

Exploring Subsurface Structures through MT Analysis in the Eastern Ghat Mobile Belt, India

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SUMMARY

Shear zones are one of the prominent features that exist in the EGMB region. These shear zones help us to understand the geological complexity and structural dynamics of the Earth's subsurface. This study aims to trace shear zones in the EGMB region to better understand the subsurface characteristics. A Magnetotellurics (MT) survey, which maps subsurface structures by monitoring fluctuations in the Earth's natural electromagnetic fields, was employed. A ~127 km profile, oriented roughly north-south, was traced on the southern side of the EGMB region, where numerous narrow shear zones exist. MT data were collected at selected locations along this profile and processed to enhance the signal-to-noise ratio. A 2D inversion was then performed to visualize the subsurface resistivity distribution. The resulting 2D resistivity model revealed a resistive zone at shallower levels, while the corresponding shear zones appeared as conductive anomalies at deeper depths.

Keywords: Eastern Ghat Mobile Belt, Shear Zone, 2D inversion, Magnetotellurics

INTRODUCTION

The Eastern Ghat Mobile Belt (EGMB) constitutes a complex orogenic belt characterized by a variety of domains and zones, each delineated by distinct tectonic boundaries and marked by unique geological histories (Nanda, 2008). The EGMB underwent intense metamorphism under gradually increasing temperature and pressure, transforming existing rocks and forming various geological structures, including lineaments, faults, and shear zones. Within the EGMB, there exists a mosaic of ductile shear zones, as elucidated by Chetty (2001). These shear zones serve as crucial indicators for delving into the geological processes and evolutionary trajectory of the Earth's subsurface. They play pivotal roles in phenomena such as migmatization, volcanic activity, mineralization, and retrogression (Chetty, 2014).

To gain insights into the subsurface dynamics, on either side of these shear zones, Magnetotelluric (MT) surveys were conducted across the EGMB region. The MT method, renowned for its non-invasive approach, harnesses naturally occurring transient signals to unveil subsurface properties. A comprehensive survey spanning approximately 127 km and predominantly aligned in the N-S direction was conducted, encompassing 31 MT stations strategically positioned across shear zones. Subsequently, 2D inversions were carried out to

obtain the resistivity distributions at greater depths along the surveyed profile.

GEOLOGY OF THE AREA

The EGMB region contains several ductile shear zones along its boundary and in its central part (Chetty and Murthy, 1993; Chetty and Murthy, 1994; 1998). In the southern part of the EGMB region, near Berhampur, the shear zones generally trend NE-SW, nearly parallel to the EGMB's regional trend (Chetty, 2001). The Chilka-Lake Shear Zone (CLSZ), Digapahandi Shear Zone (DSZ), and Aska-Taptapani Shear Zone (ATSZ) are all narrow shear zones with a similar NE-SW trend (Figure 1). Besides these, other shear zones exist in the northern part of the study area are known as the Mahanadi Shear Zone (MSZ), Bhanjanagar Shear Zone (BSZ), and Angul-Dhenkanal Shear Zone (ADSZ) which have almost E-W trending. The shear zones in the northern part exhibit strike-slip movement (Chetty, 2001).

The MSZ is located in the north and represents the southern part of the EGMB (Chetty, 2014). It extends along the Mahanadi River channel, with a length of about 150 km, oriented WNW-ESE, and a width ranging from 2 to 8 km (Chetty, 2014). The shear zone forms a 50° angle from the north, though this angle varies gradually from 30° to 50° towards the eastern part and steeply towards the western part. The dominant rocks in the MSZ region are

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charnockites and khondalites, which are retrogressed, mylonitised, and migmatized (Chetty, 2014). The MSZ exhibits strike-slip movement, with a dip of approximately 50° to the north, and is characterized by dextral movement of blocks (Chetty, 2014). This strike-slip movement produces ultra-mylonites (Chetty, 2001).

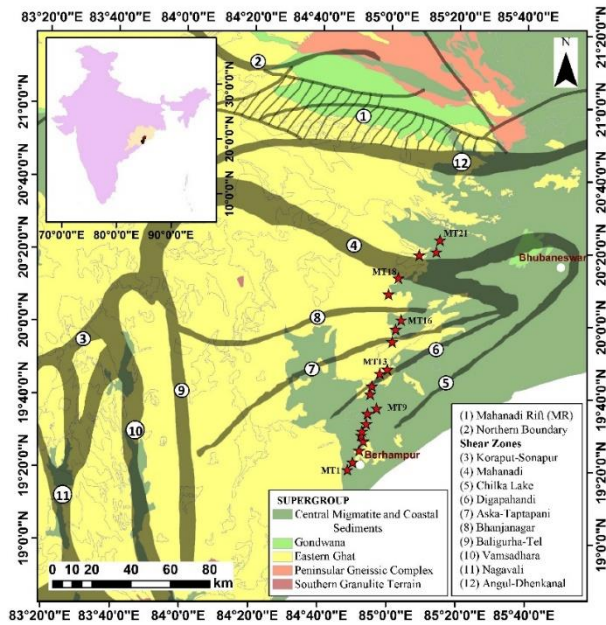


Figure 1: The map showing the geology of Odisha (<https://bhukosh.gsi.gov.in/Bhukosh/Public>), the nearby shear zones (Chetty, 2014), and the location of the MT sites (red star).

The DSZ is oriented NE-SW, running subparallel to the Chilka Lake Shear Zone. It extends eastward and merges with the MSZ. The dominant rocks along this shear zone are porphyritic megacrystic gneisses. Above the DSZ, the ATSZ follows the same NE-SW strike. As it extends eastward, it also joins the MSZ, similar to other shear zones in the region; however, on the west side, it terminates at the Baligurha-Tel Shear Zone. Another shear zone, the Bhanjanagar Shear Zone, exists above these two shear zones, striking nearly E-W and lying just beneath the MSZ and the Phulbani charnockite block.

FIELD MEASUREMENTS AND DATA PROCESSING

An ADU06 instrument (M/S Metronix GmbH, Germany) was used to record 31 MT soundings along a profile, oriented nearly N-S, that crosses all shear zones in the eastern part of the EGMB region (Figure 1). The survey began in the south near Berhampur and extended northward to the Mahanadi Shear Zone near Puranakatak. At each MT site, data were recorded for approximately 30-40 hours. Five channels (E_x , E_y , H_x , H_y , and H_z) were recorded within a frequency range of 10^{-2} to 10^4 Hz. The MT data were processed using MAPROS

software (M/S Metronix GmbH, Germany). Time series editing and windowing functions were applied to obtain the transfer functions, which were then used to calculate the apparent resistivity and phase data for each frequency point. Due to poor data quality, 10 MT stations were discarded, leaving 21 stations for further analysis and interpretation.

RESULTS AND DISCUSSION

After the pre-processing of the time-series MT data, an analysis is performed to determine the subsurface dimensionality using two parameters: the phase tensor and the skew angle. The phase tensor is graphically represented by an ellipse, with its major and minor axes indicating the principal axes. The major axis shows the preferred direction of induction current flow (Caldwell *et al.*, 2004). The skew angle helps assess whether the subsurface dimensionality is 1D, 2D, or 3D (Pranata *et al.*, 2017). According to Booker (2014), a fully circular phase tensor represents one-dimensionality, an ellipse with a smaller skew angle value indicates two-dimensionality and an ellipse with a larger skew angle value suggests three-dimensionality. In this study, the threshold value of the skew angle for a 2D structure is set between -5 and 5 . Figures 2(a) and 2(b) show phase tensors plotted at 0.1 s and 1 s, respectively, with ellipses displaying lower skew angle values, indicating that the shallower structures are 2D. However, at higher periods, the phase tensor ellipses have higher skew angle values beyond the predefined threshold, signifying the 3D nature of the subsurface (Figure 2(c)).

The subsequent phase of MT data analysis involves decomposing the MT impedance tensor. To address distortions in the datasets, the Groom-Bailey (1989) decomposition method has been applied. This method involves rotating the impedance tensor to align with the regional strike direction. By conducting tensor decomposition in this direction, regional impedances are derived, which are used in the modeling of subsurface resistivity variations.

Phase tensor decomposition, in contrast, does not presume any dimensionality and utilizes phase information from tensor elements. Consequently, phase tensor estimates remain unaffected by distortion effects linked to shallow subsurface irregularities. The phase tensor analysis was conducted using MTPy (Kirkby *et al.*, 2019; Krieger and Peacock, 2014), an open-source Python-based implementation. The analysis revealed that the impedance tensor (Z) has a strike of 40° , the phase tensor azimuth is 85° , and the tipper strike is 12.5° (Figure 3). The azimuth angle of the phase tensor (85°) was chosen as the rotation angle, as the phase tensor ellipses depicted in the dimensionality analysis (Figure 2) predominantly align close to 85° .

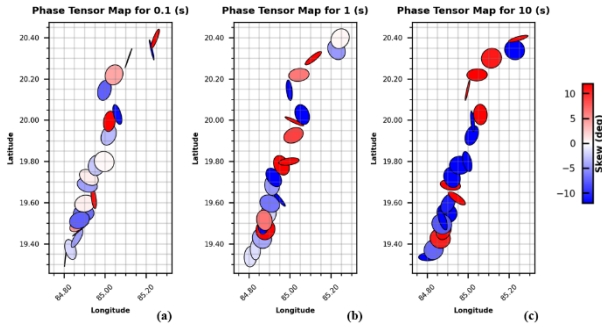


Figure 2: The phase tensor ellipses at 0.1 s, 1 s, and 10 s are filled with skew angles for all the MT sites.

The MT data inversion utilized the commercially available software GeotoolsTM, employing the non-linear conjugate gradient method (Rodi and Mackie, 2001). Generally, Tikhonov regularization is employed in the MT inversion method, and it is used in this algorithm as well. This non-linear conjugate gradient algorithm uses the regularization parameter to generate a smooth resistivity model and attempts to find the inverse solution within the given error limit. The impedance tensors were rotated by 85° as part of the processing steps.

The inversion process commenced with an initial resistivity model set at 100 Ωm. A joint inversion of both TE (transverse electric) and TM (transverse magnetic) modes of the MT data was conducted. During the inversion process, different sets of noise floors for apparent resistivity (10%, 15%, and 20%) and phase (5%, 7%, and 10%) were considered to attain a model consistent with the geological characteristics of the area.

The 2D inverted model presented here was prepared using the following parameters: a 15% error tolerance for apparent resistivity, 10% for phase, horizontal smoothing set at 5%, vertical smoothing at 1%, and an initial depth value (Z0) of 30 m, which adjusts smoothing with depth. This process was iterated up to 80 times to generate the final model with an RMS error of 17.07.

The 2D resistivity model obtained from the study area reveals two distinct features: a highly resistive zone characterized by resistivity values exceeding 250 Ωm, and a conductive zone with resistivity values less than 10 Ωm. The resistive zone is consistently observed near the surface across the entire profile, extending up to a maximum depth of 5-10 km (labeled as 'A'). This elevated resistivity is attributed to the presence of high-grade metamorphic rocks such as khondalite, migmatite, and charnockite. In contrast, the underlying conductive zones exhibit inclined structures with varying depths. Beneath sites MT-3 and MT-13, two conductive structures with opposite inclinations are

observed (labeled as 'B' and 'E' in Figure 4). At greater depths, particularly beneath sites MT-7 to MT-9, these conductive zones converge and form a syncline structure. Another notable conductive zone (marked as 'D' in Figure 4) starts below MT-15. This conductive zone widens significantly with the increasing depth from 1 km to 6 km, spanning from MT-14 to MT-17. Additionally, a conductive zone extending from 10 km to 17 km depth below MT-18 reaches up to station MT-21 (marked as 'C' in Figure 4). This conductive zone is observed towards the northern end of the profile, which might be an extension of the Mahanadi Shear Zone.

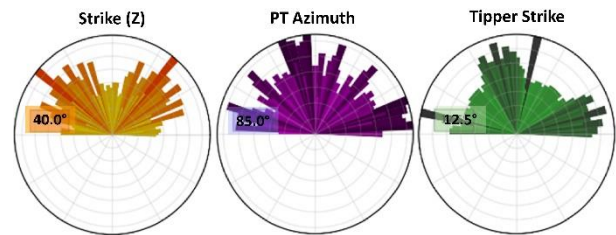


Figure 3: Rose diagrams obtained after the Phase Tensor analysis showing the Impedance Strike (Z), Phase Tensor Azimuth, and Tipper Strike for the MT data from all the sites at all time-period ranges.

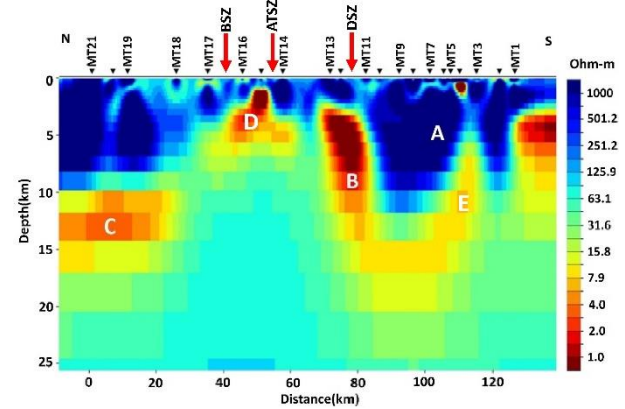


Figure 4: Regional geoelectrical model after the 2D joint inversion of TE and TM modes of MT data.

The study area map (Figure 1) indicates that MT sites 11 and 12 are positioned near the DSZ, while MT sites 14 and 15 are close to the ATSZ, and sites 16 and 17 are in the vicinity of the BSZ. The regional strike of all these shear zones is in the NE-SW direction. The inversion results reveal that the conductive regions imaged at these MT sites exhibit a similar inclination as the corresponding shear zones (DSZ, ATSZ, and BSZ) at those locations. Towards the southern end of the profile, the Chilka Lake Shear Zone is identified. Notably, the conductive zone marked as 'E' appears to extend from the Chilka Lake Shear Zone, exhibiting an inclination opposite to that of the aforementioned shear zones.

CONCLUSIONS

21 MT soundings were conducted on the southern side of the Mahanadi Shear Zone (MSZ) within the EGMB region. Analysis of the MT data has provided significant insights into subsurface structures and their dimensions. After rigorous pre-processing, dimensionality assessment was carried out using phase tensor and skew angle parameters. The findings indicated a transition from 2D to 3D characteristics with increasing depth, emphasizing the complexity of subsurface dynamics.

The 2D resistivity model was obtained after the joint inversion of TE and TM modes. The electrical resistivity model delineated two distinct features: a highly resistive zone near the surface attributed to high-grade metamorphic rocks and underlying conductive zones with varying inclinations and depths. Spatial correlation between these conductive regions and mapped shear zones, particularly near the Digapahandi, Aska-Taptapani, and Bhanjanagar Shear Zones, confirmed the reliability of the model. In particular, the Chilka Lake Shear Zone exhibited an extended section with contrasting inclinations. This observation significantly enhances our understanding of the regional geological complexities.

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