Magnetotelluric Investigations along Kuppam-Palani Geotransect, South India – 2-D Modelling Results

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Abstract

As a part of integrated geophysical studies to understand the processes related to crustal evolution of Southern Granulite Terrain (SGT), wide band magnetotelluric investigations were carried out mainly along: Kuppam-Bommidi (KB), Omalur-Kodaikanal (OK) and Kolattur-Palani (KP) profiles. 2-D modelling results show that the Proterozoic and Archaean terrains have exhibited varying deep crustal resistivity, of the order of 5000 to 100000 ohm-m, respectively. The important finding of the present study is the clinching evidence for the delineation of a block structure with variation in electrical resistivity character, and for characterization of shear zones. Such a block structure with variation in resistivity is one of the strong reasons to conclude that crustal evolution of the region originated in different tectonic regimes. These blocks are bounded by major faults and shear zones. The results have also shown good correlation with other geophysical studies. High conducting layer at middle to lower crust coincides with the low velocity layer observed from the deep seismic studies. Anomalous high conducting region in the upper crust near Palghat-Cauvery-Chennimalai shear system correlates with a large gravity high.

Keywords: Southern Granulite Terrain, Magnetotellurics, Block structure, Shear zones.

INTRODUCTION

Study of deep crustal signatures of the south Indian shield has attracted the attention of many earth scientists owing to its relation with major tectonic features (Drury et al. 1984; Radhakrishna, 1989; Ramakrishnan, 1993; GSI & ISRO, 1994; Harris et al. 1994; Valdiya, 1998; Janardhan, 1999). The high grade metamorphic province called Southern Granulite Terrain (SGT) occurs to the south of 13°N. The region can broadly be divided into 3 blocks. The northern block is essentially a granite-greenstone terrain. The central block consists mostly of migmatitic gneisses with enclaves of meta-sedimentary and metabasic-ultrabasic rocks. The southern block is dominated by quartzo-feldspathic gneisses with essentially metasedimentary enclaves. These blocks are separated by major shear zones – the Moyar-Bhavani Shear Zone (MBSZ) towards the north and the Palghat-Cauvery Shear Zone (PCSZ) towards the south (Fig.1) (Drury et al. 1984; Chetty, 1996). In order to understand the deep subsurface structure of this complex region, integrated studies of seismic refraction/reflection, magnetotellurics, gravity and deep resistivity soundings, along with geological and geochemical studies were carried out along the Kuppam-Palani geotransect (Reddy et al. 2000). As a part of the integrated programme, magnetotelluric studies were carried out in the present study area to characterize the shear zones and to study deep electrical structure, mainly along 3 profiles: Kuppam-Bommidi (KB), Omalur-Kodaikanal (OK) and Kolattur-Palani (KP) covering the Kuppam-Palani transect.

PREVIOUS STUDIES

Drury et al. (1984) proposed a generalized tectonic model for the region based on Landsat imagery data and suggested that some shear zones were developed during the Neoproterozoic period and others are products of Archaean collision. They proposed a continent to continent collision model involving northward subduction. Gravity (Mishra, 1988; Krishna Brahmam, 1993), Magsat (Mishra and Venkatrayudu, 1985) and aeromagnetic studies (Reddi et al. 1988; Harikumar et al. 2000) have also led to different tectonic models for the region. Using the aeromagnetic data. Reddi et al. (1988) have suggested a crustal structure with number of blocks and indicated that relative movement between the blocks might be responsible for the observed landforms of the region. Radhakrishna (1989) and Harris et al. (1994) considered the system of shear zones as terrane boundaries. Ramakrishnan (1993) and Rai et al. (1993) have suggested tectonic models based on geological and tomographic studies, respectively. Chetty et al. (2000) studied various shear zones in the region and suggested a 'flower structure' typical of transpressional tectonic zones.

In order to understand the processes related to the evolutionary history of the crust in a cratonic region, deep crustal studies are necessary to map the velocity variation, density variation and electrical resistivity variation. Among these, electrical resistivity is one of the important geophysical parameters to

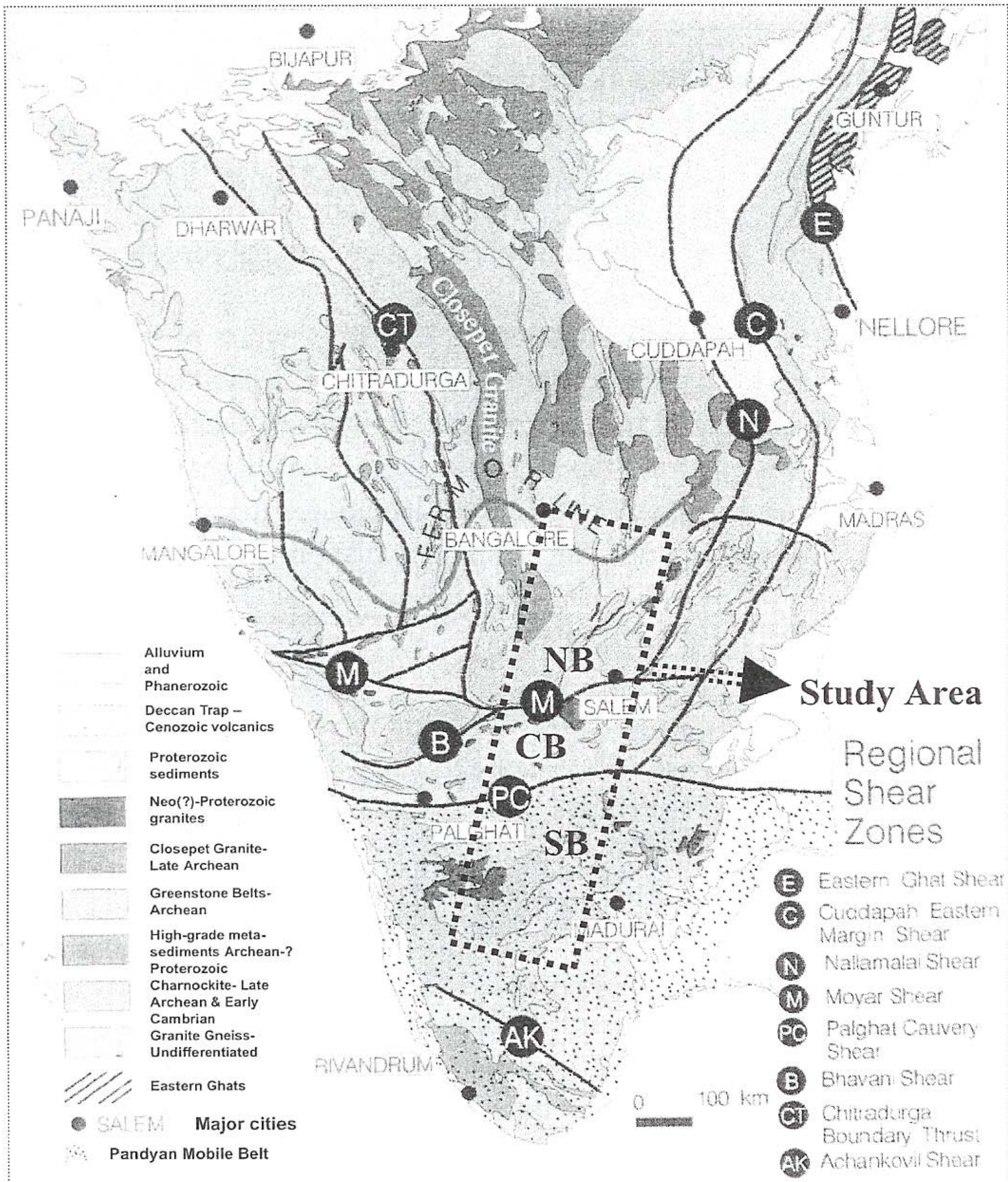

Fig.1. Location map of study region along with regional geology and tectonics (from Project Vasundhara of GSI & ISRO, 1994). NB - Northern Block; CB - Central Block; SB - Southern Block.

understand the tectonics of the region. Many deep electrical/electromagnetic studies have been reported over northern Canada, Adirondocks, Baltic and Indian shields (Sternberg, 1979; Kurtz, 1982; Jones, 1992; Gokarn et al. 1992; Korja et al. 1993). They have yielded valuable information on regional tectonics. With the objectives of characterization of the shear zones and delineation of the deep geo-electric structure, a wide band magnetotelluric study has been carried out in the study area.

MAGNETOTELLURIC STUDIES

Methodology

MT – a natural source electromagnetic method – provides information on the subsurface distribution of the electrical conductivity. The electromagnetic waves generated through solar wind-magnetosphere interaction (1 Hz to a few milli Hz) and worldwide thunder-storm activity in the earth's ionospheric cavity (audio-frequency range 10 Hz to 10 KHz) constitute the source signal for MT measurements.

MT studies would help to characterize the basic electrical nature of the crust from shallow levels to as much as several tens of km deep. This facilitates insight into the structure, composition and state of the deep interior. Since the information obtainable from magnetotellurics is also sensitive to lateral changes in the earth's crust, it helps in studying the subsurface lateral heterogeneities that might characterize different depths in the crust/upper mantle.

Data Acquisition

Data have been acquired in two field seasons along three profiles. All these profiles were oriented nearly in N-S direction. The 110 km long KB profile is covered by 13 stations from Kuppam in the north and Bommidi in the south. It traverses through Mettur Shear Zone (MSZ) and also many deep seated faults of the region documented by Grady (1971). The 160 km long KP profile from Kolattur in the north to Palani in the south is occupied by 18 stations. It crosses the PCSZ and MBSZ. Similarly, the 200 km long OK profile contains 17 stations from Omalur in the north to Kodaikanal in the south. The OK profile is nearly parallel to KP profile and cuts across PCSZ and Salem-Attur Shear Zone (SASZ) that is the eastward extension of MBSZ. The station interval, for all the profiles, is in general about 10 km. The location of MT stations with station code is shown in Fig.2.

Five component (2-electrical and 3-magnetic) MT data at each station were acquired in the frequency range of 1000-0.002 Hz. Induction coil magnetometers were used to measure magnetic field components and a set of Cd-$CdCl_2$ porous pots were used as electrodes for electric field measurements. The electrode separation was generally kept at 90 m. The time series were recorded, processed and stored after preliminary acceptance criteria. Data were normally acquired for 2 days at each station using GMS-05 units of M/s Metronix, Germany.

Data Analysis

A few stations are considered to illustrate the data analysis procedure

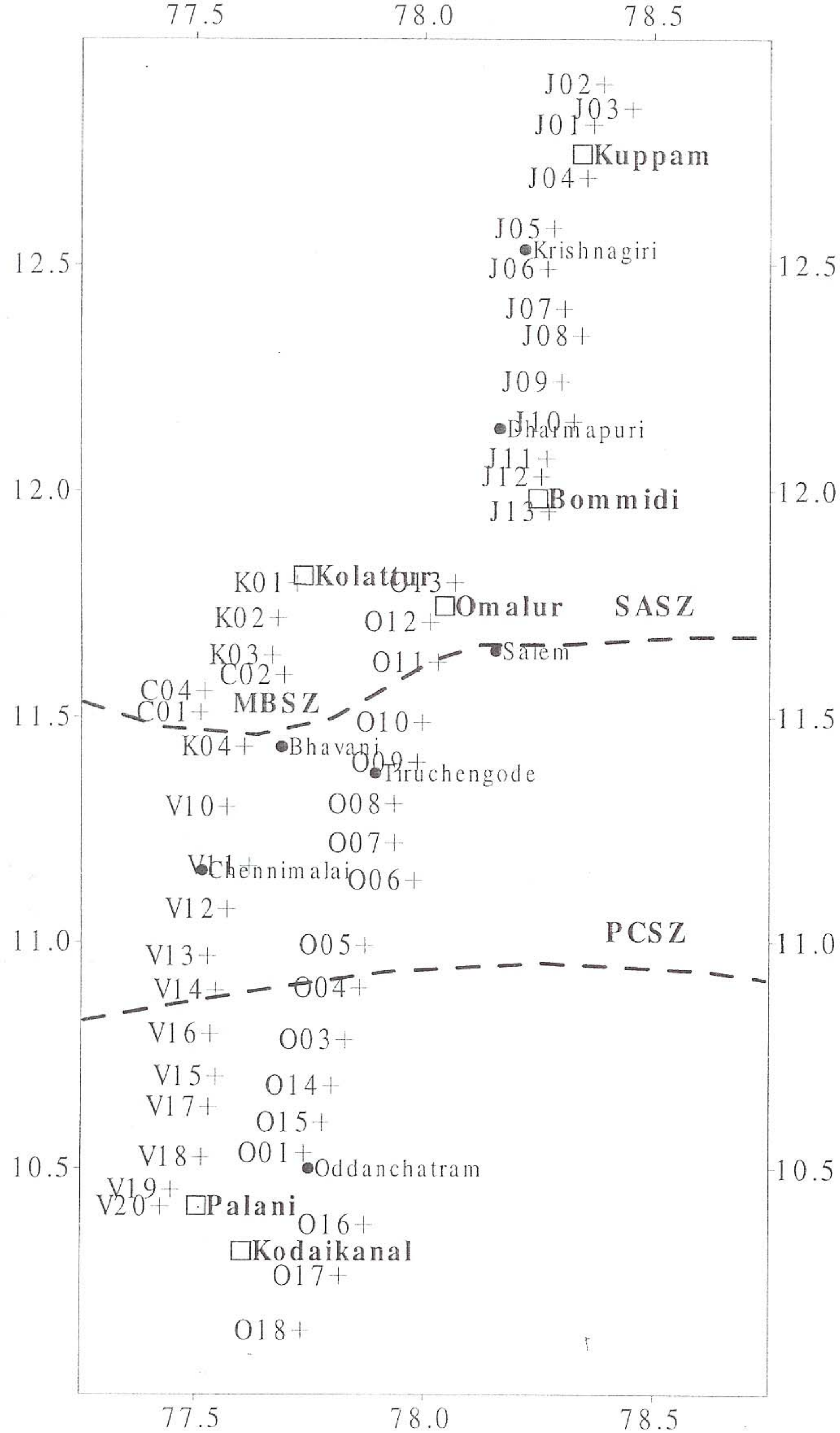

Fig.2. Location of MT stations with codes (major shear zones viz., PCSZ, MBSZ and SASZ are also shown).

followed in the present study to determine the rotation angle, strike direction and correction for static shift effects. We applied the Groom-Bailey (GB) decomposition scheme (Groom and Bailey, 1991) to all the stations of the profile. The scheme has proved to be effective in identifying the 3-D local structures superimposed over a regional 2-D structure and reducing its distortion effects. The rotation angle obtained at each station has been compiled for the KB profile and is presented in Fig.3. Large variation in rotation angle from –10° to 50° is observed. But the trend in the variation of the angle converges for longer periods (>100 sec). An average strike direction of N 40° E is obtained for the rotation angles between 100 and 1000 sec. It is consistent with the regional geological strike. As discussed earlier, the system of faults and also the MSZ are oriented in this direction. Similarly, N 85° E and S 63° E for OK and KP profiles respectively are obtained. At each station, shear, twist and rotation angles are computed using GB analysis and the values fixed successively to obtain impedances along regional strike. The data for some of the stations have exhibited large distortions due to static effects. It is well known that galvanic type boundary charges built up due to near surface inhomogenities resulted in the shift of one or both apparent resistivity curves

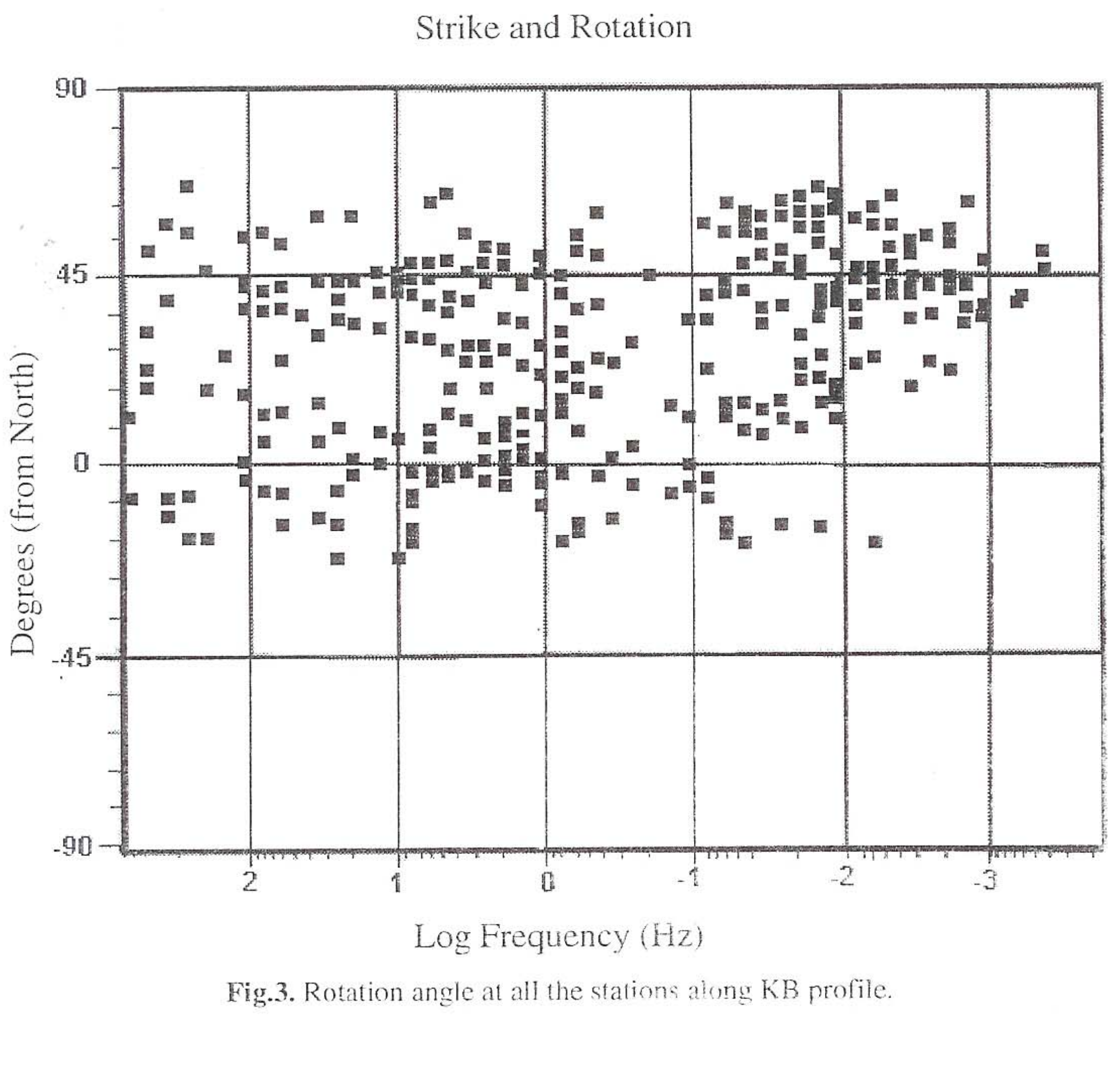

Fig.3. Rotation angle at all the stations along KB profile.

from normal position. The shift in apparent resistivity curves gives erroneous estimates of subsurface parameters. While various procedures are reported (Pellerin and Hohmann, 1990), we have corrected the data on the basis of information available from deep resistivity sounding results. It may be noted that deep resistivity soundings have been carried out (Singh et al. 2001a) at a few locations, along with other geophysical studies. MT response functions were computed for the models derived from DRS data and static shift effects are corrected. Such a correction applied to the MT data in Saurashtra region near Lodhika yielded good results with better correlation to borehole data (Harinarayana, 1999). Examples of the apparent resistivity and phase data in the measured direction and after decomposition and static shift correction (Naganjaneyulu et al. 2001) are shown in Figs.4a, b and 5a, b respectively for the stations v20 and v16.

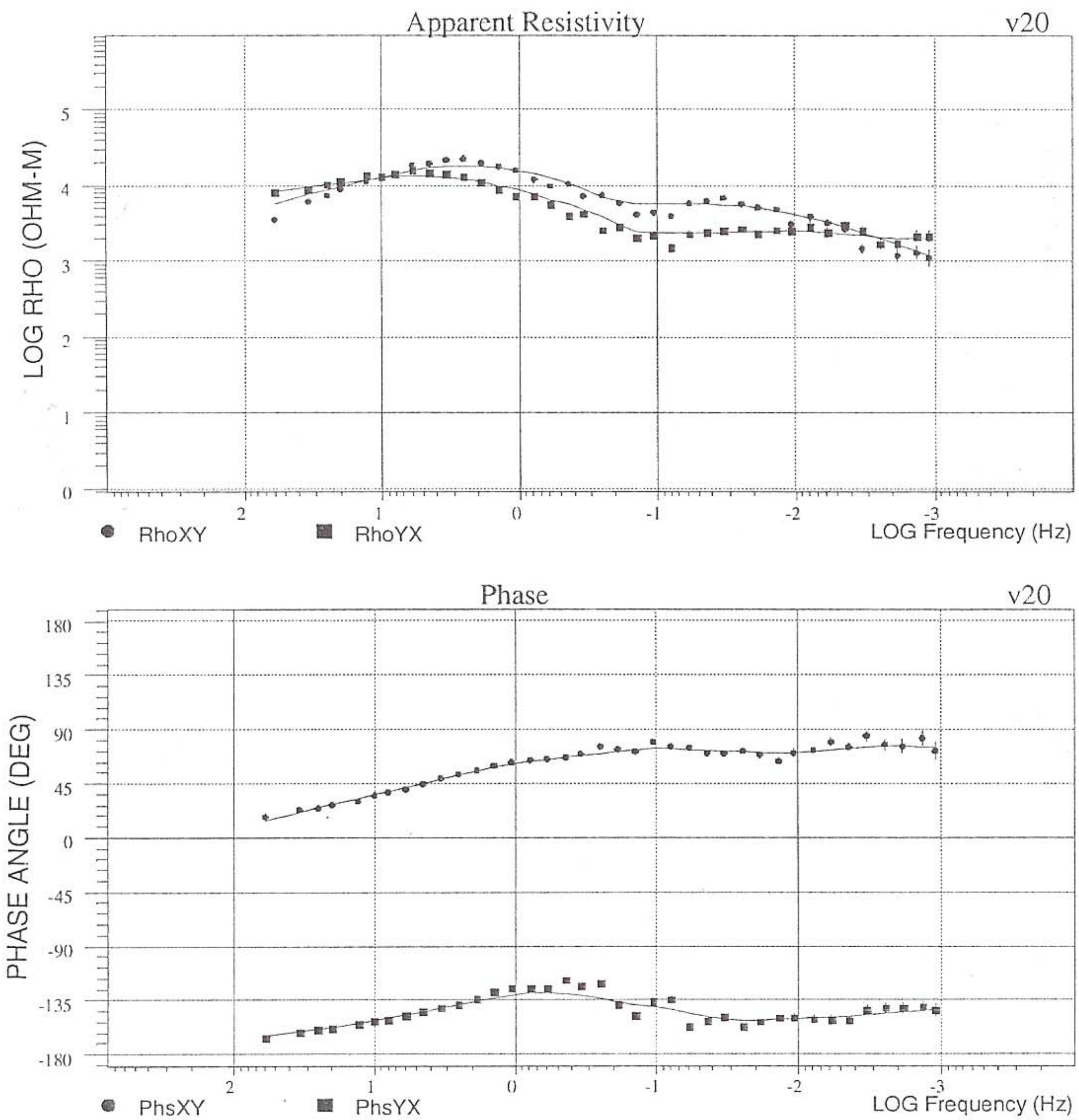

Fig.4a. Apparent resistivity and phase curves for station v20 in the measured direction.

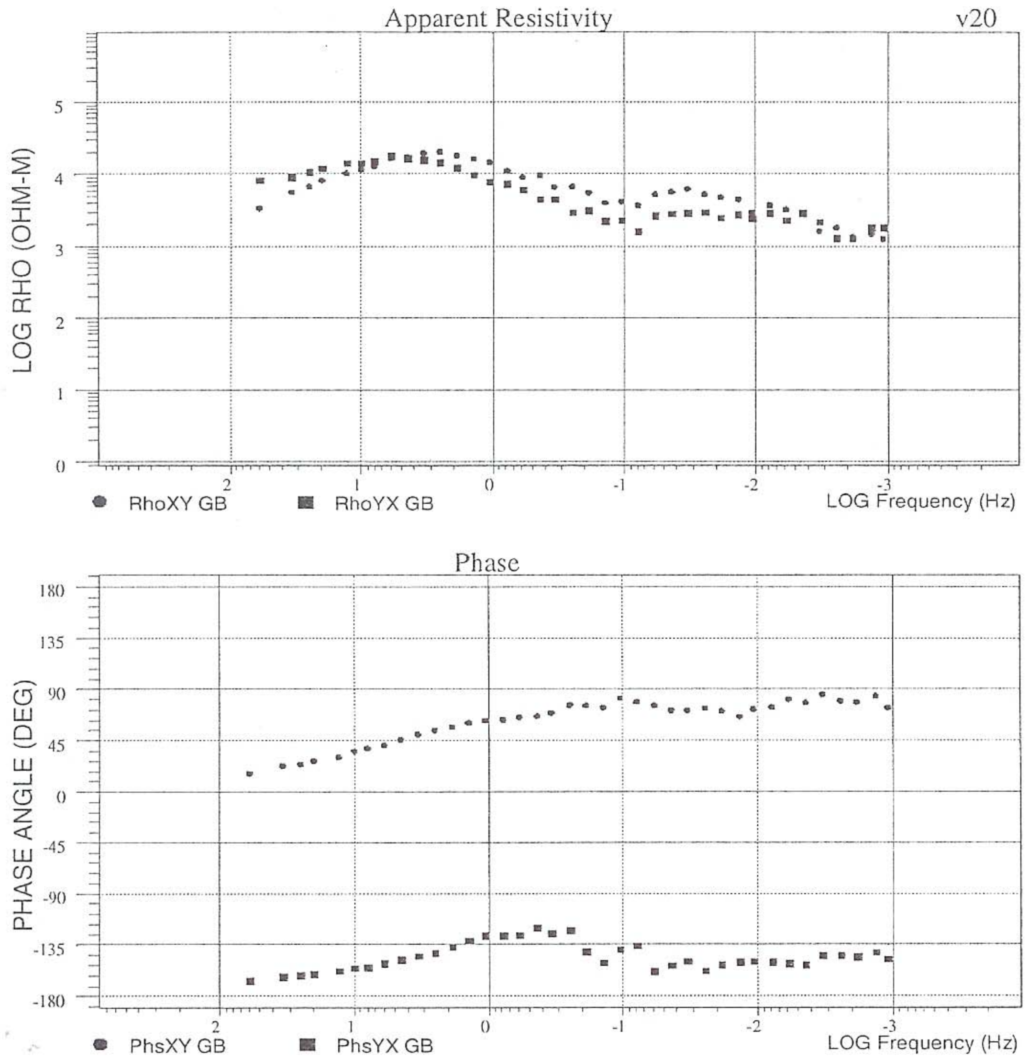

Fig.4b. Apparent resistivity and phase data (after Groom-Bailey decomposition and static shift correction) for the same station v20.

APPARENT RESISTIVITY PSUEDOSECTION

The data analysis using Groom and Bailey decomposition technique and static shift correction, are useful to initiate interpretation of the data qualitatively. This will provide an insight into the subsurface structure such that the subsurface model to be obtained using modelling schemes can have better constraints. For this purpose, the data from Kuppam to Kodaikanal have been compiled using the data sets of KB and OK profiles and presented in the form of apparent resistivity pseudo-section in TE as well as in TM modes (Fig.6). It can be seen from the figure that there are three distinct vertical low resistivity features. This can be seen more clearly in TE mode and indicated with asterisk (*) symbol at the bottom of the figure. Interestingly, these near-vertical conductive features are located close to the shear zones. For example, the system of faults mapped by Grady (1971) and also the northeastward extension of MBSZ are

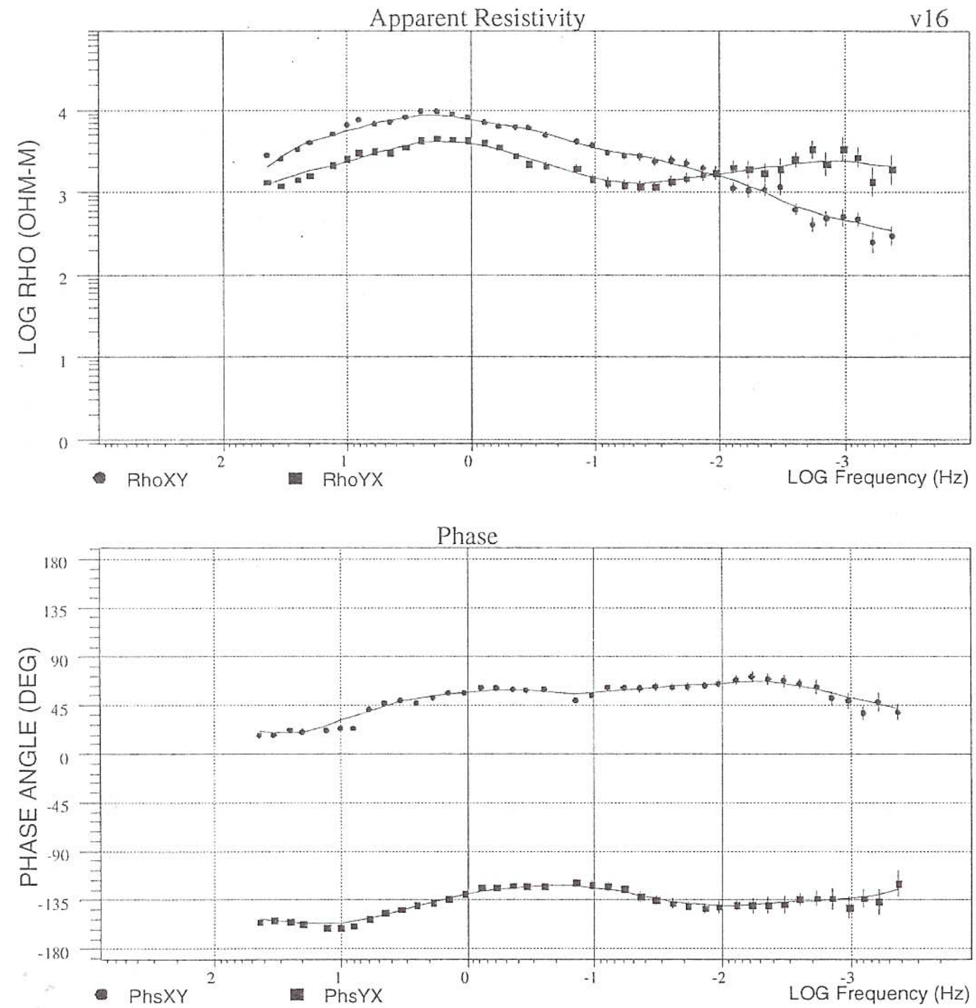

Fig.5a. Apparent resistivity and phase curves for station v16 in the measured direction.

located close to the stations 10 and 11 along KB profile. Another vertical conductive feature below the stations 11 and 12 along OK profile is located near the SASZ. Similarly, a conductive steep portion near stations 4 and 5 along OK profile is located near PCSZ. These features indicate that the shear zones have come out clearly in the form of anomalously high-conductive narrow zones. The apparent resistivity for other stations has exhibited large values of the order of 5000-10000 ohm-m or greater between 1000 and 1 Hz and less values from 1 Hz to 0.001 Hz all along the profile. This feature indicates that the upper crust is resistive and the middle to lower crust is conductive, as in the case of typical shield regions.

MODELLING

The study of apparent resistivity psuedosection has given qualitative

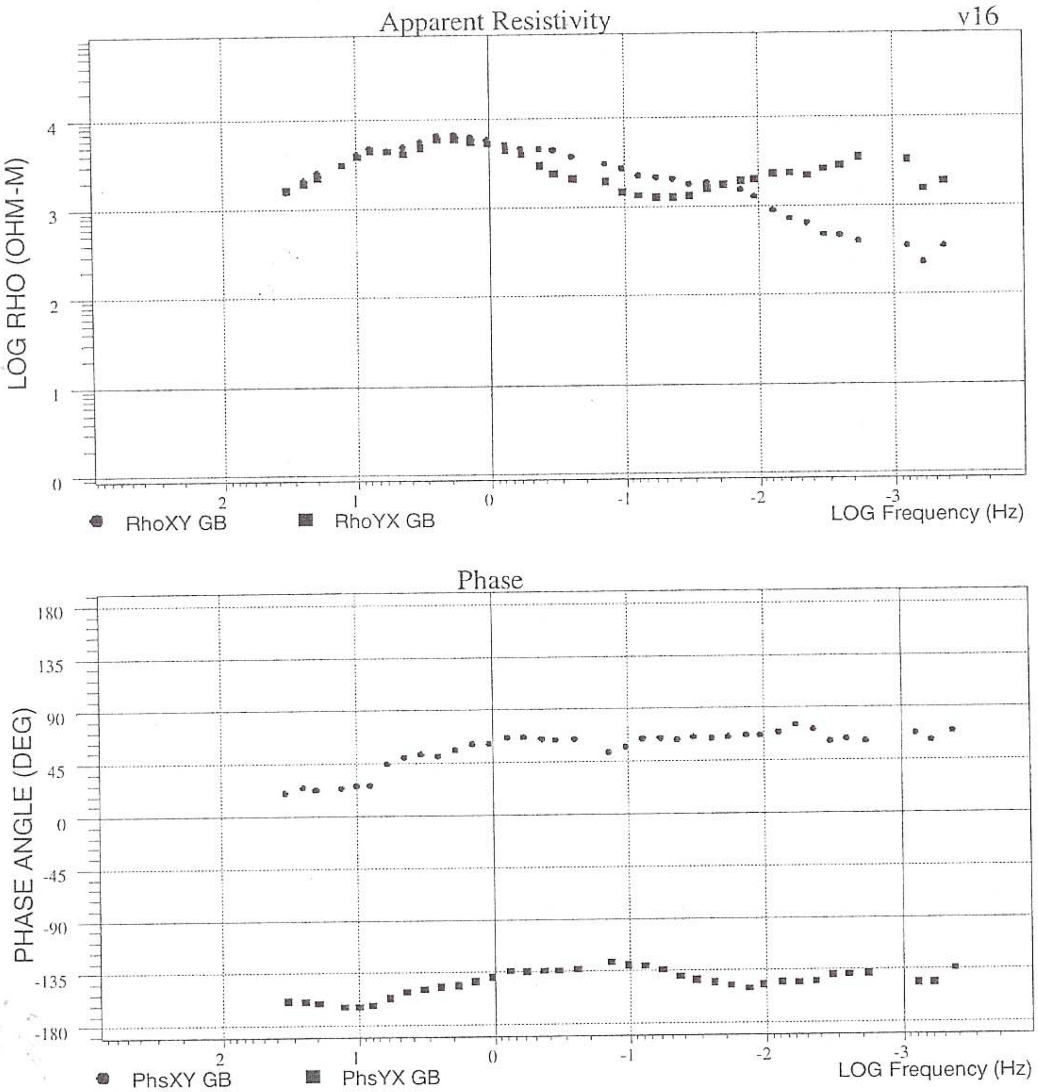

Fig.5b. Apparent resistivity and phase data after Groom-Bailey decomposition and static shift correction for the same station v16.

resistivity variation at subsurface depths. This information has been used to construct initial models for the inversion techniques. The data has been subjected to 1-D modelling before initiating the 2-D modelling. It may be noted that 1-D modelling of the data provides information about the horizontal layers at subsurface depths, whereas 2-D modelling provides information both on lateral variation of resistivity structure along the profile as well as variation with depth. In the present study, the linearized inversion schemes of Marquardt (1963) and Jupp and Vozoff (1975) have been used for 1-D modelling. An example of 1-D modelling carried out for ρ - det. (determinant) response for a station along KP profile has been presented in Fig.7. As can be seen from the figure, the high resistive upper crust and conductive crust at middle to lower crustal depths are observed. This is a general trend for many stations along the

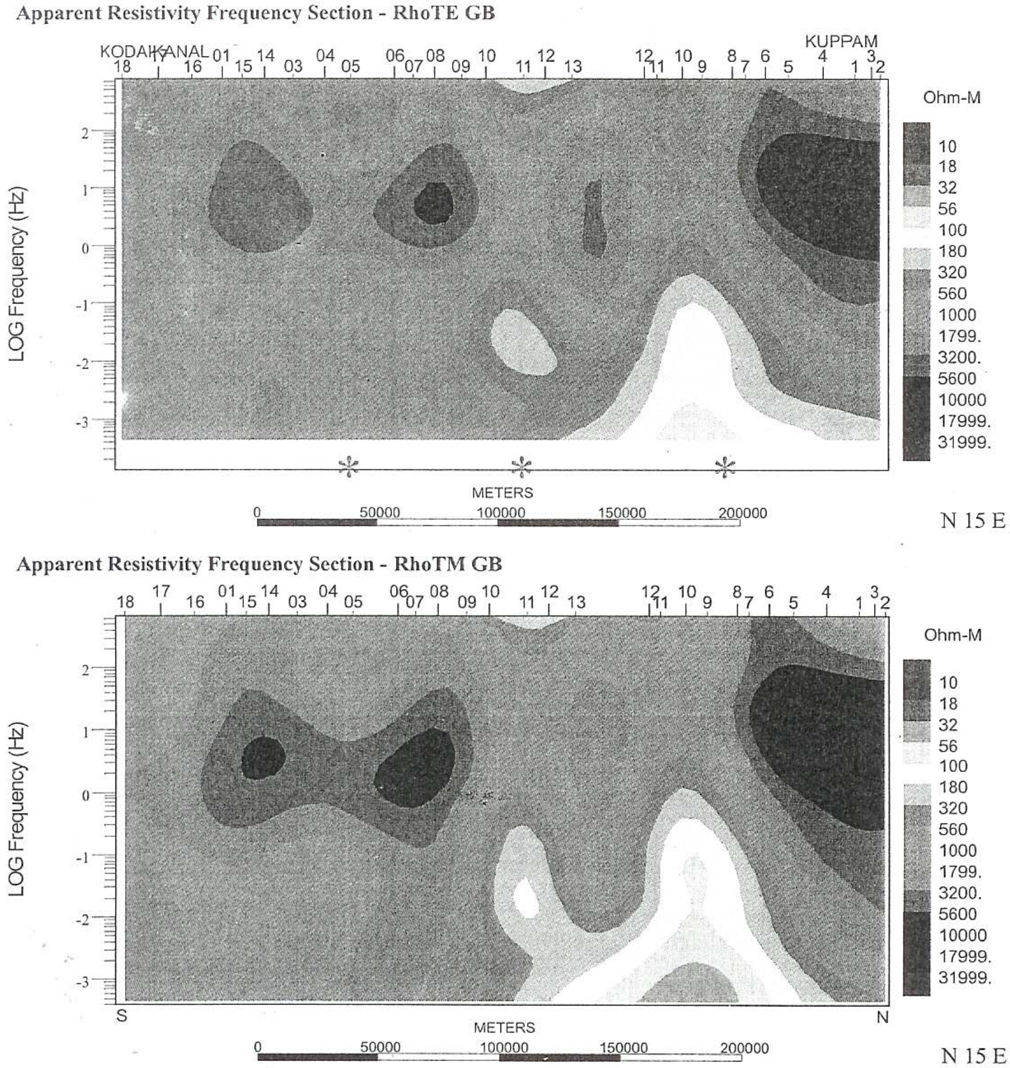

Fig.6. Apparent resistivity pseudo-section along Kuppam and Kodaikanal for TE and TM modes. Asterisk symbol at the bottom indicates the location of major shear zones of the region.

3 profiles. It is of interest to note here that a conducting layer delineated from the magnetotelluric study correlates well with low velocity layer detected from deep seismic sounding studies.

The subsurface layer parameters obtained from 1-D modelling for all the stations have been compiled and used to construct the initial model for 2-D-inversion scheme. RRI 2-D inversion (Smith and Booker, 1991) has been used for modelling. In our study, apparent resistivity and phase data for both TE and TM modes are considered. An example of fit between the observed and computed data for a profile (KP) in the form of apparent resistivity pseudo-section is presented in Fig.8. A reasonably good fit is obtained for all the stations except for a few stations (12, 13) at lower frequencies. Good fit could

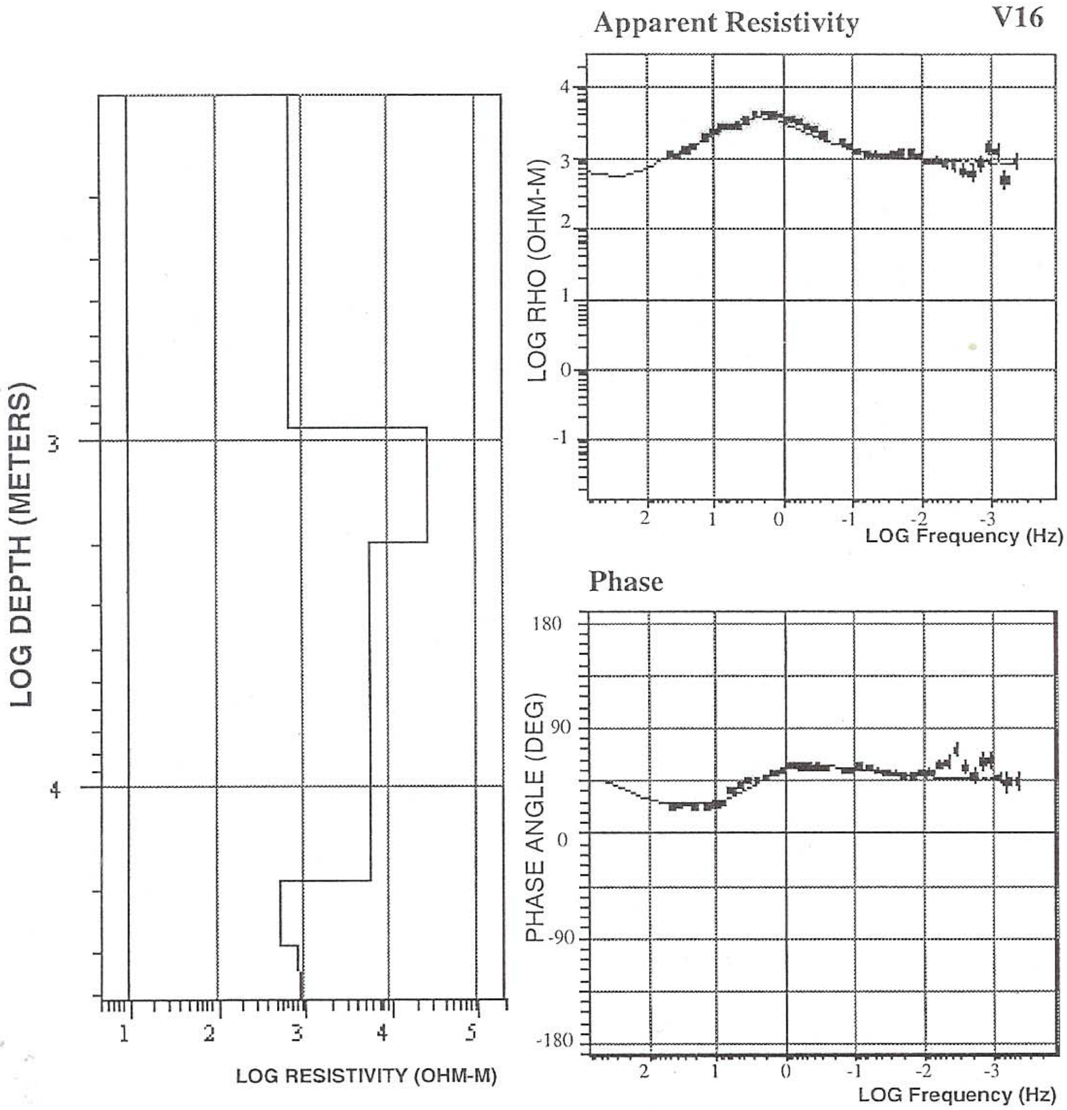

Fig.7. An example of 1-D modelling result for Rho-det showing high resistive upper crust and conductive middle to lower crust.

not be achieved at these locations, perhaps due to 3-D nature of the subsurface structure. It may be recalled that gravity study has delineated a large conspicuous gravity high near PCSZ and Chennimalai Shear Zone (CSZ) in the form of a circular anomaly indicative of a 3-D body at subsurface depths (Mishra et al. 2001). The 2-D subsurface sections obtained for all the 3 profiles following the same procedure described earlier are presented in Fig.9.

The subsurface structure along Kuppam - Bommidi has shown high resistive upper crust up to 20 km from station 2 to station 7 and low resistive below the stations 10, 11 and 12 with anomalously high-conducting narrow feature near the station 9 (Fig.9). The subsurface structure along Omalur - Kodaikanal profile has also exhibited resistive upper crust and conductive lower crust. A narrow conductive, near-vertical feature has been observed from

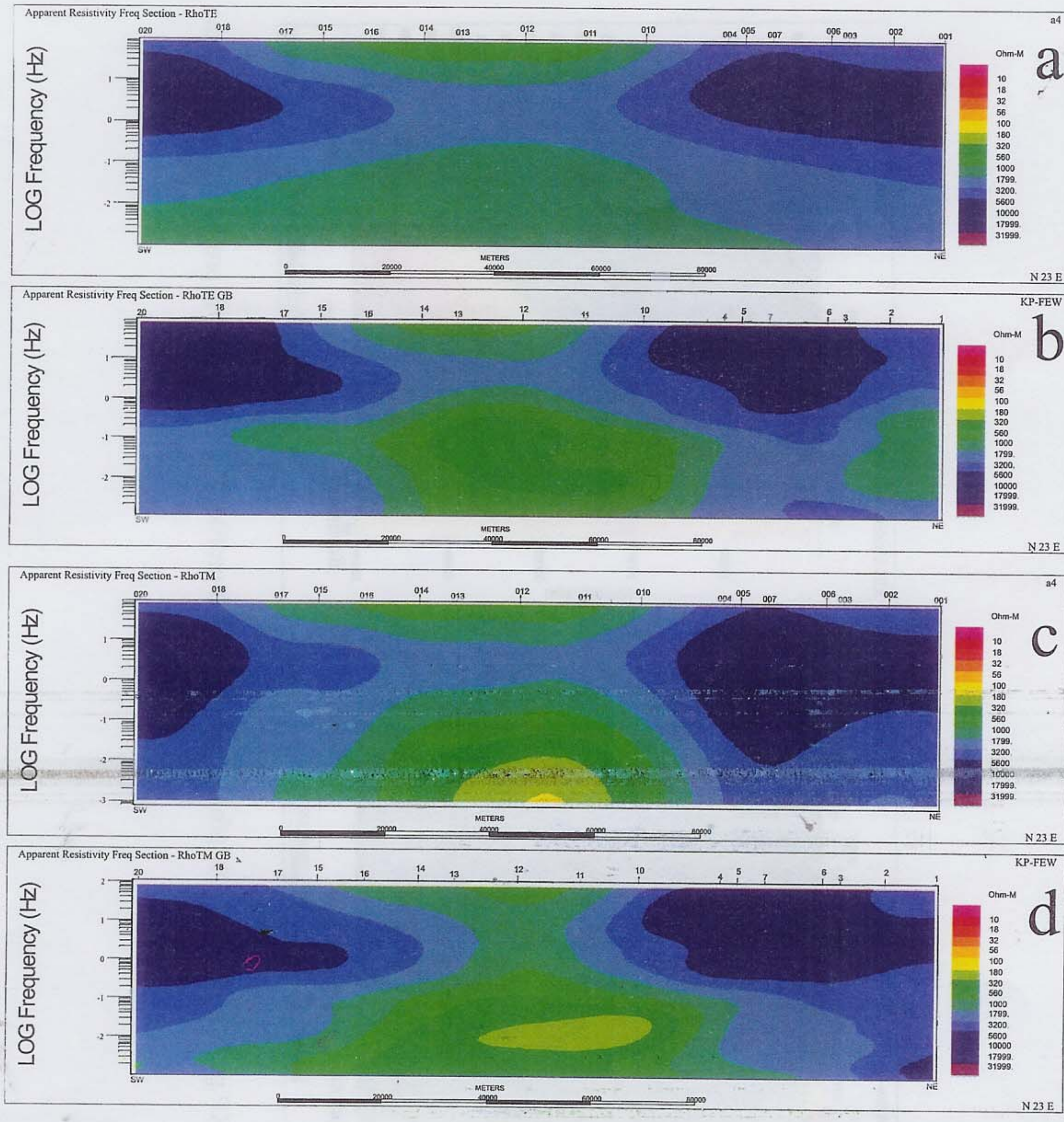

Fig.8. Apparent resistivity pseudo-section along KP profile (**a**) computed and (**b**) observed data - TE mode. (**c**) computed and (**d**) observed data - TM mode.

shallow to deep crustal depths around the station 11, located near SASZ. Another prominent conductive feature at middle to lower crustal depths below the stations 4-14 is observed and appears as conductive intrusive structure. It is of interest to note that the PCSZ is located between the stations 4 and 5. It is also of interest to observe here that the lower crust and upper crust have shown anomalous high resistivity towards north of PCSZ. The subsurface structure along Kolattur-Palani profile is similar to that of OK profile with minor variations. It may be noted that KP profile is nearly parallel to the OK profile. Anomalously high-conducting features delineated at lower crustal depths (25 km) along OK profile are also observed in the upper crust (15 km) along KP profile. One can infer from such a correlation that the conducting feature below the PCSZ has large dimension indicative of a 3-D body. It is significant

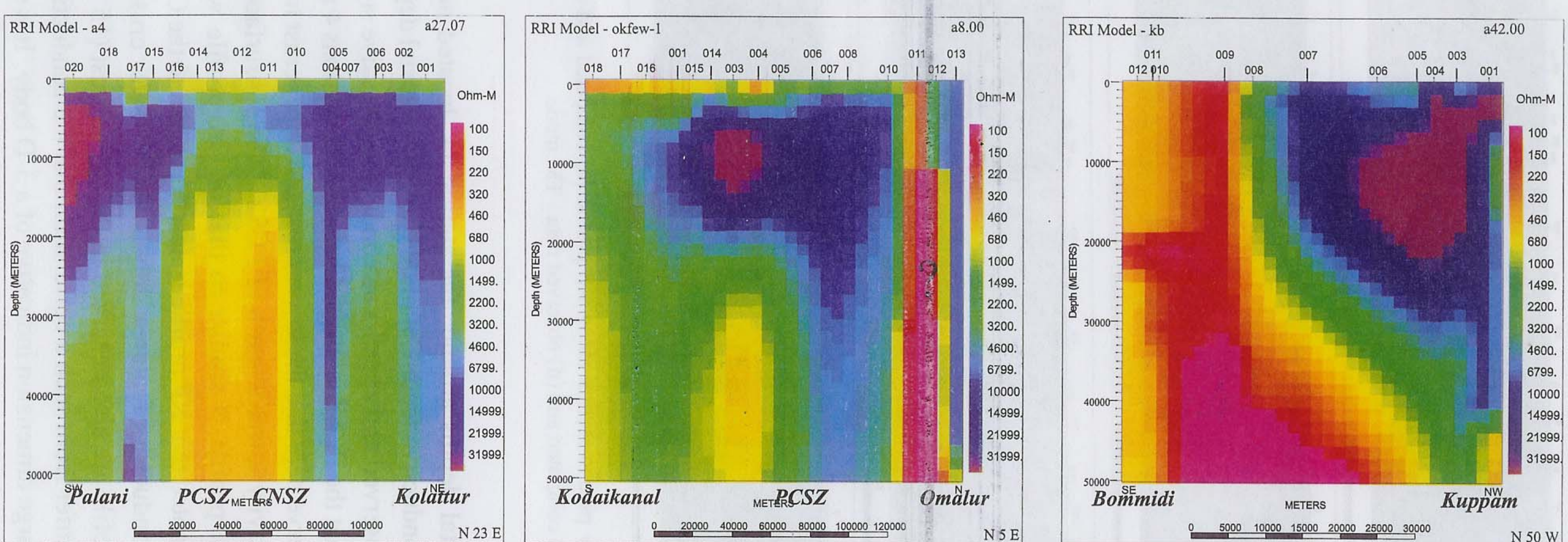

Fig.9. 2-D models for the SGT along the three profiles: Left - KP profile, Middle - OK profile and Right - KB profile. The '?' in the OK profile indicates that the conductor at lower depths is un-resolved.

that a large gravity high in the form of an elliptical anomaly is observed in this region.

DISCUSSION OF RESULTS

It has been believed for many years that south Indian Precambrian terrain is Archaean in age. The recent geochronological studies, however, have given an indication that different blocks belonging to different ages occur within the granulite terrain. It is argued that the terrain can be divided into Archaean craton towards north and Proterozoic terrain towards south with transition zone in between. Based on major lineaments, fault zones and shear zones, some attempts are made to correlate the western part of the SGT with Madagascar and eastern part with Antarctica (Yoshida and Santosh, 1996). It was also indicated that these major faults, shear zones and lineaments might be the boundaries of different blocks. The data obtained from the present study along these profiles have been processed as proposed by Groom and Bailey (1991) and 1-D, 2-D modelling has been carried out. The modelling results gave a regional variation of the electrical resistivity parameter.

The geo-electric structure along the geotransect has exhibited distinctly different geo-electric characters in the lower and upper crust, separated by major shear zones. The stations located towards northern part of KB profile have exhibited anomalous high resistive crust indicative of a typical craton. Similarly, the upper and lower crust north of PCSZ has exhibited high resistivity character, while towards the south, upper crust is resistive and lower crust is anomalously conductive (400 - 500 ohm-m). Such a feature is observed along OK as well as KP profiles. Anomalously high-conductivity at lower crustal depths could be due to the presence of fluids or partial melt, although other reasons such as presence of films of carbon on grain boundaries (Duba et al. 1988) can also be debated. However, recent heat flow studies (Labani Ray et al. 2000) have given a normal heat flow values (28-38 mW/sq.m) for this region and does not support the presence of partial melt. DSS studies have delineated a low velocity layer at middle to lower crustal depths and is correlatable well with the highly conductive layer at many places. Such a correlation is a strong evidence for the presence of fluids at middle to lower crustal depths.

Another point of interest is that the gravity anomaly reported in this region (Singh et al. this volume) has exhibited a Bouguer gravity high of about 20 mGal. The shape of the anomaly is nearly elliptical and oriented in east-west direction. Seismic studies (Reddy et al. 2001) have delineated Moho up-warp indicative of deep crustal tectonics in the study area with intense crust-mantle interaction which might have resulted in large amount of mantle-derived fluids trapped at upper crustal depths. This is consistent with the formation of extensive granulites exposed near the surface. The high conductive region associated with anomalous high density structure must have manifested as high density iron ore deposits and alkaline rock/anorthosite bodies exposed near the surface.

All the shear zones of the study area exhibit a high conductivity character. For example, the well known PCSZ, MBSZ, SASZ and CSZ have been observed as high-conducting steeply dipping features. Among these shear zones, MBSZ and SASZ have exhibited anomalously high conductivity. Shear zones are of significance in view of their association with minerals, seismic stresses, fluids and also with terrain boundaries. In such a situation, one can argue that shear zones associated with anomalous conducting features should have a close bearing with one or more of these factors as compared to the other shear zones. Since the present study has given evidence for the presence of steep anomalous conducting zones near MBSZ and SASZ from shallow to deep crustal depths as compared to PCSZ, concentration of minerals or seismic activity in the form of reactivation of block movements, etc. can be expected. Interestingly, more seismic activity is reported (Ramalingeswara Rao, 1992) nearer to MBSZ and SASZ as compared to PCSZ.

CONCLUSIONS

Magnetotelluric studies along Kuppam-Palani geotransect have clearly established a block structure with clinching evidence of contrasting electrical resistivity character. These blocks are bounded by MBSZ separating the Archaean Dharwar craton in the north from the granulitic terrain towards south. Another block structure is also observed within the granulite terrain separated by PCSZ as a major block boundary. The shear zones are strikingly marked by highly conductive zones with a steep structure to deep crustal depths. Among the shear zones, MBSZ and SASZ have exhibited anomalously high conductivity. The present study has shown good correlation with low velocity layer at middle to lower crustal depths and also with broad gravity high near PCSZ.

ACKNOWLEDGEMENTS

The Department of Science and Technology, Government of India supported this work under the Deep Continental Studies (DCS) programme. We particularly thank Dr K.R. Gupta, Director, Earth Sciences Division for his support during the execution of the project. We would like to thank the Director, NGRI for all his encouragement and permission to publish this work. Co-operation and help rendered by Drs. T. R. K. Chetty, Y. J. Bhaskara Rao, Vijaya

Rao, S. B. Singh and R. Srinivasan are gratefully acknowledged. Help given in finalizing the figures by Mrs. Aruna, Mr. Ravi Kumar and Mr. Prasanth is also acknowledged. Naganjaneyulu and Kareemunnisa Begum thank CSIR for providing Fellowship.

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