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Geoelectric Structure of Sousaki Geothermal Area (Greece) deduced from Two Dimensional Magnetotelluric Studies

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Abstract: *A short period (0.075-42 s) Magnetotelluric (MT) survey was carried to investigate the geoelectric crustal structure of Sousaki geothermal area in Greece. The MT data were initially processed and analysed by Lagios (1992) and Tzanis and Lagios (1993). They suggested that the crustal structure below Sousaki, comprises a complex geoelectric domain of intersecting conductive fault zones and resistive blocks which may include igneous intrusions. Their results were based on one dimensional (1-D) MT models, and thus to determine such a complex structure at least two dimensional (2-D) modelling should be undertaken. This was the main task of the present study. An attempt to construct a three dimensional (3-D) model for this area was proved unsuccessful due to difficulties in the design of the actual model grid. The MT data were finally modelled using a 2-D forward modelling technique. The adopted 2-D MT model concerns the top 2 km of upper crust and provides a different structure with that derived by the 1-D models. This was attributed to the presence of regional 2-D or local 3-D structures. The 2-D model is consistent with the geology and tectonics of Sousaki. The low resistivities (2.5-5 ohm-m) observed within the uppermost 100 m seem to be compatible with the Plio-Pleistocene marls and volcanics. The very low resistivities (0.5-1 ohm-m) observed at greater depths (0.5-1.5 km) are probably related to hydrothermally altered ophiolites. The low resistivities observed in the area combined with the various superficial thermal manifestations, make up a significant evidence for the existence of a geothermal field. The three major fractured zones identified in this area are probably those which should allow the rainwater and the geothermal fluids to flow and ensure the hydraulic continuation of the Earth's surface with the top weathered zone of the limestone or ophiolitic basement.*

Key words: *Geothermal Exploration, 2-D Magnetotellurics, Sousaki, Hellenic Volcanic Arc.*

INTRODUCTION

The volcanic region of Sousaki is located about 15 km east of Corinth, and belongs to the westernmost sector of the Hellenic Volcanic Arc (HVA) (Fig.1), which is formed by a series of volcanic centres extending over 450 km (Fytikas et al., 1987). The region was affected by E-W and NE-SW extensional tectonics, the latter being the younger and rather responsible for volcanism and the presence of several thermal manifestations, such as thermal waters with temperatures of about 73^{o}C measured inside boreholes, low temperature (40^{o}-50^{o}C) fumaroles (mofettes) and sulphur deposits (Kavouridis and Fytikas, 1988).

Several geophysical studies including, gravity, magnetics (Vasiliadis, 1983; Rocca, 1985) and DC resistivity measurements (Thanasoulas, 1982) were mainly undertaken by the Institute of Geology and Mineral Exploration (IGME) of Greece (Thanasoulas, 1982; Vasiliadis, 1983) to determine the subsurface geological structure, the tectonics and the potential geothermal resources of Sousaki. The first two studies have yielded considerable information relating to the regional and local tectonics of the area. The limited penetration depth (< 600 m) of the DC resistivity method at such a conductive (2-5 ohm-m) environment as that of Sousaki (Thanasoulas, 1982), confined the information concerning both the geoelectric structure and the potential geothermal resources of the area.

Therefore, in order to investigate the deep geoelectric structure of Sousaki, an MT study, in the period range 0.075-42 s, was undertaken by the Universities of Athens (Greece) and Edinburgh (UK). The field measurements were carried out during October-November 1991. The data were initially processed and analysed by Lagios (1992) and Tzanis and Lagios (1993). Their work included, spatial analysis of the impedance tensor and dimensionality tests using the 3-D rotation analysis method of Tzanis (1988), and 1-D modelling using the algorithm of Constable et al. (1987). They concluded that the crustal structure below Sousaki, comprises a complex 2-D or even 3-D geoelectric domain of intersecting conductive fault zones and resistive blocks which may include igneous intrusions. In addition, they suggested that the primary deep normal fault zones align with a direction of about 50^{o} W.

Further analysis and modelling of the initial MT data was carried out at a later stage, to obtain a more integrated picture of the complex geoelectric structure of the area and to provide potential estimates about the relevant geothermal field. The data analysis included computation of the Swift (1967) angle and additional dimensionality tests using skew (Word et al., 1971) and the Kao and Orr (1982) indices. An attempt to model the MT data with the 3-D thin sheet modelling method of McKirdy et al. (1985) was proved unsuccessful. The MT data were finally modelled with the 2-D forward modelling technique of Madden and Thompson (1965). The presentation and discussion of the results of the additional rotational analysis, dimensionality tests and the 2-D modelling is the subject of this paper.

BRIEF GEOLOGICAL AND TECTONIC ACCOUNTS

The geotectonic evolution of Northern Saronikos Gulf and especially Sousaki area is controlled by block faulting along NW-SE, NNW-SSE and E-W directions (Fig.2) which produced relatively small elongated basins and initiated volcanism (Fytikas et al., 1987). The NNW-SSE and NW-SE fault systems are probably younger and are related with the Pliocene (Fig.1, white arrows) and Pleistocene (Fig.1, black arrows) extensional processes, respectively, which took place in the Aegean and are thoroughly described by Angelier et al. (1982). The E-W fault systems are probably older and were rather reactivated during the Holocene affecting younger sediments.

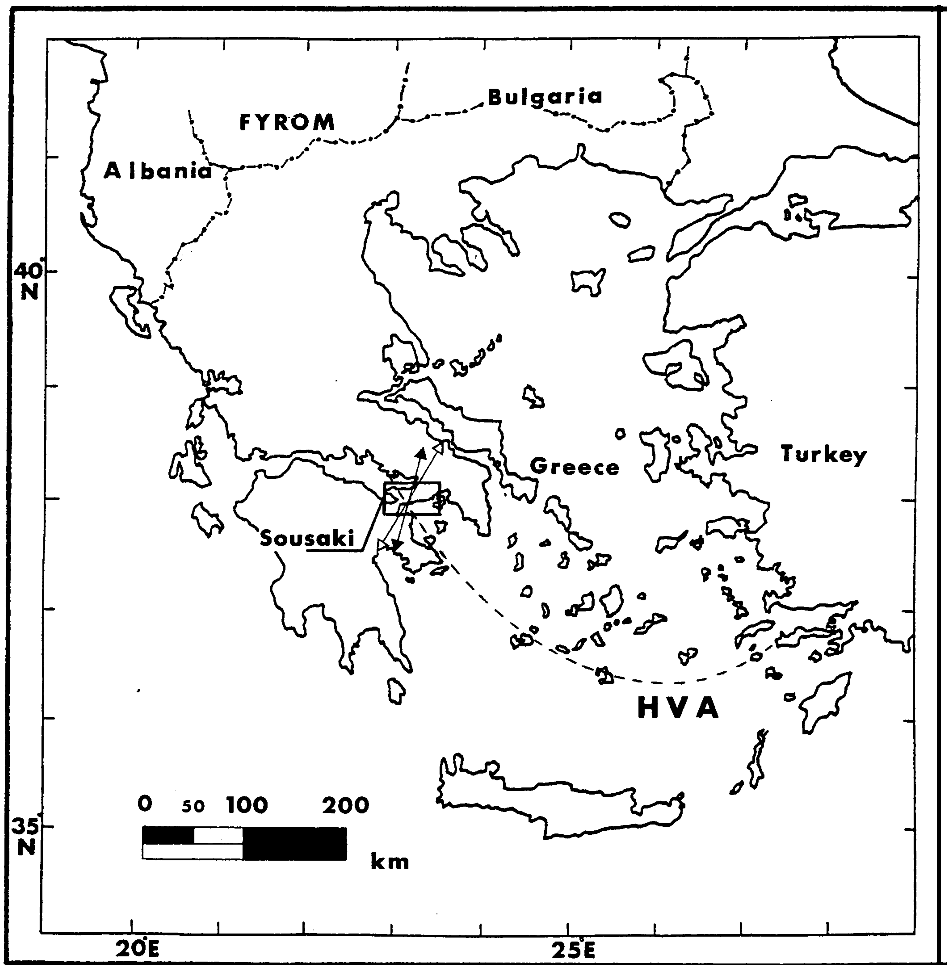


FIG. 1. Map of the Aegean Sea. Rectangular box - Sousaki volcanic region; White arrows - Average extensional directions during the Pliocene; Black arrows - Average extensional directions during the Pleistocene.

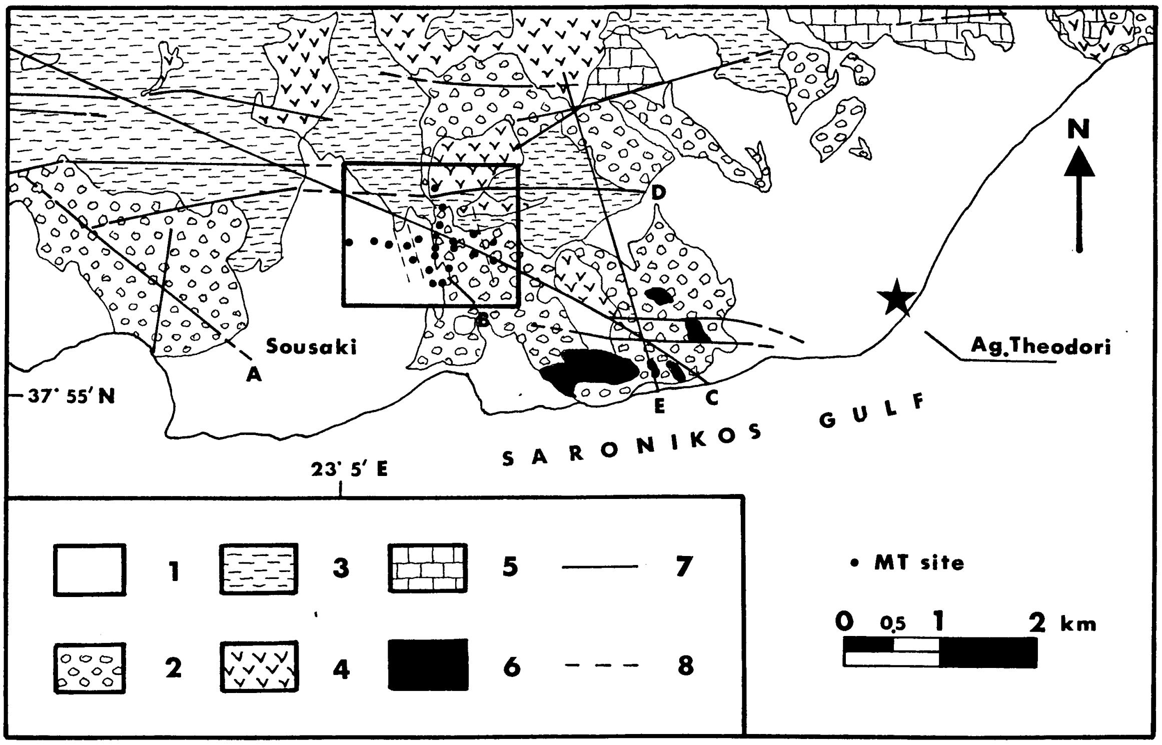


FIG. 2. Geotectonic map of Sousaki area (redrawn from Fytikas et al., 1987). Rectangular box - survey area; 1. Alluvial deposits; 2. Marls, marly limestones and conglomerates (Plio-Pleistocene); 3. Conglomerates, sandstones and marly limestones (Pliocene); 4. Ophiolitic block (Post-Upper Cretaceous); 5. Pre-volcanic limestone basement (Upper Triassic-Lower Jurassic); 6. Dacitic lava flows and domes (Pliocene); 7. Fault; 8. Fault inferred.

Geological mapping of the volcanic complex of Sousaki (Fig.2) by Gaitanakis et al. (1984) suggests that there is a pre-volcanic, Upper Triassic-Lower Jurassic limestone basement underlying a Post-Upper Cretaceous ophiolitic block of considerable thickness (maybe greater than 1000 m), which consists of serpentinites intensively altered by hydrothermal activity. Various Pliocene volcanic products such as lava flows and pyroclastic deposits, Plio-Pleistocene marly conglomerates, marly sandstones and lacustrine deposits consisting of alternations of sandy marls and cohesive conglomerates overly the ophiolitic block. The Pliocene sediments which fill the elongated basins of the area may have thicknesses of about 200-300 m and are frequently interbedded by lava flows and pyroclastic deposits. Old talus cones and recent alluvial deposits overly the Pliocene volcanics and deposits.

Geochronological data (Fytikas et al., 1987) show that the volcanic activity of the area is of late Pliocene age (2.70-3.95 M.a), being the oldest one observed along the HVA. The volcanic products of the area are found in small outcrops west of Ag.Theodori (Fig.2) and mainly consist of dacitic lavas, pyroclastic deposits and tuffs. The absence of eruptive vents and the present morphology suggest that the lava flows probably originated from rather small domes (Fytikas et al., 1987).

The distribution of the volcanic outcrops seems to follow the main (e.g. NW-SE) extensional tectonic trends of the area which are also characterized by the presence of several thermal manifestations. These manifestations are such as thermal waters with temperatures of about 73°C measured inside boreholes, low temperature (40°-50°C) fumaroles (mofettes) gypsum and sulphur deposits (Kavouridis and Fytikas, 1988).

MT DATA ACQUISITION AND PROCESSING

Twenty seven short period MT soundings were undertaken in the area of Sousaki, which most of them are illustrated in figure 2. Figure 3 shows the MT site locations with their identification numbers. The MT sites were arranged in two profiles, oriented approximately along N-S and E-W directions. An average station spacing of about 200 m was applied. The MT data were recorded in four period bands covering the range 0.075-42 s, using the Edinburgh University real-time acquisition system SPAM MkIIb (Dawes, 1984). Although SPAM MkIIb permitted simultaneous recordings at two different sites located 200-250 m apart, the remote reference facility was not used during the data processing and the two sites were treated as independent MT sites. The first site was called ‘Base station’ and included measurements of all magnetic and electric components, while the second site was called ‘Remote station’ (Fig.3) and included measurements only of the two electric components. The horizontal magnetic and electric field components were measured in the N-S and E-W directions. The electric field components were measured by using either a cross- or L-shaped configuration of electrodes and typical electrode spacings of about 100 m.

The collected MT data were initially processed and analysed by Lagios (1992) and Tzanis and Lagios (1993) using the robust methodologies of Tzanis and Beamish (1989) and Tzanis (1988). Their work included also, spatial analysis of the impedance tensor using the 3-D rotation method of Tzanis (1988). In the present study, the initial MT data were reprocessed by using different methodologies for two reasons. The first one was to test a recently developed robust estimation technique introduced by Ritter et al. (1998). The second one was to examine if Swift’s (1967) ‘classical’ method would give an electric strike compatible with the tectonic directions indicated by the 3-D rotation method of Tzanis (1988). In addition, the rotation of the impedance tensor elements was made by using the technique introduced by Word et al. (1970). The rotation of the MT data was considered clockwise with respect to a positive north and a positive east.

For each MT site, period variations of apparent resistivity and phase in both the measuring and principal directions were computed, together with values of the period variation of the azimuth (e.g. Swift’s angle) of the major axis of the impedance ellipse. A typical example of the MT data acquired at Sousaki is shown in Figure 4. In general, the collected MT data were of reasonable quality, however, at many MT sites and for periods around 1 s, relating to the so-called “dead band”, the MT data were contaminated by industrial noise and thus were finally discarded.

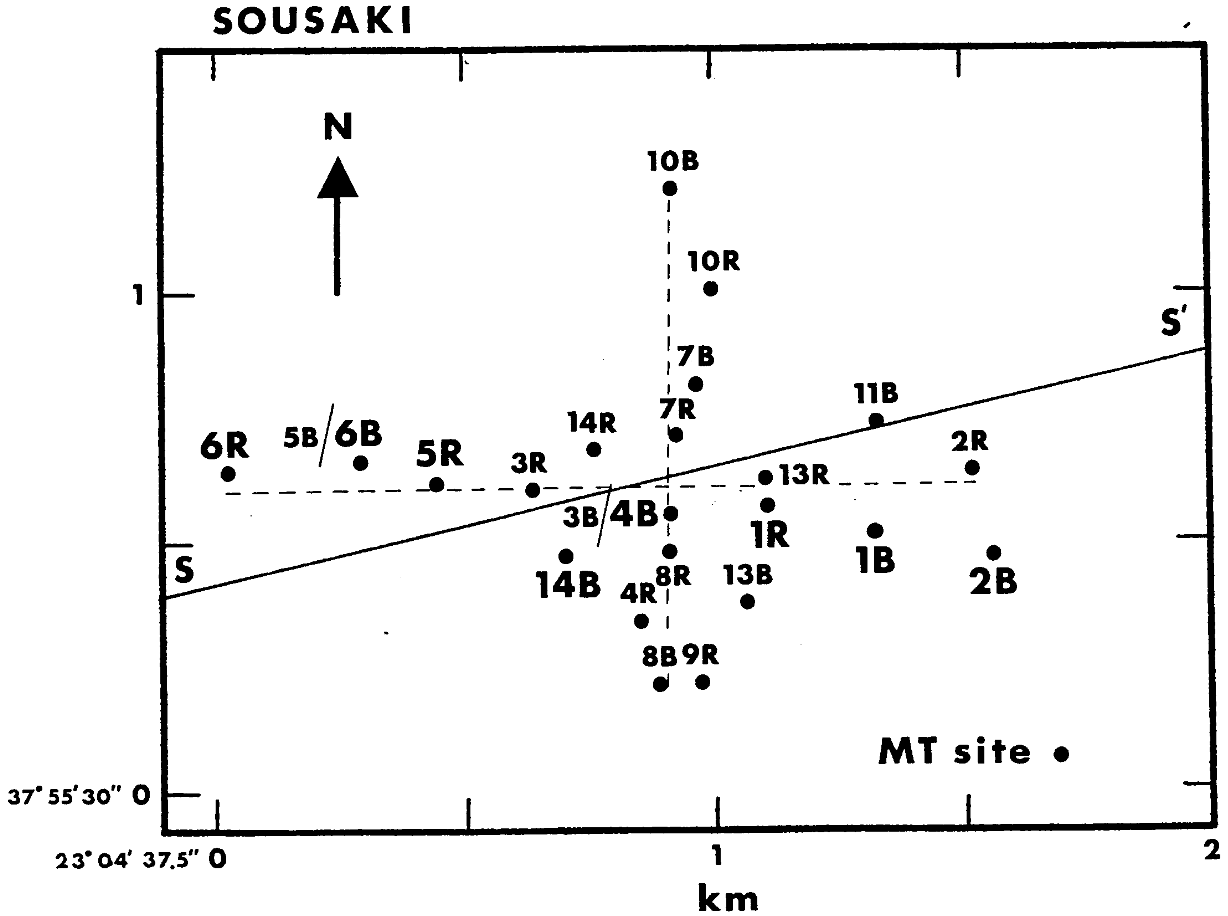


FIG. 3. Sousaki area. MT sites and profiles. B - Base station; R - Remote station; Large figures - MT sites selected for the 2-D forward calculations; dashed lines - north-south (N-S) and west-east (E-W) MT profiles; solid line - profile SS'.

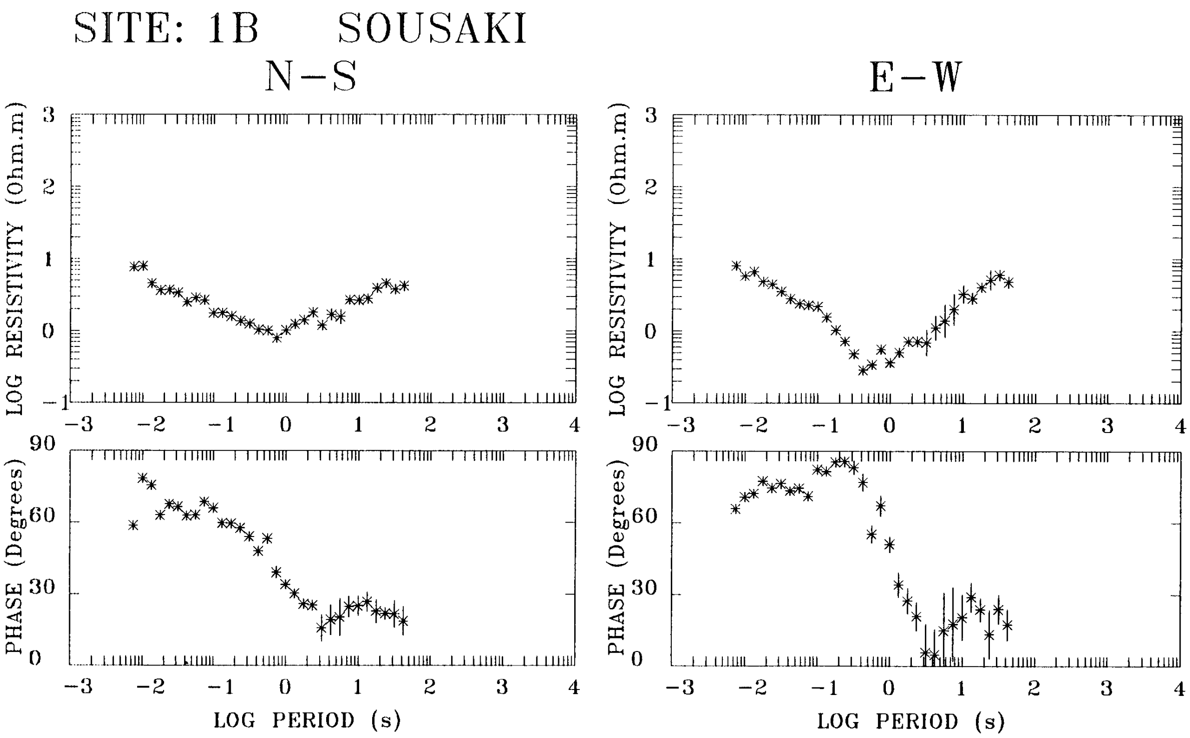


FIG. 4. The MT data for site 1B located at the E-W profile. Period variation of the unrotated MT responses along the N-S and E-W directions.

DIMENSIONALITY TESTS

The present MT data analysis included additional dimensionality tests comprising computation of four dimensionality factors. These were the skew (Word et al., 1971) and the three Kao and Orr (1982) dimensionality indices D1, D2 and D3, respectively. In this paper, the index D3 corresponds to the mean of the indices D3 and D3' defined by Kao and Orr (1982). All these dimensionality factors are expected to vary from 0 to 1. The skew defined by Word et al. (1971) and Swift (1967) is considered to be a 3-D parameter. It must approach zero for 1-D or 2-D structures (Reddy et al., 1977 ; Ting and Hohmann, 1981). Reddy et al. (1977) suggest that skew values greater than 0.2 imply 3-D effects. For 1-D structures the condition $D_1 > D_2 > D_3$ is expected to be satisfied. D_1 and D_2 have reciprocal behaviour and large D_2 and D_3 (>0.2) weights are forecasted when 2-D or 3-D structures are present (Beamish, 1986). These indices do not give an absolute measure of the dimensionality of the Earth, but, when interpreted as a whole, may provide an estimate of the contribution of the different structural components of the Earth. A typical example of the period variations of the above dimensionality parameters, representing the majority of MT sites of Sousaki, is given in Figure 5. In addition, the indices skew and D2, for these MT sites which have acceptable data quality and lie more or less along the E-W traverse (Fig.3), are mapped by means of the contour sections of figures 6a and b, respectively.

For the majority of the MT sites along each of the N-S and E-W profiles of Fig.3, the skew parameter varies from 0.0 to 0.5, while the limits of the Kao and Orr indices are 0.5<D1<1.0, 0.0<D2<0.5 and 0.0<D3<0.2. Although the condition D1 >> D2 > D3 is held at all the MT sites, one dimensionality cannot be adopted, since skew and D2 have generally high values (>0.2) at periods greater than 3 s. High skew and D2 values (>0.2) are also observed at periods shorter than 3 s, at the western end of the E-W profile (Fig.6). Although 3-D effects are apparent by the high skew values observed at periods longer than 3 s at sites located towards the centre of the region (Fig.6a), two dimensionality is also prominent at even shorter periods than 3 s, as it is indicated by the behaviour of the index D2 (Fig.6b).

TWO DIMENSIONAL FORWARD CALCULATIONS

The first attempt to model the MT data was that by using a computer program (Jones, 1992) based on the 3-D thin sheet modelling algorithm of McKirdy et al. (1985), available at that moment in the Department of Geology and Geophysics of the University of Edinburg. However, this effort was proved un-successful as it was difficult to design a proper model

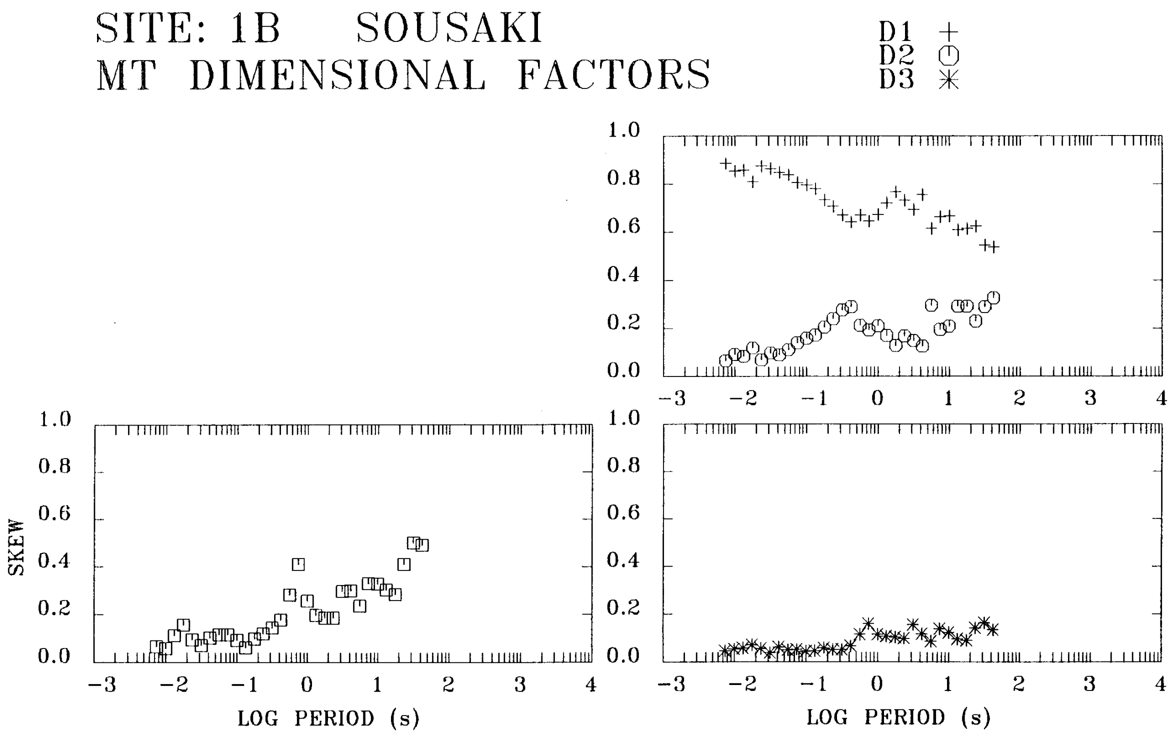


FIG. 5. MT dimensional factors for site 1B (Fig.3). Period variation of skew and the three Kao and Orr factors D1, D2 and D3.

(a)

(b)

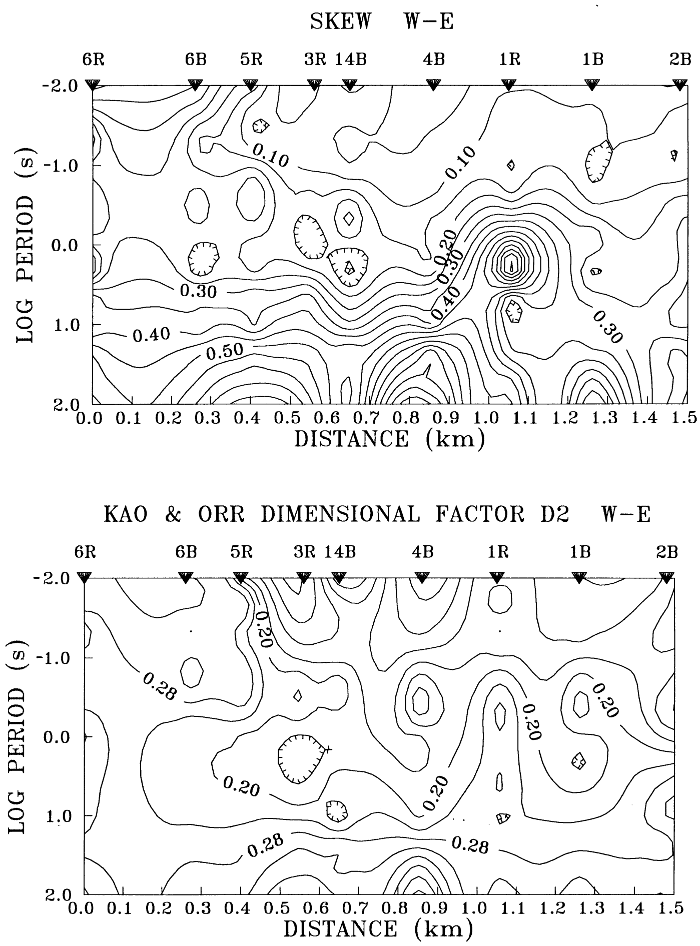


FIG. 6. Contours of (a) skew, (b) Kao and Orr factor D2 along the E-W profile.

grid for the examined area. This was partly due to the fact that in this version of the program (Jones, 1992) the maximum grid size of the thin sheet is limited to 22 by 22 cells, and partly due to that the uppermost part (<1 km) of the Earth's crust below Sousaki is very conductive (0.5-5 ohm-m) and the study area very small (1.5 km x 2 km).

The option to model the MT data by using a 2-D modelling algorithm was rather the only possibility left with respect to the software facilities available and the actual structural behaviour of the MT data.

The major and minor apparent resistivities and their corresponding azimuths are mapped, as shown in figures 7a,b,c,d, for all the MT sites, for four periods (0.03, 0.2, 1.8 and 18 s) by means of polarization ellipse axes, with the lengths of the axes representing the actual apparent resistivity values. At most of the MT sites, the maximum and minimum axes are oriented NNW-SSE (15°W) and ENE-WSW (75°E), respectively (Figs.7a,b,c), with the major axes in the more conductive regions striking NNW-SSE. At the longer period of 18 s (Fig.7d), the maximum and minimum axes are oriented NW-SE (45°W) and NE-SW (45°E), respectively, for all the MT sites. The 45°W direction seems to be compatible with the 50°W direction suggested by Tzanis and Lagios (1993) for the primary deep normal fault zones of the area. The direction of 15°W is the dominant direction of the maximum axis of the polarization ellipses within the largest part (0.075-15 s) of the recording period range. Although it varies significantly from that (45°W) representing the deeper structure, as being the more representative, it was finally adopted to be the main electrical strike in the 2-D modelling procedure.

A number of about 12-14 MT sites were initially selected for the 2-D modelling. The main selection criterion was that all sites could be projected on profile SS' (Fig.3) which was chosen to be perpendicular to the adopted electrical strike. Since the data quality was not good for many MT sites at both the Transverse Electric (TE) and Transverse Magnetic (TM) modes, respectively, only eight sites were finally selected for modelling. These were 6R, 6B, 5R, 14B, 4B, 1R, 1B and 2B. The data from these sites were rotated to the direction of the main electrical strike, as it is required by the modelling procedure. The 2-D modelling was carried out by using a computer program based on the transmission surface analogy algorithm of Madden and Thompson (1965). The method is relatively old, however it was chosen for modelling for three reasons: (i) The particular algorithm is a forward modelling method and this enabled us to include existing geological information in the starting 2-D model; (ii) The available computer program was very efficient with respect to the design of the input model grid. (iii) The available program was very efficient with respect to the actual computer time needed. In particular, 15-20 minutes were adequate to run this program in a modern PC for twelve periods for both the TE and TM modes, respectively.

The starting model consisted of a mesh of approximately 31 by 42 nodes. After the forward model responses were evaluated and visually compared with the observed ones, the resistivity values and mesh positions were successively and manually changed to try to improve the fit on a trial and error basis. The final 2-D model (model SS'-1) is illustrated in Figure 8. Since the model MT responses were evaluated for a smaller number of logarithmically equidistant periods than the observed ones, it was not possible to provide any quantitative measure of the model misfit, such as an RMS or a χ^2 value. However, as a qualitative measure of the model misfit, the model and observed responses for both the TE and TM modes for the eight modelled MT sites (6R, 6B, 5R, 14B, 4B, 1R, 1B and 2B) along the profile SS' are shown in figures 9a-h. The terms 'model data' and 'observed data' used in figures 9a-h, specify electrical resistivity and phase data.

In the case of the TE mode, the electrical resistivity and phase responses of this model seem to approximate satisfactorily the corresponding field data. This is not valid for the MT sites 14B and 4B, where the differences between the model and observed responses are more pronounced, especially at the longer periods (Figs.9d,e). In the case of the TM mode, the fit of the model and observed data is relatively good only at the MT sites 14B, 4B, 1R and 1B (Figs.9d-g), while at the rest of the MT sites seems to be rather poor. The largest differences between the model and field responses are observed at the MT sites 6R, 6B and 5R (Figs.9a-c). The relatively poor fit of the model and field resistivity data at site 2B (Fig.9h) is observed at the longer periods, where the resistivity field data seem to be upward biased, probably by industrial noise. The MT model SS'-1 of figure 8 provides the following electrical structure:

- The top 1.5 km of upper crust below the Sousaki volcanic region is characterised by very low resistivities of less than 5 ohm-m.
- A relatively conductive layer is dominant at the top 100 m. It has a resistivity of 5 ohm-m below the western and central parts of the profile and a lower resistivity of 2.5 ohm-m below the easternmost part of the profile.
- A more conductive feature (0.5-1 ohm-m) is underlying the top layer, beginning under the southwestern end of the profile at depths of 450 m dipping to the northeast at depths of 1500 m.
- A dike-like shape but less conductive (4 ohm-m) feature is interposed to the good conductor below the

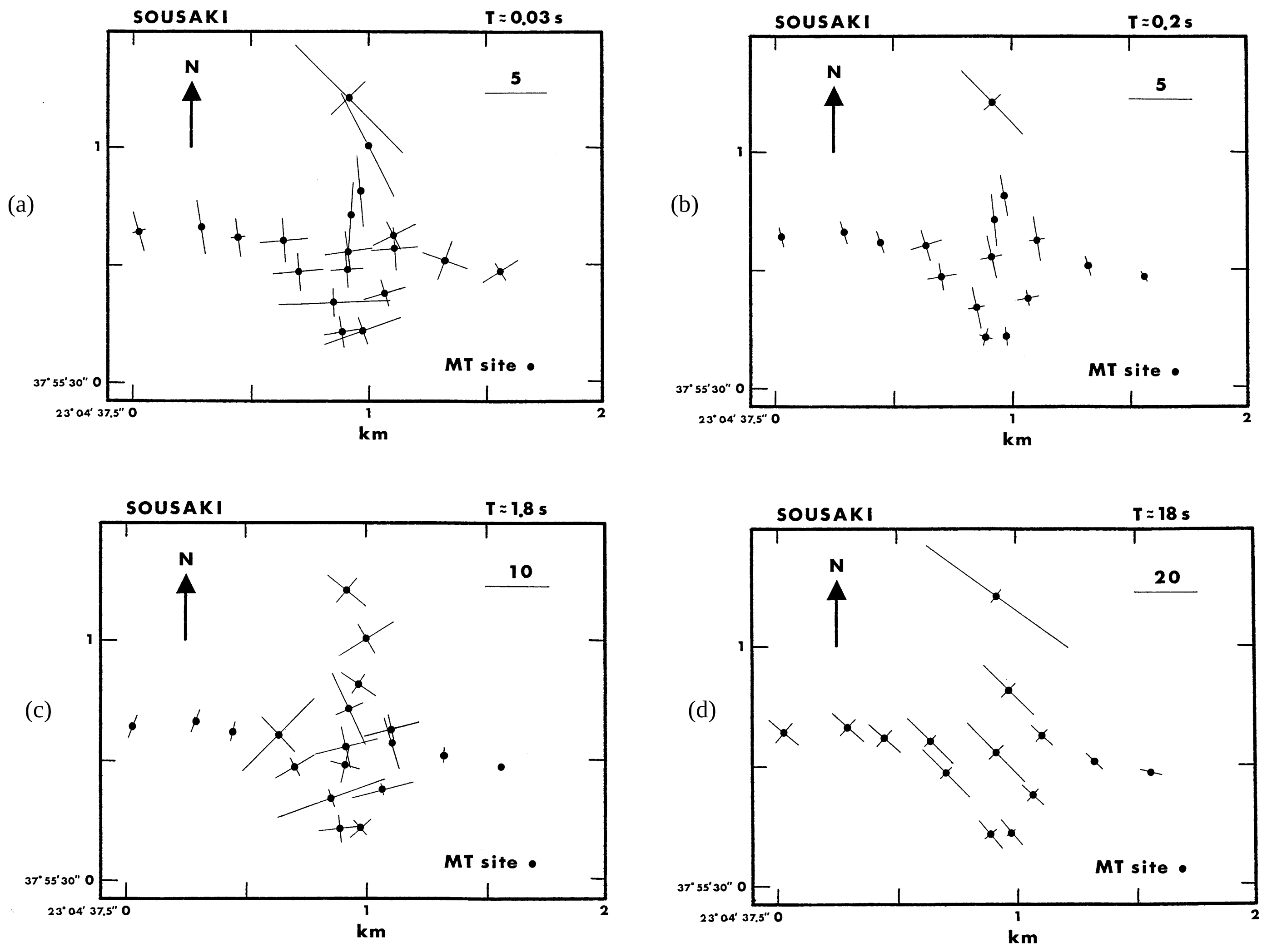


FIG. 7. Azimuths of the major and minor axes of the magnetotelluric impedance ellipses. (a) 0.03 s. (b) 0.2 s. (c) 1.8 s. (d) 18 s.

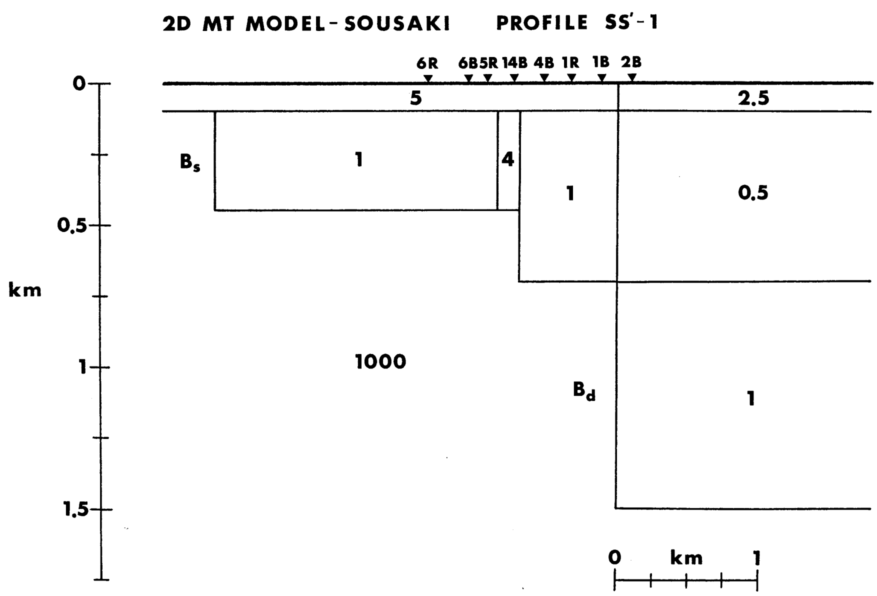
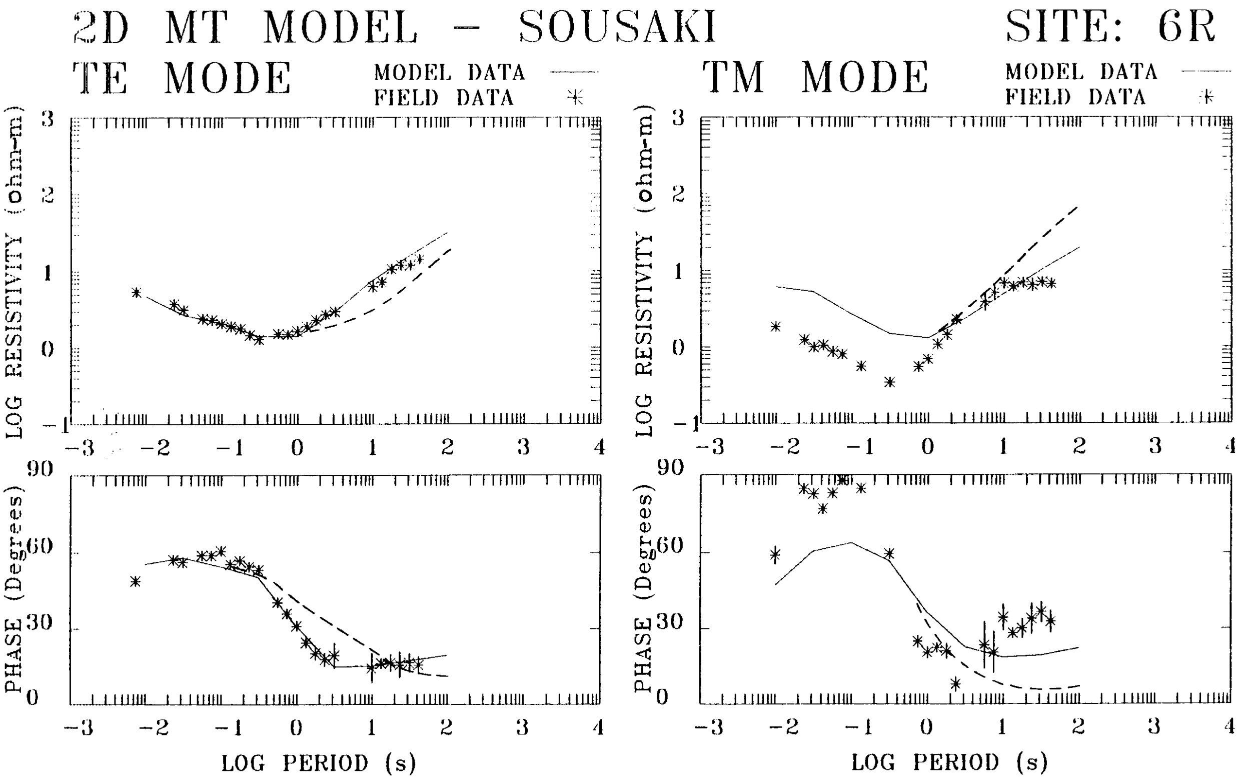


FIG. 8. The final 2-D MT model SS'-1 along profile SS'. The figures on the model are resistivity values in ohm-m.

(a)



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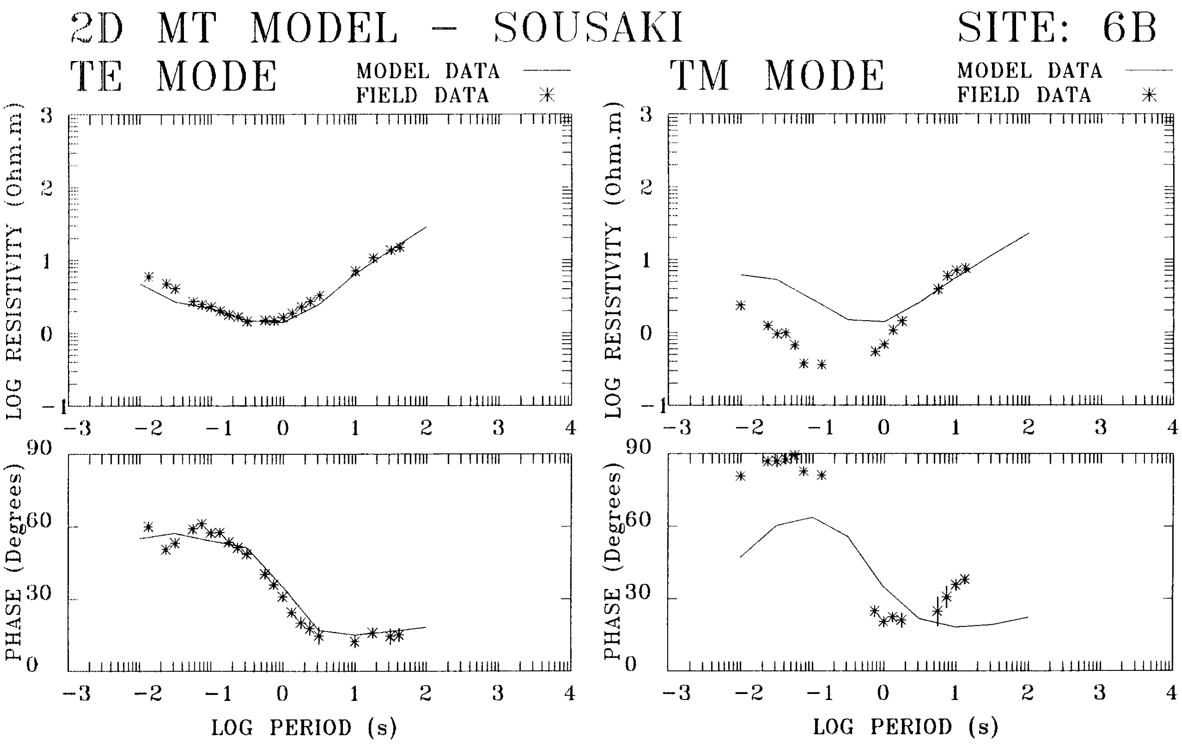
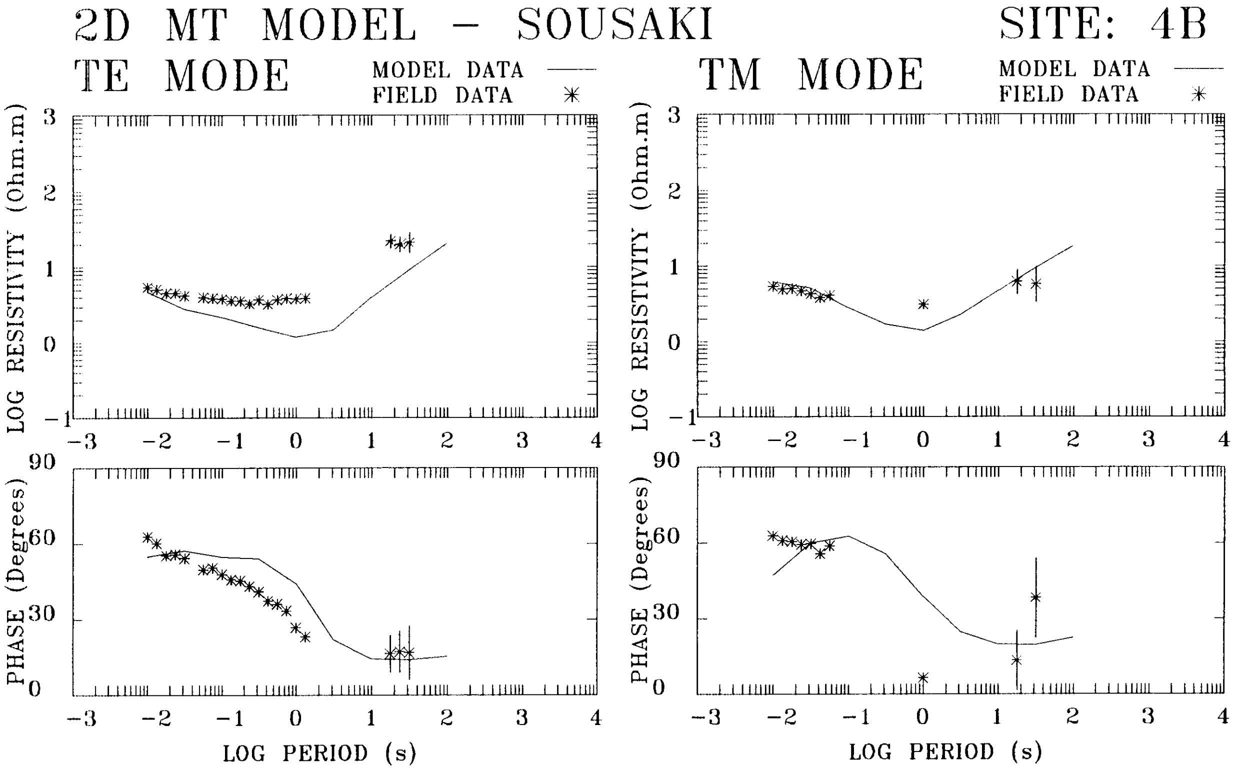


FIG. 9. Model resistivity and phase data in comparison with the field data for the TE and TM modes, respectively. Thin solid line - model SS'-1; thick solid line - model SS'-2; dashed line - model SS'-3. (a) Site 6R. (b) Site 6B. (c) Site 5R. (d) Site 14B. (e) Site 4B. (f) Site 1R. (g) Site 1B. (h) Site 2B.

(e)



(f)

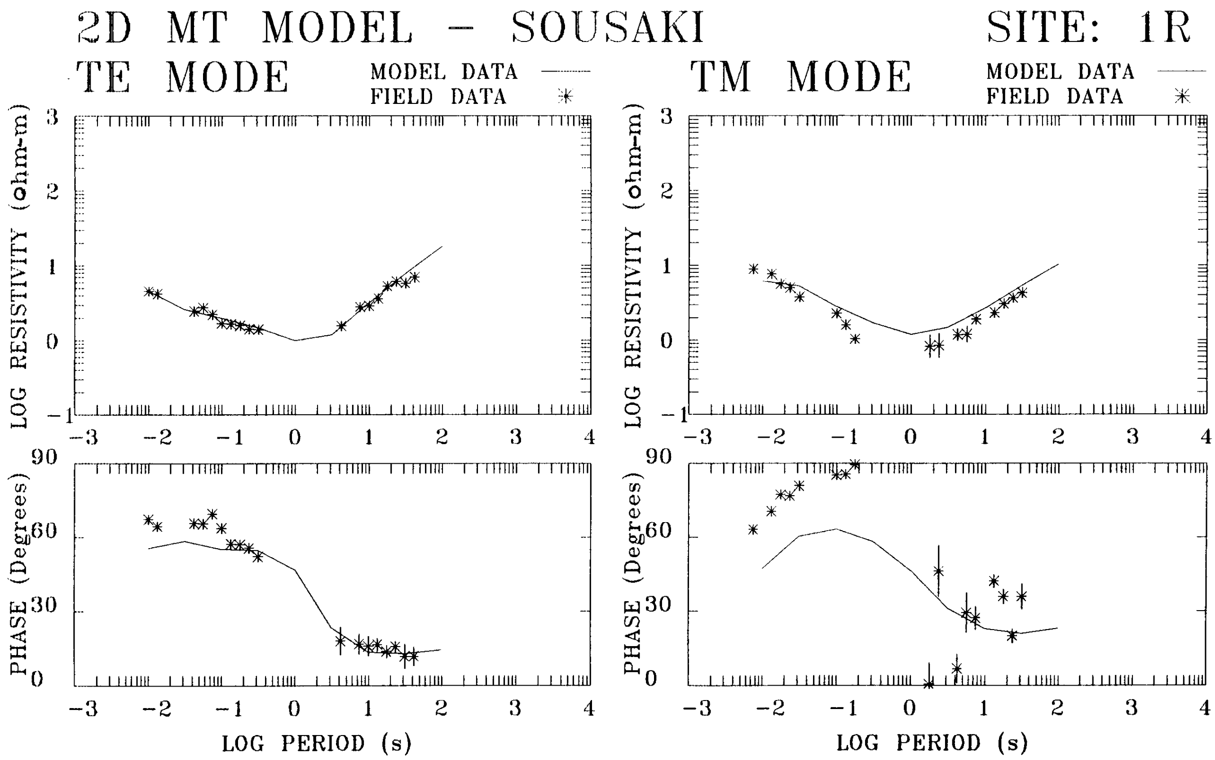
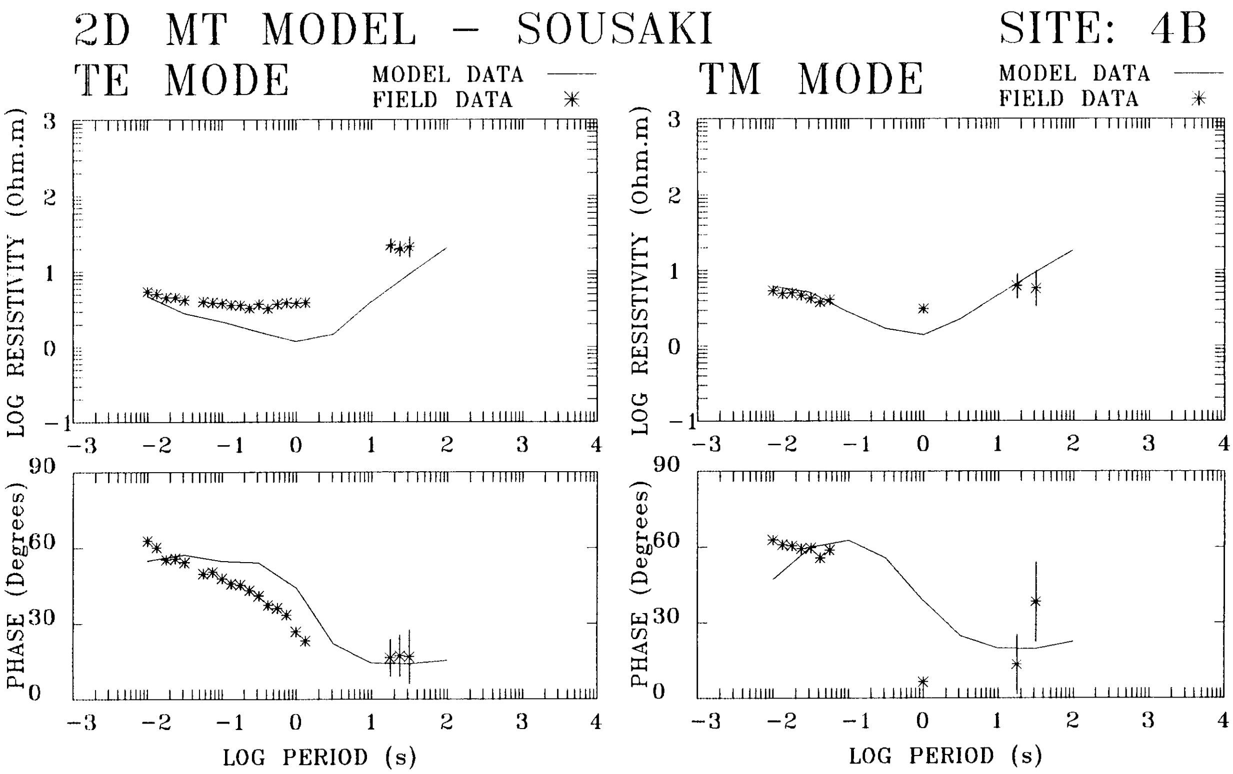


FIG. 9. (continued)

(e)



(f)

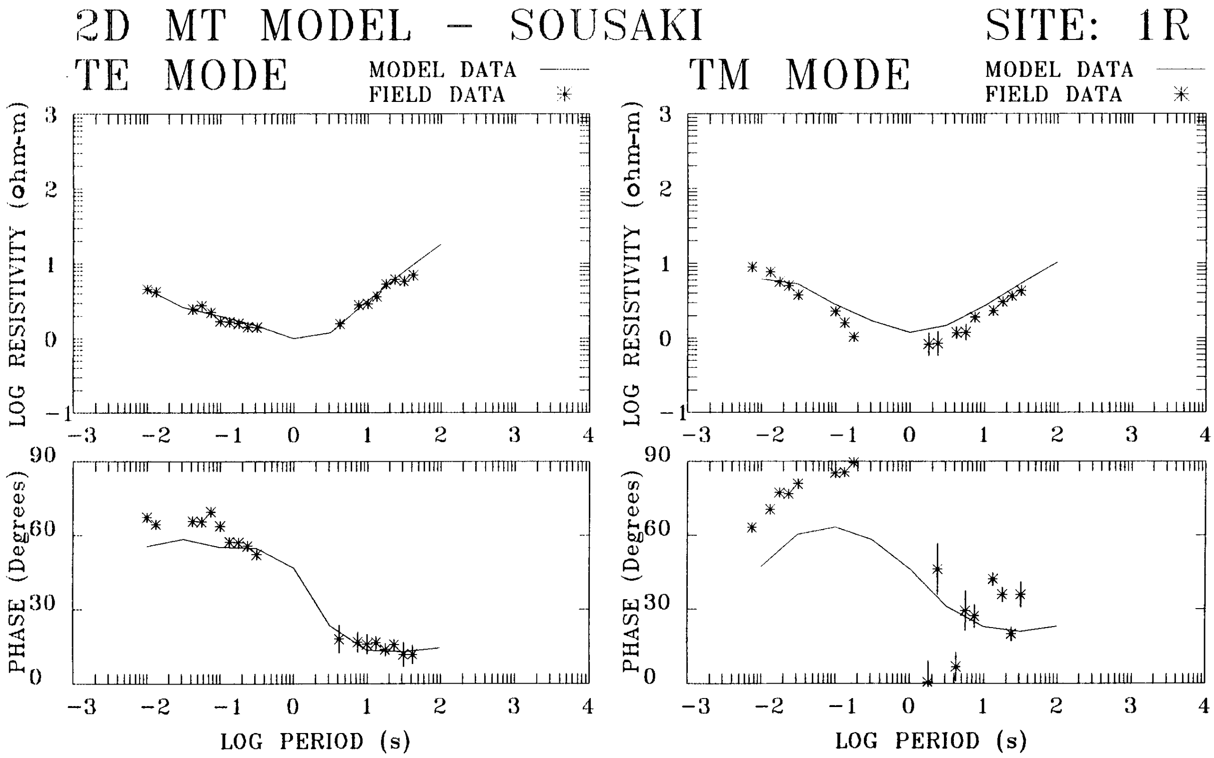
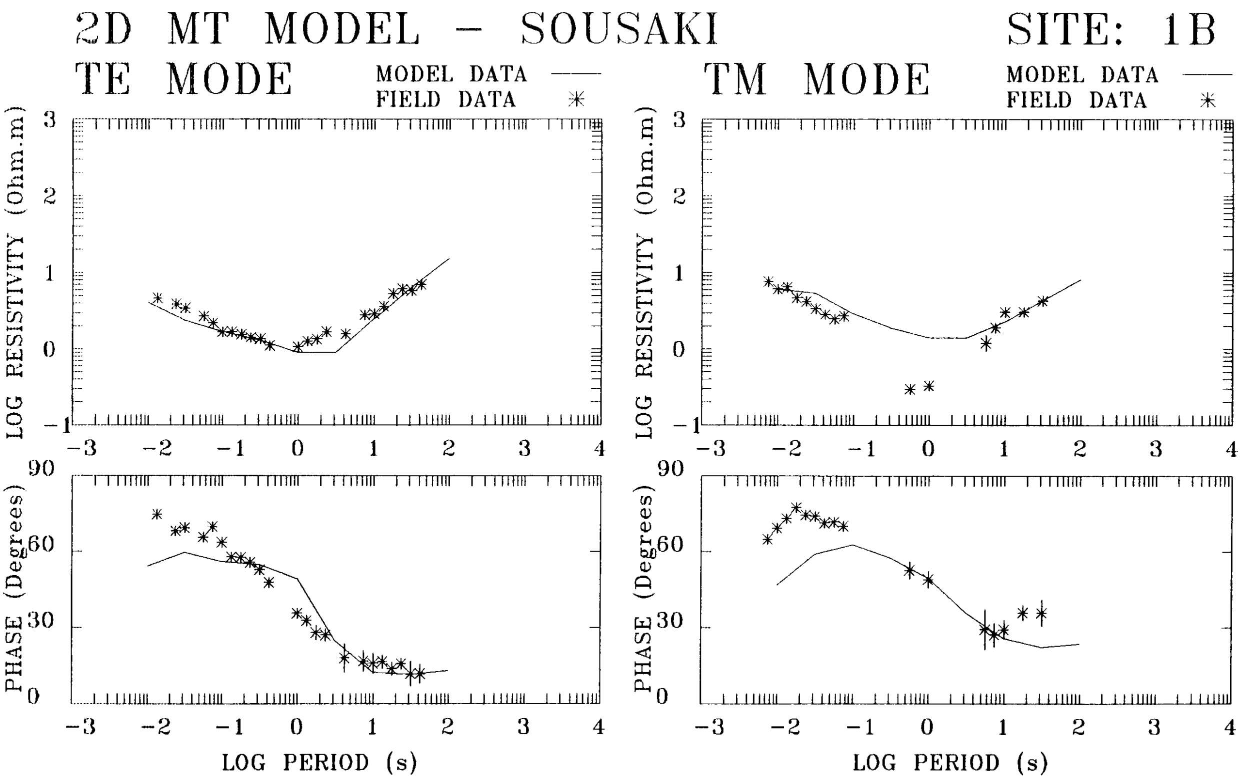
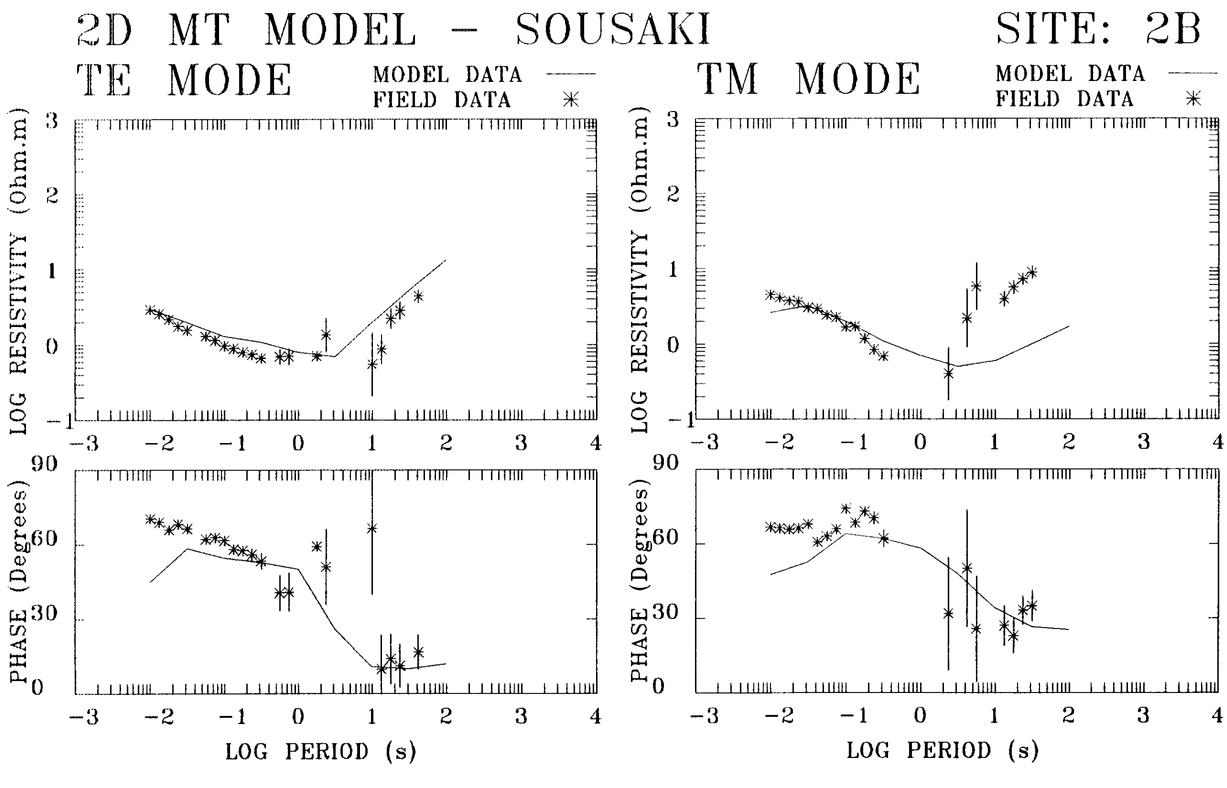


FIG. 9. (continued)



(g)



(h)

FIG. 9. (continued)

central part of the profile. This feature is about 150 m wide.

-The 0.5-1 ohm-m conductor is underlain by a resistive basement of 1000 ohm-m.

As shown in figures 9a-h, the 2-D model SS'-1 of Figure 8 displays in general a rather satisfactory fit to the field MT responses. The importance of the presence of several features on this model was tested by altering some of the model parameters during the modelling procedure. Two features were finally considered to be the most important. An equivalent number of tests were carried out and the new model responses were compared with the observed ones and with those corresponding to model SS'-1. The results of these tests could be summarised by the following.

- The existence of a dike-like shape feature of 4 ohm-m on model SS'-1 (Fig.8) between 100-450 m depths below the central part of the profile seems to be necessary in order to obtain a better fit of the model to the field responses. To demonstrate the above, this feature was removed (Fig.10a, model SS'-2). The new model responses are illustrated in figure 9d in comparison with the field data and the responses of model SS'-1 for the same site location 14B. The responses of models SS'-1 and SS’-2 are represented with thin and thick solid lines, respectively. At this site there is a remarkable deviation in the mismatch between the observed responses and the calculated ones of model SS'-2.

- The existence of a vertical boundary located 1500 m southwest of MT site 6R seems to be one possible way to obtain a model (Fig.8, model SS'-1) with a better fit to the experimental data (Fig.9a). To demonstrate the above this vertical boundary was removed and the new model SS'-3 was left to terminate to the southwest with the 1 ohm-m conductor (Fig.10b). The resistivity and phase responses of model SS'-3 are compared with those of model SS'-1 and the observed ones in figure 9a for the site location 6R. The responses of models SS'-1 and SS’-3 are represented with thin and dashed solid lines, respectively. It can be seen therefore that there is an obvious mismatch, between the model SS'-3 responses and the actual field data.

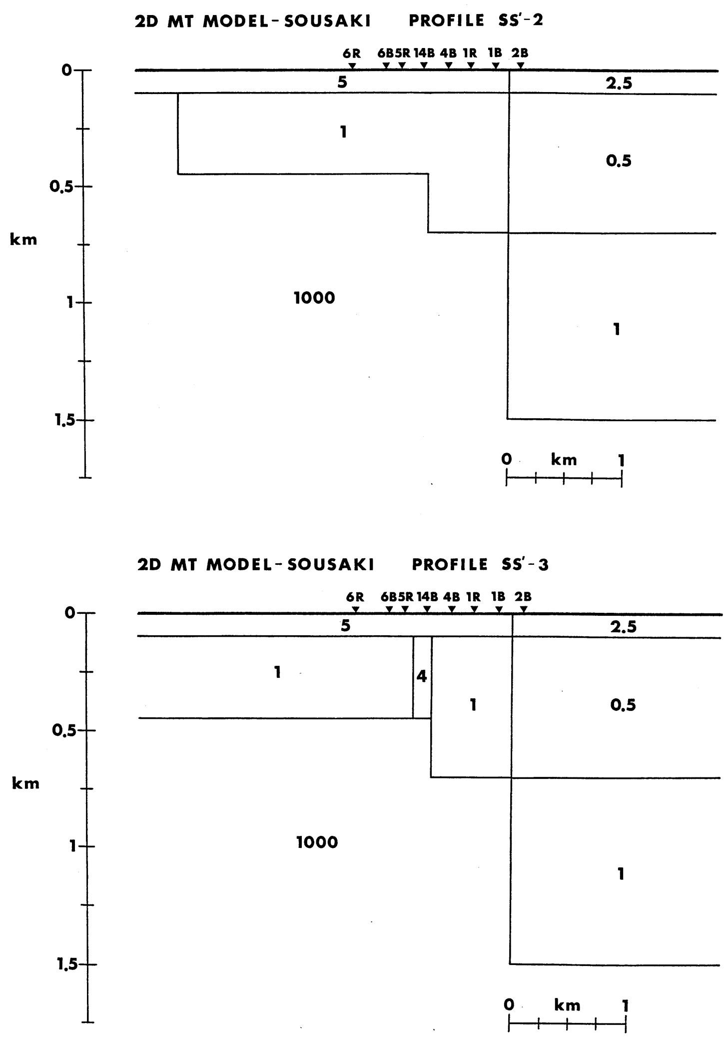


FIG. 10. 2-D models along profile SS'. (a) model SS'-2. (b) model SS'-3. The figures on the models are resistivity values in ohm-m.

DISCUSSION

The geology and the NW-SE, NNW-SSE and E-W fault systems of the western part of the HVA and Saronikos Gulf in particular, were mapped by Gaitanakis et al. (1984) and Fytikas et al. (1987). Part of the geotectonic map of Fytikas et al. (1987) was redrawn in Figure 2 to illustrate the geology and the major faults of Sousaki. The most important tectonic features on this map are indicated by the letters A, B, C, D and E, to facilitate the discussion of the MT results and permit the direct comparison of the various characteristics of the presented 2-D electrical model with these features.

In the period range of 0.075-15 s the MT data seem to be anisotropic for a large number of MT sites. The major and minor axes of the polarisation ellipses (Figs.7a,b,c) are oriented NNW-SSE (15^{o}W) and ENE-WSW (75^{o}E), respectively, with the major axes in the more conductive regions striking NNW-SSE. This direction being the dominant direction for the largest part of the recording period range was adopted as the main electrical strike and could be correlated with the Pliocene NNW-SSE tectonic directions of the area. This direction is compatible with the direction of fault E shown in Figure 2.

In the longer period range of 15-42 s, the MT data seem to be very anisotropic at all the MT sites. The major and minor axes of the polarisation ellipses are oriented along two perpendicular and rather consistent directions, NW-SE (45^{o}W) and NE-SW (45^{o}E), respectively (Fig.7d). The 45^{o}W direction seems to correlate satisfactorily with the Pleistocene NW-SE tectonic directions of the area and is rather related to deep normal faults. This direction is compatible with the direction of faults A, B and C shown in Figure 2. In addition, this direction is very similar to that of 50^{o}W, indicated for the deep normal faults of Sousaki by Lagios (1992) and Tzanis and Lagios (1993) using the 3-D rotation analysis of Tzanis (1988).

The 2-D MT model SS'-1 illustrated in Figure 8, concerns the electrical structure of the uppermost 2 km of crust below Sousaki. This model was derived by rotating the MT data at an angle of 15^{o}W. Although this direction represents the largest period range 0.075-15 s and has been adopted to be the main electrical strike, it does not account for the longer period range (15-42 s), where the dominant direction is about 45^{o}W. This fact should be taken into account while discussing the deep features of this model and the rather bad fit of the model and field data in the longer period range 15-42 s of the MT sites 5R, 14B and 4B (Figs.9c-e). Two hypotheses concerning the model SS'-1 have been tested in the previous section of this paper. Although the results of these tests imply that SS'-1 is a model with the most satisfactory fit to the field data, the derived electrical structure is interpreted with care considering the non-uniqueness of the 2-D modelling problem. In general, this structure does not deviate from what is already known from the geology and tectonics of Sousaki, and it seems to provide some new features maybe of geotectonic and geothermal significance. The 2-D model is not in a good agreement with the results of the 1-D interpretation (Lagios, 1992; Tzanis and Lagios, 1993) of the same MT data, as far as it concerns the maximum depth of the modelled features. The previously made 1-D modelling was of preliminary character and seemed to resolve features at apparently 11-12 km depth.

However, this is not observed in the present 2-D electrical model, which seems to resolve features at much shallower depths, that is the top 2 km of the upper crust. This should be explained to the regional 2-D or local 3-D structures, which should be taken into consideration, as it was inferred by the dimensionality analysis (Figs.6a,b). Interpretation of the very low resistivity values (≤ 5 ohm-m) observed in the top 1.5 km of upper crust below Sousaki area (Fig.8) with respect to the volcanic origin of the region, may imply the existence of a geothermal field. In particular, the following stand as general conclusions.

The 1000 ohm-m block seems to correspond either to the pre-volcanic, Upper Triassic-Lower Jurassic limestone basement or to the Post-Upper Cretaceous ophiolitic block. This cannot be resolved with confidence, because, in the broader area, we have the presence of both of the forementioned geological formations. Moreover, their electrical resistivity values should approximately be of the same order of magnitude, unless hydrogeological effects or weathering processes have decreased the relatively high resistivity values of the ophiolites, down to the same level of the resistivity values of the limestones. The basement is encountered at 100 m depth below the southwestern part of the profile and dips gradually to the northeast, where the depth to its top reaches a maximum value of 1.5 km.

The 0.5-1 ohm-m conductor can be related either to the various Pliocene volcanic products, sandstones and marly limestones or more probably to parts of the ophiolitic block which are intensively altered by hydrothermal activity. The relatively conductive (2.5-5 ohm-m) superficial layer can be related to Plio-Pleistocene marls, marly limestones, conglomerates and volcanics. The superficial part of this layer rather corresponds to old talus cones and recent alluvial deposits.

The shallow vertical resistivity boundary $\mathbf{B_s}$ (Fig.8), located 1.5 km southwest of site 6R seems to correlate fairly well with the NW-SE oriented fault A shown in Figure 2. The two intermediate size vertical resistivity discontinuities, which bound the 4 ohm-m conductor located below the central part of the profile, may correspond to the boundaries of a small elongated igneous intrusion. Regions of much higher resistivity, were already reported and correlated with igneous intrusions by Tzanis and Lagios (1993). The eastern boundary of this body, the deeper one, should correspond to a small fault with no superficial manifestations, maybe a northwestern continuation of fault B illustrated in Figure 2. Fault B is expected to be intersected with the major fractured zone C, north of MT sites 14B and 3R. The pair of these faults should have probably facilitated the igneous intrusions. The very low resistivitiy of this body is rather due to hydrothermal alteration processes. The deeper vertical resistivity boundary $\mathbf{B_D}$ located between the MT sites 1B and 2B (Fig.8) maybe related to the NW-SE oriented major fault designated by the letter C in Figure 2. The fractured zones A, B and C (Fig.8) are these which probably allow the rainwater and the geothermal fluids to flow and ensure the hydraulic continuation of the Eart's surface with the top weathered zone of the limestone or ophiolitic basement.

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