Integration of Various Geophysical Approaches is a Must in Groundwater Exploration in Deccan Traps

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Abstract

To cope up with ever increasing demand of groundwater, pin pointing the borewell site and to understand the evolution history of lava flows in Deccan Trap Basalt, a hard rock, an integrated geophysical study namely Electrical Resistivity Imaging (ERI), ground magnetic, was carried out in addition magnetic susceptibility in situ measurements of drilled samples in the form of susceptibility logs from borewells and finally lithologs evaluation in order to target for potential aquifer(s) in Deccan Trap Basalt where there exist real problem of groundwater at the watershed scale. This integrated study has been carried out in Central India to delineate potential basaltic aquifers, understand its geological set up and complexity including the lava flows, where as magnetic susceptibility measurements has helped in understanding the various basaltic flows and also used as supplement in delineating the potential aquifer zones.In the present study, ERI was carried out along 21 profiles mostly near the dugwells while the magnetic study was attempted at 3 sites. On analyzing the 2D inverted true resistivity sections and in correlation with the geological sections from open dugwells, it reveals that the subsurface consists of six to seven layers of basalt and nevertheless it was very successful in delineating the basaltic zones, including the potential aquifers. The layered formations of 2D resistivity sections corroborates very well especially in terms of thickness. Quantitative results shows that, black cotton soil resistivity value is < 20 Ohm-m, weathered and highly weathered basalt lie in between 15-70 Ohm-m, Intertrappean ranges between 5-20 Ohm-m, dry weathered/fractured basalt falls in 60-100 Ohm-m, saturated weathered and fractured basalt falls between 10-80 Ohm-m, spheroidal weathered basalt (jointed) has the range of 200–300 Ohm-m whereas the massive basalt resistivity is >500 Ohm-m. On the other hand, lithologs shows black cotton soil, saprolite, weathered fresh basalt, fresh basalt, fresh weathered zeolitic basalt, weathered zeolitic basalt including clay, and at the end massive basalt. At the time of drilling of the borewells based on geophysics and hydrogeology water encounter in 13 out of 15 borewells with a success rate of 86.6 % and the change in lithology exactly match with the interpreted resistivity values and its contrast. The study gives indispensable information especially in delineating the layered basaltic formations including the intertrappeans and lava flows both in terms of thicknesses and resistivities. Latter magnetic susceptibility in situ measurements of the drilled samples measured at 10 borewells at an interval of 3ft (~1 m), shows the measured susceptibilities vary from about 0.5 to 38.0×10-3 SI units which have helped (in association with ERI data) in identifying the weathered and unweathered flows. This integrated study in one hand, facilitated in delineating the layered formations of basaltic region, gives the true indication of lava flows and successfully pointed the potential groundwater zones while on the other hand, the variation in susceptibilities value gives a direct clue for the weathering process in basalt; i.e., linked to the magnetic susceptibility measurements, as when weathering occurs there is a change in the content of magnetite (Fe3O4), which is clearly reflecting from the obtained susceptibility logs and there are gradational variations too which signify the variation in the composition of the magnetic minerals. This could be possibly linked to the lava flow also, which is the future research area.

Keywords: ERI, Drilling, Magnetic Susceptibility, Deccan Trap, Central India

Introduction

The Deccan Traps province, one of the most voluminous continental flood basalt provinces on Earth, consists of basalts with a wide range of compositions not only in isotopic ratios but also in major and trace element contents (Mahoney, 1988). Most of the basalt was erupted between 65 and 60 million years ago. One such study in similar geological condition was carried out in Central India, Ghatiya watershed for groundwater exploration and management point of view. The study area, lies within the geographical coordinates between 23^{o} 19' N to 23^{o} 26' N latitude and 75^{o} 50' E to 75^{o} 59' E longitude covering an area of 75.25 km^2 and consists of Deccan Trap Basalt of upper Cretaceous to lower Eocene age. The average annual rainfall in the area is < 850 mm. Due to scanty and desiccate rainfall the life of the people of the watershed is miserable and they had to struggle a lot to quench their thrust as well as for the irrigation.

To understand the Deccan Basalt Electrical Resistivity Imaging (ERI) was carried out in detailed way in Ghatiya watershed, situated near Bhopal India, which now a days a valuable and essential geoscientific tool especially for groundwater prospecting and exploration (Kumar et al., 2008). The 2D resistivity images are created by inverting hundreds to thousands of individual resistivity measurements recorded within a short span of time to produce an approximate or true model of the subsurface resistivity variation. As a result, high-definition pseudo sections with dense sampling of apparent resistivity variation at shallow depth (0-100 m) are obtained in a short span of time with quite precision provided the acquisition of data is of good quality. It allows the detailed interpretation of 2D resistivity distribution in the ground below the surface (Loke and Barker, 1996). At present day, field techniques and equipment to carry out 2D resistivity surveys are fairly well developed (Loke, 1997, 1997a). A resistivity meter called *SYSCAL* Junior Switch, with 48 electrodes connected to the resistivity meter through a multi-core reversible cable has been used in the present study for carrying out the required work.

In the study area, ERI was carried out covering all the 11 villages along 21 profiles (fig.1) using standard Wenner-Schlumberger and Dipole-Dipole configurations employing 48 electrodes with 10 m inter-electrode spacing, excepting a few sites where 5 m spacing was used due to unavailability of sufficient space. Most of the imaging sites were carried out the open dug wells (as there are numerous wells in the watershed) so that the 2D true resistivity images/sections finally obtained on inversion can be compared with the dugwell's geological section and this has helped while interpretating the resistivity imaging data and in correlating the various thicknesses and resistivities of the geological formations.

2D Resistivity Interpretation

The 2D resistivity sections obtained from various profiles in the area revealed that the subsurface consists of layered structure and in between these layered formations the potential zone(s) for groundwater are trapped and the thin zones reflected in 2D sections with sharp resistivity contrast between the overlying and underlying formations depicts the various flows of lava or the intertrappean. This situation reveals that the multi-aquifer system persists in the watershed. Here few profiles with their interpretation are discussed below.

Profile L1

The 2D resistivity section (fig.2) shows clearly a layered structure with six major layers. Top layer consists of black cotton soil with a thickness of about 2.5 m and its resistivity of the order of <17 Ohm-m followed by weathered basalt upto a depth of 25 m with resistivity in the range of 23 – 28 Ohm-m then follows the dry weathered basalt upto a depth of 40 m with a resistivity of the order of 35 – 50 Ohm-m followed by vesicular/fractured basalt upto 57 m with a resistivity of the order of 95 Ohm-m and then another layer upto a depth of 79 m and then underlies the massive basalt up to a depth of 91 m with slightly dipping trend in the SW direction with a resistivity in the range of 150- 180 Ohm-m.

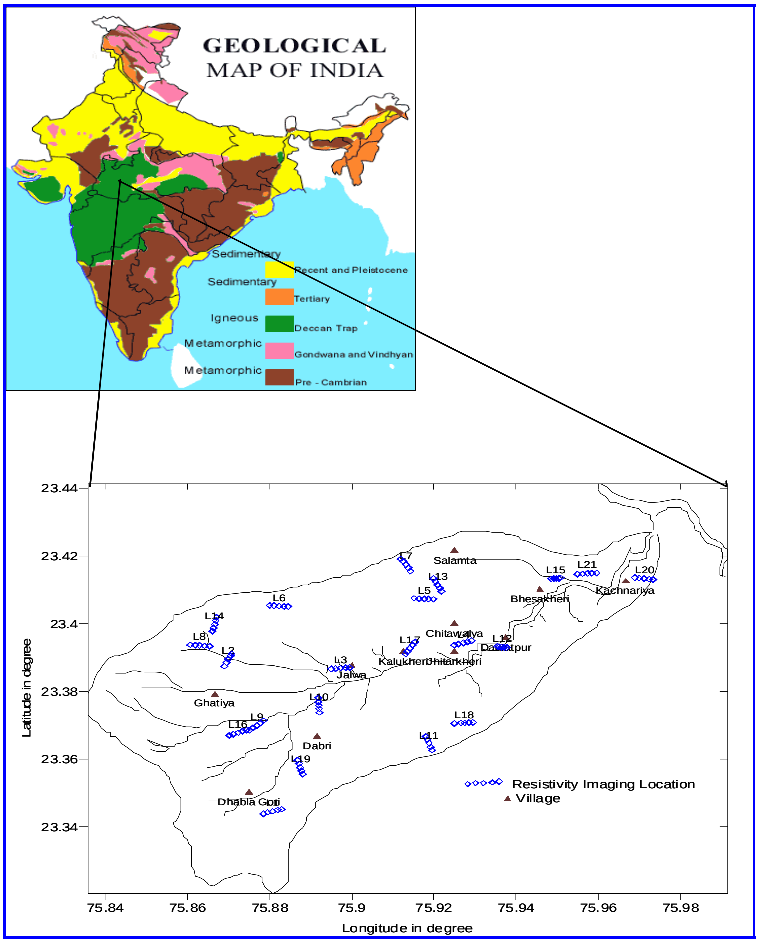

Fig.1 Study area showing location of Imaging lines at Ghatiya watershed, Madhya Pradesh, Central India

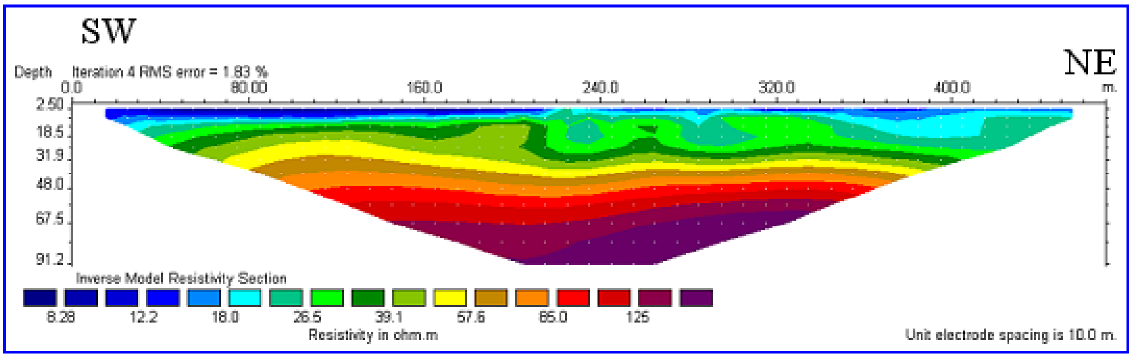

Fig.2 2D Resistivity Imaging section along line-L1

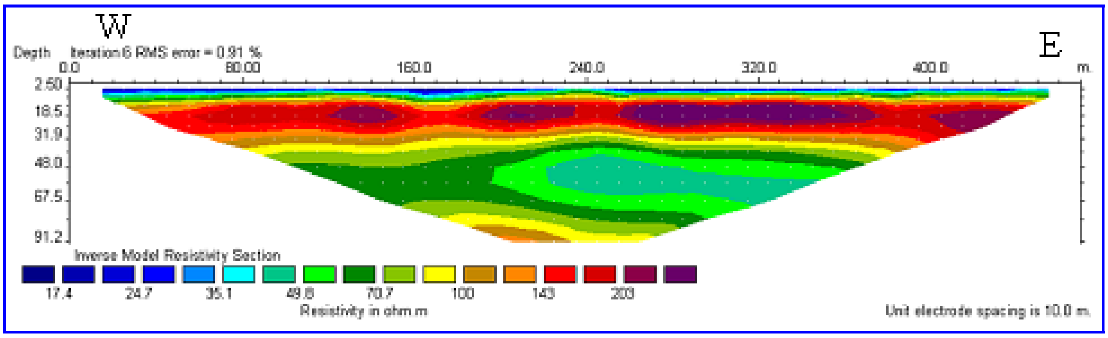

Fig.3 2D Resistivity Imaging section along line-L5

Profile L5

At this site the 2D resistivity section shows clearly a layered structure with six major layers. Top layer consists of black cotton soil with a thickness of about a metre and resistivity of the order of 18 Ohm-m (fig.3) followed by weathered basalt up to a depth of 7 m with resistivity of about 70 – 80 Ohm-m then follows high resistivity (~ 200 Ohm-m) layer from 15 to 25 m, then follows thin low resistivity layer which seems to be weathered/vesicular basalt in the range of 50 – 70 Ohm-m which is underlain by thick (~ 40 – 67 m) low resistivity zone of the order of 50 Ohm-m then follows comparatively high resistivity up to 91.2 m.

Profile L8

2D resistivity section at this site shows a layered structure having seven major layers and the sub-surface topography is dipping from NW to SE direction (fig.4) and the high resistivity zone also becomes thicker and thicker towards SE end of the profile. As in other sections, here also, the 2D section consists of top layer with black cotton soil with a thickness of about 1.0 m and resistivity of about 8 Ohm-m followed by weathered/vesicular basalt up to a depth of about 10 m with resistivity around 70-80 Ohm-m then follows thick zone of high resistivity (~200 Ohm-m) layer up to 32 m followed by comparatively low resistivity layer of about 16 m thickness with dipping trend of the geological formation followed by another still lower resistivity zone (~ 40-70 Ohm-m) up to 91 m.

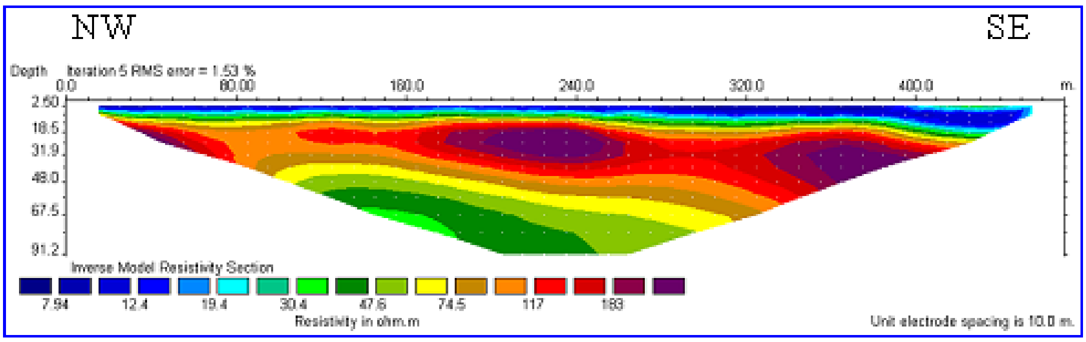

Fig.4 2D Resistivity Imaging section along line-L8

Drilling Results

Based on the results of the geophysical studies, 9 sites have been identified for drilling of borewell and in all 15 well have been drilled in the said watershed. The remaining 6 have been selected randomly to have good coverage of entire watershed. The detailed diagrammatic representations of two litholog of borewells (DG1 and DB1) are shown in fig.5. Based on the findings of the drilling results two or at the most three lava flows were encountered during the drilling. The groundwater potential of the area seems to be very low. The depth of the borewells varies from 135 ft to 285 ft. The yield of most of the wells varied from 0.25 inch to 1 inch when measured with a 90° V-Notch during airlift. Only DG1 which was drilled in Dhablagori village showed a good yield which was at times greater than 2.5 inches.

Clay beds (Malagar in local language) was encountered at several places during the drilling. The most prominent of these clay beds were observed during the drilling of DB1 in Dabri village. It continued for about more than 50 feet and prevented further drilling as it increased the chances of collapse. However latter, these clay beds collapsed leaving the total depth of the bed only up to 135 feet.

Magnetic Susceptibility Measurements

The magnetic susceptibility allows a statement to be made about the mineralogy of the medium. One can hope to recognize the oxidation or reduction fronts and variations in concentration in magnetic minerals indicating boundaries between different types of basalts (Daly and Tabbagh, 1988). Susceptibility also allows the calculation of the induced magnetization which can be subtracted from the total magnetization to obtain the remanent magnetization. In fact, the induced magnetization is often non-neglible with respect to the total magnetization, and values of the Koenigsberger ratio as low as 1 are common (Deutsch and Patzold 1976; Cokerham and Hall 1976).

Magnetic Susceptibility of the rocks is very much used in identifying magnetic bodies as well as weathered portions of the parent rock constituting the magnetic particles, as it is the ease of magnetization of rock constituting the magnetic material. In the absence of magnetic susceptibility logger, a portable hand held susceptibility measuring instrument ‘Kappameter KT6’ has been used for measuring the *in situ* susceptibility of the rock samples (Kumar et al., 2008). For this purpose, the drilling material obtained at a regular interval of 3 ft from the subsurface were collected in polythene bags of approximate size of 6” x 6” x 1” and was packed. The magnetic susceptibility measurements were made over these samples. The magnetic susceptibility logs so obtained (after plotting the consistent magnetic susceptibility values with depth) are shown below in fig.6. The susceptibility logs shows that the depths where the water struck during drilling in the borewells, its value lies between about 15 to 20×10^{-3} SI units which indicates that the water was mostly found in fractured/semi-fractured basalt as compared to weathered or massive basalt where the magnetic susceptibility values are higher. Thus, the susceptibility value of fractured basalt lies between saprolite (highly weathered) and the massive basalt. Two such susceptibility logs at borewells No. DG1 and DB1 are shown below in fig.6.

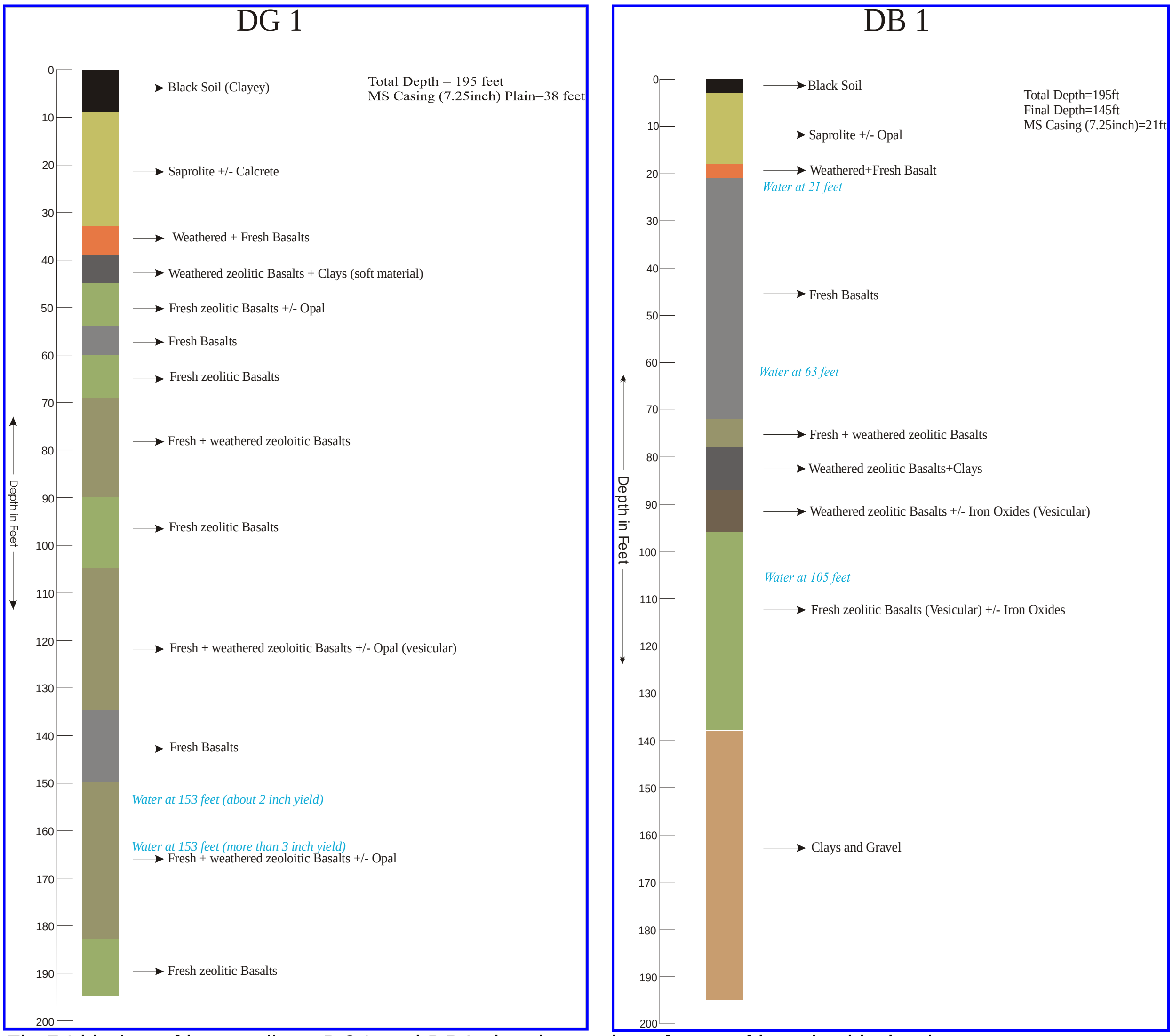

Fig.5 Litholog of borewells at DG1 and DB1 showing various forms of basalt with depths of water struck

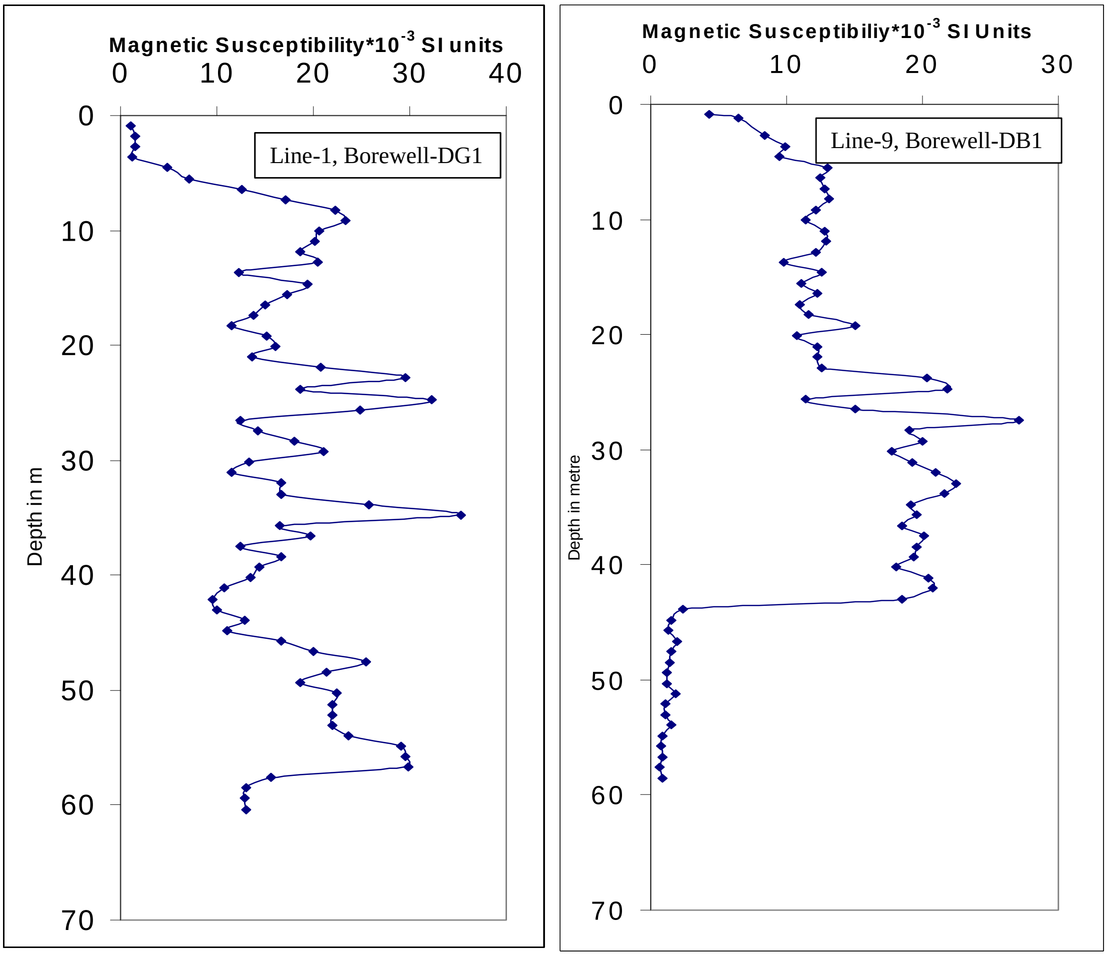

Fig.6 Susceptibility logs at Borewells No. DG1 and DB1

Conclusions

The Electrical Resistivity Imaging technique has delineated the layered formation of basalt including the intertrappeans and a lava flow, which is based on the change in the sharp resistivity contrast between intermediate layers in the Deccan trap region. The results of the 2D resistivity survey was further used in siting the potential sites for drilling the borewells and finally 15 borewells was drilled. The borewells drilled based on geophysical results are corroborative with the resistivity 2D images; especially in terms of thicknesses and most of borewells struck water at the time of drilling and few are good yielding and thus located the aquifer(s) zone. Magnetic susceptibility measurements confirms that as when weathering occurs there is a change in the content of magnetite (Fe_3O_4), which is clearly reflecting from the obtained susceptibility logs and there are gradational variations too which signify the variation in the composition of the magnetic minerals (Kumar et al., 2008a).

During the water level monitoring in July 2006 all these 15 borewells has water levels and it ranges from 9.91 m to 49.4 m (bgl), indicating the multi-aquifer system. The present study shows that the resistivity imaging technique along with susceptibility logs has proved in delineating the various geological basaltic formations and could be well applied in further understanding the other Deccan trap region of the country. The geological units studied from the well sections are compared with the resistivity imaging results and hence certain characteristic resistivity values are obtained for various lithological/geological units. Of course, some overlap of resistivities will always be present between different formations due the dependence of resistivity on several factors such as mineral constituents, differential weathering in the formations, saturation with water etc. A pumping test in the area is strongly recommended to have an idea of the aquifer geometry and the aquifer parameters which can be used for preparing a regional hydrogeological model for basaltic aquifers at the same time the mechanism of recharge process should also be studied in detail for the deeper aquifers to have a groundwater management plan for these regions.

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