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Geothermal Energy Potential in North Central Nigeria

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ABSTRACT

This research focuses on using geothermal parameters of Curie point depth, geothermal gradient and heat flow from spectral techniques of aeromagnetic data in finding the possible geothermal potential zone existing around parts of North central Nigeria to solve the energy –related challenges facing the country. The study region is confined by latitude 9.00º to 10.00º N and longitude 7.00º to 9.00º E, with an estimated total size of 24, 200 km^2. The study used a qualitative and quantitative approach to examine depth estimates from the spectral analysis of the magnetic anomalies. The Total magnetic intensity map was divided into twenty - eight overlapping blocks, each block was subjected to spectral analyses to obtained centroid depth (Zo) and depth to top of basement (Zt) obtained from the plots, were used to calculate the Curie point depth (CPD), which was then used for computation of geothermal gradient and heat flow of the area. The results computed shows that, Curie Point Depth (CPD) depth, ranged from 3.449 km and 19.31 km with an average depth of 9.196 km, The geothermal gradient ranged between 30.03 ºCkm^{-1} to 168.16 ºCkm^{-1} with average of 70.98 ºCkm-1 while the heat flow ranged from 176.24 mWm^{-2} to 262.77 mWm^{-2} with an average value of 178.17mWm^{-2} respectively. It was observed from the contour maps that the highest Curie Point Depth is located at the southern part at a depth of 18.5 km, while the northern part has the lowest Curie Point Depth at a depth of 14.5 km which corresponds to Gitata and Naraguta areas. The findings indicate that the research location is unsuitable for geothermal energy due to the high anomalous nature of heat flow.

Keywords:
Aeromagnetic data,
Curie Point,
Geothermal gradient,
Heat flow.

INTRODUCTION

This study uses high resolution aeromagnetic data to determine Curie-point depths (CPD), geothermal gradients, and subsurface heat flow anomalies for assessing geothermal potential in North Central Nigeria. The high-resolution aeromagnetic data were gathered from the Nigerian Geological Survey Agency (NGSA) as part of an aircraft magnetic survey conducted between 2005 and 2009. Several studies have demonstrated that regional magnetic data may be utilized extensively to identify the thermal structure of the Earth's crust in a variety of geological contexts (Nwankwo and Shehu, 2015). The Curie point (bottom of magnetic source) is the depth at which rocks lose their ferromagnetic characteristics when temperatures rise in the crust (Tanaka et al., 1999; Bansal et al., 2011). Geothermally active locations are likely to have shallow Curie point depths (Nuri et al., 2005). Curie point temperature varies by area, depending on the geology and mineralogical composition of the rocks. As a result, shallow Curie point depth (CPD) is typical in areas with geothermal potential, youthful volcanisms, and thin crust (Aydin and Oksum, 2010). At temperatures over CPT, thermal agitation of ferromagnetic rock minerals leads to the spontaneous alignment at which ferromagnetic materials become completely paramagnetic (Nwankwo and Sunday, 2017). The study of changes in an area's Curie-point depth can give useful information about the regional temperature distribution at depth as well as the potential for subsurface geothermal energy (Tselentis, 1991). The gradual change in temperature is geothermal gradient. Measurements have shown that a region with significant geothermal energy is characterised by an anomalous high temperature gradient and heat flow (Akinnubi and Adetona 2018). Geothermal energy varies from all other renewable energy resources, giving it an advantage. Geothermal energy is the energy stored in the earth's extreme heat that constantly radiates outward from deep within. It may be accessible and utilized by drilling for oil and gas. Geothermal energy, as compared to other renewable sources, is a massive, underutilized heat and power resource that emits little or no greenhouse gases (Dipippo & Renner, 2014). The hunt for geothermal resources focuses on places of the earth's crust where geologic processes have elevated temperatures close to the surface, allowing the heat contained to be harnessed. Such regions contain fractures and thinner crust, which allow magma to rise to the surface as lava as a result of volcanic activity inside the earth (Whitmarsh 2001). Geothermal energy is unique among renewables in that it can provide steady electricity all year round, unlike solar and wind power, which must wait for the sun to shine or the wind to blow. In some places of Nigeria, there is geological and geophysical evidence, as well as the presence of warm springs in the southwest (Ikogosi) and hot springs in the north central (Wikki), which are excellent indicators of geothermal energy potential. This study aims to provide insight into the study area's geothermal energy potential as an alternative source of sustainable power production by identifying and delineating areas with favorable geothermal resource.

Location and the Geological Setting of the Study Area

The study region is located in north central Nigeria (Figure 1). It is bounded by latitude 9.00º to 10.00º N and longitude 7.00º to 9.00º E, with an estimated total area of 24,200 km^2. The study area involves eight (8) aeromagnetic data sheets, namely Bishini, Kachia, Kafanchan, Naraguta, Abuja, Gitata, Jamaa, and Kurra. These data were obtained from the Nigeria Geological Survey Agency. The research region is located in the Precambrian Basement, which accounts for approximately 50% of Nigeria's entire surface. The Nigerian Basement Complex (Figure 1) is part of the Pan African mobile belt, located between the Congo Craton and south of the Taurage Shield (Obaje,2009). It consists of the following lithostructural units: The Migmatite-Gneiss Complex (MGC), Metasedimentary and Metavolcanic Rocks (Schist Belt). Pan-African granitoids (Older Granites), undeformed acid and basic dykes. The 600 Ma Pan African Orogeny influenced the Nigerian basement, which now occupies the reactivated zone formed by plate collision between the passive continental edges (Burke and Dewey, 1972; Dada, 2006). Late tectonic emplacement of granites and granodiorites, as well as accompanying contact metamorphism, marked the end of this formation. The Basement Complex is separated into four areas: the Migmatite-Gneiss-Quartzite Complex, the Schist Belt, the Older Granites, and the Undeformed Acid and Basic Dykes (Obaje, 2009). Migratite gneisses, schist, quartzites, and minor amphibolies form the foundation of the Kwoi region. These metasedimentary rocks have been intruded by granitic rocks spanning from the Pan-African to Jurassic suites, resulting in undulating rolling whalebacks. The geological map of the study area is shown in figure 2.

Figure 1: Geology Map of Nigeria Showing Study area (NGSA 2006**)**

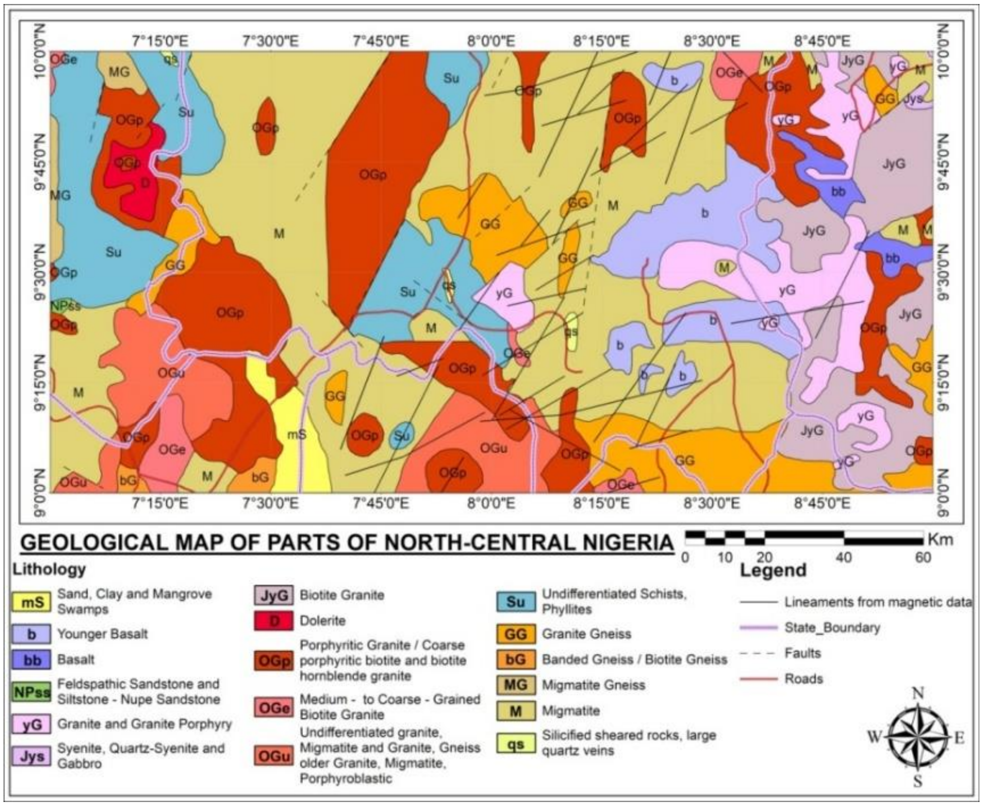

Figure 2: Geological Map of the Study Area Adopted from Nigeria Geological Survey

MATERIALS AND METHODS

The aeromagnetic data used in this study were obtained from Nigeria Geological Survey Agency. Eight aeromagnetic maps with sheets number 165, 166, 167, 168, 186, 187, 188 and 189 covering the study area within parts of North Central Nigeria were acquired from the Nigeria Geological Survey agency (NGSA). These maps were obtained as part of the nationwide aeromagnetic survey of 2009 sponsored by the NGSA. The data were acquired along a series of NE-SW flight lines with a spacing of 500 m and average flight elevation of 200 m and an average flight height of 80 m above the ground, while tie lines occur at about 2000 m intervals. These data were processed and merged together into a common dataset. The study area covered estimated total area of 24, 200 km^2 with latitude 9. 00^o to 10. 00^o N and longitude 7.00^o to 9.00 ^{o} E.

The total magnetic intensity data was processed and divided into twenty-eight overlapping blocks to carry out spectral analysis to obtain the curie point depth (CPD) of the study area. Oasis Montaj software and Mat lab were used for the analysis. In this study, the spectral analysis was made using interactive Oasis Montaj, version 8.4 which enables two dimensional frequency domain processing of potential field data. Production of Total Magnetic Intensity (TMI) map using Oasis Montaj software was done, separation of the regional and residual anomalies, and division of TMI map into twenty-eight blocks was performed, by performing spectral analysis on each blocks to evaluating the depth to the magnetic source and estimating the geothermal gradient and heat flow. Bhattacharyya and Leu (1975 and 1977) to develop the method to determine the bottom depth of magnetized bodies (Z_b). the centroid depth from the slope of the long wavelength (Z_o) and the depth to top of the magnetized body (Z_t) were evaluated.

Total magnetic intensity map (Fig. 3) was divided into twenty-eight spectral blocks (Spectral block 1-4) of overlapping sections. The spectral data obtained were exported to Microsoft excel worksheets where wave number and log of energy spectrum were extracted for plotting. The spectral blocks energy files were used as input files into spectral program plot (SPP) developed by MATLAB. The data were plotted using a program written in Matlab to deduce the centroid depth from the Slope of the long wavelength (Zo) and the Depth to top of the magnetized body (Zt).

The power spectrum, P, for a 2D assemblage of bodies can be written as follow (Spector and Grant, 1970; Blakely, 1995).

$$P(K_xK_y) = 4\lambda^2 C_m{}^2|\theta_m|^2|\theta_f|^2 e^{-2|k|Z_t}\left[1 - e^{-|k|(Z_b-Z_t)}\right]^2 \quad (1)$$

where P, is the power density spectrum of the Magnetization, K_x and K_y are the wave numbers in the x- and y- direction; Cm is proportionality constant, θ_m and

θ_f are the directional factors related to the magnetization and geomagnetic field respectively; and Z_t and Z_b are the top and bottom depths of the magnetic sources respectively. The equation can be simplified by noting that all terms except $|\theta_m|^2$ and $|\theta_f|^2$ are radially symmetric. The radial averages of θ_m and θ_f are constants. Hence, the radial average of P is:

$$P(k) = A_1 \ell^{-2|k|Z_t}\left(1 - \ell^{-|k|(Z_b - Z_t)}\right)^2 \quad (2)$$

where A_1 is a constant,k is the wave number andP|k| power spectral density Z_t and Z_b denote the depths to the top and bottom of the magnetic body respectively. CPD (Z_b) can be achieved in two stages Okubo *et al.* (1985) and (Nwankwo & Shehu, 2015). The centroid depth (Z_0) of the inmost magnetic source is appraised from the gradient of the lengthiest wavelength part of the spectrum divided by the wave number using the following equation:

$$\ln\left(\frac{P(k)^{1/2}}{k}\right) = A|k|Z_o \quad (3)$$

P(k) is the radially average power spectrum, and A is a constant and Z_o is the centroid depth of the magnetic sources (Tanaka and Matsubayashi, 1999). Secondly, the uppermost depth to the magnetic body is also derived from the gradient of high wave number portion of the power spectrum as follows:

$$ln\left(P(k)^{1/2}\right) - B|k|Z_t \quad (4)$$

Rom equation (4) B is a constant and Z_t is the depth to the top of the magnetic sources, Z_b is the depth to the bottom of the magnetization shown in equation 5:

$$Z_b = 2Z_o - Z_t \quad (5)$$

where Z_b is the depth to the bottom of magnetized body, Z_o is the centroid depth and Z_t is the depth to top of the magnetized body. Curie Point Depth(CPD) is achieved in three steps (i) dividing the TMI map into overlapping blocks, (ii) Computing the logarithm of power spectrum for blocks (iii) to calculated the basal depth using equation (5)

Heat flow is calculated using the equation bellow;

$$q = k\,\frac{dT}{dZ} \quad (6)$$

Where q is the heat flow, k is the thermal conductivity. The Curie depth is related with the Curie temperature for about (580°C) and thermal conductivity of 2.5 W/m°C^{-1}, as average for igneous rocks are used as standard in this work (Nwankwo *et al*; 2009). Tanaka, Okubo, and Matsubayashi (1999); Stampolidis *et al.,* (2005), The geothermal gradient (dT/dZ) between the Earth's surface and the Curie point depth (Z_b) is defined using the relation as follow;

$$\frac{dT}{dZ} = {\theta_c}/{Z_b} \quad (7)$$

dT/dZ is the thermal gradient,θ_c (580°) is the Curie temperature and $Z_b$is the Curie depth

RESULTS AND DISCUSSION

Total Magnetic Intensity and the Residual Maps

The total magnetic intensity (TMI) map of the area (Fig. 3) shows both positive and negative anomalies with susceptibilities values ranging from 33777.1 nT to 33460.3 nT. The map depicts the variance of highs and lows in magnetic signature. The high magnetic susceptibilities could be discovered in the north-eastern and north-western regions of the research area, which correspond to Lere, Kajuru, Toro, Bassa, Jema'a, Riyom, BarkinLadi, and ZangonKataf. These anomalies might be related to the existence of basalt in the region, as seen in Figure 2. Due to weathering of the basement rock and thick overburden, low magnetic signatures may be discovered in the south-western corner of the region, which corresponds to Gwagwalada, Abaji, Suleja, Gurara, Tafa, Bwari, Paikoro, Kagarko, and Municipal region Council. The area with low magnetic susceptibility values ranging from 33570.2 nT to 33632.4 nT shows alluvium deposits in the Muya, Kokona, and Akwanga areas.

Spectral Analysis

The Total Magnetic Intensity (Fig. 3) of the research region was split into twenty-eight overlapping blocks (Blocks 1-4) of magnetic sections. The TMI map was divided into spectral chunks of blocks using Oasis Montaj. The investigation was performed using a spectral program plot (SPP) created in MATLAB. Figure 4 depicts the graph of the logarithm of spectral energy against frequencies derived for blocks 1-4. Table 1 includes the predicted values for centroid depth and depth to the top of the magnetic body, Zo and Zt, respectively.

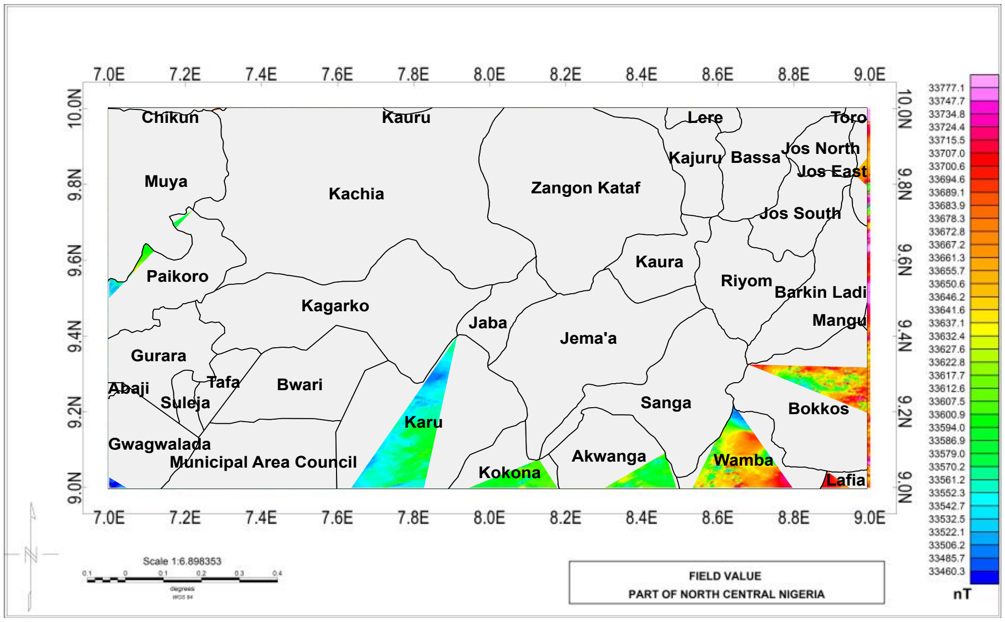

Figure 3: Total Magnetic Intensity of the Study Area

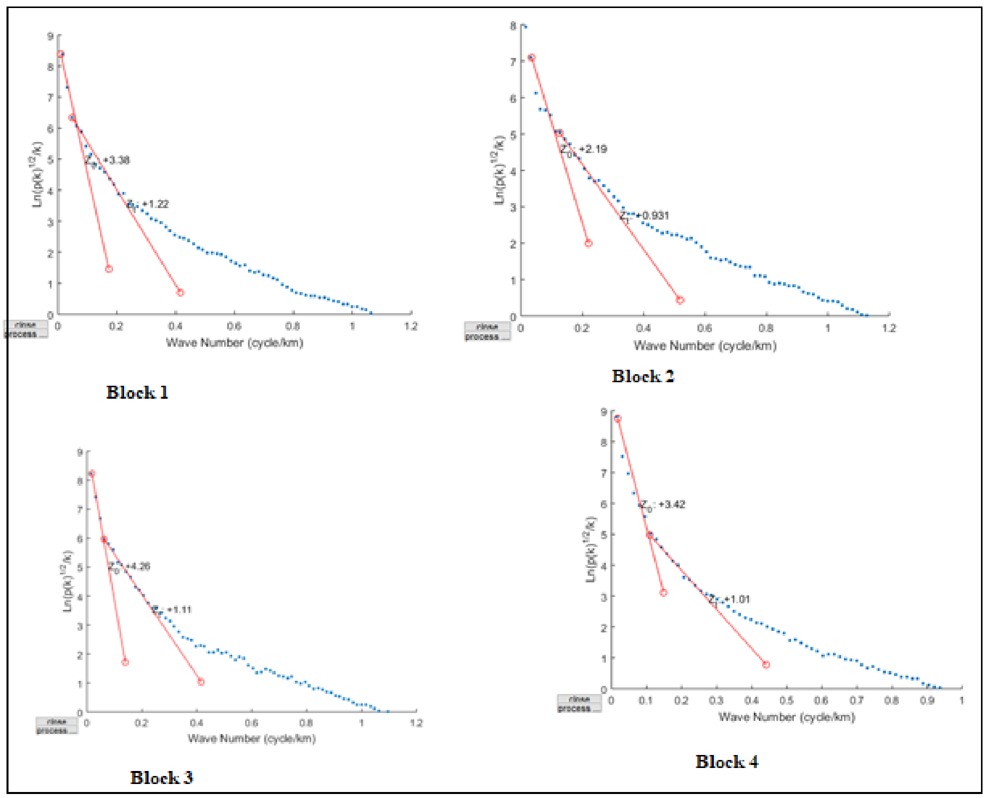

Figure 4: A Sample of Spectral Blocks 1-4 Showing the Logarithm of Spectral Energies against Frequencies Obtained for Block 1-4

Table 1: Estimated Curie Point Depth (CPD), Geothermal Gradients and Heat Flow for the 28 Blocks in the Study Area

Blocks	Long (Deg)	Lat. (Deg.)	Depth to Centroid (km)	Depth to Top (km)	Curie Depth (km)	Geothermal gradient. $^oC/Km$	Heat flow mWm^{-2}
1	7.25	9.75	3.38	1.22	5.54	104.69	262.77
2	7.5	9.75	2.19	0.931	3.449	168.16	422.09
3	7.75	9.75	4.26	1.11	7.41	78.2	196.46
4	8	9.75	3.42	1.01	5.83	99.48	249.70
5	8.25	9.75	3.93	1.28	6.58	88.14	221.24
6	8.5	9.75	3.98	1.25	6.71	86.43	216.95
7	8.75	9.75	7.22	1.39	13.05	44.44	111.55
8	7.25	9.583	4.64	1.23	8.05	72.04	180.84
9	7.5	9.583	4.86	0.991	8.729	66.44	116.77
10	7.75	9.583	4.67	0.945	8.395	69.08	173.41
11	8	9.583	5.82	1.21	10.43	55.60	139.57
12	8.25	9.583	4.18	1.26	7.1	81.69	205.04
13	8.5	9.583	4.29	1.28	7.3	79.45	199.42
14	8.75	9.583	8.47	1.34	15.6	37.17	93.32
15	7.25	9.416	3.39	1.42	5.36	108.20	271.60
16	7.5	9.416	7.52	1.31	13.73	42.24	106.03
17	7.75	9.416	10.3	1.29	19.31	30.03	75.39
18	8	9.416	5.44	1.2	9.68	59.91	150.39
19	8.25	9.416	5.14	1.36	8.92	65.02	163.20
20	8.5	9.416	4.49	1.08	7.9	73.41	184.27
21	8.75	9.416	6.04	0.857	11.223	51.67	129.71
22	7.25	9.25	5.69	1.12	10.26	56.53	141.89
23	7.5	9.25	5.0	1.35	8.65	67.05	168.300
24	7.75	9.25	5.66	1.41	9.91	58.52	146.90
25	8	9.25	5.38	1.3	9.46	61.31	153.89
26	8.25	9.25	5.71	0.992	10.428	55.61	139.60
27	8.5	9.25	5.83	1.43	10.23	56.69	142.30
28	8.75	9.25	4.65	1.04	8.26	70.21	176.24

Depth to Centroid of the Magnetized Body

The depth to centroid ranges from 10 km to 2 km (Fig. 5a), indicating that the depth to the centroid of the magnetized body is lowest in the north-west, corresponding to the Bishini area, and highest in the east and center, corresponding to the Gitata area. The depth to the top of the magnetic source ranges from 1.42 km to 0.86 km (Fig. 5b).

The Curie Point Depth (CPD) Map

The spectrum study of aeromagnetic anomalies in the region reveals that Curie point depth estimations (using equation 5) range from 3.449 km to 19.31 km, with an average of 9.196 km (Table 1). According to the literature (Tanaka et al., 1999; Elena and Udensi, 2012), CPD varies widely depending on geological environment and is shallower in volcanic and geothermal regions. CPDs in volcanic, tectonic, and related geodynamic settings are shallower than 10 km (Obande et al., 2014), the values between 15 and 25 km of Curie point depth are caused by island arcs and ridges, and values deeper than 25 km are caused by plateaus and trenches (Tanaka *et al*., 1999).

Figure 5c shows the curie point depth contour map. The southern section has the highest CPD at a depth of 18.5 km, while the northern part has the lowest CPD at a depth of 14.5 km, which corresponds to the areas near Gitata and Naraguta. Magnetic signals at this depth are attributed to variations in basement susceptibilities caused by intra-basement structures like faults and fractures.

The Geothermal Gradient Map

Figure 5d demonstrates that the geothermal gradient in ($^oCkm^{-1}$) represents the rate of depth-dependent temperature rise. The results demonstrate that geothermal gradients (Table 1) range from 30.03 $^oCkm^{-1}$ to 168.16 $^oCkm^{-1}$with an average of 70.98 $^oCkm^{-1}$. The higher values of geothermal gradient are found around the northern and southern parts of the study area.

The Heat Flow

The results (Table 1) reveal that the area's heat flow values (calculated using equation 6) range from 176.24 mWm^{-2} to 262.77 $mWm^{-2}$with heat flow contours depicted in Fig. 5e. Figure 5e shows values ranging from

80 to 420 mWm^{-2}, with an average of 178.17 mWm^{-2}The contour indicates low values of 80 mWm^{-2} to 260 mWm^{-2} in the east-southern region surrounding Gitata and Naraguta, and higher values of 420 mWm^{-2} to 280 mWm^{-2} in the far north of the area.

An abnormal (Anomalous) heat flow with depths ranging from 120 mWm-2 to 420 mWm-2 was recorded in the north-western half of the research region. The geothermal gradient (fig 5d) and heat flow contour maps (Fig 5e) are strongly connected, indicating that the majority of places with significant heat flow also have high geothermal gradients. High heat flow values are typically associated with volcanic and metamorphic environments due to their high heat conductivities. Furthermore, heat flow is greatly influenced by tectonically active places (Tanaka et al., 1999). Current research demonstrates that heat movement is highly reliant on geological conditions. Geothermal energy is also found in regions where foundation rocks with rather typical heat flow are covered by a substantial layer of thermally insulated sediments (Ofor and Udensi, 2014). It is possible that the research area's average high heat is due to tectonic activity. In thermally typical continental locations, the average heat flow is around 60 mWm-2; values between 80 and 100 mWm-2 indicate a good geothermal source; Values greater than 100mWm-2 indicate unusual geothermal conditions (Nwankwo and Sunday, 2017). In light of this, the average heat flow of 178.17 mWm-2 calculated in the research region corresponds to the Gitata and Naraguta areas, which have no indication of favorable geothermal potential.

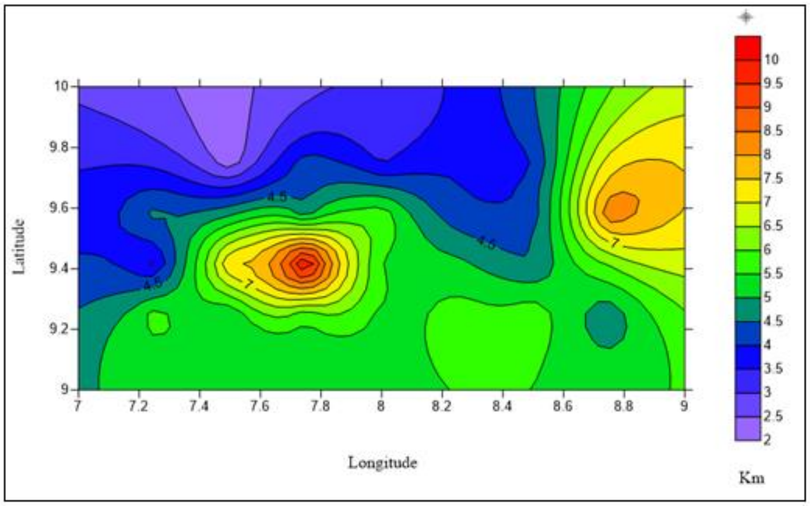

Figure 5a: Contour Map of the Depth to Centroid of the Magnetized Body

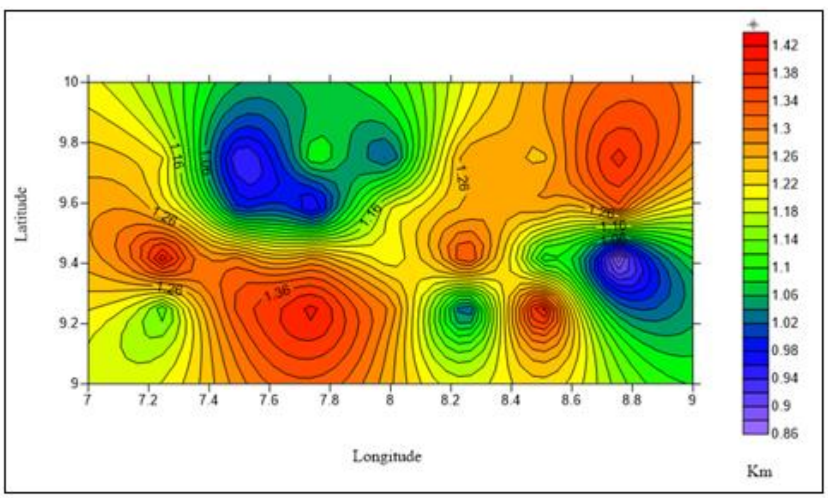

Figure 5b: Contour Map of Depth to Top of Magnetic Boundary

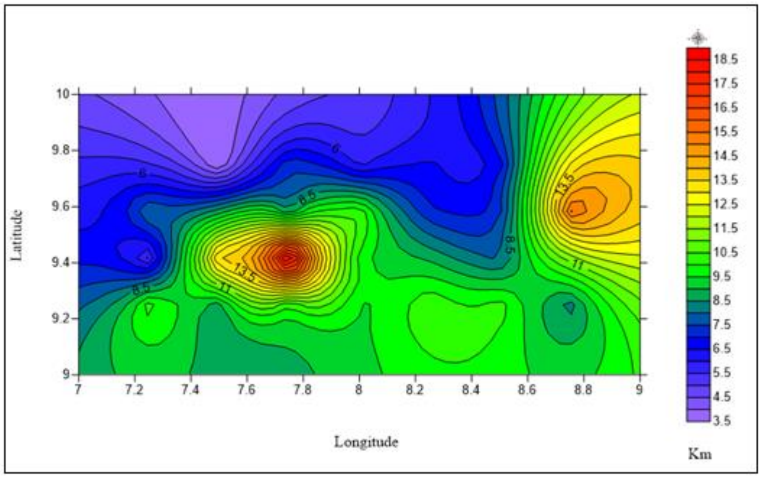

Figure 5c: Depth to Bottom of Magnetized Body (CPD) in Km

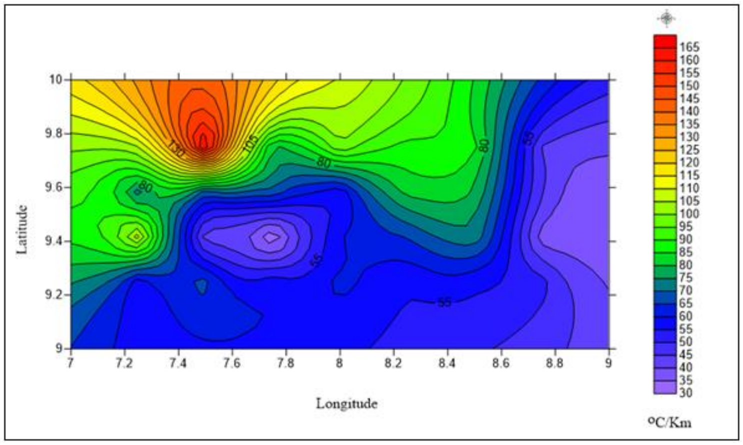

Figure 5d: Geothermal Gradient Map

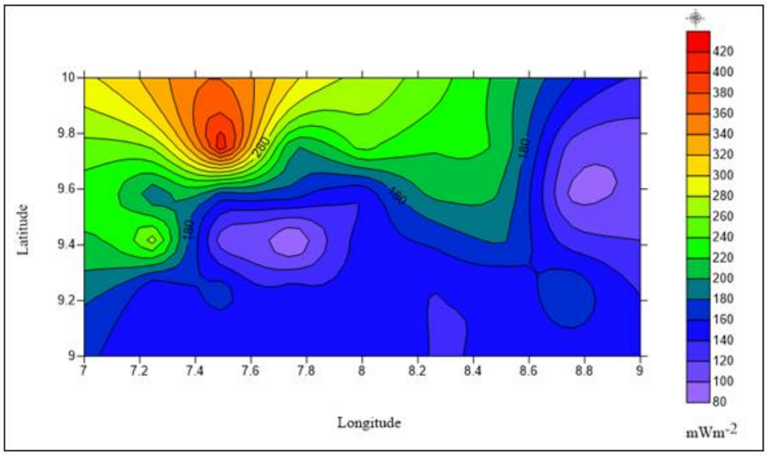

Figure 5e: Heat Flow Map

CONCLUSION

This paper shows the results of depth to centroid, depth to top, and Curie Point Depth CPD, geothermal gradient, and heat flow derived from spectrum analysis of aeromagnetic data from North Central Nigeria. The CPD depths obtained range from 3.5 km to 18.5 km, with an average of 9.196 km. The computed geothermal gradient in the studied region based on the CPD ranges from 30 to 165 $^{o}Ckm^{-1}$, with an average of 70.98 $^{o}Ckm^{-1}$. The heat flow values calculated from the geothermal gradient of the research region range from 80 mWm^{-2} to 420 mWm^{-2}, with an average of 178.17 mWm^{-2}. This study concludes that the area is not a suitable indication of geothermal energy potential due to abnormal heat flow and tectonic activity inside the study area.

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