Magnetotelluric Field Investigations in Puga Geothermal Region, Jammu and Kashmir, India: 1-D Modeling Results

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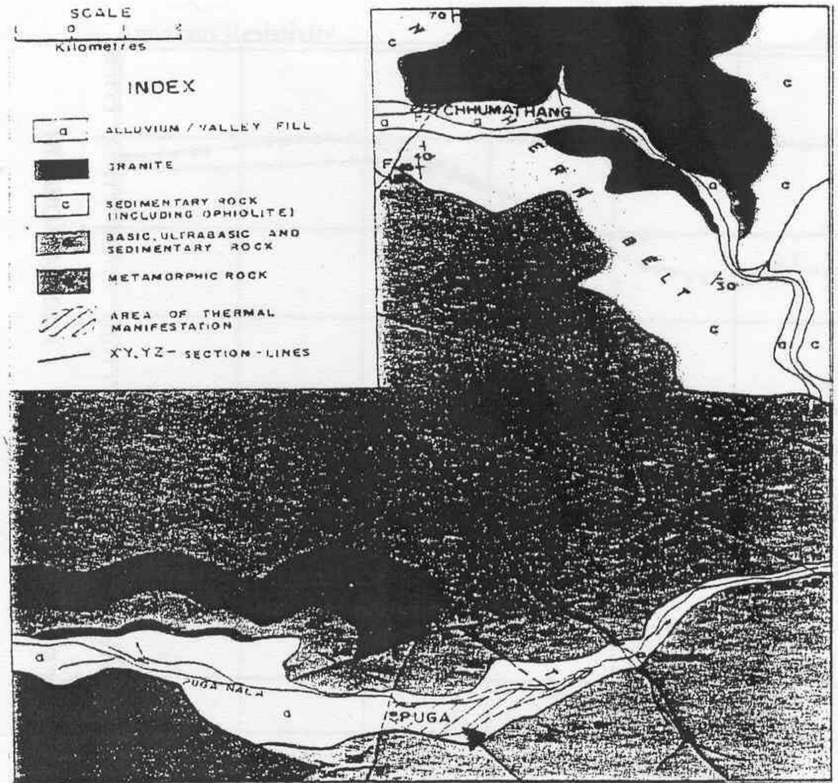
ABSTRACT

Four major thermal manifestations in India have been recognised, in which Himalayan belt forms the most important region from the viewpoint of potential for geothermal energy. A total of 72 locations have been identified where groups of hot springs are located in different places along the Himalayan belt region. Among these, Puga hot spring region is recognised as the most promising from geological, shallow geophysical and borehole data. Although it's importance is known, deep crustal signatures and the boundary parameters of Puga geothermal reservoir is poorly estimated. To understand the crustal structure and to delineate anomalous features, if any, related to geothermal reservoir deep geophysical studies are important. With a view to image the deep geoelectric structure, a wide band magnetotelluric (MT) study has been taken up in Puga valley. A total of 35 stations have been covered in the Puga valley with a closed station interval of 0.5 to 1 km. Since the area of study is relatively away from civilization, no man made noises are in the vicinity. This has provided an opportunity to get high quality of MT data. The data has been subjected to qualitative and quantitative interpretation. In the present study, a high conductive zone in the valley towards west of Sumdo village has been delineated. The conductive zone shows a shallow conductor (100-500m) is underlain by a resistive structure followed by another deep conductor (1.5-2 kms). The relation between shallow and deep conductive zones and its relation to the presence of geothermal reservoir is discussed.

Introduction

Among the various non-conventional energy resources, geothermal energy has gained importance in recent years. Geothermal energy is currently being utilized to generate electricity in many countries. The energy utilization from this source is increasing year after the year. For example, the total electricity using geothermal energy by various countries is about 3,500 MW in 1983 and increased to about 6500 MW by 1993 (Freestone, 1990). Realizing the importance of the geothermal resource, Ministry of Non-Conventional Energy Source, Government of India, New Delhi has taken up a task to explore the geothermal energy at various locations in India. In this direction, NGRI undertook a major project in Tattapani Hot Spring region, Surguja district, Chattisgarh for possible delineation of subsurface reservoir for exploitation of the geothermal energy for power generation. The investigation has delineated a major conducting region at a depth of about 2.5 - 3 Km related to geothermal reservoir (Harinarayana, *et. al.*, 2000). These results have been discussed by various technical committees and they have recommended to exploit geothermal energy by installing 1MW electric power plant near Tattapani. With the success of the investigations in Tattapani hot spring region another major project has been initiated with the support of Ministry of Non-Conventional Energy Sources. In this direction a major magnetotelluric study is initiated in one of the most important geothermal region of India, namely, the Puga hot spring region in Ladakh district of Jammu & Kashmir State. A relatively new geophysical technique, namely the Magnetotellurics has been used in the region.

There are several hot springs all along the Puga valley, located towards the west of Sumdo village. The Puga area can be divided into three distinct northwest-southeast belts. These are separated by major tectonic features. The southern belt consist of Precambrian rocks comprising granite, paragneiss, schists, quartzite. Younger granites probably belonging to tertiary age, occur as intrusives. Major folds are found broadly in east-west direction. The central belt consists of basic, ultrabasic type of rocks and sedimentaries. The northern belt consists of thick sequence of sedimentary rocks of Miocence age deposited over Mesozoic granite basement. The local geology in Puga valley is filled with material comprising of borax evaporates, sand, fluvioglacial sediments and glacial moranes. Some of these rocks have reconsolidated into hard breccia/conglomerate by the action of geothermal fluids. The details of regional geology is presented in Figure 1.



(From Ravi Shankar et al., Geothermal Atlas of India)

Figure 1. Geological map of Puga and Chumathang area, Ladakh district, Jammu and Kashmir state, India.

with the earth's Magnetosphere. The audio-magnetotelluric (AMT) part of the signals range from a few KHZ to 1HZ and are due worldwide thunderstorm activity. The availability of signals of natural origin covering such a wide band of frequencies ranging from a fraction of milli Hertz to a few Kilohertz makes the method extremely useful to probe a wide range of depths from as shallow as a few tens of meters to more than even one hundred kilometers. Electrical conductivity of various rock types in the earth shows large variation from about 0.1 to 10^6 Ohm-m. Thus, availability of source signals over a large frequency range and the wide variation of electrical property of rocks makes the magnetotelluric method very attractive for studying various geological problems connected with mineral, oil and geothermal exploration.

Magnetotelluric data acquisition comprises simultaneous measurement of orthogonal components of magnetic and the corresponding induced electric field variations of the natural electromagnetic signal. From the basic principles, the relationship between two fields i.e. orthogonal magnetic and electric components gives impedance over a range of frequencies which can be expressed in terms of two important parameters viz.. apparent resistivity and phase. These two parameters provide the basic information about the earth's subsurface conductivity distribution. Study of the apparent resistivity and phase parameters over a range of frequencies, and hence over a range of depth levels, provide a model for the subsurface geoelectric structure.

Magnetotellurics

Magnetotelluric (MT) method utilizes the natural electromagnetic signals of terrestrial / extraterrestrial origin as its source field. The MT source signal frequencies range from about 1 Hz to a fraction of mHz (i.e 0.2 Sec to several thousand seconds) and are mainly due to interaction of solar wind

A total of 48 MT soundings have been carried out in Puga region with a station intervel of 0.5 -1 Km near the hot spring and 1.5 - 2 km away from the hot springs. Two MT profiles (one NS & EW) were carried out within the valley to delineate the boundary of conductive feature indicated from MT sound-

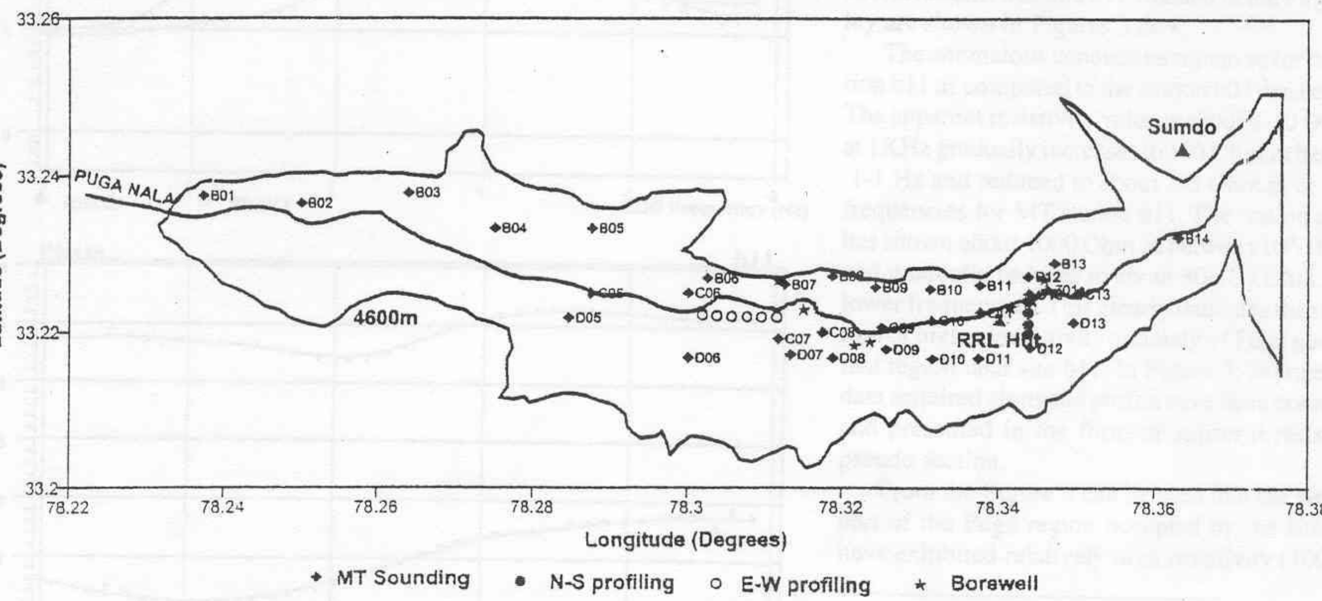


Figure 2. Location map of MT stations in Puga valley, Jammu and Kashmir State.

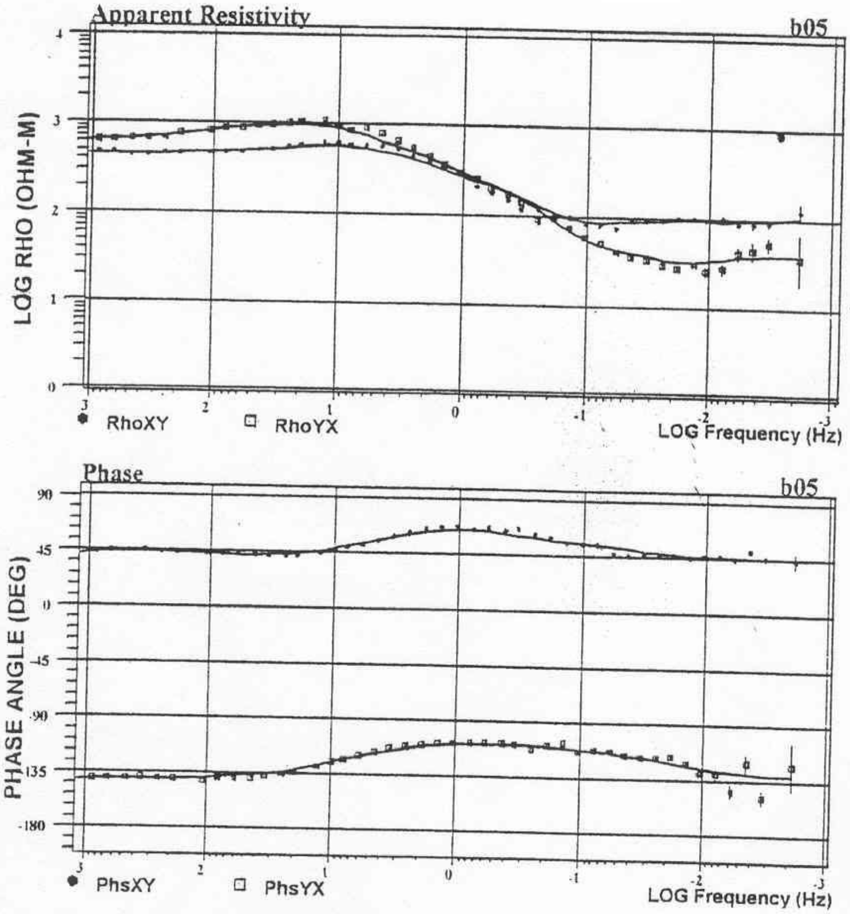


Figure 3. Magnetotelluric apparent resistivity and phase data for the station b05.

ings. Additionally 10 MT soundings have been occupied far away from the Puga valley in order to understand the regional geology and tectonics of the study region for better understanding of the geothermal regime of Puga province. Figure 2 shows MT sites occupied within the valley. Three magnetotelluric data acquisition systems (GMS05) of M/s Metronix , Germany have been deployed for recording the signals. The signal frequency is ranging from 1000 Hz to 0.001 Hz. This facilitates to probe the earth from shallow level of few meters to as deep as few tens of kilometers

The Data and Results

As described before magnetotelluric technique depends upon the natural variations of the earth's magnetic field and induced electric fields. In many locations man-made noise in the form of artificial electrical energy always poses a problem to MT data acquisition. However the region is found to be an excellent location for MT data acquisition as there are no man-made cultural noise for many kilometers around Puga valley. Thus this region forms as a magnetotelluric laboratory for testing the signals. This has helped to acquire high quality data of both telluric and magnetic field signals. Modeling of MT data was done using state-of-the art software package "Geotools". The distortions due to near surface inhomogeneities have been corrected based on the values of adjacent stations. The data acquired for two locations, b05 and b11 situated in the Puga valley are shown in Figures 3 & 4.

The anomalous conductive signature for the station b11 as compared to the station b05 can be seen. The apparent resistivity value is about 8-10 Ohm.m at 1KHz gradually increases to 100 Ohm.m between .1-1 Hz and reduced to about 2-5 Ohm.m at lower frequencies for MT station b11. The station at b05 has shown about 1000 Ohm.m between 10^{4}-10^{1} Hz. and gradually reduces to about 80-100 Ohm.m for lower frequencies. This clearly indicates the reflection of high conductivity anomaly of Fuga geothermal region near site b11. In Figure 5, overleaf, the data acquired along the profile have been contoured and presented in the form of apparent resistivity pseudo section.

From the Figure it can be seen that the western part of the Puga region occupied by the sites 1-7 have exhibited relatively high resistivity (100-500

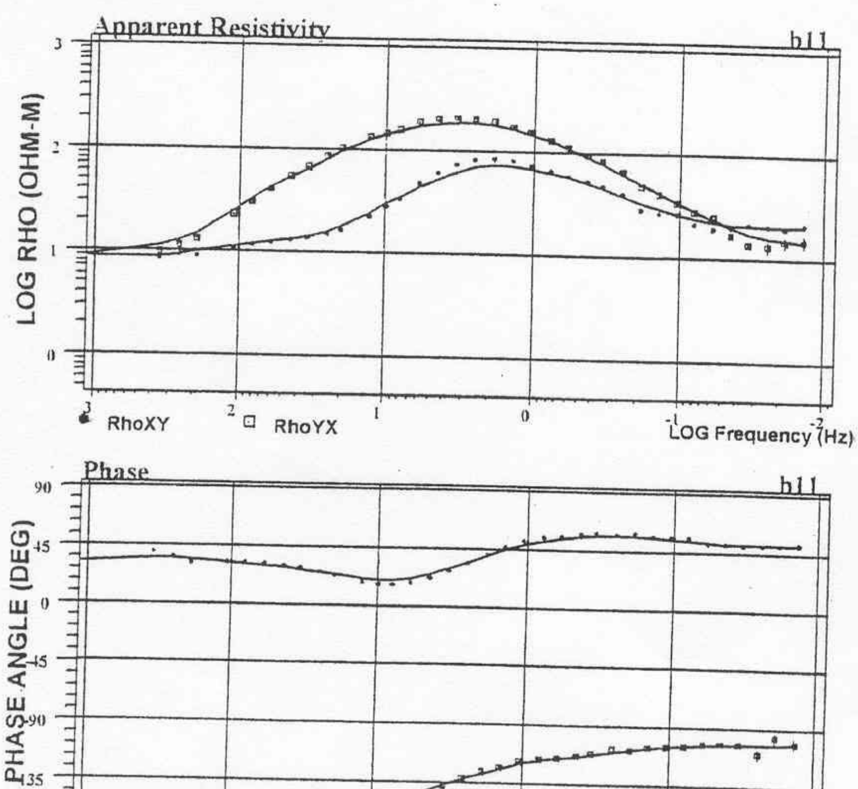


Figure 4. Magnetotelluric apparent resistivity and phase data for the station b11.

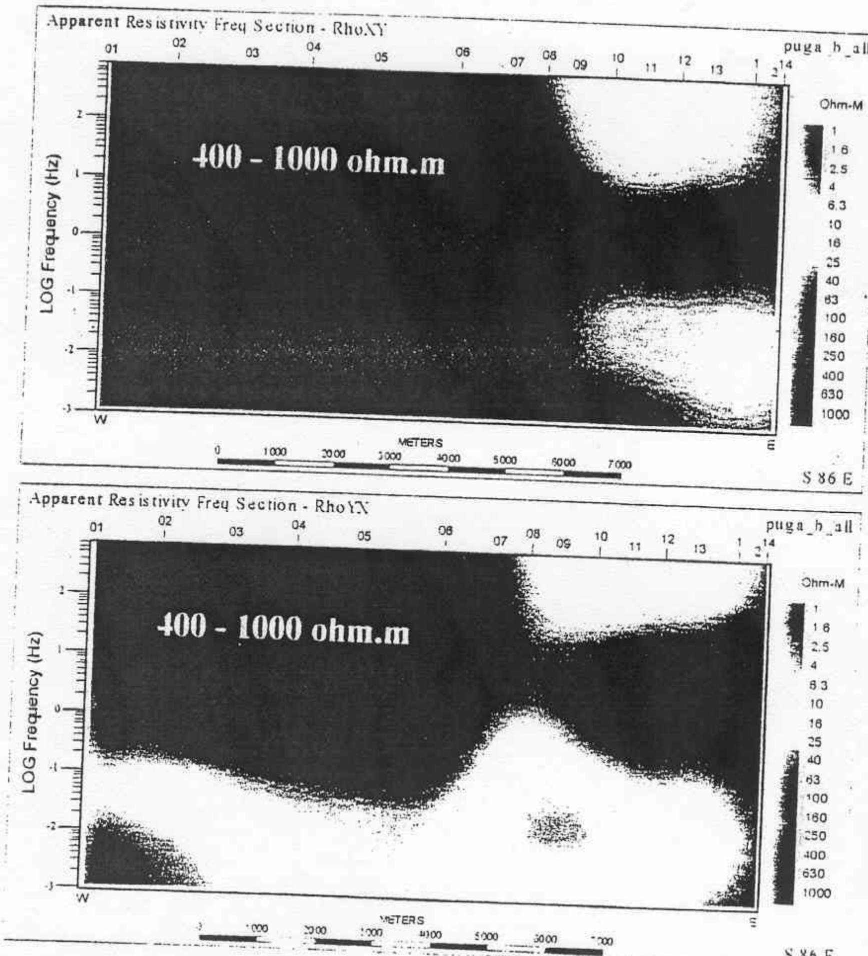


Figure 5. MT apparent resistivity pseudo section along xy and yx measured directions (NS and EW) indicating anomalous conductors towards east of the profile near the stations 7 to 13.

Ohm.m) above 1Hz whereas the sites 8-13 has clearly indicated the presence of conducting subsurface structure with an apparent resistivity value of about 3-20 Ohm.m. Same is the case for the apparent resistivity section for xy as well as yx direction. The data thus obtained have been subjected to both Bostick transformation (Bostick, 1977) as shown in Figure 6, and 1D modeling (Figures 7-8).

Figure 6 shows continuous variation of resistivity with depth. The subsurface resistivity distribution at b03 is distinctly different from b11. At b11 the deeper conductor is observed at a depth of 1.5-2 km. Figures 7 and 8 show the subsurface layered section for the stations b03 and b11. The results obtained from 1-D inversion schemes also agrees closely with the information obtained from Bostick transformation. For example, the model for the station b11, located at the centre of Puga valley region showed anomalously high conducting (8-10 Ohm.m) from a depth about 2kms. In Figure 8, the subsurface section obtained for the station b03 located away from the station b11 is presented. This clearly indicates the absence of anomalous high conducting region. The anomalous high conducting region obtained for the station is seen not only at the station b11 but also at many locations (stations 9-13) nearer to this location in Puga valley. A detailed modeling using 2D finite difference/element scheme need to be carried out for the stations along the profiles.

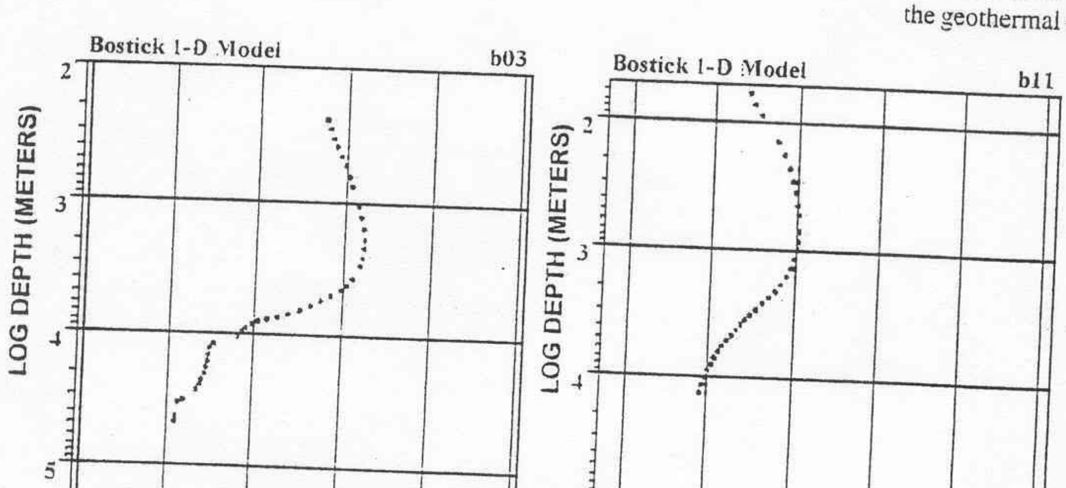


Figure 6. Bostick depth transformation of Rho-det parameter showing resistivity with depth for the stations b03 and b11.

Summary of the Results

It has been a long time since the potential for the geothermal energy has been recognised in Puga valley region by previous workers from shallow geophysical studies and also from test drilling. However, these studies have not clearly demarcated the zone for exploitation of the geothermal energy and poorly estimated the geothermal reservoir parameters at subsurface depth. With the success of magnetotelluric study in Tattapani hot spring region, Chattisgarh - where a deep conductor at a depth of 2.5-3 km related to geothermal reservoir is delineated – a detailed wide band MT studies have been taken up in Puga geothermal region, Jammu and Kashmir state. The study has confirmed the existence of shallow conductive structure delineated from earlier

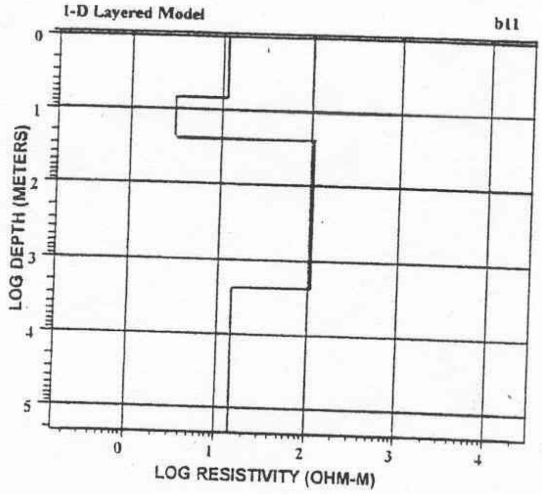


Figure 7. 1-D modelling results for the station b11.

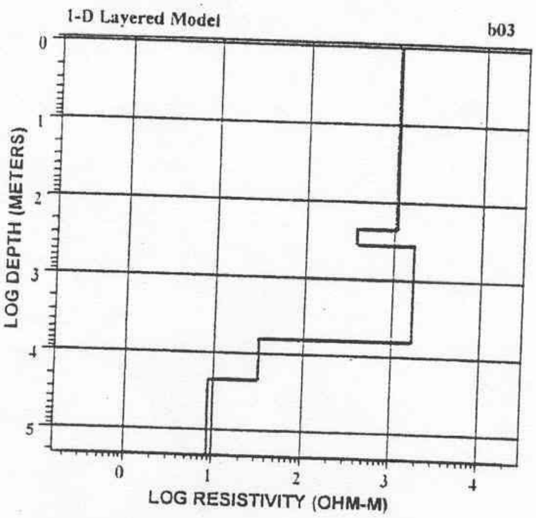


Figure 8. 1-D modelling results for the station b03.

geophysical studies and detected hitherto unknown deep anomalous conductive structure related to geothermal reservoir at a depth of about 1.5 – 2km with a clear demarcation of its boundaries. The results seems to be significant from the view point of exploitation of Puga geothermal energy.

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