ABSTRACT

This thesis contains the results of magnetotelluric field studies carried out around three base camps at Goilkera, Kamakhyanagar and Bhuban in the northern and southern margins of the Singhbhum Archaean craton of Eastern India. Goilkera is situated on the north western end of the Singhbhum Shear Zone which demarcates the boundary between the Proterozoic north Singhbhum fold belt and the Archaean Singhbhum granites and Iron ore group of rocks. Kamakhyanagar and Bhuban are situated right over the Sukinda Thrust or Collision Zone. Geologists use both the terms for this contact of the Proterozoic high grade granulite terrains of Eastern Ghats and low grade Archaean granites/granitoids and Iron ore group of rocks.

For this thesis, the author has directed his efforts along three major directions and tried to present his results in those directions only. Three major directions chosen are as follows:

(i) An attempt was made to examine the behaviours of eighteen (18) rotation invariant magnetotelluric parameters (RIP) using the field data and has chosen some of the rotation invariant parameters for data analysis and interpretation.

(ii) Second direction came from the multiplicity of the magnetotelluric parameters. Magnetotellurics has more than 30 parameters. Often it is argued that one needs the basic magnetotelluric parameters i.e., the apparent resistivities and their phases for both in TE and TM mode and rest of the parameters are not needed in routine interpretation. It is shown that, the most of the parameters have major or minor role to play in qualitative and quantitative interpretation. It will, therefore, be better if all the parameters are used to understand the crust mantle processes. Multipronged attack should reduce the level of non-uniqueness.

(iii) The third direction was an attempt to prove that, phase is a more important parameter than apparent resistivity. Both phase and apparent resistivity are needed for quantitative interpretation to generate models but phase is a much more important parameter for qualitative interpretation because it is a static shift free parameter. That gives it an edge over the apparent resistivity in qualitative and semiquantitative interpretation.

Many parameters in magnetotellurics are static shift free. All the phases viz. ϕ_{TE} : phase of transverse electric apparent resistivity, ϕ_{TM} : phase of the transverse magnetic apparent resistivity, $\phi_{average}$ or ϕ_B : phase of the rotation invariant parameter $Z_{average}$, $\phi_{determinant}$ or ϕ_{det} or ϕ_D : phase of the $Z_{determinant}$, $\phi_{central}$ or ϕ_C : phase of the $Z_{central}$, ϕ_{Ingham} : phase of the ρ_{Ingham}, $\phi_{\lambda+}$ and $\phi_{\lambda-}$: phases of the $\rho_{\lambda+}$ and $\rho_{\lambda-}$ are static shift free parameters.

All magnetotelluric parameters generated out of the magnetic transfer functions viz. tipper, tipper ellipticity, tipper phase and tipper skew are static shift free. All magnetic fields viz. H_X, H_Y and H_Z are static shift free. 'Twist' and 'shear' angles are also static shift free parameters. An attempt has been made to use these parameters for qualitative interpretation. A combined use of pseudosections and surface plots of the parameters towards qualitative interpretation is projected.

The positive aspects of this kind of interpretation are highlighted. Two-dimensional (2-D) interpretation of magnetotelluric data using Cagniard impedances and the rotation invariant apparent resistivities and their phases are presented. Eight dimensionality indicators viz. Swift skew (K), Bahr skew (η), impedance ellipticity (β_{00}), ratio of Bahr skew to the Swift skew (ξ), P_1, P_2, regional dimensionality indicator (μ) and ρ_{diag} are tested using the field data collected near Kamakhyanagar and Bhuban area.

A brief outline of the subject magnetotellurics, with some historical background, detailed developments of the subject, the scope of work and the statement of the problems are given in Chapter-1. The geology of the study area with some details are given in Chapter-2. Contributions by the author in this Ph.D. thesis are included in Chapter-3 to Chapter-7 and concluding remarks are given in Chapter-8.

Chapter-3 deals with the rotation invariant magnetotelluric impedance tensors. The properties of eighteen (18) rotation invariant tensors are tested using the field data collected near Arjunpur and Nuwagaon in the Goilkera area and Baruan (Profile-2) in the Bhuban area.

Our observations can be summarised as follows: (Please see Chapter-3 for details).

(1) Rotation invariant impedances and their phases show perfect rotation invariance properties irrespective of the data quality.

(2) $$\rho_D = \sqrt{(\rho_{\lambda+} . \rho_{\lambda-})}$$

Where $\rho_{\lambda+}$ and $\rho_{\lambda-}$ are the apparent resistivities computed from the eigen values λ_+ and λ_- of the impedance tensor Z.

(3) $$\phi_D = (\phi_{\lambda+} + \phi_{\lambda-})/2$$

Where $\phi_{\lambda+}$ and $\phi_{\lambda-}$ are the phases of $\rho_{\lambda+}$ and $\rho_{\lambda-}$ respectively.

(4) $$\rho_D = \sqrt{(\rho_{\sigma1}^2 . \rho_{\sigma2}^2)}$$

Where $\rho_{\sigma1}^2$ and $\rho_{\sigma2}^2$ are the apparent resistivities computed from the eigen values of the non-negative definite Hermitian operator $Z^!Z$. Where ! denotes Hermitian conjugation.

(5) $$\rho_{\sigma1}^2 > \rho_{\lambda+} \text{ and } \rho_{\sigma2}^2 < \rho_{\lambda-}$$

(6) $$\rho_{central}\ (\rho_C) = \rho_{average}\ (\rho_B) + \rho_{diagonal}\ (\rho_{diag})$$

Where $\rho_{central}$ and $\rho_{average}$ are both rotation invariant apparent resistivities. $\rho_{diagonal}$ is the residual resistivity originates from the diagonal elements of the impedance tensor Z_{XX} and Z_{YY} near the three-dimensional (3-D) structures.

(7) (ρ_D,ϕ_D), (ρ_C,ϕ_C) are the two important rotation invariant pairs which were used for interpretation of MT data, where the structure is three-dimensional (3-D). Although $\rho_D \neq \rho_C$ and $\phi_D \neq \phi_C$. The differences may be as high as 30%. They are better parameters than Cagniard TE and TM mode impedances and their phases. The information content in the rotation invariant parameters (RIPs) are more than those in Cagniard impedances. RIPs have the contribution from the non-zero diagonal elements of the impedance tensor Z.

(8) For nearly 2-D structures, (ρ_B,ϕ_B) can be used because the diagonal elements are nearly zero.

(9) $\rho_{Frobenius}$, $\rho_{\sigma1}^2$, $\rho_{\lambda+}$ and $\rho_{\lambda-}$, $\rho_{\sigma2}^2$ respectively give the upwardly and downwardly biased values of the apparent resistivities. It is observed that

$\rho_{Frobenius} > \rho_{\sigma1}^2 > \rho_{\lambda+} > \rho_D, \rho_C, \rho_B, \rho_{TE}$ (rotated), ρ_{TM} (rotated) $> \rho_{\lambda-} > \rho_{\sigma2}^2$

(10) Rotation invariant apparent resistivities and their phases bring better stability in the apparent resistivity and phase plots with lower error bars so that one can use longer period apparent resistivities and phases for interpretation.

Chapter-4 is written on the basis of the data collected near Goilkera at the western end of the Singhbhum Shear Zone and the north western end of the Singhbhum craton. Both apparent resistivity and phase pseudosections and the 2-D models are obtained for the parameters (ρ_{TE},ϕ_{TE}), (ρ_{TM},ϕ_{TM}), (ρ_{TE+TM},ϕ_{TE+TM}), (ρ_B,ϕ_B), (ρ_C,ϕ_C) and (ρ_D,ϕ_D). Where these apparent resistivity and phase pairs are for Cagniard TE and TM mode apparent resistivities and their phases. Both TE and TM mode data are taken together for joint inversion in (ρ_{TE+TM},ϕ_{TE+TM}) mode. (ρ_B,ϕ_B), (ρ_C,ϕ_C) and (ρ_D,ϕ_D) are the rotation invariant pairs (Please see Chapter-3 for details). MT data along Kuira - Khuntpai profile indicate the presence of two major breaks in the geological formation. They may be the signatures of the Singhbhum Shear Zone.

Chapter-5 deals with the magnetotelluric data collected across the Sukinda Collision Zone near Kamakhyanagar.

Static shift free parameters ϕ_D, ϕ_C, ϕ_B, ϕ_{ex}, ϕ_{ey}, tipper, tipper phase, tipper ellipticity, tipper skew, H_X/H_Z, H_Y/H_Z, twist and shear angles are used to draw the pseudosections across the Sukinda Collision Zone, along the Kankadahad - Tumasingha profile. Pseudosections are plotted with log time period of the MT signal as the ordinate and the station no. (or sites location) as the abscissa ; the parameter values are reflected in the contours. Profile length was about 36 km and distances between the observation points varied from 3 to 6 km.

Surface plots for ρ_{TE}, ϕ_{TE}, ρ_{TM}, ϕ_{TM}, ρ_B, ϕ_B, ρ_C, ϕ_C, ρ_D, ϕ_D, tipper, tipper ellipticity, tipper phase, tipper skew, H_X/H_Z, H_Y/H_Z, twist and shear angles are presented. Both apparent resistivity and phase surface plots show the location of the fault planes. Signatures from the phases, specially the rotation invariant phases are more convincing.

The important inferences drawn from these pseudosections are as follows:

(1) All the parameters have shown the horizontal boundary at the log time period of 3.19 sec ($\approx$ 1549 sec) of the MT signals. The apparent skin depth of the MT signals in this area and for this period range is around 200 to 300 km. Therefore MT is expected to be a very powerful tool for delineation of the lithosphere - asthenosphere (LA) boundary.

(2) The second important signal is the signatures of a series of vertical faults in the collision zone and to the north of collision zone. Several vertical faults exist and they are exposed on the surface, verified by the geologists.The interesting points are, so many genetically different parameters have given the same signatures of the faults. These parameters are ϕ_D, ϕ_C, ϕ_B, ϕ_{ex}, ϕ_{ey}, tipper, tipper skew, H_X/H_Z and H_Y/H_Z. The signatures are extended upto the MT signals at the log time period of 1.08 sec ($\approx$

12.02 sec) to 1.22 sec ($\approx$ 16.59 sec). The apparent skin depth is about 12 to 15 km. The signals reflect the approximate depth extent of these faults. The tentative interpretation is, the depth extent of these faults is the depth extent of the upper crust.

(3) The third and fourth important MT signals came from the log time period of 2.35 sec ($\approx$ 223 sec) and 2.77 sec ($\approx$ 588 sec). The horizontal boundary at these depths came respectively from 30 to 40, and 60 to 70 km. Seven parameters viz. ϕ_C, ϕ_B, ϕ_{ey}, tipper, tipper skew, tipper phase and tipper ellipticity have responded to the anomaly at 223 sec and four parameters viz. ϕ_D, ϕ_{ex}, ϕ_{ey} and tipper ellipticity responded for the horizontal boundary at 588 sec. Most of the parameters have contributed towards partial understanding of the subsurface structures.

Surface plot is a powerful tool for qualitative interpretation. Surface plots for ρ_{XY}, ϕ_{XY}, ρ_{YX}, ϕ_{YX}, ρ_D, ϕ_D, ρ_C, ϕ_C, ρ_B, $\boldsymbol{\phi_B}$, ρ_{Ingham}, ϕ_{Ingham}, $\rho_{Frobenius}$, $\rho_{\sigma 1}^2$, $\rho_{\sigma 2}^2$, tipper, tipper phase, tipper skew, tipper ellipticity, H_X/H_Z, H_Y/H_Z, shear and twist angle have indicated the zone of faulting. These plots are useful for studying the tectonic and geodynamic set up of the crust and mantle.

The important inferences are as follows:

(1) All the surface plots of apparent resistivities and their phases have clearly shown the Sukinda Collision Zone.

(2) Phase is a more powerful parameter than apparent resistivity in detecting the contact zone.

(3) Behaviours of 'twist' and 'shear' angle surface plots are similar to those of phases and the behaviours of H_X/H_Z and H_Y/H_Z are similar to those of apparent resistivities.

(4) Surface plots show that there is a distinct change in geological set up between the upper and lower crust. This feature is reflected in the fourteen parameters.

Geoelectrical models are presented for the Kankadahad - Tumasingha profile using Smith and Booker (1991), Rapid Relaxation Inversion (RRI) algorithm for 2-D inversion of the following apparent resistivity and phase pairs viz. (ρ_{TE},ϕ_{TE}), (ρ_{TM},ϕ_{TM}), (ρ_{TE+TM},ϕ_{TE+TM}), (ρ_B,ϕ_B), (ρ_C,ϕ_C), (ρ_D,ϕ_D).

The important observations are as follows:

(1) The average thickness of electrical lithosphere is around 136 ± 8 km. TE mode and rotation invariant pairs gave more consistent results.

(2) The major geological contacts between the Archaeans and the Proterozoics are reflected in these models and the predicted pseudosections.

Chapter-6 includes the magnetotelluric data and their qualitative and quantitative interpretation of Bhuban area across the Sukinda Thrust. The data are analysed in the same format as it is presented in Chapter-5. The prime intention was to check whether the signature of the crust and mantle obtained in the Kamakhyanagar area are also repeated here. The data quality in this area is, in general good. Therefore it was possible to take the observation for entire period range from 4 Hz to 4096 sec. The depth of penetration was more than 200 km. The results are presented along three profiles. The MT sites Baragaji (1), Barnali (2), Kawari (3), Dayanbili (4), Surapratappur (5) in profile-1, sites Baragaji (1), Barnali (2), Damsol colony (6), Baruan (7), Ramakrushnapur (8), Bhushal (9), Barijanga (10) in profile-2 and sites Nuadihi (11), Mulukhamba (12), Baunshakhana (13), Kumarda (14), Garhgahunpur (15), Barijanga (10) in profile-3 are included respectively.

2-D inversion models for profile-1, 2 and 3 are presented using the above mentioned six pairs of apparent resistivities and their phases. The average thickness of the electrical lithosphere is found to be 132 ± 16 km. Both the models and the pseudosections show the major contacts of the Archaeans and the Proterozoics.

The important inferences are as follows :

(1) The average thickness of electrical lithosphere is around 132 ± 16 km.

(2) Ten parameters viz. twist angle, shear angle, tipper ellipticity, tipper skew, tipper phase, tipper, ϕ_D, ϕ_C, ϕ_B , ϕ_{XY} have shown the signatures of the horizontal boundary at the log time period of 2.35 sec in pseudosections of profile-1 i.e., the Baragaji - Surapratappur profile.

(3) Twist angle, shear angle, tipper ellipticity, tipper skew, tipper phase, ϕ_C, ϕ_B pseudosections show the signatures of a horizontal discontinuity at the log time period of 2.77 sec. Therefore these signals deserve further attention for detailed studies.

(4) The signature of the faults extend upto the log time period of 0.88 sec. The approximate depth of investigation of these signals will be around 6 to 8 km.

(5) Phase surface plots show that this area is less tectonically disturbed than that near Kamakhyanagar.

(6) Phase pseudosections and surface plots are used to locate the position of the fault planes.

Chapter-7 deals with the dimensionality analysis of the magnetotelluric observations in the study area near Kamakhyanagar and Bhuban. The parameters used for this study were (i) Swift skew (K) (ii) Bahr's skew (η) (iii) impedance ellipticity (β_{00}) (iv) P_1 (v) P_2 (vi) ξ (vii) $\rho_{diagonal}$ or ρ_{diag} and μ.

The important observations can be summarised as follows:

2-D/3-D behaviour of the Archaean and the Proterozoic terrain is a continuously variable parameter. Near the faults or thrusts, the parameters K, η and P_2 show the low values where as β_{00} and ξ show the high values. Therefore these parameters can also be used for location of the faults. Impedance ellipticity (β_{00}) is a sharp parameter and may be useful for studying the tectonic set up of a terrain. ξ is also sensitive. μ is a relatively less sensitive parameter. $\rho_{diagonal}$ or ρ_{diag} used in this thesis may appear to be a better dimensionality indicator than P_2 and K.