MAGNETOELLURIC SURVEY IN BURGAS HYDROTHERMAL BASIN (SE BULGARIA)

T. Harinarayana[1], B. Srebrov2, K. Veeraswamy[1], K. Bojadgieva[3] ,V. Hristov[3]

[1]National Geophysical Research Institute, Hyderabad, India
[2]National Institute for Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences
[3]Geological Institute, Bulgarian Academy of Sciences

Abstract. The results from the first magnetotelluric (MT) survey in Bulgaria on hydrothermal reservoirs are presented. The project was initiated under Indo-Bulgarian collaborative program supported by Department of Science and Technology, New Delhi, India and Bulgarian Academy of Sciences, Sofia, Bulgaria. The main objective of this study was to search for deep seated reservoirs for the need of geothermal energy use. Field visits were made to 15 sites in Bulgaria to identify the existence of suitable conditions for magnetotelluric investigations. Three reservoirs in Burgas basin (SE Bulgaria) have been selected after complex analysis of available geological, hydrogeological and geophysical data. MT data acquisition and processing are discussed. The results are presented as distribution of apparent resistivity and phase versus frequency. A deep seated conductivity medium is clearly outlined near Polyanovo.

Key words: magnetotelluric method (MT), hydrothermal reservoirs, thermal waters

Introduction

Thermal water use has an ancient tradition in Bulgaria. The temperature of discovered water does not exceed 100^{o}C and is used only for direct application – balneology, heating of buildings and greenhouses, bottling, etc. (Bojadgieva et al. 2011). The need of electricity generation requires exploration of thermal waters with temperatures above 100°C. This article presents the results obtained during the first magnetotelluric survey on geothermal structures in the country. MT allows detection of electro-conductive zones associated with productive structures, including faults and presence of a cap rock. The investigation depth ranges from 300 m below ground down to 10,000 m or deeper with long-period soundings. The earth's natural electromagnetic field contains a very wide spectrum of frequencies as low ones are useful in probing to depths of several hundreds of kilometers. The method works best where seismic has problems in areas of high-velocity cover such as volcanic provinces, carbonate cover, salt, etc.

This study was conducted by a team of Indian and Bulgarian scientists under Inter-governmental program of cooperation in science & technology.

The paper aims at presenting the application of MT-methodology for probing deep seated hydrothermal deposits in Bulgaria and to discuss the obtained results for the selected region.

Selection criteria for geothermal sites

The selection of geothermal reservoirs suitable for MT survey was made after analysis of available geological information, basic hydrogeological parameters, conducted geophysical surveys and field conditions. The site should be significantly away from power transmission lines, highways, human settlements, large water bodies, undulating topography, etc.

Three geothermal sites located in Burgas region (NE Bulgaria) – Polyanovo, Aitos and Sadievo have been selected after visiting 15 hydrothermal deposits located in nine geothermal basins in the country. The study started with the analysis of the exiting geological and geothermal data. Temperature field distribution in depth is analyzed based on the well-log data, water temperature, measured at the wellhead and calculated temperature by chalcedony geothermometer (Bojadgieva et al. 2007).
Temperature field in Polyanovo has been studied in more details due to the largest number of wells and temperature logs in them and for the highest hydrothermal potential (Bojadgieva et al. 2006).. The measured water temperature is 49^{o}C in Polyanovo and 50^{o}C in Aitos. Higher temperatures are expected in deeper seated reservoirs.

The available geological and hydro geological information for the region (Vlaskovski, 1997) was used to layout the measuring stations along profile lines.

Methodology of MT sounding

MT is a geophysical method that measures naturally occurring, time varying magnetic and electric fields. The solar wind (plasma) disturbs the earth's magnetic field and cause ultra low-frequency signal (generally less than 1 Hertz) to penetrate the earth's surface. The higher frequency signal (greater than 1 Hertz) is created by thunderstorms, usually near the equator. Both of these sources create time varying electromagnetic waves.
The signals vary in strength over hours, days, weeks and even over the sunspot cycle. The MT field measurements last for hours at each station to get a good statistical average of data signal, especially when measuring them at the lowest frequencies (about 0.001 Hertz). The main parameter that is derived from MT is electrical resistivity. The factors affecting resistivity are lithology, hydro geological processes, pressure and temperature.

Electromagnetic (EM) theory is originated from four fundamental equations proposed by J.Maxwell (Zhdanov, 1994). The orthogonal components of the electric (Ex and Ey) and magnetic (Hx,Hy and Hz) fields are simultaneously recorded. The relationship between them can be expressed as a complex impedance tensor Z(ω) at each frequency (1),(2):

$$[Z] = \begin{bmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{bmatrix} \quad (1)$$

where

$$Z_{xy}(\omega) = \frac{E_x(\omega)}{H_y(\omega)} \quad (2)$$

As an electromagnetic wave penetrates the Earth, its amplitude will decay at a rate dependent on the conductivity of the rocks and the rate of time variation of the frequency. The apparent resistivities **(ρ)** could be derived from the amplitudes (3):

$$\rho_{a,xy}(\omega) = \frac{1}{\omega\mu}\left|\frac{E_x(\omega)}{H_y(\omega)}\right|^2 \quad (3)$$

where μ is a constant.

A typical MT station layout is given in Fig.1

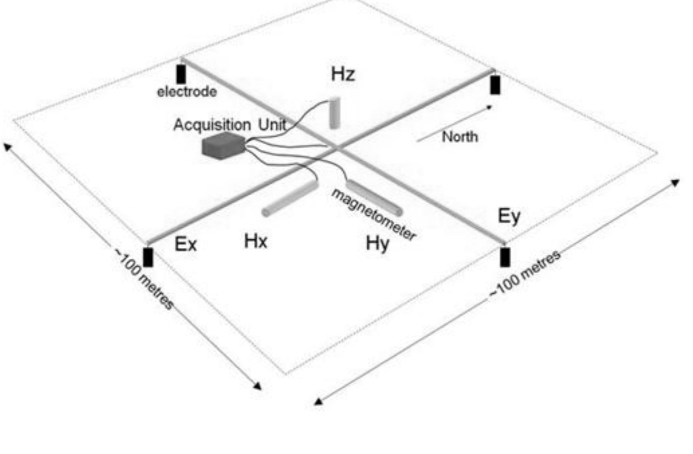


Fig. 1.. MT setup (http://www.moombarriga.com)

Five components (Hx, Hy, Hz, Ex and Ey) are measured at the surface as a set of time series. The vertical electric field is not measured because it is assumed to be zero. Several processing steps are run after acquiring these data and as a result noise is removed from them. The data are transformed from a time-domain to a frequency domain. This is achieved by using Fourier transforms.The data would be further inverted to produce a cross section of resistivity vs. depth (Zhdanov, 1994).

Field survey

The location of the study region is presented in Fig.2. It is built of Quaternary and Neogene sediments and Upper Cretaceous sediment and volcano-sediment rocks, intersected by tectonic faults. The Upper Cretaceous sediments consist of alternation of marls, siltstones, argillites, clayey limestone and sandstones, while the volcanic complex comprises andesites, basaltic andesites and tuffs. Quaternary and Neogene sediments are thin (from 0-59 m) and built mainly of clays and gravels. The thickness of Upper Cretaceous is very high and its bottom hasn't been reached. Polyanovo geothermal area has been identified for conducting MT field investigations as this area is well studied compared to other nearby geothermal sites such as Sadievo and Aitos and also suitable due to less cultural noise (e.g. power lines, vehicular traffic etc.), Fig.2. the reservoir represents an unstratifed fractured type water collector, which is characterized with a high filtration and thermal inhomogeneity (Vlaskovski, 1997).

MT measurements are done in totally 14 stations. Seven of them are placed along a regional profile (1), which is 35 km long and oriented in north-south direction (stations between 13 and14), Fig. 2a. Four shorter profiles about 1 to 3 km long are placed around Polyanovo for more detailed survey, Fig.2b.

MT data processing and interpretation

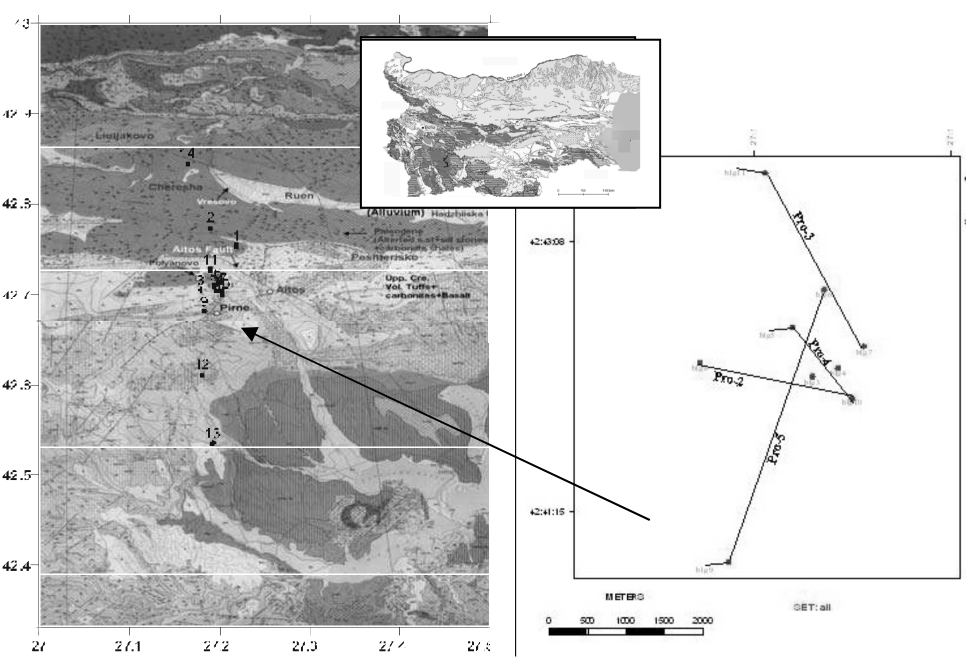
The MT field survey in Bulgaria has been carried out by equipment provided by National Geophysical Research Institute in Hyderabad, India (Harinarayana et al. 2008). The ADU (Analogue Digital Unit)-06 is the main unit of the Metronix multi-channel geophysical measurement system GMS-06. The electric and magnetic field sensors are connected directly to the ADU-06 unit. Between ten to thirty channels are recorded at one time. The ADU can be operated either by using the control software GMS (offline recording mode) or by MAPROS (online recording mode and data processing) which runs under Windows 95/98 or Windows NT/2000/XP operating system. The measured time series at 14 sounding locations are processed using Mapros MT time series analysis and processing software to estimate the best MT impedance values in the frequency range 1000 Hz – 0.001 Hz. The processed MT apparent resistivity and phase curves in the measured directions (XY – geomagnetic north-south and YX- geomagnetic east-west) are drawn for along the five profile lines.

The apparent resistivity and phase data for the station 3 (Polyanovo), located near the central part of the study region, is presented in Figure 3. The data are plotted on a log-log curve. One curve shows the apparent resistivity (RhoXY) determined from the electric field, in the north direction (Ex) and the magnetic field, in the east direction (Hy). The other curve (RhoYX) plots the data for the other two orthogonal horizontal fields, Ey and Hx.

The sediments of Quaternary, Neogene and the upper weathered part of Upper Cretaceous have exhibited conductive as compared to the below Upper Cretaceous volcano-sediment rocks. This can be seen clearly showing the apparent resistivity values of 10 Ohm.m in (100 – 1000 Hz) frequency range. For lower frequencies (10 - 1 Hz) the apparent resistivity steeply raises indicating the presence of high resistive basement below the sedimentary cover. For further lower frequency range (1 - 0.01 Hz) the apparent resistivity values show a decreasing trend indicating for the presence of deeper anomalous structure in the central part of the study area. The same trend is confirmed by the data measured in station 4 (Fig.2b), located also in Polyanovo area.

An example of MT data is presented for the station 13 located away from Polyanovo area towards southern part near Vinarsco village (Figure 4). It has exhibited relatively high resistive layer at the high frequency range indicating that the site is located over a high resistivity formations as compared to the stations 3 and 4 (near Polyanovo).

Further for the lower frequency range the apparent resistivity has shown small gradient for the station 13. The same trend is exhibited for a station 14 located towards northern end of the study area (near Shivarovo). From these stations 13 and 14 it is clear that the deeper anomalous conductor indicated near the central part of the profile 1 of the study area has not extended to far away locations.



a) b)

Fig. 2.. Location of MT stations and regional profile -1 (a) and short profiles - 2,3, 4 and 5 layout in Polyanovo area (b)

The pseudo-section prepared using apparent resistivity data along both xy and yx are presented along the stations of regional profile-1 (Figure 5). The stations located towards north covering the stations 14, 2, 1 and also another station 12 towards south have exhibited relatively high resistivity as compared to the stations 11, 5, 9 located near centre of the profile. Near the center shallow section corresponds to high frequency up to about 100 Hz conducting sediments of Quaternary, Neogene and weathered volcano-sediments rocks of Upper Cretaceous. This is followed by high apparent resistivity for the frequencies (10-1) Hz and further lower frequencies has tendency to show conductive formations at 0.1 Hz.

Similarly, phase pseudo-section for profile 1 is presented in Fig.5. The high frequency band near the middle part of the profile has phase values ranging between 35 and 55 and as the frequency decreases the phase value also decreases to 10 to 30 and for further lower frequencies the phase again exhibited higher values of 35 to 50. This is compatible with the apparent resistivity pseudo section in the form of conductor-resistor-conductor layers near the central part of the profile 1.

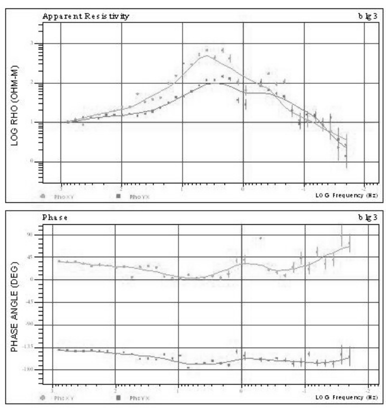


Fig. 3.. MT data for station 3 after processing

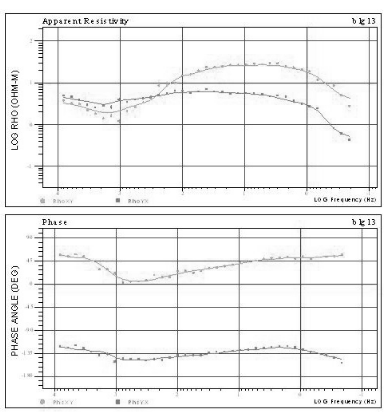


Fig. 4. MT data for station 13 after processin

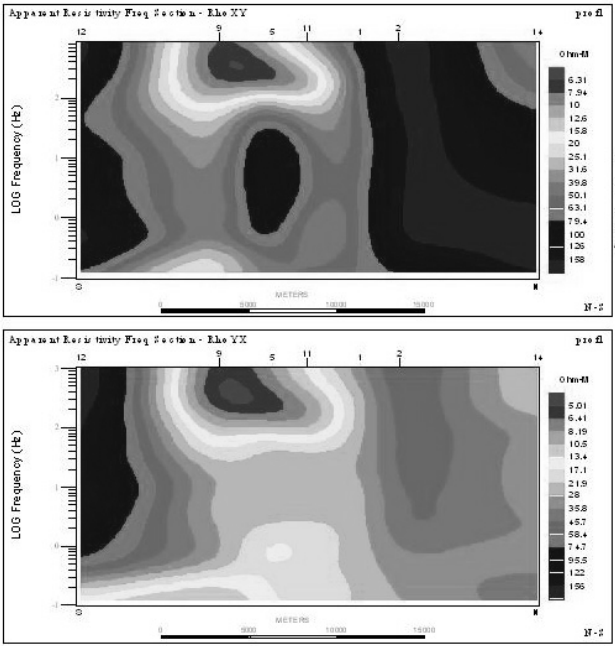


Fig.5. Regional distribution of apparent resistivity as a function of frequency (profile-1)

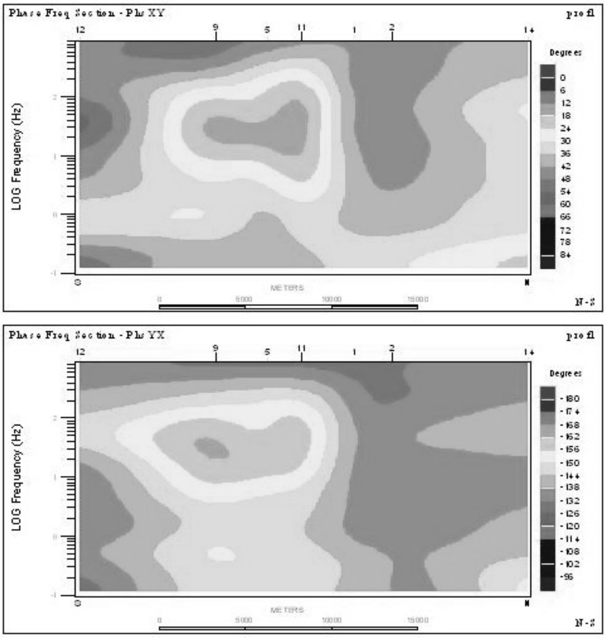


Fig. 6. Regional distribution of phase values as a function of frequency (profile 1).

The existing conductive zone in the middle of profile-1 is marked also on the apparent resistivity and phase pseudo-sections along profiles 2 and 4, located in the Polyanovo hydrothermal zone.
Indications of deep seated hydrothermal zones are registered in other hydrothermal basins in the country, where suitable conditions for MT sounding are also available.

Conclusions

About 15 geothermal sites in Bulgaria were visited to select the best conditions for conducting magneto telluric sounding - Polyanovo geothermal reservoir (SE Bulgaria). A detailed study of temperature field distribution, geological and hydrogeological conditions in Polyanovo had been done before the execution of the magnetotelluric survey.
The distribution of apparent resistivity and phase values along one regional and four local profiles clearly define two conductive zones. The next step is the assessment of resistivity variations versus depth.

Acknowledgements

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Маогнитотелурични проучвания в Бургаския хидротермален басеин (СИ България)

Харинараяна Т., Сребров Б., Веерасуами К., Бояджиева К., Христов В.

Резюме. Представени са резултати от първите магнитотелурични (МТ) проучвания на хидротермален резервоар в България. Този проект беше инициирал в рамките на Българско-Индийската програма за сътрудничество между Департамента за наука и технологии, Ню Дели, Индия и Българската академия на науките. Главния цел на това изследване е да се търсят дълбоки геотермални резервоари за добиване на геотермална енергия. Бяха посетени 15 обекта в България за да се определят такива, с подходящи условия за провеждане на магнитотелурични изследвания. Бяха избрани три резервоара в Бургаския басеин (СИ-България) за комплексен анализ на наличните геоложични, хидрогеологични и геофизични данни. В статията е представено получаването на МТ данни и тяхната обработка. Резултатите са представени като разпределение на привидното съпротивление и фазата в зависимост от честотата. В резултат от проведеното МТ проучване е намерена зона с висока електропроводимост в близост до с. Поляново.