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10. Deep Electrical Conductivity Investigations in Some Geothermal Areas of India

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1. Introduction

Among various groups of hot springs distributed over different regions of India, four provinces have been identified as having geothermal significance. These are Himalayan belt region, where the hot springs are reported to occur at 72 locations, Konkan province occupied by Deccan traps along the west coast region, in which hot springs emerge at 23 locations, the hot springs associated with the Narmada-Son lineament zone and the groups of hot springs distributed in Bihar and Bengal which are associated with Rajgir-Monghyr belt (Krishnaswamy, 1976; Gupta et al, 1976; Ravishanker, 1988). Amongst the four regions, the Himalayan belt regions has thus far received the maximum attention of earth scientists, while the remaining regions have recently gained importance (Ravishanker et al, 1991). Various groups of hot springs and geothermal provinces distributed in India are shown in Fig. 1.

Since most of the geothermal fields are closely associated with the high conductive zones, owing to occurrence of hot fluids and associated minerals, deep electrical and electromagnetic methods like tellurics and MT are useful in delineating the geothermal regions (Combs and Wilt, 1976; Long and Kaufman, 1980; Hutton et al, 1989). Since both telluric and MT methods depend on the same physical property, namely, the electrical conductivity, joint field studies should provide a better understanding of the subsurface condition. In the present study, results of telluric and MT field investigations in northern part of the Konkan province and telluric field investigations in Tatapani hot spring area are presented.

2. Data Acquisition and Analysis

For the telluric field measurement, the dipole length was 200m and signals were recorded along two orthogonal directions oriented along magnetic north-south (Ex) and east-west (Ey) directions. Telluric field signals in the frequency range 0.02–0.05 Hz were recorded simultaneously both at the base as well as at the field stations on portable strip chart recorders. Indigenously developed analog telluric field instruments (Virupakshi and

Murthy, 1988) were used for data acquisition. Detailed description of the field procedures followed in the present study can be seen in Harinarayana (1984).

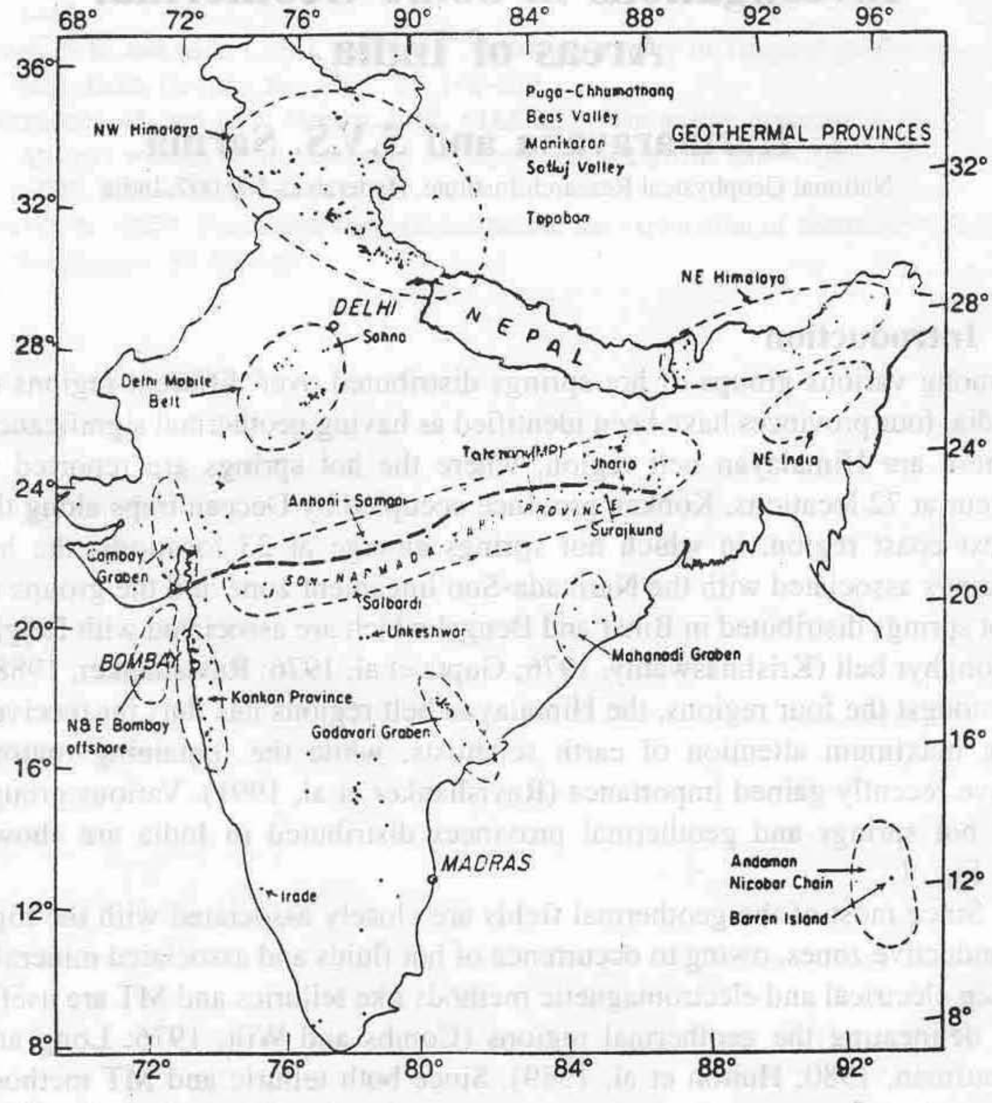


Fig. 1 Groups of hot springs and geothermal provinces of India (from Pandey and Negi, 1995)

The analysis of telluric field data involves obtaining a parameter representing μ, the telluric field ratio between the field and the base stations. Several procedures are discussed by Berdecheviskii (1965) to obtain the telluric field parameter. In the present study amplitude ratio method has been used, considering the spectral amplitudes of telluric fields (Sarma et al, 1978). Modeling of the telluric field data along selected profiles have been carried out using the 2-D forward E-pol and B-pol algorithms (Jupp and Vozoff, 1977).

For MT measurements, the analog equipment developed at NGRI

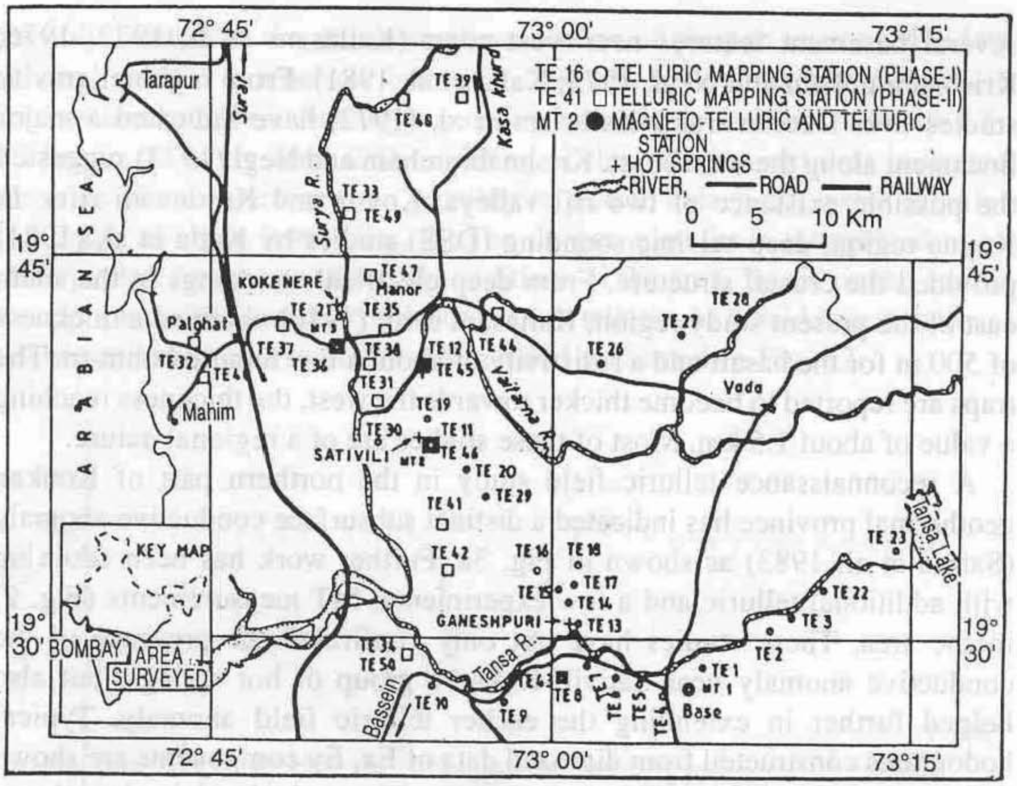


Fig. 2 Location map of telluric and MT stations of Konkan province

(Virupakshi and Murthy, 1988) was used. The MT assembly consists of magnetic sensor coils, the magnetic and telluric field instruments and an analog recorder. The natural signals (Hx, Hy and Ex, Ey) were recorded simultaneously for several hours in the low frequency range 0.1–0.01 Hz. Classical tensorial technique (for eg. see Vozoff, 1972) was used for processing the data obtained through manual digitization of the records with an interval of 3 sec. Modeling of the data using effective impedance (Ranganayaki, 1984) has been carried out. The data thus obtained at three stations (Fig. 2) are subjected to 1-D modeling using linearized inversion scheme of Jupp and Vozoff (1975). In the following section the results obtained in both the regions are discussed.

3. Konkan Geothermal Province

This province spreads nearly a few hundred kilometers in Deccan basalt along the west coast of India. In this region, hot springs are known to be located at 23 locations, 9 located north of Bombay and 14 in the southern part. The entire province is covered by basalt of upper Cretaceous—Paleocene age. It is believed that the water from the springs is of meteoric origin. Originated from the steep hills of Western ghats situated at a few kilometers away from the springs towards the east, the water must have seeped into the subsurface through deep fractures and got heated up down below due to anomalous geothermal gradient and emerge to the surface through suitable conduits to appear as hot springs. Regional geophysical studies have indicated several basement features near west coast (Kailasam et al, 1972, 1976; Krishnabramham and Negi, 1973; Kaila et al, 1981). From regional gravity studies over Deccan traps, Kailasam et al, (1972) have indicated a major lineament along the west coast. Krishnabramham and Negi (1973) suggested the possible existence of two rift valleys, Koyna and Kurduvadi rifts. In Koyna region, deep seismic sounding (DSS) studies by Kaila et al, (1981) provided the crustal structure. From deep electrical soundings in the south east of the present study region, Kailasam et al, (1976) obtained a thickness of 500 m for the basalt and a resistivity of about a few hundred ohm-m. The traps are reported to become thicker towards the west, the thickness reaching a value of about 1.5 km. Most of these studies are of a regional nature.

A reconnaissance telluric field study in the northern part of Konkan geothermal province has indicated a distinct subsurface conductive anomaly (Sarma et al, 1983) as shown in Fig. 3a. Further work has been taken up with additional telluric and a few experimental MT measurements (Fig. 2) in the area. These studies have not only confirmed the presence of the conductive anomaly near Sativili-Koknere group of hot springs, but also helped further in extending the earlier telluric field anomaly. Typical hodograms constructed from digitized data of Ex, Ey components are shown in Fig. 4 for both the base and field stations. The analysis of the data shows that the telluric field parameter, 'μ' varies from 1.0 to 0.7 in the southern part of the study area near Ganeshpuri-Akloli group of hot springs and tend to decrease northwards to about 0.2 towards the Sativili-Koknere group of hot springs. It is observed that this decreasing trend continues even further towards north of Koknere as shown from the telluric field contour map (Fig. 3b). The contour map also indicated that the telluric anomaly representing a subsurface conductive anomaly is not a localized feature but covers a large region.

2-D modeling along a profile AA' across the telluric field anomally (Fig. 3b) has been carried out using forward algorithm of Jupp and Vozoff (1977). In its simplest form the anomaly may be explained by a near surface horizontally extending conductive zone (2–5 ohm-m) located at shallow depths (< 1 km) as shown in Fig. 5. But for the reasons discussed in greater detail (Sarma et al, 1983; Harinarayana and Sarma, 1996) and from the observation that it is improbable that such a high conductive zone could be explained from any known geological or any hydrological considerations, it is inferred that the anomaly should be attributed to deeper source. Accordingly, from a detailed modeling studies, it is concluded that a deeper conductive zone with a 1 km thickness and a resistivity of 4 ohm-m and located at a depth of about 2 km (Harinarayana and Sarma, 1996) would account for the observed telluric field anomaly in addition to the shallow conductors indicated (Chatterjee et al, 1976) from deep electrical resistivity sounding results (Fig. 6).

From modeling of the MT data (1-100 sec), it is observed that an electrically

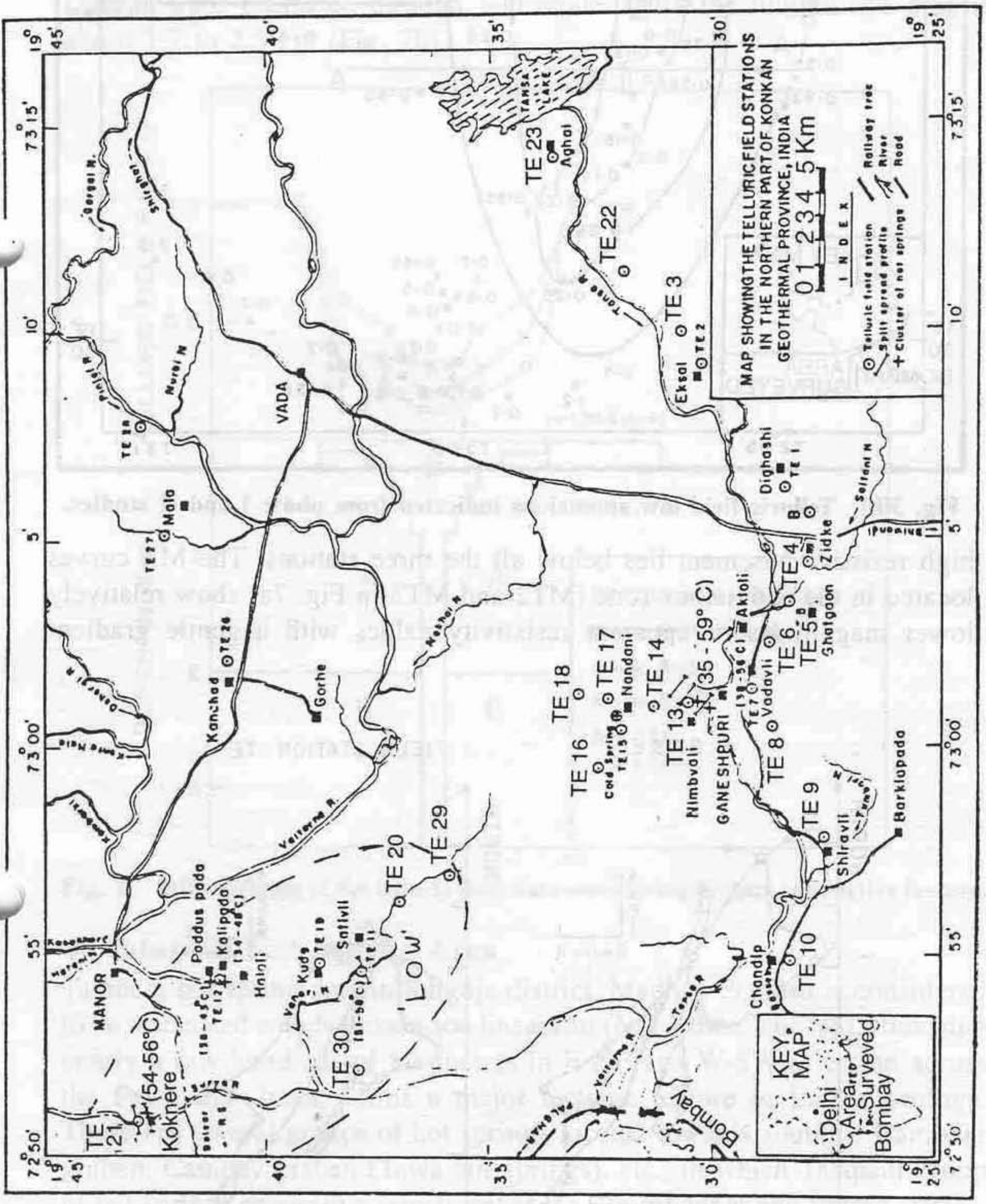


Fig. 3(a) Telluric field low anomalous indicated from phase I study.

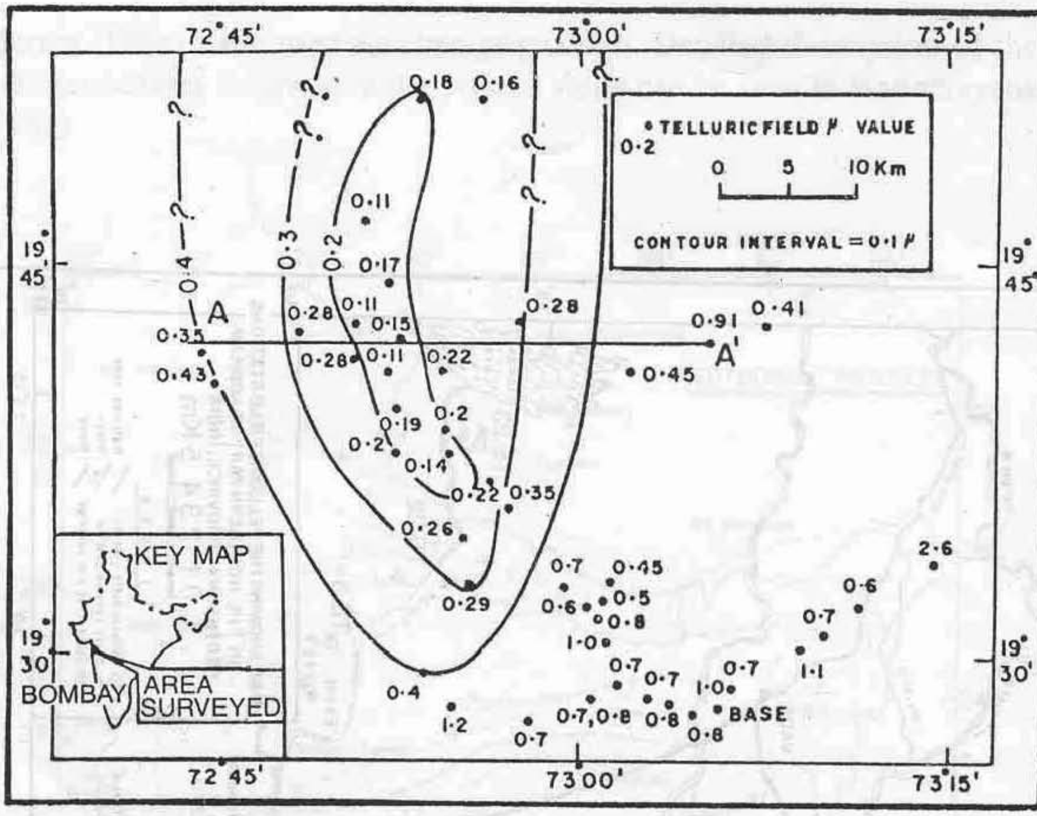


Fig. 3(b) Telluric field low anomalous indicated from phase I and II studies.

high resistive basement lies below all the three stations. The MT curves located in the anomalous zone (MT2 and MT3 in Fig. 7a) show relatively lower magnitudes of apparent resistivity values with a gentle gradient

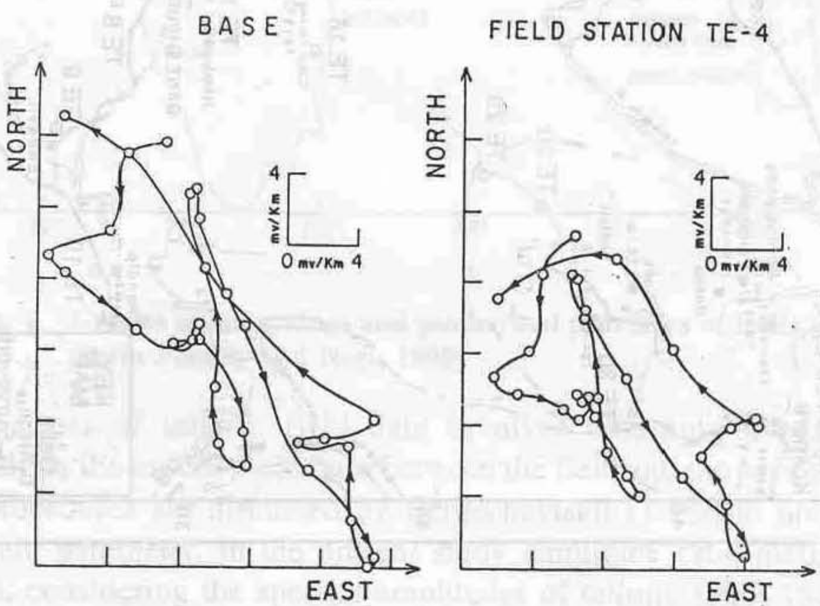


Fig. 4 Telluric field hodograms constructed from digitized data of telluric field Ex, Ey components, Konkan province, Maharashtra.

compared to that of MT1, located near the telluric base station. This indicates that the MT apparent resistivities also corroborate the presence of the conductor in the area corresponding to conductive anomaly delineated from telluric field studies. No attempt has been made to estimate the parameters of the conductive zone as this cannot be resolved since the MT data considered in the region is limited to a narrow frequency range. The thickness of the Deccan traps estimated through 1-D modeling of the limited MT data is about 1.7 to 2.5 km (Fig. 7b).

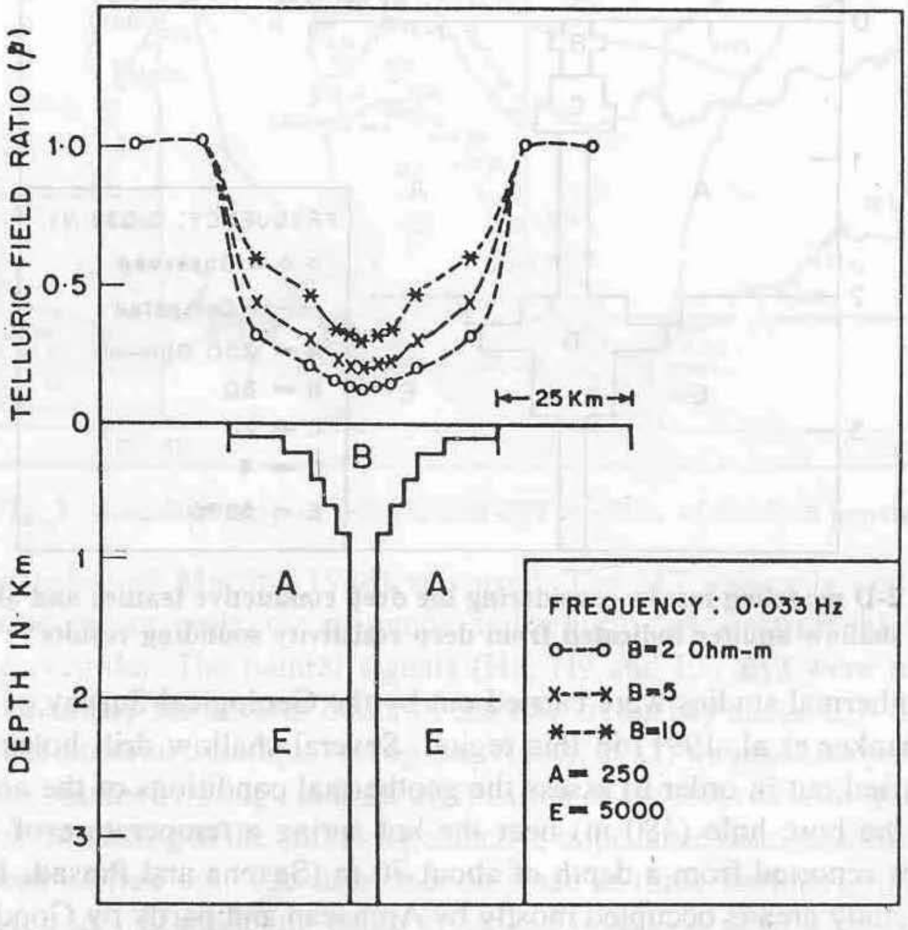


Fig. 5 **2-D modeling of the telluric field data considering surface conductive feature.**

4. Tatapani Hot Spring Area

Tatapani hot spring area in Surguja district, Madhya Pradesh is considered to be associated with Narmada-son lineament (NSL) zone. The NSL stretching nearly a few hundreds of kilometers in E-NE and W-SW direction across the Peninsular India, forms a major tectonic feature in Indian geology. There are several groups of hot springs located towards south of Damodar graben, Cambay graben (Tawa hot springs), etc., in which Tatapani group of hot springs occupies a significant place (Ravishanker and Prasad, 1988). This area is considered to be important in view of the relatively high temperature (60–80°C) of the discharged water (Ray, 1974; Krishnaswamy, 1976). Tatapani group of hot springs are distributed at 23 different locations lying in a zone oriented nearly in an EW direction. Extensive geological

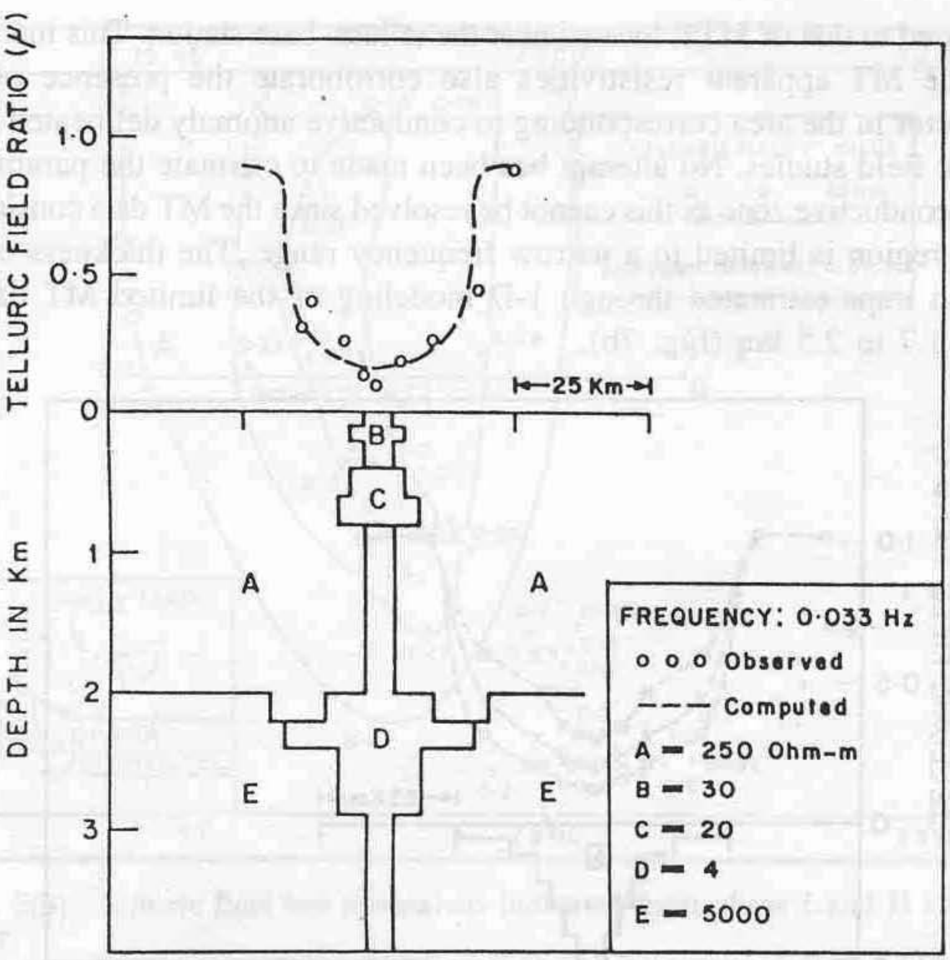
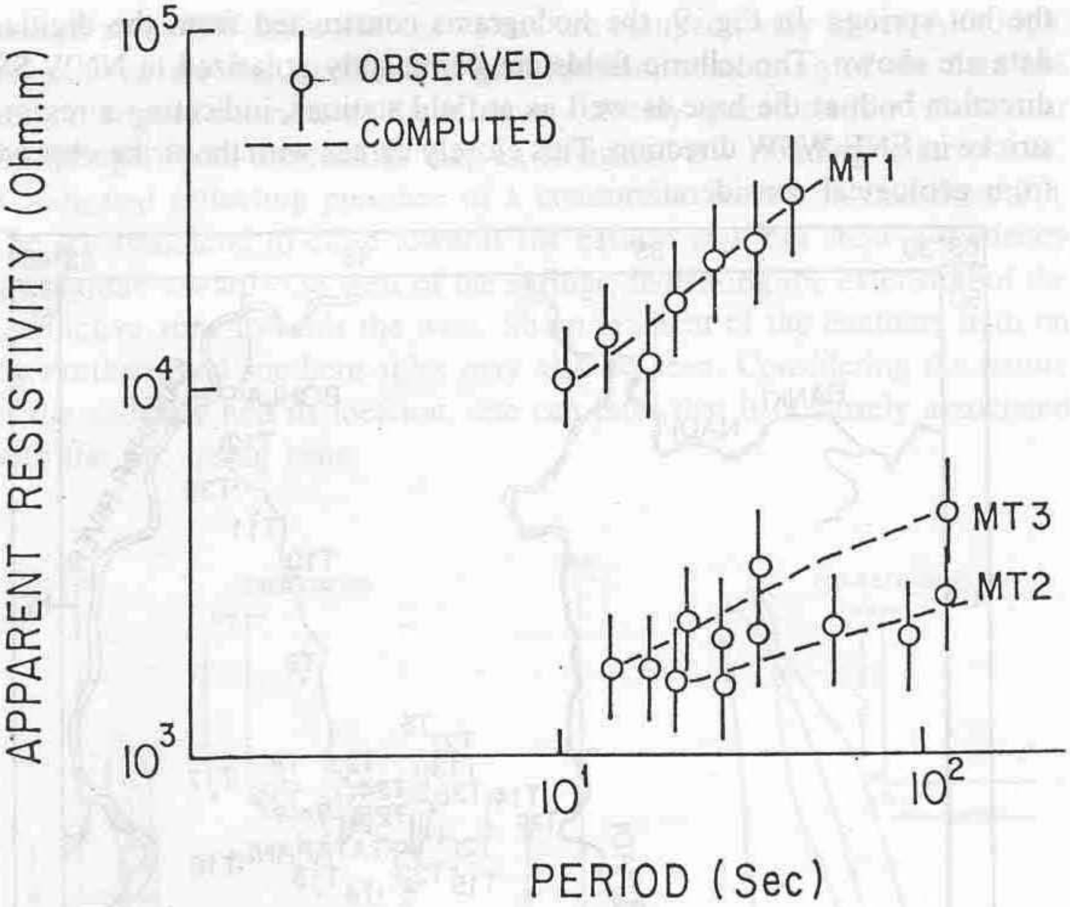


Fig. 6 2-D modeling results considering the deep conductive feature and also the shallow aquifer indicated from deep resistivity sounding results

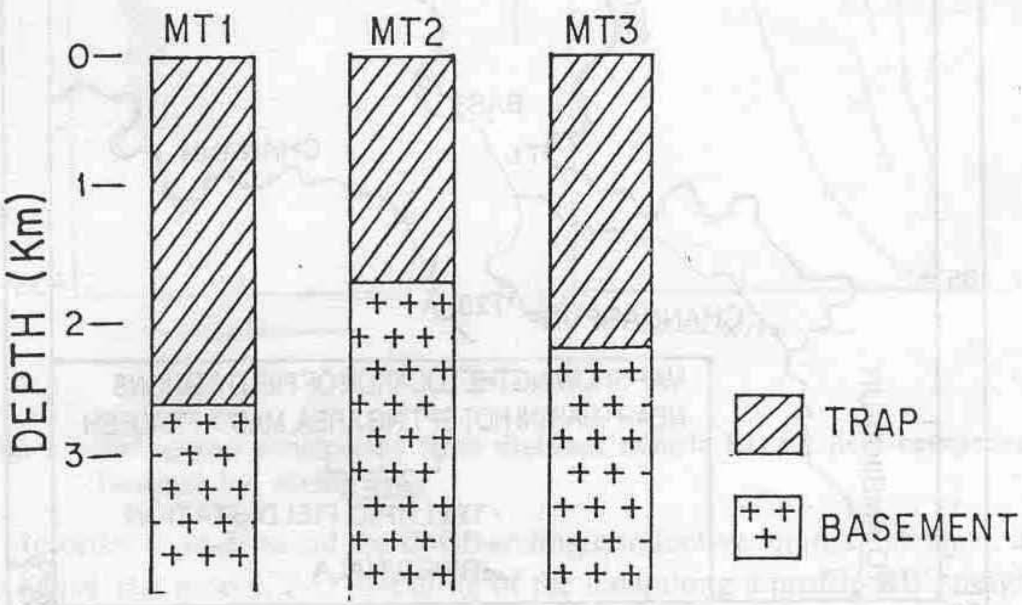
and geothermal studies were carried out by the Geological Survey of India (Ravishanker et al, 1991) in this region. Several shallow drill holes were also carried out in order to assess the geothermal conditions of the area. In one of the bore hole (480 m) near the hot spring a temperature of about 110°C is reported from a depth of about 70 m (Saxena and Prasad, 1983).

The study area is occupied mostly by Archaean and partly by Gondwana rocks. The possible occurrence of a fault striking approximately in EW direction near the springs has been reported (Ravishanker and Prasad, 1988). The Archaean rocks in the area comprise granite gneisses, pegmatites, metamorphosed basic rocks such as hornblende schists, pegmatites, granite bearing amphibolites etc. The strike of the schists and gneisses varies over a wide range of directions with the east-west strike being more common. The gondwana rocks, towards the west and northwest in the study area, consist of Talchirs and Barakar formations, mostly coal bearing (Modak, 1961; Ravishanker and Prasad, 1988).

A total of 30 telluric field stations at intervals of about 2 km were established covering the study area. The stations were distributed roughly in the NS direction along the road connecting the Chandarpur and Bohla villages (Fig. 8). Relatively more number of stations are located near the



(a)



(b)

Fig. 7 (a) Observed and computed MT data from all the three stations and (b) model obtained from 1-D modeling of MT data using linearized inversion scheme

hot spring in order to obtain the details of the anomalous zone. The base station was established at a location situated between the Chandarpur and the hot springs. In Fig. 9, the hodograms constructed from the digitized data are shown. The telluric fields are dominantly polarized in NNW-SSE direction both at the base as well as at field stations, indicating a regional stricke in ENE-WSW direction. This closely agrees with the strike observed from geological considerations.

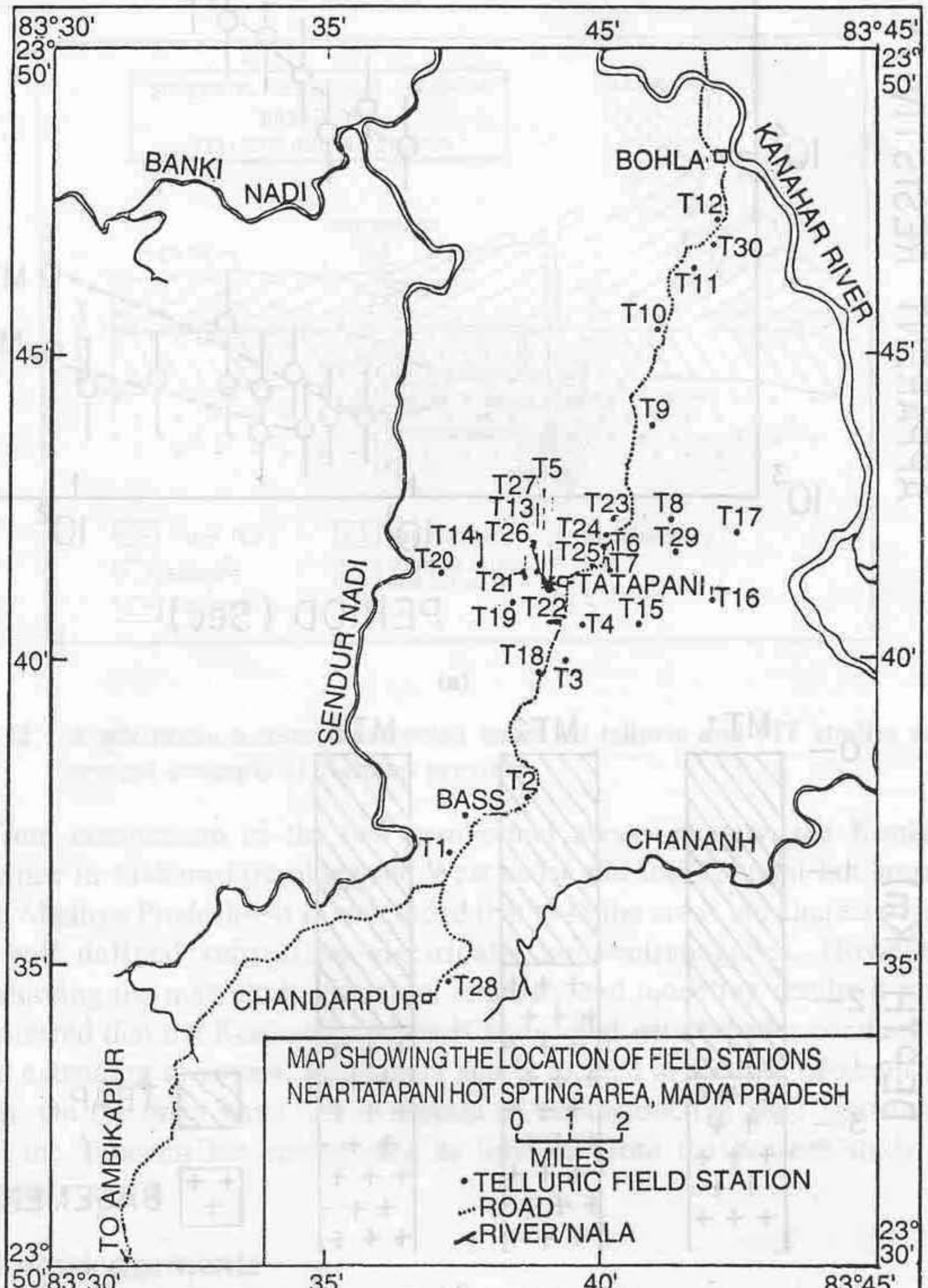


Fig. 8 Location map of telluric stations in Tatapani hotspring area, Surguja district, Madhya Pradesh

The telluric field parameter 'μ' computed from the data for each station in the area is shown in Fig. 10. It is clear that the field values are fairly high in the north as well as south of the hot springs, where it ranges from 0.6 to 1.0. For the stations located near the springs and also for those located along EW direction, the values are comparatively lower. Although, the stations are not located in a grid fashion, contouring of the data has been attempted considering the relatively closely spaced station values near the springs. From the contour map an elongated EW trending telluric 'low' is indicated reflecting presence of a conductive feature in that direction. The contours tend to close towards the eastern end, but show a tendency to continue towards the west of the springs, indicating the extension of the conductive zone towards the west. Sharp gradient of the contours both on the northern and southern sides may also be seen. Considering the nature of the anomaly and its location, one can infer that it is closely associated with the hot spring zone.

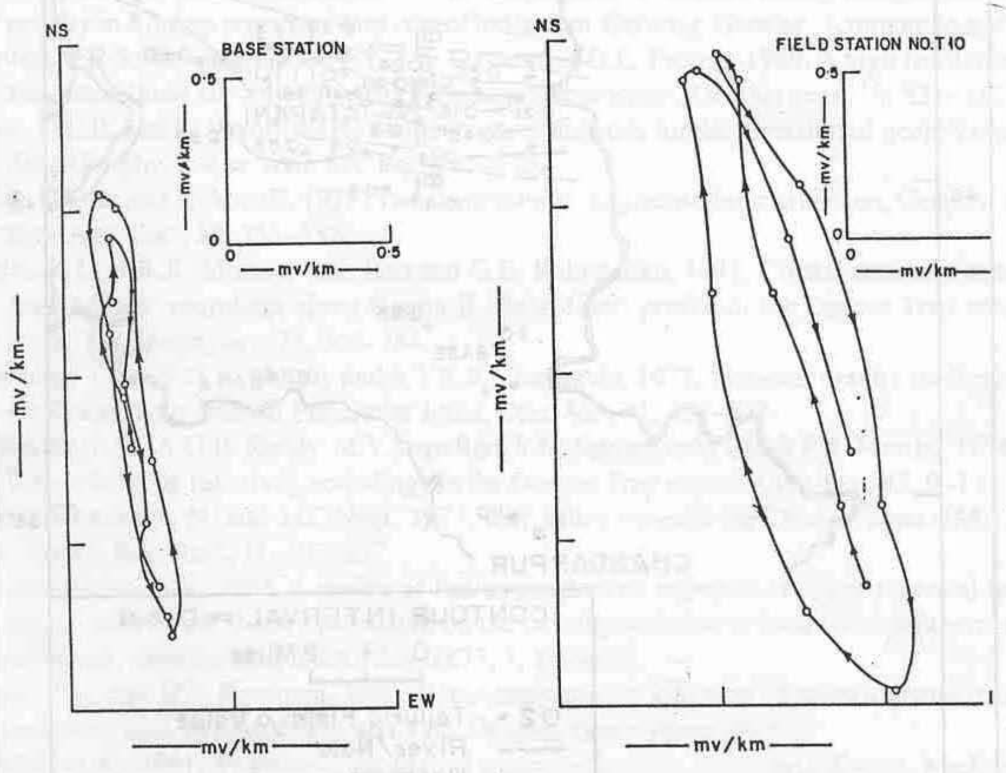


Fig. 9 Hodograms constructed from digitized telluric Ex, Ey field components, Tatapani hot spring area

In order to understand the EW trending conductive anomalous zone, and to arrive at a model, 2-D modeling of the data along a profile BB′, roughly in NS direction, has been attempted using Jupp and Vozoff's (1977) forward scheme. The nature of the geological conditions such as the presence of fault zone near the springs, as also the results of earlier resistivity soundings (Singh and Gupta, 1986) were considered while constructing models. After several attempts, a model which shows an acquifer at 200–400 m depth, together with a vertical fracture zone having resistivity of 100 ohm-m as shown in Fig. 11 is found to fit the field data very closely. It is thus inferred that the Tatapani hot spring telluric conductive anomaly is associated with

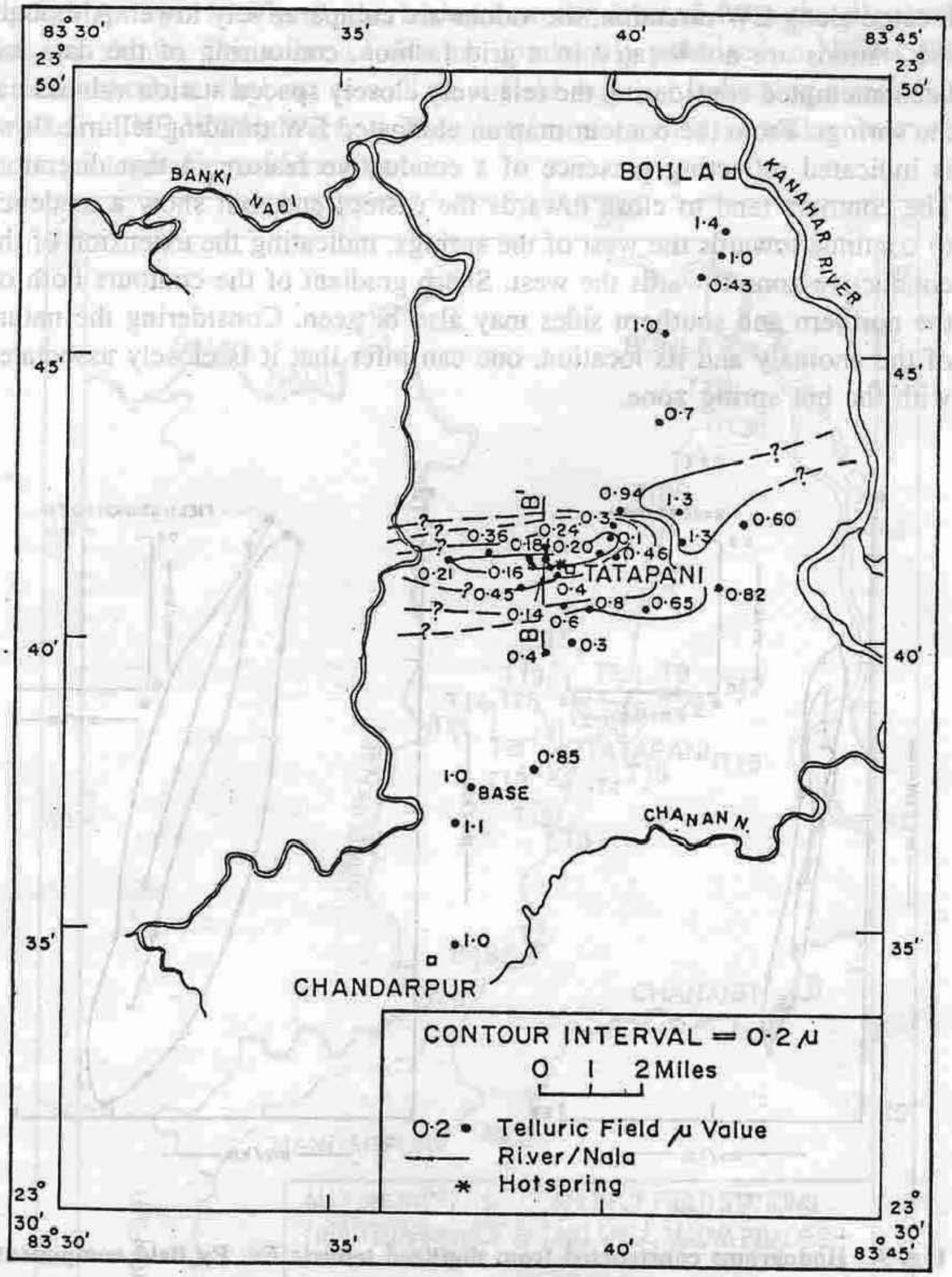


Fig. 10 Telluric field low values around the Tatapani group of hot springs. The trend of contours are in E-W direction

a narrow conductive fault/fracture zone extending to deeper levels in addition to the shallow localized acquifer with a width of about 3 km.

3. Concluding Remarks

Telluric field investigation in Konkan province carried out in two phases (Sarma et al, 1983; Harinarayana and Sarma, 1996) has brought out a well defined broad telluric low near the Sativili-Koknere group of hotsprings, possibly related to the geothermal conditions of deeper source. MT data although limited to a narrow band of 1–100 sec, have supported the telluric field results besides indicating a resistive basement at a depth of about 1.7–2.5 km in the study area. 2-D modeling of the telluric field data indicated presence of a conductive zone possibly related to a deep hot water acquifer at a depth of about 2 km (Fig. 6). The deeper acquifer is interpreted to be closely related to the geothermal conditions of the area. Based on the earlier concepts and also from the results of present telluric, MT field investigations, a schematic section has been prepared and presented in Fig. 12.

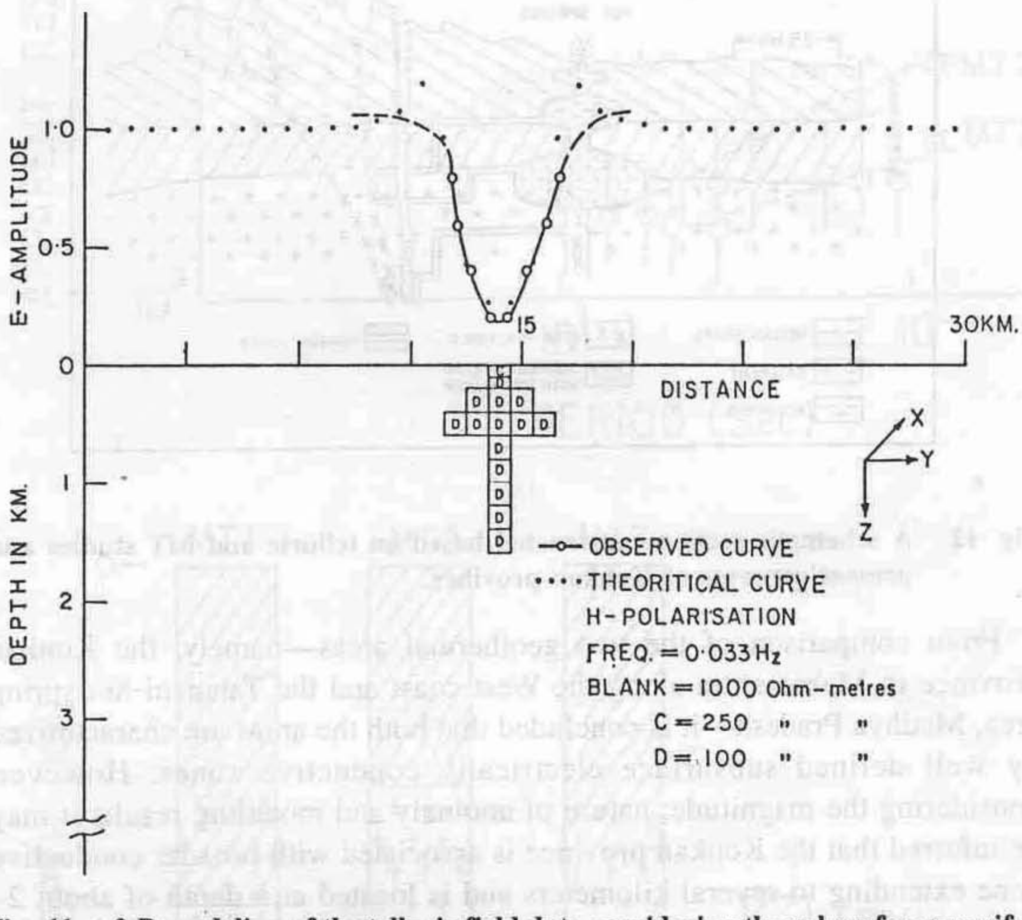


Fig. 11 2-D modeling of the telluric field data considering the subsurface acquifer and a narrow deep conductive zone.

The telluric field study in Tatapani hot spring area clearly delineates an EW trending conductive anomalous zone. The hodograms in the area at both base and several field locations have shown a dominant NS polarization trend, indicating a regional EW strike for the formations. The contours of the telluric field parameter also trending in EW direction gave an evidence for the presence of a narrow, deep conductive zone near the hot springs and gave an indication of its further extension towards the west. From modeling results in Fig. 11, it is clear that there exists a shallow acquifer with a width of about 3 km connected to a deep but narrow fault/fracture zone near the hot spring area. It is presumed that this zone is related to the tectonics of the well known Narmada-Sone lineament, which might be associated with several sympathetic fracture zones.

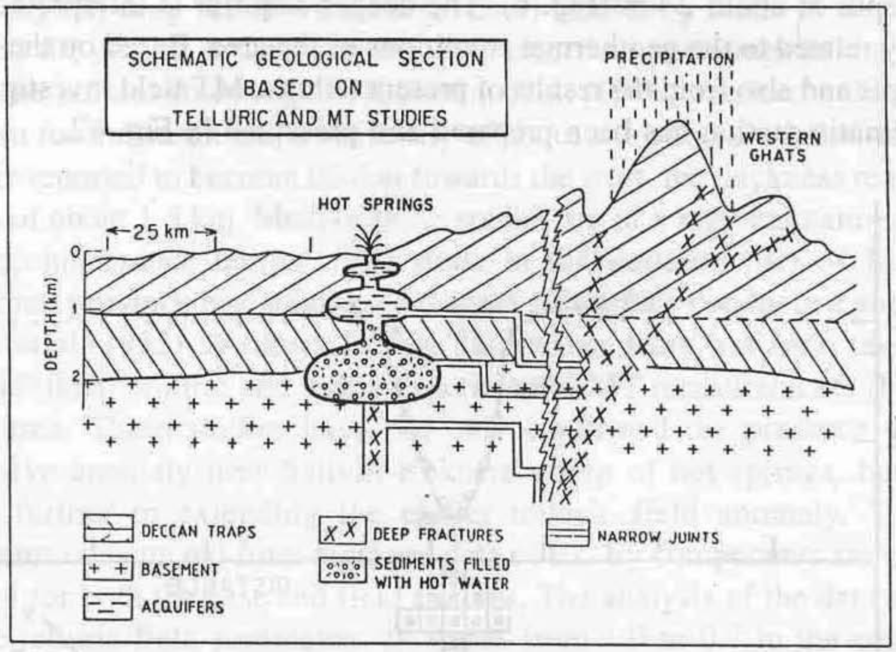


Fig. 12 A schematic section constructed based on telluric and MT studies and present concepts of Konkan province.

From comparison of the two geothermal areas—namely, the Konkan province in Maharashtra along the West coast and the Tatapani hot spring area, Madhya Pradesh—it is concluded that both the areas are characterized by well defined subsurface electrically conductive zones. However, considering the magnitude, nature of anomaly and modeling results it may be inferred that the Konkan province is associated with broader conductive zone extending to several kilometers and is located at a depth of about 2–3 km. On the other hand, the extension of the conductive zone associated with the Tatapani hot spring area as inferred from the present study is relatively small.

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