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TELLURICS AND MAGNETOTELLURICS-THEIR ROLE IN EXPLORATION PROGRAMMES IN INDIA

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Abstract

Because of their vast application potential in understading subsurface electrical conductivity distribution to great depths, as well as under different geological conditions, Telluric and Magnetotelluric methods play an important role in Geophysical Exploration programmes. With the initiation of efforts for the development of these techniques at the National Geophysical Research Institute, the introduction of these methods in India has just begun and during the last few years the telluric method has been applied successfully for a variety of geological problems. This review, besides giving a broad outline of the basic principles of data acquisition and interpretational techniques underlying these methods, also discusses a few examples of field investigations in India. Need and scope of applications of these methods for different geological problems in India are also discussed.

Introduction

Telluric and magnetotelluric methods, constitute an important subgroup of one of the major branches of geophysical prospecting namely the electrical/electromagnetic methods. Both the methods aim at probing the nature of subsurface electrical conductivity distribution and its variations associated with lithological and structural changes. While the basic principles of telluric method were known since the early decades of the present century (Schlumberger, 1939), the magnetotelluric methods took its shape during the last three decades (Cagniard 1953, Tikhonov 1950, Madden & Nelson 1964, Keller 1971, Vozoff 1972, Kurtz & Garland 1976, Adam 1976). Both methods use the naturally occuring low frequency electromagnetic signals as their source fields and are considered to be very effective geophysical tools for studying subsurface conductivity structure to great depths as much as a few tens of kilometers, and thus find application in a variety of geological problems, including geothermal exploration, sedimentary basin studies, mineral exploration, deep crustal and upper mantle studies etc..

General principles

Tellurics : Low frequency fluctuations of the geomagnetic field (a few Hz to 10^{-3} Hz) called "pulsations" provide the source signals measured in the telluric and magnetotelluric field investigations. The pulsations generated in the magnetosphere appear at the earth's surface as quasi-sinusoidal waves of the geomagnetic field and as these waves pass through the conductive earth, they induce electrical currents in the earth, known as telluric currents, which bear close resemblance to the magnetic pulsations. While the telluric current pulsations form the source field measured in the telluric method, both magnetic and corresponding telluric signal are used in the MT signal measurements.

The strength and direction of telluric field pulsations measured at a place are influenced by the electrical conductivity of the subsurface medium and hence are strongly controlled by the subsurface lithology and structure. Thus a study of relative strength of telluric signals on the earth's surface at various places in an area would yield information with regard to broad variations in the electrical character of the subsurface medium under investigation and this forms the basis for the development of telluric current method of prospecting.

Field procedure in telluric surveys for study of sedimentary basins, consists of recording telluric signals *simultaneously* at a Base station and field stations, by employing atleast two similar telluric signal recording units one for the Bass station and the other for occupying field stations. Signals are recorded generally in the low frequency range 0.05 to 0.01 Hz and at each field station the interval of recording may range from about 15 minutes to one hour depending upon the nature and quality of signals. During field measurements, telluric signals are picked up as voltage differences across pairs of non-polarizing electrodes fixed in the electrical contact with ground. Normally at a telluric station, the telluric field is measured across two orthogonal dipoles i.e., across a pair of orthogonal telluric field lines consisting of an array either in the form of "+" or "T" or "L". Field equipment is highly portable and is mainly comprised of an amplifier unit, and a recording unit, besides the cables, electrodes and portable accumulators.

In the basic theory of the telluric current methods, as applied to study of sedimentary basins it is assumed that the telluric field is a steady state direct current field and the primary telluric field is homogeneous over large areas. It can be shown from these theoretical considerations that, components of telluric field observed simultaneously at two stations (say a Base and a field station) which are not too far apart, are linearly related and based on this relationship, a parameter representing the average telluric field strength for each field stations with respect to a Base station can be computed (Berdichevskiy 1965). The telluric data analysis thus involves mainly the computation of the relevant telluric field parameters usually referred to as J.K. and M, representing the average telluric field strength at various stations for which there exist several conventional techniques like triangle method, ellipse method, vectogram method etc., (Berdichevskiy 1965, Yungul 1977). The spatial distribution of this parameter in a given area would provide the basic telluric anomally map for further interpretation in terms of subsurface geology.

The interpretation of telluric data in general is mostly qualitative, nevertheless one can go in for quantitative interpretation of telluric anomaly maps when additional information on longitudinal conductance and depth to basement at a few select places obtainable independently say from D.C resistivity or MT soundings or test drillings, are available. Results of several field investigations show that such quantitative estimates of basement topography agree well with those from refraction seismics.

Though the area of application of telluric method has been mainly in the exploration of large sedimentary basins, and geothermal studies, its utility as a lateral exploration tool for studies of targets of limited dimensions such as those encountered in mineral exploration is yet to be fully utilised. One of the commonly adopted field procedure meant for continuous coverage of a profile is the well known split spread method (Yungul 1977). This is a single station single component measurement technique which employs a field set up having collinear and equally spaced three electrode array forming two successive electrode lines across which telluric field signals are tapped and recorded. The array is leap-frogged along the profile and the successive telluric field ratios (ER) ER being the amplitude ratios of telluric signals recorded simultaneously on adjacent telluric field lines on the profile (Yungul 1977) are computed. This method of measurement provides a rapid and continuous coverage of the profile and brings out local resistivity changes such as those associated with faults, shear and fracture zones, and targets of limited extent.

Magnetotellurics (MT)

The MT method. utilizes the same source field as that used for telluric method. namely the pulsations of the earth's natural electromagnetic field in the low frequency range, but in this case both the telluric and magnetic pulsations are picked up. As mentioned earlier the E-field components. i.e., the telluric current field components. hold most of the geologic diagnostic power in their signature. The study of the relationship between E-field components and the corresponding 'H' – field components, observed simultaneously at a place as a function of frequency, brings out the essential information on the subsurface conductivity distribution and thus forms the main basis for the development of the magnetotelluric method. The frequency of the signals measured provides the basic depth control, since waves of different frequencies penetrate to different depths due to skin depth effects. Accordingly MT signal measurements are carried out over a wide frequency band, usually from a few tens of Hz to as low as 10^{-3} Hz which would cover the depths of interest in Geophysical exploration say from a few hundred meters to several kilometers.

The field data recorded for a magnetotelluric sounding include three mutually perpendicular components of magnetic field Hx, Hy and Hz, (Hx, Hy–two horizontal orthogonal components, Hz-vertical component) and two telluric components (Ex, Ey–the two orthogonal telluric components corresponding to the two magnetic components). While the sensing of telluric field signals is simpler the signal recording of magnetic field component is a difficult task and the familiar core-coil induction magnetometers are by far the simplest and the best magnetic signal sensors, employed in MT field surveys. The MT field lay out thus consists of a pair of orthogonal telluric field lines of each about 500 to 1000 m, long and three core coil induction magnetometers placed firmly in the ground and oriented in appropriate directions (x, y and z) to pick up the respective field components. The signals picked up at the sensore are amplified using very low noise, low drift high gain amplifiers and are recorded in digital form in discrete frequency bands.

In proposing the basic theory of MT method, Cogniard (1953) has considered the source field as plane waves, a valid assumption atleast for the frequencies of interest in exploration problems, (Price 1962, Srivastava 1965), and showed for a homogeneous or a one dimensional medium, that E and H fields observed simultaneously at a place are related to each other in such a way that the apparent resistivity (ρa) as a function frequency 'f' (or period T) can be obtained from the formula

$$\rho_a = \frac{1}{5f}\left|\frac{E}{H}\right|^2$$

The ration E/H is usually referred to as impedence "Z" and is related to the electrical properties of the medium as shown above. It can be seen that computation of "Z" over a frequency range would provide 'ρa' versus 'f' plot which would form the basis for determination of subsurface geoelectric structure.

In the simple cases of homogeneous and isotropic or one dimensional earth, the relationship between E & H vectors are related through a simple scalar impedence term as shown above. However, in the case of anisotropy, and two/three dimensional structures, the impedence term becomes tensorial and in such cases the relation between the magnetic and telluric components are described by the following relation:

$$\begin{vmatrix} Ex \\ Ey \end{vmatrix} = \begin{vmatrix} Zxx & Zxy \\ Zyx & Zyy \end{vmatrix} \begin{vmatrix} Hx \\ Hy \end{vmatrix}$$

Where Hx, Ey; Hy, Ex are the orthogonal magnetotelluric field componenth. Zxx, Zyy, Zyx and Zxy are the elements of impedence tensor relating the magnetic and telluric fields which form the main set of parameters, determind In the regular processing of MT data. Methods mainly used in MT data processing have been reviewed extensively by Vozoff (1972) and Hermance (1973).

Interpretation of MT data essentially aims at the development of a plausible picture of subsurface geoelectric section, in terms of one, two or three dimensional geometry, that is consistant with the observed MT data. Interpretation for the case of one dimensional earth (layered sequence) and to some extent for the two dimensional (2D) case has come to a fairly organised state particularly through the use of inversion techniques (Wu 1968, Jupp and Vozoff 1975, Muller 1977, Oldenburg 1979). Though several 2D numerical modelling techniques have been developed and successfully adopted in MT (Losecke and Muller 1975, Jupp and Vozoff 1977), present efforts in 3D modelling technique are yet to produce reliable results (Fozoff 1980).

Some recent advances in MT

During the past one decade the MT data has gone through several stages of significant developments particularly through (i) the introduction of microprocessor/minicomputer controlled data acquisition systems, (ii) innovation of special noise reduction schemes such as "remote reference stations" techniques, (iii) development of 2D and to some extent 3D modelling programmes in MT interpretation using inversion techniques.

Most of the present day MT data acquisition systems are micro processor/computer based and this facilitates the completion of a good amount of data processing and obtaining some preliminary results at the MT site itself. Such infield data processing helps in exercising control checks on the quality and quantum of data being acquired during the programme of MT sounding in the field as also in introducing necessary changes in the field lay out of MT stations, if any required on the basis of such preliminary results.

It is generally seen that final estimates of apparent resistivity obtained from even the best MT data are found quite often to show considerable scatter and this has been a problem in MT data analysis and interpretation, for a long time. This has been resolved very recently through the introduction of the "remote reference station technique" in MT field data acquisition (Gamble *et al.* 1979, Coubau *et al.* 1978). It has been shown that noise in the form of local fields would enter the data and produce scatter in the impedence estimates and it was proposed that such noise fields could be removed by employing an additional MT station i.e. a remote reference magnetic field station. In this tenhique field that which are coherent between the two stations (i.e., the its reference station) would be used for impedence estimates and such data would yield scatter free impedence estimates since the noise, which is uncorrelated between the two stations, will get averaged to zero.

The MT thus provides the basic and independent quantitative information on subsurface geoelectric structure. Though the resolution capabilities are not as high as some of the other geophysical techniques like reflection seismics, the ambiguity in interpretation of MT results, is much less as compared to gravity and magnetic methods. Further, the depth of investigation that could be achieved with MT is quite remarkable and one can get reasonably reliable estimates of conductivity distribution to depths as much as a few tens of kilometers, with the conventional D.C. resistivity methods using artificial source, is very hard to imagine. MT finds its application in a variety of geological problems such as crustal & upper mantle studies, sedimentary basin studies, geothermal exploration and to some extent in mining and engineering problems) Kaufman & Keller 1981; Vozoff 1972)

It can thus be seen that while "tellurics" provide an excellent qualitative picture of lateral variation in subsurface conductivity, the 'magnetotellrics' offers the unique advantage of obtaining quantitative estimates of surface conductivity distribution. With the awareness of the vast application potential of these methods in subsurface exploration, the National Geophysical Research Institute, has initiated a developmental project in this branch of Geophysics, with the main objective of introducing the 'tellurics' and 'magnetotellurics' into the geophysical activity for subsurface investigations in India. The work accomplished during the last few years under the first phase of this programme, mainly relate to the telluric field investigations which include the development of (i) necessary field equipment, necessary software for computer analysis of telluric field data development of a few techniques for telluric data analysis and interpretation (Sarma *et al.* 1978; Harinarayana and Sarma 1982; Rakeshkumar 1980, 81; Harinarayana and Sarma 1982) and applications of "tellurics" for different types of geological problems (Sarma, 1978; Sankernarayan *et al.* 1979. Rakesh Kumar *et al.*, 1979, Sarma *et al.*, 1981, Sarma *et al.*, 1981; Sankernarayan *et al.*, 1982; Sarma *et al.*, 1982). The results of telluric field investigations are proved to be quite useful and interesting and what follows is a brief account of some of these investigations:

i) Sedimentary basin studies:

Telluric field investigations in Cuddapah Basin :—

A telluric field survey was conducted along two profiles, Tadapatri to Anantapur and Bhogasamudram to Gooty, in the south-western region of Cuddapah basin. The profiles traverse across quartzites, limestones, quartzites and shales in order from west to east and, of these the limestones and shales are the major units. The formations dip towards east, with dips ranging from 10° to 15° and there are also a few exposures basic sills in this region. The base station was chosen at a place near Bhogasamudram and field stations were occupied with a station interval of 2 to 4 km to cover all types of geological formations along the profiles. The telluric field profiles along these two traverses resenble each other very closely and Fig.1 shows the Tadapatri—Anantapur profile. The profile, besides reflecting the lateral resistivity changes associated with lithological changes, also indicate (i) a thickening sedimentary column from west to east (ii) possible presence of a deeply buried high resistive body, represented by the domal shaped telluric 'high' on the eastern half of the profile, (iii) possible fracture zones at the western margin of the basin, represented by depressions in telluric field profile (Sankernarayan *et al.* 1979, Sarma *et al.* 1980). Thus the telluric field picture along these profiles, besides responding well to some of the known geological facts, has also provided some clues to understand the subsurface details.

(ii) Geothermal investigations:

Tellurics has been tried in three important, geothermal areas in India, namely the Puga Valley in Ladakh Himalayas, Konkan geothermal province on the west coast, and the Tattapani hot spring area in Madhya Pradesh and the results are found to be highly promising as detailed below briefly.

(a) The Puga Valley, Ladakh:

The Puga Valley is believed to be perhaps the most promising area from the Geothermal resources point of view and considerable geophysical work has been carried out in this area by the Geological Survey of India and the NGRI. Field investigations were conducted in Puga Valley to examine the telluric field response of the suspected geothermal reservoir in this region. Both telluric mapping and telluric split-spread methods were used in the field investigations. Since the valley is narrow and is bordered by steep hills, only one profile could be covered and this was laid along the axis of the valley along which stations were occupied at 1-2 km interval. The telluric field anomaly curve, represented by 'J' values (J, parameter representing the average telluric field intensity at each station) along the traverse is shown in Fig. 2. This curve exhibits a distinct telluric 'low' stretching in E-W direction, which reflects the presence of highly conducting material in this region probably related to subsurface geothermal reservoir. It may however be mentioned that the geothermal fluids in this area, presenting a good near surface conductor, do naturally influence the telluric anomaly and hence part of this anomaly is attributable to these surface conducting zones. (Rakeshkumar *et al.* 1979). In addition the results of telluric split spread survey carried out in the northern side of the valley indicate the presence of some narrow channel like features extending across the direction of valley axis.

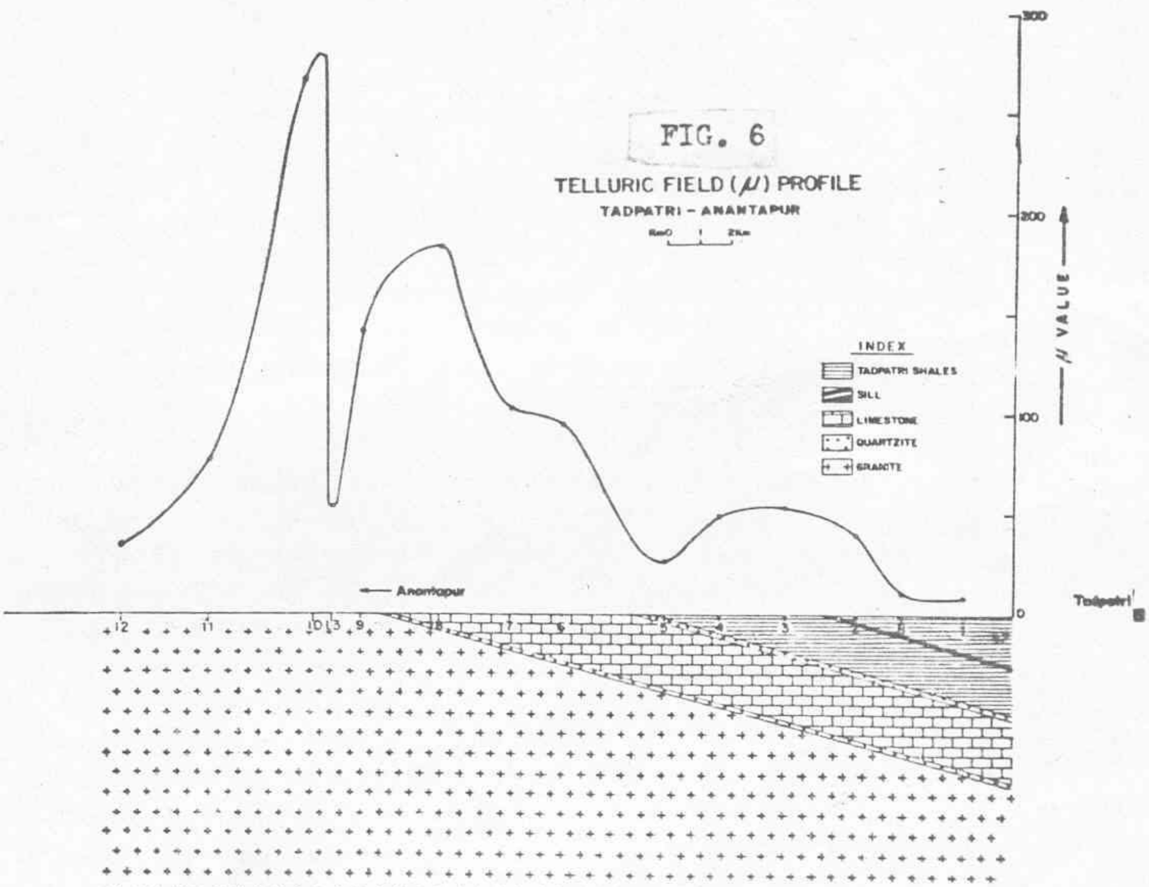

FIG. 6

TELLURIC FIELD (μ) PROFILE

TADPATRI – ANANTAPUR

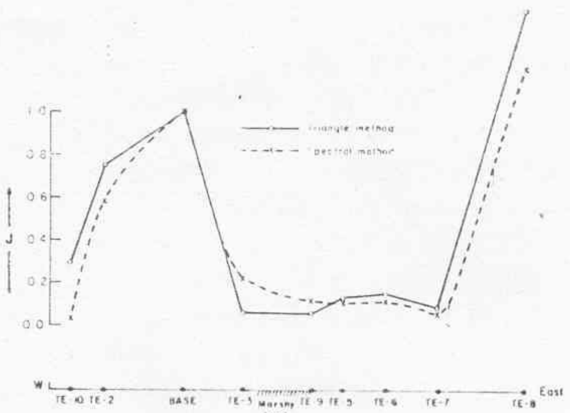

Fig.2. TELLURIC ANOMALY PROFILE ALONG THE AXIS OF THE PUGA VALLEY

(b) Konkan geothermal province-west coast;

Tellurics has been utilised to investigate yet another important geothermal province in India, namely the Konkan geothermal province. The Konkan hot spring zone extends for over a few hundred kilometers along the west coast, in an area occupied mostly by Deccan basalts. Though there exist several hot springs in this belt, the results of earlier geological, geochemical and geophysical investigations do not indicate with any definiteness the existence of a geothermal reservoir in this area and thus leave vast scope for further investigations. In view of this, a reconnaissance telluric survey was carried out covering an area of more than 200 sq. km surrounding the Akloli-Ganeshpuri-Sativili-Koknere hot spring zone. The results of this investigation has brought out the existence of a well defined telluric low located in the northwestern part of the area surveyed as shown in Fig. 3. This anomaly reflects positively the presence of a highly conducting zone at fairly deeper levels which appears to have a close bearing on the geothermal setting of this region (Sarma *et al.* 1982).

(c) Tatapani hot spring area. Sarguja Dt.,M.P.:

A detailed telluric survey has been carried out in the vicinity of Tatapani hot spring zone, Surguja of M.P. covering an area of about 150 sq. km. The results of analysis of the data have clearly delineated an East-West trending electrically highly conducting zone. From geological considerations, this zone may be well correlated with an E-W fault zone traversing across this area along the axis of which the known hot springs occur.

(iii) Other applications
Kalava area, Kurnool district, A.P.:

The Gani-Kalava area, a mineralized belt in Cuddapah Basin had drawn special attention in exploration programmes of geological survey of India during the past several years. As a part of a multiparameter geophysical experiment carried out by NGRI in this area a split spread telluric survey has been conducted on an experimental basis along twelve traverses cutting across the known conducting belt in the Kalva area. The "ER" profiles show a well defined pattern with a 'low' in the middle of the profile sandwitched between two 'highs' as could be seen from Fig. 4. While the 'highs' are attributed to intrusive dominated shale country on the south and the high resistive Kalva wall on the north, the narrow 'low' in the middle reflects the conducting zone. The 'lows' as seen on the profiles are shown to clearly demarcate the known conducting zone. Considering its rapidity, simplicity and effectiveness in delineating resistivity contrasts, the telluric method is shown to have a vital role to play in the exploration programmes in investigating this mineralized belt. (Sanker Narayan *et al.* 1982).

(b) Kimberlite pipes area near Vajrakarur and Lattavaram Anantapur District, A.P.:

Occurrence of a few kimberlite pipes in the area near Vajrakarur and Lattavaarm was known since long, and considerable geological and geophysical work has been carried out in this area. Besides the influence of weathering of the pipes, the complex nature of host rocks granites/gneisses and the presence of numerous basic dykes in the area make the geophysical picture more complex from the view point of identification of individual geophysical anomalies associated with hidden pipes if any. Since obtaining an additional and independent geophysical signature over the pipes would be helpful in the overall exploration programme, the telluric method has been tried in this area on an experimental basis. The acquisition of telluric data was accomplished through a split spread telluric survey over all the known Kimberlite pipes in this area. Results of this investigation clearly established that Kimberlite diatremes found characteristic expressions mostly in the form of 'lows' in the telluric field picture, and it is shown that 'tellurics' as a prospecting tool holds considerable promise in exploration of Kimberlite targets in this area (Sarma *et al*, 1981).

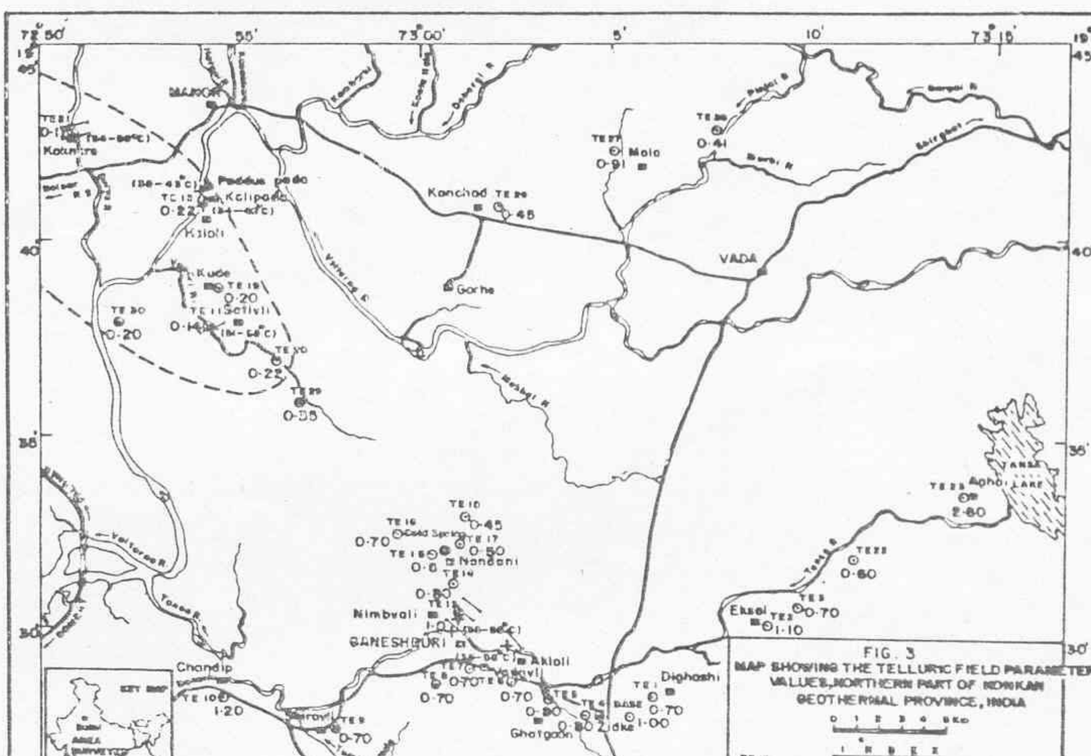

FIG. 3
MAP SHOWING THE TELLURIC FIELD PARAMETER VALUES, NORTHERN PART OF KONKAN GEOTHERMAL PROVINCE, INDIA

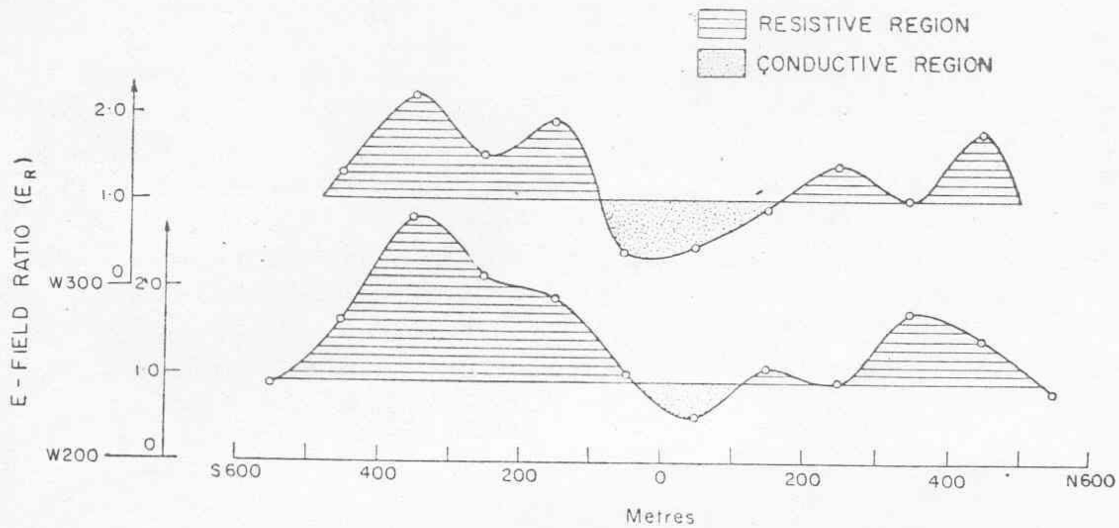

FIG - 4 TELLURIC FIELD PROFILES - KALAVA AREA. KURNOOL Dist, A.P

In addition to the above investigations 'Tellurics' has been utilized, along with other geophysical techniques for investigations of a suspected fault zone in the Dul-Hasti, hydro-electric power project area, Jammu & Kashmir (Balakrishna *et al.* 1982). Another recent application of 'Tellurics' is an attempt to monitor possible resistivity changes, if any, associated with some earth tremor activity reported near Hyderabad and the results of preliminary examination of data are interesting.

Role of tellurics and magnetotellurics in India

It is obvious from the foregoing that the utilization potential of these methods is quite significant and wide ranging geological problems can be tackled through the introduction of telluric and magnetotelluric methods into the complex of geophysical activity in India. A few aspects of the scope of application and the role that these methods might play in tackling some of the specific geological problems in the country is discussed in the following sections.

Cuddapah basin ;

The Cuddapah basin occupies a significant place in Indian Geology particularly because of its known mineral potential as also because of its complex geology and interesting tectonic history. This is one of the very few sedimentary basins in the country where both geological and geophysical techniques have been employed extensively. However, lack of sufficent contrast between the density (and also seismic velocity) of some of the Cuddapah sediments and the basement rocks, and the complex variations in the magnitude and direction of magnetization of the magnetic members of Cuddapah group of rocks are some of the problem factors which have set limitations on the interpretation of data from gravity, magnetic and to some extent seismic methods. However, considering the existence of appreciable contrasts in the electrical properties of different geological units in this basin, the electrical/electromagnetic group of geophysical methods should play an important role in providing additional information to understand the subsurface structure in this basin as could be seen from the foregoing results of the telluric survey in the south-western region of Cuddapah basin. Thus in view of their proven effectiveness of these methods, a judicial combination of tellurics, magnetotelluric and D.C. resistivity techniques would yield valuable information to arrive at a reasonably acceptable geological model of subsurface section in Cuddapah basin.

Ganga basin :

The usefulness of magnetotellurics method in understanding the subsurface details of geologically featureless sedimentary basins is very promising and one such area in India is the Indo-gangetic basin. A good amount of the geophysical work including seismics has been carried out in this basin, mainly for oil exploration and there appears still oonsiderable for application of magnetotellurics in this vast basin particularly in view of certain features viz. the presence of velocity sedimentary layers, geological and structural complexity as we approach the foot hills of Himalayas, which pose problems in the interpretation of seismic data. In this basin magnetotellurics, as a reconnaissance tool, aid in delineating the zones of high porosities and thick zones of sediments, which are of direct interest in oil exploration. Similarly MT data, in combination with existing geophysical data can profitably be used to get additional subsurface detail in other important basins such as Godavari and Cauvery. In addition to providing independent information, MT results in basin evaluation studies will; in general serve as a very effective guide for locating and designing detailed seismic reflection surveys.

Deccan traps

The Deccan basalts constitute one of the major geological units occupying large area in Indian Peninsula. Unfortunately this vast sheet of basaltic cover acts almost as a geophysical shield for everything underneath them, thus hindering the full and effective utilization of conventional geophysical techniques to understand subsurface details here. We do not yet have any reliable detailed estimates of thickness of Deccan traps or their structure and much less knowledge on what lies under Deccan traps. Though there are some evidences for the possible occurrence of subtrappean sediments, which might be important from both hydrocarbon exploration point of view, as also from the point of view of geothermal reservoirs in this area, details regarding the thickness, spatial extent and structural details of such sedimentary layers are yet to be known. In a situation such as this, MT should act as an effective additional geophysical tool by providing a geoelectric section of the region, which would go a long way in aiding the geological interpretation in general.

Geothermal studies :

It is well established that most of the geothermal reservoirs are associated with well defined electrical conductivity anomalies, and the tellurics, AMT (Audiofrequency MT) and to some extent MT, play an important role in delineating such conducting zones. As could be seen from the foregoing sections the 'tellurics' has played a very effective role in bringing out significant conductivity anomalies in some of the geothermal areas, namely the Puga in Himalayas, Konkan Geothermal Province in the West coast, Tatapani hot spring area in Madhya Pradesh. In view of these, both the methods (Tellurics and MT/AMT) can be applied on a more detailed scale in these areas, particularly the Himalayan and West coast geothermal provinces which hold considerable potential for tapping thermal energy, in addition to a systematic coverage of other geothermal prospects in the country through these investigations.

Mineral exploration :

Though tellurics and magnetotellurics are mainly and extensively used for exploration of deeper subsurface features they could as well be deployed, by utilizing high frequency source signals, for investigation of relatively shallower or near surface feature such as those encountered in mineral explorations. Strangway *et al.* (1973) showed that AMT (Audio Magnetotellurics) can determine subsurface electrical conductivity structure at depths appropriate for mineral exploration. This may be used as a supplement and also as a substitute to the conventional EM technique in some of the problem areas, for e.g. horizontally layered massive sulphide deposits where the EM results become ambiguous, and also in areas where mineral resources occur at deeper levels say a few hundred meters. Similarly Slankis *et al.* (1972) show that high frequency tellurics (8Hz) can be used as a rapid tool for location of conducting ore deposits; Results of field investigations in India presented in the earlier sections too showed that tellurics could be very effectively used in delineating near surface or shallow zones of high electrical conductivity associated with mineralized belts as in Kalva area, and also for exploration of Kimberlite pipes. It may thus be seen that telluric and AMT could profitably be used particularly in certain mineralized zones characterised by electrical conductivity contrasts and also in exploration for Kimberlite pipes.

There exist several complex geological problem of this type enumerated above which call for an integrated exploration strategy embracing as many independent geophysical parameters methods as possible. It is in this context that the introduction of these methods namely Tellurics, Magnetotellurics including AMT would make geophysical exploration activity more balanced and versatile in tackling abilities extending from deep crustal investigations to shallow level mineral exploration.

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