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Applications of Magnetotelluric Studies in India

T. HARINARAYANA*
National Geophysical Research Institute, Hyderabad-500606,
(Council of Scientific and Industrial Research)
***Email**: thari54@yahoo.com

Abstract

Electromagnetic (EM) induction technique is one of the most important geophysical techniques in understanding the subsurface structure. The theory of magnetotelluric (MT) method, the main branch of the EM technique, was introduced during 50’s by Tickonov (1950) and Cagniard (1953) with the natural variation of electromagnetic fields, as its source. In India, National Geophysical Research Institute (NGRI) initiated this technique during 70’s with the establishment of stationary geoelectric observatory at Choutuppal, Hyderabad. Application of this technique has grown up steadily over the years for various geological problems in India.

Indian geology is quite complex with it’s vast cover of basalt occupied in most parts of western India, thrust regions of north and northeast Himalayan terrains with collision tectonics, mosaic of cratons in peninsular India and large sedimentary basins. MT method has brought out deep crustal structure in these terrains. It is also being used extensively for oil and geothermal explorations, and geo-engineering problems. Apart from this, continuous monitoring of MT signals to study the earthquake precursor phenomena near Koyna and also exploration of the Antarctic continent are new initiatives. Very recently, NGRI has conducted MT measurements for the first time in our country in marine environment i.e. marine magnetotellurics (MMT).

NGRI, along with various other institutions such as Indian Institute of Geomagnetism, Mumbai, Indian Institute of Technology at Kanpur, Kharagpur and Roorkee and Indian School of Mines, Dhanbad, Osmania University, Hyderabad have contributed significantly for deep crustal studies in different parts of India. In the present paper, an overview of the contributions of the technique, applied to various geological problems in India for the last three decades is presented.

Keywords: Magnetotellurics, Oil exploration, Geothermal studies, Seismotectonics, Deep crust, Marine magnetotellurics, Earthquake monitoring

INTRODUCTION

The magnetotelluric method, since its inception during 50's, had a phenomenal growth, both in development of the methodology and also the capability of the method for solving different geological problems. In the following, brief details are provided on theoretical development, its application, and major results obtained by National Geophysical Research Institute (NGRI) and other organizations in India. It is difficult to cover all the aspects of the work carried out in MT by all the organizations in India in the limited space. However, attempts have been made to describe the significant results.

Theoretical developments of the method

Electromagnetic (EM) theory is originated from four fundamental equations proposed by James Clerk Maxwell. These equations are from the well-known principles of Ampere's and Faraday's laws related to electric and magnetic fields. They are further analyzed by Tickonov (1950) and Cagniard (1953) and proposed a relation between the resistivity of a medium and electric-magnetic field variations. These relations gave birth to a new geophysical method, namely 'the Magnetotellurics (MT)'. The fundamental relations in MT can be written as,

$$\rho_a = 0.2\, T\ |Z|^2 \qquad \ldots\ldots\ldots (1)$$

$$\Phi = \tan^{-1} (Z) \qquad \ldots\ldots\ldots (2)$$

Where,
$Z = E/H$
E = Electric field variation in mV/km
H = Magnetic field variation in nT
Φ = Phase in degrees

These scalar equations are modified with the introduction of tensor concepts (Rokityanski, 1961; Wait, 1962). This means that the induced (electric or telluric) field in x-direction can be related to the variations of magnetic fields in both x and y directions. The relations can thus be expressed as,

$$Ex = Zxx\ Hx + Zxy\ Hy \qquad \ldots\ldots\ldots (3)$$

$$Ey = Zyx\ Hx + Zyy\ Hy \qquad \ldots\ldots\ldots (4)$$

Where Zxx, Zxy, Zyx, Zyy are called impedance elements relating electric and magnetic fields. They contain vital information on the resistivity parameter, the dimensionality (1D, 2D or 3D) and directionality (geoelectric strike direction) of the subsurface. Their estimation is therefore the main task in MT data processing.

These equations are valid on the assumption that the incoming natural EM field is a plane wave. The validity of plane wave assumption was questioned by Wait (1954), which was resolved by Price (1962) and Madden and Nelson (1964). Later the use of natural variations of EM field of micro pulsations that was limited in the frequency range, from 1 sec to few thousand seconds, has been extended to audio frequencies and higher, a few Kilo-Hz. These changes in methodology and revolutionary concepts in digital instrumentation and micro-processor based computers paved a way for both exploration problems as well as deep crust-mantle studies. The extension of the method to audio-frequency magnetotelluric (AMT) technique introduced during mid 70's (Strangway et al., 1973; Hoover et al., 1975). The AMT method uses the signals originated from worldwide thunderstorm activity. This means, in order to know the information from near surface to deep crust-mantle depths one need to acquire the data in the range from a few hundreds of Kilo-Hz to a few thousands of seconds (i.e., 10^4 Hz - 10^{-4} Hz covering 7 decades on a log scale). Initially major problems are faced by the data acquisition systems due to extremely low amplitudes of the variations of natural electric and magnetic fields which are in the range of a few tens of micro volts/km and a few tens of pico-Tesla, respectively. As mentioned before, with innovative approaches in amplifying the signals by instrumentation and also with the help of digital micro-processors these problems are solved.

Since the method depends on the natural source fields, the cultural noise posed a major problem to get good quality data. Clarke et al. (1983) have introduced remote reference techniques, in which the noise at a field site can considerably be reduced by cross correlation of the signals from the base site located at a relatively noise free location, provided the data are recorded simultaneously. Decomposition techniques are proposed by Groom and Bailey (1971) to reduce local near surface distortions on the data. Static shift effects can distort the data. Several procedures are suggested to eliminate the distortions (Jones, 1988; Pellerin and Hohmann, 1990; Ogawa and Uchida, 1996; Harinarayana, 1999).

The method has undergone phenomenal growth in different sectors such as data acquisition i.e. developments in instrumentation and recording of the data, processing procedures using robust methods (Egbert and Booker, 1986) i.e. computation of earth response functions from time varying electric and magnetic fields and modeling schemes in 1D (Marquardt, 1963; Constable, 1987), 2D (Wannamaker et al.,1987; Rodi and Mackie, 2001), and 3D (Smith and Booker, 1991; Santos et al., 2002) to derive the subsurface parameters of variation of resistivity as a function of depth from earth response functions.

NGRI along with other organizations have made significant contributions in the theoretical development of magnetotellurics. At NGRI, Harinaryana (1982) have computed theoretical responses of different geological and topographic structures using Scharz-Christoffel conformal transformation techniques. Other significant contributions are in the development of joint inversion schemes (Harinarayana, 1992; Manglik and Verma, 1998) and application of artificial neural network for processing of MT data (Manoj and Nagarajan, 2003) and also on source field studies (Sarma et al., 1987; Madhusudhan Rao, 2002). Indian Institute of Technology (IIT), Kharagpur has contributed significantly in theoretical development of the method. Telluric field response has been studied for a faulted basement, an anticline, infinite throw, and step fault (Roy and Ganguli, 1969); Roy and Naidu, 1970; Roy, 1973; Roy et al., 1982; Roy and Singh, 1993), study of invariant parameters (Roy et al., 1998) and also on joint inversion (Sharma et al., 2005). IIT, Roorkee has contributed mainly for theoretical development of resolving power (Srivastava and Sri Niwas, 1976; Sri Niwas and Kumar, 1991), development of inversion scheme (Sri Niwas et al., 1976, 2005), 2D forward modeling (Anupama et al., 1997; Gupta et al., 1999), and 3D forward modeling (Gupta et al., 1987). IIT, Kanpur has studied time domain MT response (Singh et al., 2007), Tilt characteristics of EM (Singh and Lal, 1980), Reflection characteristics of EM (Singh and Lal, 1980), permeability and tilt characteristics of EM wave (Singh and Lal, 1982). ISM, Dhanbad in contribution to theoretical development and modeling, have studied remote reference technique (Bhattacharya and Shalivahan, 1999, 2002a,b; Shalivahan and Bhattacharya, 2002; Shalivahan et al., 2006) and also on optimization techniques (Shaw and Shalivahan, 2007). At Osmania University, Hyderabad theoretical development has been in the near field CSAMT method (Rao et al., 2000).

Application for geological problems

Due to wide range of depth levels of investigation capability, the method has attracted interest to solve many geological problems related to oil and geothermal explorations, deep crustal studies, engineering problems etc. Like other geophysical methods such as gravity, seismics, magnetics etc. which depends on the density, velocity and susceptibility, respectively magnetotelluric method depends mainly on the electrical resistivity parameter of the earth. The various rock types exhibit a wide range of electrical resistivity parameter (from 10^{-1} to 10^{6} Ohm.m). Such wide range of resistivity is another advantage for electrical and EM methods to differentiate various rock types and its character with ease as compared to other geophysical methods.

MT group, since its inception at National Geophysical Research Institute (NGRI), Hyderabad, India during late 70's has carried out extensive MT surveys to addres various geological problems and with the support of various national organizations (Fig. 1), NGRI has acquired the wideband data at more than 2500 stations covering different geological terrains.

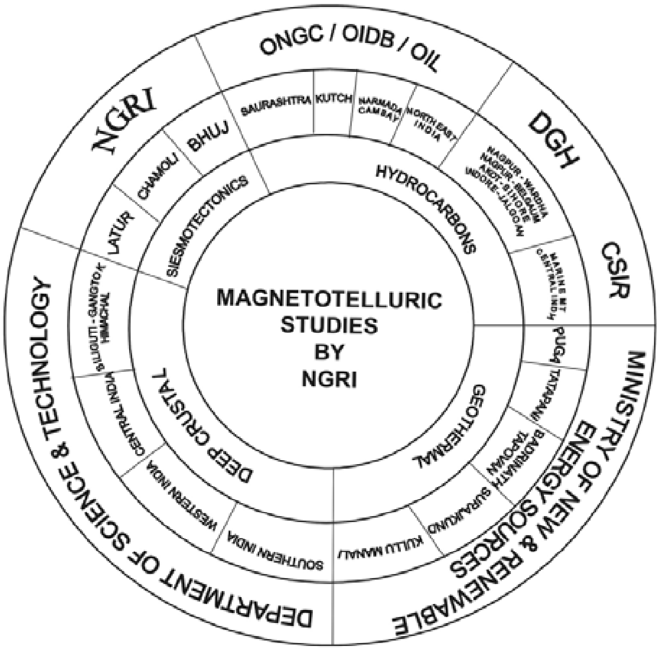

Fig.1. Diagrammatic view of the MT surveys carried out by NGRI for different geological problems, areas surveyed and the sponsoring agencies.

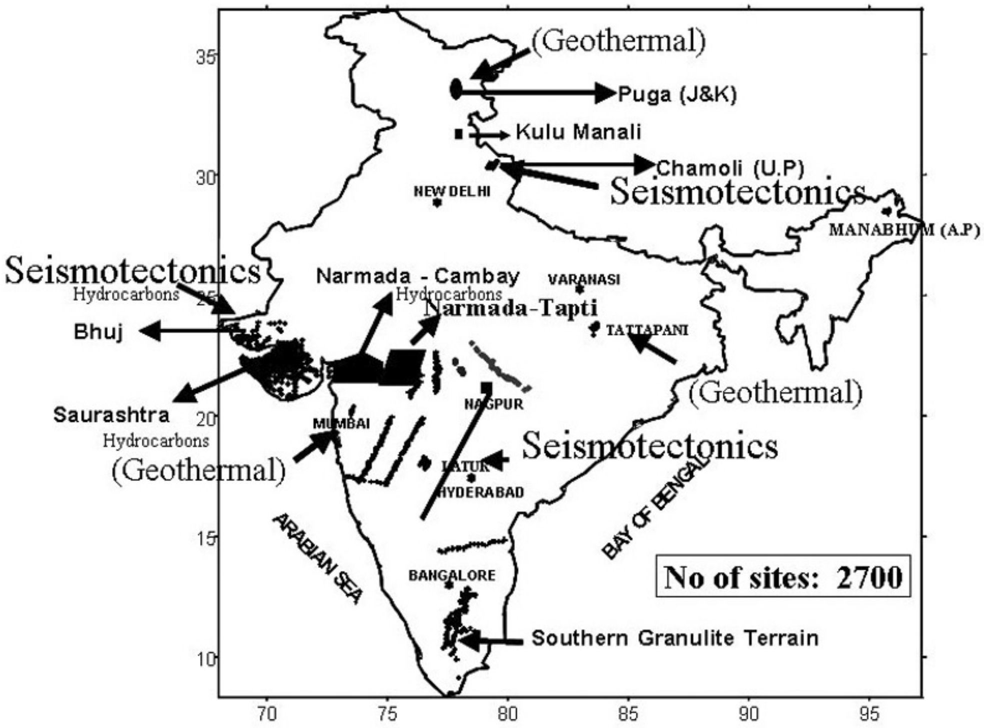

Fig. 2 Location of all MT stations occupied in different geological terrains distributed all over India. A total of about 2700 stations were occupied for the last 3 decades (1980-2008).

MT has been successfully applied for a) delineation of sedimentary structures buried below the volcanic rock covered areas in Saurashtra, Kutch and central India for hydrocarbon exploration, b) mapping of anomalous conductive regions related to geothermal reservoirs near Tatapani, Chattisgarh, Puga region in J & K, Sutlej-Spiti valley and Beas-Parbati valley in Himachal Pradesh, Tapovan-Vishnugad, Badrinath and Lohari-Nag-Pala in Uttarakhand, c) deep crustal studies in central and southern Granulite Terrain (SGT), and d) delineation of anomalous conductive features near Latur, Chamoli, Koyna and Bhuj earthquake epicentral regions. Fig. 2 presents the locations of MT sites, covered by NGRI, in India over different geological terrains (Sarma et al., 1992, 1998, 1999; Harinarayana et al., 2000a, b, 2001, 2002a,b, 2003, 2004, 2005a,b, 2006).

MT FOR OIL EXPLORATION – AN EXAMPLE FROM SAURASHTRA

The presence of hydrocarbon potential in the sediments (Mesozoics) buried below the volcanic rock covered areas, limitations of seismic method to delineate a low velocity middle layer and effective mapping of such layer by MT technique was one of the factors that encouraged the Indian Oil Industry to support the technique for exploration programs. Due to large resistivity contrast between volcanic rock and the buried sediments, MT is proved to be superior as compared to other geophysical methods as demonstrated in India and also at many locations around the world. Prior to MT survey in Saurashtra, the geological model from paleo-river channel study indicated gradual thickening of sediments towards south from the exposed Dhrangadhara and Wadhwan sediments towards north near Chotila. MT studies carried out by NGRI, on an experimental basis were initiated along two profiles – one in NS and the other in EW direction (Fig. 3). Contrary to the earlier geological concepts, MT study has indicated thin sediment towards south and thick sediments towards western part. This result has changed the whole concept of the basin structure. This new information encouraged the oil industry to verify the results and ventured a deep drilling (~3.5 km) near Lodhika. The drilling result showed the existence of 2 km thick buried sediments below 1.5 km thick Deccan traps. Validation of MT interpretation with deep drilling (3.5 km) at Lodhika, Saurashtra (Fig. 3) and also at Latur, Maharashtra (Gupta and Dwivedi, 1996) has proved the efficacy of MT method in the exploration of subtrappean sediments for oil exploration. Due to this, Saurashtra region, which was considered as a low priority region became important for oil exploration. Later on, with the aid from oil industry, the whole of Saurashtra region was covered with 600 stations along with other geophysical surveys as an

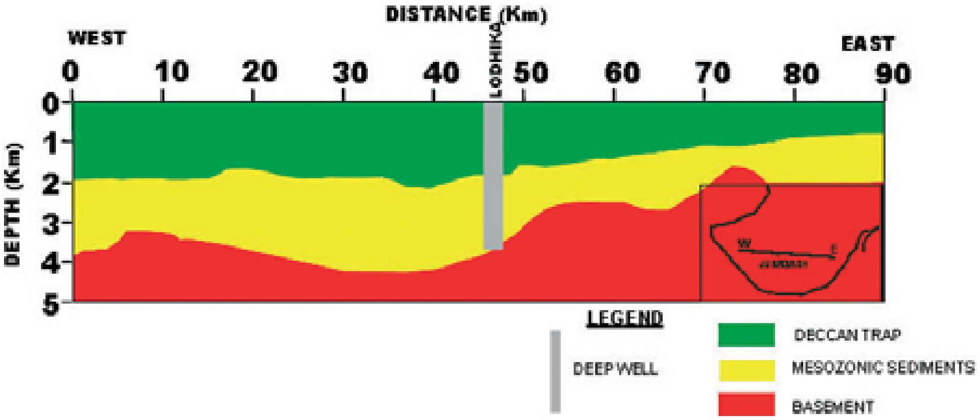

Fig. 3 Thick sediments towards EW direction of Saurashtra. A breakthrough result in India which has opened up a new scenario for the magnetotellurics in India for oil exploration.

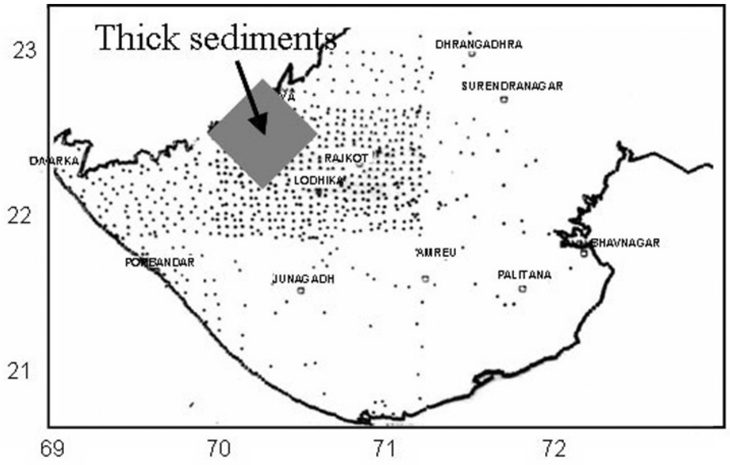

Fig.4. Thick sediments buried below 1.5 km thick trap cover is indicated towards NW quadrant of Saurashtra (indicated by a square in the figure) from magnetotelluric study along with other geophysical methods as a part of integrated studies. Locations of 688 stations are also seen.

integrated approach. Location map of MT sites in Saurashtra region is presented in Fig. 4. The results show thick sediments towards north-western part of Saurashtra below the trap cover as shown in Fig. 4. The success story of Saurashtra region has paved the way to investigate other trap covered regions like Kutch, Narmada-Cambay and Narmada-Tapti rift regions by integrated geophysical studies involving gravity, seismics, deep resistivity surveys along with MT (Sarma, et al., 1998; Harinarayana, et al., 2003).

MT FOR EARTHQUAKE STUDIES

Although the Indian shield is known to be one of the stable continental region (SCR), it has experienced many major earthquakes (Mb>6) within the last decade. MT studies have been taken up in the epicentral zones to map the deep electrical structure. The results obtained using wide band MT technique in four earthquake epicentral regions namely, a) Latur and Koyna regions located in Deccan traps, Maharashtra (Sarma et al., 2004), b) Bhuj in Kutch, Gujarat (Gupta et al., 2001), and c) Chamoli in Himalayan region, Uttarakhand (Begum, 2003) are analyzed for possible relation of the subsurface electrical conductivity structure with seismic activity. These studies have delineated anomalous electrical conductivity and offered better understanding of the tectonics of the region. One of the important results from the analysis of the MT data in these regions is the spatial correlation between aftershock clusters and boundary of anomalous conductivity in epicenter zones. As an example, the MT results from Latur region is described in the following.

The seismic hazardous map of India has five zones (IS, 1984; Khattri et al., 1984). The south Indian region was believed to be stable and considered as a low seismic risk zone, zone-II. With the onset of 6.2 Mb earthquake in 1993 near Killari, Latur district, Maharashtra in trap covered region of south central India, it was felt that the map parameters need to be upgraded. This earthquake also attracted the attention of earth scientists as the death toll crossed 10,000. MT studies were carried out in the Latur epicentral zone in an area of about 40X40 km^2. A total of 16 broad band (1000-0.001 Hz) soundings were occupied using MMS04 equipment. The data were subjected to both approximate inversion using Rho*-Z* and also 1-D and 2-D inversion schemes (Sarma et al., 1994). The result indicated a resistivity of 40-60 Ohm.m for 300-400 m thick Deccan traps underlain by high resistive granitic basement. Absence or thin sediments between the trap and the basement is an interesting observation. These estimates are validated by deep drilling (Gupta and Dwivedi, 1996). The subsurface structure indicated the presence of anomalous electrical conductor (15-25 Ohm.m) at a depth of 4-10 km (Fig. 5). From the seismograph analysis, Pc phase lags behind the Pg phase by 0.6-0.8 sec indicating the possible presence of a low velocity at 7-10 km. This appears to be consistently seen in earthquake aftershock seismograms recorded within the epicentral distances of 30-60 km (Gupta et al., 1996). Such phase lags are indication for the presence of low velocity layers in other regions (Wenzel and Sandmeir, 1992). The spatial correlation of low velocity layer with high conductivity is the reason to believe that fluid is a favorable factor for the anomalous conductive zone (Gupta et al., 1996). This indicates that fluids might have played a crucial role in triggering of the Latur earthquake.

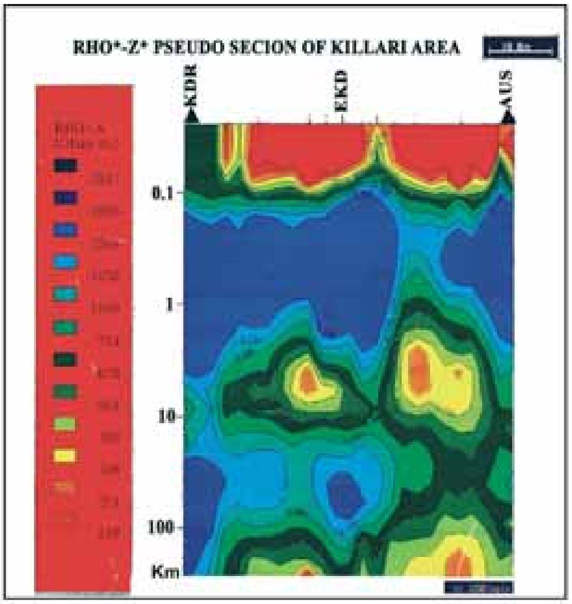

Fig. 5 Anomalous high conductive zone is delineated near the epicentral zone, which leads to interpretation for the presence fluid filled zone responsible for triggering of the earthquake.

MT FOR GEOTHERMAL STUDIES

The hot springs present in the country are grouped into seven provinces (Ravishankar, 1988). The geothermal activity in Puga area is confined to the eastern one third of an E-W trending Puga valley which is about 15 km long and 1 km wide. Thermal manifestation in the form of hot springs, occur on either banks of Puga Nala and also in the Nala bed. Discharge temperature of these springs vary from 30° to 84° C, the latter being the local boiling point at the altitude of Puga, i.e., 4450 m above mean sea level.

Prior to MT study by NGRI, the subsurface information has been well mapped using different geophysical methods and also probed with about 20 bore holes by Geological Survey of India (GSI). However, all these studies have limited depth range - only about 0.5 km. Additionally, there is no clue about the location of deeper geothermal source or it’s dimensions. In order to probe the Puga geothermal deeper structure, wide band MT study has been taken up with the support of Ministry of New and Renewable Energy (MNRE). MT data along 3 profiles in EW directions were collected and 2D modeling results along the profiles delineated a deeper anomalous conductive feature related to geothermal reservoir (Azeez, 2005). Fig. 6 shows the geoelectric structure derived along one of the profiles (profile-c) in the valley. Modeling of the MT data along the Puga valley confirms that the area is characterized by a surface low resistive (10–30 Ohm-m), thin layer (~400m) correlating with the area of thermal manifestation in the area, and an anomalous conductive (~5 Ohm-m) structure in the upper crust of the area commencing from a depth of about 2 km. The high temperature conditions at shallow depths under the geothermal field make the area highly favorable for thermal resource utilization for power production as well as for other industrial applications of geothermal energy. The large depth extension (~8 km) of the anomalous conductive structure accounts for a huge volume of the heat source substantiating its long-term sustainability.

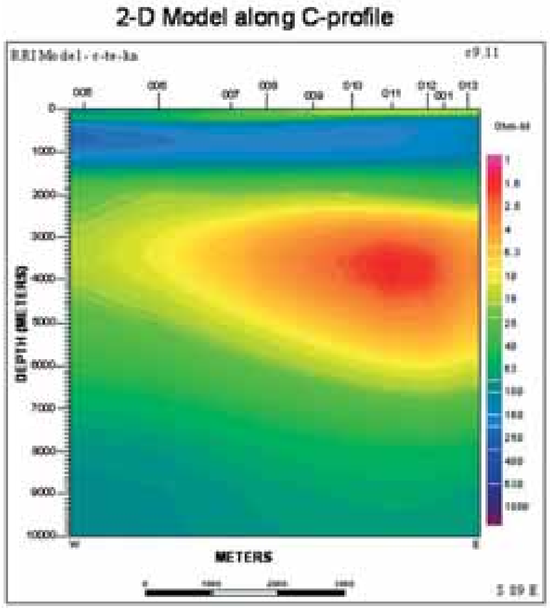

Fig. 6 Geoelectric section from 2D modeling of the data in Puga showing anomalous conductive feature related to deep geothermal reservoir at a depth of about 1.5 km.

However, detailed evaluation of these results and the geothermal characterization of the area need to be made with experimental deep drilling to a depth of at least 2 km. MT studies have also been carried out to access the geothermal resources of west coast and gangetic plain by Singh and Singh (1997) and Puga geothermal region by Singh and Nabetani (1995). Bakreshwar geothermal spring region is studied by Sinha Ray, et al., (2001) and Srivastava, et al., (2007).

MT FOR DEEP CRUSTAL STUDIES

As a part of Deep Continental Studies project of the Department of Science and Technology, New Delhi, NGRI has initiated wide band MT measurements to map the electrical structure of the earth from shallow to deep crustal depths along a few geotraverses (Fig. 7). The traverses covered are A: Seoni-Rajnandgaon across the Central Indian Shear Zone, (Sarma et al., 1997, 1999), B: Edulabad to Khandwa across the Narmada-Son Lineament Zone in Central India (Harinarayana et al., 2002a; Prasanta et al., 2005a, b), C: in Deccan trap region of western India (Harinarayana et al., 2002a), D: Kavali-Anantapur across Cuddapah Basin in eastern India (Naganjaneyulu, 2003; Naganjaneyulu and Harinarayana, 2004), and E & F: in SGT, south India (Harinarayana et al., 2003, 2006). These studies have thrown light on the relation between seismotectonics of the region and upper crustal rocks. In the following, deep crustal character along these six major traverses undertaken by NGRI are compared between upper and lower crustal rocks (Fig. 7). An example of the geoelectric section from near surface to a depth of 50 km along profile-C is presented in Fig. 8. As can be seen from the figure, about 1 km thick top near surface layer corresponds to Deccan traps followed by high resistive crust to a depth of about 30-40 km. The high resistive crust is dissected by narrow conductive features which may be related to buried rift structures/ fracture zones as discussed in detail by Patro et al. (2005).

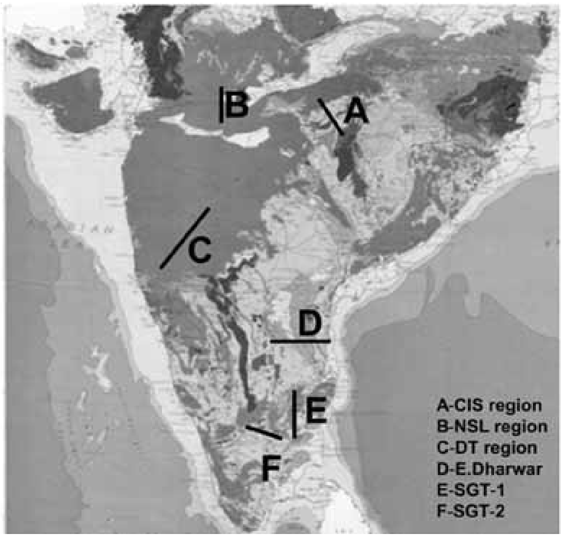

Fig.7. Location of MT traverses distributed in peninsular India as a part of deep crustal studies under Deep Continental programme.

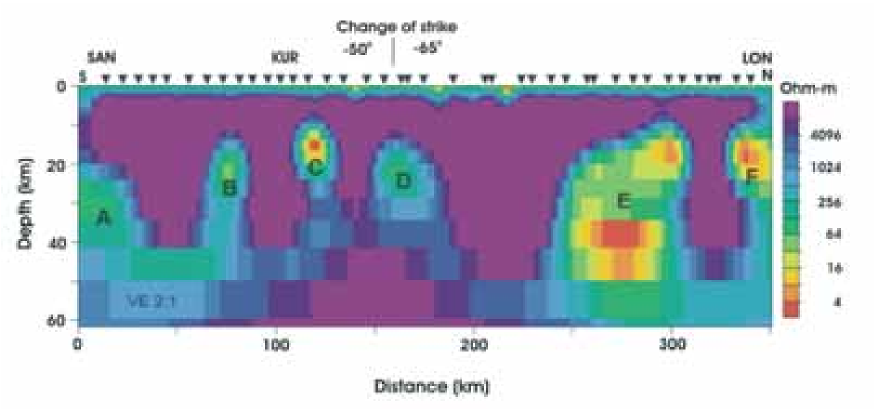

Fig.8. Deep geoelectric structure in Deccan traps along profile-C showing anomalous conductive features related to possible presence of fracture/rift zones.

MT studies in different tectonic regimes of peninsular India have shown distinct nature for each region. Identification of younger or older crust in relative sense can be judged based on the resistivity values (Haak and Hutton, 1986; Jones, 1992). The same rock type of older formation exhibits high resistivity values as compared to the younger ones. In our present study, the upper crustal resistivity is very high, of the order of 30000–50000 Ohm.m, in SGT (Naganjaneyulu, 2003) and southern part of CIS regions as compared to other cratonic regions of peninsular India. Mid and lower crust are in general less resistive, however, their resistivities seems to be relatively high for SGT and south of CIS regions (Table 1 in Harinarayana, 2007).

The marked high resistive upper crust indicates that the crust from CIS region towards south up to about SGT marked by MTSZ (Harinarayana et al., 2001) can be considered as major cratonic structure. On the other hand the region south of MTSZ has shown distinctly different upper crustal signature that might have originated in a different geological scenario. Average electrical lithosphere thickness for DVP is about 100 km. The electrical signature of the anomalous conductive features of the crust relate to (1) major shear zone in the CIS region, (2) surface faults in NSL region, and (3) extension of the shear zones to deep crust in SGT. Electrical resistivity at mid-lower crust strongly depends on the temperature. Interpretation of anomalous conductivity at these depths involves compositional variations within the crust, for example presence of increased amount of fluids or free carbon (graphite?). Although these geotraverses provide us information to understand the deep crustal structure, the western Dharwar region needs to be mapped in more detail to get an overall picture of peninsular India. It is particularly more important in view of a thick lithosphere indicated by recent seismic tomography studies (e.g., Sandeep Gupta et al., 2003). The anomalous conductive features at crustal depths in all the regions studied indicate that the geological structures such as faults, fracture and shear zones have association with the deep crust. Variation in the thickness of upper crustal rocks and the orientation of the underneath faults seems to be responsible for the development of high seismic activity as compared to other regions.

Deep electrical structures of various geotectonic provinces of India have also been probed by IIG, Mumbai. For example, in Dharwar craton and Chitradurg schist belt (Gokarn et al., 2004), Siwalik Himalayas (Gokarn et al., 2002), Rohtak region, near Delhi (Gupta et al., 1997), Mohand-Ramnagar region, (Gupta et al., 1994), Narmada-Son lineament, central India (Rao et al., 2004), central Indian shield region (Singh et al., 2002), Damoh-Mandla region (Gokarn et al., 2001), Indus Tsangpo suture zone (Gokarn et al., 2002), Higher Himalayas and southern Tibet as a part of INDEPTH profile (Unsworth et al., 2005), Shillong plateau, NE India (Gokarn et al., 2008), Tectonics of Deccan traps (Gokarn., 2003). These studies have unravel the deep crustal character of Indian cratons and helped to understand the tectonics of the region. IIT, Kharagpur has investigated deep electrical structure of Singhbhum Granite Batholith region (Roy and Ghosh, 1985; Roy et al., 1989, 1992, 1998), Sukhinda thrust (Roy et al., 2000), western Singhbhum, Bihar (Roy et al., 1998), NSL zone along Khandwa-Indore (Srivastava and Roy, 2002) etc. ISM, Dhanbad investigated East Indian craton (Bhattacharya and Shalivahan, 2002), anisotropy (Shalivahan and Bhattacharya, 2005), Singhbhum Granite (Bhattacharya et al., 2000, 2002), Koyna region in Deccan traps (Singh et al., 1984).

MT FOR MARINE STUDIES

Delineation of thick sediments towards NW part of Saurashtra region and southern part of Kutch has led to the initiation of investigation in Gulf of Kutch region to map the buried Mesozoic sediments. Marine Magnetotelluric (MMT) survey has been carried out under collaborative project with Scripps Institution of Oceanography, San Diego. MMT unit deployed for marine studies is shown in Fig. 9. This unit measures two electrical and two magnetic channels mutually perpendicular to each other. Electric field is picked up through low noise and low impedance silver-silver chloride electrodes. Two BF-4 magnetometer coils from Electromagnetic Instruments Inc. (EMI) cased inside the high pressure tubes are attached to the unit for picking up magnetic field.

The present Cruise of MMT technique is first deployment of its kind in India and attempted on an experimental basis. The survey was successful completed, by testing the methodology in all types of bathymetry in Gulf of Kutch region. At few locations, the data is affected by the natural tidal variations which need special processing techniques to get the magnetotelluric parameters. Preliminary data analysis shows trap layer of about 1 km thickness followed by about 2 km thick sediments in the Gulf of Kutch region. The locations of MMT stations occupied are shown in Fig. 10.

Fig.9. Marine MT equipment of Scripps Institution of Oceanography, Sandiago used in Gulf of Kutch region. This is the first ever experiment using marine magnetotelluric technique in India.

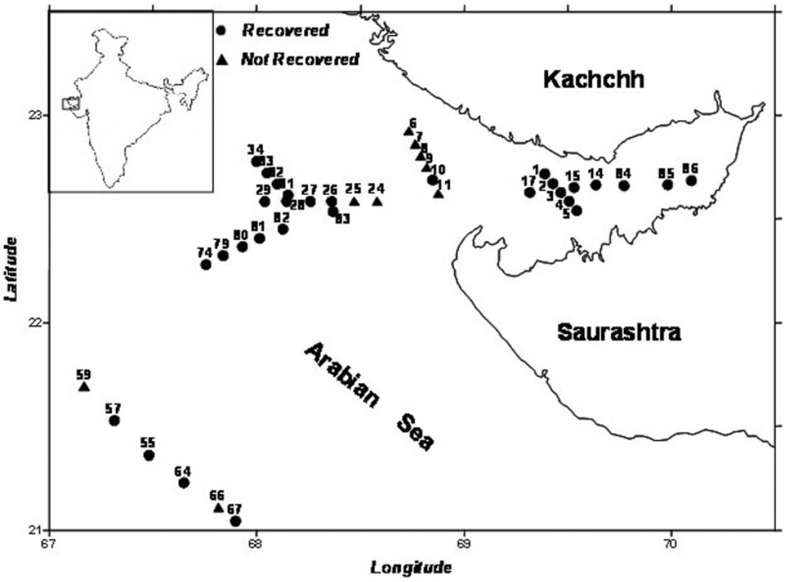

Fig. 10 Location of marine MT stations deployed in Gulf of Kutch.

MT STUDIES IN ICE COVERED REGIONS – ANTARCTICA

Wide band (1000-0.001 Hz) MT soundings were carried out during Jan.-Feb. 2005 along an EW profile. The general problems related to data acquisition in cold climate were overcome with computer aided online processing facility using internally heated lap top computer and using special electrodes made of Titanium metal plates. Use of titanium electrodes has reduced the contact resistance and facilitated to record the high frequency signals. A total of ten stations have been occupied with a station interval of about 5 km (Fig. 11). The signals were recorded for about 5 days at each station to acquire long period signals and also to obtain good quality of short period signals. The upper crust is resistive, of the order of 10000 Ohm.m underlain by relatively more conductive middle and lower crust. The results are comparable to the subsurface structure of SGT of south India.

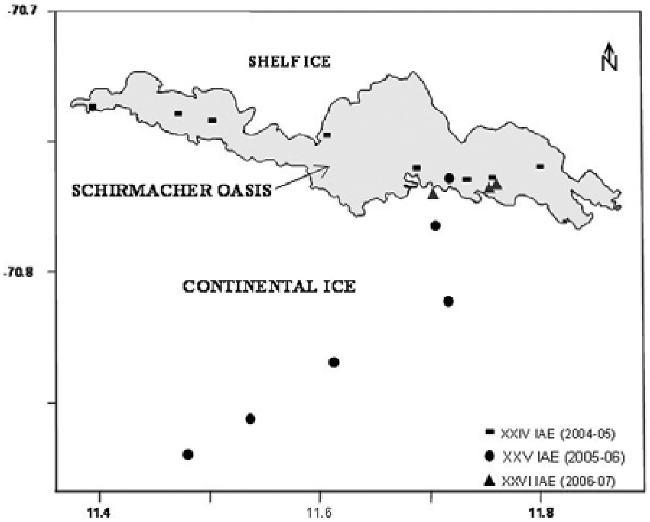

Fig.11. Location of MT sites in Antarctica.

SUMMARY

MT technique over the past decades has proved its effectiveness in India and has become a part of regular geophysical surveys on par with age old geophysical techniques like gravity, magnetic, electrical and seismic methods. Oil industry in India, which used to rely mostly on seismic, has turned towards this technique due to successful validation of the MT results by deep drilling at two locations namely, near Lodhika in Saurashtra region of Gujarat and near Latur in Maharashtra. MT has delineated deep crustal structures which provided much needed input for tectonic evolution of different geological terrains. It will provide a pivotal role in seismotectonics and earthquake studies in future. Successful deployment of Marine MT in Gulf of Kutch appears to have large potential in delineating the buried sediments below the trap cover of Western and Eastern offshore region.

The development of new data acquisition systems allow the sensors to be placed at remote locations and the data can be viewed at base location in real time using GSM technology. These changes again make the technique more attractive and useful and therefore, MT in the coming years will play an important role in various exploration and geodynamic programs both on land and also in off-shore regions.

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