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Ground Magnetic Survey of the Charnokitic Dykes in the Areas Around Omu-Ijelu, Southwestern Nigeria

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Abstract: *A ground magnetic survey was carried out in the areas around Omu-Ijelu in the basement complex of southwestern Nigeria, using the Proton precession magnetometer. The aim was to map the magnetic mineralization of the charnokitic dykes in the area and determine their approximate burial depths and lateral extents. Total magnetic field intensity data was acquired along four irregularly spaced E-W traverses at stations spaced 10 m along each traverse. Diurnal correction was applied to the data after which they were smoothed using a running mean technique. Polynomial fitting was used to estimate the regional magnetic field in the area, and this was removed from the smoothed data to obtain the residual magnetic field. Two major dykes with very high positive magnetic intensity were delineated in the eastern and western parts of the area at subsurface depths of 25 m and 18.75 m, respectively. The dykes may have been caused by multiphase intrusions emplaced over time. The results also show two distinct zones of weakness, fracturing and/or shearing associated with large negative magnetic anomalies. One of these is massive, and straddles NE-SW across the entire breath of the survey area. These zones may be the result of residual forces arising from deformation, and tend to infer that intense tectonic activities occurred in the area in the past. They are likely to be the main acquiferous zones and therefore prospective zones for hydrogeologic activities in the area.*

Keywords: *Basement complex, Charnokitic dykes, Magnetometer, Diurnal correction, Magnetic anomalies.*

I. Introduction

The earth has a magnetic field which, at any point on the surface of the earth, is a vector defined by magnitude and direction. About 99% of the geomagnetic field is thought to originate within the earth, from convection processes in the fluid, outer core of the earth. The remaining 1% contribution arises from sources external to the earth, and results mainly from the interaction of ionospheric currents with the solar wind. Certain rocks and minerals found within the earth are magnetized by induction by the geomagnetic field, and they retain a permanent magnetization resulting from the induced field at temperatures below the Curie point. Within the area occupied by these rocks and minerals, there is an additional magnetic field such that the total magnetic field is the vector sum of the retained localized magnetic field, called remanent magnetization, and the inducing geomagnetic field. The magnitude, otherwise known as intensity of the total magnetic field at any point on the earth's surface therefore constitutes the sum of the localized magnetic field and geomagnetic field at that point, and the direction of the field, being a vector, is described by the magnetic inclination and declination at that point. The magnitude or intensity of the acquired magnetization, I, is proportional to the magnetic field causing the magnetization, and is given by:

$$I = kH \tag{1}$$

where,

$k =$ magnetic susceptibility

$H =$ strength of the magnetic field causing the magnetization

The ratio of the scalar magnitudes of the component of the remanent magnetization to the component of the inducing geomagnetic field is called the Koenigsberger ratio, Q, for the rock [1] and is given by:

$$Q = \frac{I_{rm}}{I_{in}} \tag{2}$$

where,

I_{rm} = scalar magnitude of magnetism retained

I_{in} = scalar magnitude of inducing geomagnetic field

The localized magnetic field, otherwise known as the residual magnetic anomaly can be determined by removing the effect of the geomagnetic field from the total magnetic field intensity recorded at a station.

Magnetic survey is a natural source geophysical exploration method employed to map rocks and ore-bearing minerals, including other subsurface geologic features such as faults, contact zones and intrusions on the basis of variations in the earth's magnetic field. The magnetic susceptibility, k , is the rock's physical property that is measured, and is a measure of the response of a rock and associated minerals to magnetization. Ground magnetic surveys are particularly important because they enable a detailed mapping of potentially localized zones of valuable magnetic minerals such as pyrrhotites, magnetites, pyrites, chalcopyrites, sphalerites and pentlandites, and other geologic features.

In the present study, ground magnetic survey was carried out in the areas around Omu Ijelu with the aim of delineating the underlying charnokitic dykes in the area, determine the depth to basement and possibly map their aerial extents. Charnokitic rocks have igneous and metamorphic origins [2]. They are of interest to earth scientists due to their aesthetic value especially when polished, and the controversy surrounding their origin [3].

Location and Geology

The study area, Omu Ijelu, is situated in Ekiti State, Nigeria, and lies approximately between Latitudes 7^0 30' 00" N and 8^0 00' 00" N and Longitudes 4^0 30' 00" E and 5^0 30' 00" E. The area is within the Precambrian basement complex of southwestern Nigeria (Figure 1). Rahaman [4] identified five major rock groups in the basement complex of southwestern Nigeria, namely migmatite, slightly migmatised to unmigmatized paraschists and meta-igneous rocks, charnokites, older granites and unmetamorphosed dolerite dykes which include pegmatite, quartz veins and doleritic dykes. The migmatites include gneiss, quartzite, calc silicates, biotite hornblende schists and amphibolites, all of which generally belong to the gneiss complex. There are also the younger granites which comprise gabbro, granites, granite porphyry, rhyolites and syenites. A similar trace of these rock types are also found in Ekiti, and are referred to as the charnokite series [5].

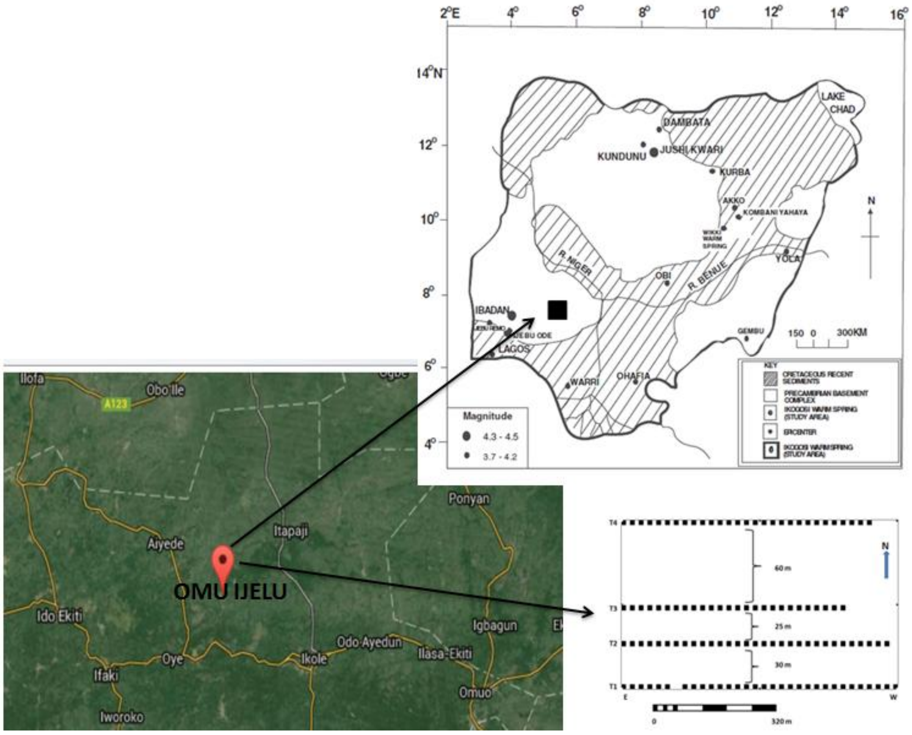

Figure 1: Map of Nigeria Showing Study Location: Adapted From [6] and Modified From [7].

The study area is predominantly underlain by charnokitic rocks which generally trend in the NE-SW direction. Petrographic studies carried out by [3] reveal that these rocks contain the mineral hornblende, plagioclase, hypersthene, orthoclase, quartz, muscovite and accessory quantity of opaque minerals (probably iron oxide), most of which are concealed by thick overburden. The rocks have both igneous and metamorphic origins; the metasomatic model of the origin of the rocks was presented by [8]; [9] and [10] presented a model of their igneous origin.

II. Materials and Methods

A total of four (4) traverses running E-W were established in a grid of 115 m x 320 m, giving a total surface area of 36,800 m^2. The traverses were 320 m long and measurement stations were marked at 10 m spacing along each traverse. The traverses were not uniformly spaced due to accessibility problems and as such, traverse two (T2) was spaced 30 m from traverse one (T1), traverse three (T3) was 25 m from T2 and traverse four (T4) was spaced 60 m from T3 (Figure 2). Measurements were acquired at 1 m above the ground at every station with the G-856X proton precession magnetometer whose sensor axis was mounted in the vertical direction during each measurement. This procedure was to ensure that the magnetometer was oriented approximately normal to the earth's field for optimum reading, and also to ensure that the instrument was oriented in the same direction at every station to enhance accuracy of interpretation.

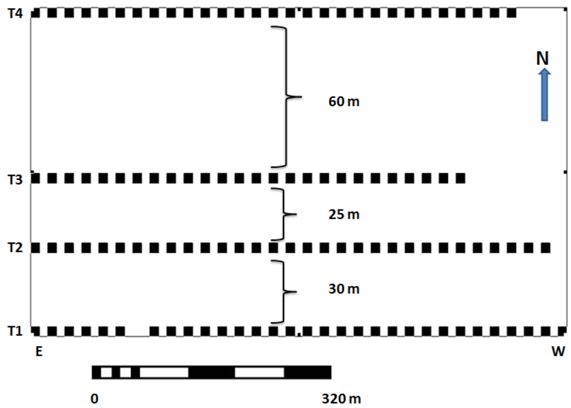

Figure 2: Field Layout for Data Acquisition

The proton precession magnetometer measures the intensity of the earth's total magnetic field at the measurement location. The working principle of the proton precession magnetometer has been concisely described by [11] and [12]. At each measurement location, the total magnetic field intensity in gamma (γ) was recorded, together with the measurement time and coordinates of the station. The first station on each traverse was taken as the base station, and due to the small size of the survey, the base station was re-occupied to repeat the measurement after completion of readings for a particular traverse.

Diurnal Correction and Filtering

This was carried out to remove the temporal variations which occur in the earth's magnetic field over the course of a day, arising from interactions of electric currents in the ionosphere with the solar wind. Repeated measurements of the total magnetic field intensity made at a base station provided data for diurnal correction of magnetic field intensity acquired along a particular traverse. The correction was carried out by using the relation:

$$D_C = \ell * \Delta T, \tag{3}$$

where,

$\Delta T = T_S - T_{BS}$ = time difference between measurements at station (S) and base station (BS), and ℓ is a constant given by:

$$\ell = \frac{I_R - I_{In}}{T_R - T_{In}} \tag{4}$$

where,

I_{In} = initial magnetometer reading at base station (BS)

I_R = magnetometer reading of "repeat measurement" at BS

T_{In} = time of initial magnetometer reading at BS

T_R = time of magnetometer reading of "repeat measurement" at BS

Table 1 Shows an Example of the Correction Procedure Used for this Study.

Stations	**Time of measurement**	**Magnetometer reading (Gamma γ)**	**Diurnal correction**	**Corrected (Gamma γ)**
1 (BS)	10.38 am	475.00	0.00	475.00
2	10.39 am	450.00	1.25	448.75
*	*	*	*	*
*	*	*	*	*
*	*	*	*	*
*	*	*	*	*
*	*	*	*	*
29	10.54 am	500.00	20.00	480.00
1 (BS)	10.58 am	500.00	25.00	475.00

Table 1: Diurnal correction procedure

In the above measurement,

$$I_{In} = 475 \text{ gamma}$$

$$I_R = 500 \text{ gamma}$$

$$T_{In} = 10.38 \text{ am}$$

$$T_R = 10.58 \text{ am}$$

$\therefore \ \ell = \dfrac{I_R - I_{In}}{T_R - T_{In}} = \dfrac{500-475}{58-38} = \dfrac{25}{20} = 1.25$, giving the following corrections at the respective measurement stations:

Station 1 (BS): $D_C = 1.25(38-38) = 0.00$

Corrected magnetometer reading = I_1 = 475.00 – 0 = 475 gamma

Station 2: $D_C = 1.25(39-38) = 1.25$

Corrected magnetometer reading = I_2 = 450.00 – 1.25 = 448.75 gamma

Station 29: $D_C = 1.25(54-38) = 20.00$

Corrected magnetometer reading = I_{29} = 500.00 – 20.00 = 480.00 gamma

After the diurnal correction, a three-point running mean technique [13]; [14] was employed to filter the data. The aim was to remove magnetic noise superimposed on the main data in order to obtain a smoothing of the data. The running mean at each station was implemented as illustrated in Figure 3.

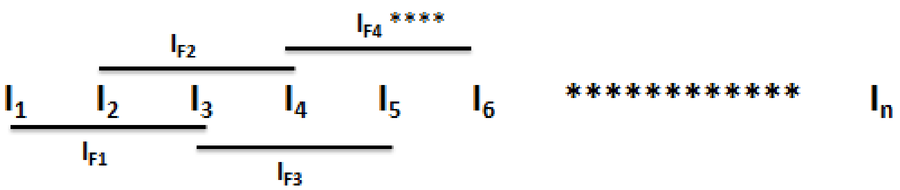

Fig. 3: 3-Point Running Mean Implementation for Magnetic Field Intensity Denoise.

Following from the above, the filtered magnetic intensity for station 1, I_{F1}, was obtained by:

$$I_{F1} = (I_1 + I_2 + I_3)/3 \tag{5}$$

where,

$I_i : i = 1, 2, 3, ,,,, n$ is diurnal-corrected magnetic field intensity for station i

Regional-Residual Anomaly Separation

The method of polynomial fitting was adopted for regional – residual magnetic field intensity separation in this study. In the method, a regional gradient surface was fitted to the total magnetic field intensity presented as profile along a traverse. Values on this surface are then computed to represent the regional magnetic field intensity along that traverse. The value computed for a station is thereafter subtracted from the filtered, total magnetic field intensity at that station; the difference constitutes the residual magnetic field at the station. The values obtained from this regional-residual anomaly separation method are in-situ, and should be more representative of the causative body than anomaly values computed from the alternative separation method in where the theoretical value of the regional field is determined from the International Geomagnetic Reference Field (IGRF).

The IGRF defines the theoretical value of the unperturbed geomagnetic field at any point on the earth's surface; the value at any point is assumed to be the regional geomagnetic field at that point. This value, if specifically known is subtracted from the diurnal-corrected, filtered total magnetic field measured in an area to obtain the magnetic field due to the causative body (residual magnetic field). Due to advancement in technology, this mathematical value can now be calculated for any point on the earth's surface once the coordinates of that point are known. Unfortunately, only a single theoretical value is calculated in most cases, even for large surveys and this can lead to over simplification of the regional magnetic field in the area. A theoretical value of 3.32 gammas was calculated for the study area, but the value was not used for the regional-residual separation.

Determination of Depth to Top

Numerous methods are in the literature for the determination of depths to top of magnetic sources. The half-slope method [15] has been adopted for this study due to its easy implementation and reliability. In this depth determination technique, points at which lines with half the maximum slope are tangents to the magnetic profile are determined. For a given anomaly, the tangents are drawn parallel to one another and the horizontal distance, S , between the points of tangency is obtained. This distance S is related to the source depth by:

$$S = f\,Z \tag{6}$$

where f is a proportionality factor with values of $1.2 \le f \le 2.0$, depending on the size of the causative body. [16] suggests $f = 1.6$ and as such, we used Equation (7) to estimate the depth to the top of the causative body in this study.

$$S = 1.6\,Z \tag{7}$$

III. Results and Discussion

Figure 4 shows the diurnal-corrected, filtered and regional magnetic field intensity presented as profiles and the corresponding residual magnetic anomaly for each traverse. Residual magnetic field in the study area varies between about -982.89 and 1,216.92 gammas. The variation is a function of the magnetic mineral present in the underlying charnokitic rocks, the topography and depth of the basement rocks as well as orientation of the rocks at depths. Very high anomaly may be suggestive of a shallow buried underlying basement rocks or zones of high magnetic rock intrusions. These zones, if expansive, would be prospective zones for geotechnical activities whereas, low values may be indicative of relatively deep, poorly magnetized basement rocks. Large negative values may be associated with zones of weakness, faulting and/or shearing, which may be favourable to hydrogeologic activities.

Moving along the 36,800 m^2 survey area from East to West, the profiles delineate two distinct dykes. The first and major dyke occurs between 60 m and 150 m from the survey edge, and has magnetic anomaly amplitude of 1,216.92 gammas. Location of this dyke, its aerial extent and approximate depth to its top was the main objective of the survey. The second dyke has a peak magnetic intensity of about 855 gammas, and is situated towards the western part of the area, starting at about 240 m from the east. The dykes may have been multiphase intrusions emplaced over time [17]. Approximate depths to these high magnetic anomaly structures are 25.0 m and 18.75 m respectively, and were estimated from traverse 2 and traverse 3 where they respectively feature prominently. The aerial extent of the second dyke, located at the western part of the survey could not be completely determined since traverses were not long enough to map it. The estimated depth to its top, however, is a reasonable estimate because the half slope depth determination method [15] adopted in this study does not necessarily take into cognizance of the fact that the anomaly must be symmetric or asymmetric over the causative body before depth could be accurately determined. The half width depth determination method of [18], for instance, would have been incapable of determining the depth to the top of this dyke.

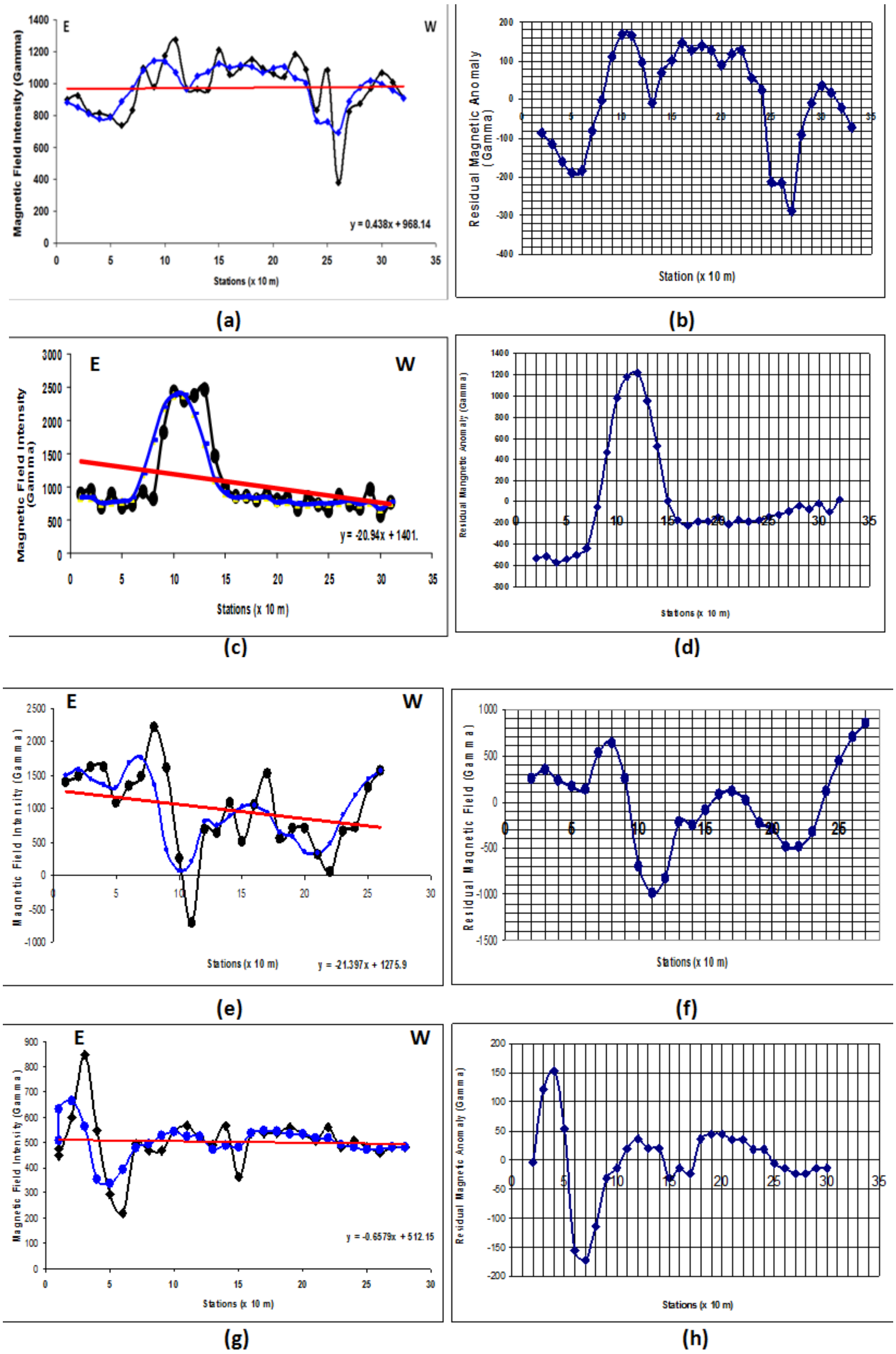

Fig. 4: Magnetic profiles (a, c, e and g) showing Diurnal-corrected magnetic field intensity (Black), Filtered magnetic field intensity (Blue) and Regional magnetic field (Red) for Traverse 1, 2, 3 and 4 respectively; and profiles (b, d, f and h) showing Residual magnetic field for Traverse 1, 2, 3 and 4 respectively.

Low magnetic field intensity values were observed along traverses 1 and 4. Magnetic anomaly amplitudes range between -212.97 and 169.58 gammas, and -172.61 and 153.33 gammas along the respective traverse. The low positive magnetic anomaly observed along these traverses may be the result of deep-seated basement rocks, and not the result of the underlying rocks being non-magnetized since the area has been investigated to be underlain by charnokitic rocks which have magnetic minerals.

Figure 5 shows the residual magnetic anomaly map of the area. The map clearly reveals the two zones of high magnetic anomaly seen in the profiles, one towards the southeast and the other at the north western part of the survey, and two other distinct zones of weakness or faulting/shearing which have large negative magnetic anomalies. One of these zones of weakness is massive, and straddles NE-SW across the entire breath of the survey while the other occurs at the onset of the survey in the eastern part. The massive structure has a magnetic anomaly of about -50 gamma in the northeastern and southwestern edges, deepening to about -982.89 gamma around the central part, at about 110 m from the east around traverse 3. The peak negative magnetic anomaly of the second zone of weakness is about -500 gamma, and occurs at the beginning of the survey in the eastern part. These zones may have been heavily fractured, jointed and/or sheared, and may contain grabens with sediment fills [19]. The zones constitute the main acquiferous zones in the survey area, and are therefore prospective zones for hydrogeologic activities in the area.

The structural trends shown by the presence of the heavily fractured zones on the map, which are also evident in the profiles is suggestive of the fact that the survey area might have been subjected to several intense tectonic activities [20]. These features are also clearly visible in the 3D surface map shown in Figure 6. Features such as joints, fractures, shear zones and/or faulting are visible expressions of residual forces produced after rocks have been subjected to deformation, and they are a confirmation that tectonic events took place in the past in an area. A similar case had been reported by [21].

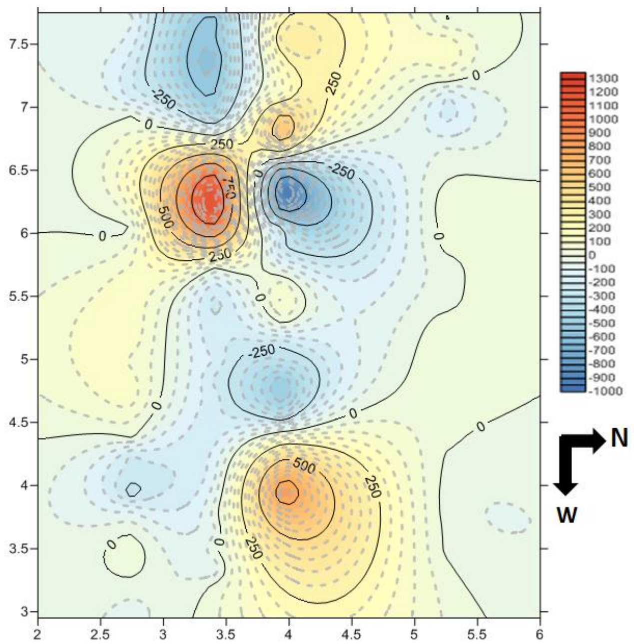

Fig. 5: Residual Magnetic Anomaly Map

Figure 7 shows the filtered, total magnetic field intensity map before regional-residual anomaly separation. Although regions of high and low magnetic intensity can be identified, the map does not reveal as much structural detail as is seen in the residual map.

Figure 8 shows the regional magnetic field map in the area. The contour lines generally trend in the northeast-southwest, in agreement with the general structural trend in the area. The regional values decrease in a northerly direction in the survey area.

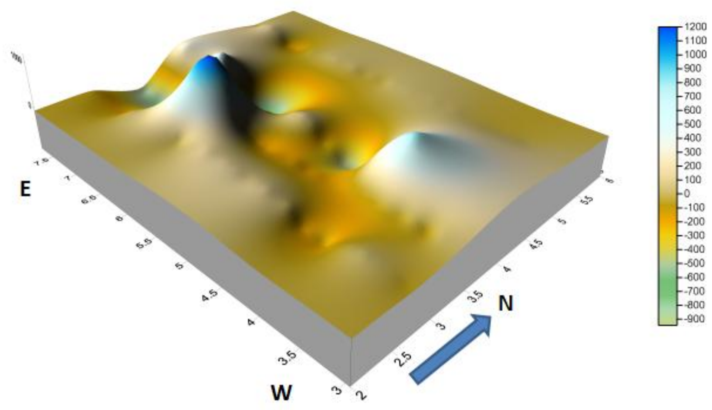

Fig. 6: 3D Surface Map from Residual Magnetic Anomaly

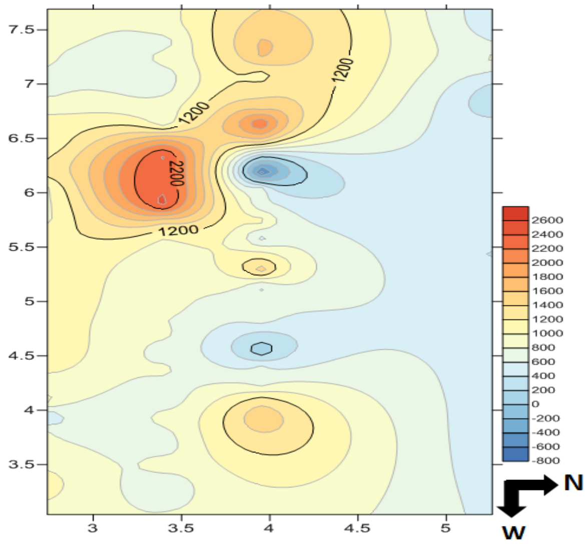

Fig. 7: Diurnal-Corrected, Filtered Total Magnetic Field Intensity Map

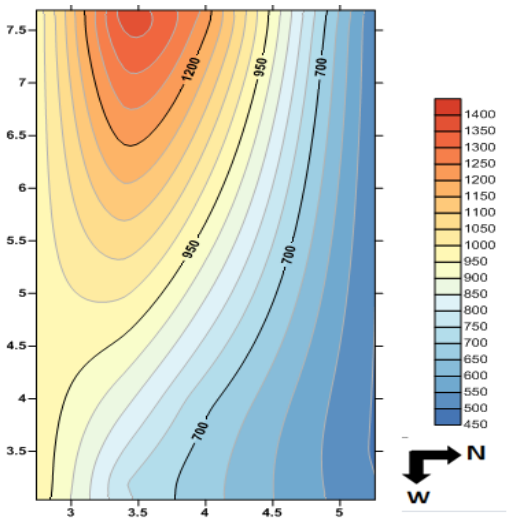

Fig. 8: Regional magnetic field intensity map

IV. Conclusion

The ground magnetic survey carried out in this study has been successful in delineating the charnokitic dykes underlying the study area and their approximate burial depths. The dykes are associated with very high positive magnetic anomalies and may have been caused by multiphase intrusions emplaced over time. Two zones of weakness, fracturing and/or shearing are also delineated, one of which is massive and straddles northeast-southwest across the entire breath of the survey area. These zones may be the result of residual forces arising from deformation, and are suggestive of the fact that intense tectonic activities may have taken place in the area in the past. This can further be confirmed by a detailed petrographic study of the rocks in the area. Based on the results of the study, locations within the survey with high potentials for geotechnical and hydrogeologic activities can be clearly inferred.

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