Original Research Article

Estimation of Curie Point Depth, Heat Flow and Geothermal Gradient Deduced from Aeromagnetic Data Over Lamurde and Environs North-Eastern Nigeria

ABSTRACT

A estimation of curie point depth, (CPD), heat flow and geothermal gradient has been carried out from the spectral analysis of the recently acquiredhigh resolution aeromagnetic data overLamurde and Environs, north-eastern Nigeria. The data were divided into 4 overlapping blocks and each block was subjected to spectral analyses to obtain depths to the top boundary, centroid and empirically calculated depth to bottom of the magnetic sources. The depth values were then used to assess the CPD, heat flow and geothermal gradient in the area. The result shows that the CPD varies between 9.62 to 10.92km with an average of 10.45k, the heat flow varies between 150.73 to 132.78 $mWm^{-2 0}C^{-1}$ with an average of $139.12mwm^{-20}C$-1 and the geothermal gradient in the study area vary between 12.16 to 15.67^{0C}/km with an average of 13.39^{0C}/km. In view of the above results, the high heat flow may be responsible for maturation of hydrocarbon in Benue Trough as well as responsible for the lead Zinc Mineralization. Again by implication, Lomurde area can be a good area for geothermal reservoir exploration for an alternative source for power generation.

Key words: Head flow, Curie depth, lead Zinc, Geothermal gradient, Aeromagnetic data and spectral analysis

Introduction

The study area lies in the upper Benue Trough between latitude $9^{0}00$ to $9^{0}30'^{N}$ and longitude $11^{0}00$ to $12^{0}00$'E,(figure 1). It is one of the areas that received limited attention from geoscientists in the past.

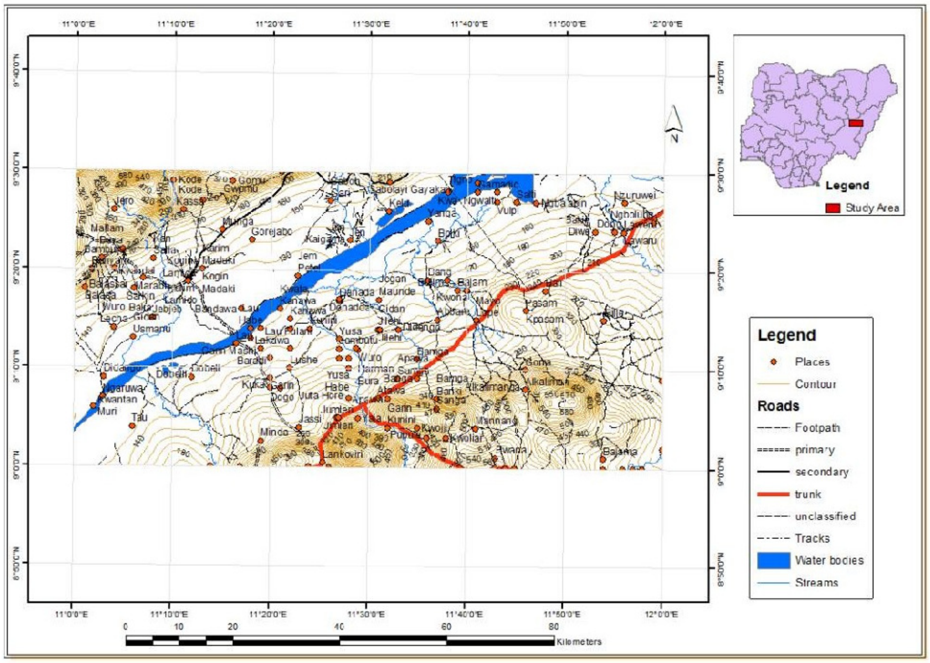

Figure 1: Location/topographic map of the study area

This research aims at estimation of Curie Point Depth (CPD), heat flow and geothermal gradient inLamurde and Environs, North-Eastern Nigeria using spectral analysis of high resolution aeromagnetic data.

One of the tools used in investigating thermal structure of crust via aeromagnetic studies is spectral analysis. Several studies have shown that magnetic data can be used to determine the thermal structure of the earth's crust in various geologic environments (Spector and Grant, 1970; Blakely and Hassanzadeh, 1981; Okudo et al, 1985, 2003). For example, dominant magnetic minerals in the earth crust change from being ferromagnetic to paramagnetic at a temperature known as Curie Point Temperature (CPT). Magnetite ($Fez0_4$) is the most common magnetic materials in igneous rocks and has an approximate CPT of 580^0C (Stacey, 1977). At temperature above CPT, the thermal agitation of the ferromagnetic rock material leads to the spontaneous alignment of the different domains in the minerals and become randomized to the point that ferromagnetic minerals become totally paramagnetic (Langel and Hinze, 1998).

The surface lineaments around the study area and their influence on the hot springs manifestations have not been previously investigated. The depth to the heat sources which could provide information on the thermal structure has not been investigated either. In this research, the thermal structure around Larmurde and Environs, North-Eastern Nigeria was investigated in order to explore the geothermal potential using aeromagnetic data.

The Geology of the Study Area.

The geology of the area is made up of precambian basement complex rock which are believed to be mainly of gneiss – migmatites complex remnants of meta sediments and older granite.

The Bima Sandstone which overlies the basement complex at the base of sedimentary succession was derived from granitic rocks (Offodile, 1977). The lower beds of the formation are invariably series of calcareous sandstone and shale which marks the transition from continental to marine shale with a number of limestone beds towards the base of the formation. The Territory-Recent Volcanic rocks in the study area consist of the basalts, trachyte, rhyolite and newer basalts of eastern arm of Cameroon volcanic line area through is not evident on geologic map (Figure 2)

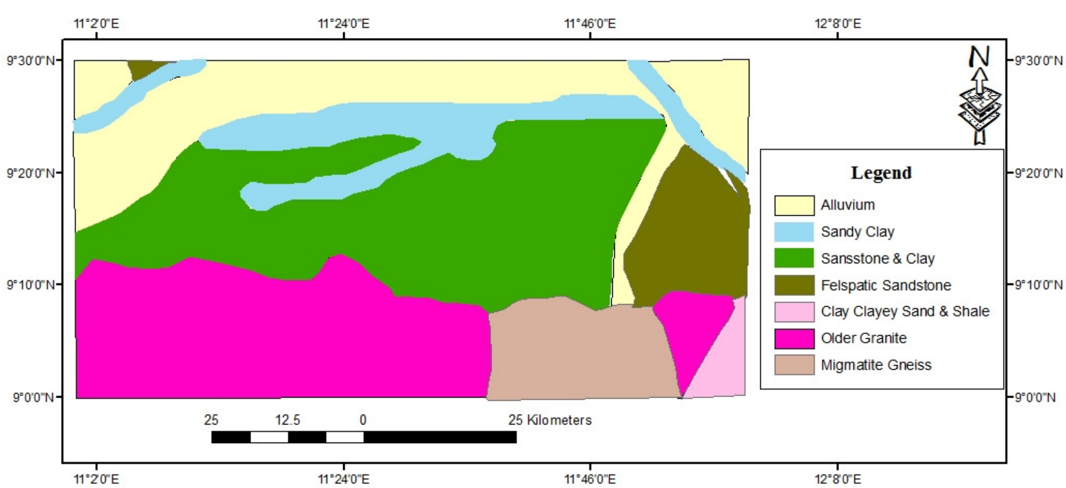

Figure 2: Geologic map of the study area

Materials and Methods

The data for this study is a high resolution aeromagnetic data obtained from Nigeria geological surveyAgency (NGNA, 2010). The total magnetic intensity data was used for spectral analysis, which was then used to obtained the depths of magnetic anomalies in the area. Steps for determining depth to magnetic sources have been discussed extensively (Anakwuba et al, 2011; Chinwuko et al, 2013; Ikumburet al, 2013; Spector and Grant, 1970; Onwuemesi, 1997; stampolidis et al, 2005; Abubakar et al, 2010).

The analysis was done using computer program software (Oasis Montaj)designed for analysis of potential field data. In this research, the spectral analysis was made using interactive Oasis Montaj, Version 8.2 which enables two dimensional frequency domain processing of potential field data. The result of the analysis are plotted on a logarithmic scale against the radial wave number. On such a plot, if a group of sources has the same depth, they will fall onto a line of constant slope (tangent of the line fitted to the power spectra). Thus, if there are sources at different depths, such as a shallow plutonic formation over a deep basement, the plot will be separate into two or more sections with different slope. The reciprocal of the angle of slope is a measure of the depth to the source. This process was carried out to obtain the depth to the top boundary (Z_t) and depth to the centroid (Z_0) for the four overlapping blocks (figure 3).

To carry out the analysis, the initial step according to Bhattacharyya and Leu (1975) wasfollowed estimate the depth to the centroid (Z_0) of the magnetic sources from the slope of the longest wave length of the spectrum as given:

$$\text{Log}\left(P\frac{(K)^{\frac{1}{2}}}{/K/}\right) = \text{Log (A)} - 2\pi\, Z_0\, /K/ \qquad (1)$$

Where P (K) is the radially averaged power spectrum of the anomaly /K/ is the spatial wave number and A is a constant.

The second step was to estimation of the depth to the top boundary (Z_t) of the magnetic source from the slope of the line with the second wave length (Okubo et al, 1985).

$$\text{Log}\left(P(K)^{\frac{1}{2}}\right) = \text{Log (B)} - 2\pi Z_t /K/ \quad (2)$$

Where B is a sum of constants independent of /K/. the basal depth (Z_t) of the magnetic source is then computed from the equation:

$$Z_b = 2Z_0 - Z_t \quad (3)$$

The obtained bottom depth (Z_b) of a magnetic source is assumed to be equal to the CPD.

Analysis of CPD is one of the method used to estimate the temperature gradient and the heat flow in the crust. Heat flow is defined by Fourier's Law as:

$$Q = d\left[\frac{dT}{dZ}\right] \quad (4)$$

Where Q is the heat flow and d is the coefficient of thermal conductivity. In this equation, it is assumed that the direction of the temperature variation is vertical and the temperature gradient dT/dZ is constant. According to Tanaka et al, (1999) the Curie Temperatureø; can be obtained from the Curie Point depth (Z_b) and the thermal gradient dT/dZ using the following equation:

$$\text{ø} = Z_b\left[\frac{dT}{dZ}\right] \quad (5)$$

Equations (4) and (5) give a relationship between the CPD (Z_b) and the heat flow (Q) as:

$$Q = d\left[\frac{Q}{Zb}\right] \quad (6)$$

In equation (6), the curie point depth is inversely proportional to the heat flow (Tanaka et al, 1999). In this research, the Curie Point Temperature of 580^0C and thermal conductivity of $2.5mwm^{-1}\,{}^0C^{-1}$ as average for igneous rocks was used as Standard (Nwanko et al, 2011). In order to calculate the thermal gradient and heat flow in the study area, equations (5) and (6) were used

Results

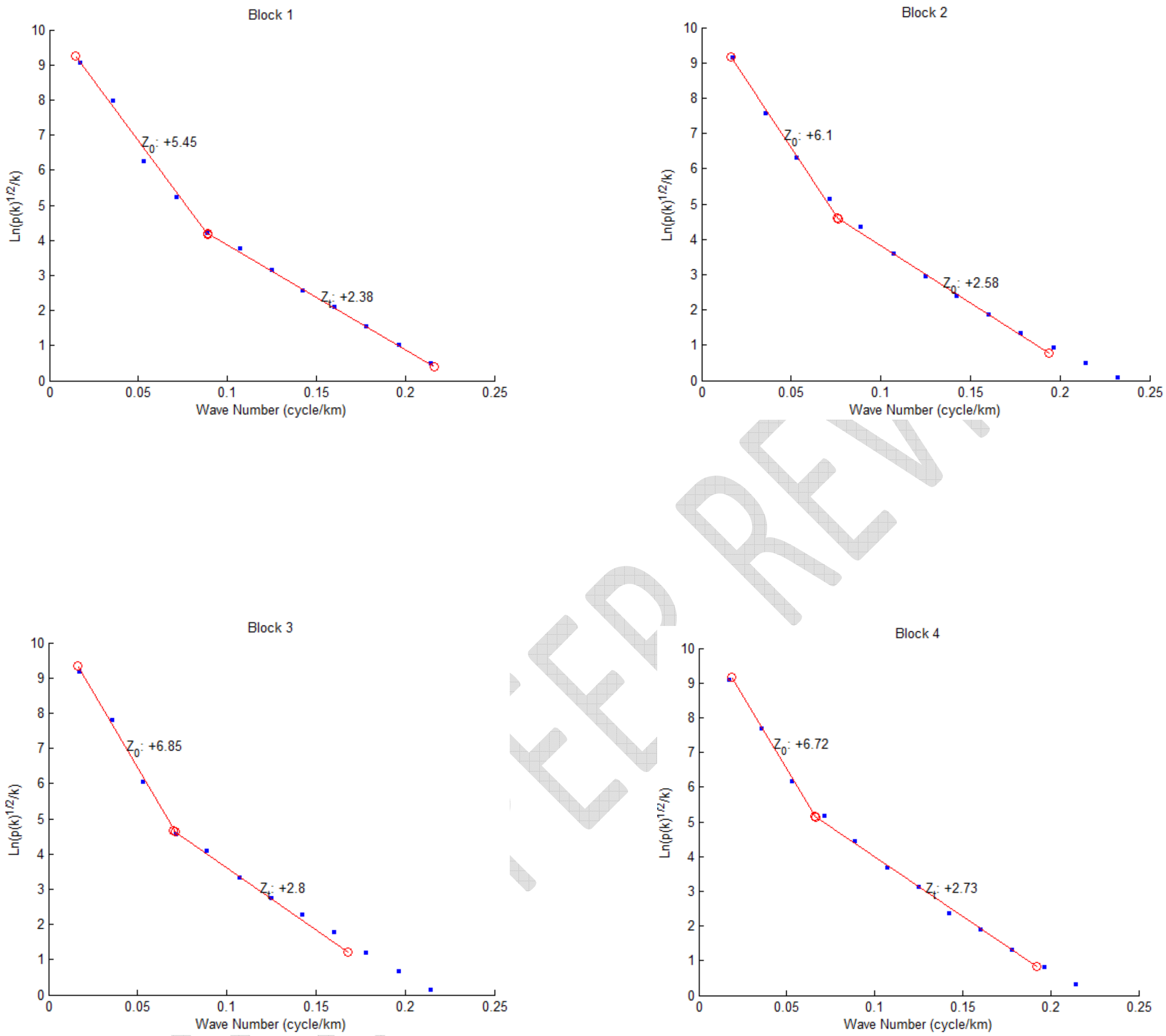

Figure 3: Graphs of the Logarithms of the spectral energies for the blocks 1-4

Table 1: Calculated curie depth, head flow and geothermal gradient

Block	Depth to Top boundary (Z_E) in km	Depth to centroid (Z_0) in km	Curie Point Depth (Z_b) in km	Heat flow in mWm^{-2} $^0C^{-1}$	Geothermal Gradient $^0C/KM$
1	2.38	6.46	10.54	137.57	13.10

2	2.58	6.10	9.62	150.73	15.67
3	2.80	6.86	10.92	132.78	12.16
4	2.73	6.72	10.71	135.38	12.64

Discussion

The average power and wave number spectra for each of the four overlapping blocks were calculated and used to estimate the CDPs (Figures 3). The right-hand side of high-wave-number portion of the spectra which was used to estimate the depth to top boundary of the magnetic sources (Z_t), while the left –hand side indicated the slope of the lower-wave-number-scaled spectra, which was also used to estimate the depth to centroid (Z_0) of the magnetic sources.

The estimated results are shown in table 1. The table shows that estimated CDP varies between 9.62 to 10.92km with an average of 10.45km. the CPD varies significantly with different geologic environments (Tanaka et al, 1999; Salk et al, 2005). Tanaka (1999), after compilation of CPD results across the world, opined that volcanic, tectonic and associated geodynamic environments have CPD shallower than 10km, while CPDs ranging between 15 to 25km are as a result of island arcs and ridges and deeper than 25km in plateaus and tranches.

Generally, the units that comprise high heat flow values corresponds to volcanic and metamorphic regions since these have high thermal conductivity.

Similarly, table 1 indicates that the heat flow in the study area vary between 150.73 to 132.73 $mWm^{-20}C^{-1}$ with an average of 139.12 $mWm^{-20}C^{-1}$, while the thermal gradient varies between 12.16 to 15.67 $^{0}C/km$ with an average of 13.39 $^{0}C/km$.

Conclusion

The high resolution aeromagnetic anomaly data over Lamurde and Environs, North-Eastern Nigeria have been analyzed to estimate Curie Point Depth, heat flow and geothermal gradient. The result shows that CPD varies between 9.62 to 10.92km with an average or 10.45km, the heat flow varies between 150.73 to 132.78 $mWm^{-20}C^{-1}$ with an average of 139.12 $mWm^{-20}C^{-1}$ and geothermal gradient varies between 12.16 to 15.67 $^{0}C/km$ with an average of 13.39 $^{0}C/km$.

The area observed with shallow curie point depth (below 9km) and corresponding high heat flow (above 150 $mWm^{-20}C^{-1}$), thus, suggesting anomalous geothermal condition. Hence, further detail studies are recommended in the study area. It is known that geodynamics processes are mainly controlled by the thermal structure of the earth crust (Nwankwo, et al, 2011); therefore, this study is anticipated to contribute significantly to the quantitative appraisal of the CPD, heat flow and geothermal gradient in Lamurde and Environs.

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