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ANALYSIS OF AEROMAGNETIC DATA FOR MAPPING OF LINEAR STRUCTURES: A CASE STUDY OF IGABI, BASEMENT COMPLEX OF NIGERIA

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ABSTRACT
Analysis of aeromagnetic data over Igabi, Kaduna state, which is part of the Basement Complex of Nigeria, was carried out to highlight linear structures, and to infer the effects of such features on regional groundwater, solid mineral availability, as well as hydrocarbon potential. The study area lies within latitudes 10^0 33' - 10^0 35' N and longitudes 7 ^{0} 26' - 7 ^{0} 46' E, and it is located in the Younger Granite Province, known to be characterized by granitic plutonism, igneous intrusion and magmatism. Data was processed using Oasis Montaj software and ArcGIS. Structural trend characteristics of the study area, and depth to basement of magnetic anomalies were highlighted using the Euler deconvolution methods. Deconvolution of aeromagnetic profiles, were utilized to determine the depth to magnetic sources. These depths were found to range from (0 – 3000m). The study area was found to be characterized by major and minor faults, with a dextral movement in the N-E, N-W and S-E directions. Predominant lineament trends were also observed to be in the N-E, and S-W directions. Areas overlain by a major crossover of lineaments implying the presence of a weak zone was found to correspond to areas with low magnetic intensities on the residual aeromagnetic field map of the study area. These were suggested as regions for possible groundwater targeting. Findings suggested that study area is also good for mineral prospecting, but not favorable for hydrocarbon prospecting.

Key words: Basement complex, lineament, Younger granite, aeromagnetic, Euler deconvolution

INTRODUCTION
A Lineament is a linear feature in a given landscape which expresses the presence of an underlying structure such as a fault. It consists typically of fractures, aligned valley series, or fold aligned hills. Fractured zones, shear zones, and an intrusion of igneous rocks cutting across existing strata (dykes) can also give rise to lineaments. They may be visible and apparent in geological or topographic maps. The relevance for lineament study, analysis and interest stems from the fact that lineaments are known to be overlain by weak fractured zones of increased permeability, and these serve as conduits for mineralization and groundwater recharge. This claim is however supported by research some scholars, notably Latmann and Parizek (1964), Magowe and Carr (1999) and Mabee *et al.*, (1994). Also studies by Ananaba and Ajakaiye (1987) established that solid minerals in Nigeria were structurally controlled, due to a good correlation between lineament density action on the general lineament map of Nigeria and the occurrence of economic

minerals such as zinc, gold, tourmaline, amethyst, lead, uranium and casseterite. In the same vein, studies by Ijeh et al (2018); Ngama and Akanbi, (2017); Okereke et al (2012) and Bruning et al (2011) corroborated the effectiveness lineament detection and extraction in identifying zones of groundwater and mineral deposits.

Due to the problems of borehole failure and acute water scarcity experienced in the study area, this study aims at providing qualitative and quantitative information, which would serve as reconnaissance for further groundwater targeting expedition on a regional scale. The specific objectives of this study however include:

(i) Identifying and delineating structures associated with the area and interpreting their relationship with basin formation with regards to ground water and hydrocarbon availability in the study area.

(ii) Determining the depth to magnetic sources giving rise to magnetic anomalies of interest using Euler deconvolution method.

Geology of study area

The Nigeria Basement complex is part of the Benin-Nigeria shield, situated within the Pan-African mobile zone extending between the West-African Craton in the west and the Gabon–Congo Craton in the south east. The Nigeria basement complex comprises of gnesis, Migmatites and supracrustal sequences which have yielded relics of the Archean paleoproterozoic as well as neoproterozoic ages (Ferre *et al.*, 1998; Dada, 1998; Annor, 1995; Ekwueme and Kroner, 1993; Oversby, 1975;). The neoproterozoic (Pan African) orogenic imprints in the Nigeria basement complex were characterized by high grade metamorphism, folding, faulting and wide spread granite plutonism.

Within the basement complex of Nigeria lie four major lithological units. Namely:

(i) The Migmatite Complex (MGC). A heterogenous assemblage, predominantly of amphibolites-facies, migmatites, orthognesis, paragnesis and minor basic to ultrabasic rocks (Rahaman, 1988).

(ii) The Schist belts, believed to overlie the MGC and consist of mainly pasmmitic to politic metasedimentary rocks with interlayered granitoid gnesis and rare amphibolites, interpreted as metavolcanic rocks (Turner, 1983).

(iii) The Jurassic younger Granite, intruding both the migmatite gnesis complex and the schist belts and composed of tonalitic to granitic plutons and charnokites, strongly foliated to almost unfoliated and considered to have been emplaced during the pan-African orogeny (Tubosun *et al.*, 1984).

(iv) Underformed acid and basic dyke.

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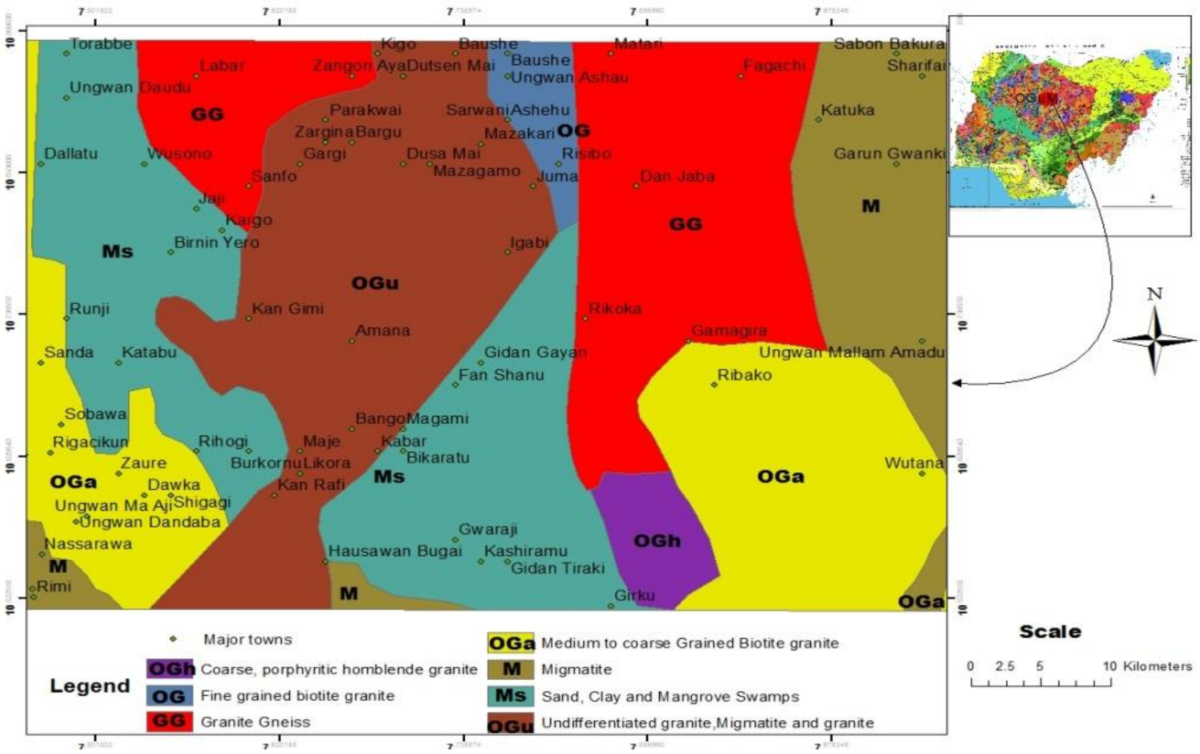

Figure 1: Geological Map of Study Area (generated from ArcGIS)

As revealed by the geological map (figure 1), the study area is largely covered by basement rocks while the rest is covered by ring complexes. The basement rocks consists of two groups: the ancient metasediments considered to be older than 200ma and the group that mainly consist of migmatites, granite-gnesis and older granites, believed to have resulted from remobilization during the pan-African orogeny (Dada, I998). This basement has been subjected to different episodes of faulting and folding, with dominant foliation roughly N-S, with variations between NW-SE and NE-SW (Rahaman, 1989). Fractures and shear zones also characterize the basement. They consist of E-W trending fractures, which are perhaps the oldest fractures and most obliterated. Others are N-S fractures that resulted from brittle deformation and twin conjugate sets of NE/SW and NW/SE and the NNE/SSW and NNW/SSE sets, produced by transcurrent movement (Obaje, 2009).

MATERIALS AND METHODS

There are numerous digital processing techniques which could be employed to enhance aeromagnetic data sets for maximum extraction and display of the required lithologic and structural information (e.g. Kowalik and Glean, 1987, Reeves and Zeil, 1990). A summary of the processing techniques applied in this study is highlighted below. In-depth and further details can be obtained from various texts (e.g. Reeves, 2005; Blakely, 1995 and Drury, 1993).

Data Acquisition

The digitized aeromagnetic data (Igabi aeromagnetic grid map, sheet 124) was obtained from the Nigeria Geological Survey Agency (NGSA) Abuja, Nigeria.

The survey which was aimed at mineral and groundwater development, through improved geological mapping was collected at a flight of 80 m altitude, flight line spacing of 500 m and tie line spacing of 2000 m and a flight line direction of NE-SW. The Data covered a total area of about 3800 square kilometers and was supplied in ASCII file, Geosoft format but was converted to Microsoft excel format for easy compatibility with other applications.

Qualitative Data Processing

Reduction to pole

The aeromagnetic data was reduced to pole to correct for the effect of magnetic inclination, for purely induced magnetism or remanent magnetization. Reduction to pole (RTP) attempts to reduce data dependence on magnetic inclination and shifts the anomalies to lie directly over their sources, thus, producing anomaly maps that can be easily and readily correlated to the surface geology (Blakely, 1995). The Geosoft algorithm was used to calculate the reduction to pole caters for both high and low magnetic points.

Upward Continuation

This is a way of enhancing large scale (usually deep) features in the study area, it attenuates anomalies with respect to wavelengths, the shorter the wavelength, the greater the attenuation. It is a way of enhancing large scale features in the survey area. Also upward continuation tends to accentuate anomalies caused by deep sources at the expense of anomalies caused by shallow sources (Mekonnen, 2004). The upward continuation process was applied on magnetic data of Igabi area at 100m, and 1000m respectively to expose the basement at these various depths, as shown in figures (4 and 5)

Regional-Residual Separation

The data were converted to excel format and fed into a computer programme (Geosoft Oasis Montaj, version 6.4.2). The programme was developed to pick out points row by row. The software was used to derive the residual magnetic values, by separating regional and residual magnetic fields. This separation is achieved by inverting the observed magnetic data from a large area to construct a regional susceptibility distribution. The magnetic field produced by the regional susceptibility model is then used as the regional field and the residual data are obtained by simple subtraction of regional magnetic fields from total magnetic field values.

A composite contour map for the obtained residual data is shown in figure (3), giving a more accurate and clearer idea of the surface distribution of magnetic anomalies. The advantages of this method are that it introduces little distortion to the shape of the extracted anomaly and it is not affected significantly by factors such as topography and the overlap of power spectra of regional and residual fields.

Quantitative Data processing

Euler Deconvolution provides estimates of geometrical parameters for elementary causative bodies from magnetic anomalies and their horizontal and vertical derivatives. This method assumes that the anomalies are a homogeneous function of spatial coordinates. This method was originally reported by Thompson (1982) and Reid *et al.,* (1990), in order to detect the depth to the causative magnetic bodies. To apply the Euler method on the data, the package Geosoft Oasis Motaj software was used.

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Magnetic field derivatives must be in the X, Y and Z parameters (longitude, latitude and magnetic intensity), which are very necessary for the Euler Deconvolution process. Appropriate window sizes are selected and the Euler method is applied to the residual data.

Depth estimation by Euler Deconvolution technique was used for delineation of geologic contacts where faults and lineaments usually occur. This method is based on Euler's homogeneity equation.

$$(x - x_0)\frac{\delta f}{\delta x} + (y - y_0)\frac{\delta f}{\delta y} + (z - z_0)\frac{\delta f}{\delta z} = -Nf \quad (1)$$

Where

f *is* the homogenous function, i.e the observed field at location (x, y, z) caused by the anomalous source at location (x_0 y_0 z_0), and

N *is* the degree of homogeneity, and is interpreted as the structural index which relates directly to the shape of the source of the field.

RESULTS

The qualitative interpretations of aeromagnetic data directly illustrate geological information by looking at it without any calculations. Figure 2 shows the total magnetic intensity map and reveals variations in magnetic field intensities throughout the study area.

Small magnetic clusters are revealed by the residual map shown in figure 3. It is indicative of the igneous intrusion, granitic rocks, mineral bodies and rhyolite which greatly characterize the area, especially the mountainous and hilly areas of Dutsen Bakura and Dutsen Gidan Rawo..

Figures 4 and 5 are the upward continuation maps at 100 m and 1000 m of the study area. This is a filtering technique to smooth the data i.e. reduce high frequencies (hence the signal-to-noise ratio). This is usually applied when the deep structure imaging is desired.

Figure 6 shows the regional aeromagnetic map of the study area. The filtering procedure that produced figures 4 and 5 was done in conjunction with the regional and residual data separation.

Figure 7 is the lineament map of the study area which was produced using the ArcGIS.

The results produced from the Euler depth computation are shown in figures 8 to 11, while the Euler deconvolution depth contour map is shown in figure 12.

Table 1 shows the summary of the structural indices for simple geometrical models in magnetic field and the corresponding depth ranges as observed in the study area.

DISCUSSION

A visible inspection of the total magnetic intensity map (figure 2) reveals variations in magnetic field intensities throughout the area. The magnetic field intensity is largely positive (high) throughout the north-eastern area of the study area. Rock types which predominates the area (migmatites and gnesis) are dominant causes of magnetic anomalies. The magnetite content of basement rocks is usually greater than those in sedimentary rocks. The magnetic anomaly signature characteristics are a result of one or more physical parameters, such as the configuration of the anomalous zone, the magnetic susceptibility contrast and the depth to the magnetic body.

Figure 3 also reveals that faulting and fractures are a major structural feature in the area, observed in the NW-SE Direction with a dextral movement interpreted as irregularities and disruptions in the linear patterns of magnetic anomalies. Further discontinuities in the magnetic signature may be indicative of lineament actions and possibly more fault zones within the study area. The high magnetic values predominantly around the north-western and south-western parts of the study are also suggestive regions where the magnetite rich basements igneous rocks are shallow. Magnetite may not be the only magnetic mineral responsible for magnetic highs, but is dominant in the area. Intermediate values represented by the green color are generally suggested as granitic rocks. The negative anomalies prominent around the south eastern part of the residual map suggests the presence of quaternary sediments, or from sources buried much deeper, such as the intrusion of basement igneous rocks into sedimentary regions.

Correct estimation and removal of the regional field from the initial field observations yields the residual field produced by the target sources. Interpretation and numerical modeling are carried out on the residual field data, and the reliability of the interpretation depends to a great extent upon the success of the regional-residual separation (Li and Oldenburg, 1998). Figure 3 was thus produced after separation. It can be observed that deeper structures were enhanced after the upward continuation at 100 m and 1000 m (see figures 4 and 5).

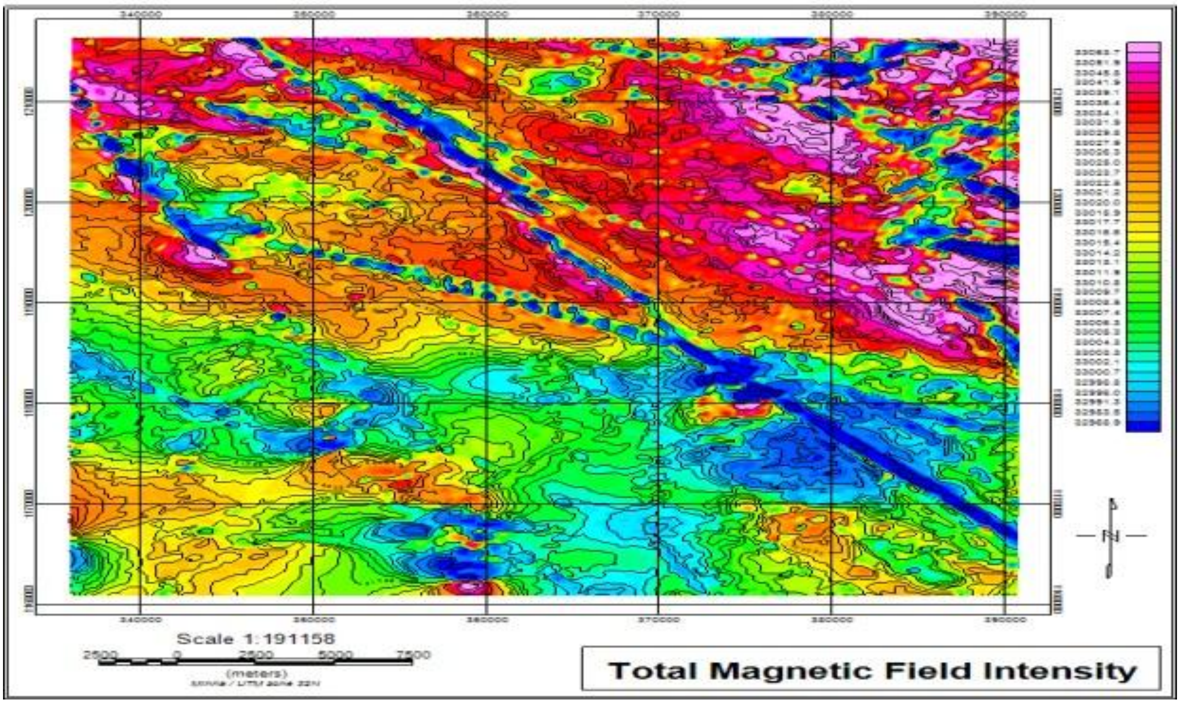

Figure 2: Total Magnetic Field Intensity Map

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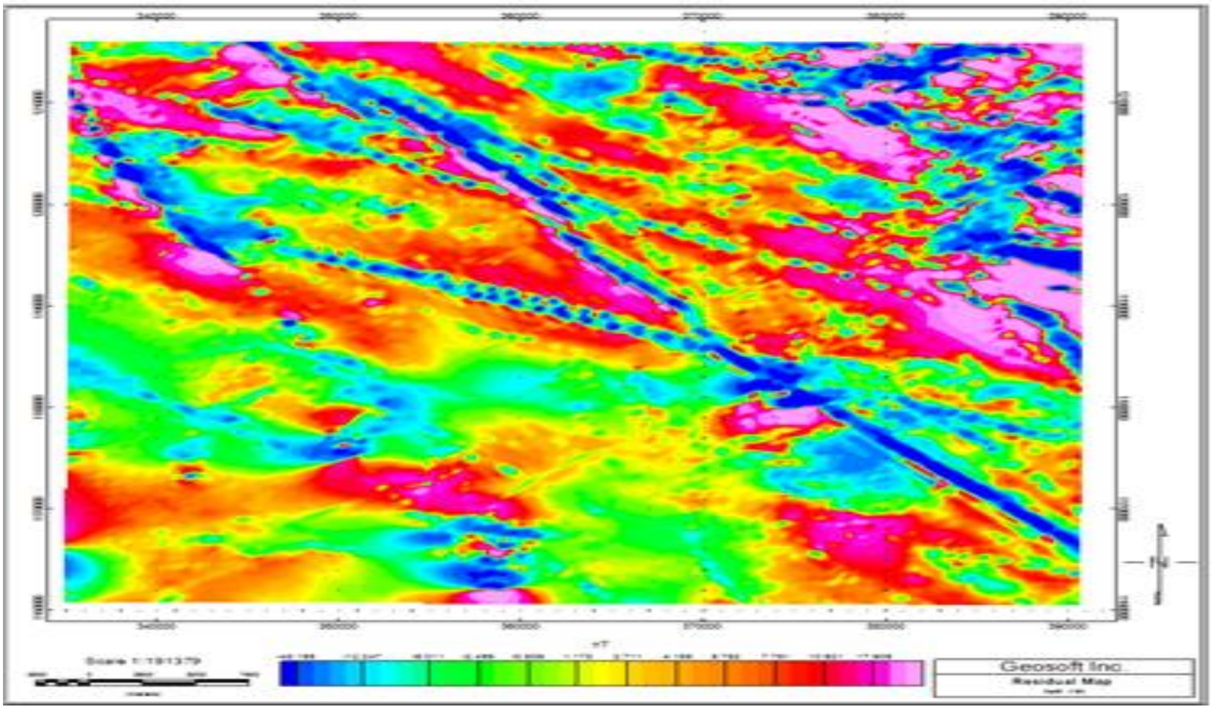

Figure 3: Residual Aeromagnetic Map

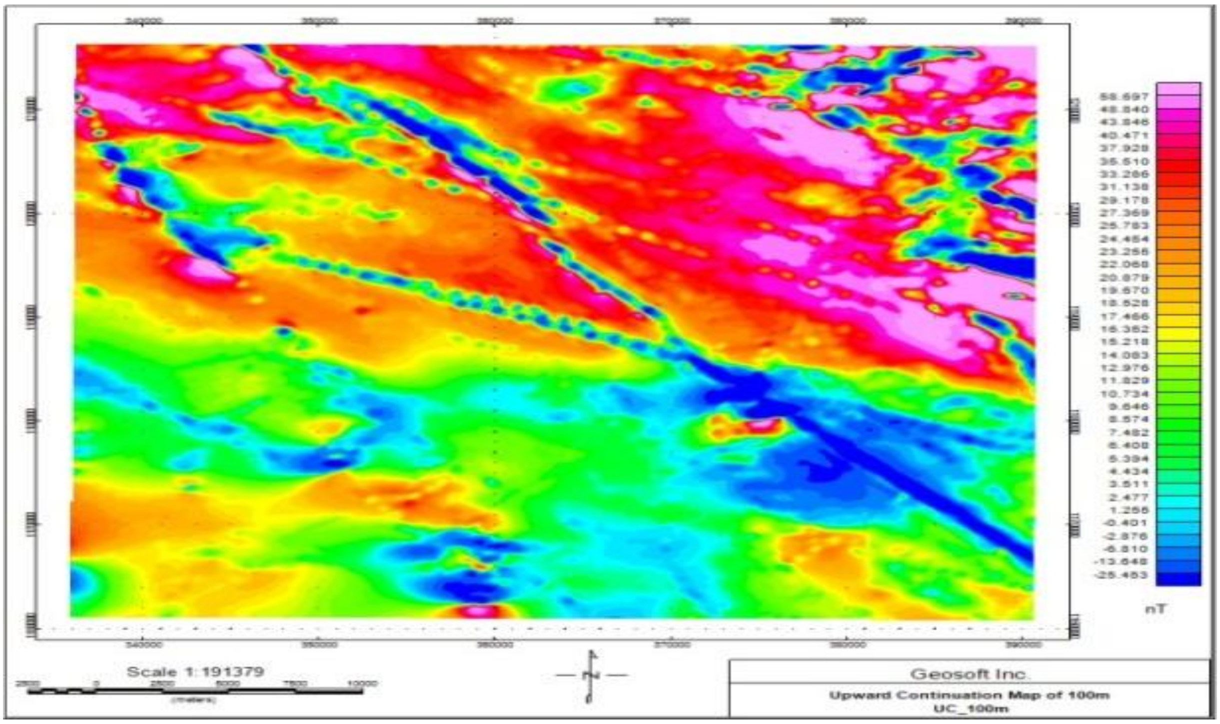

Figure 4: Upward Continuation Map at 100m

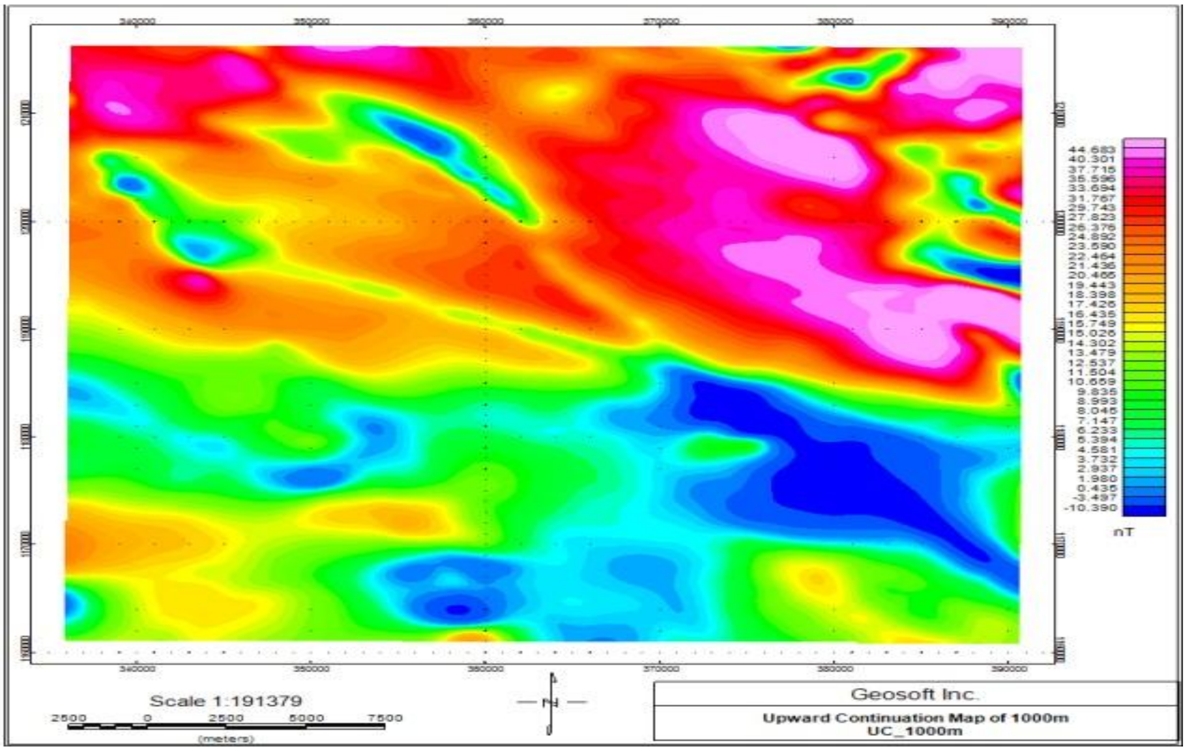

Figure 5: Upward Continuation Map at 1000m

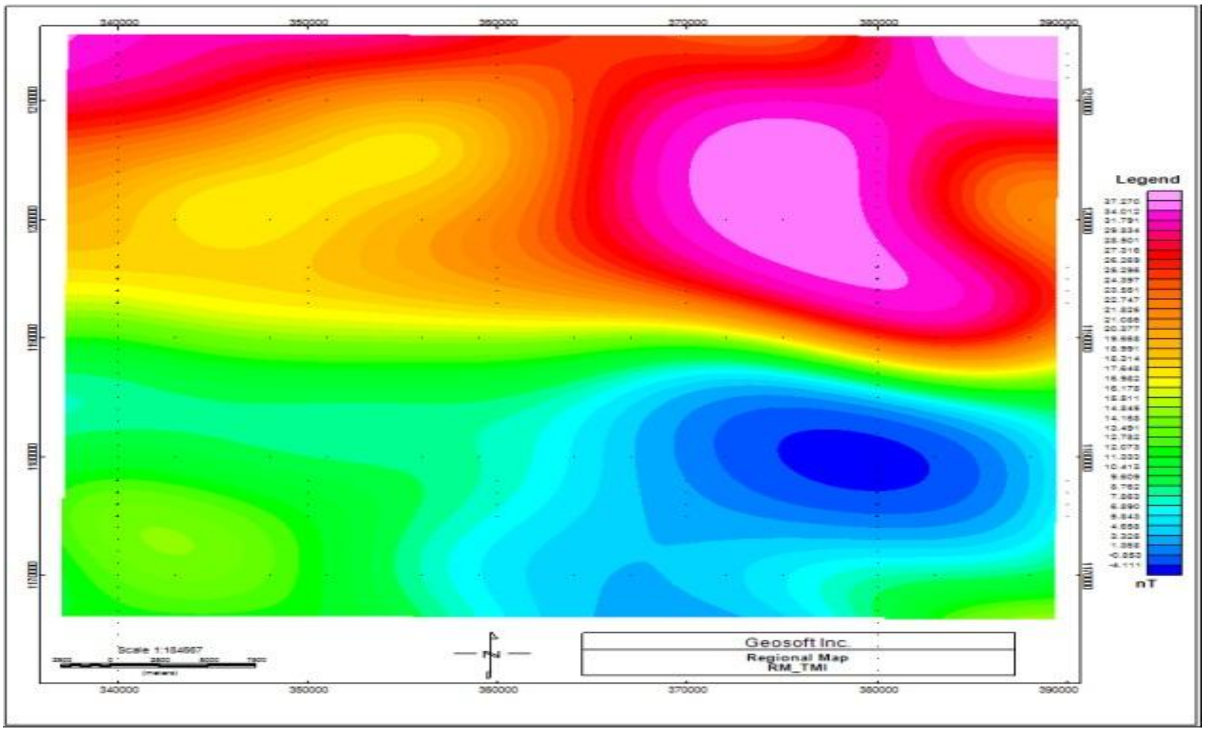

Figure 6: Regional Aeromagnetic Map

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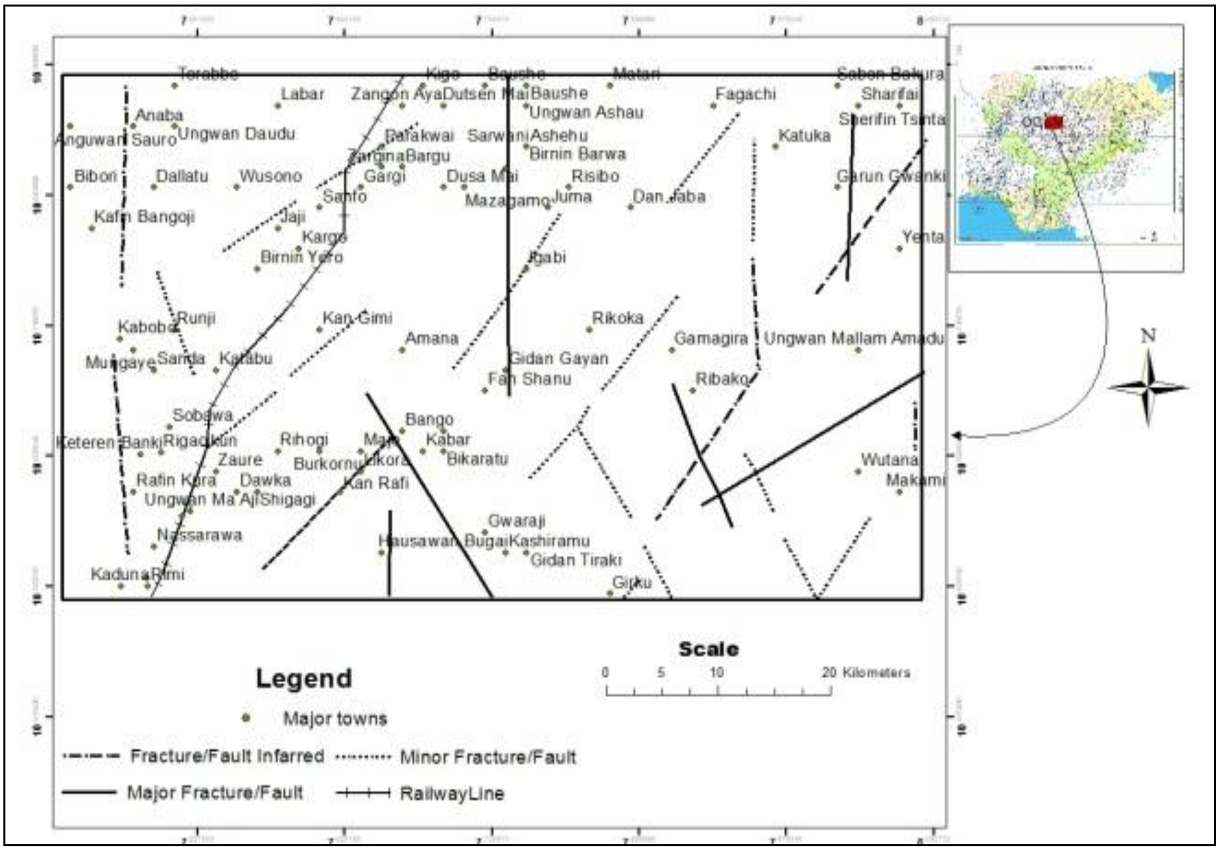

Figure 7: Lineament map of study area (extracted from ArcGIS**)**

A comparison between the aeromagnetic map (figure 6) and lineaments map (figure 7) of study area revealed that areas with high density of lineament action correspond to areas on the residual aeromagnetic map having lower aeromagnetic intensities, prominently the south-eastern parts of both maps.

While areas with higher magnetic field intensity values are characterized by the presence of little or no lineament and fracture density action. There is therefore almost a good correlation between the aeromagnetic anomalies and the mapped lineaments.

The aeromagnetic field data interpretation was performed qualitatively through two steps. First is by comparing the residual aeromagnetic anomaly map with the geological map, and secondly by comparing the residual aeromagnetic anomaly map with the lineaments map of study area. It is important to however mention that not all aeromagnetic anomalies have been discussed and interpreted since the data set contains a great richness of details beyond the scope and objectives of this study.

The study area is generally not favorable for hydrocarbon prospecting but more viable for groundwater targeting and mineral exploration, owing to the fact that the study area is dominated by numerous intrusive and linear features which in general may serve as conduits for mineralization and groundwater recharge. It should be noted however, that trapped hydrocarbon will be baked as a result of granitic intrusions and contact metamorphism at intrusion point.

Quantitative Interpretation

The quantitative interpretation of aeromagnetic data can be complex; however, rigorous analysis is carried out on a routine basis only when simple geometrical models are utilized to represent the subsurface sources. In this study, faults and fractures overlain by major and minor lineaments action are considered as the predominant structural sources of magnetic anomaly of interest.

Depth to Basement

The quantitative interpretation of geophysical anomalies is often based on the assessment of data observed along selected profiles. In computing the Euler depth and to produce a contour depth map and legend, standard Euler deconvolution was carried out with structural index (SI) values ranging from 0-3, revealing four main structural geometrical models, i.e. SI=3 (for spherical bodies), SI=2 (for cylindrical bodies), SI=1 (for sills and dyke) and SI=0 (for contact features). The results are therefore displayed in figures (8, 9, 10 and 11). The resulting maps were then examined feature by feature, and the index which gave the best solution was chosen. A structural index (1) was chosen, because magnetic field of linear structures, fractures and faults can be inferred with the body. This index was preferred because it gave the closest and most compact cluster of solutions that fitted the expected geological structure.

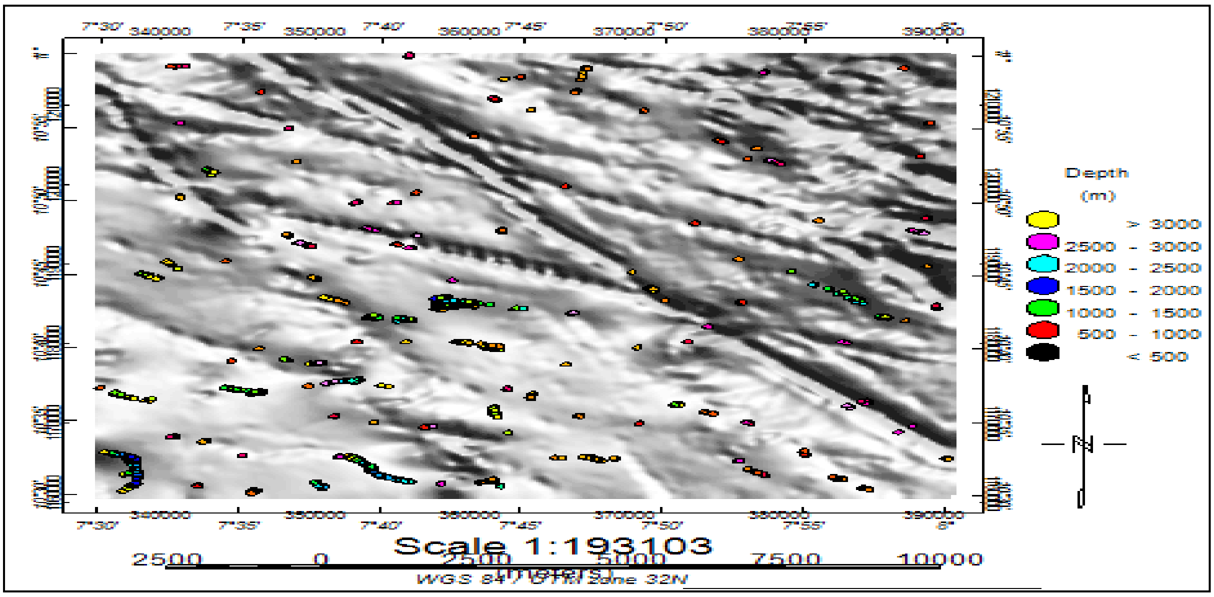

Figure 8: Euler Deconvolution for SI = 0

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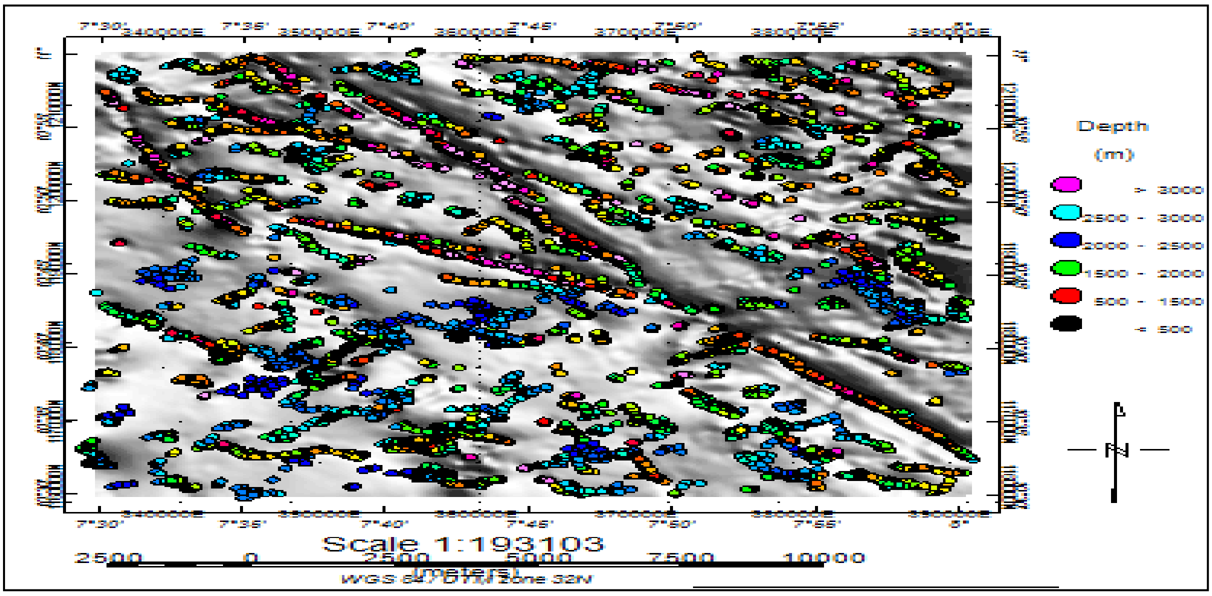

Figure 9: Euler Deconvolution for SI = 1

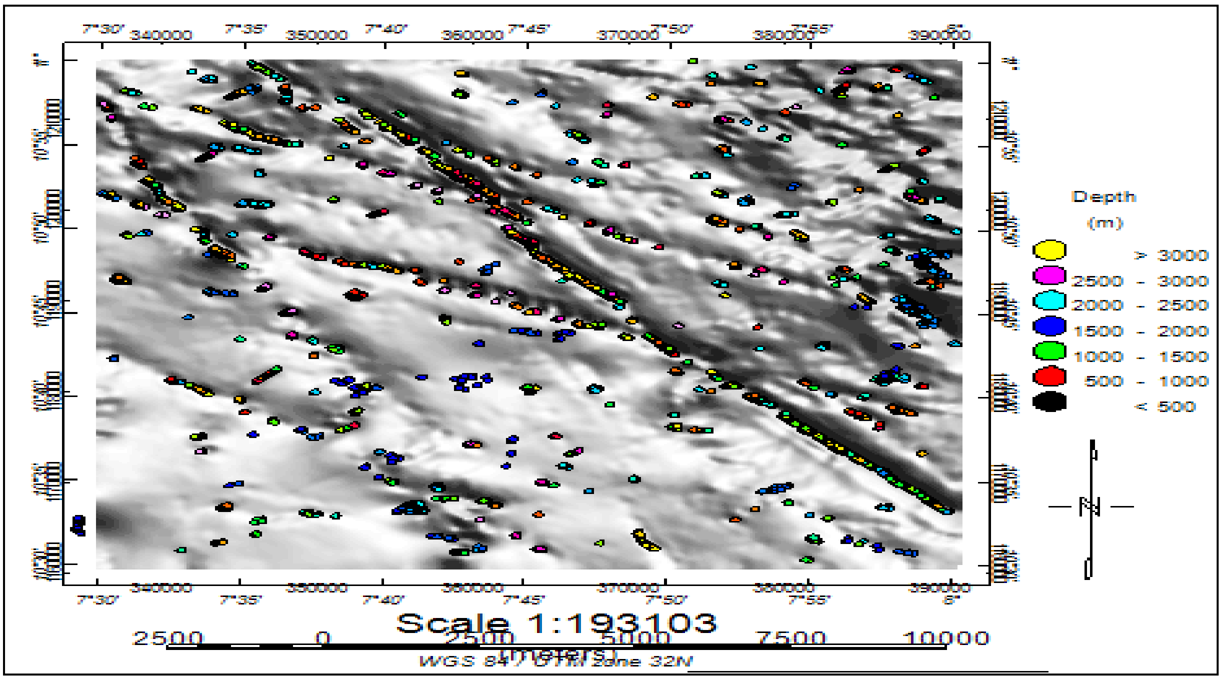

Figure 10: Euler Deconvolution for SI = 2

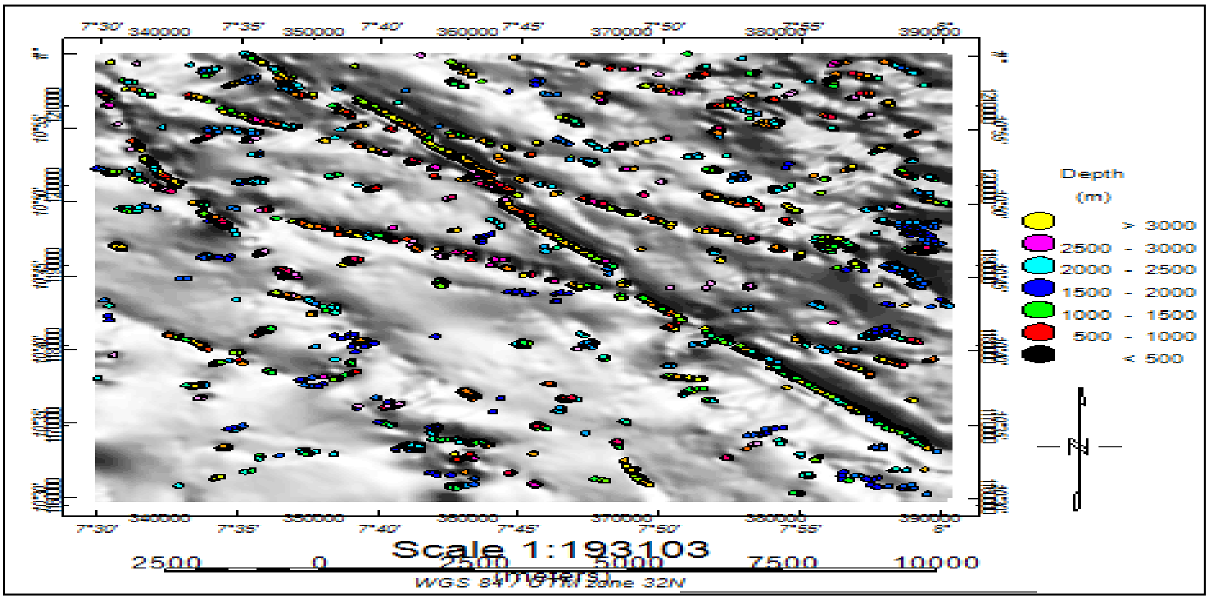

Figure 11: Euler Deconvolution for SI = 3

Areas on the map in figure (9) without magnetic body signatures or color (depth) indicate that there is no Euler solution (depth) for the chosen structural index for those areas. The yellow and purple colors indicate deeper seated magnetic bodies, while blue, green, and red colors indicate shallower magnetic bodies in that order. Ring complexes are indicated by circular clusters of anomalies observed at the north-eastern part of figure (12). Table 1 gave a summary of the structural indices for simple geometric models in a magnetic field and their corresponding depth ranges. The results of the Euler solutions indicate that the closest linear cluster of solutions along the inferred major fracture and fault zones ranged from (500-3000m).

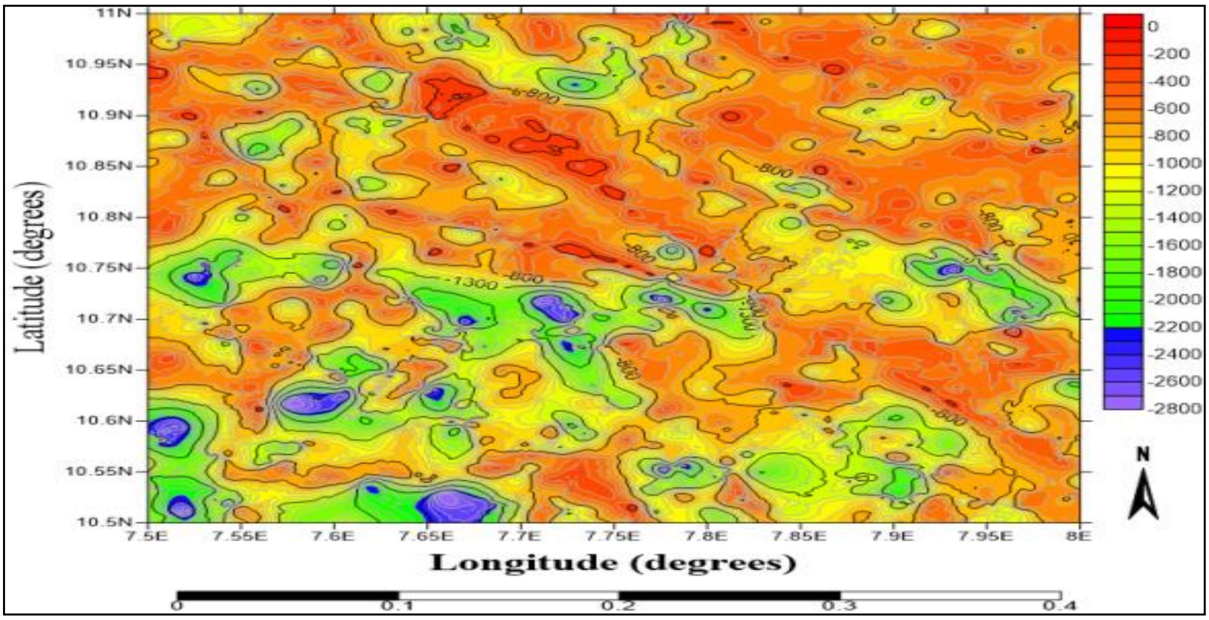

Figure 12: Euler Deconvolution depth contour map

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Table 1: A summary of the structural indices for simple geometrical models in a magnetic field and the Corresponding depth ranges as observed in the study area.

Structural Index (N)	Type of magnetic model	Characteristics	Observed depth range (m)
0.0	Contact with large extent	Circles are intertwined with no particular pattern	500-2500
1.0	Sill, dyke, and thin prism with large circles	Circles are intertwined in a straight line	500-3000
2.0	Vertical and horizontal Cylinders	Occurs like a vertical pipe and circles are intertwined neatly with regular circumference	1000-2500
3.0	Spheres	Occurs as spherical body of circles with a common axis connecting them	500-2500

Airborne geophysical study was utilized to qualitatively describe magnetic susceptibility distribution in the study area, and quantitatively, to delineate the subsurface structures which control the anomalous hydrogeology as well as mineralization zones of the study area. The depth to top of intrusive causative targets was calculated from the aeromagnetic map using Euler deconvolution method. It was found that the computed depths range between (0 - 3000m). The relatively shallow values were observed predominantly towards the north-eastern region of study area dominated by basement igneous rocks such as migmatite, gnesis, and amethyst. The deep values observed around the north-eastern part of the study area predominantly, may suggest the occurrence of quaternary sediments. The interpreted depths help greatly in the interpretation of the basement relief as well as understanding the major structural trends in study area. In addition, the aeromagnetic data interpretation was compared with the lineament and fracture maps and regions of high density lineament action was found to correspond to areas of low magnetic intensities (the north-eastern region), these are possible areas for regional groundwater targeting.

The result of this research has assisted greatly in further understanding the structural setting of the studied area, the distribution of magnetic anomalies, as well as revealing structural details previously not known about studied area. The Euler depth map (figure 9) reveals the presence of a major crossover of lineaments, fractures and a cluster of magnetic anomalies with features typical of those associated with ring complexes. The study area is not viable for hydrocarbon exploration but generally good for groundwater prospecting and may also be associated with a number of economic minerals because of the historical knowledge of mining activities notably of tourmaline and gold.

Based on the results obtained from the study, the following recommendations are made:

- The use of other geophysical techniques such as seismic, resistivity and well logging in drilled boreholes should be encouraged in the area

- A new series of maps much current and recently published by the Nigerian Geological survey agency should be compared with the old ones in view to check for discrepancies in results.
- Further quantitative analysis using other depth estimation techniques should be carried out to fully understand the quantitative prospect of ground water resources of the area, and consequently designing a model for effective and efficient ground water targeting and development.

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