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Determination of Geoelectric Strike and 2D inversion of Magnetotelluric Data from Himalayan Region

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Summary

Broadband magnetotelluric (MT) soundings have been applied to determine the deep electrical conductivity structure across Garhwal Himalaya corridor along the Deoband-Gangotri profile passing through major Himalayan thrusts: Himalayan Frontal Thrust (HFT), Main Boundary Thrust (MBT) and Main Central Thrust (MCT). The average Geoelectric Strike estimated for the 15 station MT data of Deoband-Gangotri profile along NE-SW was N75°W, and after that 2D smooth inversion was carried out for 15 station MT data. Where the near surface conductive feature in foothills and Siwalik Himalaya is relating to the molassic sediments transported from Higher Himalayan region. The strong lateral discontinuities along the profile are associated with the various thrust zones. The conducting zone near MCT is a typical example of presence of mid crustal conductor. Along this profile the mid crustal conducting zone near MCT coincides with the intense microseismic activity zone (Khattri, 1992). Then we have correlated this model with the geoelectrical model of Roorkee-Gangotri profile of Himalaya Region (Tyagi et al, 2007) and also with geoelectrical model along the central Nepal – Himalaya profile (Lemonier et al., 1999).

Introduction

The tectonics and geology along the profile (Deoband-Gangotri) has given below-
Tectonics in the Himalayan foothills is a result of the active compressional forces since the collision between Indian and Eurasian plates and is best understood as a combination of thin skin tectonics and the basement level Faulting. Himalaya is a part of an arcuate orogenic belt extending over about 2500 km on the northern part of the Indian plate, resulting from a collision between the Indian and Eurasian plates. The tectonic setting of the Himalayan mountain belt can be described in terms of four prominent structural breaks (MFT, MBT, MCT, ITS) running along the entire length of the Himalayan strike. Siwaliks are the Late Tertiary foothills.

After the seismicity studies, most of the subsequent subduction seems to be occurring along central thrust (MCT) and MBT (Gansser, 1977). Many thrusts and fold belts have been developed in this region as a result of the post-collision compressional forces, which were subsequently covered by various sedimentary deposits brought down by the rivers and streams in this vast mountain chain.

The goal of this paper is to find out the electrical conductivity structure in Garhwal Himalaya corridor along the Deoband-Gangotri profile passing through major Himalayan thrusts: Himalayan Frontal Thrust (HFT), Main Boundary Thrust (MBT) and Main central thrust (MCT). The distance of the profile over the entire length of the Himalayan is 180km, and each the entire length of the Himalayan is 180km, and each approximately.

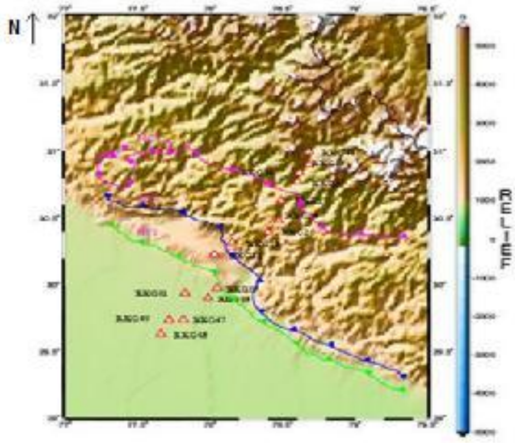

Figure 1 The Locations of MT Sites in Garhwal Himalaya and thrust boundary (HFT (green color), MBT (blue color), MCT (pink color) showing between the station.

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The data was acquired by a group (M. Israil) during the two field seasons, over the period from 27 Dec 2010 to 07 Jan 2011 and 07 May 2011 to 15 May 2011. In this period we have taken 5 station MT data (table 1).

Magnetotelluric data were recorded at 50 sites from Garhwal Himalaya corridor (Israil et al, 2008), only 15 sites were selected for calculating the geoelectric strike and for 2D inversion along a profile line drawn approximately perpendicular to the strike direction.

Field Survey and Data recording

Using magnetotelluric technique we have recorded the orthogonal component of the electric and magnetic field. We record 5-component (2-component of electric field and 3-component of magnetic field) with respect to time, and form the magnetotelluric time series in ATS format. Where the electric field Ex, Ey have been recorded in x-y direction and magnetic field Hx, Hy, Hz record in x- y-z direction. The measurement is usually made in wide range of frequency of different bandwidth and with different sampling intervals; Bands (HF, LF1, Free, LF2 and LF3) at different sampling rates (table 2).

The locations of the 15 stations are shown in figure 1. The profile extends from Deoband to Gangotri passing through major Himalayan thrust zones and is approximately perpendicular to the regional geological strike.

Geoelectric Strike estimation

Separation of local and regional effects is a critical question of magnetotellurics. The problem has been described by many authors (Bahr, 1988 and 1991), (Groom and Bailey, 1989), (Chave and Smith, 1994) and (McNeice and Jones, 2001).

Near-surface inhomogeneities can have significant effects on the MT impedance tensors and must therefore be recognized and corrected (Groom and Bahr, 1992). The distortion of the regional data is caused by charge accumulations on the electrical boundaries of surficial inhomogenieties. The Groom- Bailey (GB) decomposition (Groom and Bailey, 1989; Groom et al., 1993) is based on a physical model of distortion, and includes statistical tests for model validity.

Using the regional coordinate system with *x*- and *y*- axes along and across the strike of the regional structure,
The observed impedance tensor along the *x, y*-axes

$$\left[Z^S\right]=\left[R(\alpha_R)\right]^{-1}\left[T\right]\left[S\right]\left[Z^R\right]\left[R(\alpha_R)\right] \qquad (1)$$

Where α_R is the regional strike angle measured clockwise from the *x*-axis.

This matrix equation enables the determination of regional strike angle, α_R, along with apparent regional impedance, $\left[Z^R\right]$, and shear and twist parameters, *s* and t. The system is slightly overdetermined. It can be solved by a least squares fitting procedure with the $\frac{\pi}{2}$-ambiguity in the regional strike angle α_R. A detailed analysis has been done, to obtain consistent estimates of the geoelectric strike direction, using “strike” code, in single-site single frequency (SSSF), and single-site multi-frequency (SSMF) modes (McNeice and Jones 2001). In SSSF mode frequency dependent estimate of decomposition parameters is iteratively constrained to their respective stable values. The unconstrained decomposition at individual frequency revealed that the twist has stable value at most frequencies, so we have constraint twist first and step by step shear and strike were then constrained to their stable values. The estimated geoelectric strike angle is shown in figure 2 for a site rkg47 located in Indo-Gangetic Plain. The average rms error, after constraining all the parameters for the three MT data sites lehboli, rankhande and salhapur of IGP are 2.2, 1.2, 1.46 and the twist, shear and strike are (-3.83, -1.13, 4.20), (3.43, 2.17, 0.34), (N5˚E, N16˚E, N9˚E) respectively.

Next the “strike“ code was run in SSMF mode. The entire period (0.001 to 1000 s) is divided into 6 decades. Step by step program was run for 2-decade, 3-decade and whole decade. It has been observed that the strike is N32°E at low period and N15°E at high period. The rose diagram for whole decade shows that the geoelectric strike for all 15 sites is N15°E and along with the relative rms error for all

15 sites has been given in figure 3. The average estimated geoelectric strike for entire profile line is N75ºW. The geoelectric strike estimated by (Tyagi et al, 2007) for the entire profile was N70°W. There is no much difference in the two estimated strike direction.

Table 1 The GPS location, elevation and site details of the 5 sites, also given are the grounding resistance between the end points of the telluric lines measuring E_x and E_y .

Site No.	Village	MT Sites Code	Latitude	Longitude	Elevation (m)	Start date and time	Stop date and time	Resistance (Ω)	
								E_x	E_y
49	Salhapur	RKG49	29:44:21.73	77:43:03.68	213	29.12.10 & 3:13 pm	2.01.11& 9:10 am	653	593
50	Kulshat	RKG50	29:39:28.63	77:38:7.72	206	02.01.11 & 5.25pm	08.01.11& 11.00 pm	1536	1512
51	Anandchowk	RKG51	30:21:40.71	78:12:16.95	1839	08.05.11 & 7.07 pm	10.05.11 & 9.30 pm	1060	1759
53	Mathiyangaon	RKG53	30:19:35.49	78:16:51.63	1478	11.05.11 & 4.00 pm	13.05.11 & 8.30 pm	3422	5692
54	Uniyalgaon_2	RKG54	30:23:58.87	78:17:44.30	2164	13.05.11 & 7.40 pm	15.05.11 &1.00 pm	2834	2611

Table 2 Recording bands of ADU06 with sampling frequency, corresponding frequency range and recording length of the MT data in field.

Band	Sampling frequency/period	Frequency/period range	Recording length in field
HF	40960 Hz	20000 Hz - 500 Hz	7 s
LF1	4096 Hz	1000 Hz - DC	8 – 10 m
Free	128, 256, 512, 1024 or 2048 Hz	60, 120, 240, 480 or 960 Hz – DC	30 – 45 m
LF2	64 Hz	30 Hz - DC	10– 12 h
LF3	2 Hz	0.9 Hz to DC	48 -70 h

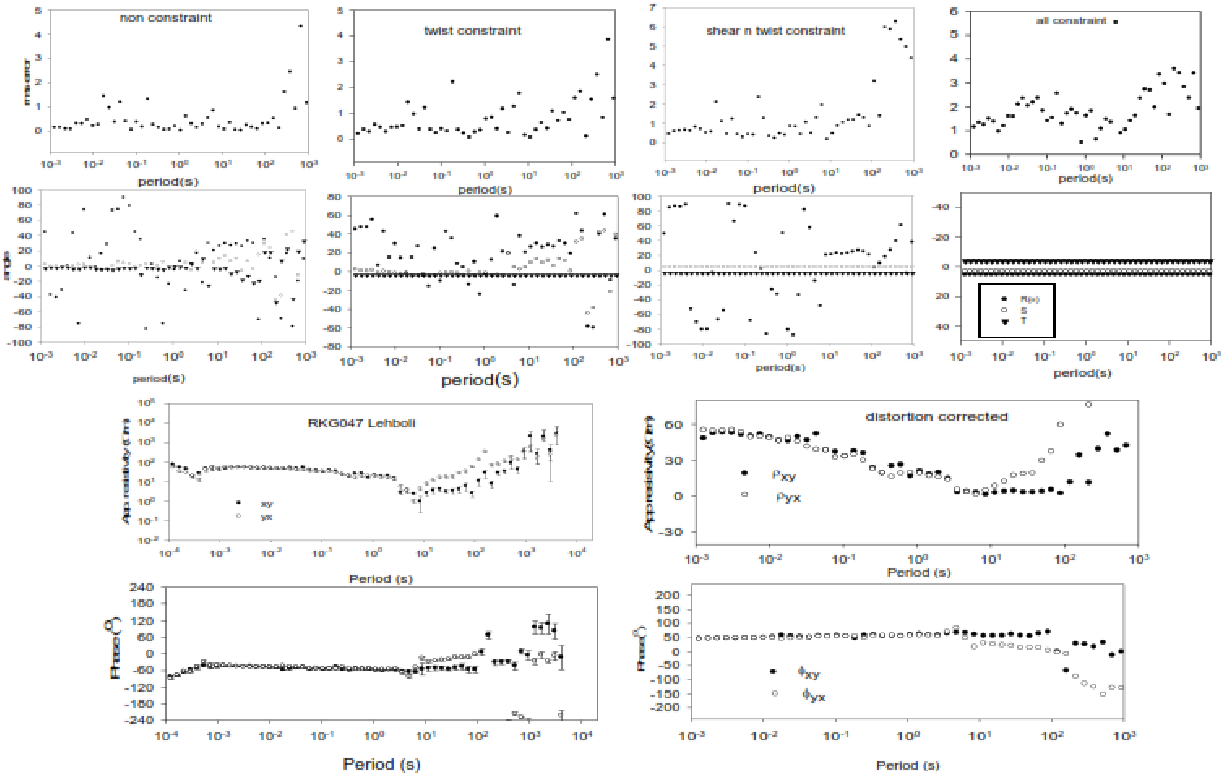

Figure 2 Single-site, Single-frequency Groom-Bailey decomposition to estimate the strike angle and distortion parameter (Shear and twist) of lehboli (RKG47) MT site.

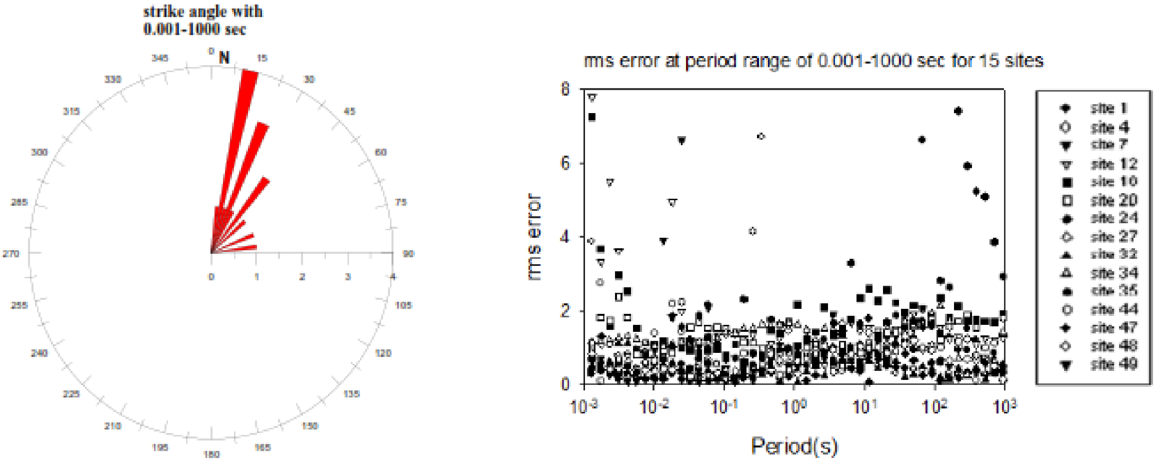

Figure 3 Decade width rose diagram (whole band width) for strike angle and rms error of 15 MT data sites for whole range of period

2D Inversion of MT data

We solved the inverse problem in the sense of (Tikhonov and Arsenin, 1977), taking a “regularized solution” to be a model minimizing an objective function, ψ , defined by

$$\psi(m) = (d - F(m))^T V^{-1}(D - F(m)) + \lambda m^T L^T L m \qquad (2)$$

For given , λ , V, and L, the regularization parameter, λ , is a positive number.

The positive-definite matrix V plays the role of the variance of the error vector e. ψ defines a stabilizing functional on the model space. In above equation the first term measures the data misfit and the second term, model smoothness. The trade-off between data misfit and model smoothness is controlled by the regularization parameter λ . We have used Rodi and Mackie (2001) code as implemented in WinGlink software package for 2D smooth inversion of MT data. We have used Laplacian operator as smoothing operator, L, which is defined as

$$L = \alpha \partial^2 / \partial y^2 + \beta \partial^2 / \partial z^2 \qquad (3)$$

We have used 15 stations MT data (Israil et al, 2008) for 2D inversion after processing and distortion analysis. The inversion for selected 15 station data is carried out in four stages: TE-, TM-, joint inversion of TE, TM modes and finally joint inversion of TE, TM and tipper data.

The initial model for this case was constructed from the sequential inversion of individual TE and TM mode data. Finally choosing the non- homogeneous model with three layers of 1km, 5km, and below and the resistivity 100 ohm.m, 500 ohm.m, and 1000 ohm.m respectively.

The electrical characteristics, the importance and possible geological inferences of each feature of the 2D inverted TE and TM model (figure 4) are given below

Features A and G This is a shallow conductive structure less than 16 ohm.m mainly confined in the southern part of the profile located in Indo-Gangetic Plains (IGP) and Lower Himalaya(LH). The conductive structure extended upto a depth of 5 km. Geologically, these zone corresponds to the loose sediments of tertiary age transported from higher Himalayan region (figure 4).

Features B and C The feature B represents the conducting body from 10km to 35 km depth. The feature C is a resistivity variation (resistivity>2512Ωm) with strong lateral discontinuity (figure 4), surface zone of this feature is seen near MBT and appearing that it is dipping northward.

Feature D This is a highly conducting zone, present between station rkg27 to rkg35. This zone is a typical example of mid crustal conductor in Himalayan region.

Feature E and F The feature E is a low conducting zone below 10 km at rkg44. The feature F is a resistivity variation in deep beneath the subsurface from 12km to 50km giving an idea that this is a resistive formation below the near surface sediments representing the top of Indian basement.

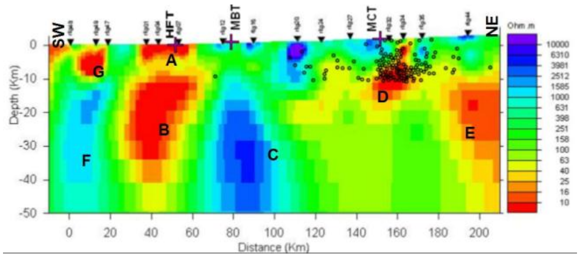

Figure 4 2D resistivity models of Deoband-Gangotri profile in Garhwal Himalaya corridor with topography on the top, 2D smooth geoelectric model obtained from the joint inversion of TE, TM responses, the local seismicity (hypocenters) locations plotted as circles in the model, locations of 15 MT sites indicated by triangle, and the major Himalayan thrusts by plus symbol (HFT, MBT, MCT).

Conclusions

The final geoelectrical model (figure 4) is related to the possible geological and tectonic features along the profile. Whereas the near surface conductive feature in foothills and Siwalik Himalaya is related to the molassic sediments transported from Higher Himalayan region. The strong lateral discontinuities along the profile are associated with the various thrust zones. The conducting zone near MCT is a typical example of presence of mid crustal conductor. Along this profile, the mid crustal conducting zone near MCT coincides with the intense microseismic activity zone (Khattri, 1992).

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