RESISTIVITY STRIJCTURE OF PUGA GEOTHERMAL FIELD

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1. ABSTRACT

The magnetotelluric recordings at 14 locations have been camed out at Puga geothermal field. Five components of the electric and magnetic fields have been recorded at each stations. The electric field components have been found very noisy at each stations. In order to infer the resistivity structure from the noisy magnetotelluric data, the Geoelectromagnetic Induction Tomography (GEMIT) technique (Nabetani 1987) has been used. In the present paper, we present the results **in** terms of two-dimensional map of the electrical resistivity structure inferred only from magnetic fields. The depth **of** the geothennal reservoir and the extent ofthe geothermal reservoir have been discussed in view ofthe resistivity inferred **from** the magnetotelluric recodings.

2. INTRODUCTION

The magnetotelluric (MT) method is widely used for deeper subsurface mapping and exploration of oil and gas in **USA,** Canada. Australia and European countries (Hjelt 1978, Hermance and Neumann, 1988, Jones and Craven 1990, Gupta and Jones, 1990) The MT method has been successfully employed for the mapping of hydrocarbon deposits in the basaltic provinces Seismic method has been widely used in India for the mapping of hydrocarbon deposits In the geologically complex areas such as the Deccan trap. the Himalayan foothills and in the densely populated area such as the Iudo-Gaugetic basin, the seismic method failed to reveal information about the deeper subsurface structure. The MT method has been used in these areas to infer the deeper resistivity structure.

The Puga geothermal field is known to be one of the potential geothermal fields in India which is situated in a complex geological terrain. Due to the complex geological situation. very little geophysical information exists about the area, which has hampered the exploitation of this geothermal field. Recently, the MT method was employed in the area in order to get information about the subsurface resistivity structure. In the present paper, we discuss the two-dimensional resistivity structure of the Puga geothermal field. The resistivity structure shows a low resistivity zone which seems to represent the geothermal zone at a depth below 1000 m. The distribution **of** the low resistivity zone has been discussed.

3 THE PUGA GEOTHERMAL FIELD

The Puga valley is located at an elevation of 4000 meters above mean sea level with the surrounding hills rising up to an altitude **of** about 6000 **m** in the Laddakh district of Jammu and Kashmir state, India. It is about 220 km southeast from Leh (Figure 1). This valley is well known for its numerous hot springs with temperature up to 84^{0}C (the boiling point of water at that altitude) and occurrence of sulphur and borax deposits.

A large number **of** hot springs issue on either flank of the valley near the banks of the **Puga** nala, a tributory of the Indus river. **A** few hot springs are also located in the main river bed. The valley trends in almost **E-W** direction over a stretch of about 1.5km with a maximum width of about 1 km and lies to the south of the Indus-Tsangpo suture zone. It is believed to be the expression of a major crustal subduction zone based upon i) the presence of blue schist facies and *ii*) its basic rocks (Virdi et al. 1977). The valley appears to be a down-faulted block with its northern and southern faults concealed under the valley material.

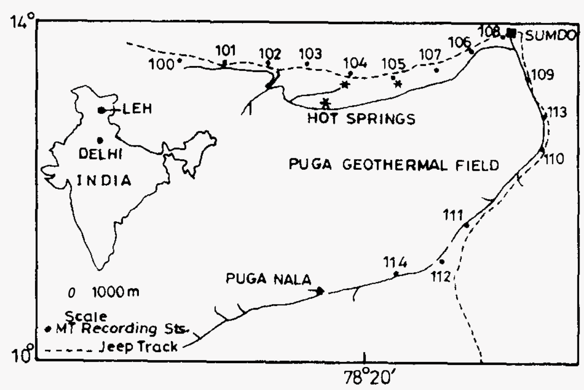


Figure 1. The inset shows map of India and location of Leh. Location of MT recording stations in Puga Geothermal field is shown.

The eastem part of the Puga valley is covered by recent and subrecent deposits of glacial moraines and eolian sand which is encrusted with borax, sulphur and other hot spring deposits. The western part of the valley is covered with alluvium and sandy soil. The borax has been deposited by capillery action from the thermal fluids. Therefore. the area which is marked by borax deposition gives a visual indication of the probable extent of the hot, fractured subsurface. The valley is filled with loose material which continues to a depth ranging from 15-65 meters. The rock sequence in the western and the southern part of the Puga valley consists of granites and gneiss of unknown age at the base followed by the Puga formation of probable Paleozoic age (Raina et al. 1963, Baweja 1967). This formation is made up of lower unit of para-gneisses and an upper unit of quartz schist and quartz mica schists, which at places are gypsiferous. Both the quartz and quartz mica schist contain sulphur as fillings along the fissure and cracks.

The Puga formation is seen on both flanks of the valley and thrust over by a createaceous volcanic formation of basic volcanic flows, traps and phyllites in the east (Gupta, 1974). The Puga valley is aligned along the faulted crest of an asymmetrical anticline in the Puga formation. Several thin limestone bands have been noticed on the northern hill scarp of the central part of the valley. The ultimate heat sources for the Puga geothermal field is probably intrusive rocks lying at a shallow depth below the valley **floor.** The most probable reservoir temperature in the Puga valley seems to be slightly over 200°C (Moon and Dhavam, 1988). Various geological. geochemical and geophysical investigations, including drilling, have been carried out in the valley and have shown that a definite potential for geothermal resources exist (Gupta 1967, Gupta and Rao 1970, Gupta et al. 1971, 1975, 1983, Krishnaswamy and Shanker 1980. Shanker 1988).

Hot springs, hot pools, sulphur and borax deposits have been found in an area of **3** sq. km along a 4 km long stretch of the eastem part **of** the 15 km long Puga valley, On the basis of the inferred subsurface thermal conditions. the valley is divided into two parts: one part which is characterized by low (normal for the location of the valley) subsurface temperature and another part which is characterized by abnormal surface and subsurface temperature.

4. MAGNETOTELLURIC DATA ACQUISITION AND ANALYSIS

The MT soundings were carried out at 14 locations (Figure 1) in two perpendicular directions (east-west and north-south) simultaneously. The location of the 14 recording stations are marked as stations 101-114. All the stations are along the Puga nala.

Near recording stations 101 - 108, hot springs are present. These stations are on the flat valley surface. The location of stations 109 - 114 are south to the Sumdo village on the other side of the mountain. All the station locations were reached by Jeep. At each location. three components Hx, Hy and Hz of magnetic field and two components of the electric field Ex and Ey were measured. For measurement of the magnetic field. induction coils were used. whereas for the measurement of the electric field electrodes of the $Cu\text{-}CuSO_4$ type with a separation of 50-75 m were used. Band pass filtering of the signal 0.1 - 0.01 and 0.1-100 sec was carried out before recording. The total recording time for the two filter bands was 2-3 hours. At each station, data were recorded **on** floppy and processed using GEMIT approach (Nabetani, 1987)

GEMIT Method

Parkinson (1964) found a tendency of the vertical magnetic field to increase when the horizontal components change in a particular horizontal direction and to decrease when the horizontal components change in the opposite direction. Often this correlation is sufficently good that the amount of vertical variation is proportional to the component of the horizontal variation in that particular direction. Both the direction which correlates with maximum vertical change and the ratio **of** the vertical to the horizontal change vary from station to station, even when the stations have similar latitudes and are not far apart. By measuring the changes in three components of the magnetic fields during some time intervals one can define a vector showing the change in magnetic field during these time intervals. The directions of the change in vectors can be plotted on a polar diagram From the three components of the magnetic fields one can calculate the preferred planes which give an idea of the conductive zones and their orientations.

Nabetani (1987) proposed GEMIT for the reconstruction *of* conductivity structure based on the measurement of three components of magnetic fields. The processing **of** magnetic fields observed at various locations have been carried out using GEMIT method. The naturally and artificially induced noises have been reduced in the processing of data using statistical techniques described by Nabetani (1987). In the conventional MT method most of the noises come from the unstable electric fields which excite a substantial noise level in the magnetic fields, due to which the accuracy of impedance analysis is reduced to the lowest level of electric field. This is the main drawback of MT method. In the GEMIT method, from the processing of three component of magnetic fields. a preferred plane is determined. The distrihation of the preferred plane is determined for the electromagnetic waves in the period range 0.1-100 sec. The refracted wavefronts for the constant phase of magnetic fields are computed around all the recording stations, radially. The GEMIT method provides three-dimensional lateral and vertical resistivity structure based on the magnetic fields recorded at all stations. The initial assumption of subsurface resistivity is taken as constant for computation convenience. The main advantage of GEMIT processing over conventional MT appraoch is that the depth of penetration in MT is limited due to the presence of conducting zone. whereas the GEMIT analysis does not suffer from this limitation.

5 RESIJLTS AND DISCUSSION

In Figure 2, we have shown the **2-D** resistivity maps at various depth (0.5, 1.0, 1.5 and 2.0 km.) inferred from GEMIT method. The location of the recording stations are shown as black dots. In Figure 2a, very low to low resistivity zones are represented in black and black shades at the eastern and western sides (i.e. at stations 102-105 and stations 110 and 111) of line D is seen at a depth of 500 m. At 1 **km** depth, the low resistivity zone extend at the western side of the line D i.e. station 101-104. At the eastern side, the extent of the low resistivity zone seems to be further extend, however. its reliability may be questionable due to lack of data.

At 1.5 km, the low resistivity zone extends over the area and it seems that the stations 101 - 105 and stations 110-113 lie at the boundary of the low resistivity zone. Stations 106-109 lie far away from the low resistivity zone (Figure 2c). In Figure 2d the conductivity level has increased, the low resistivity zone seems to be migrated to the north-west side.

The vertical distribution of resistivity along west-east profiles A, B and C are shown in Figures 3a-3c. From Figures **3a-3c**, it is seen that a relatively low resistivity zone exist below 1 km along profiles B and **C.** Along profile C, the low resistivity zone Lies compratively at greater depth than those of profile **B.** The vertical resistivity map shows the concentration of low resistivity zone in the central and eastern sides along the profile **B** and C. The vertical resistivity map along profile A shows a relatively low resistivity small pockets below 2 km which seems to be present due to the inhomogeneity in subsurface formation.

In Figure 3d, the resistivty map is shown along north-south profile D. The **low** resistivity zone is found below 1.5 km along north-

Figure 2.a. 2-D **resistivity map in a horizontal plane at a depth** of **0.5 km**.

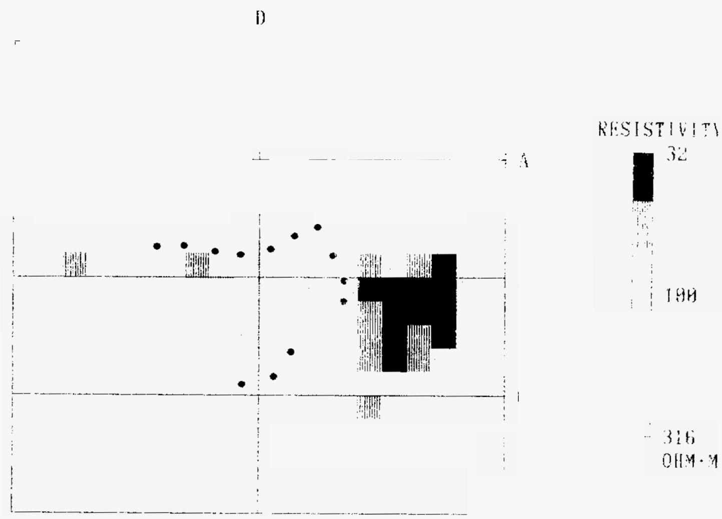


Figure 2.b. 2-D **resistivity map in a horizontal plane at a depth** of **1.0 km**.

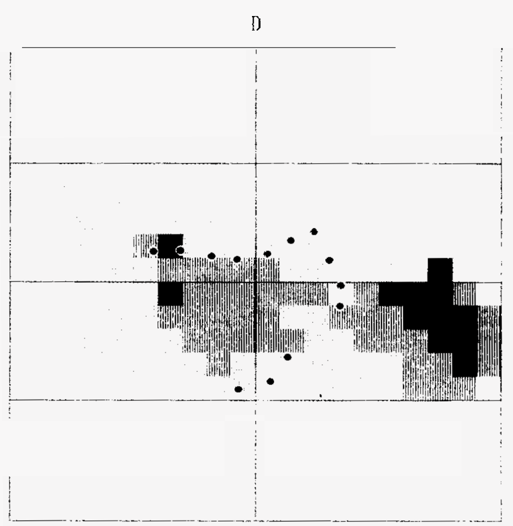


Figure 2.c. 2-D **resistivity map** m **a horizontal plane at a depth** of 1.5 **km**.

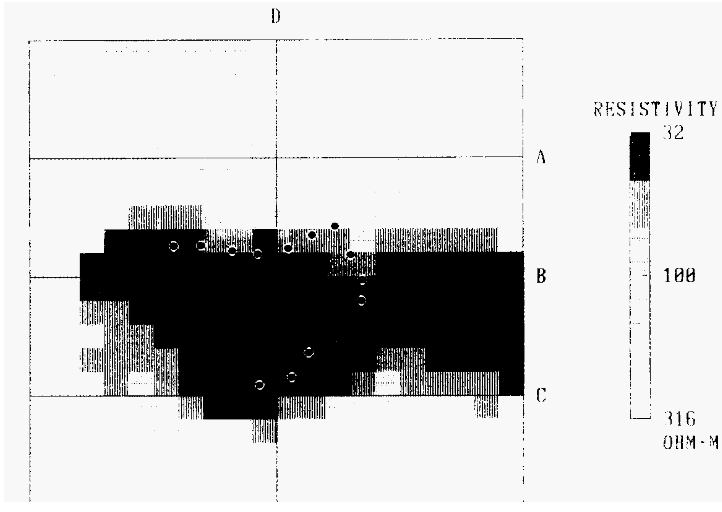


Figure 2.d. 2-D resistivity map in a horizontal plane at a depth of 2 0 km.

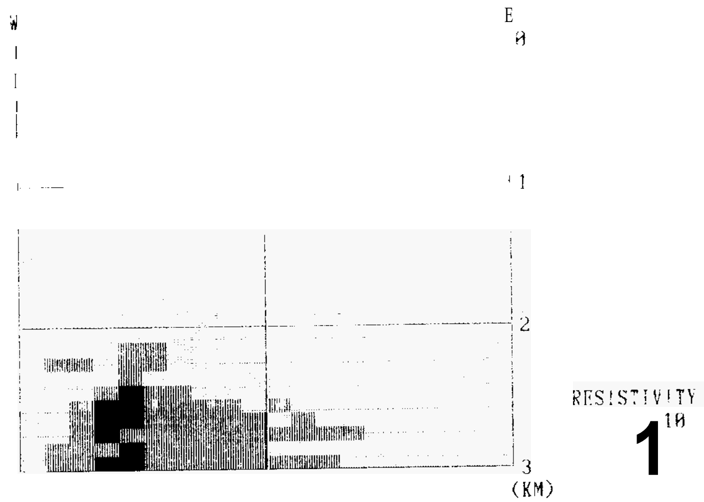


Figure 3. a. 2-D resistivity map along vertical plane upto 3 km along profile A as shown in Figure 2.

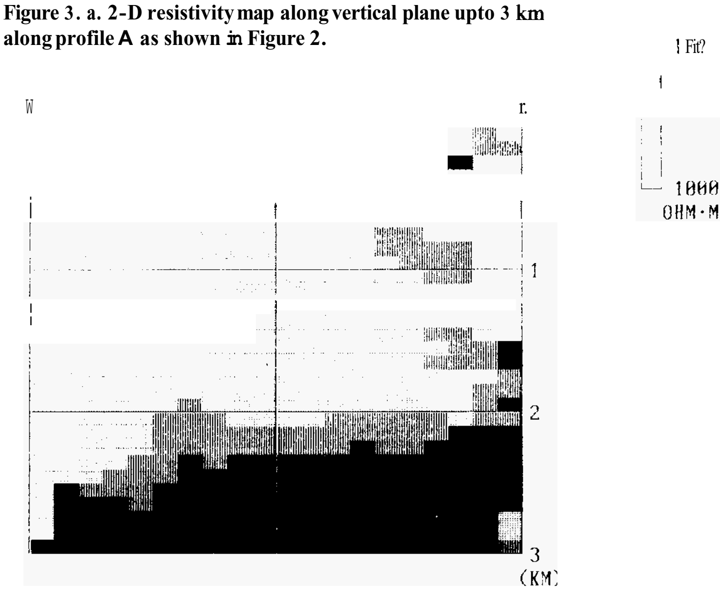


Figure 3.b. 2-D resistivity map along vertical plane upto 3 km along profile B as shown in Figure 2.

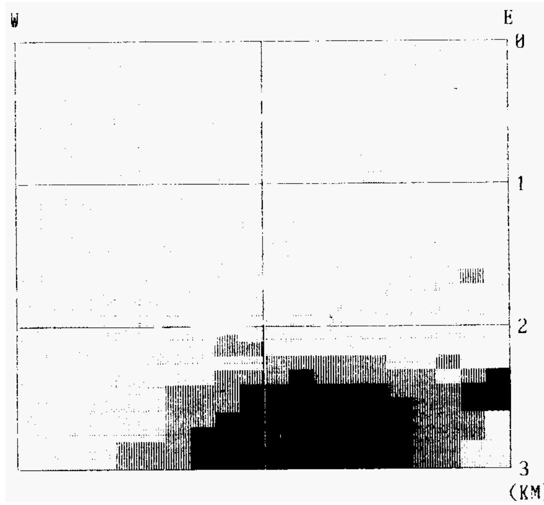
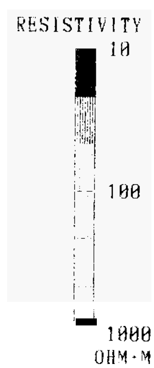


Figure 3.c. 2-D resistivity map along vertical plane upto 3 km along profile C as shown in Figure 2.



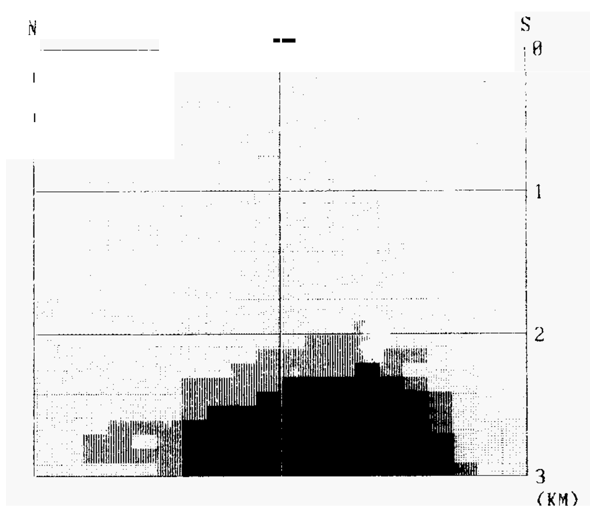


Figure 3.d. 2-D resistivity map along vertical plane upto 3 km along profile D as shown in Figure 2.

south direction between stations 104 and 112.

6. CONCLUSIONS

The present results gives the depth map of low resistivity zone along various east-west and north-south profiles in Puga valley. The low resistivity zone is attributed due to the presence of geothermal reservoir. From the resistivity-depth maps, it is found that the geothermal reservoir exist in between profiles B and C. The depth of the geothermal reservoir is found to be about 1 km along west-east profile B and it continues upto 3 km depth. The extent of the geothermal reservoir seems to be limited upto 3 km and is surrounded by high resistivity formation. The GEMIT results show a qualitative result of the low resistivity zone present in the valley. The quantitative result is not possible due to the noisy electric field data which is attributed since the region is mountaneous.

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