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GROUND MAGNETIC MAPPING OF SUBSURFACE STRUCTURES BENEATH OBANLA, FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE NIGERIA: IMPLICATION FOR HYDROGEOLOGICAL STUDY

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ABSTRACT

In basement complex terrains, groundwater potential is controlled principally by the subsurface structures and thickness of the overburden. The applicability of the magnetic method in mapping geologic structures vis-à-vis delineation of fault / fracture zones and rock contacts as well as estimation of their depths beneath Obanla area of Federal University of Technology, Akure is addressed in this paper. The magnetic data were acquired along five traverses namely; TR1, TR2, TR3, TR4 and TR5 established in a NW - SE direction. The analyses made on the diurnal corrected ground magnetic data acquired from the area includes Upward Continuation, Vertical / Horizontal Derivative and Analytical Signal computed in the wave number domain. The anomaly patterns identified in the upward continued map are used to outline the study area into distinct structural zones. The north western and south western region with maximum magnetic intensity values (33660nT – 33980nT) possibly suggest shallow basement (i.e. thin overburden thickness) while the eastern region characterized by relatively low magnetic anomaly amplitude (33500nT – 33380nT) indicates a relatively deep source (thick overburden). The derivative maps and analytic signal map delineated fault and / or fracture zones and rock contacts respectively in the area. For the quantitative interpretation, Euler deconvolution technique was utilized to estimate depths to magnetic sources in the area i.e. 10 – 50m. The results of this study could serve as a guide for future groundwater prospect in the area using electrical survey.

Key words: Groundwater potential, magnetic, Euler deconvolution, fault, analytic signal.

INTRODUCTION

Magnetic survey is a well known technique for petrographic differentiation of the basement and its ability to highlight structural features like faults, fracture zones and rock contacts. These features are reflected significantly in the intensities of observed magnetic anomalies and trend patterns; consequently, magnetic method has been extensively employed in the Nigerian basement complex (Amigun *et al*, 2012a). The speed with which the magnetic measurements can be made and the low cost of operation are additional justification for its attractiveness.

In magnetic method, a significant formula that shows the relations between the fields and the magnetization within materials (Telford *et al*., 1990) is expressed by equation (1):

$$B = \mu_o (H + M) \qquad (1)$$

Where B, the magnetic induction is the total flux of magnetic field lines through a cross-sectional area of a material, μ_o is the permeability of free space ($4\pi \times 10^{-7}$ Wb/Am^{-1}), H is the magnetic field applied to the material and M is magnetization or response of the material to the applied magnetic field. Magnetic susceptibility (k) is another important parameter, the relationship between magnetic induction B, magnetizing force H and susceptibility k (Reynolds, 1997) is given as:

$$B = \mu_o H (1 + k) \qquad (2)$$

Where B is in tesla, μ_o is free space permeability, H is given in amperes / meters and k is dimensionless in SI units.

The magnetic survey in this particular study was aimed at outlining the structural framework of the study area subsurface, delineates features and estimates the depths. Different algorithms were applied that enables easier identification of fault, fracture and contact features in the area (Hood and Teskey, 1989; Aboud *et al.*, 2005; Falebita *at al.*, 2011). The result will make possible the demarcation of subsurface structures that might be controlling the area groundwater flow and moreover serve as guidance for future electrical survey for groundwater within the campus.

Study Area and Geologic Setting.

The study area is located within the campus of the Federal University of Technology, Akure and bounded by the northing coordinate 807485N and 808250N and the easting coordinate 735560N and 736350E (Fig. 1). The area is underlain by the Precambrian basement complex rocks of southwestern Nigeria (Rahaman, 1989). The local lithological units identified within the campus include the gneissic rocks (migmatite gneiss and biotite granite gneiss), quartzite and charnockite (Kareem, 1997). At the middle part of the campus, outcrops of biotite granite gneiss are predominant. Porphyritic granites are discovered to have intruded the migmatite gneiss. In Figure 1, quartzite occurs as band while charnockite exists as intrusive in the low-lying outcrops within the migmatite gneiss.

MATERIALS AND METHODS

Data Acquisition

The magnetic data in the study area were acquired along five traverses TR1, TR2, TR3, TR4 and TR5. These traverses run almost in the NW-SE direction (Fig. 1). The magnetic measurements were made with a GSM-19T Proton Precession magnetometer at a nominal station spacing of 10m. This instrument measures the Earth's total magnetic field in gamma (nanotesla). Two hundred and forty magnetic stations were occupied along the five traverses. The changes in magnetometer reading with time caused by the time-dependent variation of diurnal variation were taken into consideration. A base station established at the start of the magnetic survey was re-occupied at regular time interval of 2 hours to monitor the drift (diurnal variation) for drift correction purpose.

Furthermore, the removal of the International Geomagnetic Reference Field (IGRF) from the corrected magnetic data was done using the IGRF model obtained from http://www.ngdc.noaa.gov. In the present ground magnetic survey, and due to the relatively small spatial extent of the surveyed area, the coordinates of 808020N, and 735780E were used as the base coordinates for IGRF calculations for the whole survey grid. The geomagnetic field parameters were calculated for the study area using the above model and listed as: declination $= -2.5^0$, inclination = -11.1^0 and total field = 32784 nT. The total magnetic intensity (TMI) map of the study area where diurnal correction and IGRF were removed is presented in Figure 2.

Data Analyses

The various analyses carried out on the diurnal corrected ground magnetic data includes Upward Continuation, Vertical / Horizontal Derivative and Analytical Signal which are computed in the wave number domain using Fast Fourier Transform (FFT). These analyses were performed to improve the quality of the magnetic data for better understanding of the subsurface geology (Hildenbrand *et al*, 2003 and Hinze *et al*, 2005). Reduction to Pole was discarded since the study location is at a region of low magnetic latitude (Fieberg, 2002).

The upward continuation filter operation allows the transformation of data measured on one surface to some higher surface (Nabighian *et al*, 2005) i.e. from ground surface to a height of 100 m above sea level in the case of this study. This is expressed as;

$$L(r) = e^{-hr}$$

Where h is distance in ground units and r is wavenumber in radians/m. This filter tends to smooth the original data by attenuating short-wavelength anomalies relative to their long – wavelength counterparts (Fig.3). In this work, the Horizontal derivative (Fig.4b) was applied to the upward continued data (Fig.3) to complement the first vertical derivative enhancement (Fig 4a) which effectively reduces anomaly complexity and allowing a clearer imaging of the causative structures. This Horizontal derivative filter usually produces a more exact location for faults than the first vertical derivative. According to Hansen *et al.* (2005), the horizontal gradient *Z (x, y)* is given by the equation:

$$Z(x, y) = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2} \qquad (4)$$

The analytic signal (Fig.5) was calculated for the area of study to extract the location of magnetic sources contacts or edges. The analytic signal amplitude is defined as

$$|A(x, y)|^2 = \left(\frac{\partial T}{\partial x}\right) + \left(\frac{\partial T}{\partial y}\right) + \left(\frac{\partial T}{\partial z}\right) \qquad (5)$$

When applied to the observed magnetic field, the analytic signal method generally produces good horizontal locations for contacts and sheet sources regardless of their geologic dip or the geomagnetic latitude (Al-Garni, 2010).

The Euler deconvolution preference over the profile techniques such as Peters' (1949) method (half slope) is that it requires no prior knowledge of the source magnetization direction. This has prompted its application in this study for the determination of depths to magnetic sources and their locations. The Euler's homogeneity equation (Euler deconvolution) relates the magnetic field and its gradient components to the location of the source of an anomaly, with the degree of homogeneity expressed as a structural index (Yaghoobian *et al*., 1992).

Euler's homogeneity relationship can be written (Reid *et al*., 1990) for magnetic data in the form:

$$(x - x_0)\ \partial T/\partial x + (y - y_0)\ \partial T/\partial y + (z - z_0) \qquad n$$
$$\partial T/\partial z = N\,(B - T) \qquad (6)$$

point, *N*= -*n*, where *n* is degree of homogeneity, and *N* is a coefficient, called structural index (Thompson, 1982).

RESULTS AND DISCUSSION

Qualitative Interpretation

Qualitatively, the corrected total magnetic intensity and IGRF removed map (Fig. 2) shows the magnetic field amplitude, which reaches 3600 nT i.e. ranges in amplitude from -1000 nT to 2600 nT. This is relatively high compared with its spatial distribution of the survey, and the acute variation in its magnetic intensity may be an indication of the variations in either lithology or basement topography (Dobrin and Savit, 1988). These variations are better revealed on its upward continued filter map in Figure 3

The anomaly patterns identified in the upward continuation derivative map are a qualitative representation of spatial variation in the magnetic properties of nearly deep basement rocks and structures in the area. There is a good correlation in the trend of the clearly defined magnetic anomalies in Figure 3 with those in Figure 2. The maximum magnetic intensity values (33660nT – 33980nT) are located at the north western and south western part of the study area. These regions may represent very shallow basement, the north western feature is trending in a NW – SE direction while the south western anomaly is circular in shape.

To the eastern part of the study area is a region characterized by relatively low magnetic anomaly amplitude (33500nT – 33380nT) indicating a relatively deep and or / non magnetized source with a slope directed toward east. This approximately north – south trending low amplitude lineament anomaly is estimated about 0.6km in length and may define the regional trend which relate to the subsurface structures beneath the study area. Located far to the north western border of the study area is a small size, west – east linear anomaly also characterized by relatively low magnetic amplitude.

On the first Vertical Derivative map (Fig.4a); areas with relatively low values i.e. - 4.5 to – 1.5 nT/m and that with relatively high values 0.5 to 3.0 nT/m corresponds in anomaly pattern (i.e. shapes and trend) with areas of high and low magnetic values respectively in Figure 3. The NW – SE low amplitude lineament anomaly (-2.5 nT/m to -0.5 nT/m) in Figure 4a may represent fault or fracture zone. This feature match in spatial location with the contour line -0.2nT/m on the Horizontal Derivative map (Fig.4b). According to Dobrin and Savit (1990), areas with sharp change in magnetic intensity value from high amplitude anomaly to low amplitude anomaly exhibited as narrow boundaries are inferred fault zones. Analysis of the analytic signal (Fig.5) confirmed the existence of bounding structures such as lineaments / or rock contacts in the studied area i.e. displayed as anomaly peaks. The density of contour lines often provides a useful criterion about the structures. The closer the contours, i.e. the greater the gradients and the shallower in general is the source. This characteristic is exhibited by the circular shape magnetic anomaly south west of Figs. 3, 4a and 5)

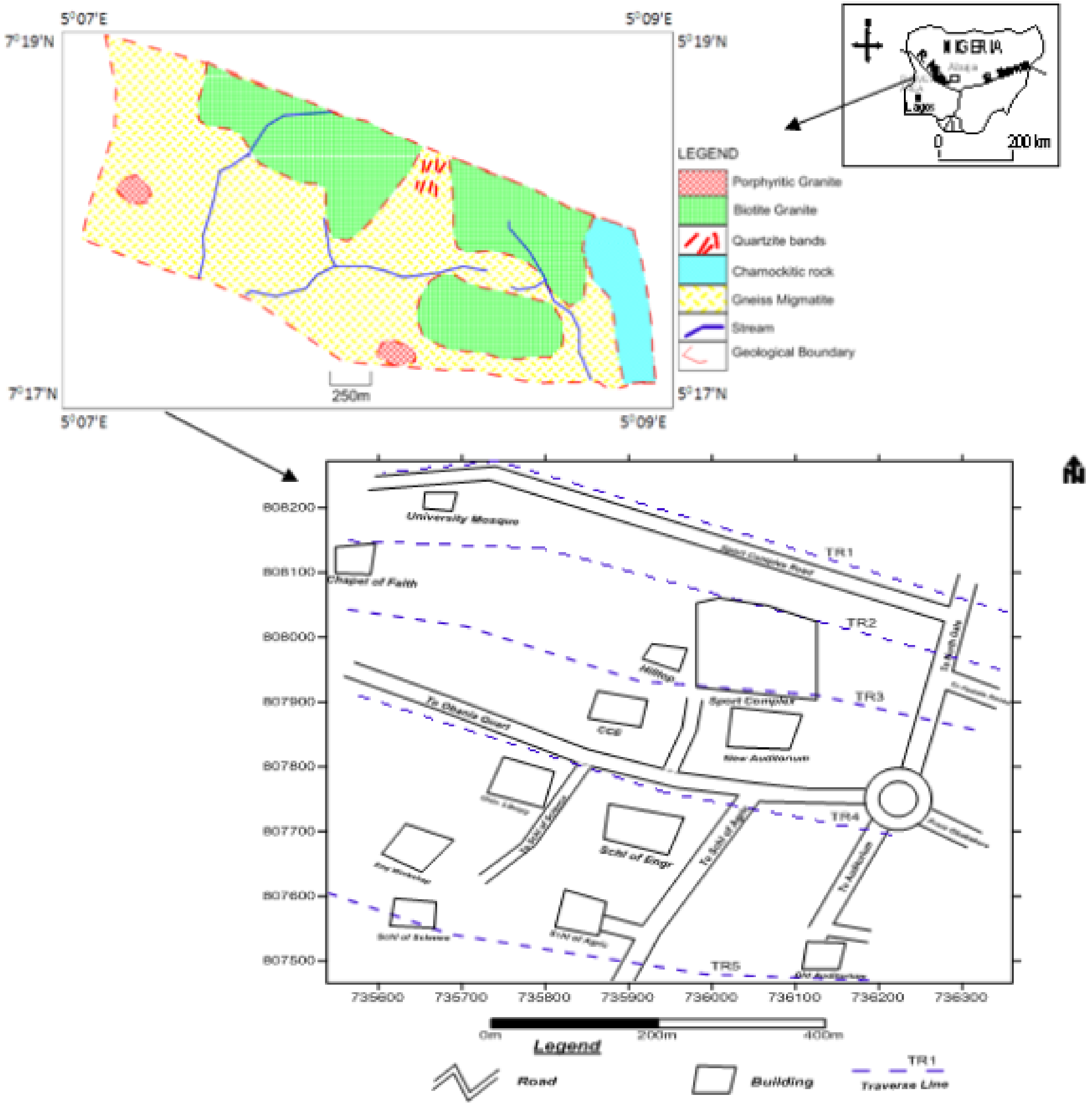

Figure 1: Location and the Geological Map of the Study Area (Modified after Kareem, 1997).

Table 1: Relationship between structural index (*n*), type of magnetic model, and position of calculated depth (modified after Hsu 2002)

Structural index (*n*)	Types of magnetic model	Position of Euler depth
0.0	Contact with large depth extent	At top and edge
0.5	Contact with small depth extent	-
1.0	Thin prism with large depth	At top and center , or at edge
2.0	Vertical or horizontal cylinder	At center
3.0	Sphere	At center

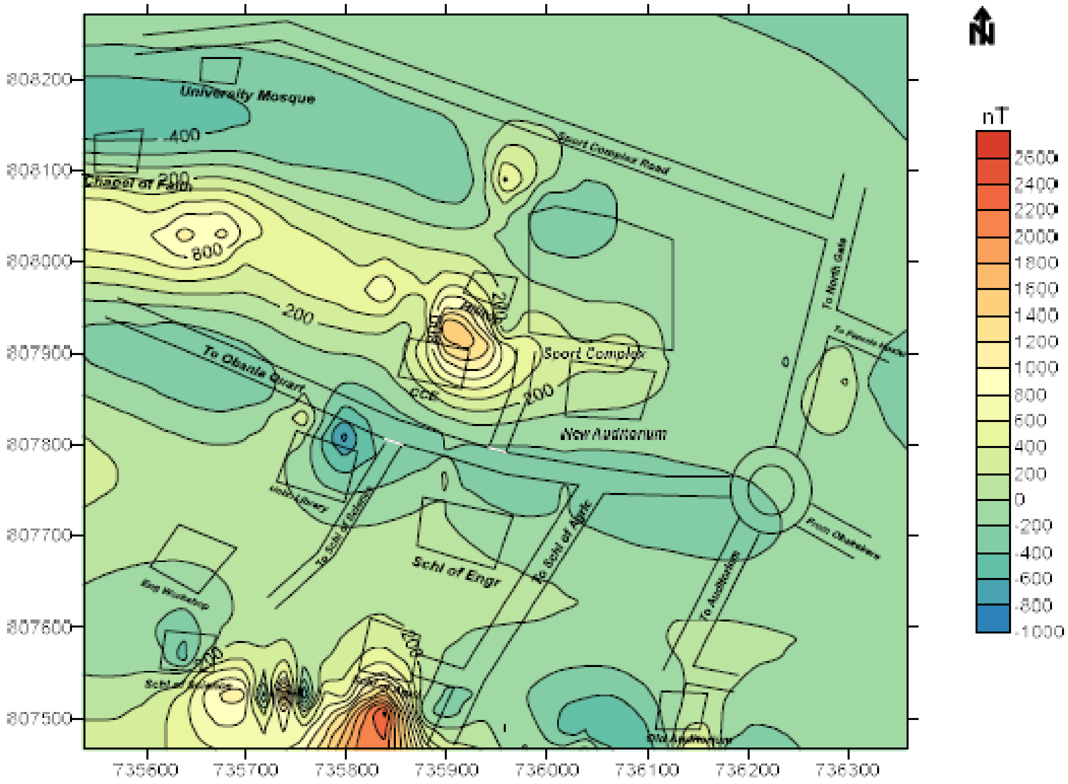

Figure 2: Total Intensity Ground magnetic Map of the Study Area. (diurnally Corrected and IGRF removed).

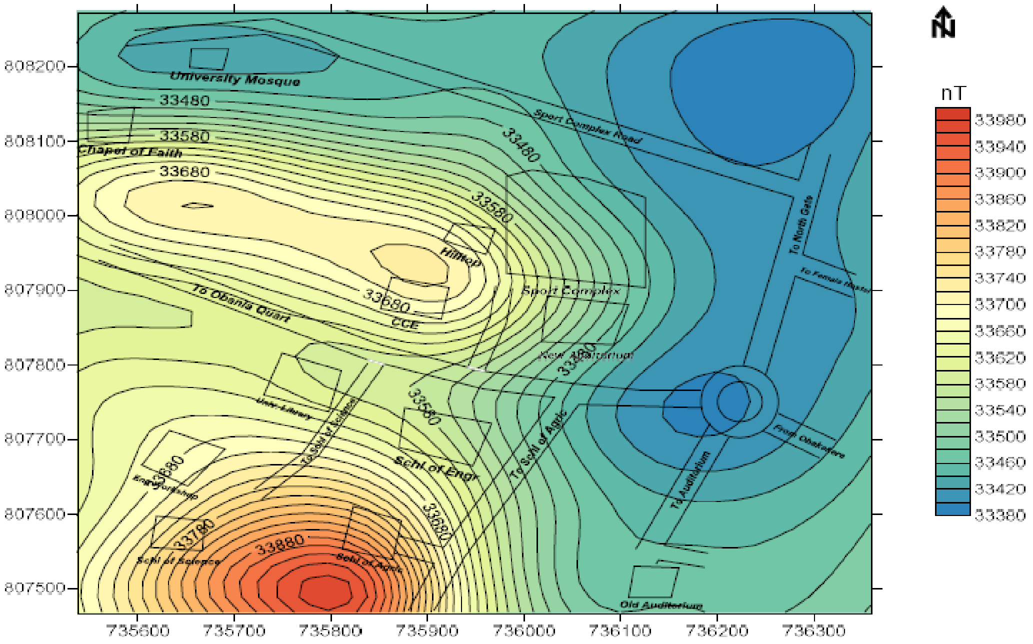

Figure 3: The Upward Continuation Filter Map of the Ground magnetic data at 100 m altitude. The approximately north – south trending lineament anomaly may define the regional trend.

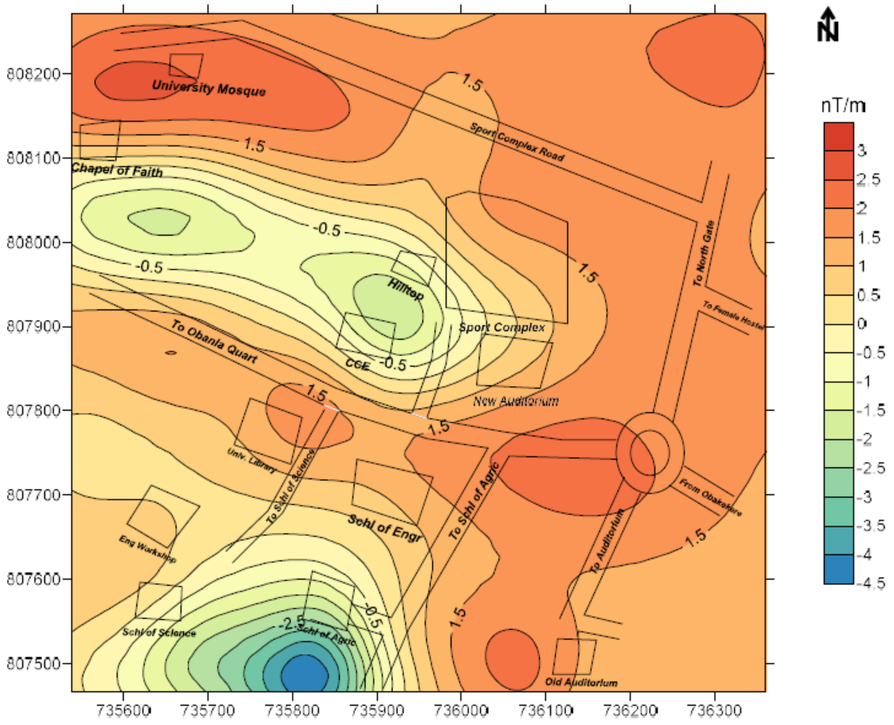

Figure 4a: First Vertical Derivative Map, the NW – SE elongated low magnetic intensity anomaly is identified as a possible fault zone.

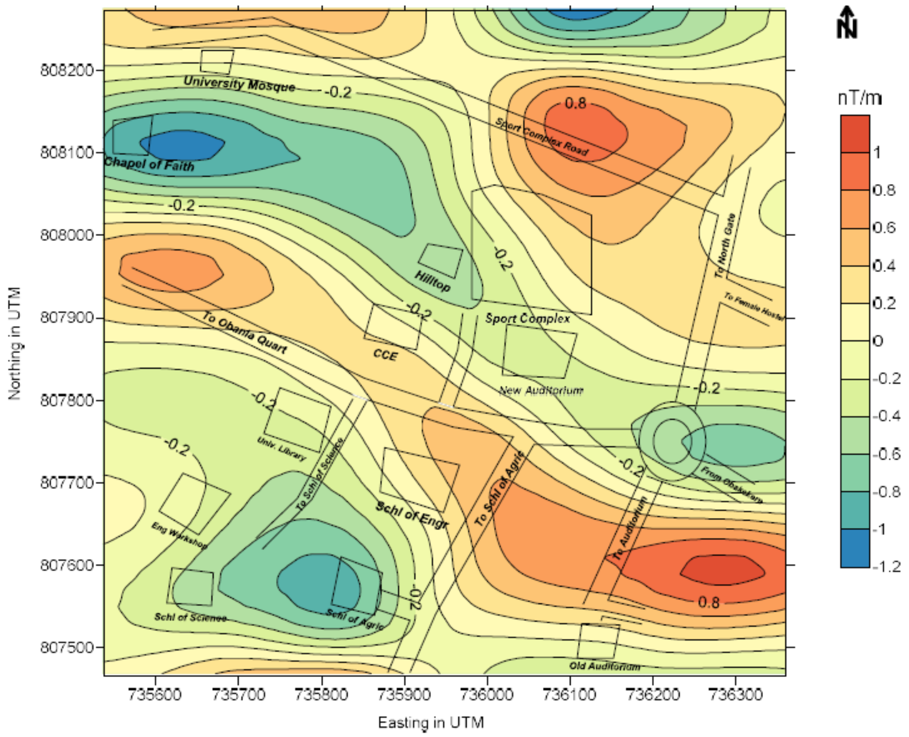

Figure 4b: Horizontal Derivative Map, the areas with sharp change in magnetic intensity value (i.e. contour line -0.2nT/m) exhibited as narrow boundaries are inferred fault zones.

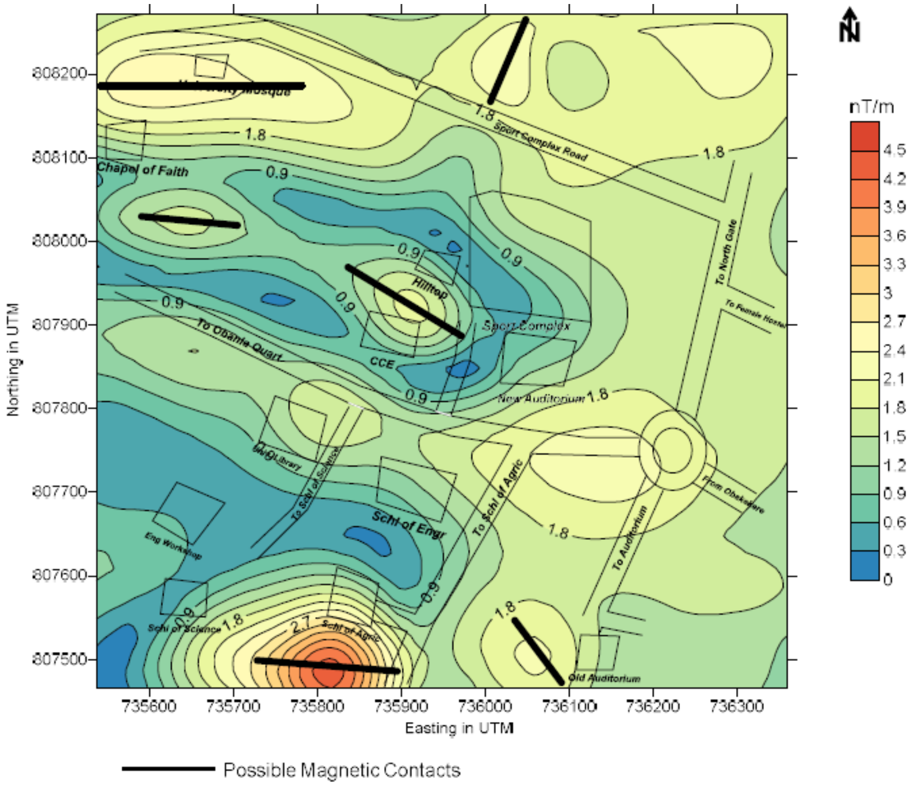

Figure 5: Analytical Signal Map, the Peak Positive Anomalies are Marked

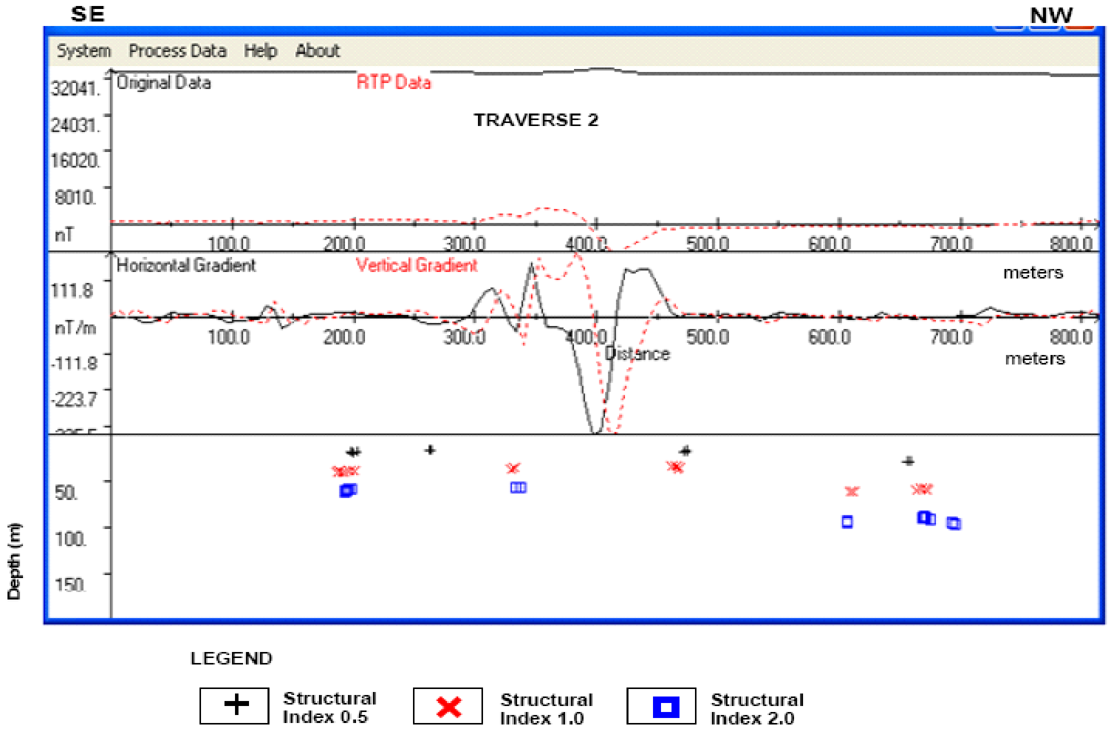

Figure6: Results of Euler Deconvolution of Magnetic Data along Traverse 2

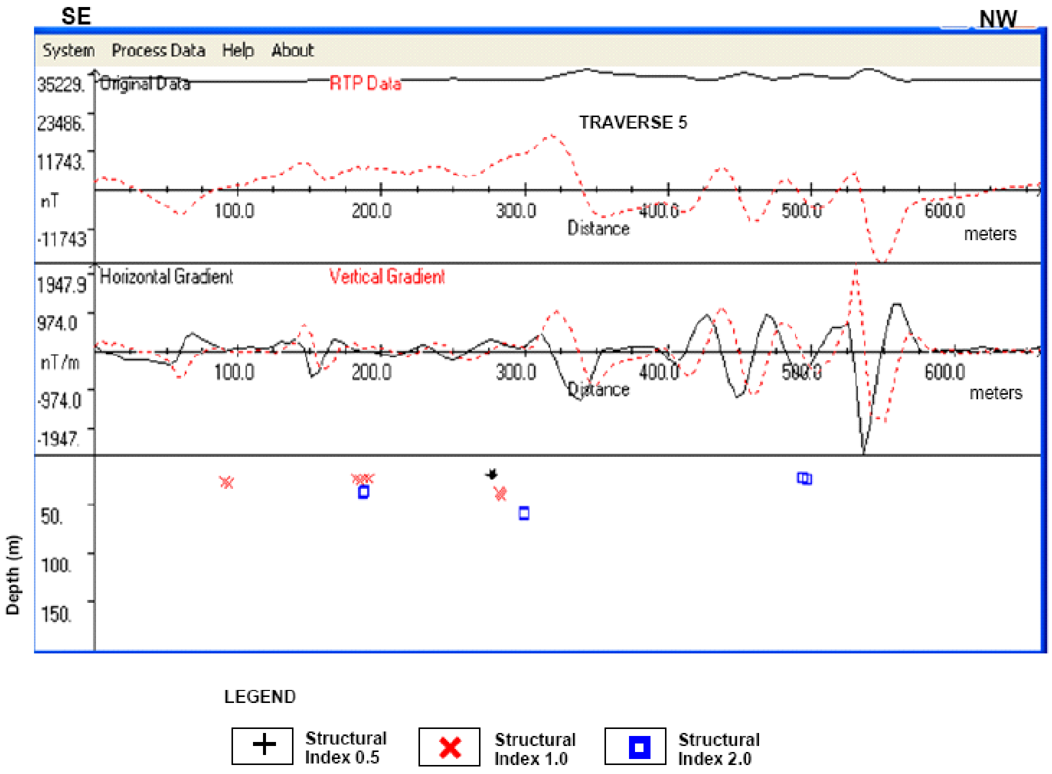

Figure7: Results of Euler Deconvolution of Magnetic Data along Traverse 5

Quantitative Interpretation

In the study area, depth estimation was made along five traverse lines TR1, TR2, TR3, TR4 and TR5 in Figure 1 using the Euler deconvolution. The Euler solutions were obtained for structural index values of 0.5, 1.0 and 2.0 Sources are characterized by their structural indices, which correspond to the rate of decay of the field strength with distance from the source (Cooper, 2002). Some examples are given in Table 1, the common accepted structural element in the study area is fault / or fracture and magnetic contact. To constrain the Euler results obtained in this study, depth limits obtained through vertical electrical sounding (VES) and electromagnetic methods by Omosuyi *et al*, (2008) in previous study were used. Therefore, solutions that fall outside these ranges have been rejected.

Typical Euler solutions obtained along these traverses are shown in Figures 6 and 7. At the depth column, distinct clustering of solutions coincides with the edges of geological structures i.e. contacts and faults in the study area. Cluster representing contact indicates as the most common structural index. These structures are well defined between the distance 50 and 450m on profiles TR1 – TR3 and between 100 to 650m on profiles TR4 and TR5. Vertical gradient maxima and horizontal gradient minima were used to delimit the lateral extent of main structures in the area (Ravat *et al.*, 2002; Adepelumi *et al.*, 2005). The horizontal magnetic gradients suggest that two main structures are delineated on TR1, three structures on TR4 and one structure each on TR2 and TR3 respectively. Also from the depth columns, it was observed that the source of these structures is relatively shallow i.e. 10 – 50m.

Hydrogeological Implication

Structural zones in the study area are outlined using the anomaly patterns identified in the upward continuation derivative map. The north western and south western region with maximum magnetic intensity values (33660nT – 33980nT) represent thin overburden thickness while the eastern region characterized by relatively low magnetic anomaly amplitude (33500nT – 33380nT) indicate thick overburden. Aquiferious zones are found within thick weathered layer (Amigun *et al*, 2012b), therefore the eastern region with magnetic anomaly approximately north – south and estimated about 0.6km in length may be identify as good groundwater potential zone.

The delineation of fault /or fracture zone and rock contacts using Euler deconvolution, derivative maps and analytic signal map in this study, may facilitate the demarcation of groundwater prospect zones, which are known to accommodate abundant groundwater (Omosuyi *et al.*, 2003)

CONCLUSION

This study have shown that magnetic survey with application of different algorithms is capable of presenting a clear picture of the subsurface structures that might control the groundwater potential and which further could be used as guidance for future electrical survey.

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