Magnetotellurics - a natural EM source method for oil exploration

A case for mapping 3D Lithospheric electrical resistivity structure

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Magnetotellurics helps to explore hydrocarbons, geothermal resources, deep crust, earthquake regions etc. Since it's introduction in India during early 80's, this has been applied at many locations to test the efficacy of the method. The method depends on the natural variation of Earth's magnetic field and also the induce electric field (telluric field)

Exploration of natural resources is one of the main concerns of an earth scientist. Electrical and electromagnetic methods are quite useful in the exploration of oil, mineral, water, etc., as they exhibit anomalous electrical conductivity compared to the surrounding media and thus can be identified with ease. Here we discuss a geophysical technique- Magnetotellurics - based on the natural electromagnetic field as it's source. The method helps to explore hydrocarbons, geothermal resources, deep crust, earthquake regions etc. Since it's introduction in India during early 80's, this has been applied at many locations to test the efficacy of the method. For details see the research publication by Harinarayana 2011 and also figure 1. The method depends on the natural variation of Earth's magnetic field and also the induce electric field (telluric field). Natural variation of magnetic field happens mainly due to two major phenomena in space, namely, Thunderstorm activity and Interaction of Solar plasma with magnetosphere. Thunderstorm activity is responsible for providing signals greater than 1 Hz and variation of low frequency (<1 Hz) signals are generated from

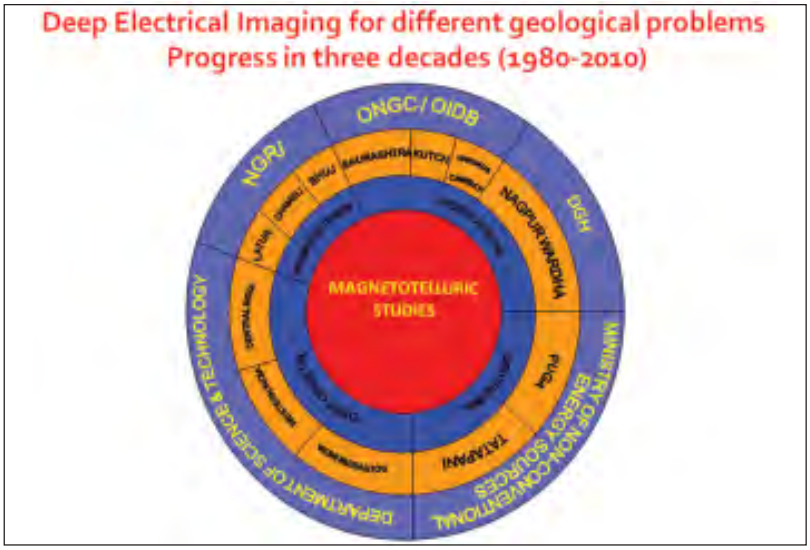

Fig.1 Various geological problems tackled by magnetotelluric technique showing different regions and also the fund supporting organizations

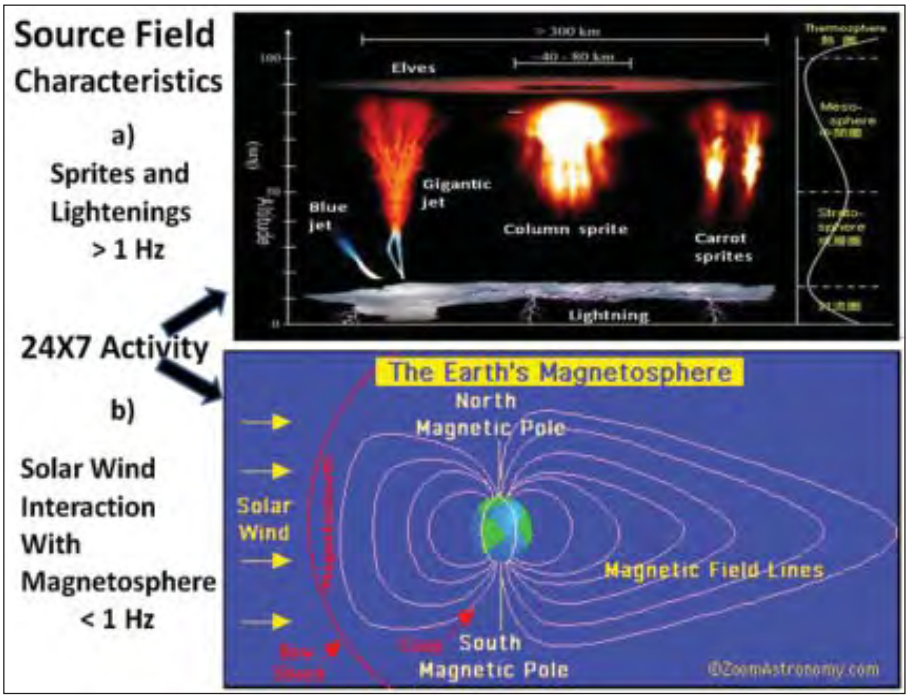

Fig.2 Source field characteristics showing the various phenomena and activity in outer space

Ionosphere-magnetosphere with solar plasma (see figure2).

In our discussion, it's application for different problems related to geothermal, deep crust, earthquake etc. with a focussed attention to oil exploration are presented with case studies in India in the following. Exploration for geothermal regions has been taken up as a major programme in India by Geological Survey of India-GSI. With conventional geophysical techniques and drilling test boreholes, shallow (< 1 km) geothermal potential has been established. However, due to lack of deep subsurface mapping, deeper source could not be established. A breakthrough in geothermal region is achieved through magnetotellurics. This is shown with a case study in Puga geothermal region, Ladakh, Jammu and Kashmir State. (see Figure 3).

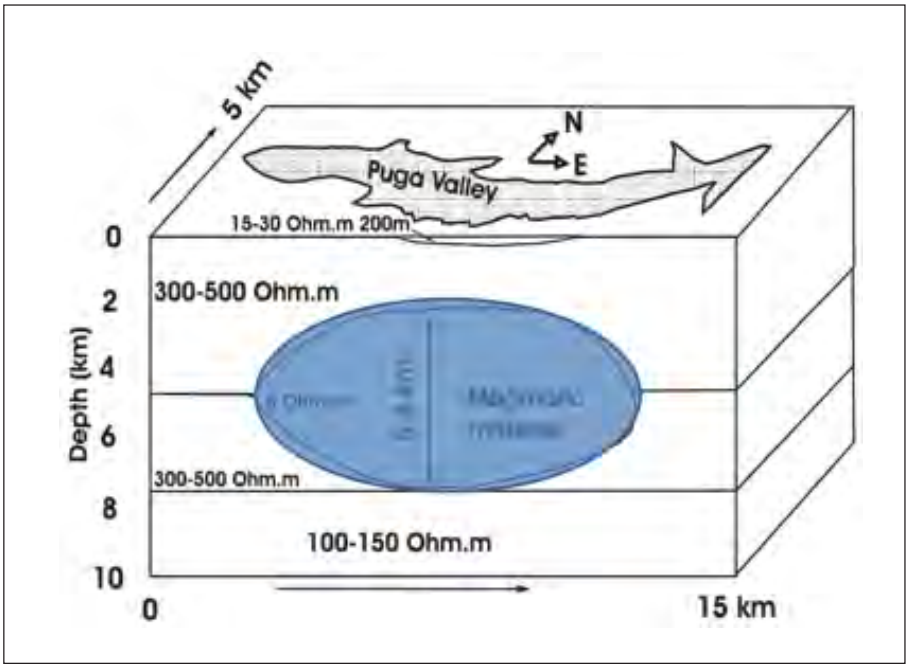

Fig.3 A schematic diagram showing the geothermal scenario of Puga region, Jammu and Kashmir state. Large high conducting high temperature magmatic body is delineated at about 1.5-2 km.

Killari earthquake in Latur, Maharashtra has occurred and taken away more than 10000 human lives. It is quite unexpected to many seismologists as this area was believed to be an aseismic region. The cause of the earthquake has become a puzzle to many earth-scientists. Magnetotellurics has delineated a large conductor at a depth of around 7 km and gave an evidence for the existence of fluids trapped at upper crustal depth and tries to escape to the surface is the cause for Killari earthquake. Later scientists have explored many other regions in the world for possible existence of such a similar signatures in the area.

There are several tectonic blocks exist in India. However, it is difficult to assess their past events and signatures, for example it's movements. Due to tectonic activity, surface

and shallow geological features are deformed. This makes the geological reconstruction of the region as a major problem. However, deep crustal features are relatively undisturbed. Deep crustal features help to understand the ancient tectonic activity. Through magnetotelluric studies, past geological events of Narmada Sone lineament (NSL) region are well understood. Deep electrical structure to a depth of about 50 km mapped across NSL region and the past tectonic history of the region will be presented.

Fig.4 The vessel used in Gulf of Kutch region to conduct marine magnetotellurics to map the buried sediments.

Detection of hydrocarbons in a relatively difficult region – sub-basalt – is discussed considering a few examples- from Saurashtra region and also from Gulf of Kutch region in marine environment. Saurashtra region is mostly covered by Deccan Trap region. From paleochannel studies, it was believed that the exposed sediments towards the north might have been migrated towards the south and thus the thickness of the sediments increases through river transportation towards the south. However, after the application of magnetotellurics along NS-EW profiles, it was shown that the sediments are thin towards the south as compared to north. Additionally, thick sediments are indicated towards the western part of the region. This has been proved later by deep drilling at Lodhika. The estimations for the thickness of Deccan traps is also validated. Later the region is well explored by more number of stations in a grid fashion and also with other geophysical methods. Similarly, western part of Narmada Son region is studied in greater detail that has indicated large thickness of sediments below the traps. Areas identified based on magnetotellurics integrating with other geophysical methods have been demarcated by DGH for detailed exploration and exploitation under NELP.

Presence of large thickness of sediments towards NW part of Saurashtra near Jamnagar and large thickness of sediments towards southern part of Kutch region gave an indication for large thickness of sediments in Gulf of Kutch region. This area is explored by applying marine magnetotellurics and also through marine seismics. Results indicated nearly 4 km thick sediments in Gulf of Kutch region. This information demands more detailed study of the area with a few exploratory bore wells. Boris Petrov research vessel (Fig.4) is used and marine magnetotelluric equipment from Scrips Institute of Oceanography, USA has been hired under a collaborative research programme for this project.

From all the above case studies, it is clear that magnetotellurics has played a key role in understanding various complex geological problems related to geothermal, tectonics, earthquake studies and also in oil exploration. It can map the electrical resistivity structure of the Earth from a shallow depth of 10/ 100m to as deep as 100-200 km. Since application of seismic is expensive, magnetotelluric method need to be applied to prioritize the area for detailed seismic survey. This way exploration cost can be optimized. ONGC-KDMIPE has been exploring various sedimentary basins of India for oil and gas exploration. Out of 26 sedimentary basins, only a few of

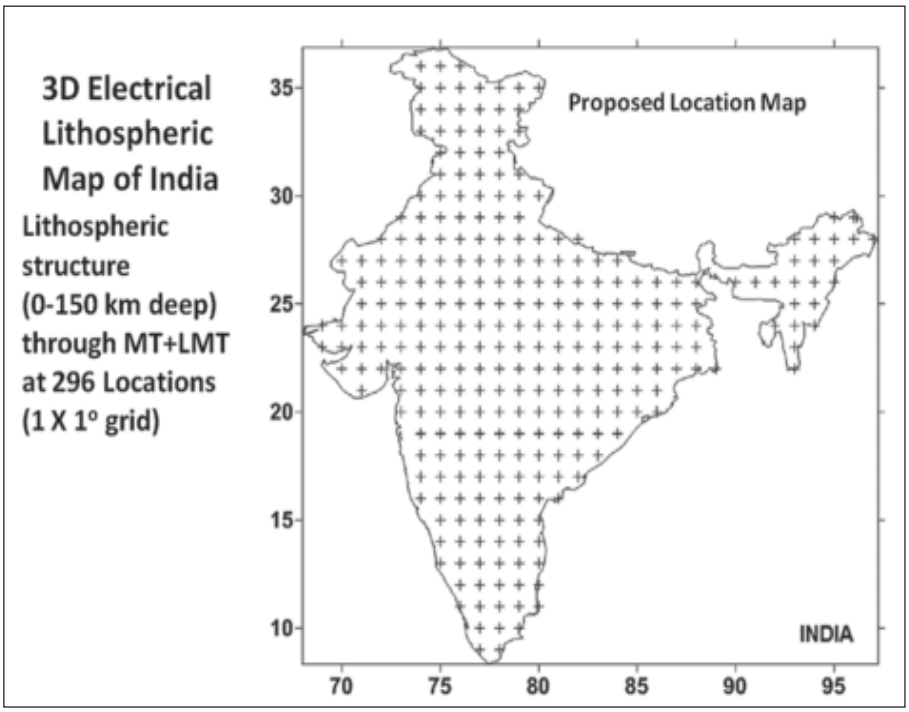

Fig.5 A schematic map showing the possible locations of broadband magnetotellurics with the objective of preparation of a 3D Lithosphere structure.

them are well explored and much need to be done in Category-II and Category-III type basins. In this context, it is of utmost important to understand the 3D Lithospheric structure of India. Accordingly, it is proposed to scan the entire India through magnetotelluric technique. For this purpose long period magnetotelluric technique involving the measurement of signals from 1 KHz to 50,000 - 100,000 sec. is required. This helps to map the Earth from shallow to Lithospheric structure. It is suggested to acquire the data for every grid cross point, say 1 X 1°. Suggested location map is shown in Figure 5.

Summary

Magnetotelluric geophysical technique has proved it's capability for various exploration problems. It's usage in oil exploration need to be applied judiciously to demarcate the areas to investigate for more detailed exploration using seismics. This greatly reduces the cost involved in exploration strategy. Additionally, it is suggested to map the deep structure that greatly helps to understand the evolution of sedimentary basins and inturn may provide clues for exploration targets. Accordingly, it is necessary to take up measurements with broadband magnetotellurics in a grid fashion at each crossing of the degree as shown in Fig.5.

Reference

Harinarayana T. Natural Signals to Map the Earth's Natural Resources In: chapter-1, Earth's Magnetic Interior, IAGA Special Sopron Book Series, Vol.1, pp.1-17, 2011.

about the author

Prof (Dr.) T. Harinarayana is the Director of the Gujarat Energy Research and Management Institute, Gandhinagar, Gujarat. He has over 30 years of experience of working with CSIR-National Geophysical Research Institute as Scientist "G". He is a leading scientist, well recognized for his excellence in deep EM Technique- Magnetotellurics among the national and international scientists.

Prof. T. Harinarayana holds two doctoral degrees in the field of Electro magnetics-one from Edinburgh University, UK & the other from Indian School of Mines, Dhanbad. He served as a visiting professor at the University of Tokyo, Japan and the University of Texas at Austin, USA. Prof. Harinarayana has worked as Dy. Director at NGRI, Hyderabad. His studies includes Geothermal, Hydrocarbon, Earth quake and Deep crust.

Dr. T. Harinarayana is a member of the Russian Academy of Natural Sciences, Moscow. Became a Member of Governing Council of newly formed IIIT-Vadodara. Recently, he has received ISCA-International Best Researcher Award-2013. He has received the National Mineral Award-1991, the Andhra Pradesh Scientist Award-2008. While serving as Scientist and Head of the magnetotelluric Division, NGRI, Hyderabad he became a fellow and a member of national (IGU, AEG, APAS etc.) and international (IAGA, EMSEV etc.) scientific societies, academic forums and editorial boards of various techno-scientific journals of global importance.