DETECTION OF GEOTHERMAL INTERFERENCE IN THE TUNNEL EXCAVATION USING MAGNETOTELLURICS TECHNIQUE

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ABSTRACT

A difficult task for geo-engineers involved in tunnel construction in Himalayas is to know the possible interference of hot water regimes that may pose a problem during the construction of the tunnel. One possible solution for such a problem is to estimate the subsurface parameters using geophysical and geothermal investigations. Magnetotelluric (MT) studies have been carried out over a 35 km long North-South profile in Loharinag Pala area of lesser Himalayas in Uttaranchal. Rishikund, Sunagarh and Bhukki are prominent hotsprings in this region. A total of 16 MT stations could be occupied along the profile, many of them being close to the proposed tunnel alignment; four of these being situated away from the profile towards north as well as South. Electrical structure of the subsurface has been derived from 2-D modeling. To determine the strike direction we have used Groom-Bailey (GB) decomposition and Parkinson Induction vectors. North- West (-55^0) direction coinciding with the regional strike direction is derived. Geothermal investigation has also been carried out to estimate the temperature at different depths from bore holes. Modeling study showed conductive feature with 5-40 ohm-m resistivity and predominantly appears in TE component as compared to TM. The southern part of the profile showed high resistive zone with a resistivity, of the order of 500-1000 ohm-m. The resistivity structure along the tunnel alignment showed anomalous conductive zone towards north probably due to fractured rocks filled with water and minerals. The results obtained from the present study are useful to the geo-engineers in order to devise safety measures suitable during construction of the tunnel for hydroelectric power project.

Key words: Himalayas; Tunnel Construction; Geothermal Interference; Magnetotellurics

1. Introduction

Interference from geothermal springs to civil construction sites has posed a major problem in many areas in Himalayan region. Himalayan region is well known to be an important geothermal belt, in which several groups of hot springs are reported to occur (Thussu, 2002). The subsurface temperature of the hot springs is as high as 90^0C at some places. Major civil construction sites such as dams, tunnels etc. need to be carefully planned to avoid the hot spring locations. For example, high temperature of water and rock matrix heats the air in a tunnel that can make the working condition along the construction very difficult. It requires extensive refrigeration and rapid circulation of air in the tunnel. Due to acute power shortage in India it has become necessary to generate renewable sources of energy. Hydropower generation has thus become a major source of power generation, especially in Himalayan region as there are number of perennial rivers flowing all the time with steep gradient. Diversion of the water from the river through a tunnel over a short distance of a few kilometers helps in attaining a large gradient that could be used to generate electric power. Tunnel construction is feasible if there is no interference from major heat source and large water bodies along the tunnel course. Prior information on this aspect helps in diverting the tunnel trace, if necessary, including logistic precautions that can be taken during the course of tunneling.

Due to complex geology and tectonics of the Himalayan region, it is very difficult to trace the path or find the source of the geothermal springs from geological and shallow geophysical studies. This region is pronounced for earthquakes and land slide hazards (Gupta and Dave, 1979). One solution could be to drill a number of deep bore holes along the tunnel trace and measure temperature in the bore holes for assessing possible interference from the hot springs. Due to logistics problems, the expenditure due to deep drilling work in hilly terrain is very high. One optimum solution could be to use a few shallow drill holes in suitable locations for temperature measurements and combine the results with subsurface structure derived from other geophysical methods. This optimum methodology has been followed in Loharinag Pala region of Uttaranchal region in Higher Himalayas and the results have been presented in this paper.

2. Geology of the area

The Himalayas are a unique and classical example of continental collision tectonics. Under thrusting of the Indian plate with respect to the Eurasian plate is reported during the Cenozoic (Molnar and Tapponier, 1975). After initial collision, the crystalline basement of the Himalaya was remobilized due to major intra-continental ductile shear zones (Bouchez and Pecher, 1981; Brunel, 1986; Jain and Anand, 1988). The Himalayan orogeny displays a unique interplay of large scale Nappe translation and extensional tectonics at different levels.

The study area falls in the region of Kumaun Himalayas. Kumaun Himalayas are divided into five divisions based on stratigraphical and structural studies, viz., Tethyan, Central, Garhwal, Kumaun and Siwalik separated by major thrust zones/faults. Fig. 1 shows the general geology of the area under study.

The Loharinag Pala area lies all along the course of the Bhagirathi river.

The catchment of Bhagirathi comes under the Central Himalaya and the rocks belong to the Central crystallines. The general trend of the central crystallines is NW-SE with dips varying between 25-65° due NE. The central crystallines of the Bhagirathi valley consists of meta sediments, meta basics, granite gneisses, garnetiferous schists and migmatites and are thrust over the Gamri quartzites of Garhwal group. The geological petrological evidences show that the rocks of the area have undergone three episodes of metamorphism related to different phases of deformation (Gupta and Dave, 1979).

The Main Central Thrust (MCT) is situated south of Bhatwari, where it has almost E-W course and separates the granite gneisses and garnetiferous schists of central crystallines and the cream colored Gamri quartzites. Beyond Bhatwari, Bhagirathi river course is dissected by a number of fault zones. Occurrence of depositional terraces with quaternary sediments along Bhagirathi river can be noticed between Harsil and Gangnani.

Besides the MCT, other thrust zones/faults have also been traced along Suparage, Bhatwari and Paper streams with a general trend of NW-SE. There is a major thrust passing through Joti, trending WNW-ESE and has been affected by N-S running fault near Dabrani. Migmatisation is mostly observed along the weak tectonic zones. It is followed by dynamic metamorphism with attendant retrograde changes. The last magmatic activity is evident as mafic intrusives cutting across the MCT. Fig. 2 describes the course of Bhagirathi river along with MT sites and hot springs.

3. Methodology

Magnetotelluric (MT) technique, one of the geophysical techniques, depends on the natural variations of electromagnetic field. Large frequency range of signals helps to probe the earth from shallow level of 50-100m to as deep as tens of kilometers. Due to skin effect, high frequency signals scan the earth to shallow depths, while the low frequency provides information to deep crustal depths.

3.1. Data Acquisition

In the present study, MT data has been collected using GMS05 system (Metronix, Germany) in the frequency range 0.001-128s. Two horizontal orthogonal electric field components of T or L-type dipoles with a separation of 60-70m have been used depending on the availability of space in the rugged terrain. Cadmium-Cadmium Chloride solution porous pots have been used as electrodes. The vertical and horizontal magnetic field components have been measured with induction coil magnetometers. The measurements have been made during April-June 2004 covering Uttarkhasi (south) – Gangnani (north) areas, extending the profile over a length of 35 km. A total of 16 MT soundings have been carried out with a station spacing of 3-5 km depending upon the site accessibility. Measurement locations are as close to the required area of tunnel alignment as possible. Most of the sites are along the tunnel trace, with small deviations from the original plan because of the difficulty in approaching the rugged terrain. Since the area is electrified with power lines for domestic purposes and irrigation of lands, selection of a reasonably good MT site has been a difficult task.

3.2. Data Processing and Analysis

The time series has been manually edited by rejecting the bad segments containing spikes before processing. The data has been analyzed using robust processing procedures of MAPROS (M/s. Metronix, Germany) software package and MT impedance tensor and the magnetic transfer functions have been calculated. Unfortunately, at most of the sites high frequency vertical magnetic field (HZ) data has been noisy. MT response for site S16 is given in Fig. 3.

GB decomposition technique (Groom and Bailey, 1989) has been used to reduce the local distortions and to derive the 2-D strike. The Parkinson induction vectors have further constrained the strike. The strike direction for all the stations for lower frequencies 0.9-0.006 Hz have been compiled in the form of a rose diagram and presented in Fig. 4. As can be seen from the figure North 35° East seems to be the dominant Z strike direction. Due to 90° ambiguity, N 55° W can also be considered as strike direction. From the study of the induction vector direction, N55°W can be taken as the strike and it is consistent with the regional Himalayan trend. In view of these observations, the data for all the sites have been rotated to N55°W. The response functions associated with the electric field parallel to the strike is regarded as TE-mode and that perpendicular to the strike is TM-mode.

3.3. Modeling of the data

The subsurface structure can be derived from 2-D modeling of the data. Half space resistivity of 100 Ohm-m is given as initial model. The distortion corrected TE and TM apparent resistivity and phase data are simultaneously inverted using Non

Linear Conjugate Gradient (NLCG) algorithm (Rodi and Mackie, 2001). In order to accommodate the static shift effects, the errors on the apparent resistivities in the data set are increased by a factor of 10 over the impedance phases before inverting the data so as to decrease their weight in the inversion process. Tau, the regularization parameter, is fixed as 3 and error floor of the data is given as 20 and 5 percent for apparent resistivity and phase respectively. After several attempts of inversion procedure, with different parameters of Tau and error floor values, 4.7 rms error has been obtained.

4. Discussion of the results:

The subsurface electric structure derived from 2-D modeling of the data up to a depth of 10 Km, is shown in Fig. 5. As can be seen from the figure, the southern half of the subsurface structure of the profile is high resistive with a resistivity of the order of 1000-8000 Ohm-m. The rocks with less porous and devoid of major fracture zones can have such a high resistivity. From this observation, one can infer that southern part of the profile, i.e., towards south of the site S07 is dominated by crystalline rocks. Whereas towards the northern part of the profile, i.e., towards north of Ganganani (S 04) hot spring zone, it is medium to low resistive structure. Anomalously low resistive structure (5-10 ohm-m) near the two sites, namely, S04 and S03 is an indication for the possible presence of a fractured rock matrix dominated with water circulation. This location falls close to the proposed Barrage site. In other part of the profile, it shows medium resistivity of the order of 100-500 ohm-m. The observed and computed data for TE and TM modes of apparent resistivity and phase are presented in Fig. 6a & 6b. Qualitatively, one can see the good fit between the observed and computed data for TM mode apparent resistivity. Reasonably good fit can also be seen for the phase data. By comparison, TM data fit is more satisfactory to the TE data fit.

It may be noted that the proposed tunnel trace falls to maximum 1 km depth from the surface. In such a case, from the above result, one can construct a model of resistivity of rock matrix at a depth of about 1 km. Resistivity model with different values estimated from the present study at a depth of 1 km is presented in Fig. 7 in the form of a tunnel trace. Based on the resistivity values, five zones have been identified with high resistive rock matrix as Zone-A, a very low resistive as Zone-E. The zones B, C and D with medium resistivity can be interpreted as semi weathered rock. This information helps the geo-engineers for better planning of the tunnel during construction. While the present MT results have clearly indicated the nature of the rock matrix along the profile, geothermal studies with temperature well log measurements have provided some clues on the geothermal regime of the region. Seven shallow boreholes (DH03-10A, DH03-11, DH03-14, DH03-12, DH03-07, DH03-04, and DH03-01 in Fig. 7) drilled in the area to a maximum depth of 200m have not shown anomalous high geothermal gradient. Maximum estimated geothermal gradient in this region is 23^0 (Harinarayana et al., 2005). Negative gradient at a few boreholes have also been observed indicating cold water mixing with maximum bottom hole temperature reaching below 18°C.

5. Summary and Conclusions

Magnetotelluric (MT) field investigations have been carried out in

Loharinag Pala hydroelectric project area, Uttarkashi district, Uttaranchal. Sixteen stations have been occupied in the region along the proposed headrace tunnel. The profile is oriented in NNE and SSW direction with a length of about 14 km. The stations are distributed near Rishikund, Bhukki, Sunagarh and Thirang hot springs as shown in Fig.2. Natural electromagnetic field signals are recorded using GMS05 magnetotelluric digital data acquisition system. The frequency ranges from 1 KHz to 0.01 Hz, facilitating penetration of the signals to a minimum depth of 5 - 10 km, although the required target depth of the present study is about 1 - 1.5 km. The data sets have been analyzed using Groom-Bailey decomposition procedures in order to reduce the effect of near surface distortions on the data. Such procedures are being followed by many research workers (Bai et al., 2001, Harinarayana et al., 2004). The data has been modeled using 2-D modeling inversion schemes (Rodi and Mackie 2001).

Based on 2-D modelling of the data, the following conclusions can be drawn.

1. The MT studies have provided valuable information on the subsurface electrical resistivity structure. This has helped in assessing the nature of rock formation along the proposed tunnel alignment, at a depth of about 1 km from the surface as required from the objectives of the present project.
2. The apparent resistivity pseudo section from 1 KHz to 1 Hz along the profile both in XY and YX directions has provided qualitative information about the subsurface structure. Towards the

southern part of the profile, that is up to the station S07, the apparent resistivity ranges from 1000 - 2000 ohm-m. Further towards north, the resistivity decreases to about 50 - 100 ohm-m at 100 Hz - 1 Hz. This is an indication of change in lithological sequence of the rock matrix structure. Interestingly, the presence of a fault zone in NS direction (Gupta and Dave, 1979) is also mapped from surface geology located close to the site S07 as shown in Fig. 1.

3. The geo-electric strike dominantly points to WNW direction (N 55^0 W). This is consistent with the surface geological formations mapped in the area and also the regional Himalayan trend.

4. The geo-electric section derived from 2-D modelling has shown sharp variations near the site (S07). The structure below the sites from S16 - S07 is dominated by resistive formation (> 1000 ohm-m), whereas the stations located towards north indicate less resistive formation (< 500 ohm-m). The low resistivity formation corresponds to schists and gneisses, probably a fractured zone. The rock structure towards north is mostly migmatites with granitic ferrous mica schists, calcareous schists and marble.

5. Based on the geoelectric section derived from 2-D modelling schemes, the resistivity structure along the tunnel located at a depth of about 1 km has been inferred as hard rock, fractured

rock and semi fractured rock. The resistivity section along the headrace tunnel is shown in Fig. 7. This may help the geo-engineers for better planning during the tunnel construction.

6. As discussed above, the magnetotelluric study has given an estimation of the nature of rock formations. The results derived from the study have clearly established, as discussed above, and indicated for the presence of fractured and hard rock.
7. From shallow (<200m) bore hole thermal log data the bottom hole temperature recorded is $<18^0$C (Sukanto et al., 2005). Thermal data from deep bore holes of 500m depth near highly fractured zone will further help in refining models and confirm the results derived from the magnetotelluric study.

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FIGURE CAPTIONS:

FIG.I GEOLOGICAL MAP OF LOHARINAG PALA TRAVERSE WITH MT SITES

FIG.2. MT SITE LOCATIONS AND HOTSPRINGS IN LOHARINAG PALA REGION

FIG.3. APPARENT RESISTIVITY AND PHASE FOR STATION S16

FIG.4. INDUCTION VECTORS AND GB STRIKE

FIG.5. MODEL UPTO 10KM DEPTH INTE AND TM MODE

FIG.6a. COMPARISON OF OBSERVED AND CALCULATED RESULTS OF TM MODE

FIG.6b. COMPARISON OF OBSERVED AND CALCULATED RESULTS OF TE MODE

FIG.7. RESISTIVITY STRUCTURE AT AN AVERAGE DEPTH OF 1KM ALONG THE PROPOSED LOHARINAG PALA TUNNEL ALLIGNMENT OBTAINED FROM MAGNETOTELLURIC SOUNDINGS. THE TEMPERATURE SHOWN IN THE FIGURE OR OBTAINED FROM DIRECT MEASUREMENTS AT THE TUNNEL INVERT AVAILABLE BORE HOLES.

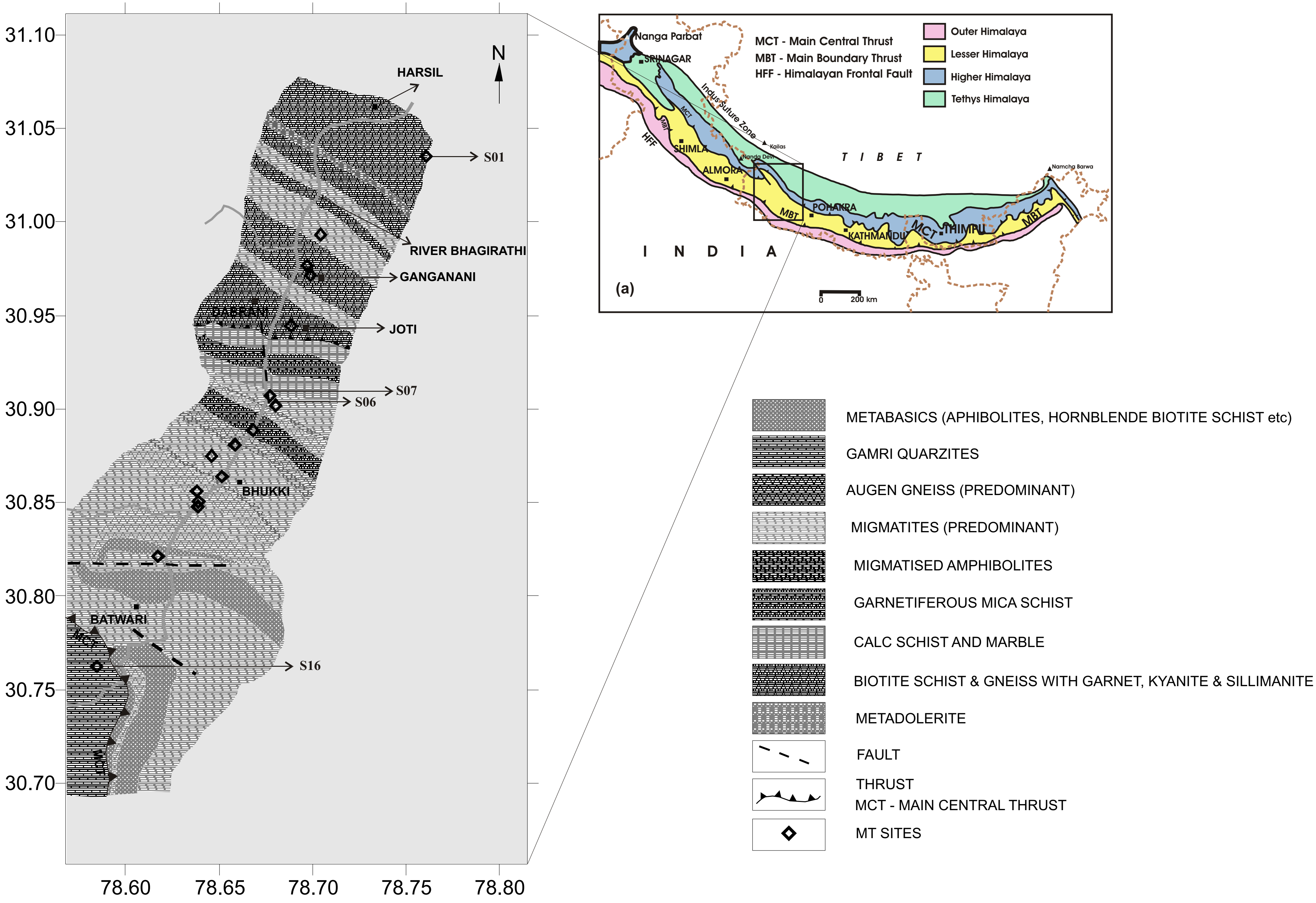

Fig. 1 GEOLOGICAL MAP OF LOHARI NAG PALA TRAVERSE WITH MT SITES

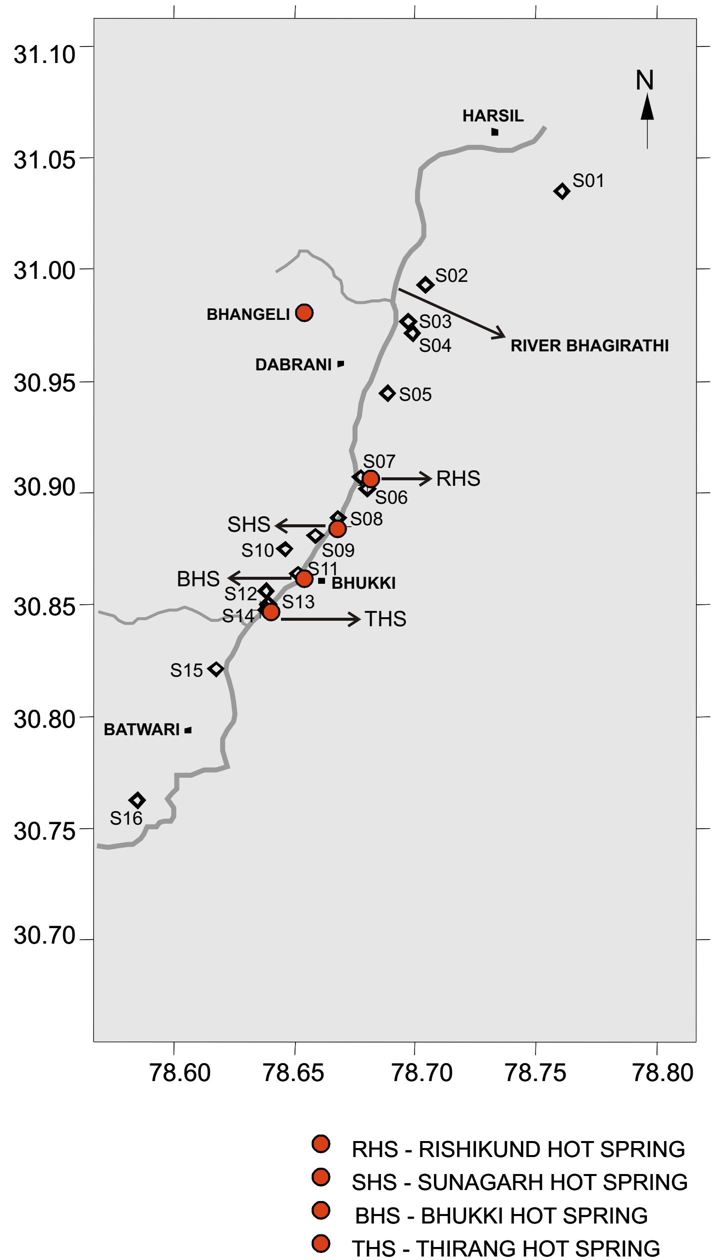

Fig. 2 MT site Locations and hotsprings in Loharinag Pala region

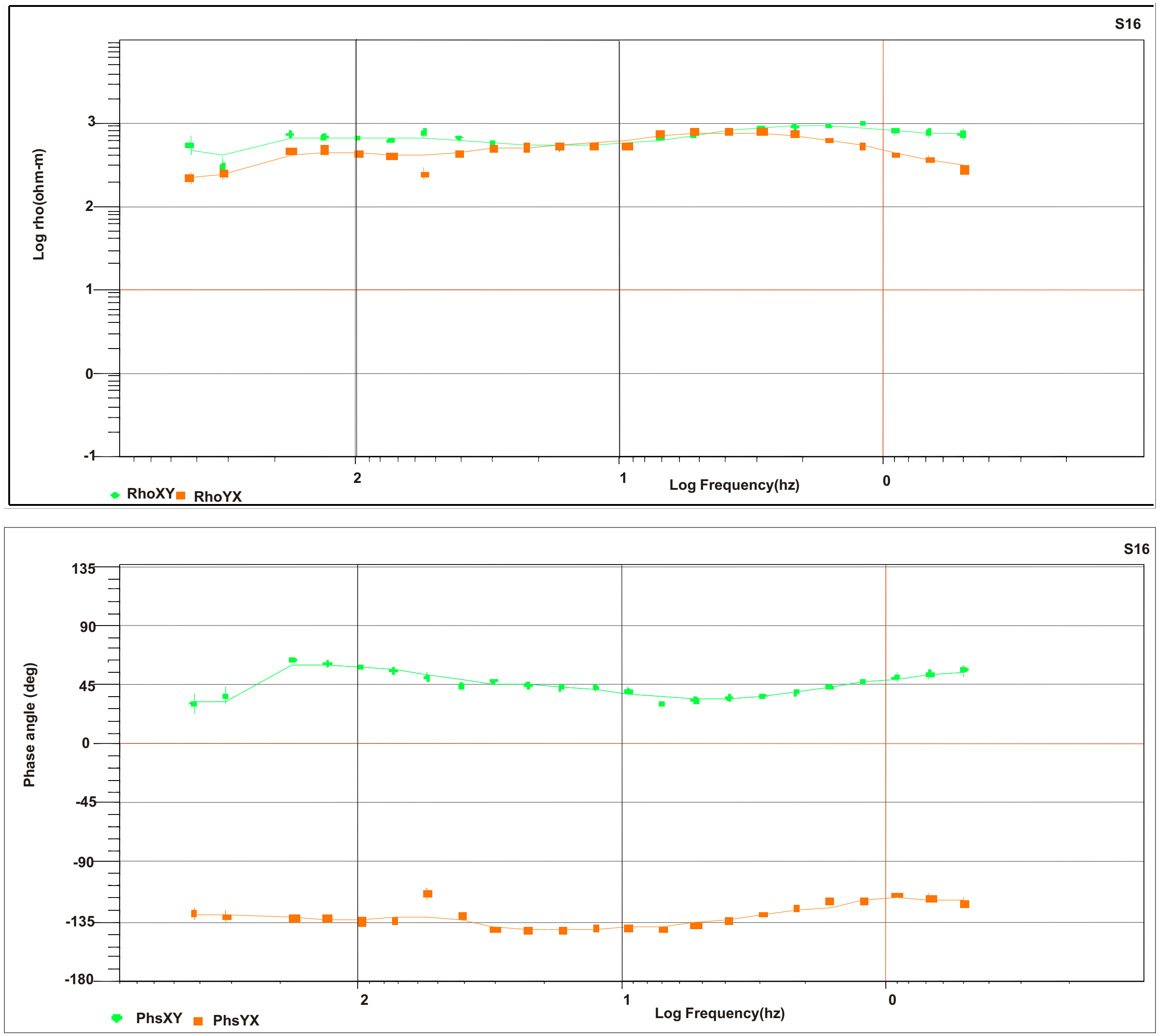

Fig. 3 Apparent resistivity and phase for station S16

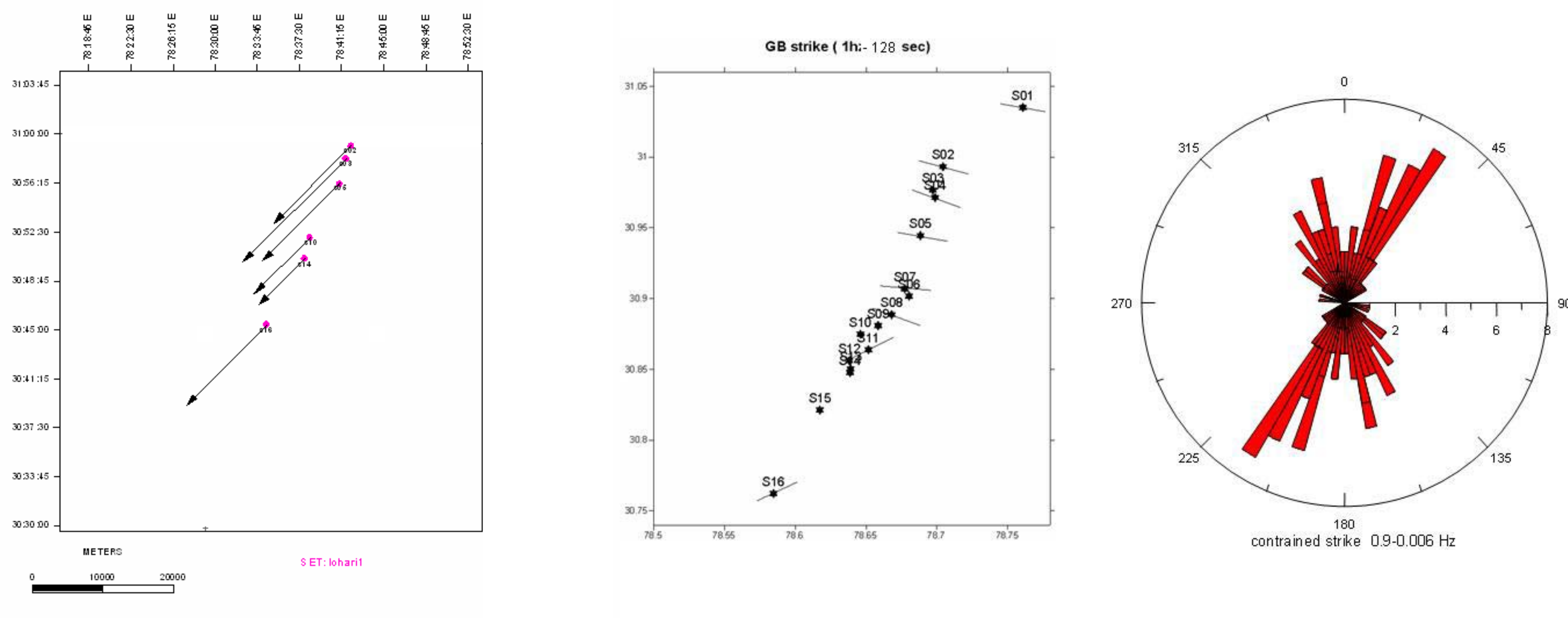

Fig. 4 Induction vectors and GB Strike

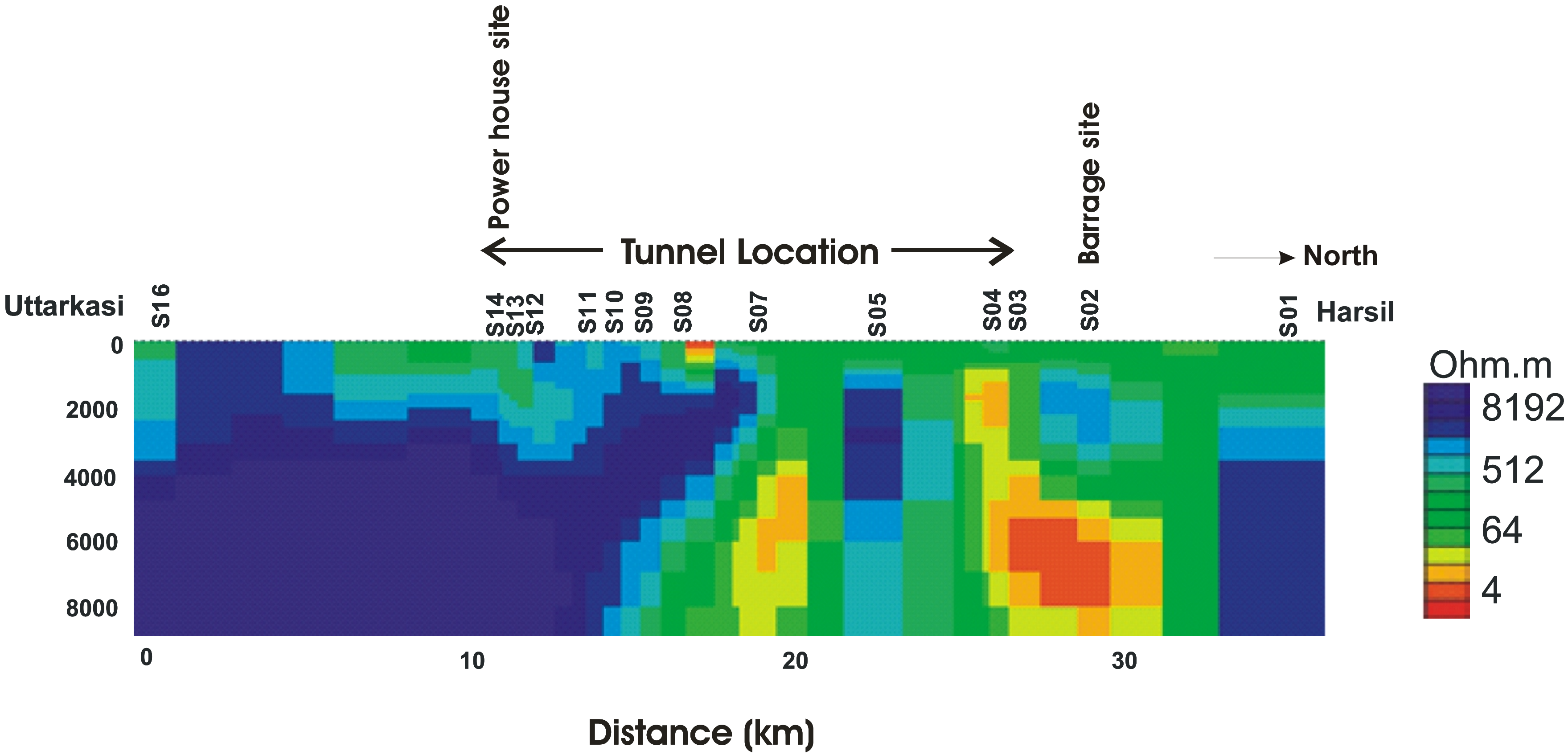

Fig. 5 Model upto 10 Km depth in TE and TM mode

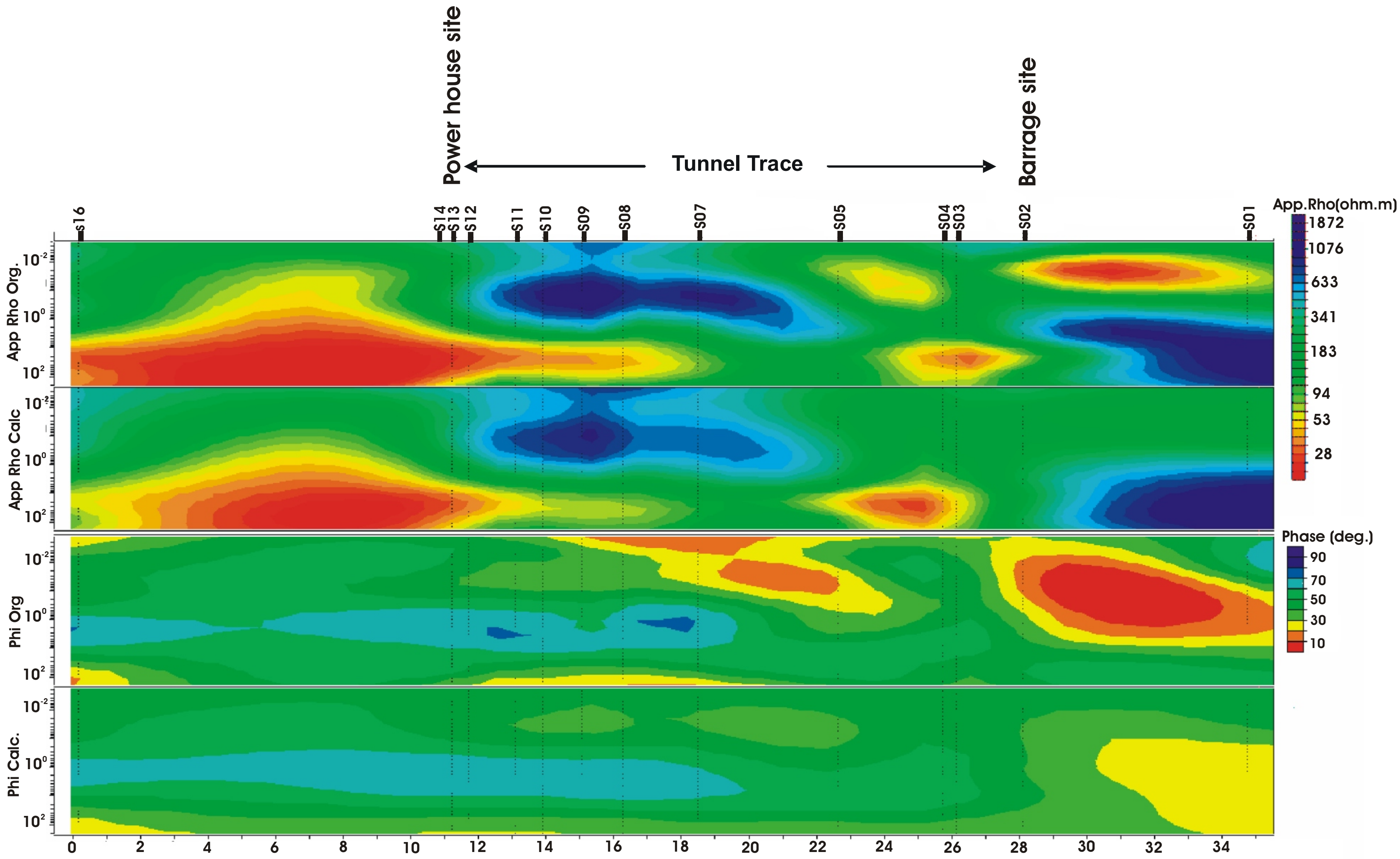

Fig. 6a Comparison of observed and calculated results of TM mode

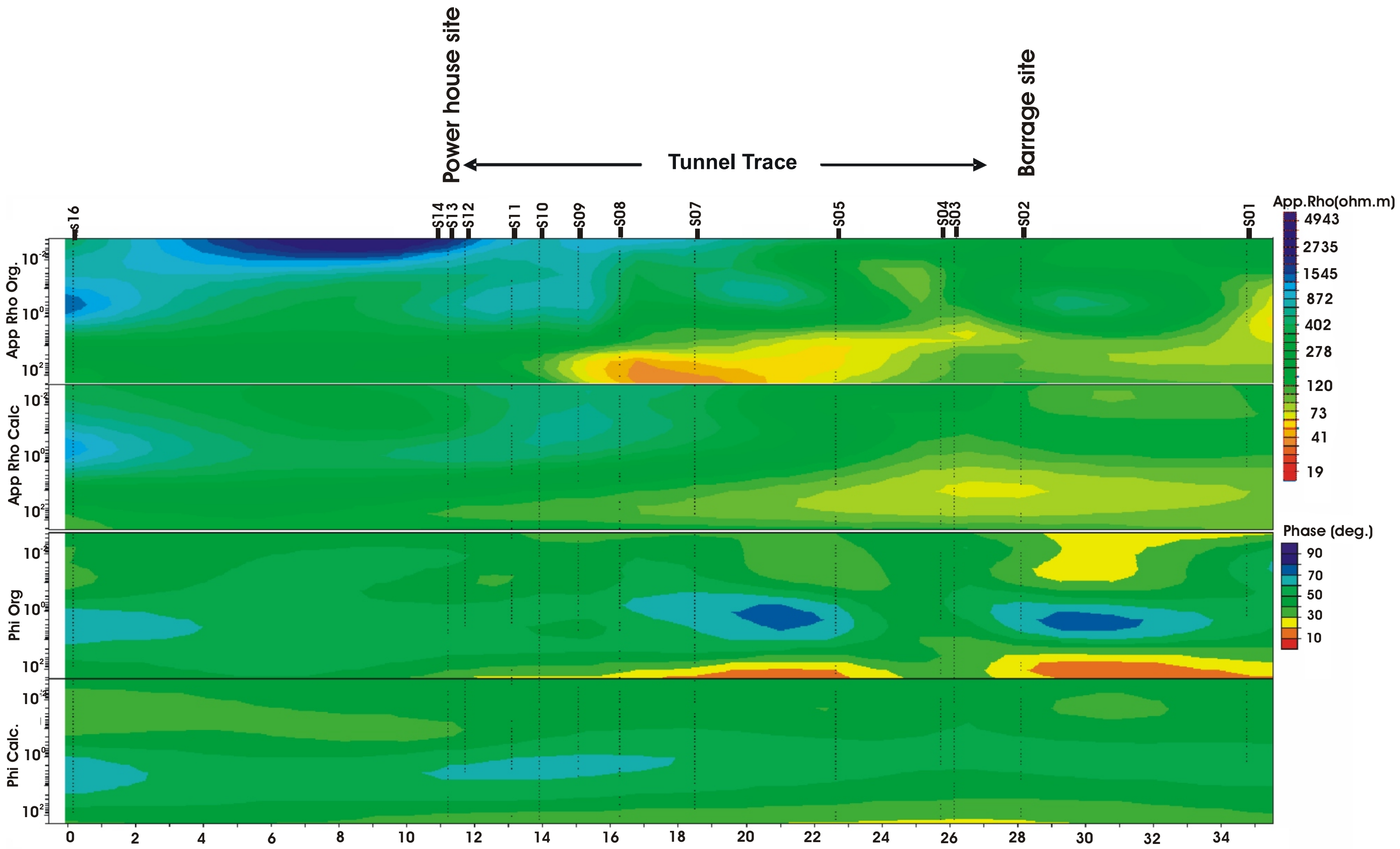

Fig. 6b Comparison of observed and calculated results of TE mode

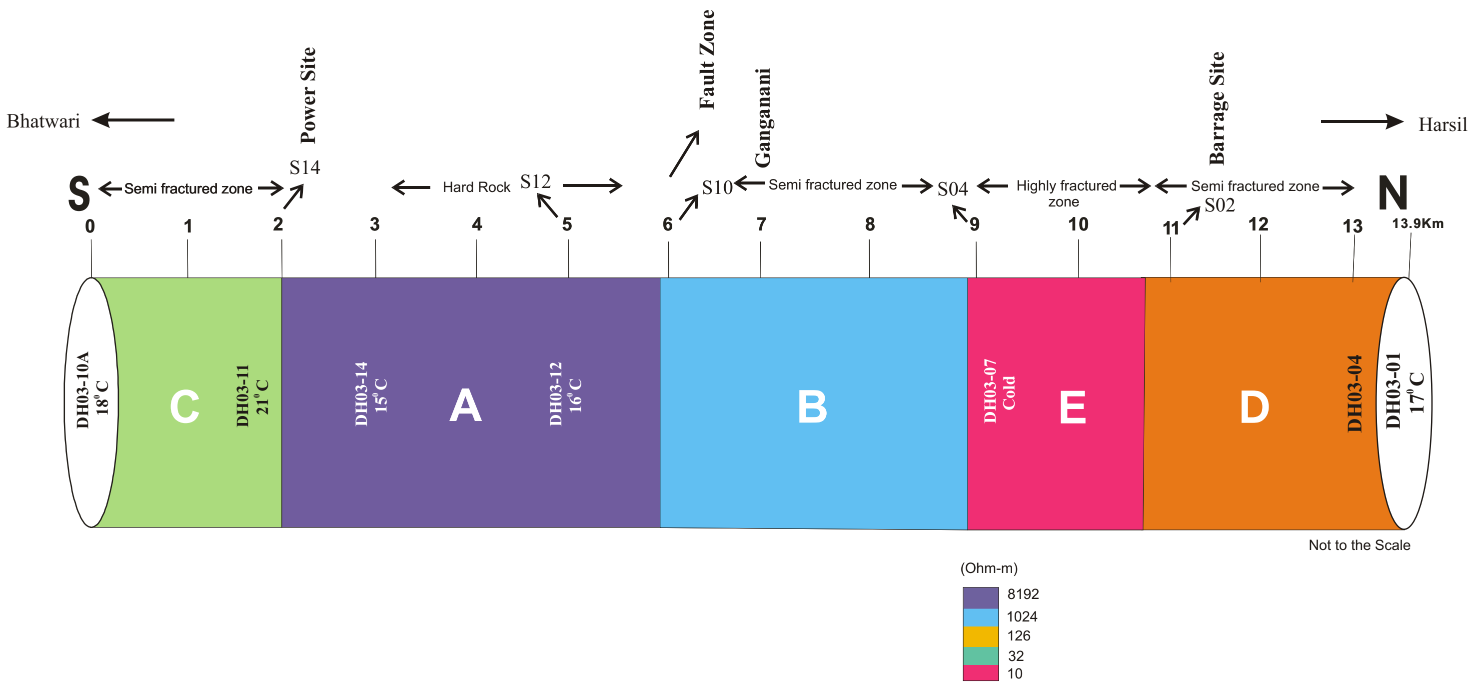

Fig. 7 Resistivity structureat an average depth of 1Km along the proposed Loharinag Pala tunnel alignment obtained from Magnetotelluric soundings. The temperature shown in the figure are obtained from direct measurements at the tunnel invert available boreholes