ANNALI DI GEOFISICA, VOL. 41, N. 3, August 1998

Magnetotelluric and DC electrical soundings in the Po plain (Veneto region)

Luigi Alfano (1), **Mauro Giudici** (1) **and Annalisa Zaja** (2)
(1) *Dipartimento di Scienze della Terra, Sezione di Geofisica, Università di Milano, Italy*
(2) *Dipartimento di Geologia, Paleontologia e Geofisica, Università di Padova, Italy*

Abstract
Eleven MT soundings and two dipole-dipole electrical soundings were carried out in the area of the Po plain south of the town of Padua. MT soundings were performed in the frequency band from 100 to 1/64 Hz; DC soundings were achieved, respectively, with a 2000 and 4000 m length of the array. The electrical interpretative models show a predominant monoclinalic tectonic behaviour with an evident deepening of the resistive basement toward NE. The joint use of the two electrical techniques defined the geological and structural setting up to a depth of 2 km in a highly conductive area.

Key words *magnetotelluric – dipole-dipole DC measurements – Veneto region*

1. Introduction

In the last 15 years geophysical prospecting (Norinelli, 1979; Norinelli *et al.*, 1988) has revealed the presence of a faulting system in the area of the Po plain south-east of Padua (Veneto region). Zaja *et al.* (1989) proposed a 1D magnetotelluric interpretation along two profiles. The two 1D models showed a deepening of the electrical basement towards NE.

In order to establish the presence of the faults system, namely to point out the amount of displacement of these faults, five new MT soundings were carried out by the operating unit of University of Padua; moreover, as in the previous electrical interpretation some doubts arose as to the resistivity value of the electrical basement, dipole-dipole DC soundings were performed by the operating unit of University of Milan.

Because of the highly conductive environment and the low signal-to-noise ratio, two dipole-dipole soundings only were carried out in a restricted area where MT soundings detected the resistive basement at shallow depth.

2. Geological outlines

The area under study is shown in fig. 1 and lies south of Padua between Legnaro and Conselve villages and it is bounded by the Colli Euganei on the western side. Geological information derives from field geological surveys over the prealpine hills, Colli Euganei and other hill ranges surrounding the study area; these results are integrated with lithostratigraphic data from deep wells and geophysical data.

Mailing address: Dr. Annalisa Zaja, Dipartimento di Geologia, Paleontologia e Geofisica, Sezione di Geofisica, Università di Padova, Via Rudena 3, 35125 Padova, Italy; e-mail: terra03@ipdunivx.unipd.it

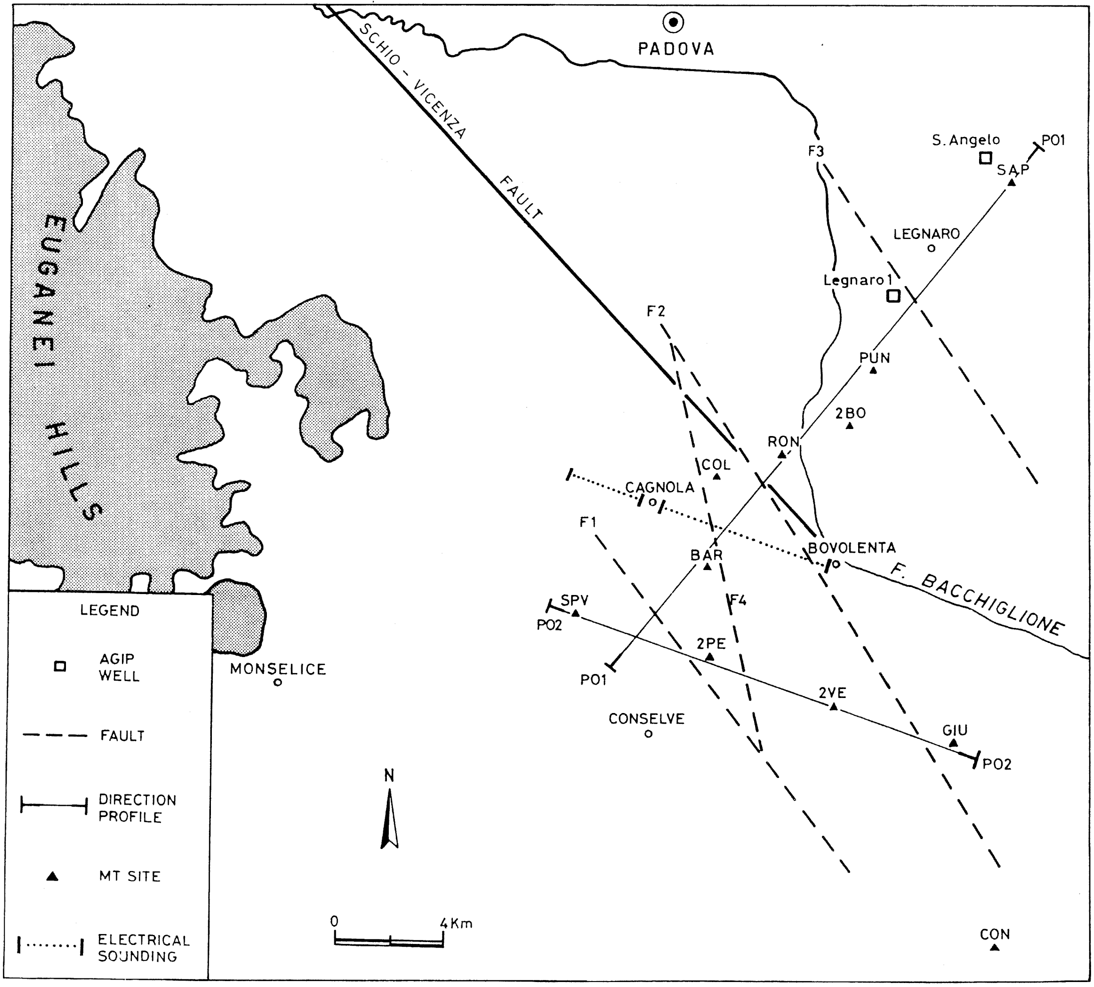


Fig. 1. Map of the study area; locations of magnetotelluric and electrical soundings as from the legend.

The older portion of the stratigraphic sequence is given by the pre-Permian crystalline basement that outcrops in the near prealpine areas (Antonelli *et al.*, 1983). Both seismic prospecting (Finetti, 1972) and drillings (AA.VV., 1972) confirmed its presence below the Po plain in the Veneto region and in the Northern Adriatic Sea. Above the crystalline basement the Permo-Triassic sequence is found, which consists of an alternation of sedimentary rocks with varying lithology (limestone, dolomite, silty-sandstone and clay). The «Legnaro 1» well (AA.VV., 1972) (see fig. 1) shows the existence of an evaporitic marl-sandstone unit, which is not found at the surface. The Jurassic-Cretaceous sequence consists of carbonatic and carbo-siliceous rocks: they outcrop at Colli Euganei over a limited area (Antonelli *et al.*, 1983), showing a strong dip towards the plain. The Tertiary sequence, as revealed by stratigraphic analyses of the «Legnaro 1» and «S. Angelo 1» wells

(AA.VV., 1972), shows very thin, if not absent, Miocene deposits, whereas Pliocene and Quaternary deposits have greater thickness. This sequence consists mainly of marls, as indicated from stratigraphic data from the «Legnaro 1» well. The marine Quaternary formations, transgressive over Pliocene formations, are represented by clay and sands, whereas thick continental Quaternary units mainly consist of alluvial materials coming from the erosion of morenic deposits.

From the structural point of view, the bedrock is characterized by a fast deepening below the plain, moving from Colli Euganei towards the east (Leonardi *et al.*, 1973). This phenomenon is caused both by subsidence of the present plain region during the Pliocene and Quaternary and by disjunctive tectonic activity long NW-SE and ENE-WSW directions. These directions are parallel to the Schio-Vicenza fault (Molon, 1882, 1883) and to the pedemountain flexure, respectively. The Schio-Vicenza fault is the main structural feature of the region and has been mapped from field geological survey north of the study area. Geophysical data support the hypothesis of a continuation towards the south, where the principal fault appears associated with a number of minor faults with the same direction (Zaja *et al.*, 1989): this faulting system extends towards the east for about 10 km and determines the deepening of the bedrock in the plain. Another effect associated with the Schio-Vicenza fault is a second system of faults, with NNW-SSE direction.

3. Geophysical survey

Figure 1 shows the position of the old magnetotelluric stations, SPV, BAR, PUN, SAP, GIU, CON (Zaja *et al.*, 1989), the new magnetotelluric sites COL, RON, 2BO, 2PE, 2VE, along with the position of the dipole-dipole soundings.

Data from new magnetotelluric soundings were recorded with MSPM, a real time acquisition system (Bon *et al.*, 1987), in three different overlapping frequency bands: 100-1 Hz, 8-1/8 Hz, 1-1/64 Hz. Apparent resistivity and phase curves along the measurement directions and along the strike direction were estimated with standard processing methods (Swift, 1967). The strike direction and the skewness parameter were also computed to establish the dimensionality of the area (Vozoff, 1972).

Two continuous polar dipole-dipole soundings, named «Cagnola» and «Bovolenta» were recorded with an analog recording system for the smallest distances and with a digital one for the potential difference at the potentiometric dipole for distances greater than 1 km. The signal to noise ratio was very small so that the array lengths for the two soundings were 2 and 4 km, respectively for «Cagnola» and «Bovolenta» soundings. Results of the dipole-dipole soundings have been transformed into apparent resistivity diagrams for the corresponding half-Schlumberger arrays, following the methodology described in Alfano (1974). Figure 2a,b shows the apparent resistivity diagrams for the two soundings.

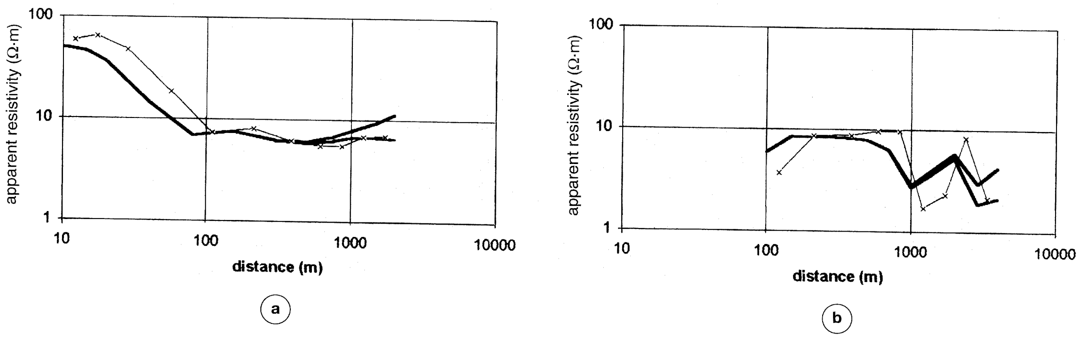
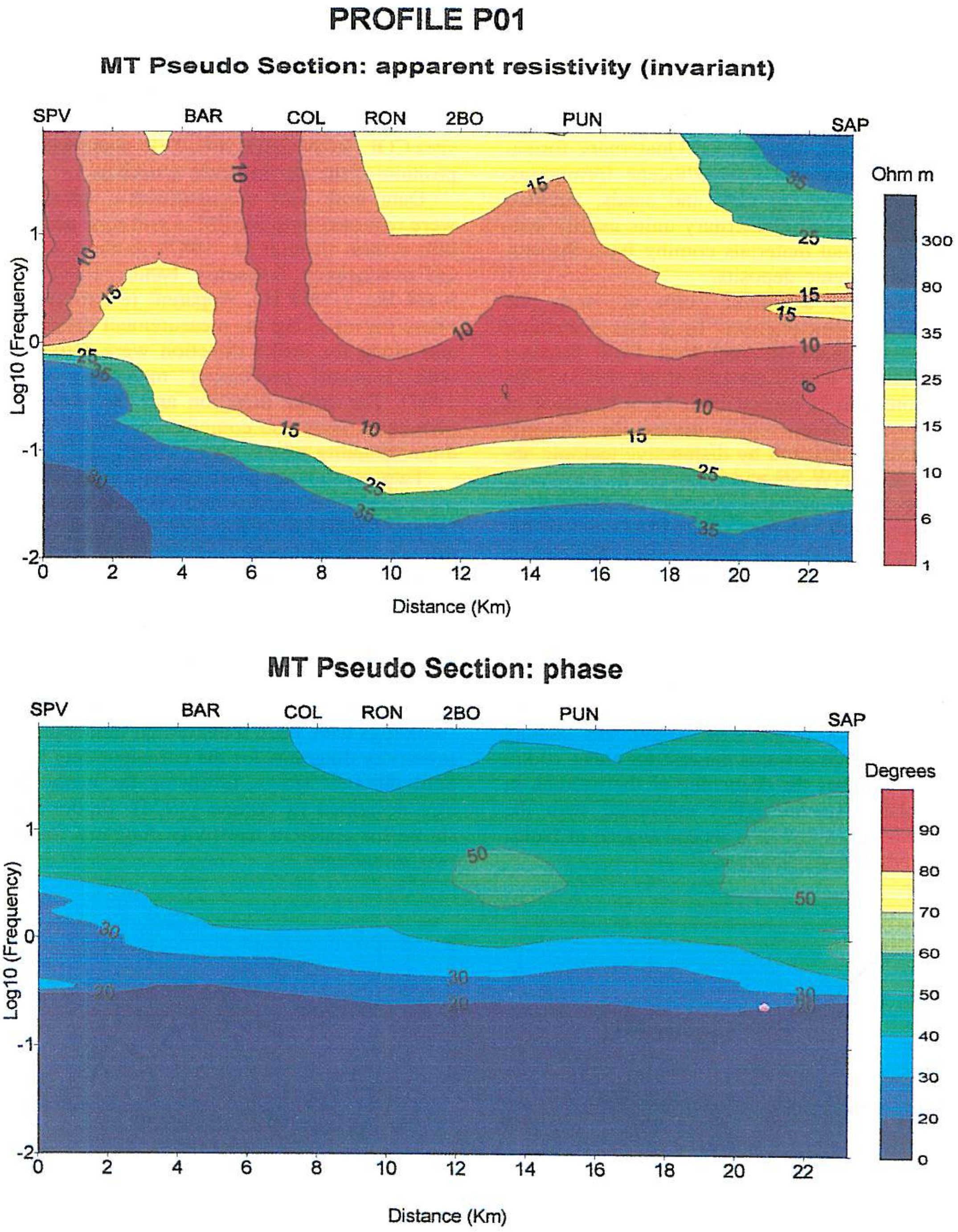


Fig. 2a,b. Diagrams of apparent resistivity for dipole-dipole soundings: a) «Cagnola» sounding; b) «Bovolenta» sounding. Crosses and thin line: field dipole-dipole diagram. Thick lines: half-Schlumberger transformed diagrams.

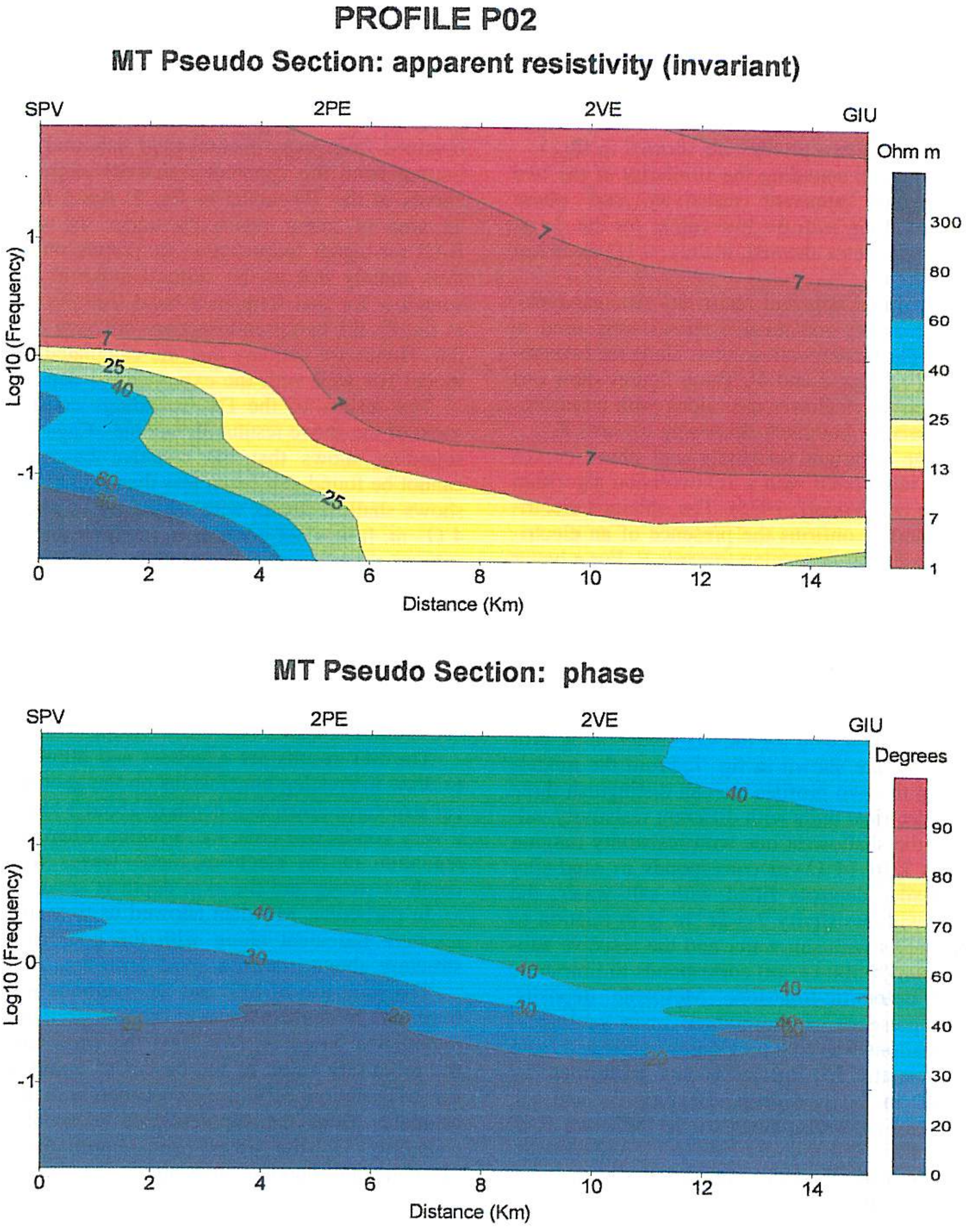


PROFILE P01

MT Pseudo Section: apparent resistivity (invariant)

MT Pseudo Section: phase

Fig. 3. Pseudosections of invariant apparent resistivity and corresponding phase for profile P01.


PROFILE P02

MT Pseudo Section: apparent resistivity (invariant)

MT Pseudo Section: phase

Fig. 4. Pseudosections of invariant apparent resistivity and corresponding phase for profile P02.

4. Data analysis and interpretation

MT soundings were used to define two magnetotelluric profiles, P01 and P02, in the N40E and N120E directions respectively. Directions of the two profiles are showed in fig. 1.

For each sounding the similarity of the two orthogonal apparent resistivity and phase curves along with the low values for the skewness parameter showed, mainly, a 1D electrical behaviour.

Invariant apparent resistivity (Ranganayaki, 1984) curves and relative phases were used to build electrical pseudosections along the two profiles (see figs. 3 and 4). These figures show one conductive shallower area along with an electrical resistive basement deepening towards E.

The invariant resistivity and phase curves were interpreted with a 1D inversion algorithm (Jupp and Vozoff, 1975). The obtained electrical model confirms the presence of an electrical basement deepening towards E. For a better definition of the deepening a 2D forward modelling interpretation (Wannamaker *et al.*, 1986) along profile P01 was also used. The results along P01 (2D modelling) and P02 (1D modelling) profiles are shown in figs. 5 and 6; the fitting of the response model curves with the experimental data for the 2D model along profile P01 are shown in fig. 7. From the models along the two profiles we can distinguish three geoelectrical units with different resistivity values: the shallowest one with resistivity ranging from 7 to 14 $\Omega \cdot$ m corresponds to sand-silty and silty deposits filled with salt water; the unit with resistivity 2-3 $\Omega \cdot$ m is in relation to silt marls with salt water and the resistive substratum (> 500 $\Omega \cdot$ m) corresponds to limestone and dolomitic-limestone Mesozoic deposits. The presence of these three main geological formations was also previously confirmed from the electric log measurements performed by AGIP in the two deep «Legnaro 1» and «S. Angelo 1» wells, close to the MT site SAP (fig. 1).

From the modelling results, the most interesting feature is the sequence of blocks that belong to the resistive basement and that are found at different depths. The effect of four dislocation lines make possible a deepening of the top of the limestone substratum from about 550 m at site SPV down to about 1700 m at the eastern site SAP.

Figure 8 compares two apparent resistivity pseudosections along profile P01: the top was obtained from experimental field data and the bottom from the apparent resistivity response curves of the 2D model in fig. 5. Apart from an area of major resistivity under the sites BAR for higher frequencies (see picture on the top), mainly due to the cultural noise in this sounding for that frequency band (see the site in fig. 7), the two pseudosections are very similar. Hence we can say that the calculated 2D model fits well with the experimental data.

The results of the DC soundings confirm some of the above results. In fact the «Cagnola» sounding shows that the resistive basement cannot be found at a depth less than 600 m and shows shallow layers with resistivity of about 4 $\Omega \cdot$ m. It was not possible to interpret the results of the «Bovolenta» sounding with a simple structure; in fact it clearly shows evidence of strong lateral heterogeneity (fig. 2b).

5. Conclusions

The MT results are excellent and allow us to draw interesting conclusions on the geological structures down to a depth of about 2 km in a very conductive area, *i.e.* a region where attenuation of the electromagnetic waves with depth is strong and the skin depth is small.

In particular, MT data allowed us to map a resistive basement along with the geological structure above it with a good definition.

The joint use of MT and DC methods was important to confirm some of the interpretative hypotheses based on MT data: the depth and the resistivity value of the basement found at the MT station SPV are consistent with the estimates from the dipole-dipole «Cagnola» sounding. On the other hand dipole-dipole «Bovolenta» sounding does not reach the resistive basement and shows strong lateral variations, which are consistent with the hypothesis of the existence of the fault F1. MT and DC data show that this structural element in-

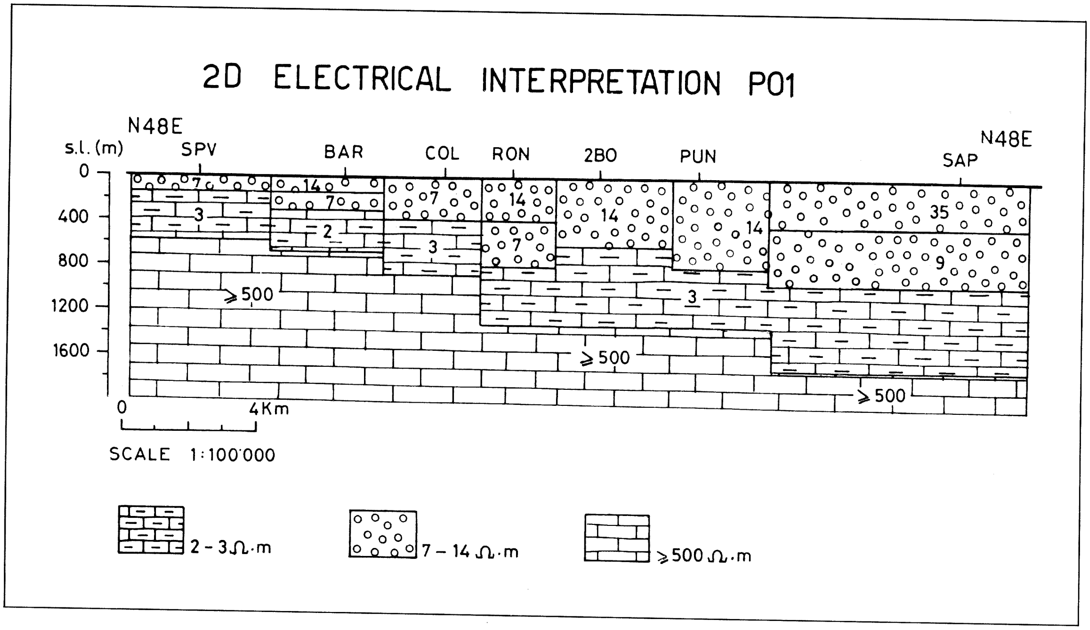


Fig. 5. Results of 2D modelling for profile P01.

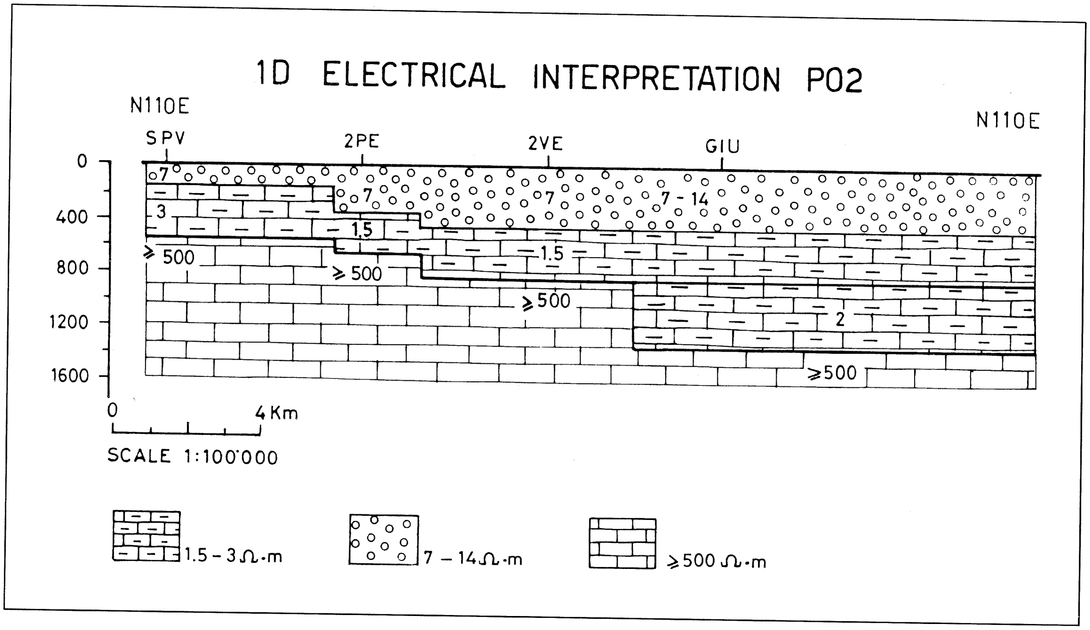


Fig. 6. Results of 1D modeling for profile P02.

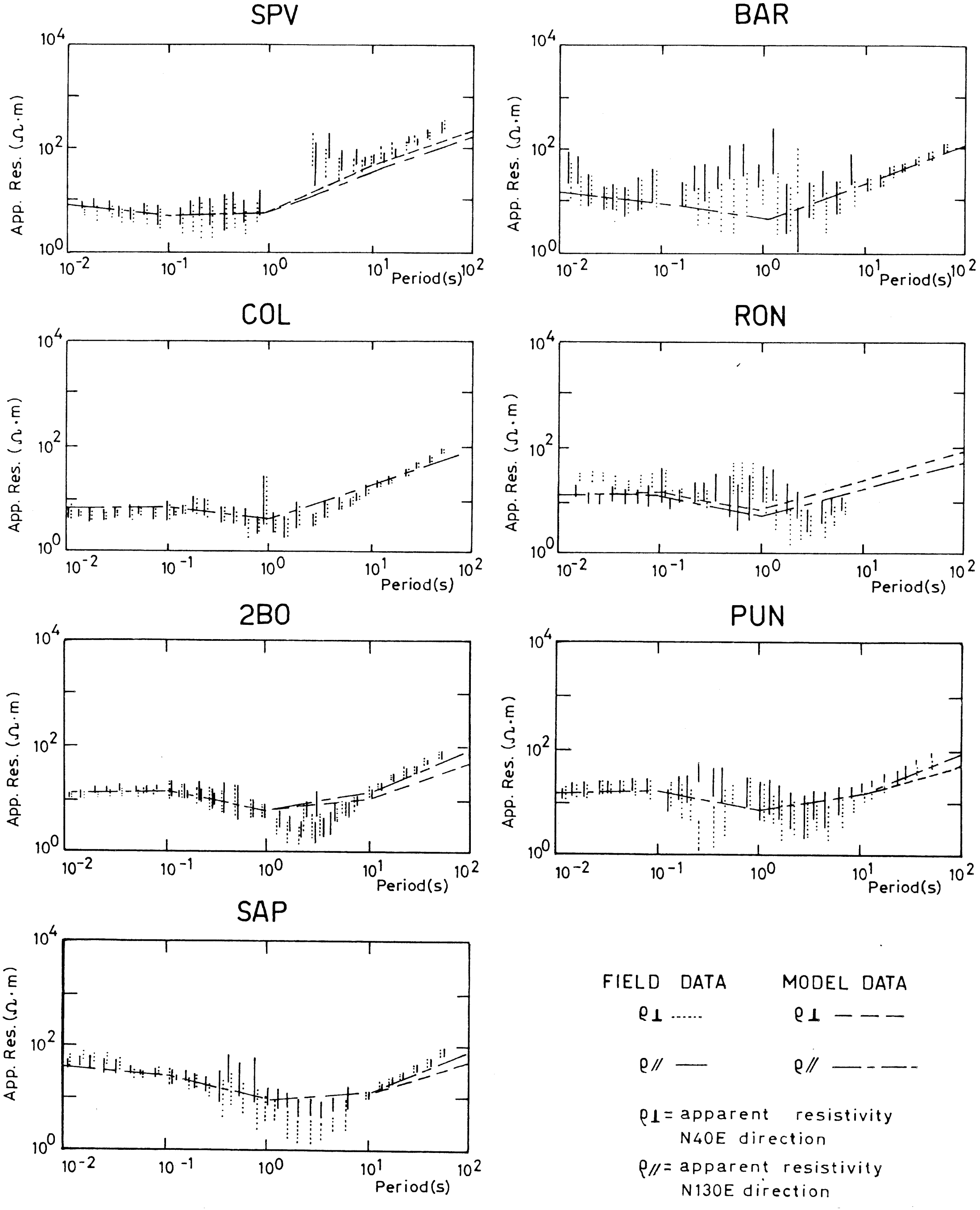


Fig. 7. Comparison of the results from 2D forward modelling (see fig. 5) and field data for profile P01.

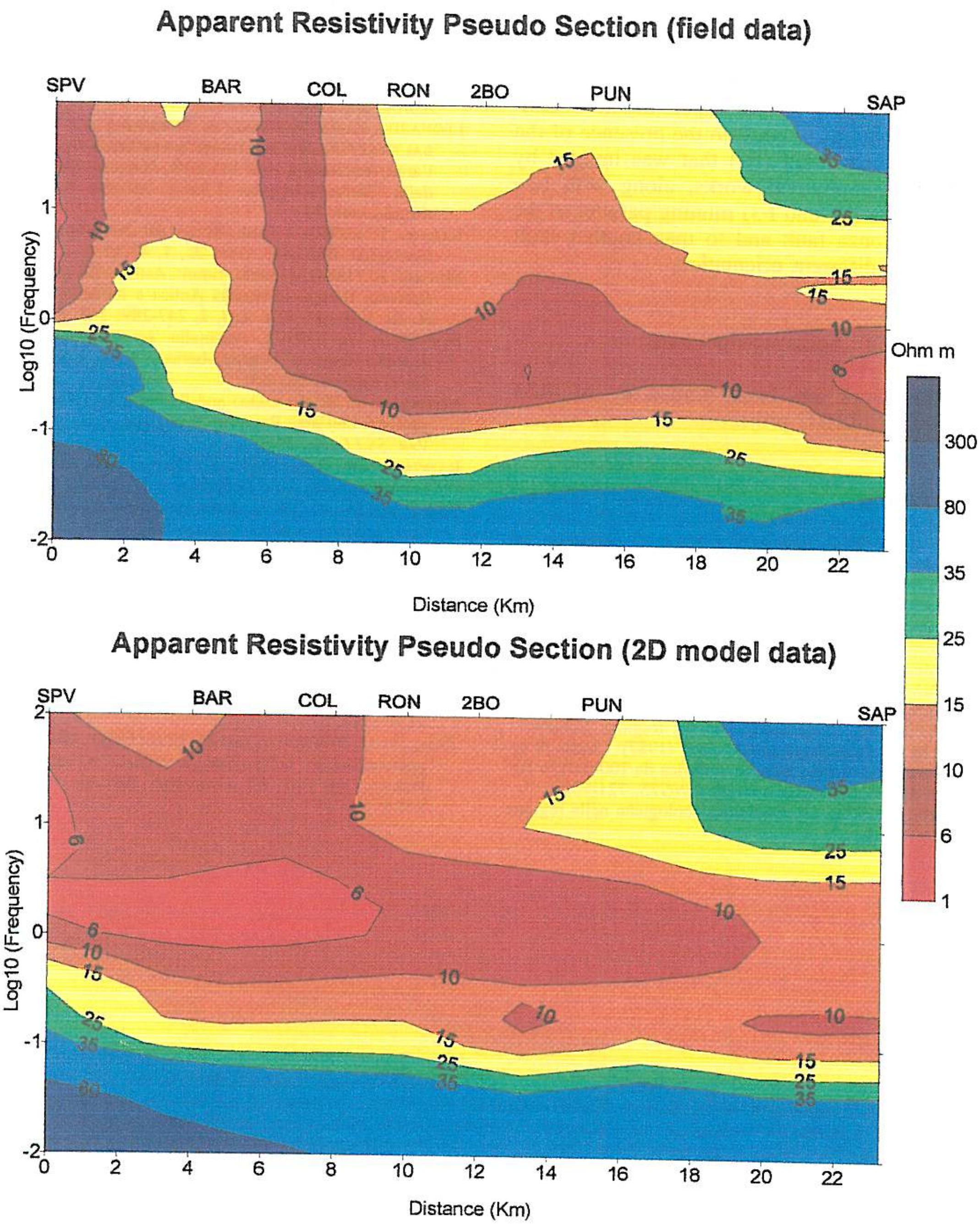


Fig. 8. Comparison of the resistivity pseudosection along profile P01. Top: experimental field data; bottom: 2D forward model results.

duces important variations both at shallow and deep levels.

Finally, the new data acquired in this area, MT soundings and two dipole-dipole soundings, allowed us to confirm the presence of the Schio-Vicenza fault (F2) that was imaged by previous geophysical works, along with two other faults (F1 and F3) running parallel to the Schio-Vicenza fault and to map another fault (F4) with different orientation.

Acknowledgements

This work has been funded by MURST (ex 40%) - LEMI project.

REFERENCES

AA.VV. (1972): Acque dolci sotterranee. Inventario dei dati raccolti dall'AGIP durante la ricerca di idrocarburi in Italia, *AGIP, ENI*, pp. 914.

ALFANO, L. (1974): A modified geoelectrical procedure using polar-dipole arrays. An example of application to deep exploration, *Geophys. Prospect.*, **22**, 510-525.

ANTONELLI, R., G. BARBIERI, G.V. DAL PIAZ, A. DAL PRÀ, V. DE ZANCHE, P. GRANDESSO, P. MIETTO, R. SEDEA and A. ZANFERRARI (1983): *Carta Geologica del Veneto*, Università di Padova, Regione Veneto.

BON, M., A. NORINELLI and A. ZAJA (1987): Catena di acquisizione dati per magnetotellurica da 100-0.0156 Hz, in *Atti 6° Convegno Annuale GNGTS*, 721-732.

FINETTI, I. (1972): Le condizioni geologiche nella regione di Venezia alla luce di recenti indagini sismiche, *Boll. Geofis. Teor. Appl.*, **14**, 291-342.

JUPP, D.L.B. and K. VOZOFF (1975): Stable iterative methods for the inversion of geophysical data, *Geophys. J. Astron. Soc.*, **42**, 957-976.

LEONARDI, P., C. MORELLI, A. NORINELLI and G. TRIBALTO (1973): Sintesi geologica e geofisica riguardante l'area veneziana e zone limitrofe, *Memorie Descrittive della Carta Geologica d'Italia, Servizio Geologico d'Italia*, vol. 34.

MOLON, F. (1882): I Colli Berici del Vicentino. Sunto Geologico, *Boll. Soc. Geol. It.*, **1**, 47-49.

MOLON, F. (1883): I nostri fiumi: Astico, Bacchiglione, Retrone, Brenta. Idrografia Antica e moderna, in *Atti R. Ist. Ven. Sci. Lett. Arti*, **1**, 247-289; 347-391.

NORINELLI, A. (1979): Anomalie aeromagnetiche del distretto eruttivo euganeo-berico, *Mem. Soc. Geol. Univ. Padova*, **32**, 4-8.

NORINELLI, A., E. CASSANO and R. FICHERA (1988): Dati geofisici dell'area Patavino-Veneziana, *Adun. Ord. Ist. Ven. SS.LL.AA.*, 21/5.

RANGANAYAKI, R.P. (1984): An interpretative analysis of magnetotelluric data, *Geophysics*, **49**, 1730-1748.

SWIFT, VC. M. JR. (1967): A magnetotelluric investigation of a electrical conductivity anomaly in the southwestern United States, *Ph.D. Thesis*, Massachusetts Institute of Technology.

VOZOFF, K. (1972): The magnetotelluric method in the exploration of sedimentary basins, *Geophysics*, **37**, 98-141.

WANNAMAKER, P.E., J.A. STODT and L. RIJO (1986): Two-dimensional topographic responses in magnetotellurics modeled using finite elements, *Geophysics*, **51**, 2131-2144.

ZAJA, A., G. BENVENUTI and M. BON (1989): Misure magnetotelluriche nella Pianura Veneta a sud-est di Padova, in *Atti 8° Convegno Annuale GNGTS*, 871-879.