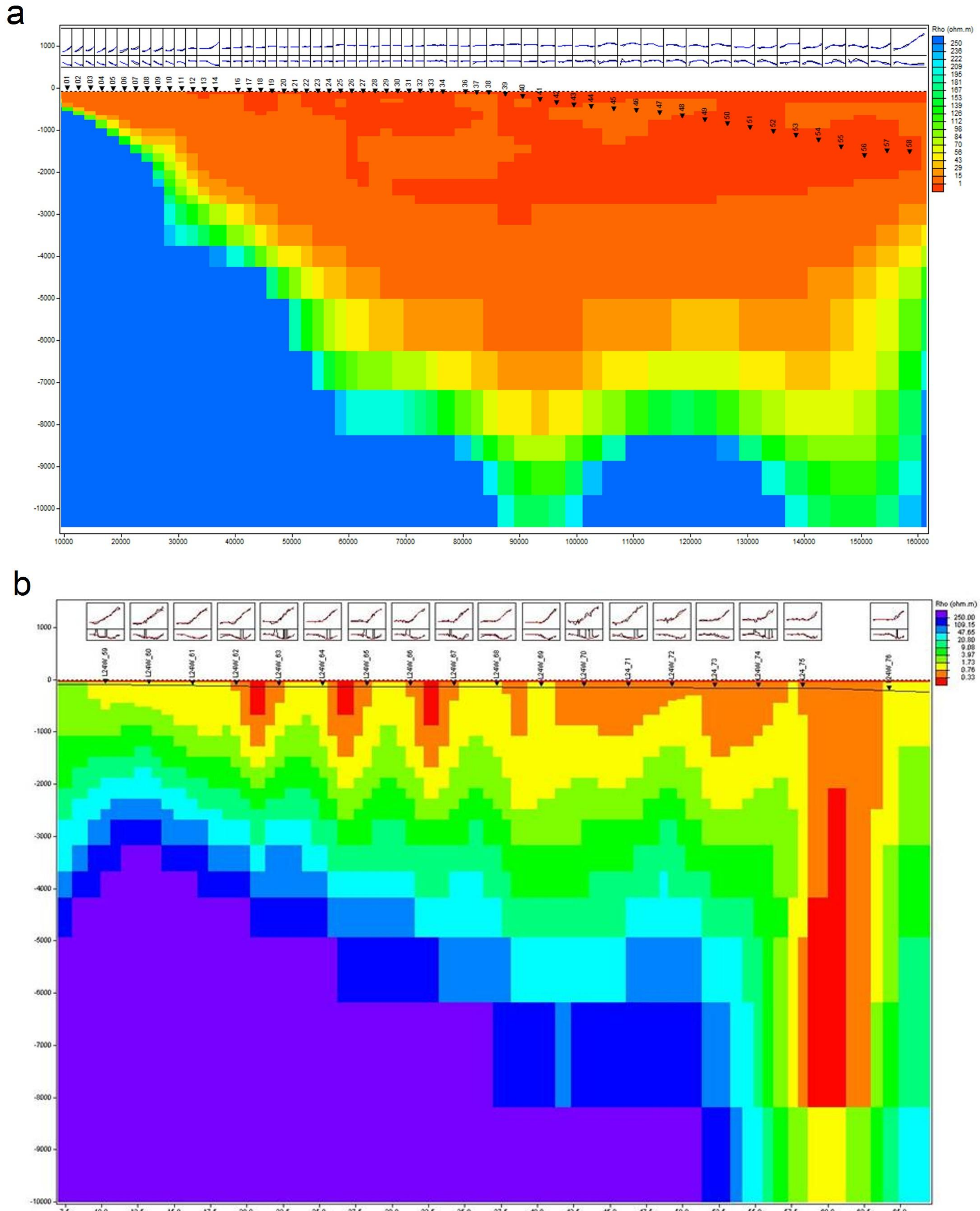

Figure 5: Jointly geoelectrical model of profile P02 obtained from 2D-inversions and well log data (a). Model obtained for profile P01 using only magnetotelluric data. Note that the basement depth is estimated to be at 1000 m near-shore although is uncertain in the seismic section (Figure 2).