EVALUATION OF AEROMAGNETIC ANOMALIES OF ABUJA SHEET 186 AND GITATA SHEET 187, NORTHCENTRAL NIGERIA

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ABSTRACT

Interpretations of High-Resolution Aeromagnetic Data of Abuja Sheet 186 and Gitata Sheet 187, Northcentral Nigeria, were carried out with the aim to determine Curie Point Depth, Geothermal Gradient, Heat Flow, and depth to a magnetic source. Euler Deconvolution method was adopted, and the software used for analysis include: Oasis Montaj Version 8.4, Matlab Version R2020a, Grapher 5, SUFER 11, Georient, and Microsoft Excel. The Total Magnetic Intensity ranges from 32919.5 to 33083.5 nT, and the residual magnetic values range from -392.5 to -171.6 nT. The depth estimates were obtained from the Euler deconvolution technique, using four structural indices of 0.0, 1.0, 2.0 and 3.0. The structural index (0.0) represents contacts and ranges from 60.2 to 318.3m while 1.0 stands for dyke and sill and ranges from 200.7 to 762.2m. Cylinder has structural index of 2.0 and ranges from 206.3 to 1167.0 m. Structural index, 3.0 represents the presence of spheres and ranges from 151 to 1588m. The depth of magnetic sources varies across the study area due to underlying topography. The depth to the Centroid (Zo) ranges from 11.60 to 13.56 km and the depth to the top boundary (Zt) of magnetic sources ranges from 0.311 to 2.16 km. The equivalent curie depth obtained ranges from 22.89 to 25.64 km and could be as a result of the intruded Older Granite suite in the area. The average heat flow (59.32 mWm-2) and geothermal gradients (23.72^{0}C km^{-1}) indicate that the heat flows and geothermal gradients were not uniform, which possibly revealed that the magma conduits were randomly distributed and thus could be considered as typical of the continental crust.

Keywords: heat flows, geothermal, curie, centroid, and euler

INTRODUCTION

Aeromagnetic data is a magnetic data rapidly collected over large and sometimes inaccessible areas at minimal cost for regional reconnaissance with a magnetometer towed behind an Aircraft. Aeromagnetic data is incomplete without emphasis on the parameters and tools required to carry out a successful aeromagnetic survey (Reynolds, 2005). In the interpretation of magnetic anomalies by means of local power spectra, there are three main parameters to be considered namely: the depth, thickness and magnetization of the disturbing bodies. It is necessary to define the power spectrum of a magnetic anomaly in relation to the average depth of the disturbing interface (Spector and Grant, 1970).

The previous aeromagnetic survey in the study area was conducted in 1975 and interpreted by Ajakaiye et al. (1985) across the central crystalline shield area of Nigeria. The recently obtained High-resolution aeromagnetic data in 2009 have not been interpreted. The present study aims at determining the Curie Point Depth, Geothermal Gradient and Heat Flow.

Location and Geology of Study Area

The study area covers longitudes 7° 00' to 8° 00'E and latitudes 9° 00' to 9°30'N (Figure 1) with estimated area of 6,050km^2. Nasarawa State which forms part of the study area is known as the home of solid mineral, while Abuja which also form part of the study area also boast considerable amount of solid mineral resources of their own. Therefore, the study of mineralization in this area is promising (Andrew & Salako, 2017). The topography is rugged and undulating with the Basement rocks outcropping as hills and inselbergs. The Gwagwa plains occurring at the west of the FCT are underlain by migmatites and gneisses (Figure 1 & 2). These plains form part of River Abuja that originates in the Bwari-Aso hills, the northeastern part of Abuja (Figure 1). The drainage pattern varies from trellis to dendritic and is drained by Rivers Gwagwalada and Abuja (Itiowe & Hassan, 2019).

The study area is covered with 60% basement complex rocks while the remaining 40% is made up migmatite gneiss intricately associated with old granite occupy the areas of Gurku, Panda, and Gitata (Adewumi and Salako, 2017). These areas are almost predominantly underlain by high-grade metamorphic and igneous rocks of Precambrian age generally trending NW – SE (Obaje, 2008). These rocks consists of Medium-grained Biotite granite, Biotite Hornblende granite, Granite Gneiss, Quartzite, Undifferentiated Older Granite, Porphryroblastic Gneiss, Coarse Porphyritic Biotite hornblende Granite, Migmatite Gneiss and migmatites as shown in figure 2.

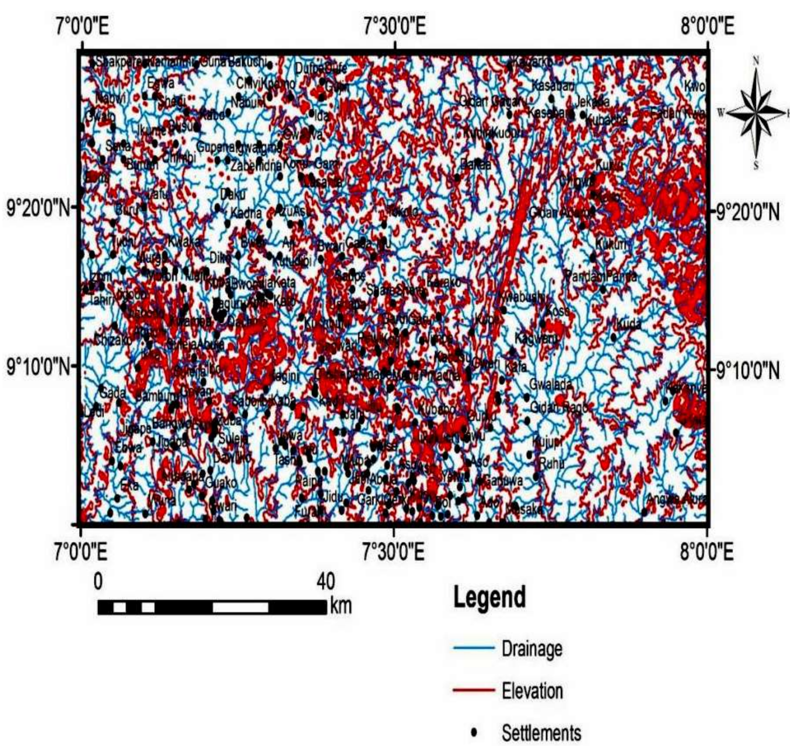

Figure 1: Topographical Map of the Study Area (Extracted from Topographical map of Abuja. Sheet 186 and Gitata Sheet 187, Federal Surveys of Nigeria, 1962)

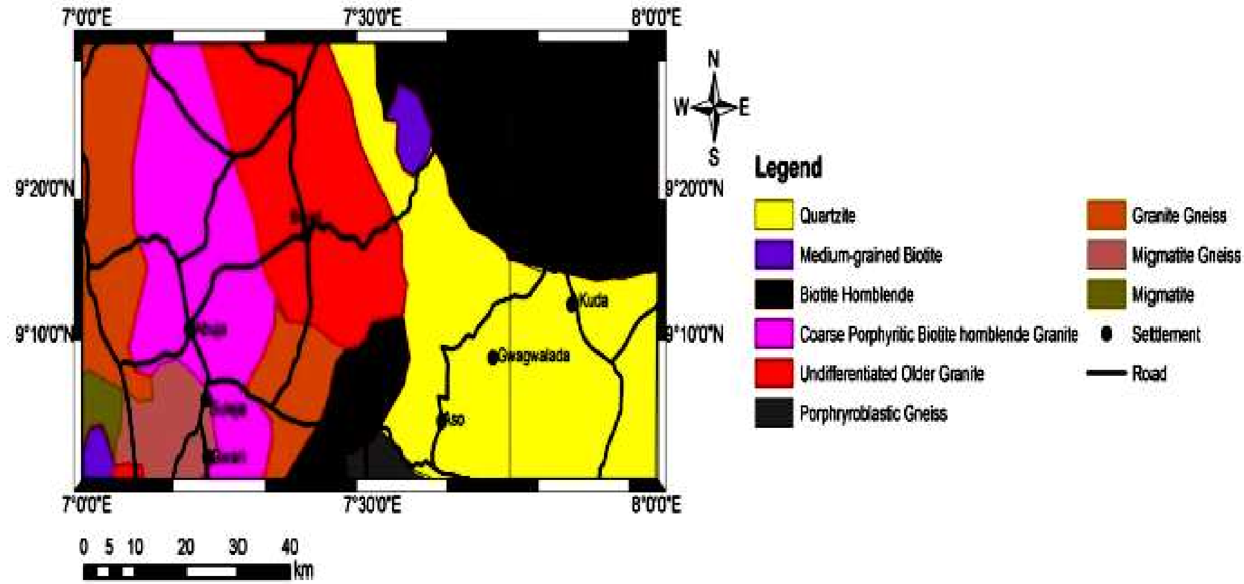

Figure 2: Geological Map of the Study area (Extracted from Geology map of Abuja Sheet 186 and Gitata Sheet 187, Nigerian Geological Survey Agency, 1963)

MATERIALS AND METHODS

The Standard 3D Euler method is based on Euler's homogeneity equation, which relates the potential Field (magnetic or gravity) and its gradient components to the location of the sources, by the degree of homogeneity N, which can be interpreted as a structural index (Reid et al., 1990). The method makes use of a structural index in addition to producing depth estimates. The objective of the Euler deconvolution process is to produce a map showing the locations and the corresponding depth estimations of geologic sources of magnetic or gravimetric anomalies in a two-dimensional grid. In combination, the structural index and the depth estimates have the potential to identify and calculate depth estimates for a variety of geologic structures such as faults, magnetic contacts, dykes, sills, etc. The algorithm uses a least-square method to solve Euler's equation simultaneously for each grid position within a sub-grid.

A square window of predefined dimensions (number of grid cells) is moved over the grid along each row. At each grid point a system of equations are solved, from which the four unknowns (x, y as location in the grid, z as depth estimation and the background value) are obtained for a given structural index. Reid (1990) showed that for any homogenous, three-dimensional function f (x; y; z) of degree n:

$$f(tx, ty, tz) = t^n f(x, y, z) \quad (1)$$

In general, for a homogenous function of *x, y, z*... of degree *n*, it is always the case that

$$x\frac{\delta f}{\delta x} + y\frac{\delta f}{\delta y} + z\frac{\delta f}{\delta z} = nf \quad (2)$$

In geophysics, the function f(x, y, z) can have the general functional form:

$$f(x, y, z) = \frac{G}{r^N} (3)$$

Where

$$r^2 = (x - x_o)^2 + (y - y_o)^2 + (z - z_o)^2, \quad (4)$$

N is a real number (1, 2, 3...) and G is a constant (independent of x, y, z). Many simple point magnetic sources can be described by equation (3),
Where (x_o; y_o; z_o)is the position of the source whose field F is measured.

The method of using spectral analysis in-depth determination is based on the principle that a magnetic field measured at the surface can be considered the integral of magnetic signatures from all depths (Opara, 2011). The power spectrum computes the thickness of the sedimentary basin and that of the crustal Moho depth (Spector and Grant, 1970).

Given a residual magnetic anomaly map of dimension L x L digitized at equal intervals, the residual intervals and total intensity anomaly values can be expressed in terms of double Fourier series expansion, which is given by:

$$T(x,y) = \sum_{n=1}^{N}\sum_{m=1}^{M} P_m^n\,[\cos(\tfrac{2\pi}{l})(nx+my)] + Q_m^n \sin[(\tfrac{2\pi}{l})(nx+my)] \qquad (5)$$

where: lis the dimension of the block, $P_m^n and Q_m^n$ are the Fourier amplitudes, while N, M represent the number of grid points along the x and y directions respectively. Equation (5) can be combined into a single partial wave thus:

$$\cos[(\tfrac{2\pi}{l})(nx+my)] + Q_m^n \sin[(\tfrac{2\pi}{l})(nx+my)] = C_m^n \cos[(\tfrac{2\pi}{l})(nx+my) - \delta_m^n] \quad (6)$$

Where$(P_m^n)^2 + (Q_m^n)^2 = (C_m^n)^2 and \delta_m^n$ is the appropriate phase angle. Each (C_m^n) is amplitude of the partial wave.The frequency of this wave is given by

$$F_m^n = \sqrt{n^2+m^2} \qquad (7)$$

The filtered Reduced To Equator (RTE) as shown in figure 5 from the crustal field map was divided into eight square grids and each window grid was 27.5 x 27.5 km in size (fig.6). The estimation of the Curie point depth was based on spectral analysis of the reduced to equator data. To minimize the effect of frequency noise caused by tiny structures near ground surface, the RTE anomaly map was upward continued to 15km to determine the regional field at curie point isotherm. Bhattacharyya and Leu (1975) presented that depth to bottom (z_b) of a magnetic source body could be estimated using two methods. Firstly, by estimation of depth to the centroid (z_0) and secondly, estimation of depth to the top (Z_t) of the magnetic sources which was quantitatively computed.
The lower bound (Z_b) of the magnetic source corresponding to Curie point depth was derived from the equation given by Bhattacharyya and Leu (1975) as:

$$Z_b = 2Z_o - Z_t \qquad 1$$

The geothermal gradient (dT/dZ) between the earth and the Curie point depth (Z_b) was defined by the equation:

$$\frac{dT}{dZ} = \frac{580℃}{Z_b} \qquad 2$$

Where 580°C is the Curie temperature (since granite is an igneous rock hence the curie temperature of igneous rock, 580°C was utilized) at which ferromagnetic minerals are converted to paramagnetic minerals (Rowland & Ahmed, 2018). The geothermal gradient was related to heat flow (q) using the formula:

$$q = \lambda\left(\frac{dT}{dZ}\right) = \lambda(\frac{580℃}{Z_b}) \qquad 3$$

Where λ is the coefficient of thermal conductivity.
A thermal conductivity of 2.5 mWm^{-2} as the average value for igneous rocks was used to compute the subsurface heat flow. The data so obtained from the computations was used to generate the Curie isotherm depth, heat flow and geothermal gradient map.

RESULTS

The Total Magnetic Intensity map shows values ranging from 32919.5 to 33083.5 nT as shown in figure 3 while Figure 4 shows the residual magnetic values ranging from -392.5 to -171.6 nT. The reduced-to-equator (RTE) map shows magnetic intensity values ranging from -388.9 to -177.1 nT, Figure 5. The Standard Euler solution for contacts (0.0) as shown in Figure 6 revealed a depth range of -60.2 to 318.3 meters and, with isolated cluster of solutions and this indicate that magnetic contacts are not a dominant geological feature. The depth estimation for a structural index of 1.0, figure 7 implies to a geologic model of dyke and sill structures as sources and this has dense clustering of solutions in the range of -200.7 to 762.2 metres with an uncertainty of the order of 661.5±100. It is therefore revealed that sills/dykes are dominant geological features in the study area as the clusters of solutions are in most part of the map especially around the northeastern and southeastern parts of the map.

For structural index 2 (horizontal cylinders/pipes), the estimated depth ranges from -206.3 to 1167.0 metres, figure 8. Several clusters of solutions were observed all over the map of the study area and horizontal cylinders/pipes are therefore observed to be dominant structural/geological feature in the study area. Structural index 3 (Spheres) as shown in figure 9 revealed a concentration of clusters of solution at the northeastern and southeastern parts. There is also a concentration of the cluster of solutions representing spheres around Abuja, Suleja and Gwagwalada area. The depth of the interpreted cluster of solutions varies between -151.0 to 1588.0 metres.

The values of depth to Top (Z_t), Centroid (Z_0), Basal (Z_b), Geothermal gradient and Heat flow over Abuja sheet 186 and Gitata sheet 187 are presented in Table 1. The depth to the Centroid (Z_o) ranges from 11.60 to 13.56 km, while the depth to the top boundary (Z_t) of magnetic sources ranges from 0.311 to 2.16 km (below sea level) and the computed curie / basal depth obtained using equation 17 ranges from 22.89 to 25.64 Km as shown in Table 1. The Z_o is due to magnetic sources within the basement while the Z_t is due to magnetic sources within the sedimentary section. In other words, Z_o and Z_t reflect magnetic sources due to deep and shallow seated features. Z_C is a true reflection of Precambrian magnetic basement bodies, while Z_t possibly depicts magnetic effect due to short-wavelength that is, shallow sources.

It is observed that the curie depth in the Southern part of the study area is the lowest (shallow depth) and perceived to be the crystalline basement area due to the upwelling of magma during the tertiary period ranging from 22.8 to 23 km while the highest curie depth (25.6 to 25.8km) is found in the Northern part of the study area. The average heat flow and geothermal gradients obtained in the study area are 59.32mWm-2 and 23.72^{0}C km^{-1} respectively, Table 1

Table 1: The values of depth to Top (Z_t), Centroid (Z_0), Basal (Z_b), Geothermal gradient, and Heat flow over Abuja sheet 186 and Gitata sheet 187.

S/No	Spectral Block	Longitude		Latitude		Centroid depth Z_0 (Km)	Depth to Top Z_t (Km)	Curie depth Z_b(Km)	Geothermal gradient. ($^0C\ km^{-1}$)	Heat flow (mWm^{-2})
		X_1	X_2	Y_1	Y_2					
1	B1	7.0	7.25	9.25	9.5	13.40	1.16	25.64	22.62	56.55
2	B2	7.25	7.5	9.25	9.5	13.18	0.89	25.47	22.77	56.93
3	B3	7.5	7.75	9.25	9.5	12.16	0.691	23.63	24.55	61.36
4	B4	7.75	8.0	9.25	9.5	13.56	2.16	24.96	23.24	58.09
5	B5	7.0	7.25	9.0	9.25	12.70	0.99	24.41	23.76	59.40
6	B6	7.25	7.5	9.0	9.25	11.60	0.311	22.889	25.34	63.35
7	B7	7.5	7.75	9.0	9.25	12.49	0.712	24.268	23.80	59.75
8	B8	7.75	8.0	9.0	9.25	13.09	1.68	24.50	23.67	59.18
Average						12.77	1.07	24.47	23.72	59.32

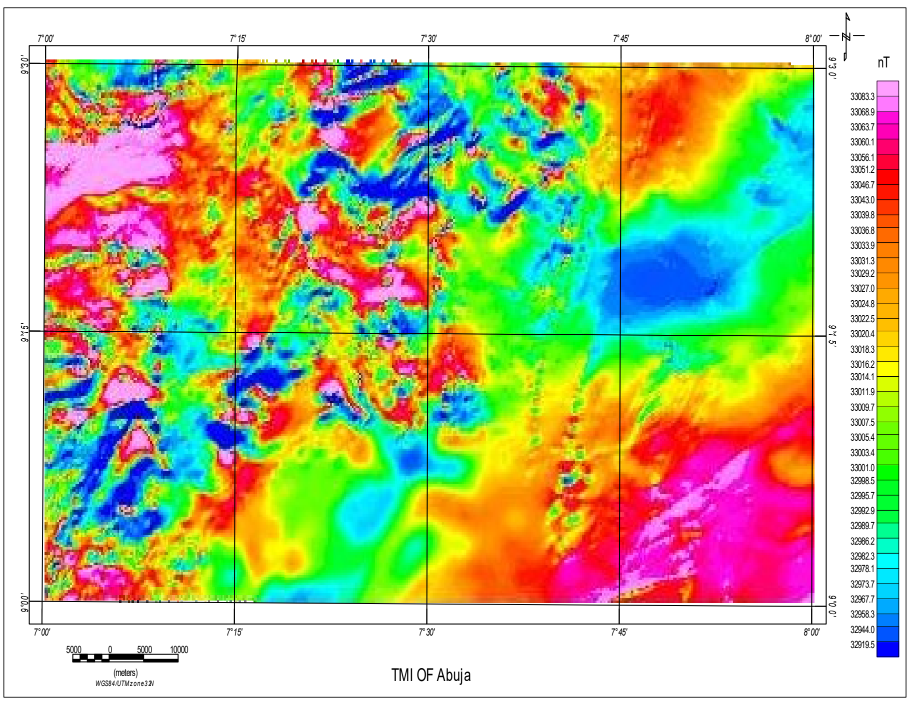

Figure 3: Total Magnetic Intensity map of Abuja sheet 186 and Gitata sheet 187 (Source: Nigeria Geological Survey Agency (NGSA), 2009).

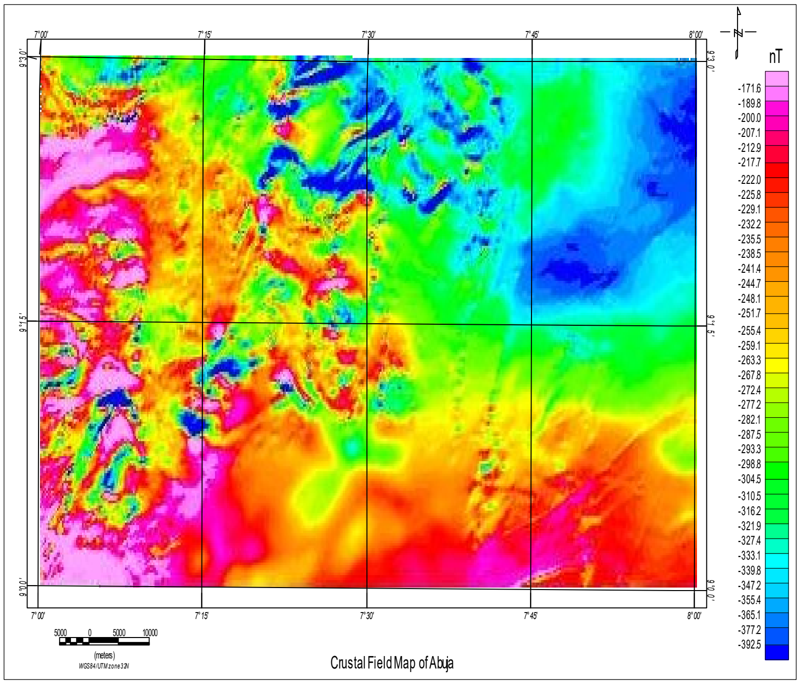

Figure 4: Residual or Crustal Field Map of Abuja sheet 186 and Gitata Sheet 187

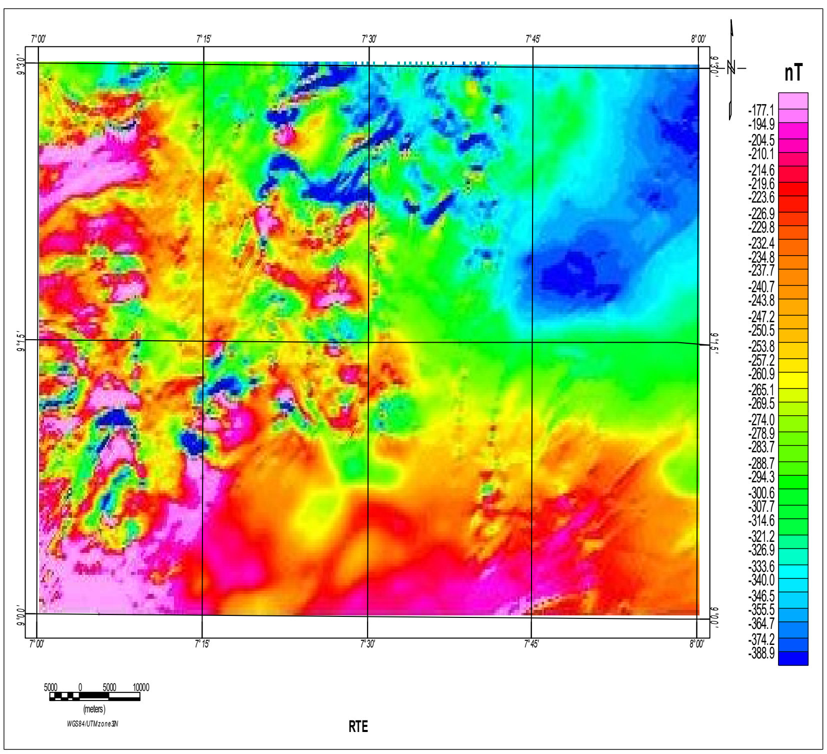

Figure 5: Reduced to equator map of Abuja sheet 186 and Gitata sheet 187.

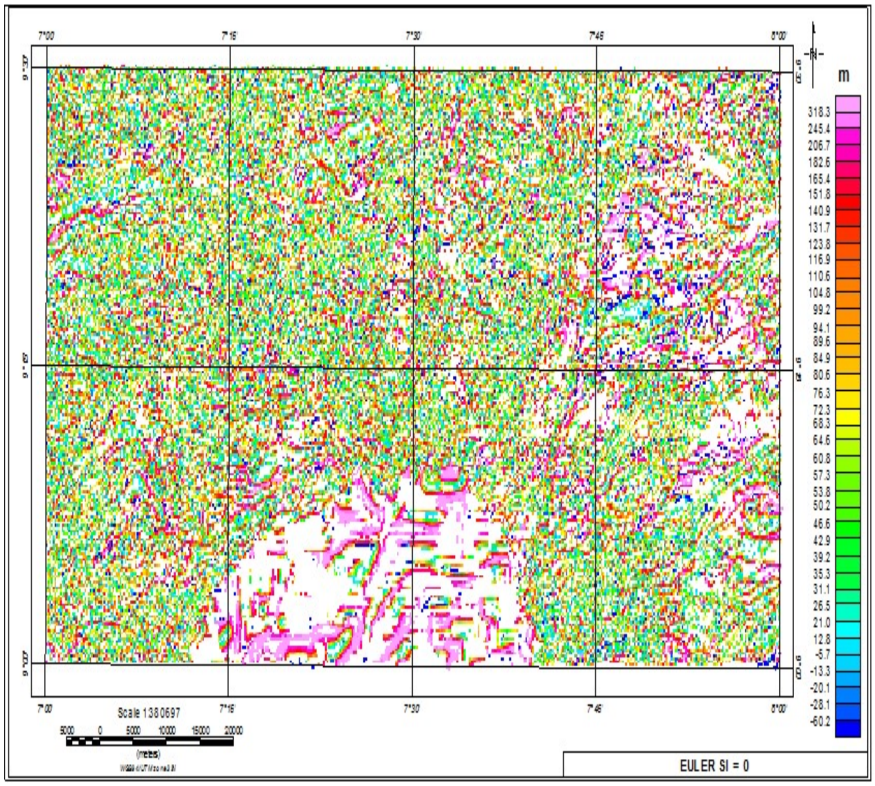

Figure 6: Euler map of Abuja sheet 186 and Gitata sheet 187 (SI = 0).

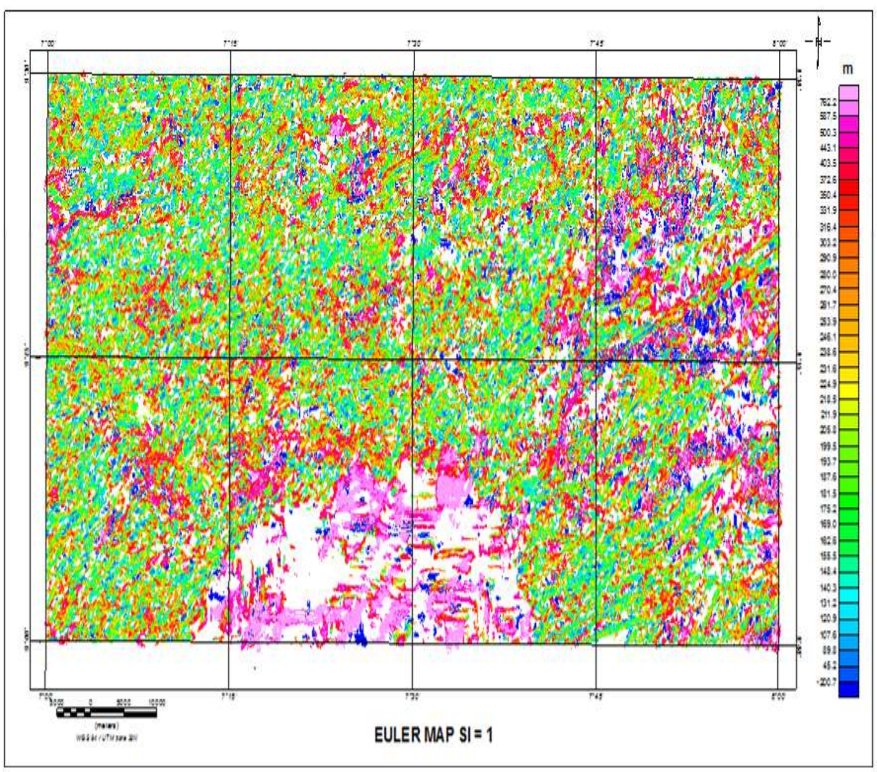

Figure 7: Euler map of the Abuja sheet 186 and Gitata sheet 187 (SI = 1).

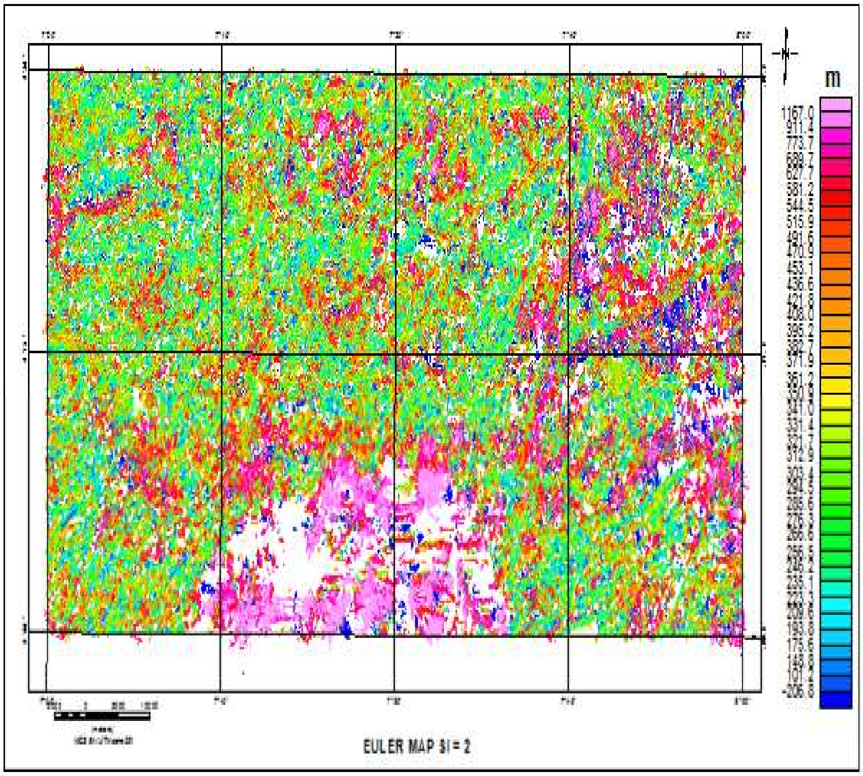

Figure 8: Euler map of Abuja sheet 186 and Gitata sheet 187 Area (SI = 2).

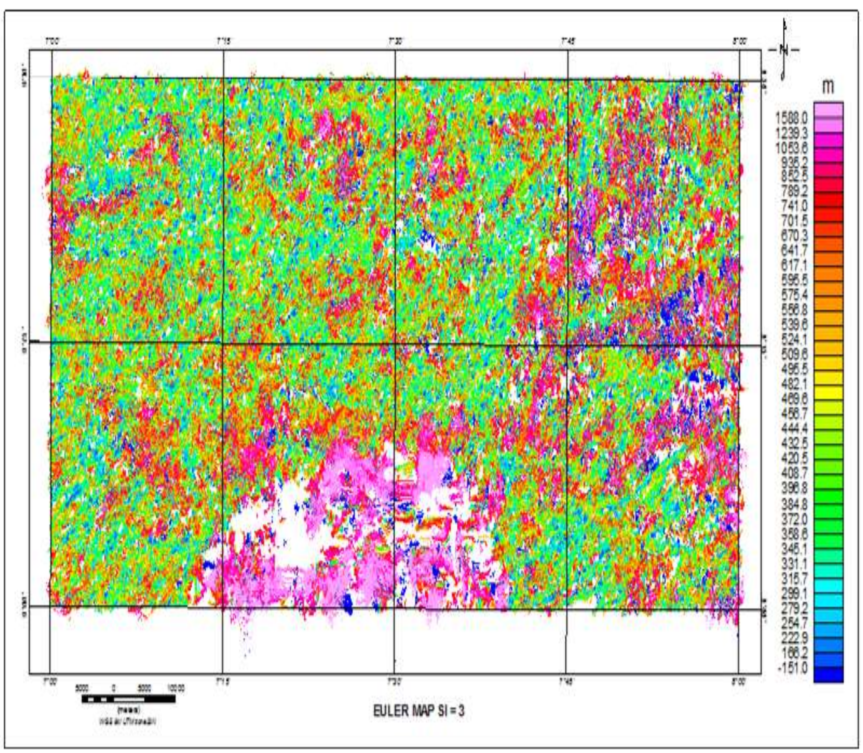

Figure 9: Euler map of Abuja sheet 186 and Gitata sheet 187 (SI = 3)

DISCUSSION

The Standard Euler solution for contacts (0.0) as shown in Figure 6 revealed a depth range of -60.2 to 318.3 m with an isolated cluster of solutions and this indicates that magnetic contacts are not a dominant geological features. The depth estimation for a structural index of 1.0 Figure 7 implies to a geologic model of dyke and sill structures as sources, and this has a dense clustering of solutions in the range of -200.7 to 762.2 m. It is therefore revealed that sills/dykes are dominant geological features in the study area as the clusters of solutions are in most part of the map especially around the northeastern and southeastern parts of the map.

For structural index 2 (horizontal cylinders/pipes), the estimated depth ranges from -206.3 to 1167.0 metres Figure 8. Several clusters of solutions were observed all over the map of the study area and horizontal cylinders/pipes are therefore observed to be dominant structural/geological feature in the study area. Spheres (3.0) as shown in figure 9 revealed a concentration of clusters of solution at the northeastern and southeastern parts. There is also a concentration of the cluster of solutions representing spheres and the depth of the interpreted cluster of solutions varies from -151.0 to 1588.0 m.

In consideration of the fact that a structural index that is too low gives depths that are too shallow and one that is too high gives estimates that are too deep (Reid et al., 1990), the structural indices of 2.0 and 3.0 are considered too high and cannot be explicitly correlated with known source bodies in the study area, hence the corresponding solutions were disregarded. However, a euler depth range of -60.2 to 318.3 metres (figure 6). Comparing these depth estimates with the information inferred from the spectral analysis result, there is a positive correlation between the results from both depth estimation methods.

The depth to the Centroid (Z_o) ranges from 11.60 to 13.56 km Figure 11, while the depth to the top boundary (Z_t) of magnetic sources ranges from 0.311 to 2.16 km (below sea level) and the computed curie / basal depth ranges from 22.89 to 25.64 Km Table 2 . The Z_o is due to magnetic sources within the basement while the Z_t is due to magnetic sources within the sedimentary section. In other words, Z_o and Z_t reflect magnetic sources due to deep and shallow seated features. Z_C is a true reflection of Precambrian magnetic basement bodies while Z_t possibly depicts magnetic effect due to short-wavelength (shallow) sources. It is observed that the curie depth in the Southern part of the study area is the lowest (shallow depth) and perceived to be the crystalline basement area due to the upwelling of magma during the tertiary period ranging from 22.8 to 23km while the highest curie depth (25.6 to 25.8km) is found in the Northern part of the study area.

The direction of the magnetic anomalies cannot be over-emphasised due to its significant in structural analysis and interpretation. The anomaly trends and TMI values reported by Ajakaiye, Hall and Millar (1985) are mostly in the NE-SW directions and ranges from 32750 to 32900nT respectively, which correspond with the tectonic trend directions and magnetic values observed in this study. The Curie point depth in conjunction with geothermal gradient and heat flow values revealed a distinct inverse relationship except between heat flow and geothermal gradient that is inversely proportional. In most part of the study area, heat flows were found to be less than 65 mWm^{-2} (Figure 12) while geothermal gradients were found to be less than 30 $^{\circ}C\ km^{-1}$ Figure 13. This implies that the heat flows and geothermal gradients in the study area are not uniform, which possibly indicates that the magma conduits were randomly distributed.

The average heat flow and geothermal gradients obtained in the study area are 59.32 mWm-2 and 23.72 ˚C km^{-1} respectively Table 1. These values may be considered typical of the continental crust. The heat flow and geothermal gradient are significantly high in the South-western area, which corresponds with the area of shallow curie depth Figure 11. Such heat flow values are suggestive of anomalous geothermal conditions and are recommended for detailed geothermal exploration.

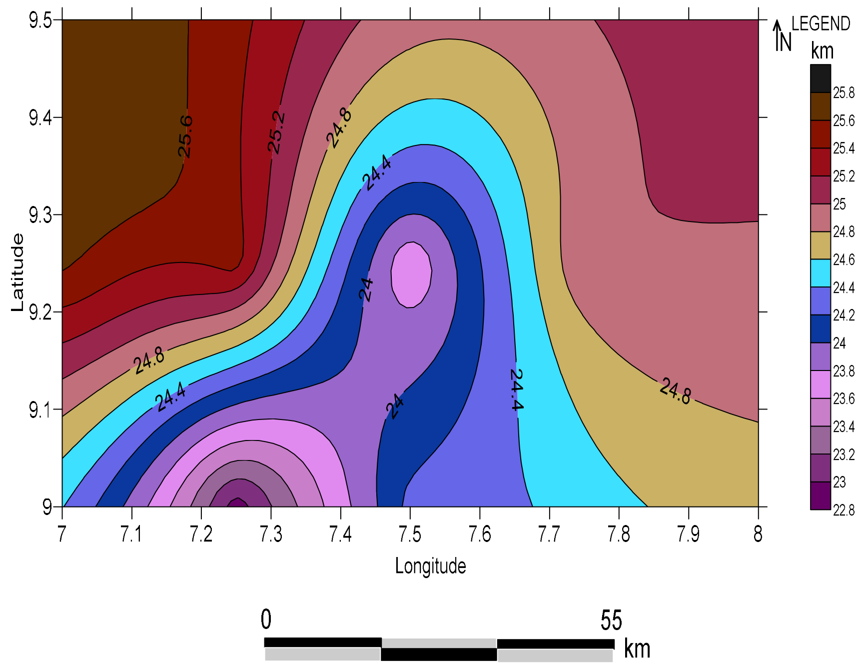

Figure 11: Curie depth point map of Abuja sheet 186 and Gitata sheet 187.

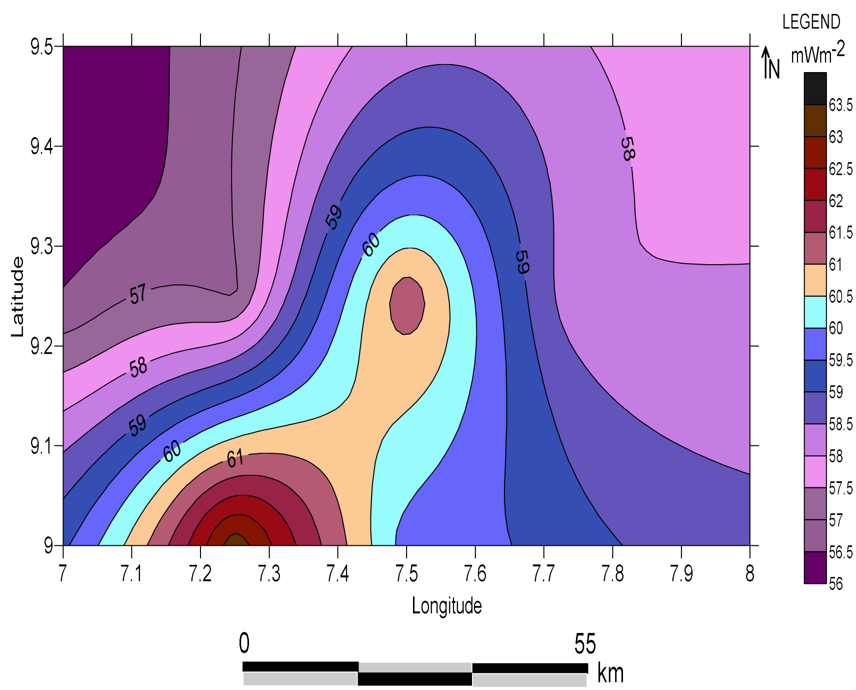

Figure 12: Heat flow map of Abuja sheet 186 and Gitata sheet187

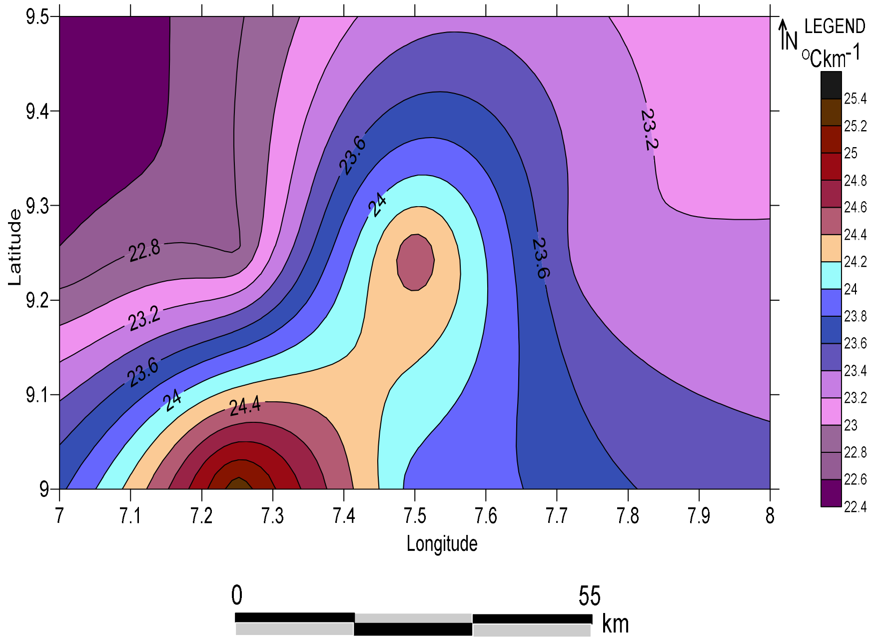

Figure 13: Geothermal gradient map of Abuja sheet 186 and Gitata sheet 187

CONCLUSION

The Crustal field anomalies observed were in the form of closures which can be said to be circular features, long narrow anomaly and dislocation, mostly around northwestern and southwestern parts of the study area. The circular patterns are usually associated with granite intrusion or ore bodies, while narrow patterns are frequently due to dykes, tectonic shear zones and long ore bodies. Euler deconvolution method is best suited for anomalies caused by isolating and multiple anomalous sources. The method is applied to a long profile of aeromagnetic measurements, located over Abuja and Gitata areas. The anomalous features of the field example are simple feature and located at shallow depths. The equivalent curie depth obtained ranges from 22.89 to 25.64 Km. It is observed that the curie depth in the southwestern part of the study is shallow ranging from 22.8 to 23 km compared to the other part of the study area. The shallow Curie depth observed could be as a result of the intruded Older Granite unit in the region. In most part of the study area, heat flows were found to be less than 65 mWm-2 while geothermal gradients were found to be less than 30 ^{0}C km$^{-1.}$ This implies that the heat flows and geothermal gradients in the study area are not uniform, which possibly indicate that the magma conduits were randomly distributed. The average heat flow (59.32mWm-2) and geothermal gradients (23.72^{0}C km^{-1}) values may be considered as typical of the continental crust. The heat flow and geothermal gradient are significantly high in the South-western area which corresponds with the area of shallow curie depth. Such heat flow values are suggestive of anomalous geothermal conditions.

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