

Interpretation of High Resolution Aeromagnetic Data to Determine an Alternative Source for Power Generation in Biu Plateau and Environs North Eastern Nigeria

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Abstract

Interpretation of High Resolution Aeromagnetic data was carried out to determine an Alternative Source of Power generation in Biu Plateau and Environs North Eastern Nigeria, with the aim of estimating the Curie point depth, Geothermal Gradient and Heat flow for geothermal exploration. The data used for this research work was obtained from the Nigerian Geological Survey Agency Abuja. Total intensity Aeromagnetic data used was processed using Computer software Oasis Montaj Version 8.2. The residual data was divided into four overlapping blocks, spectral analysis was performed on the four overlapping blocks where the depth to the top boundary (Z_t) and the depth to the centroid (Z_0) was obtained. The result obtained indicates that the depth to top boundary (Z_t) varies between 5.90 to 7.16 km with an average of 6.31 km. The depths Centroid varies between 10.5 to 11.50 km with an average of 10.9 km. Depth to curie points varies between 14.84 to 16.83 km with an average of 15.50 km. Using an empirical formula, Heat flow obtained varies between 86.16 to 97.71 $\text{mW}\cdot\text{m}^{-1}\cdot\text{C}^{-1}$ with an average of 93.83 $\text{mW}\cdot\text{m}^{-1}\cdot\text{C}^{-1}$ and the Geothermal gradient varies between 34.46 to 39.08 $^{\circ}\text{C}/\text{km}$ with an average of 37.53 $^{\circ}\text{C}/\text{km}$. Therefore, from the result obtained, it is clear that the study area is a good indicator for geothermal energy potential been a plateau and could be utilized for geothermal exploration of an alternative source for Power generation in Nigeria.

Keywords

Biu Plateau, Clean Energy, Geothermal Potentials, Power Generation, Power Spectrum and Cameroun Volcanic Line

1. Introduction

Energy is the power to push the industrialization and modernization forwards. The development and utilization of clean energy is what a country's competitive strength and comprehensive national power hinge on. Geothermal energy is an important kind of clean energy that is concealed beneath the Earth, which is as a result of the tectonic activities that either took place during the formation of the Earth or after the formation of the Earth [1]. The major sources of heat within the Earth include: heat of formation *i.e.* heat that was trapped within the Earth during its formation, heat as a result of disintegration of radioactive minerals within the Earth, heat generated from magmatic activities etc. [2]. These heat do emanate to the surface through fissures and fractures which usually forms hot springs as a result of groundwater that comes in contact with the heat source, example is the water spring in Ruwan Zafi in Lamurde local government area of Adamawa State [3]. This geothermal energy resource, if tapped, will be of great importance to the community and the entire country, which will also boost the existing power supply of the area [4]. For this energy resource to be explored for its wholesome benefits, different geophysical methods are used to identify its existence and to quantify its viability and its extent. The study area was chosen based on the fact that it forms part of Northern arm of Cameroon Volcanic line, which is believed to have a lot of recent intrusive. In this work, high resolution aeromagnetic data was used to assess the geothermal energy potentials of the area. However, the study is in line with the global movement towards the generation of low-carbon (clean) sustainable energy which is underway to help reduce global greenhouse gas emissions. This is because there is a serious need for the development of clean and renewable geothermal energy in the world today, both in the developed and the developing countries of the world including Nigeria.

This research involves the estimation of curie-depth point (CPD), geothermal gradients and subsurface heat flow anomalies for the assessment of geothermal potentials in Biu plateau and environs north eastern Nigeria using high resolution aeromagnetic data.

The method adopted in this work has been used by several authors in determining the potentials site for exploration of geothermal energy. These include the works of [5]-[11].

The study area is located between latitude 10°00' to 11°00'N and longitude 11°30' to 12°30'E (**Figure 1**).

Research has shown that, Nigeria is one of the largest economies in the sub-Saharan Africa, which is endowed with abundant energy resources (Clean renewable energy), when properly utilized, can provide sufficient power that can serve the whole country at large. Despite the abundant resources, it is one of the countries that provide the lowest electricity for its citizens in Africa and it really affects the economic growth of the country [12].

Nigeria in its efforts to venture into exploring renewable energy to improve its economy, the use of geothermal energy as an alternative source of clean energy

has remain the best source of power supply. Nigeria is recognized as one of the African countries with potential for geothermal energy. Surface manifestations of subsurface heat as springs and lava flows have been reported in both the sedimentary and the Precambrian Basement Complex area of Nigeria. Based on the finding of some authors, the deeper curie depth is associated with low heat flow while the shallow Curie depth is associated with high heat flow [13]. Measurements have shown that have shown that a region with significant geothermal energy is characterized by an anomalous high temperature gradient and heat flow [14]. It is therefore a known fact that, the temperature inside the earth directly controls most of the geodynamic processes that are visible on the surface [15].

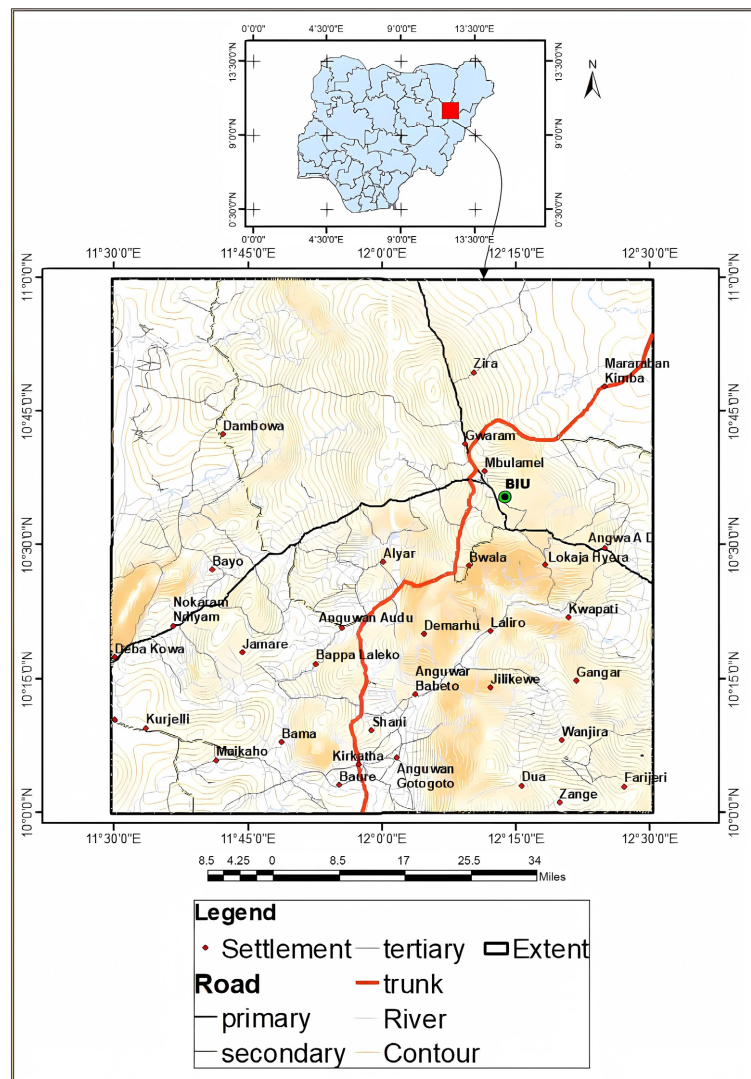


Figure 1. Location map of the study area.

2. Regional Geology and Tectonic Setting

The region forms part of the Pan-African mobile belt, the basement complex, which lies to the east of the West African Craton. The belt which is sandwiched

between Benin to the west and Cameroon in the east and includes the Beninian Gneisses of the internal zone of the Pan-African mobile belt as well as a vast expanse of reactivated high-grade Gneisses believed to be Achaean in age and a supra-crustal succession thought to be Paleo Proterozoic [16]. Two generations of granites can be identified and these are prominent within the basement rocks.

The older granites as termed by [17] range widely in composition and age from 450 Ma to 750 Ma [18]. The younger granites (Jurassic in age) are prominently distributed in the North Central Nigerian Basement and occur as ring complexes that form part of a wider province of alkaline and orogenic magmatism.

The study area lies within the northeastern Nigeria, located within the Hawal Massif. These rock assemblage according to the works of [19] and [20] who considered it as the largest component of the Nigerian basement complex. The Basement Complex also consists of rocks like Mica-Schist, Tremolite-Schist, Graphite-Schist, with occasional Marbles and Dolomites, Calc-Silicate rocks, Meta-Conglomerates and banded iron formation (BIF) and Precambrian granites including Porphyritic/Porphyroblastic Muscovite Granites, Biotite Granites, Hornblende-Biotite Granites, Non-Porphyritic/Non-Porphyroblastic Granites, Aplites, Granodiorites, Diorites, Quartz-Diorites, Syenites, Quartz-Enstatite Granites and Enstatite Granites (Charnockites).

Hawal Massif is a subdivision of the Nigerian Basement complex which is found between the Achaean blocks of West African Craton and the Congo Craton. Only little has been done on the account of the geology, stratigraphy, and the tectonic events of the Hawal massif. This basement rocks are emplaced within the Pan-African Mobile belt of Late Proterozoic (500 - 750 Ma) age [21]. The rock units composed dominantly of the massive granitic plutons in association with diorite and gabbro collectively termed "the Older Granites" which have been dated severally elsewhere at 500 - 750 Ma. Other rock units in the area are Migmatites and gneisses, which were dated as Achaean (2700 Ma) and Proterozoic, (2000 Ma) [22]. The granites are products of Late Proterozoic (Pan-African) events, and are characterized by high-grade metamorphism. It is important to note that, being part of the Pan African Mobile Belt [23], the Nigerian Basement Complex has also been intruded by the Ring complexes of Mesozoic age, around Jos area in central Nigeria. These complexes are overlain uncomfortably by cretaceous to quaternary sediments and these have given rise to the present sedimentary basins. Several Coarser granitic occurrences have been investigated and reported in Nigeria.

The geology of the study area is made up of basement complex rocks which are usually undifferentiated rocks. It is mainly made up of older granites and Migmatites gneisses with cretaceous and tertiary volcanic rocks. The mode of the spread of the tertiary to recent volcanic is very wide and the rocks in the study area belongs to the northern arm of Cameroon volcanic line which is believed to have a lots of intrusive and the volcanics which varies in composition ranging from basalts to trachyte and rhyolite. The Tertiary-Recent volcanic rocks in the study area consist of the basalts, trachyte, rhyolite, and newer basalts of northern arm of

Cameroon volcanic line. The gneiss-Migmatites complex is the most wide spread and occupies more than half of the area and is the oldest rock there. They are heterogeneous rock group, which is composed of gneiss, Migmatites of various origin and series of metamorphosed basic and ultrabasic rocks (Figure 2).

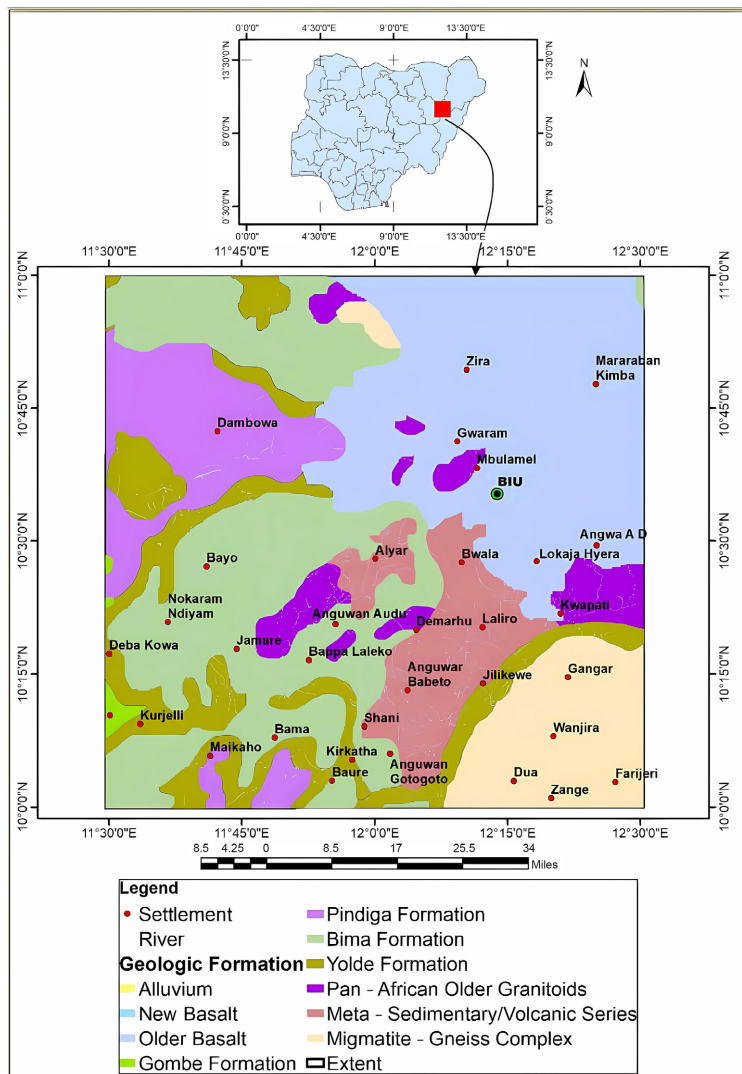


Figure 2. Geological map of the study area.

3. Materials and Methods

The high resolution aeromagnetic data used for this study was obtained digitally from the Nigerian Geological survey Agency [24], Abuja as Total Magnetic intensity(TMI) Map (Figure 3). The data was part of the survey conducted in 2010 by Messrs Fugro. The survey was carried out at 0.05 seconds magnetic data recording interval, at 80 m terrain clearance; flight line spacing was 500 meters at 135 degrees (NW-SE) flight line trend. Tie line spacing was 5000 meters at 225 degrees (NE-SW) tie line trend. Cesium vapor SCINTREX CS2 magnetometer was used for the survey. The geomagnetic gradient was removed using the International Geomag-

netic Reference Field formula (IGRF-10) Model. The data was generally plotted using Universal Transverse Mercator (UTM) projection method and WGS 1984 datum were also used. Grids mesh size of 125 meters (**Figure 3**). Geosoft Oasis Montaj version 8.2 and MATLAB programme was used for data processing and analysis.

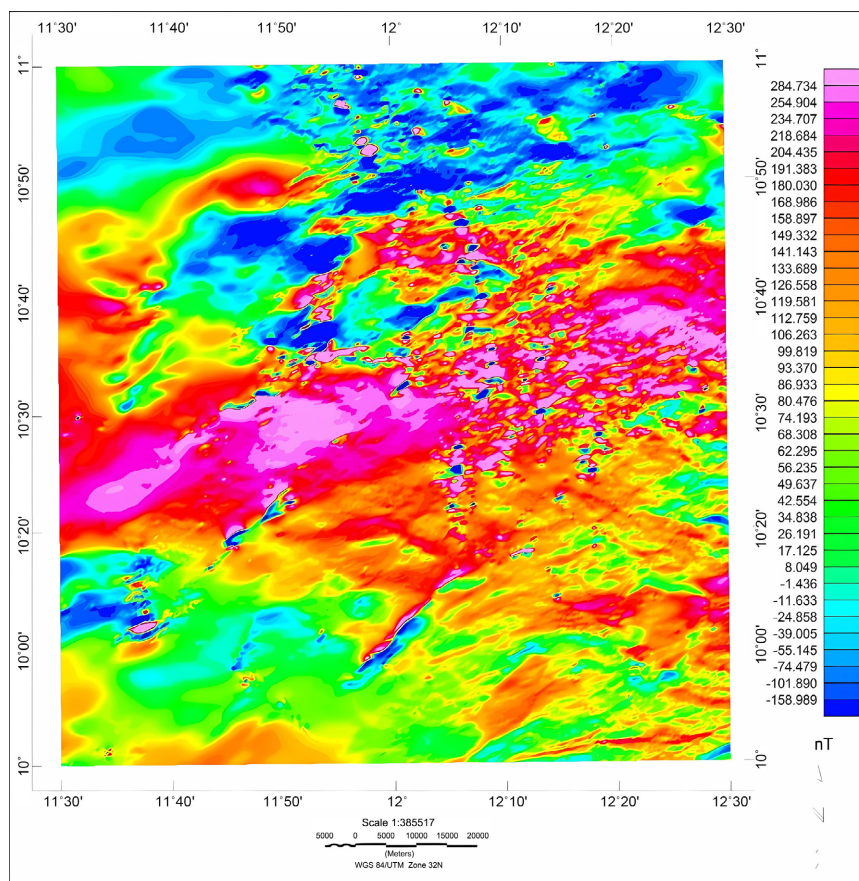


Figure 3. Total Magnetic Intensity (TMI) map of the study area.

4. Data Processing

4.1. Upward Continuation

The primary goal for upward continuation is to enhance the visibility of deeper, regional geological structures by attenuating the effects of shallow near surface features and cultural noise. Mathematically transforms magnetic field to a higher level. This process enhances long wavelength anomalies (associated with deeper structures). The high resolution aeromagnetic data was subjected to upward continuation to simplify the appearance of regional magnetic anomaly in the study area. The data was continued upward to 4 km. The regional features are often overly detailed, obscured by the proliferation of local magnetic anomalies. Thus, these disruptions were smoothed out without affecting the primary regional features via upward continuation. The main objective of upward continuation is to monitor the magnetic field intensity above the level of flight in order to minimize

the occurrence of short wavelength anomalies and enhance longer wavelength anomalies that correspond to regional features [25] (Figure 4).

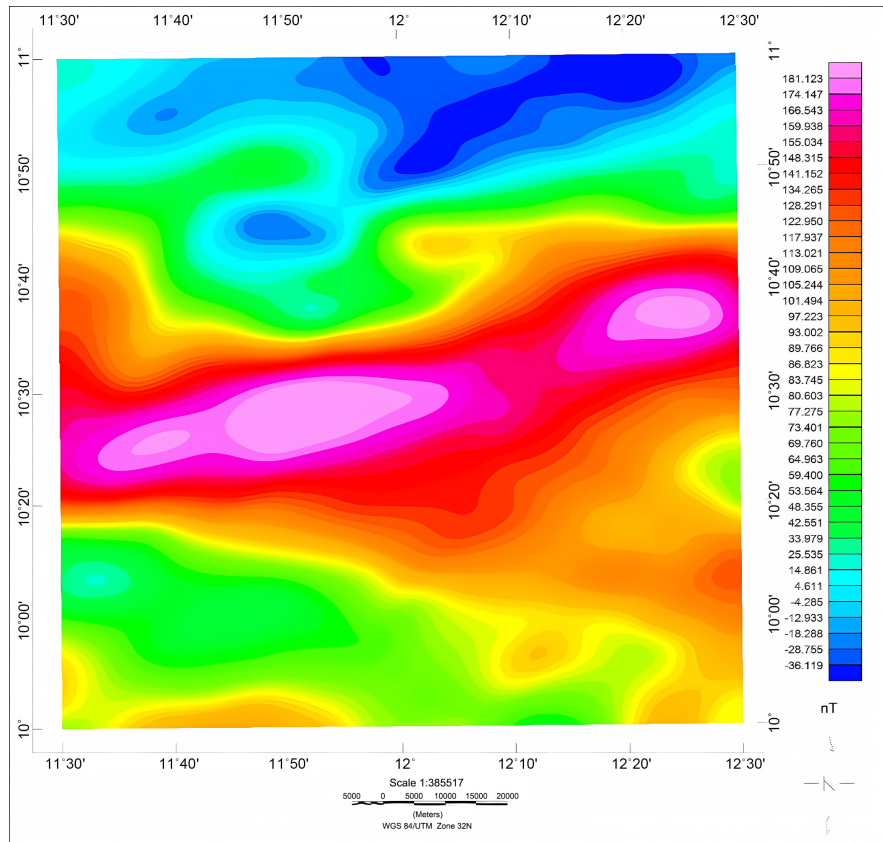


Figure 4. TMI Map continued upward to the height of 4 km.

The equation of upward continuation is given by [26]. The upward continuous F (magnetic anomaly) at a higher level ($Z = -h$) is given by:

$$F(x, y, -h) = \frac{h}{2\pi} \iint \frac{f(x, y, 0) \partial x \partial y}{((x-x')^2 + (y-y')^2 + h^2)^{3/2}} \quad (1)$$

where $F(x, y, -h)$ = total field at a point $F(x', y', -h)$ above the surface on which $F(x', y', 0)$ is known. h = continuation height.

4.2. Spectral Analysis

The total magnetic intensity data was continued upward to remove effects due to shallow magnetic sources and then divided into four overlapping blocks, each measuring 60×60 kilometers, totaling four data blocks. Each block was further exported into MATLAB programme to plot the spectral depths, the Top boundary (Z_t) and the centroid (Z_o).

4.3. Curie-Point Depth

Two steps are involved in estimating Curie point depth [27]. The first step in do-

ing the analysis is to use the slope of the longest component of the wave length spectrum to estimate the depth to the centroid of the magnetic source (Z_o).

$$\ln \left[\frac{p(s)^{1/2}}{|s|} \right] = \ln A - 2\pi |s| Z_o \quad (2)$$

where A is a constant, $|s|$ is the wave number, and $p(s)$ is the anomaly's radially average power spectrum.

The slope of the second longest wave length special segment is used to estimate the depth to the top boundary (Z_t) of that distribution in the second step.

$$\ln \left[p(s)^{1/2} \right] = \ln B - 2\pi |s| Z_t \quad (3)$$

where B is the sum of the constant, the basal depth independent of $|s|$.

In calculating Curie point depth, the basal depth (Z_b) of the magnetic source in the area is assumed to be the Curie point depth [27]. Therefore, the basal depth (Z_b) of the magnetic source is calculated as follows:

$$Z_b = 2Z_o - Z_t \quad (4)$$

4.4. Heat Flow and Geothermal Gradient

The earth's core cooling process and radioactive heat generation in the upper 20 to 40 kilometers of the crust are the main sources of heat on Earth. Fourier's law is the fundamental formula for conductive heat transfer [28]. Using Fourier's Law, Empirical formula was used to calculate the heat flow and thermal gradient as follow:

$$q = \lambda \left[\frac{\partial T}{\partial Z} \right] \quad (5)$$

In order to relate the Curie point depth (Z_b) to Curie point temperature variation, the vertical direction of temperature variation and the constant thermal gradient was assumed. The geothermal gradient $\left(\frac{\partial T}{\partial Z} \right)$ between the earth and the Curie point depth (Z_b) was defined by the equation:

$$\frac{\partial T}{\partial Z} = \frac{580^\circ\text{C}}{Z_b} \quad (6)$$

where 580°C is the Curie temperature at which ferromagnetic minerals are converted to paramagnetic minerals. Furthermore, the geothermal gradient was related to heat flow (q) using an empirical formula. However, by this calculation an average thermal conductivity value of $2.5 \text{ W}\cdot\text{m}^{-1}\cdot^\circ\text{C}^{-1}$ for the dominant rock in the region (Igneous rock) was also applied.

$$q = \lambda \left(\frac{\partial T}{\partial Z} \right) = \lambda \left(\frac{580^\circ\text{C}}{Z_b} \right) \quad (7)$$

where λ is the coefficient of thermal conductivity.

The results obtained from this spectral analysis are presented on **Figure 5** and the summaries of calculations using empirical formula are presented on **Table 1**.

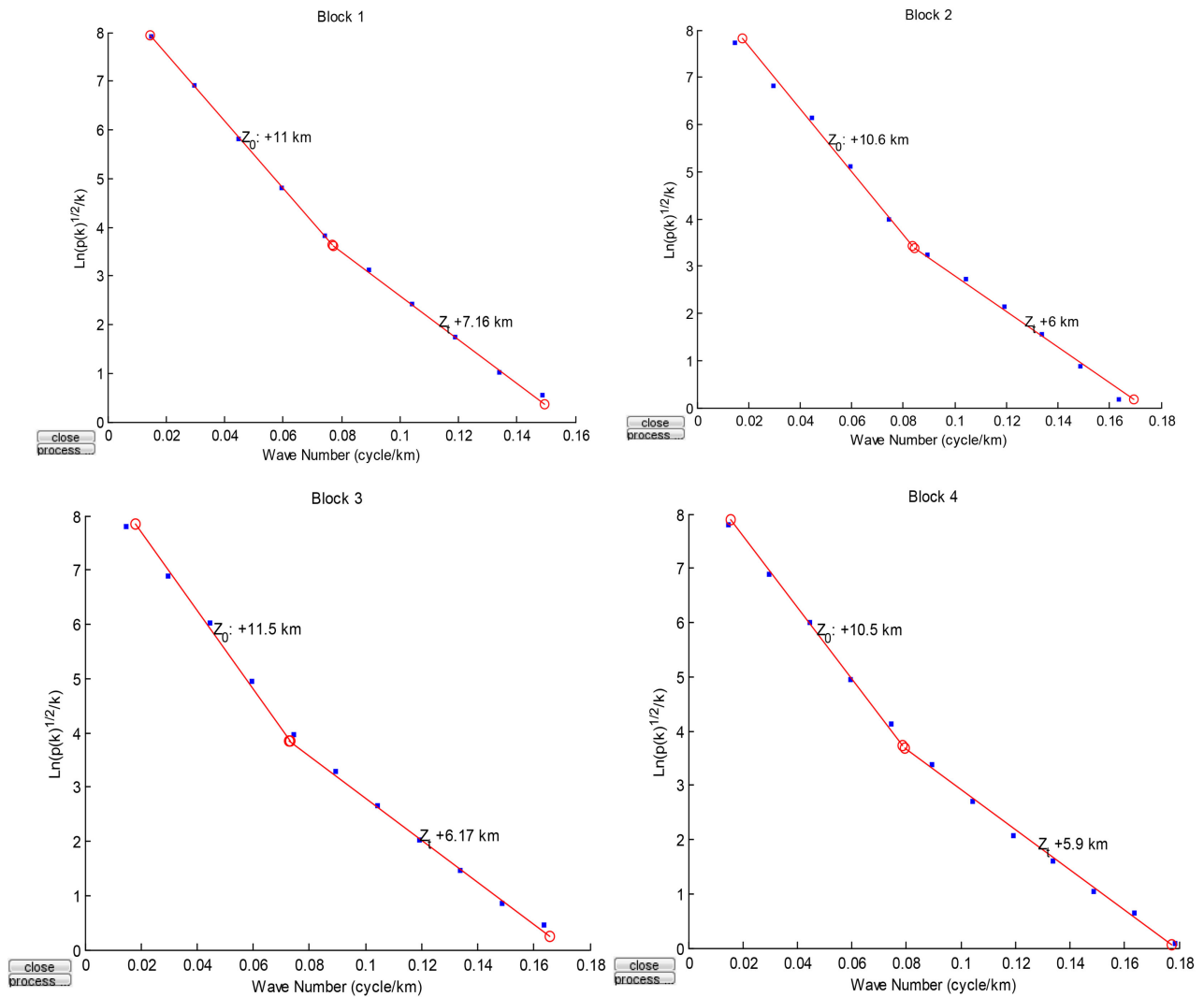


Figure 5. Graphs of the logarithms of the spectral energies for the blocks 1-4.

Table 1. Curie point depth, geothermal gradient and heat flow.

Blocks	Depth to Top Boundary (Z_i) (km)	Depth Centroid (Z_0) (km)	Curie Point Depth (Z_b) (km)	Geothermal Gradient °C/km	Heat Flow $mW \cdot m^{-1} \cdot ^\circ C^{-1}$
1	7.16	11.00	14.84	39.08	97.71
2	6.00	10.60	15.20	38.16	95.40
3	6.17	11.50	16.83	34.46	86.16
4	5.90	10.50	15.10	38.41	96.03
Average:	6.31	10.9	15.50	37.53	93.83

5. Discussion of Result

The total magnetic intensity (TMI) map of the study area consists of short and long wavelength magnetic anomaly which correspond to shallow and deep magnetic sources. It also consists of both magnetic low which varies from -55.145 to

–158.969 nT and magnetic high which varies from 106.263 to 284.73 nT, these correspond well with geology of the study area (**Figure 3**). The magnetic low which is dominantly in the northern part of the study area reflects the Chad Basin, while the magnetic high which dominates the central part of the study area reflects the extension of the Northern arm of Cameroun Volcanic line. However, the data when continued upward up to 4km to eliminate effects due to shallow magnetic materials (**Figure 4**), it clearly indicates that, the northern part is dominated by magnetic low while the magnetic high is dominated in the central part corresponding to northern arm of Cameroun Volcanic line (CVL).

The assessment of geothermal potentials from these data was determined from Curie depth as observed from the graphs of power spectrum of the four overlapping blocks (**Figure 5**) above and from which depth to top boundary (Z_t) and depth to the centroid (Z_o) were computed with an empirical formula. **Table 1** shows the results obtained from the calculations of basal depth (Z_b), Heat flow and geothermal potentials. The results obtained indicate that the depth to top boundary varies between 5.90 to 7.16 km with an average value of 6.31 km, depth to centroid varies between 10.50 to 11.50 km with an average of 10.9 km, depth curie point varies between 14.84 to 16.83 km with also an average of 15.50 km, with heat flow varying from 86.16 to 97.71 $\text{mW}\cdot\text{m}^{-1}\cdot\text{C}^{-1}$ with an average of 93.83 $\text{mW}\cdot\text{m}^{-1}\cdot\text{C}^{-1}$ and geothermal gradient (increase in heat with depth) of 34.46 to 39.08 $^{\circ}\text{C}/\text{km}$ with an average of 37.53 $^{\circ}\text{C}/\text{km}$. With the depth to Curie point and the nature of heat flux and the geothermal gradient value the study area is a potential site for geothermal reservoir exploration which lies in the north eastern part of Nigeria. Based on the result obtained, the study area can be recommended for additional investigation techniques to be able to come up with a stand on the geothermal exploration work.

6. Conclusion

The analysis of High Resolution Aeromagnetic Data over Biu plateau and environs Northeastern Nigeria was carried Out to assess the geothermal potential of Biu plateau and environs due to the facts that, Biu plateau is the Northern arm of Cameroun Volcanic Line (CVL) and since the major source of heat of the earth is the long-term cooling especially in volcanic areas. The results obtained from this research indicate that, the values obtained for the curie depth, heat flow and geothermal gradient are evident that the study area is a potential site for geothermal reservoir exploration for alternative sources of power generation which can be utilized in Nigeria as done by the Bulgarian government. The study area if utilized can provide electricity for northeastern Nigeria.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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