



## Simulation of Magnetotelluric Response Across the Godavari Graben, Andhra Pradesh, India: A 2-Dimensional Numerical Study

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### Keywords

Magnetotelluric, Godavari graben, Apparent Resistivity, Structure, Forward Modelling, Sediments.

### Summary

The Godavari graben is one of the important geotectonic structures located between the Dharwar and Baster cratons, India. A seismic refraction/wide angle reflection study of 100 km length was carried out across this sedimentary basin. In the present study, we have selected 11 MT stations along the Kallur to Polavaram (E-W) deep seismic profile. The Magnetotelluric model of the sedimentary depth section of this profile is prepared using the resistivity values of sediments and crystalline basement. Forward modelling reveals that the apparent resistivity along the strike ( $\rho_{xy}$ ), apparent resistivity across the strike ( $\rho_{yx}$ ) and phase ( $\Phi_{xy}$ ,  $\Phi_{yx}$ ) components overlap and represent one dimensional structure below initial 10km and 80-100km distance of the profile. There is no change in resistivity in horizontal direction in this area. Further at 10-20 km and 60-80 km distance, the  $\rho_{xy}$  curve is located below the  $\rho_{yx}$  curve. These stations are located outside of the graben, but close to the fault. Contrarily, the  $\rho_{xy}$  and  $\rho_{yx}$  curves from the stations located within the graben, i.e. from 20-60km, are split and  $\rho_{xy}$  curve is located above the  $\rho_{yx}$  curve. The split between  $\rho_{xy}$  and  $\rho_{yx}$  indicates 2-D or 3-D structures. The phase angle of  $<45^\circ$  is between 20-60 km because of increases of resistivity with depth. The phase angle is  $45^\circ$  in remaining area, because of constant resistivity. From these observations, we interpret that shoulders of the graben can be traced by using nature of the sounding curves. The present method utilizes approximate resistivity values for the sediments in a virgin area.

### 1. Introduction

The Oil and Natural Gas Commission (ONGC) has carried several seismic studies in the Godavari

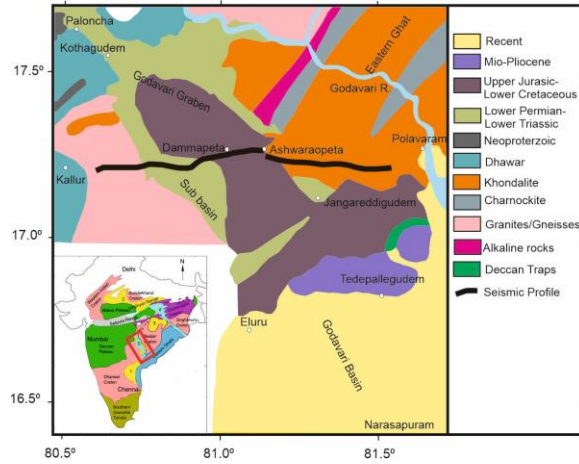
(coastal) basin, southern India, in connection with exploration of hydrocarbons. The CSIR-National Geophysical Research Institute (NGRI) has carried out a deep seismic sounding investigation along Kallur to Polavaram profile of the Godavari graben (Figure1). The NW-SE trending Godavari graben is nearly 400 km long and 50 km wide, prominent linear geological province within a complex framework of the Archean basement. The Godavari graben located between the Dharwar craton in the southwest and the Baster craton in the northeast. The magnetotelluric response has been prepared for the model constrain seismic depth section in the area with relevant resistivity values by using WingLink software.

### 2. Geology and Tectonics:

The graben is a large intra-cratonic Gondwana basin trending NW-SE, located in the eastern part of Peninsular India. The thickness of the sediment in the basin is 3000 m deposited from the Late Carboniferous/Early Permian to the Cretaceous (Biswas, 2003). The Gondwana sedimentation seems to have occurred on block-faulted Proterozoic basins that evolved due to repeated sagging along SW and NE faults. The entire sediments of the graben, overlying the Archean basement can be divided into two groups viz., (i) Purana Group (Proterozoic) and (ii) Gondwana Super-group (upper Carboniferous to upper Cretaceous). The generalised stratigraphy of the graben, modified after Raiverman (1985). The Archean basement complex comprises both Dharwarian and Eastern Ghat suites of rocks. They are mostly in faulted contact with the younger sediments along the graben margins. The Purana group rocks confined to this graben are represented by (a) Pakhal Formation and (b) Sullavai Formation. Both the lower and upper contacts of this group and

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also the contacts of the two formations within the group are unconformable. The Gondwana Super-group has been subdivided into four groups, viz., (i) Singareni, (ii) Kamthi, (iii) Sironcha and (iv) Peddavagu (Figure 1).



**Figure 1:** Geology map of the Godavari graben. Deep Seismic sounding (DSS) profile from Kollur to Polavaram is marked over it in black line.

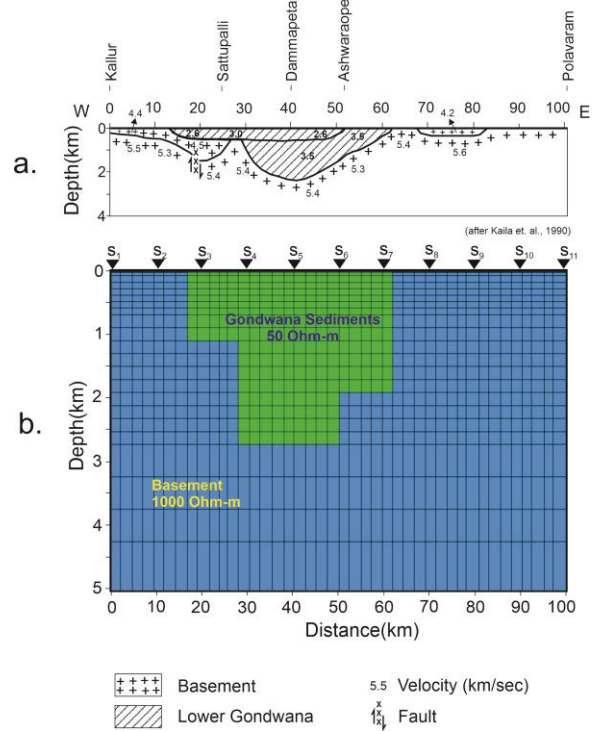
### 3. Present Study:

#### 3.1 Methodology:

The Magnetotelluric (MT) method uses the natural electromagnetic field variation to image subsurface resistivity structure, and usually involves measuring two horizontal electric field components ( $E_x$  and  $E_y$ ) and three magnetic field components ( $B_x$ ,  $B_y$ ,  $B_z$ ) at the Earth's surface, where the subscript x and y indicate the N-S and E-W directions respectively. This method is preferred due to the great depth of penetration over the seismic and provides information on resistivity. The shallow seismic depth section derived from DSS data along the Kallur – Polavaram 100 km long profile (Figure 2a) has been utilized to prepare the electrical resistivity model. The 11 MT stations ( $S_1$  to  $S_{11}$ ) are used with a station interval of 10 km to compute the Magnetotelluric response. The Gondwana sediments with resistivity of  $50 \Omega\text{-m}$  and crystalline basement with resistivity of  $1000 \Omega\text{-m}$  (Based on resistivity values given by Naskar and Saha, 2015) have been considered in the numerical model. The Gondwana sediments are

located at Sattupalli, Dammapeta and Ashwaraopet at 20-70 km in this profile.

The 2-D resistivity model has been prepared from the resistivity values of the above profile, by using forward option in the WinGlink software (WinGlink, 2004). In this process, we have computed a model with the X-axis corresponds to distance in kilometers and Y-axis represents depth in meters. The entire resistivity section has been divided into 56 columns and 31 rows with a minimum cell width of 2.04 km and minimum column thickness of 49.75m. The blue colour in the model indicates basement with resistivity of ( $1000 \Omega\text{-m}$ ) and green colour indicates Gondwana sediments with  $50 \Omega\text{-m}$  resistivity. The final resistivity section derived for the above said DSS profile is shown in Figure 2b.

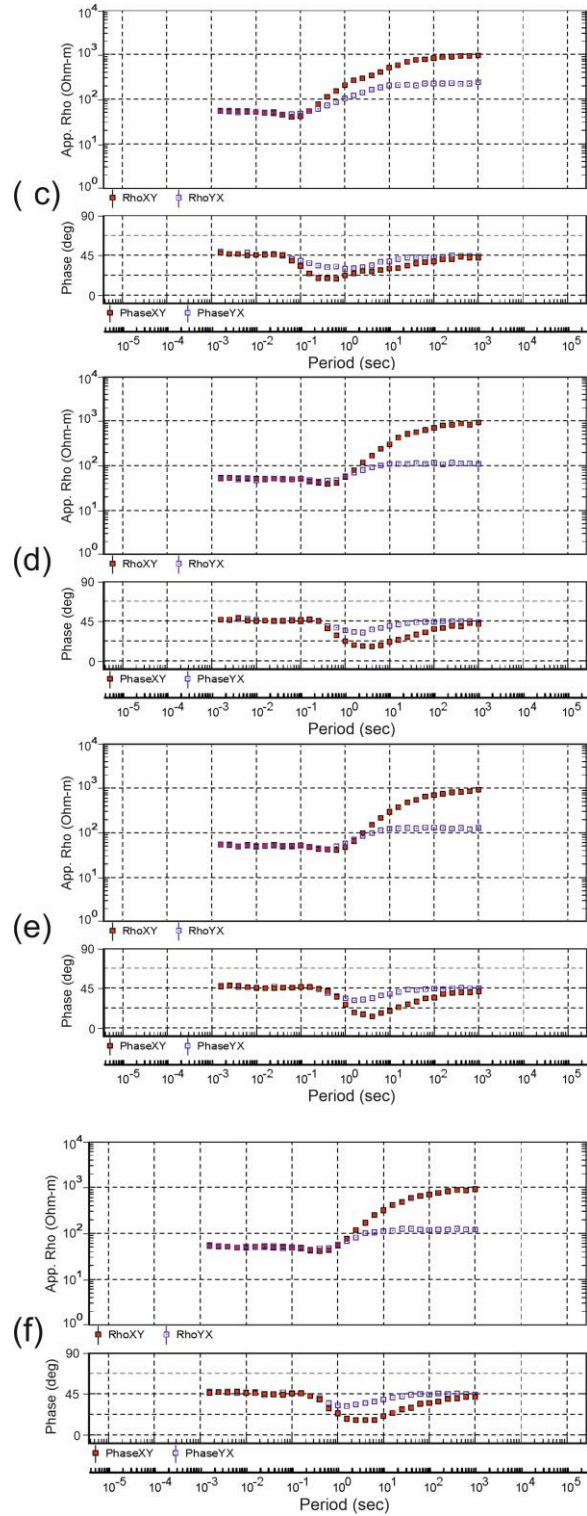
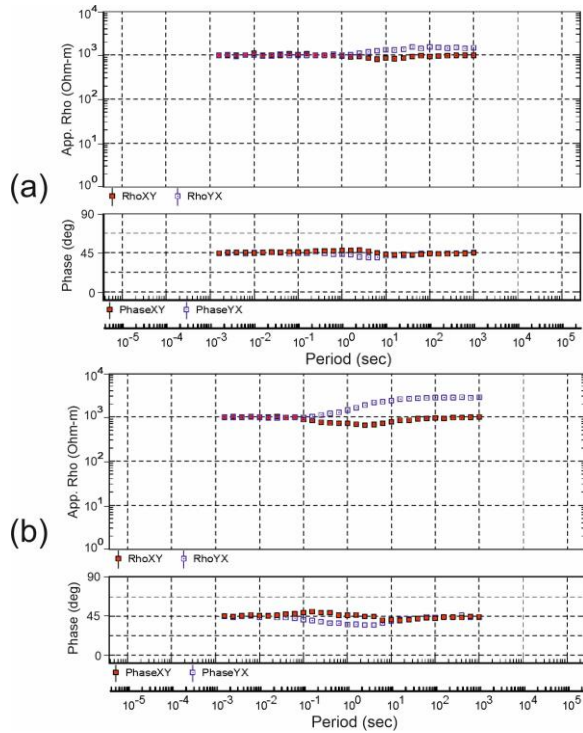


**Figure 2:** a. Basement configuration along the Kollur – Polavaram DSS profile (modified from Kaila et. al., 1990). b. Resistivity section derived from DSS results.

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#### 3.2 Numerical simulation of 2-D Magnetotelluric response:

MT response (Apparent resistivity and Phase) has been computed at 11 locations for both  $\rho_{xy}$  and  $\rho_{yx}$  covering 6 decades period (i.e. from  $10^{-3}$  to  $10^3$  sec). The numerically computed MT responses at 11 locations cutting across the Godavari graben are shown below the Figure 3. The X-axis is time period (sec) and Y-axis is apparent resistivity ( $\Omega$ -m) and phase (degree). The red color curve indicates  $\rho_{xy}$  and the blue color curve indicates  $\rho_{yx}$ . The  $\rho_{xy}$  and  $\rho_{yx}$  curves overlapping each other indicate 1-D structure (i.e. no change in physical properties in horizontal direction) and the split between  $\rho_{xy}$  and  $\rho_{yx}$  indicates 2-D or 3-D structures.



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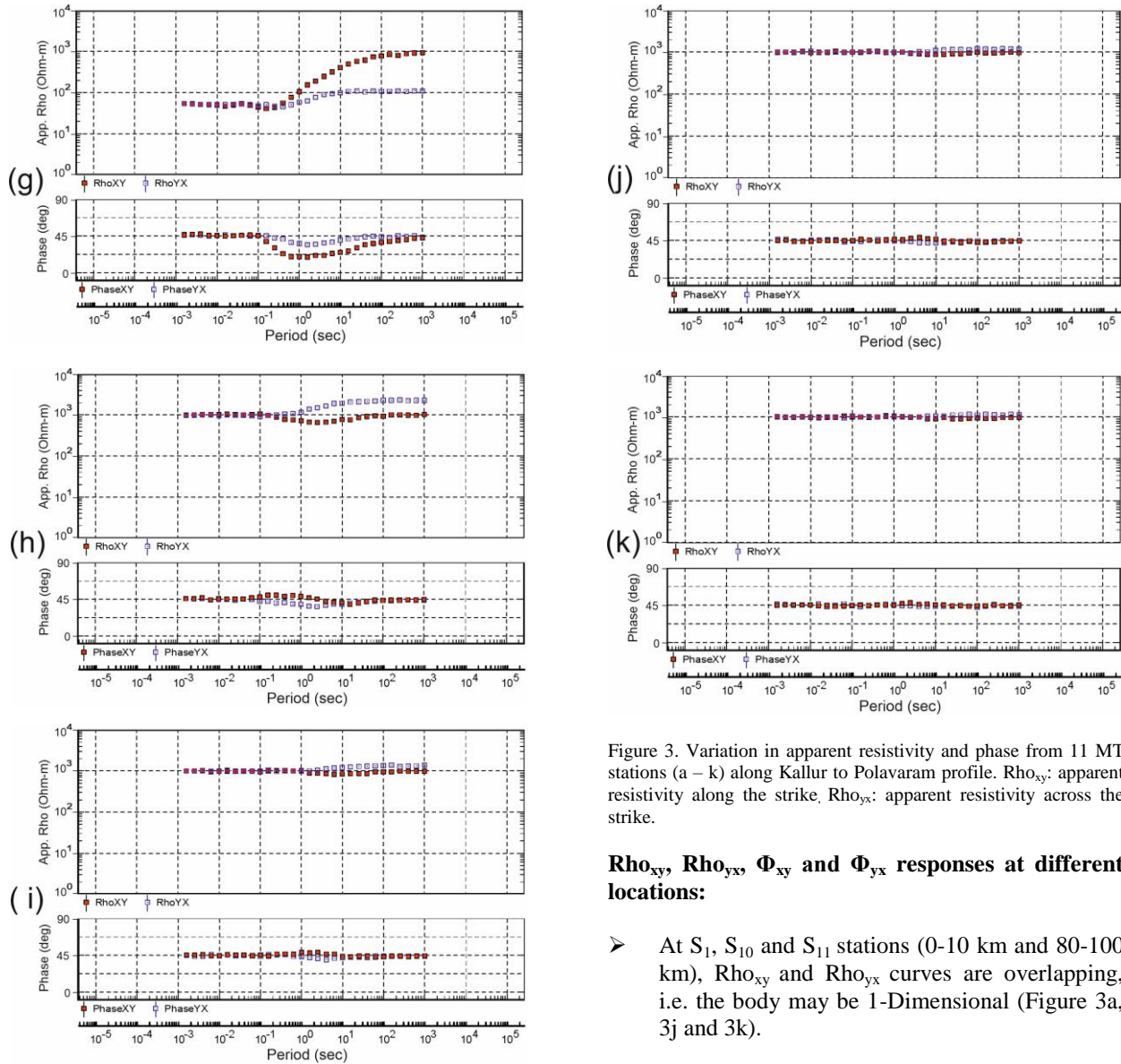


Figure 3. Variation in apparent resistivity and phase from 11 MT stations (a – k) along Kallur to Polavaram profile.  $Rho_{xy}$ : apparent resistivity along the strike,  $Rho_{yx}$ : apparent resistivity across the strike.

**$Rho_{xy}$ ,  $Rho_{yx}$ ,  $\Phi_{xy}$  and  $\Phi_{yx}$  responses at different locations:**

- At  $S_1$ ,  $S_{10}$  and  $S_{11}$  stations (0-10 km and 80-100 km),  $Rho_{xy}$  and  $Rho_{yx}$  curves are overlapping, i.e. the body may be 1-Dimensional (Figure 3a, 3j and 3k).
- At  $S_2$ ,  $S_8$  and  $S_9$  stations (10-20 km and 60-80 km),  $Rho_{xy}$  and  $Rho_{yx}$  curves are split into  $Rho_{yx}$  curve is located above the  $Rho_{xy}$  curve, i.e. the site is outside the graben, but close to the fault (Figure 3b, 3h and 3i).
- At  $S_3$ ,  $S_4$ ,  $S_5$ ,  $S_6$  and  $S_7$  stations (20-60km),  $Rho_{xy}$  and  $Rho_{yx}$  curves are split into  $Rho_{xy}$  curve is located above the  $Rho_{yx}$  curve, i.e. the site is within the graben but close to the fault (Figure 3c, 3d, 3e, 3f and 3g).

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### 3.3 Apparent resistivity and Phase pseudo sections:

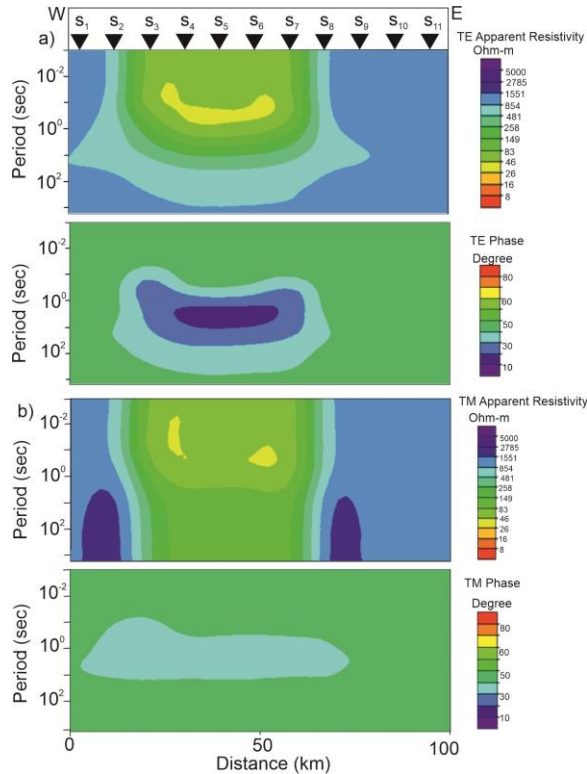


Figure 4: Pseudo sections of the modelled MT data along Kallur - Polavaram profile a) TE apparent resistivity and Phase pseudo section b) TM apparent resistivity and Phase pseudo section.

The TE (Transverse electric) mode apparent resistivity pseudo section is more clearly reflects 2-D resistivity structure, but the TM (Transverse magnetic) mode apparent resistivity pseudo section shows a low-resistive zone extending to deeper levels in the middle of the section. The sediments mostly composed nonmagnetic, so TM mode has poor resolution compared to TE mode (Figure 4).

### 4. Discussions and Conclusions:

In this study crustal seismic section derived from the deep seismic study by Kaila et al. (1990) has been transformed into the resistivity section to simulate Magnetotelluric response at different locations across the Godavari graben. The resistivity and phase components in the initial distance and in end of the profile, where the stations are away from the graben,

almost overlaps and represents 1D structure below these stations. When the stations are located on the western and eastern side of the near the graben, the value of  $Rho_{yx}$  is more as compared to  $Rho_{xy}$ . The moment the stations are located in the graben, the value of  $Rho_{yx}$  becomes less as compared to  $Rho_{xy}$ . After crossing the graben again the value of  $Rho_{yx}$  is increased as compared to  $Rho_{xy}$ . The higher-frequency data correspond to shallower structure, where the lower frequency data correspond to deeper resistivity structure. The phase angle of  $<45^\circ$  is between 20-60 km because of increases of resistivity with depth. The phase angle is  $45^\circ$  in remaining area, because of constant resistivity. The TE mode apparent resistivity pseudo section is more clearly reflects 2-D resistivity structure, but the TM mode apparent resistivity pseudo section shows a low-resistive zone extending to deeper levels in the middle of section. The sediments mostly composed nonmagnetic, so TE mode is more resolution compared to TM mode. From these observations, we interpret that shoulders of the graben can be traced by using nature of the sounding curves. The present method utilizes approximate resistivity values for the sediments in a virgin area.

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