ESTIMATION OF CURIE DEPTHS, HEAT FLOW AND GEOTHWERMAL GRADIENT OF MUBI AND ENVIRONS NORTH EASTERN NIGERIA

ABSTRACT

This study, is to estimate the curie point depth, heat flow and geothermal gradient using spectral analysis and empirical formula of aeromagnetic data, over Mubi and Environs, north-eastern part of Nigeria. The Aeromagnetic data was divided into equal interval of 15" by 15". The results of curie point depth obtained varies between 9.48 and 10.33km, geothermal gradient varies between 21 and 24°C km-^{1}*, while the heat flow varies between 52 and 60 mWm-2. The relationship between curie depth and heat flow is an inverse linear while the geothermal gradient is proportional to the heat flow in the study area. These results are consistent with the prevailing geotectonic regime in the study area. However, this study illustrates that surface magnetic data can be used to produce Curie point depth estimate even for region with paucity of heat flow and geothermal gradient data.*

Key words: *Oasis Montaj, Aeromagnetic data, Heat flow, Geothermal Gradient and Curie Depth*

1. INTRODUCTION

Mubi and environs form part of the north eastern sector of the Nigerian basement complex and has been amongst the least studied of the basement terrains of Nigeria. Most authors describe it as undifferentiated basement complex due to lack of enough geological information covering the area.

The assessment of variations of the curie isotherm of an area can provide valuable information about the regional temperature distribution at depth and the concentration of subsurface geothermal energy (*Tselentis,* 1991). One of the important parameters that determine the relative depth of the curie isotherm with respect to sea level is the local thermal gradient. *i.e*. heat flow (*Hisarli*, 1996). Measurements have shown that a region with significant geothermal energy is characterized by an anomalous high temperature gradient and heat flow (*Tselentis* 1991). It is therefore expected that geothermically active areas would be associated with shallow curie point depth (Nuri D, M. Timur U, Z. Mumtaz H, and Naci O. 2005). It is also a known fact that the temperature inside the earth directly controls most of the geodynamic processes that are visible on the surface (Okubo Y.J. R. Graf, R. O. Hansen, K. Ogawa, and, H.Tsu. 1985)

The mathematical model on which the great mass of the analysis is based is a collection of data from a uniform distribution of grid data, each having a constant magnetization. The model which was introduced by Spector and Grant (1970), has proven very successful in estimating average depths to the top of magnetized bodies. One principal result of their analysis is that the expected value of the spectrum for the model is the same as that of a single body with the average parameters for the collection.

The idea of using high resolution aeromagnetic data to estimate Curie point depth is not new and it has been applied to various parts of the world, either by analyzing isolated magnetic anomalies due to discrete sources or employing the frequency domain approach (*Hisarli*, 1996). This research utilizes spectral analysis to estimate the curie depth and heat flow to determine the geothermal history of the study area. The curie Point Depth is known as the depth at which the dominant magnetic mineral in the crust passes from a ferromagnetic state to a paramagnetic state under the effect of increasing temperature (Nagata, 1961).

The Curie temperature is an intrinsic property of rocks, which depends on chemical composition and crustal structure. Long range magnetic ordering below this temperature is achieved by the mechanism of exchange interactions between the individual magnetic domains causing their core alignment. Above the curie temperature (or point), the demagnetized condition occurs, corresponding to a random distribution of the vectors representing the domain magnetization. Hence both induced and remnant magnetizations vanish. While paramagnetic and diamagnetic effects are insignificant contributors to the geomagnetic field. Most naturally occurring minerals are paramagnetic or diamagnetic and hence have exceedingly low susceptibilities. The study area also forms part of the northern arm of Cameroon volcanic line (Ferre, et al.1996,; Ekwueme and Kroner, 1987, 1998), which is a remobilized Pan-African terrain formed in the Neo-Proterozoic (ca.600 Ma) by continental collision between the converging West African Craton, the Congo Craton and the East Saharan block (Ferre et al.1996).

The study area is located within parts of sheet 155 (Garkida) and sheet 156 (Uba) with a scale of 1:100,000, covering an area of about 7,200 Km^2 (Fig.1). The area of study is located within Longitudes $12^{o}50^{'}$ E to $13^{o}25^{'}$ E and Latitudes $10^{o}00^{'}$ N to $10^{o}30^{'}$ N.

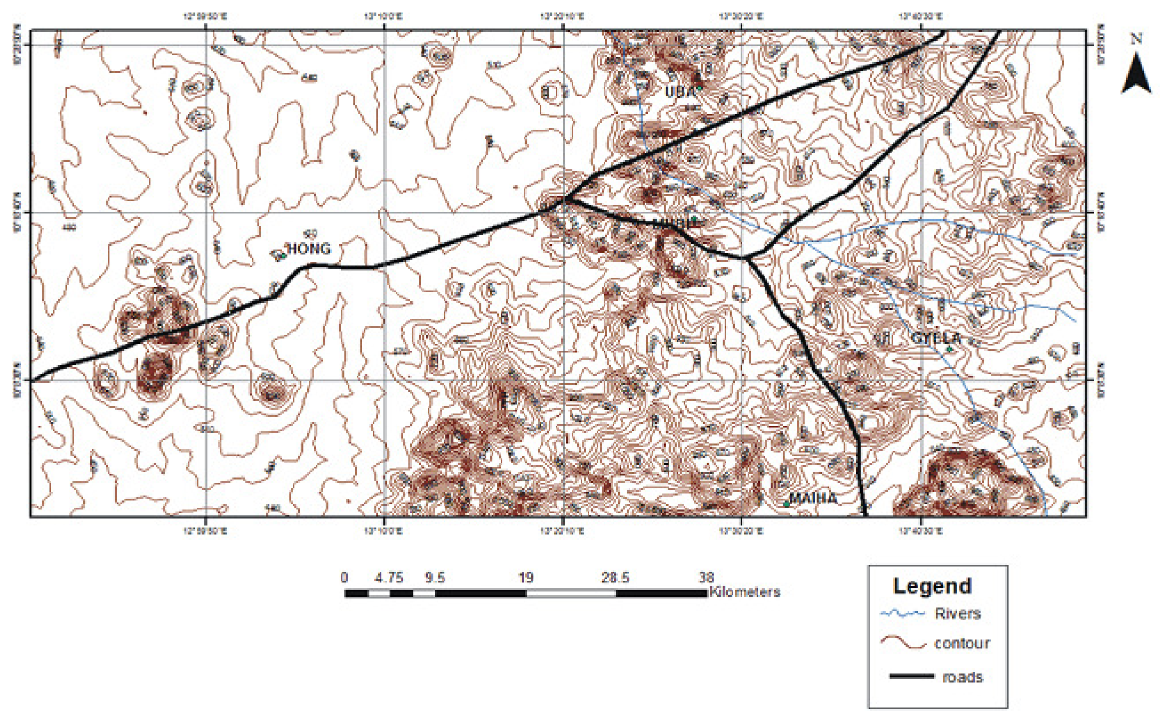


Fig.1. Topographic map of the study area (USGS, 2017)

1.1.GEOLOGY OF THE STUDY AREA

The geology of Mubi and environs consists of basement complex rocks mainly metamorphic (migmatitic gneisses, amphibolites, mylonites), igneous (intrusive granitoids and volcanics) rocks and alluvium. The study area covers parts of Hawal Massif. Of all the Massifs in Nigeria, it is the least studied in detail (Ekwueme and Onyeagocha, 1985; Ekwueme, 2003). In this study, Parts of Garkida sheet 155 and Uba sheet 156 have been covered. Major towns and settlements in the area includes Mubi, Maiha, Uba, Gyella and Hong area. The geology of northeastern region consists mainly of ancient (Precambrian) crystalline Basement Complex represented mainly by granitic and migmatitic rocks, on which rest the sedimentary and volcanic rocks ranging in age from Cretaceous to Quaternary (Carter *et al*., 1963) as follows;

i). Migmatite-Gneiss Complex which constitute the oldest rocks in the region are made up of remnants of an ancient sedimentary series now almost completely transformed into anatectic migmatites, gneisses and granites through migmatization and granitization. Relics of the metasediments are found only as xenoliths and small pendants in the granitic rocks. They are widely distributed but individual exposures are of few square meters (Carter *et al*.1963). The metasediments include quartzo-feldspartic, biotite and calc-silicate rocks. However, biotite and hornblende gneisses are amongst the most frequently occurring types. Mineral assemblages correspond to those of the amphibolites facies. (ii) Older Granites which are widespread consists of three phases (Carter *et al.*, 1963). They are distinguished as basic and intermediate plutonic rocks, fine grained granites and syn-tectonic granites. These rocks vary considerably in structure, texture and mineralogy and show diverse contact relationships with the gneisses and migmatites. The granitic members of the Older Granites are characteristically rich in potash, which usually occur as microcline phenocrysts. The basic and intermediate plutonic rocks include small irregular bodies of gabbro; quartz-diorite and granodiorite are of widespread occurrences. The fine-grained granites were intruded prior to the emplacement of the syn-tectonic granites, are a group of minor, discordant intrusions of small extent. No relationship has been established between the fine grained granites and basic plutonic rocks (Carter *et al.* 1963).

Turner (1971) and McCurry (1976) reported that the predominant rock type of the Adamawa Massif, is believed to have been subjected to phases of migmatization that culminated in the emplacement of the Older Granites during the Pan African (600 ± 150 Ma) thermotectonic event (Fig. 2)

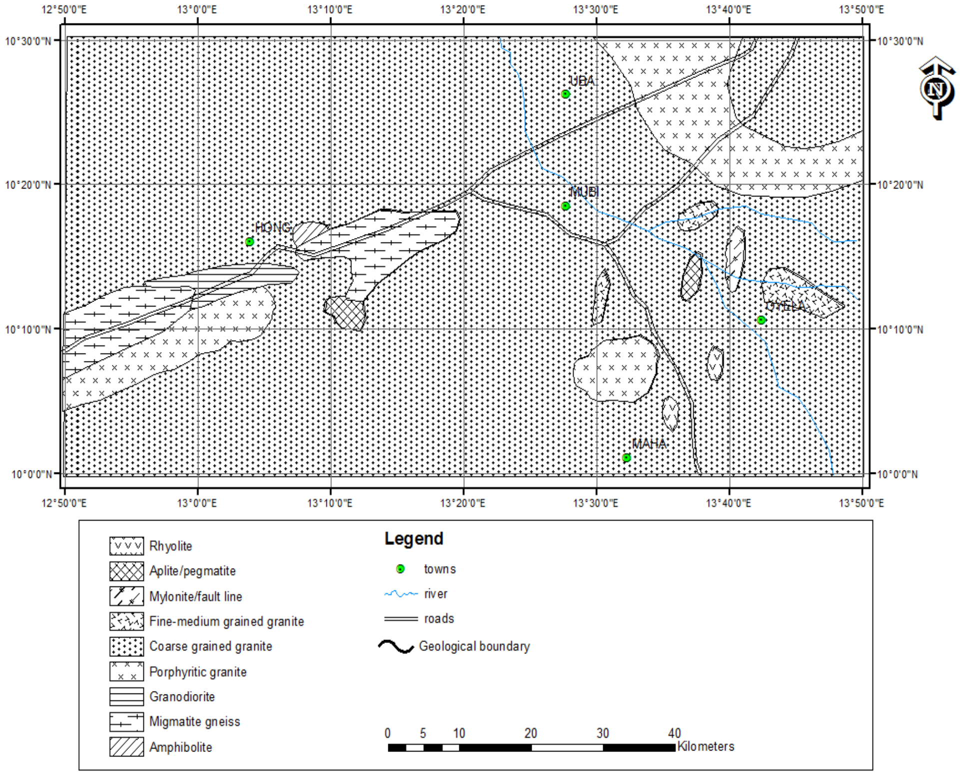


Fig.2. Geologic Map of the study area

2. Materials and Methods

2.1. Data acquisition

The aeromagnetic data used for this work (Fig. 3) was acquired in 2010 by Fugro Airborne survey services for Nigeria Geological Survey Agency. The data was acquired using magnetometers 3x scintrexCS3 Cesium vapour. The survey was conducted along NW-SE flight lines and tie line along NE-SW direction with 500 m flight line spacing, Terrain clearance of 80 m and line spacing of 2 km were used. The magnetic data recording interval during the survey was 0.1 seconds. All grid data were saved and delivered in Oasis montaj geosoft raster file format. The total intensity magnetic map used is presented in (Fig. 3). The total magnetic intensity of the study area consit of short, medium and long wave magnetic anomaly as well as low, moderate and high magnetic intensity describe by deep blue, yelloow and pink colours.The high magnetic intensity is observed to be concentrated in the northeastern part of the map while the low magnetic intensity is concentrated in the northwestern part. The short wave magnetic anomaly correspond to shallow magnetic source while medium and long wave magnetic anomaly correspond to deep seated magnetic sources. In processing the data certain parameters were considered;

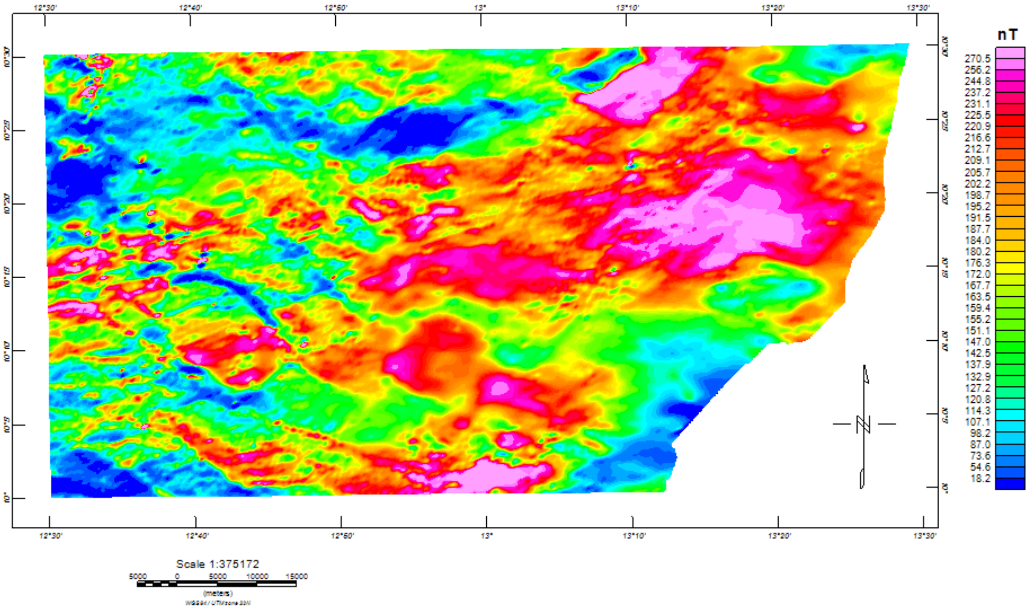


Fig. 3.Total Magnetic Intensity (TMI) Map of the study area

2.2. Curie Point depth Estimation

The methods for estimating the Curie depth have been described by several Authors, Bhattacharrya and Leu, 1975,, Okubo *et al.,* 1985, Onwuemesi, 1997; Tanaka, A. Y. Okubo and O. Matsubayashi 1999; Stampolidis, A. Kane, I. Tsokas G.N. and Tsourlo P., 2005, Nwanko, ,L.I, Olasehinde , P.I and Akoshile, C.O., 2011 and Kasidi and Nur 2012b and are classified into two categories: those that examine the shape of isolated magnetic anomalies and those that examine the patterns of the anomalies (Spector and Grant 1970). However, both methods provide the relationship between the spectrum of the magnetic anomalies and the depth of a magnetic source by transforming the spatial data into frequency domain. In this research, the method adopted is the latter, in which the top boundary and the Centroid of magnetic sources were calculated from the spectrum of magnetic anomalies and are used to estimate the basal depth of magnetic source.

To compute the depth to Curie point, the high resolution aeromagnetic data of the study area was divided into four overlapping blocks. The dimension of the square grids used is based on a minimum ratio of 12:1 of block size to prism dimensions (magnetic sources) as demonstrated by (Tselentis 1991). Thus assuming a minimum anomaly of approximately 5km, this meant a minimum block size of about 60 km. To effect the processing, upward continuation technique was utilized for each block to get rid of short wavelength component of the magnetic data. The analysis was carried out using computer program Oasis Montaj and Mat lab program.

The relationship used is given as follows; first step, is to estimate the depth to Centroid (Z_o) of the magnetic source from the slope of the longest wavelength part of the spectrum,

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

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

The second step is the estimation of the depth to the top boundary (Z_t) of that distribution from the slope of the second longest wavelength spectral segment (Okubo *et al.* 1985)

$$\ln\left[P(s)^{1/2}\right]=\ln B-2\pi/s/Z_t \qquad (2)$$

Where B, is the sum of constants independent of **/s/.**

Then the basal depth (Z_b) of the magnetic source was calculated from the equation below,

$$Z_b=2Z_o-Z_t \qquad (3)$$

The obtained basal depth (Z_b) of magnetic sources is assumed to be the Curie point depth (Bhattacharrya and Leu 1975, Okubo *et al.*, 1985).

2.3. Estimation of Heat Flow and Geothermal Gradient

In the absence of heat flow data in the study area, an empirical formula which is a one-dimensional heat conductive transport model was used to estimate the heat flow and geothermal gradient. The model is based on Fourier's law.

In one dimensional case under assumptions, the direction of temperature variation is vertical and the temperature gradient $\frac{dT}{dZ}$ is assumed constant, Fourier's law then takes the form:

$$q = \lambda \frac{dT}{dZ} \tag{4}$$

Where q is the heat flow and λ is the coefficient of thermal conductivity.

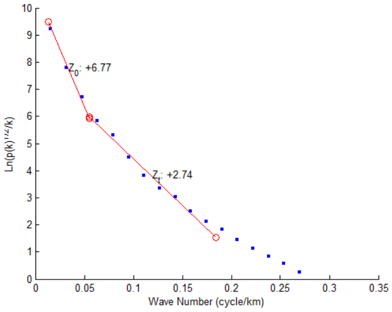
According to Tanaka *et al.,* (1999) the Curie temperature (θ_c) can then be defined as

$$\theta = \left[\frac{dT}{dZ} \right] Z_b \tag{5}$$

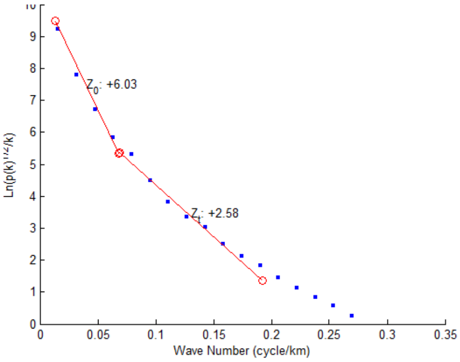
In addition to that, from equation (4) and equation (5) a relationship was determined between the Curie point depth (Z_b) and the heat flow (q) as follows.

$$q = \lambda \left[\frac{\theta}{Z_b} \right] \tag{6}$$

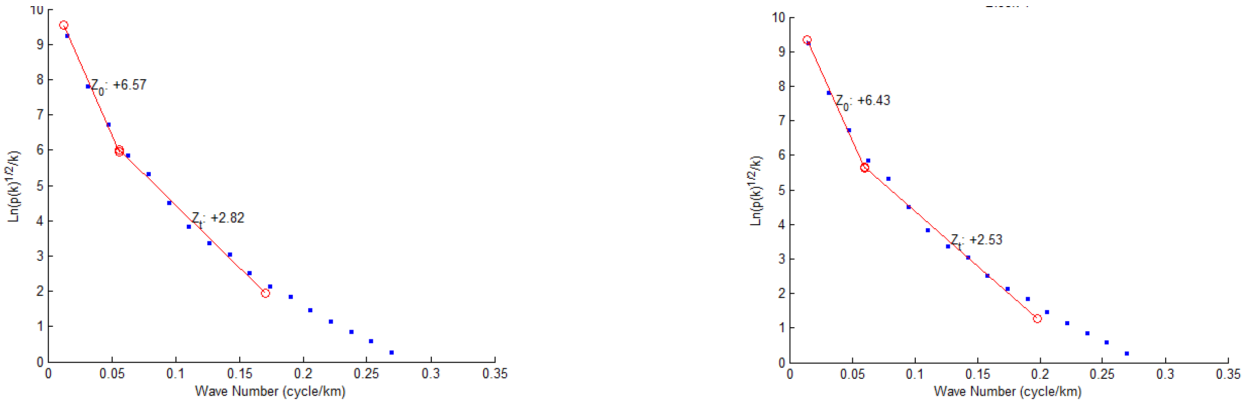
From equation 6, it is evident that, Curie point depth is inversely proportional to the heat flow; With this equation the heat flow (q) were calculated in the study area. We also compute the thermal gradient from Equation (5) using a Curie point temperature of 580 °C and thermal conductivity of 2.5 $\mathrm{Wm^{-1}{}^{\circ}C^{-1}}$, Nwankwo*, et al*., (2011).The results obtained are presented below as Fig. 4 and Table 1.



Block 1



Block 2



Block 3

Block 4

Figure. 5. Spectral blocks 1-5

Table 1. Calculated Average Curie Point Depth from Graphs of the Logarithms of Spectral Energies of Blocks (1-5) (km)

Block 1	Block 2	Block 3	Block 4
Z_O = 6.77	Z_O = 6.03	Z_O = 6.57	Z_O = 6.43
Z_t = 2.76	Z_t = 2.58	Z_t = 2.82	Z_t = 2.53
Z_b = 10	Z_b = 9.48	Z_b = 10.32	Z_b = 10.33

Table 2. Calculated Heat Flow and Geothermal Gradient from Curie Depths.

Blocks	Z_o(km	Z_t(km)	Z_b(km)	Geothermal(^{o}Ckm^{-1})	Heat flow(mWm^{-2})
1	6.77	2.76	10.00	24	60
2	6.03	2.58	9.48	22	57
3	6.57	2.82	10.32	23	52

4	6.43	2.53	10.33	21	52

3. DISCUSSION OF RESULT

The graphs of spectral energies used to estimate curie point indicate that the depth to top boundary (Z_t) ranges between 2.53 to 2.82 km , while the depth to centroid (Z_o) varies between 6.03 to 6.77 km and the basal depths (curie point) (Z_b) varies between 9.48 to 10.33 km table 1. However, results from geothermal gradient and heat flow indicate 21 to 24 ^{o}Ckm^{-1} and 52 to 60 mWm^{-2} respectively. The obtained Curie point depth reflects the average local curie depth point values beneath each block. It is observed that the curie depth of the study is shallower (9.48-10.33 km) compared to the other part of North Eastern Nigeria, these reflect the thinning of the crust due to upwelling of magma on Cameroon Volcanic Line (CVL) during the tertiary period. These compared well to other crystalline basement area that have been affected by volcanic activities. The obtained Curie point in this area is a good pathfinder for exploration of alternative sources for power generation in some part of North Eastern Nigeria.

Results of curie point depth in conjunction with heat flow values revealed a distinct inverse linear relationship. That is, heat flow increases with decrease in Curie point depth, and vice-versa. The average heat flow obtained in the study area is 55.25 mWm^{-2}, this may be considered as typical of continental crust (Yamano, 1995). In most part of the study area, heat flows were found to be less than 60mWm$^{-2,}$ this is consistent with the values of Curie point depth noted in this area. The heat flow values observed in this area correspond to Northern arm of Cameroon volcanic line represented by Mandara shield; this could be as result of thinning of the crust due to isostatic compensation as well as the age of the last magmatic activities which took place during tertiary period. The quantitative change in Curie depth observed in table 2 implies that, the heat flow in the study area is more or less uniform. The calculated geothermal gradient in the study area varies between 21 and 24 ^{O}Ckm^{-1} with an average of 22.5 ^{O}Ckm^{-1}. Measurements have also shown that, a region with significant geothermal energy is characterized by an anomalous high temperature gradient and heat flow. It is expected that geothermal active areas are associated with shallow Curie point..

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