ELECTRICAL CONDUCTIVITY INHOMOGENEITIES IN GREECE ON THE WEST MARGIN OF THE ANATOLIAN FAULT

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Abstract

Qualitative interpretation of the magnetotelluric results, based on the calculated polar diagrams and impedance tensors, is presented. The experimental data have been collected in Sterea Ellas region in Greece. Our interpretation allowed us to localize two conductive faults in the study area. One of them is probably a continuation of the west margin of the well-known Anatolian Fault.

Key words: magnetotelluric sounding, selectivity effect, polar diagram.

1. INTRODUCTION

Measurements of magnetic field and telluric current variations have been carried out in a search for electromagnetic precursors of earthquakes in various regions of the world for many years. Such precursors may include, for instance, changes in the calculated apparent resistivity curves prior to the earthquake (Jóźwiak et al., 1992; Ernst et al., 1994). Another, more popular approach to this problem is an attempt to find a relation between non-inductive electric signals and seismic activity. The latter approach is represented by Professor P. Varotsos and his co-workers (the group called VAN). The VAN group, in their research carried out on a wide scale at a number of measurement points localized in various regions of Greece, introduced a term seismic electric signals (SES), to mean the electric signals recorded in association with the forthcoming earthquake (Varotsos and Alexopoulos, 1984; Varotsos, 2005). They also introduced the notion of selectivity effect, which means that the electric signal recorded at a measurement point depends not only on the distance to the epicentre but also on the kind of structures located between the epicentre and the measurement point (Sarlis et al., 1999).
The disputable problem of selectivity of the SES signals detection, as well as some controversies related to the criteria of distinguishing such signals, motivated us at the Institute of Geophysics to undertake, in response to the kind invitation of Professor P. Varotsos, magnetotellic survey in Greece, and join the cooperation with the University of Athens.

Polish long-period magnetotellic instruments have been installed at six measurement points for a period of four months at the end of 1997. Each point was equipped with a TPM (Torsion Photoelectric Magnetometer – see Jankowski et al., 1984) and a telluric recording system (measuring lines in the N-S and E-W directions, about 100 m long). The sampling rate for each channel was 10 s. The measurement points were located NW of Athens in the Sterea Ellas region, 35-50 km apart. We took care to deploy them away of local sources of magnetic and telluric field noise.

The location of measurement points was proposed by the Greek side, upon taking into account the selectivity in the SES detection, and tectonic data. The aim of the research was to recognize differentiation in the conductivity distribution in order to find out whether any fault structures might be present in the study area. The presence

Fig. 1. Location of measurement points.
of a conducting fault might explain the selectivity of the signal detection, under the assumption that the signals propagate along such structures. We also planned an analysis of possible SES signals, independent of the routine recordings carried out by the Greeks. The location of measurement points is shown on the map of Greece (Fig. 1). The main geotectonic units in the study area (Ager, 1980) are shown in Fig. 2, and the regional geotectonic layout (Reilinger et al., 1997) in Fig. 3.

Fig. 2. The main geotectonic units in the study area (modified from Ager, 1980).

2. DATA TREATMENT

Geomagnetic vectors

On the basis of selected fragments of records from the enhanced magnetic activity periods we calculated magnetic vectors for each point of the profile in a wide range of frequencies. All the calculated vectors have directions close to NE, and do not form systems characteristic for 2D structures. Such a system of vectors is a result of very
strong influence of coast effects due to concentration of electric currents in the seas surrounding the study region (notably the current concentration in the Ionian Sea). That is why our later interpretation was not based on the calculated geomagnetic vectors.

**Apparent resistivity curves and polar diagrams**

Relations between the electric and magnetic field components to describe the electromagnetic induction in the Earth are as follows:

In the time domain

\[ E_i(t) = \sum_{k=1,2} Z_{ik}(t) * H_k(t), \]

where symbol * represents the convolution, \( Z_{ik}(t) \) are the impulse responses, \( E_i \) are the electric components, and \( H_k \) are the horizontal magnetic components.

In the frequency domain

\[
\begin{bmatrix}
\hat{E}_x(\omega) \\
\hat{E}_y(\omega)
\end{bmatrix} =
\begin{bmatrix}
\hat{Z}_{xx}(\omega) & \hat{Z}_{xy}(\omega) \\
\hat{Z}_{yx}(\omega) & \hat{Z}_{yy}(\omega)
\end{bmatrix}
\begin{bmatrix}
\hat{H}_x(\omega) \\
\hat{H}_y(\omega)
\end{bmatrix},
\]
Fig. 4. Apparent resistivity and phase curves for principal directions $\rho_{\text{min}}$ (lower curves) and $\rho_{\text{max}}$ (upper curves) for the two sites, FYL and FOU.
where $\hat{E}_i(\omega)$ and $\hat{H}_i(\omega)$ are the Fourier transforms of the electromagnetic field components. Tensor $\hat{Z}_a(\omega)$ is called the impedance tensor, and its components are Fourier transforms of impulse responses.

Knowing the components of this tensor we can calculate the values of apparent resistivities and phases for given frequencies, according to the formulae

$$\rho_a = 0.2T |\hat{Z}_a(\omega)|^2 \quad i \neq k, \quad \text{phase} = \arctg \left( \frac{\text{Im} (\hat{Z}_a(\omega))}{\text{Re} (\hat{Z}_a(\omega))} \right).$$

Apparent resistivity and phase curves were constructed for each measurement point for periods from 100 to 8000 s. Figure 4 shows the $\rho_{\text{max}}$ and $\rho_{\text{min}}$ curves calculated in two selected points, FYL and FOU. These points were selected with a view to a very low noise level in the recordings, and hence the good accuracy of calculations.

For all calculations we used an algorithm in the time domain, based on the linear least-square method. The estimation of accuracy in our algorithm is made on the basis of the approximate covariance matrix, utilizing the standard linear least-square analysis (Wielądek and Ernst, 1977; Ernst, 1981; Ernst et al., 2001; Nowożyński, 2004).

Rotating the impedance tensors, we constructed polar diagrams for components $Z_{xy}$ (solid lines) and $Z_{xx}$ (dashed lines). The polar diagrams obtained at all the points are presented in Fig. 5 for selected five periods: 250 s, 500 s, 1000 s, 2500 s and 5000 s. Various scales were used for different points, in order to make the picture more legible.

The large discrepancy in the apparent resistivity curves for the two directions ($\rho_{\text{max}}$ and $\rho_{\text{min}}$), as well as the shapes of polar diagrams, give evidence for the three-dimensionality of geoelectric structures in the study area, which – unfortunately – rendered a quantitative, model interpretation impossible. Hence, we had to make only a qualitative interpretation, still, as we believe, helpful for localizing the layout of conducting faults in the study area. In our interpretation we used first of all the polar diagrams of impedance tensor calculated at our measurement points.

3. GEOTECTONIC AND GEOELECTRIC STRUCTURES

The majority of tectonic structures in the study area (Fig. 2) strike almost longitudinally (with a deviation towards NW-SE). An exception is the western edge of the Anatolian fault, which is a tectonic element of different, nearly latitudinal strike (Fig. 3). In a structure that is so geologically complicated, the presence of conducting faults seems very likely. An additional argument in favor of such a E-W striking fault is provided by the results of Groom-Bailey decomposition made for points FOU and FYL (Groom and Bailey, 1989). Such a decomposition enables us to eliminate, in some cases, the effect of a local 3D structure and to find a 2D structure of regional charac-
Fig. 5. The polar diagrams for the selected five periods: 250, 500, 1000, 2500, and 5000 seconds. The solid lines represent off-diagonal elements of the impedance tensors, the dashed lines the diagonal elements.
The calculations made for points FOU and FYL with the use of programs from the GEOTOOLS packet yielded very good results. The determined directions were very stable for a wide range of periods and coincided with the main directions of impedance tensors. The results are shown in Fig. 6.

Fig. 6. The Groom-Bailey strike directions for the sites FYL and FOU.

The conducting fault may be treated as a 2D structure. To determine the conductivity distribution of such a structure we made use of the results of 1D inversions at points FOU and FYL. We are of course aware of the fact that the results of 1D inversion in so complicated structures are very approximate and just indicative. On the basis of $\rho_{\text{max}}$ resistivity curves (TE mode) and phase curves calculated in these points, we constructed 1D conductivity distribution models, using the OCCAM inversion algorithm from the above-mentioned GEOTOOLS packet. The results of these inversions are shown in Fig. 7. In both cases we clearly see the existence of a conductive layer at a depth of 8-15 km.

Fig. 7. Results of 1D inversion in the two sites: FYL and FOU. The average resistivity distribution is marked in grey.
The above findings were used to construct a very simplified 2D fault model which takes into account the presence of a good conductor at 8-15 km depth. The purpose for creating such a model was only to get some orientation what might be the shape of polar diagrams calculated on the basis of this model on a line perpendicular to the proposed structure (over the conductor or beyond).

In the calculations, we applied the algorithm of forward and inverse modelling developed at our Institute basing on the finite-difference method. In this algorithm, the Helmholtz equations are approximated by a five-point differential scheme (Nowożyński and Pushkarev, 2001).

The model, together with the polar diagrams calculated from it for two selected periods: 250, 1000 seconds, is shown in Fig. 8. Also in this figure the diagrams are presented in different scales, to improve legibility. One clearly sees that the shape of polar diagrams is as follows: they are elongated towards the structure at points situated above the good conductor, yet perpendicular to the structure at points situated outside the good conductor. These features, as well as the polar diagrams calculated for all the measurement points, enabled us to delineate the shape of two conducting channels, as shown in Fig. 9. The conducting faults are also indicated (in red) on the regional tectonic map (Fig. 3). It is to be noted that the proposed shape of the longitudinally striking, conducting zone indicates that in its eastern part this zone may be a continuation of the Anatolian fault, while the conductivity zone extending southward from station FOU is conform to the tectonic structures of this region of Greece.

![Fig. 8. The 2D model of resistivity distribution for a fault structure, and the respective polar diagrams calculated for the two periods: 250 and 1000 seconds.](image-url)
4. ANALYSIS OF NON-INDUCTIVE PART OF THE ELECTRIC FIELD

The non-inductive part of the electric field components was obtained by subtracting from the recorded signals the predicted electric field, that is, the convolution of magnetic horizontal variations with the respective impulse responses:

\[
E^\text{pred}_i(t) = \sum_{k=1}^{15} Z_k(t) \ast H_k(t),
\]

\[
E^\text{non}_i(t) = E_i(t) - E^\text{pred}_i(t).
\]
The field thus calculated, also called a residual field, may be related to the tectonic factors we study or to any electric signals which do not result from the electromagnetic induction in the Earth (e.g., industrial noise, piezoelectric phenomena, etc.).

We calculated residual fields of electric components at all measurement points and made their detailed analysis. However, at the time the study was made, the seismic activity was very low, which made it impossible to find a relation between the non-inductive part of the field and seismic events. No distinct SES signals have been recorded either.

It is worth noting, though, that the removal of the inductive part from the electric components not only makes it much easier to retrieve such signals, but also makes it much more convenient to analyse their relation to seismic activity (Ernst et al., 1994).

5. CONCLUSIONS

We localized two conducting faults; their existence supports, to some extent, the hypothesis of SES signals propagation and enables us to better understand the complex selectivity mechanisms observed by the VAN group in Greece.

An analysis of residual field seems to be a better tool for short-period seismic activity forecasting than the investigation of resistivity curves variations, as the latter are of more local character and are much more difficult to detect.

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