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Delineation of groundwater potential zones in hard rock terrain from magnetic anomalies in Siddipet district (Telangana), India

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ABSTRACT
Systematic and synergistic approaches are required for groundwater prospecting in hard rock areas, where secondary porosity plays a major role. A total field magnetic survey was carried out over a part of the Siddipet District (Telangana) covering an area between $17^0 35'$-$18^0 18'$N and $78^0 25'$-$79^0 10'$E, for identifying structural features and associated dykes apart from marking weathered zones and lithological variations. The magnetic survey consists of about 1000 stations, distributed at an interval of 500 m and covering an approximate area of about 2500 km^2. Processing and interpretation of the acquired data resulted in accessing the thickness of weathered layers and the underlying fractured and fissured zones. We discuss these results in the light of groundwater potential in the studied region.

Keywords: Granitic terrain, weathered zone, fractured rocks, Magnetic anomaly, Groundwater potential.

INTRODUCTION

Major part of Peninsular India is covered by hard rocks, associated with varied conditions of drought to arid or semi-arid nature. Availability of groundwater in these areas is controlled by the limited rainfall, high evaporation and surface runoff, apart from negligible primary porosity, low permeability and structural/lithologic complexities. Spatial variation of the characteristic parameters like composition, texture, grain size, fracturing, metamorphism, tectonic set-up, degree of weathering are related to the development of secondary porosity in such rocks. As a result, the groundwater potential also varies significantly from place to place, sometimes within a few meters within the same geological formations, making the resource exploration a challenging job. Normal hydrogeological studies in locating ground water may not be of much use in this type of terrain, because the hydraulic conductivity which is one of the important factors in ground water exploration varies within short distance due to varying thickness of the weatherd zone. However, a systematic and integrated surface exploration can result in locating high yield sites successfully (Rangarajan and Avathale, 2000; Venkata Swamy, et al., 2008; Ramdass and Chary, 1992).

Major parts of Siddipet district in Telangana district, forms one such region which faces acute shortage of surface water resources. Efforts to find groundwater for drinking, as well as for agricultural purposes, have been made here by various governmental and private agencies with varying degrees of success. Thus, location of proper resources of groundwater in the region by systematic scientific approaches is required. In view of this, a systematic surface magnetic investigation was carried out in a region bounded by latitudes $17^0 35'$-$18^0 18'$ N and longitudes $78^0 25'$-$79^0 10'$ E, that cover an area of about 2500 km^2.

GEOMOROPHOLOGY AND GEOHYDROLOGY

Based on geological and hydrogeological studies, this area can be divided into several geomorphological units which are mostly structural, denudational and fluviatile in origin. The crystalline complex, represented by metasediments, gneisses and granites, forms a distinct pediplain (Figure 1). This is the result of the denudational process comprising landforms like residual hills, inselbergs and shallow weathered pediplain.

The study area is predominantly covered by hard Archaean/Precambrian rocks, comprising granite, adamellite, tonalite, amphibolite, and hornblende biotite schist. These formations were subjected to tectonism and green schist facies metamorphism. Based on mineral composition, they were further classified as alkali feldspar granite, migmatite granite gneisses, adamellite, granodiorite, tonalite and trondjhemite. A few patches of amphibolite and pyroxene granulites are seen around Siddipet. All these rock formations are traversed by NE-SW and N-S trending basic (dolerite) dykes and quartz veins. The area experienced volcanism at the time of eruption of the Deccan Traps. Small portions of Deccan volcanic cover can be seen north and south of Chegunta (Figure 1) (Geology and Mineral resources, 2006).

No major river flows in this area, except a few rivulets e.g. Kudaliar (Kudavelly) and Haldi (Pasupuyeru) that originate from the hills on the southern portions of the study area. They are seasonal in nature and hardly of any use to farmers for their irrigation purposes. Haldi is a tributary of the river Manjeera, which in turn is a major tributary to river Godavari. The drainage pattern is sub-dendritic in nature with poor drainage density. Average elevation of the area is about 500 m a.m.s.l.

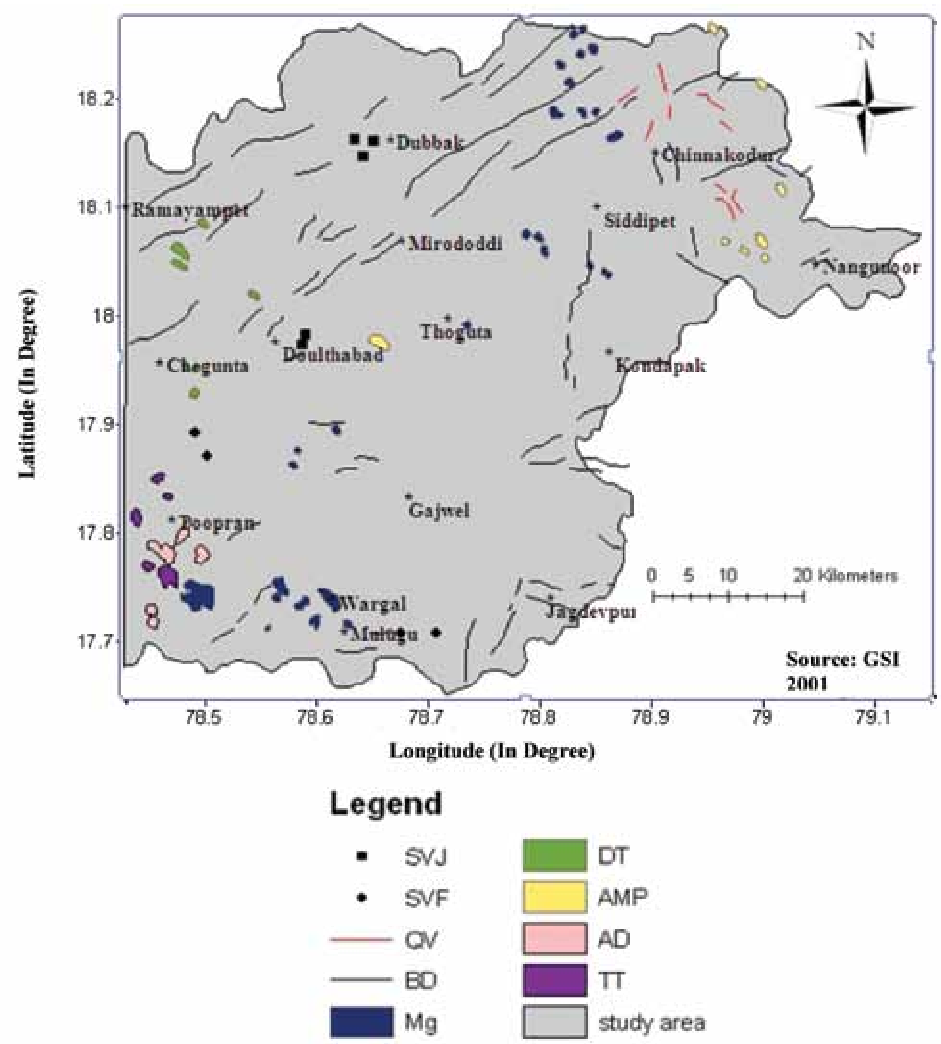


Figure 1. Geology of the area. SVJ- Strike of Vertical Joint, SVF- Strike of Vertical Foliation, QV- Quartz Veins/Reefs, BD-Dolerite Dykes, Mg- Migmatites, DT- Basalts, AMP-Amphibolites, AD- Adamellite, TT- Tonalites.

Significance of subsurface structures in hard rock

In India, a variable thickness of weathered material is encountered over the granite gneiss hard-rock terrains. The former is a regolith produced by in situ weathering of the basement rocks. The regolith normally grades into solid, unfractured basement over several tens of meters, although often the boundary between the two may be fairly sharp. Hydrogeologically, the weathered overburden has a high porosity and contains a significant amount of water, but because of its relatively high clay content, it has a low permeability. The bedrock on the other hand is fresh but fractured, showing relatively more permeability. However, as fractures do not constitute a significant volume of the rock, the fractured basement has a low porosity. As such, a good borehole which penetrates a large thickness of regolith or large areal extent of regolith with interconnected fractures and additionally intersects the fractures in the underlying bedrock, can provide long term high yield. These structures (called concealed lineament) and fractures, provide a rapid transport mechanism from the reservoir and hence provide high yield. Boreholes which intersect fractures, but which are not overlain by thick saturated regolith, cannot be expected to provide high yield in the long term. On the other hand, boreholes which penetrate saturated concealed lineament with underlying fractures in the bedrock, are likely to provide sufficient yield.

GEOPHYSICAL INVESTIGATIONS

The geophysical methods provide information on aquifer geometry and lithologic composition that are useful in conceptualization of the aquifer system. Hence, electrical resistivity and magnetic surveys were carried out in the eastern part of the study area for structural and lithological variations. Dolerite dykes are seen in the northern, northeastern and western parts of the study area. Due to over-exploitation of the groundwater resources, water level has gone down and at present, groundwater occurs mainly in the fractured/fissured rock. As the aquifer is unconfined in nature, it gets recharged from the top surface during precipitation. In such a case, knowledge of depth to the interface between the hard rock and weathered/fractured zones is desirable (Cull and Massie, 2002).

The magnetic materials present within the weathered zone are depleted due to the weathering process during the geological time. This depletion of magnetic minerals reduces the susceptibility of the weathered zone, whereas it is unaltered in hard rock. Thus the geological contact between the overburden and the hard rock becomes a good magnetic interface with considerable susceptibility contrast (Table 1) therefore can be traced by magnetic surveys (Raghavan, 1999 and Dewashish Kumar et al., 2006).

Table 1. Magnetic Susceptibility values of the major rock types of the area.

S.No.	Major rock type	Magnetic susceptibility ($Kx10^{-6}$cgs)
1	Gray granite	400-10000
2	Pink Granite	350-600
3	Dolerite	500-3000

In this study, magnetic stations are located at an interval of about 0.5 km all along the available motor able roads, canals and motorable country tracks. Magnetic observations were made using Proton Precession Magnetometer (Terra Science, make). In all, a total of about 1000 magnetic observations were made in the study area. Base station was located at the Government Degree College, Siddipet by maintaining a second magnetometer for diurnal correction. A contour map was prepared after applying normal and diurnal corrections with reference to the base station (Figure 2).

The magnetic map (Figure 2) shows distinct trend. It is characterised by closures and alignments that are attributable to known and unknown surface and subsurface geological and structural features. The anomalies reveal a narrow range of 42420 nT to 42820 nT, with a prominent low that has been observed in the southwest and northern parts of the area. A moderately high anomaly lies near west of Nangunoor in the northwest part. The magnetic contours in the central part extend approximately in E-W direction. The magnetic anomalies correlate well with the geology of the studied area. The significant features like NW-SE Dharwarian trend, NE-SW basic dyke trend and the lineaments trend that appear in figure 1, are noticeable in the total field magnetic map. Further, drainage pattern indicated by Kudaliar and Haldi rivers is in the SE-NW direction, which corresponds with the Dharwarian trend. These trends also appear in the magnetic anomaly map (Figure 2). It may be noted that the streams, rivers and rivulets in this hard rock crystalline terrain, mainly follow the structural trends like faults, intrusives, lineaments, litho boundaries etc.

The Archaean granites and granitic gneisses occurring in the area are intruded by dolerite dykes, pegmatite and quartz veins in preferred directions. Pink granites are rich in K-feldspars and show relatively low magnetic response compared to the gray granites, which are rich in mafic minerals and therefore contain relatively higher amount of iron. Dolerites are essentially of basic composition and show higher magnetic responses. Dolerite dykes with their limited occurrence, range from one meter to a few meters.

In general, the boundary between pink and gray granites is transitory and gradational, both in the lateral and vertical directions, although the origin of these granites being the same. Continuous exposure of granites to weathering, coupled with the effect of tectonic forces cause changes not only in physical properties but also in the development of faults, fractures and joints, in turn sometimes revealing the boundary between the pink and gray granites. Thus, the variation in magnetic anomaly distribution could be helpful in inferring the litho boundaries in the area (Ram Babu, H.V. et al., 1991; Madhusudhan Rao et al., 2002)

Spectral analysis of 2d-magnetic data

Power spectrum analysis is an established approach in obtaining depth to the magnetic interfaces in a layered subsurface sequences (Bhattacharyya 1966, Spector and Grant 1970, Mishra and Naidu 1974, Shuey et al., 1977, Connard et al., 1983). The radially averaged power spectrum of the magnetic data was computed (Figure 3) and best-fit straight lines were drawn on the spectra. Two best fit segments correspond to two depth levels, representing deep (regional), and shallow (residual) depths. The slop/4π of each segment gives the average depth of magnetic sources corresponding to each segment.Depth computations performed on these segments, show two ranges of depths with average values as 0.47 km and 1.6 km for the magnetic sources. Depths less than 0.47 km are considered as due to noise.

Regional-residual separation

Magnetic data observed in geophysical surveys are the sum of magnetic fields produced by all the subsurface sources. The magnetic responses of the small-scale structures from shallow depths are embedded in the regional fields that arise from magnetic sources usually larger and deeper. Estimation of the regional, low frequency and the residual high frequency component of fields, can be realized by power spectral analysis. Accordingly, the frequency of the deep-seated magnetic component frequency varies from 0.00 to 0.35

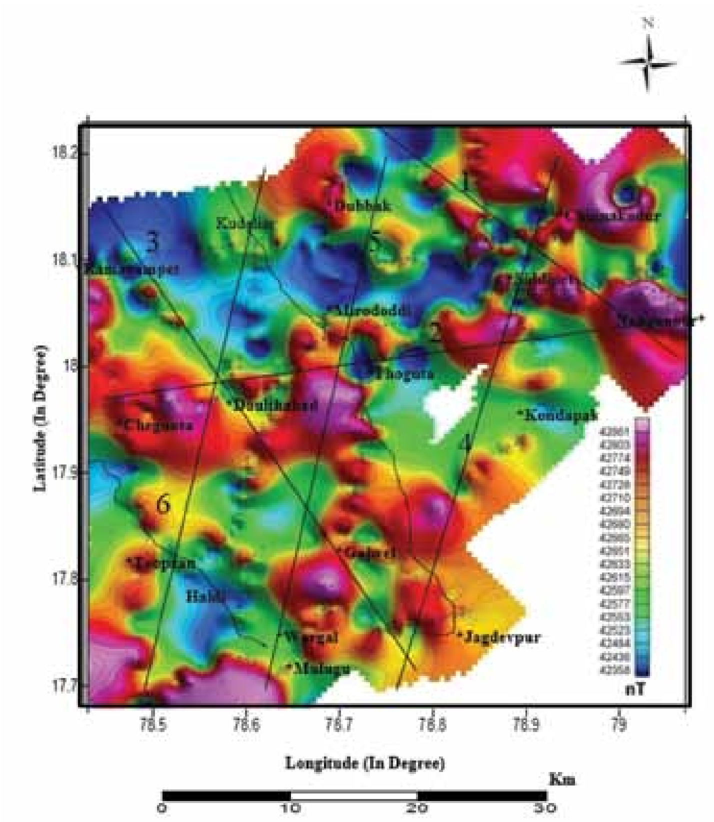


Figure 2. Total field magnetic anomaly map.

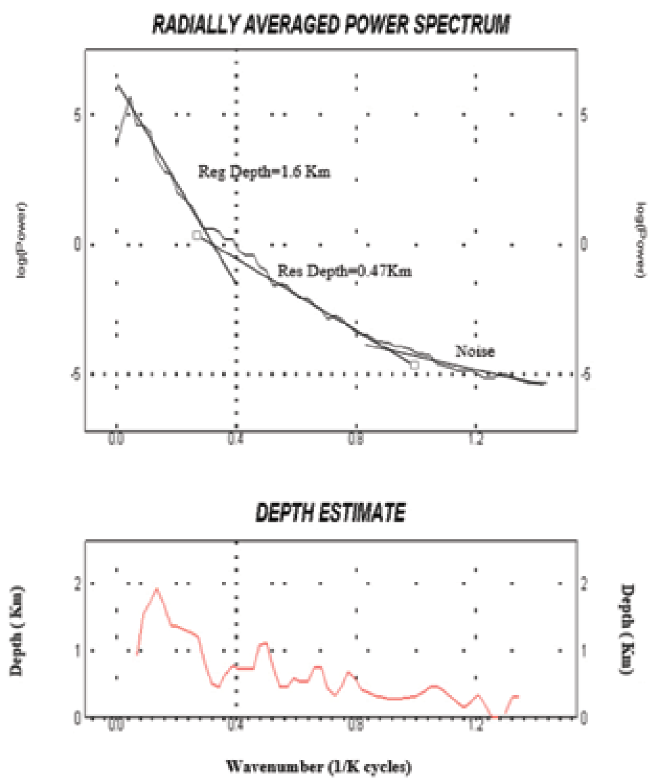
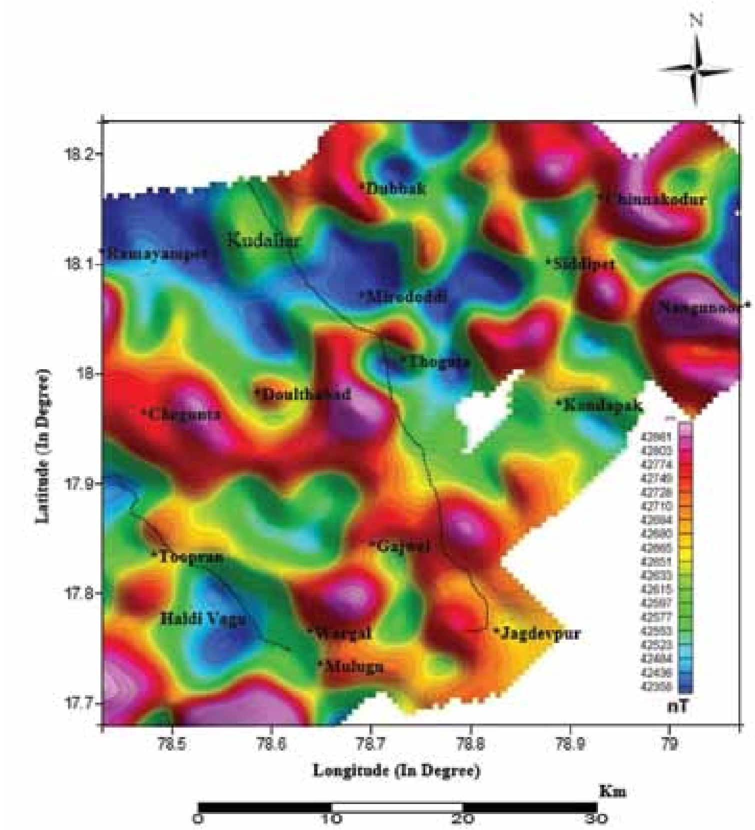


Figure 3. Radially Averaged Power Spectrum and Depth estimate.



Figures 4. Regional magnetic anomaly map

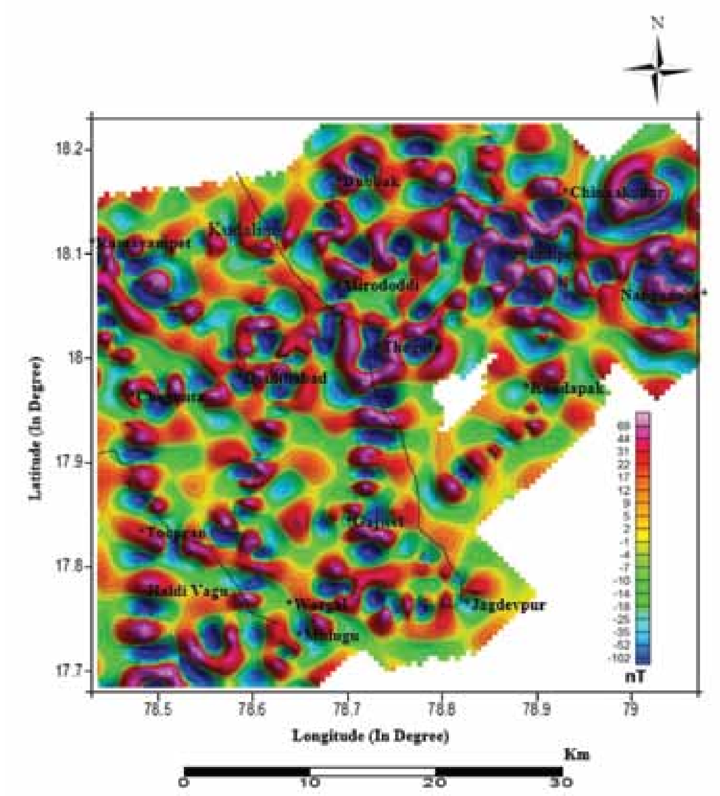


Figure 5. Residual magnetic anomaly map.

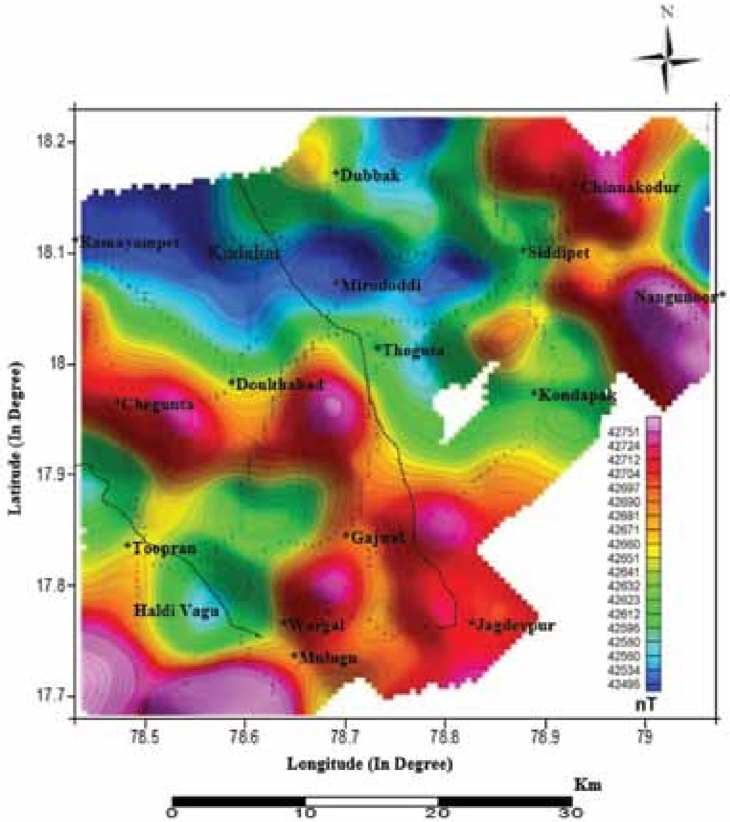


Figure 6. Upward continuation map at level 1.5 km from the surface

radians/km (Figure 3), while that of near-surface magnetic component, ranges from 0.35 to 0.91 radians/km. These bands of frequency signal were used through the low-pass and band-pass filters to separate the regional and residual magnetic maps respectively (Figures 4 and 5).

In the regional magnetic map (Figure 4) anomalies are broad and extend over larger areas and have high amplitudes and low frequencies. These anomalies are of considerable significance in the regional tectonic studies of the basement complex. On the other hand, in the residual magnetic map (Figure 5), small anomalies of local extent were also observed inside the major anomalies. The residual anomaly map (Figure 5) shows a prominent low in the northern and central part of the area. A magnetic high is seen approximately along N-S direction near Nangunoor. The magnetic highs are aligned along NE-SW direction and are supported by the presence of lineaments in the study area. A few exposed/weathered basic dykes are also traceable in this map through the lineament of local magnetic contours and or by their absence.

Upward Continuation

The application of upward continuation at different levels from the plane of observation, acts as a slice of potential field distribution at the chosen level. These levels are chosen based on the results of power spectrum from plane of observation with fixed contour interval in order to simplify comparison. In the continuation map at the level of 0.5 km, small size anomalies get merged with adjacent anomalies to form wider anomalies. The Continuation map at level 1.5 km (Figure 6) is nothing more than a smooth version of the map at level 0.5 km, since it has all the features with lesser amplitude. Meanwhile, all structural features in the magnetic anomaly map are still found at this level, indicating the continuation of structural features to depths more than 1.5 km from plane of observation. Further, almost all small size features are lost in the continuation map at level 3.0 km, but the main structural features are still present. Such an interpretation of the upward continuation helps us in the construction of the initial 2D magnetic modeling.

2D-MODELLING

In constructing the initial geological model to be used in 2D forward modelling, several input parameters and their criteria should be taken into consideration. Such criteria essentially include; the prevailing structure in the study area according to the inferred geological information, magnetic susceptibilities of different lithologic units and the depths of each rock unit, especially the basement in

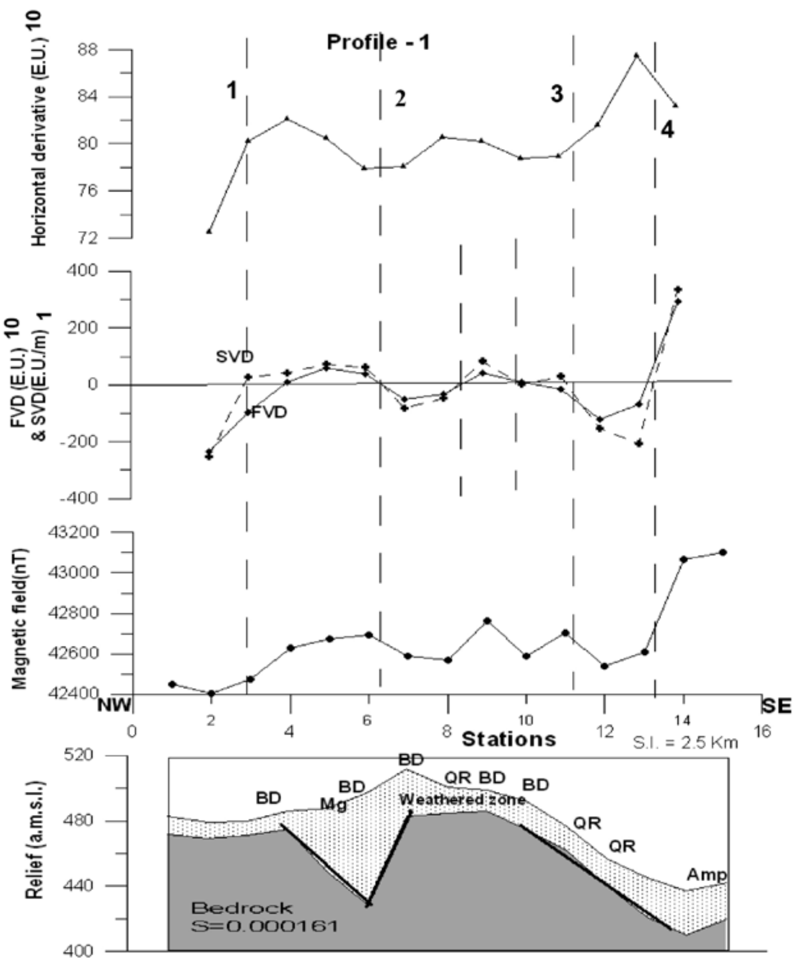


Figure 7. 2D forward modelling of magnetic profile -1. SVD-Second Vertical Derivative, FVD-First Vertical Derivative, BD-Dolerite Dykes, Mg- Migmatites, QR- Quartz Reefs, AMP-Amphibolites

the study area. 2D forward modeling has been carried out on six preselected profiles, (Figure 2) based on the GM-SYS modeling package. Results of modelled profile-1 is shown in Figure 7. The minimum depth to basement in the study (along profile 4) is found to be about 10 m from the surface (Venkata Rama Lingam, 2012) (Figures 2 and 7) and the maximum depth to basement is about 115 m. The median value of depths calculated along all profiles is about 70 m. The main structural features obtained along the profile 1 are represented in Figures 7.

INFERRED TECTONIC MAP OF THE STUDY AREA

It may be emphasized here that the faults are the main deformational structures that control the magnetic anomalies variations in the study area. The trends of the major faults are SE-NW and N-S, apart from a few isolated anomalies that may be integrated to form the well-known E-W fault system as plotted in the basement tectonic map as shown in Figure 8. This map is based on the interpretation of magnetic data and available geologic information. The SE-NW fault trend is extending from the southeastern corner to the northwestern corner of the study area and has three prominent residual magnetic anomalies in the central part. This is clearly represented in the modelled profile in Figure 7. Part of Kudaliar basin in the study area lies to the northeast of SE-NW fault trend and appear to be controlled by this trend, apart from the east-west tectonic trend. Critical correlation between surface geological map and the magnetic anomaly map shows that this trend is parallel to the Dharwarian trend. The east-west tectonic trend lies in the northeastern, southwestern and central part of the study area with moderate amplitude of magnetic anomalies (Figure 8). As mentioned above, the drainage basins of Kudaliar and Haldi rivulet in the study area seem to be controlled by E-W as well as SW-NE trends.

Surface topographic features, (Figure 1) and the subsurface basement structure, (Figure 8) of the study area are highly correlatable, especially in the Kudaliar and Haldi basins.

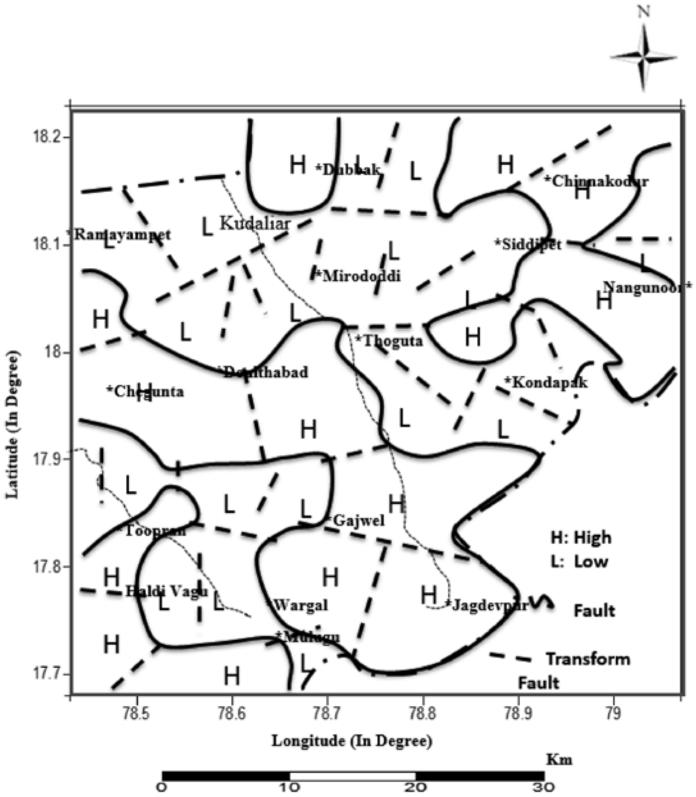


Figure 8. Structural tectonic trends map based on the interpretation of magnetic data and available geologic information.

RESULTS AND DISCUSSION

The investigations carried out by magnetic survey across a number of exposed dykes in the study area, revealed a characteristic anomaly pattern that correlate well with the regional geology, including Kudaliar rivulet and Haldi river drainage locality. Further, the variation in magnetic anomaly changes with the litho-boundaries is well noticed. It can be seen from the figs. 4-6 that a large low susceptibility zones (relatively magnetically calm) exist in the area, extending almost NE-SW direction and also parallel to the dykes. The pattern of the magnetic anomaly revealed that most of these dykes act groundwater flow channels at shallow depth and also act as barriers at deeper depths.

With available knowledge from vertical electrical sounding (VES), a geological section consisting of susceptibility stratification, corresponding to different types of soils, weathered products and fractured variants, including depth to the granites/gneissic basement may be drawn. Deeper basement is found to occur along valley fill areas and in a few other places, where Pediplain is moderately weathered. Similarly, shallow basement is expected in upland areas, which are associated with Pediment, Inselberg complex and are occasionally associated with shallow weathered Pediplains.

CONCLUSIONS

(i) Magnetic anomaly maps, prepared on the basis of about 1000 total field magnetic observations, revealed significant variations in the surface and near surface geology and other structural features.

(ii) The radially averaged power spectrum of the magnetic data resulted in two best fitting segments representing two depth levels corresponding to deep (Regional) and shallow (Residual) depths, with average depths from the surface as 1.6 km and 0.47 km respectively.

(iii)The results of 2D forward modeling on selected six profiles (Figure 2), indicates the minimum and maximum variation of depth to basement in the study area (Figure 7). The modeling results revealed close correspondence with the First Vertical Derivative (FVD), Second Vertical Derivative (SVD), Horizontal Derivative and Magnetic component values. They seem to correspond well to the known and unknown geological features. Further, the basement tectonic map explains the trends of faults and their directions, which in turn control the drainage pattern including Kudaliar rivulet and Haldi river (Figure 8)

(iv) In general, the hard rock formations do not have good groundwater potential and in specific cases, if it exists, it is difficult to trace out. It may be ascertained here that geophysical studies, particularly based on magnetic method, can help not only to trace the presence of hidden water bearing formations in those areas but can also estimate the thickness of weathered zone besides the depth to fractured layers.

(v) The present study successfully identified the thickness of the weathered/fractured zones and tectonic boundaries for locating favourable groundwater potential zones. Further, the results are also useful in calibrating the numerical aquifer model of the groundwater flow zones. Hence the method suits well in the present conditions and could be used in similar geological environments elsewhere.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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