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Dykes of Deccan Volcanics as Potential Groundwater Zones: A Joint Interpretation based on Ground Magnetic and Resistivity Data

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Abstract: The Deccan Volcanic Province (DVP) has a severe scarcity of potable water and the need is felt for locating secondary sources of groundwater almost all over the region. Dykes are important features commonly occurring in the DVP. However, the significance of dyke features in hydrogeological set up of the hard rock terrain like DVP is not clearly known though some information are available on the groundwater potential of dykes. In view of this fact, the present work is undertaken to study the hydrogeological characteristics of dykes and their function from a small watershed in Upper Panjhara basin, Dhule district of Maharashtra using electrical resistivity sounding and ground magnetic measurements. A total of 16 vertical electrical soundings (VES) over two major dykes (D1 and D9) were carried out for appraising the nature and distribution of subsurface water bearing zones contained by dykes. Modeling of the resistivity data suggest multilayer subsurface medium along with the heterogeneous hydrogeological distinctiveness. 2-D geoelectrical sections along the dykes D1 and D9 demonstrate carrier stretch along D1 passing through VES 7, 10 and 18 and barrier from VES 17 to 19. Similarly, D9 shows carrier aligned with VES 14, 21 and 23 and barrier associated with VES 4, 8, 22 and 26. Ground magnetic observations were carried out at 118 points in the study area which revealed two different zones of various magnetic characteristics in the total field magnetic anomaly map (F). Another significant observation is the magnetic value taken over the two dykes D1 and D9 are different from one another showing different cluster of magnetic lows and highs. The VES sections broadly match with the magnetic highs and lows thus indicating the presence of carrier and barrier stretches along the dykes D1 and D9.

Keywords: Deccan dykes, Aquifers, Dhule, resistivity, ground magnetic.

INTRODUCTION

It is a well known fact that in India there is severe dearth of groundwater in hard rock terrains. The fracturing, faulting etc within these hard rocks traps limited amount of groundwater. The structural discontinuities that exist to some extent in this hard terrain could also be potential zones for groundwater occurrences. An integrated study using ground magnetic data and vertical electrical sounding (VES) has been carried out in the Narmada-Tapi rift zone bordering the Dhule district of Maharashtra and occupying the headwater portion of Panjhara watershed. These studies will help in understanding the aquifer system, the movement of groundwater flow, to delineate the carrier and barrier stretches within the dykes and the depth to which these dykes holds potential to amass ground water. Several workers (Singh and Jamal, 2002; Nilsen et al., 2003; Tam et al., 2004; Babiker and Gudmundsson, 2004) have classified the dykes as carrier or barrier to the groundwater flow depending upon strength of fracturing in them. It has also been reported that a single dyke may function as carrier or barrier with respect to occurrence and flow of groundwater (Kulkarni, 1990; Duraiswami, 2005).

The Panjhara watershed covers an area of 434 sq. km and the annual rainfall here ranges from 300 mm to 862 mm (average 512 mm/yr). This region attains regional significance wherein the dykes and dyke swarms occur as parallel to sub-parallel bodies intruding basaltic flows and forming linear ridges of moderate relief (GSI, 2001). These are partly exposed and partly concealed, while some are exposed only in streams, wells and road cuts. Doleritic and gabbroic dykes mutually show fine-grained inter-granular to coarse-grained hypidiomorphic textures with ophitic and sub-ophitic characters infesting the flows (Sethna et al., 1996).

Groundwater occurrence along dykes appears to have dependability on degree of jointing, fracturing and weathering. Dug well sections (Pawar et al., 2008) studied at DW2, DW12, DW36, DW38 and DW41 (Figs.1 and 2) showed three sets of joints (vertical, horizontal and inclined)

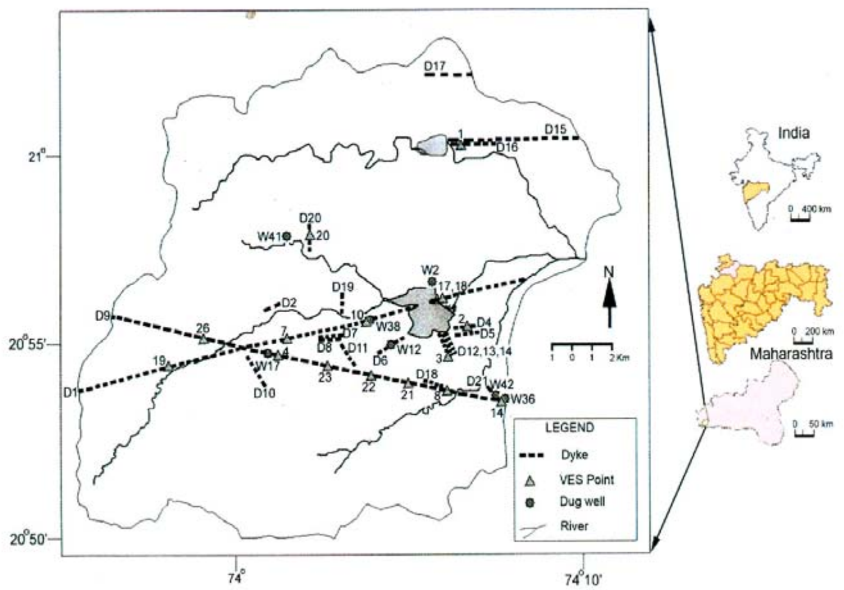


Fig.1. Location map of the study region showing the dykes, the VES points and the dug wells in Deccan Volcanic Province.

that are very closely spaced in doleritic and widely placed in gabbroic dykes. It is seen that the density of fracturing and jointing of the dug wells decreases with depth, as a result only shallow water table aquifers are broadly developed in the area.

HYDROGEOLOGICAL CHARACTERISTICS OF THE STUDY AREA

Doleritic and gabbroic dykes have been encountered and mapped from the study area. The hydrogeological map of the study region is shown in Fig.2. Both types of dykes control the occurrence and movement of groundwater in the study area. Here the dykes exceed length of 25 km crossing over the basin boundaries. Majority of them are running in east west direction and displaying variable width ranging from 1.20 m to 79 m, due to pinching and swelling character. Width of 79 m was recorded for dyke D1 at some places in the study area while dyke D9 is also a major dyke running over 25 km having width ranging from 10 to 17 m.

As mentioned earlier, doleritic dykes show three sets of joints, resulting into higher joint density due to less spacing between joints. Closely spaced jointing has induced rapid weathering and erosion of dykes showing negative and slightly positive relief in topography of doleritic dykes. Depth of weathering of these dykes varies from 15 m to 20 m. In nutshell high density of jointing and relatively deeper depth of weathering have favored doleritic dykes as loci of groundwater accumulation (Singh and Jamal, 2002). In comparison with these dykes the country rock basalt shows relatively less jointing, fracturing and weathering making it less favorable for occurrence of groundwater, which is evidenced by large number of dry wells in summer. However, the wells located in doleritic dykes (DW12 and DW41) produce fairly good amount of water even in summer.

Highly weathered contacts of gabbroic dykes are potential zones of groundwater occurrence wherein majority of dug wells are located in the study area (Fig.2). Longer stretches of these dykes have developed positive relief forming elongated ridges and hills separated by plains of negative relief with flat topography. However, the density of wells in gabbroic dykes is higher than doleritic dykes. On the dyke D9, within a length 125 meters 5 wells have been located with 20 to 25 meters inter-well spacing. Wells

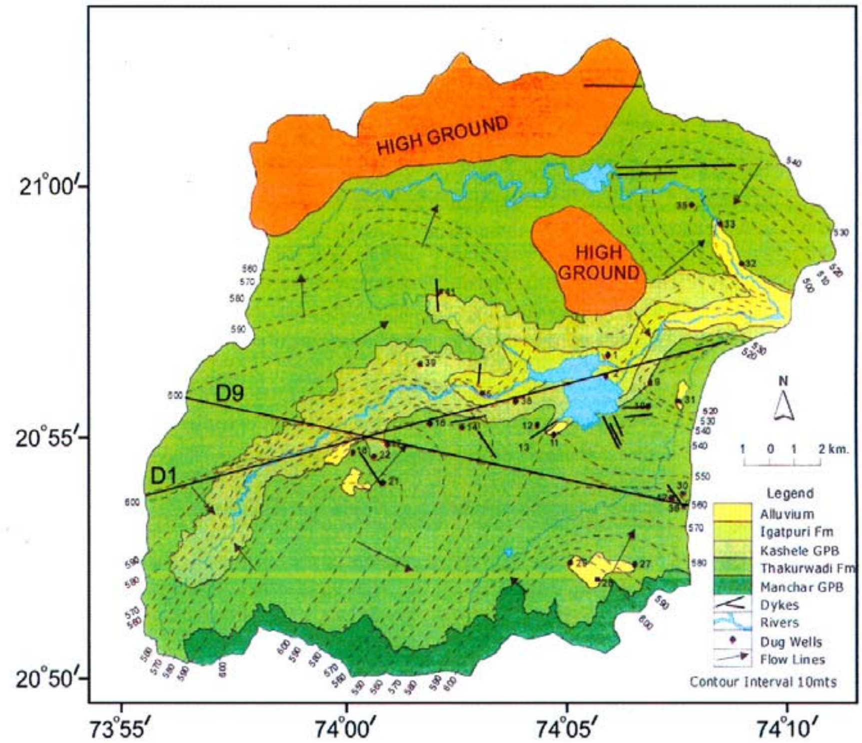


Fig.2. Hydrogeological map of the Upper Panjhara basin showing the dykes and the location of the dug wells.

DW2, DW17, DW36, DW38 and DW42 tapping gabbroic dyke aquifer are highly productive wells. Depth of water table in wells from doleritic dykes is between 1.4 mbgl and 4.8 mbgl in post-monsoon period and between 6.3 mbgl and 6.4 mbgl in summer, whereas, it ranges from 1.6 mbgl to 3.7 mbgl in post-monsoon and 4.5 mbgl to 6.9 mbgl in summer in the wells from gabbroic dykes. From hydrogeological point of view such dykes are classified as carrier dykes. Characteristic feature here is that groundwater flows into well from margins of dykes as well as through the dyke rocks.

METHODOLOGY AND ANALYSIS

Electrical resistivity studies

In all 20 dykes were mapped from the area and geological mapping revealed field distinctiveness of dykes, their attitude, thickness and structure above and beyond hydrogeological and structural facets that are important for groundwater occurrence and flow. After visual observations on dykes at road cuttings, excavations and well sections, six of them were chosen for detailed geophysical investigations. A total of 16 electrical resistivity soundings were conducted, covering different types of dykes in the study area (Fig.1). Schlumberger VES technique was adopted for delineating vertical changes across and along dykes. Resulting geoelectrical layer succession was used for predicting various conducting zones on the basis of true resistivities (Kearey and Brooks, 1984). The data obtained from the field was processed and modeled using IPI2WIN software, version 3.0.1.a7.01.03 (Bobachev, 2003) for interactive semi-automated interpretation. Apparent resistivity geoelectrical cross-sections generated to understand 2-D geometry of the aquifer developed along the regional dykes D1 and D9 (Pawar et al., 2008) indicate that dykes have formed separate potential aquifers in the Upper Panjhara basin and an individual dyke can behave as carrier or barrier along its length. The cross-sections of the 2-D geometry of the aquifers developed along dyke D1 (Fig.3a) show presence of bowl-shaped depression epitomized by aquifer body, which shrivels towards west (VES 7) in the upper part of the basin. This explains that dyke D1 has potential to store and transmit water along its carrier elongate inflated on either sides of VES 10 starting at 2 km and terminating at 7 km on horizontal scale (Fig.3a). The part of the dyke between VES 7 and 19 is barrier as it is composed of hard bedrock at very shallow depths of less than 3 m. In the conductive part of dyke the aquifer thickness is maximum up to 25 m at VES 10 and minimum of about 5 m at VES 7. A small part next to VES 17 is barrier, which towards VES 18 again becomes carrier.

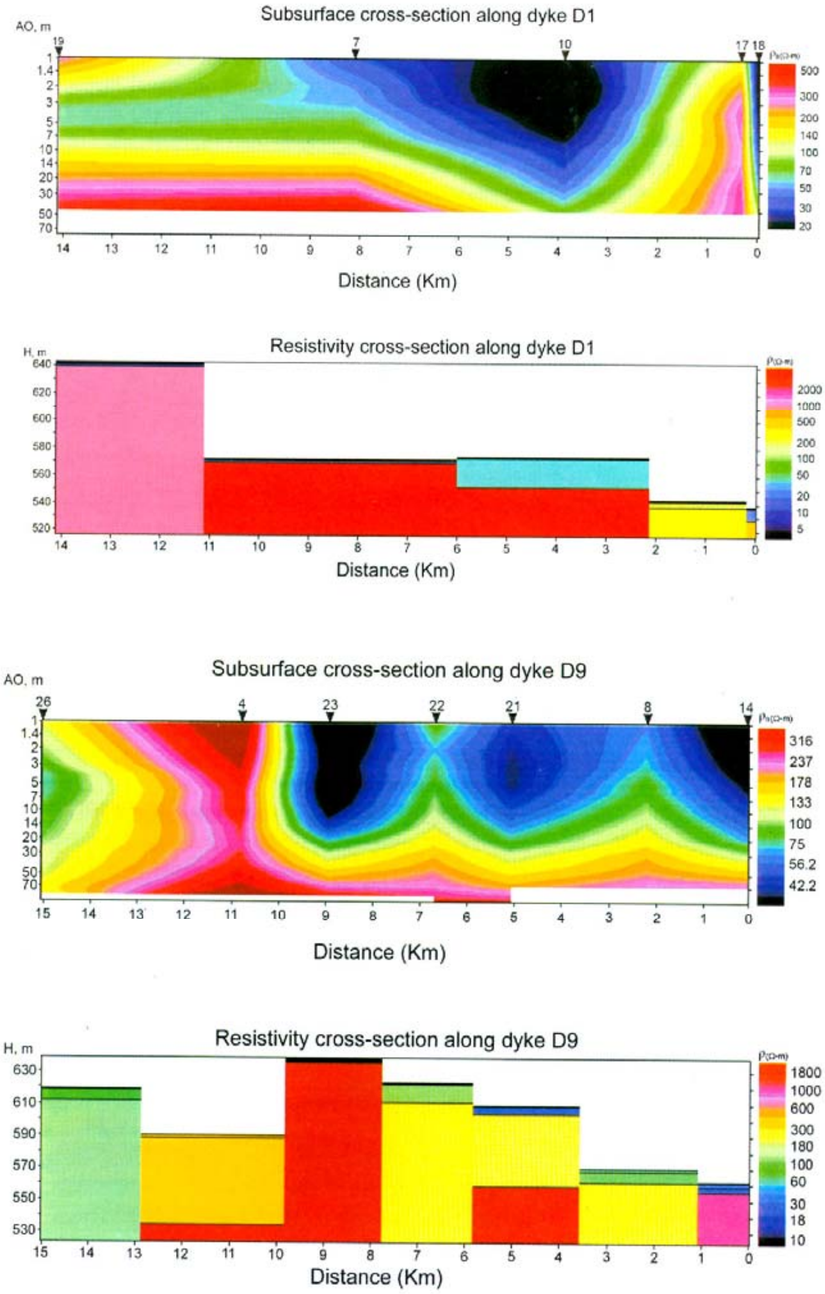
Longitudinal geo-electrical section flanking D9 (Fig.3b) illustrates existence of concave to oval shaped depressions separated by small barrier stretches at VES 8 and 22. The higher branch of the aquifer body slightly shrinks to very shallow depth level towards VES 22. At higher depth levels, presence of hard rock (VES 22) unfavourable for groundwater occurrence is inferred. Hence, this part of the dyke can be graded as typically barrier segment. Further towards east of VES 8, barrier widens because of presence of hard rock at shallow depth, which finally amalgamates into aquifer body at VES 14. The aquifer at VES 21 is egg-shaped and becomes concave at VES 23. The total length of discontinuous aquifer estimated in different carrier segments of dyke is about 5 km on horizontal scale and the vertical thickness is about 20 m. In the barrier part of the D9 (VES 8 and 22), the upper two / three layers have resistivities varying between 110 and 120 Ùm. This confirms that the dyke rock is characterized by moderate degree of jointing and shallow depth of weathering. The part of dyke between VES 4 and 26 is completely barrier stretch having high resistivity hard rock at very shallow depth (<1m). In the conductive division the aquifer thickness varies from 10m (VES 21) to about 20m (VES 14 and VES 23) at lowest elevation.

Thus the longitudinal geoelectrical sections along regional dykes D1 and D9 demonstrate carrier stretch along D1 passing through VES 7, 10 and 18 and barrier from VES 17 to 19. Similarly D9 shows carrier aligned with VES 14, 21 and 23 and barrier associated with VES 4, 8, 22 and 26.

Electrical layers of relatively low resistivities were matched with observed litho-sections at the dug wells DW38 in the vicinity of VES 10 and DW2 close to VES 18. At these wells, litho-section shows presence of soil layer (top layer), followed by weathered rock (IInd layer), which is further followed by intensely fractured and jointed rock (IIIrd layer). The deepest layer (IVth) is of moderately fractured hard rock. Using this analogy all the VES data were interpreted to understand the variations in lithology. The second and third layer (weathered, fractured and jointed rocks) reflects presence of favorable hydrogeological conditions for the occurrence of groundwater. Field observations also indicate that dykes characterized by these curve type are of carrier nature; an inference that is supported by presence of productive dug wells. The shallow depth dug well (DW36 close to VES 14) from gabbroic dyke is more productive than the dug wells in the adjoining host rock basalt. This implies that dykes have better groundwater potential than the basaltic aquifers in the area. It is also to be noted that these dykes and the wells located on them are in the physiographic zone coinciding with the low-lying plains. Thus local physiographic set up has influenced the hydrogeological conditions of the dykes. This in turn has further influenced the recharge process and groundwater flow along the dykes. It can be therefore stated that the physiographically higher zones of dykes with favorable hydrogeological conditions (e.g. VES 23, 22 and 21 along D9) are acting as areas of recharge for the groundwater occurring along dykes in low-lying plains.

Further it can be depicted from Fig.2 that the clustering of water table contours in the southern part indicates recharge zones. On the other hand, widely spaced contours in the central part denote discharge zones. The groundwater movement is from the recharge zone to discharge zone.

It can be thus surmised that dykes form potential and distinct aquifers in the study area, as they possess sufficient width, length and favorable hydrogeological structure. Hydrogeological and electrical resistivity investigations revealed that dykes behave as a medium for ground water flow provided porosity and permeability characteristics of dyke rocks are superior to the host rock and their trends in relation to topography are pertinent. Since density of jointing, fracturing and weathering of dykes increases as hydraulic gradient decreases, the low-lying areas are favored as loci of groundwater accumulation. On the other hand, hilly areas with steeper hydraulic gradient exhibit low to moderate density of jointing, fracturing and weathering that develop barrier type dyke segments. In such cases groundwater from upper reaches is transported along weathered margins of dykes to the high permeability zones in topographic



Figs. 3a & b. Longitudinal geoelectrical sections along dykes D1 and D9.

depressions that are in hydraulic continuity with host rock basaltic aquifer.

Ground magnetic studies

The efficacy of ground magnetic studies in delineation of groundwater prospective zones in hard rock areas is well-known (Dewashish Kumar et al., 2006). These studies give an idea about the depth to the interface between the hard rock and the fractured zones. Subsequently the availability of ground water and its movement within the subsurface can be identified. The magnetic total field (F) was measured in the study region using proton precession magnetometer. A total of 118 magnetic observations (Fig.4) were carried out over the two major dykes (D1 and D 9) and surrounding region of the study area.

For the preparation of crustal anomaly map the contributions due to the main core field and the external current systems were removed. IGRF-2000 was used to represent the main field at each observation point; the magnetogram at Alibag observatory corresponding to the date and time of field recording was used to determine the magnetic field due to external current system. The total field anomaly map (F) (Fig.4) thus prepared contain information from sources at different depth levels, right up to Curie isotherm.

RESULTS AND DISCUSSIONS

Two different zones of various magnetic characteristics is identified based on visual inspection of the total field magnetic anomaly map (F) (Fig.4) with respect to the differences in their characteristics of the magnetic anomaly i.e., their wavelengths, amplitude and pattern. The first zone (Z1) covers the northern and the southern portion of the study area and is associated with low amplitude magnetic anomalies. The second zone (Z2) is situated at the central part of the study area and is characterized by a group of relatively strong positive amplitude anomalies. These anomalies are associated with the two main regional dykes D1 and D9 (gabbroic / doleritic), which are running across the area passing through the central portion. These dykes are trending approximately in E-W direction. The region occupied by the dykes can be easily identified from the anomaly map where there are intense anomalies with moderate wavelength changes. This highly varying nature of the magnetic field over the dykes can be attributed to the varying magnetic mineral content within the dykes.

The magnetic response over both the dykes was computed and is shown in Figs.5 and 6. It is seen that the magnetic anomaly ranges from -2000 to 2000 nT. This high range can be attributed to 1) gabbroic/doleritic nature of the dykes which exhibits strong magnetic properties because

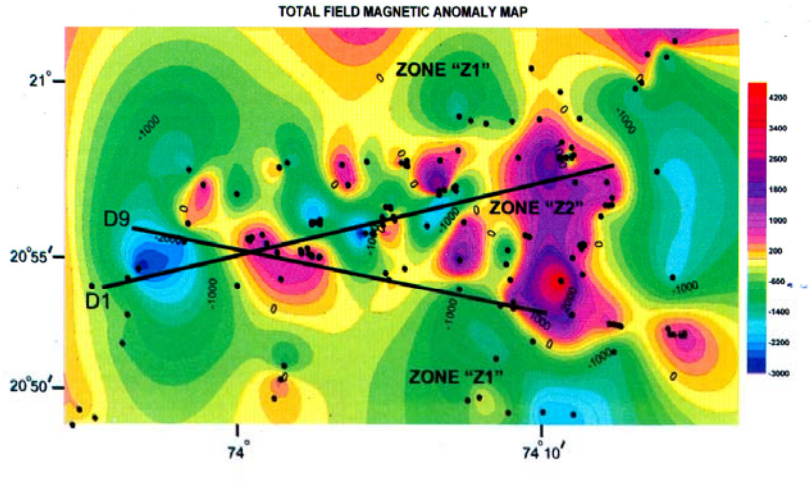


Fig.4. Data distribution and total field magnetic anomaly map over dykes D1 and D9.

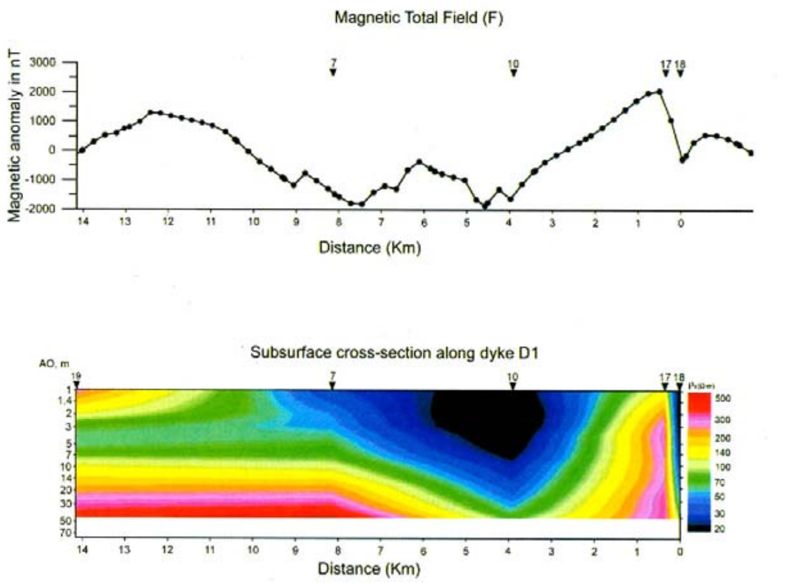


Fig.5. Total field magnetic response over dyke D1 (top panel) and subsurface geoelectrical cross-section over dyke D1 (bottom panel).

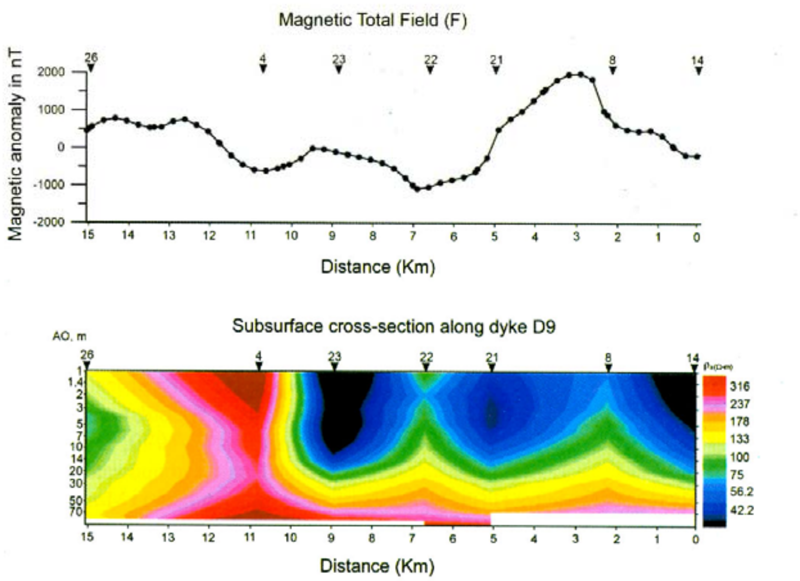


Fig.6. Total field magnetic response over dyke D9 (top panel) and subsurface geoelectrical cross-section over dyke D9 (bottom panel).

of its contiguity with iron formation (McEnroe et al., 2001; Bhaskara Rao and Lakshmipati Raju, 1981) or 2) the presence of high remnant magnetism. Thin section studies of dykes (Pawar et al., 2008) carried out in the study area from dug wells shows iron oxides (magnetite and ilmenite) apart from augite, plagioclase and olivine. Hysteresis loop measurements of Precambrian dykes (Hodych, 1996) also suggest that ilmenite have high coercivity. Mineralogical and rock magnetic studies over dykes from this region (Pawar et al., 2008) show the presence of ilmenite in these dykes. It was shown that ilmenite tends to have high remenance (Grant, 1974). Thus we can conclude that this high magnetic anomaly is due to the remnant magnetism rather than induced magnetism. This also suggests that the dykes have comparatively less amount of magnetite.

Notwithstanding this fact, an attempt is made here to compare the magnetic response obtained along with the longitudinal resistivity profiles over the two dykes (Figs.5 & 6). The VES subsurface pseudo sections broadly match with the magnetic highs and lows thus indicating the presence of carrier and barrier stretches along the dykes D1 and D9. The magnetic total field response over dyke D1 shows a broad syncline (magnetic low) between stations 7 and 10 corresponding to the carrier stretch in the VES subsurface cross-section (Fig.5). As the resistivity increases on either side of stations 7 and 10, the magnetic values also increase and cluster as high magnetic anomaly. However, comparison of magnetic total field response with VES profile over the dyke D9 (Fig.6) shows that magnetic field values with high magnetic readings coincide with barrier type of dyke stretch in the vicinity of station 26 and 4, but at places, high magnetic values have also been obtained even over the carrier type of stretch (between stations 21 and 8) where the resistivity is decreasing. This mismatching stretch of the dyke D9 could be due to compositional variation enhancing the magnetic signal than that caused by water content. Except this stretch, the preliminary results of ground magnetic and electrical resistivity broadly depict similar pattern except a few points where the comparison is not very clear at least along D9.

CONCLUSIONS

Hydrogeological and VES studies carried out in the Upper Panjhara basin concludes that dykes have formed separate potential aquifers in the study region and a dyke can behave as carrier or barrier along its length, a finding, which differs from previous studies reporting them either completely carrier or barrier type. The present studies also portray that the magnetic response over dykes could be a useful supplement to the VES studies in identifying the carrier and barrier stretches within the dykes. However, more integrated studies elsewhere in similar geological environment will further give a proper understanding of the nature of the magnetic response associated with the subsurface geoelectrical structure for groundwater studies.

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Devotion must not be like the flood of the rainy season in which all get washed away.

Devotion should be like the river that retains water even in the hottest season.

- Kabir