Estimation of Geothermal gradient and heat flow for determination of geothermal energy sources in Monguno Area of northeastern Nigeria.

ABSTRACT

The aeromagnetic data of Monguno area northeastern Nigeria have been used to estimate Curie point depth, geothermal gradients and heat flow using spectral analysis. These geothermal parameters were subsequently employed to identify areas of geothermal resources. First order polynomial fitting was applied in Regional-residual separation. The Curie point depth obtained in this area ranges from 10.318 to 24.476 km with an average of 13.387 km, the geothermal gradient of the area varies from 23.697 to 56.212 °C /km, with an average of 46.195°C /km, while the heat flow ranges from 59.242 to 136.176 mWm^{-2}, with an average value of about 112.364 mWm^{-2}. It was also observed that the deepest Curie depth in the area is identified in the south, while the shallow depth is located in the northeast and spread toward the southwest. On the other hand, the highest geothermal gradient in the area is identified in the northern part of Moguno, while in the south, the lowest, geothermal gradient is located. The highest heat flow in the area is seen in the south-west and north-east, while the lowest heat flow is observed in the south. The high heat flow and geothermal gradient in the area show that geothermal energy could be found in Monguno region of the northeastern Nigeria.

Keywords: Nigeria, Chad basin, Curie point, geothermal gradients, heat flow, geothermal parameters, geothermal energy

1. INTRODUCTION

The non constant power supply in Nigeria has affected business activities, scientific and non scientific researches, social activities and so on. This situation has led to the use of generators as an alternative source of electricity supply, which is mostly used at homes, business centers, markets, offices and so on, thereby increasing gaseous pollutants in the environment. Meanwhile, gaseous pollutants have adverse effects on the lungs, causing lung cancer and they irritate the eyes. If this situation continues, it can adversely affect the health of many people. To enhance economic activities and to eliminate the negative health effects, efforts are being made to search for alternative sources of electricity generation. These include solar and wind power generations. However, these forms of power generation depend on climatic conditions just like the hydropower generation, hence, they may not generate sufficient electricity throughout the year.

On the other hand, the geothermal energy, which is energy in the form of heat flows out continuously from the Earth's subsurface as a result of the decay of naturally occurring radioactive isotopes. This form of energy is renewable and environmental friendly. It is all over beneath the Earth's surface but varies in concentration from place to place. Geothermal parameter such as geothermal gradient and subsurface heat flow provide the evidence, where this form of energy can be identified. Geothermal plants convert this form of energy into electricity [1]. This will generate much energy that will constantly supply electricity. Most countries including United State of America, Kenya, Newzealand, Mexico, Indonesia, Italy, Ice land, Turkey, Japan, Kenya, Sweden, Norway, Germany, Denmark and so on use geothermal energy as their other source of power generation [2].

The Nigerian sector of Chad basin has been identified to have high prospect for geothermal energy [3 - 4]. But only few works have investigated geothermal parameters in the Nigerian sector of Chad basin [5 -12]. In addition, these works used data from oil wells. This might be restricted to only areas with oil wells, hence; it might not have given a good representation of the area. Finally, some of these works combine aeromagnetic data of Monguno and other areas. Hence, this might not have given adequate geologic information of the area. Therefore, this work investigates the geothermal parameters (geothermal gradient and heat flow) in Monguno area. This is aimed at providing areas where geothermal energy could be harnessed and used for electricity generation.

2. LOCATION AND GEOLOGY OF THE STUDY AREA

The study area, Monguno (Fig, 1) is within the Nigerian Chad Basin (latitudes. 12° 00' to 13° 00' N and longitudes 12° 30' to 14° 00' E). Nigerian Chad basin lies within a vast area of central and west Africa at an elevation between 200 and 500 m above sea level and covers approximately 230,000 km^2 [13]. The area generally is endowed with rock mineral base resources such as clay, salt, limestone, kaolin, iron ore, uranium, mica etc [13].

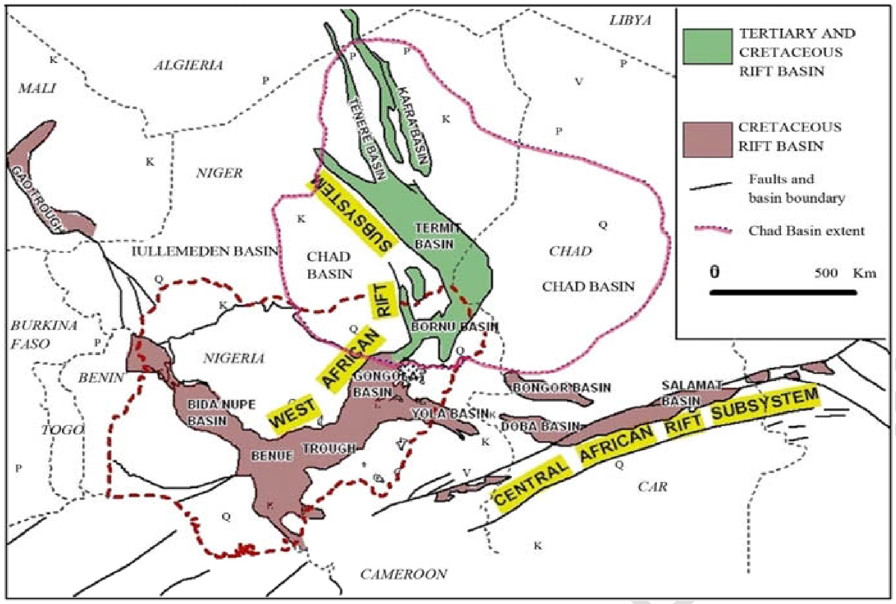

Fig. 1: Location of Chad/Bornu Basin within Regional Geological Map with rifts of West and Central African Rift System [14]

3. SOURCE OF DATA

The aeromagnetic and aerogravity data were of high resolution and were obtained from Nigerian Geological Survey Agency (NGSA). The airborne gravity data were obtained in 2013 using GRACE GRAVITY MODEL Sensor on-board 2 satellites by the National Aeronautics and Space Administration (NASA) and German Aerospace Center, while the aeromagnetic data were obtained using a 3 x Scintrex CS2cesium vapour magnetometer by Fugro Airborne Surveys in 2009. The airborne magnetic survey was carried out at 80 m elevation along flight lines spaced 500 m apart. The flight line direction was 135°, while the tie line direction was 225°. A correction based on the International Geomagnetic Reference Field (IGRF) 2010 was applied.

4 METHODS

4.1 Qualitative interpretations

The total magnetic intensity data were analyzed using Oasis Montaj 6.4. Data gridding was carried out by the method of minimum curvature. First order polynomial fitting was used to separate residual from regional anomalies.

4.2 Estimation of Curie point, geothermal gradient and heat flow estimation (Quantitative interpretation)

The residual magnetic map of Monguno was divided into 9 equal spectral cells using the filtering tool of the Microsoft excel software. Each profile covers a square area of 18.33 by 18.33 km.

A Fast Fourier Transform (FFT) algorithm was used to compute the Discrete Fourier Transform (DFT) of a sequence, or its inverse as given by [15]:

$$Y_i(x) = \sum_{n=1}^{N}\left[a_n \cos\left(\frac{2\pi n x_i}{L}\right) + b_n \sin\left(\frac{2\pi n x_i}{L}\right)\right] \quad (1)$$

where, $Y_i(x)$ is the reading at x_i position, L is length of the cross-section of the anomaly, n is harmonic number of the partial wave number, N is number of data points, a_n is real part of the amplitude spectrum and b_n is imaginary part of the amplitude spectrum; for $i = 0,\ 1,\ 2,\ 3, \ldots$ Thus, the expression in equation 1 was used in Microsoft (MS) excel program to transform the magnetic data into the radial energy spectrum for each block. The average radial energy spectral was calculated and displayed in a logarithm of energy versus frequency.

The plots of the logarithms of the energy spectra (Log E) against the domain frequencies were made. The gradients (m_1 and m_2) of two linear segments drawn from each graph were used to estimate the centroid depth (Z_o), the depth to top boundary (Z_t), Curie point depth (Z_b), geothermal gradient ($\frac{dT}{dZ}$) and heat flow (q) using the relations shown in equations 3 – 7 respectively [16 -19], [8]:

$$\text{Slope } (m_1, m_2) = \frac{Log\ Energy}{Frequency} \quad (2)$$

$$Z_o = -\frac{m_1}{2\pi} \quad (3)$$

$$Z_t = -\frac{m_2}{2\pi} \quad (4)$$

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

$$\frac{dT}{dZ} = \frac{\theta}{Z_b} \quad (6)$$

$$q = \lambda\left[\frac{\theta}{Z_b}\right] \quad (7)$$

The θ depicts the Curie temperature; and for magnetite, θ is equivalent to 580°C [22]

5 RESULTS

Figures 2 and 3 give the total magnetic intensity and the residual magnetic maps (respectively) of the area. The estimated geothermal parameters of the area are recorded on Table 1. Figures 4 - 6 present the contour maps of geothermal parameters, which include the Curie depth, geothermal gradient and the heat flow maps respectively.

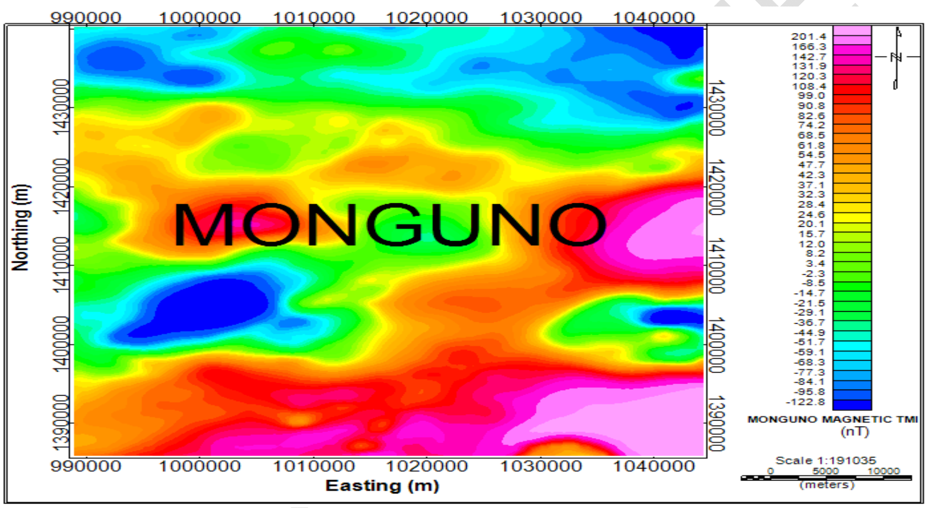

Fig. 2: Total magnetic intensity map

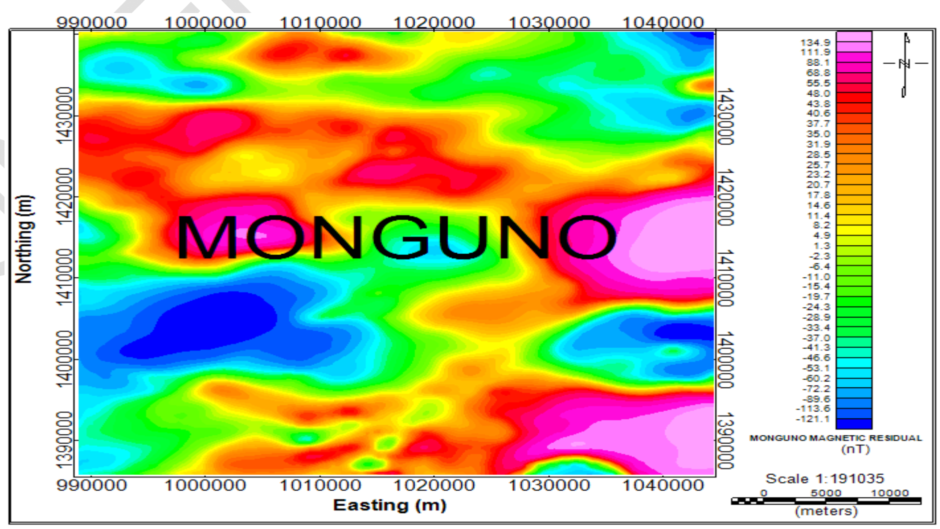

Fig.3: Residual magnetic map

Table 1: Estimated Geothermal parameters

SPECTRAL BLOCKS	DEPTH TO CENTROID (Z_0) (KM)	DEPTH TO TOP BOUNDARY(Z_t) (KM)	CURIE DEPTH (Z_b) (KM)	GEOTHERMAL GRADIENT ($\frac{dT}{dZ}$) (°C/KM)	HEAT FLOW(Q) (mWm^{-2})
1	5.952	0.811	11.093	52.285	130.713
2	13.095	1.714	24.476	23.697	59.242
3	7.483	1.478	13.488	43.001	107.503
4	6.349	1.299	11.399	50.882	127.204
5	6.052	1.786	10.318	56.212	112.425
6	7.937	1.965	13.909	41.700	104.249
7	7.407	0.774	14.040	41.311	103.276
8	5.853	1.058	10.648	54.470	136.176
9	6.151	1.190	11.112	52.196	130.490
AVERAGE DEPTH					
			13.387	46.195	112.364

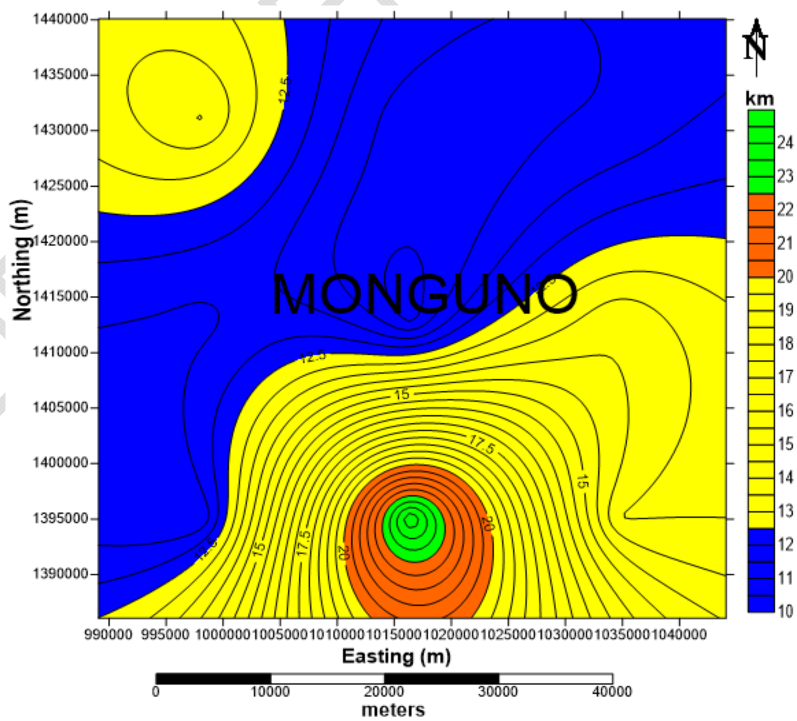

Fig. 4: Curie Depth map (contour interval of 0.5km).

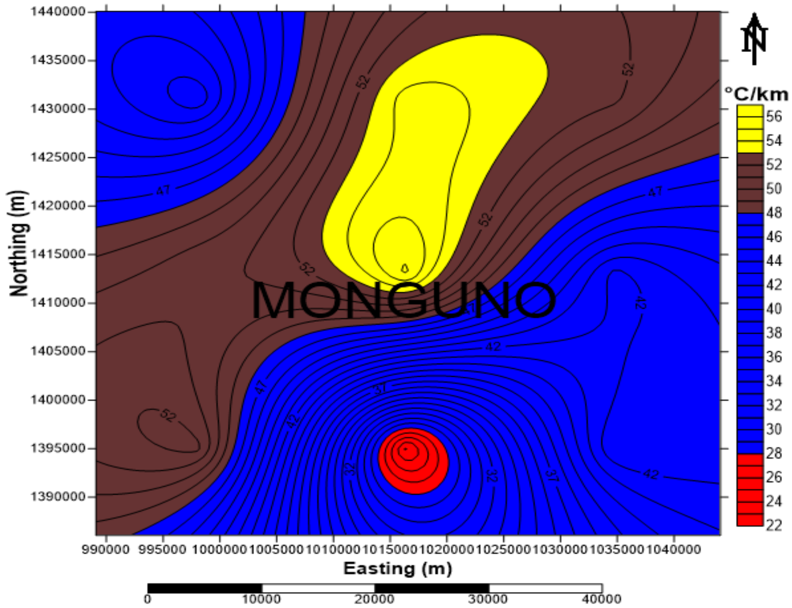

Fig. 5: Geothermal gradient map (contour interval of 0.5 °C/km).

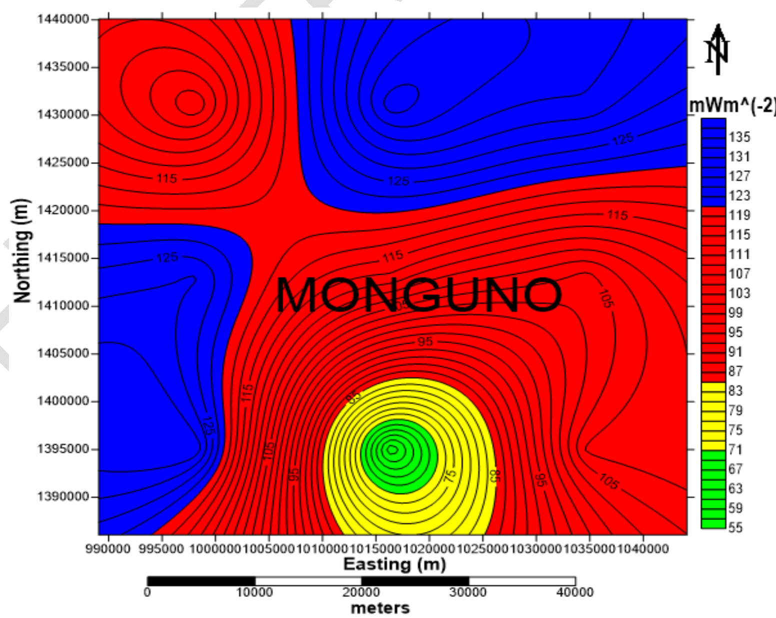

Fig. 6: Heat flow contour map (Contour interval of 0.1 mWm^{-2})

7 DISCUSSION

The total magnetic field intensity in Monguno area (Fig. 2) ranges from -122.8 to 201.4 nT. This shows that the study area is characterized by both low and high frequency magnetic signatures. Meanwhile, magnetic signature of low frequency dominates the northern area. This implies relatively high basement depth in the northern part of the area. The high frequency magnetic signatures observed in the southern part of the area indicate relatively shallow depth. The low frequency magnetic signatures in the area could be attributed to magnetic bodies which are deeply seated, while high frequency magnetic signatures could be due to intrusion or near surface magnetic bodies. This agrees with the author [3] who observed that high magnetic anomaly in most parts of the Nigerian Chad basin is as a result of intrusions into the sedimentary cover.

2-D residual magnetic map (Fig. 3) of the study area reveals that the residual magnetic intensity ranges from -121.1 to 134.9 nT. Thus, the area is composed of negative and positive magnetic anomalies. Areas of strong positive magnetic anomalies are noticed in the northwest and east (especially southeast),while large areas of negative magnetic anomalies are observed in the southwest and northeast, small areas of negative magnetic anomalies are equally seen in the northwest and southeast. Consequently, strong positive magnetic anomalies could be an indication of a high concentration of minerals of high magnetic susceptibility, while areas of negative magnetic anomalies could indicate a concentration of minerals of low magnetic susceptibility [20-21]

The Curie depths in the area vary from 10.318 to 24.476 km, with an average value of about 13.387 km (Table 1). The deepest Curie depth in the area is identified in the south, while the shallow Curie depth is seen in the northeast and spread toward the southwestern part of the map (Fig. 4). On the other hand, the highest geothermal gradient in the area (Fig 5) is identified in the northern part of Moguno, while the lowest geothermal gradient is observed in the southern part of the area. However, the geothermal gradient in the area varies between 23.697 and 56.212 ^{o}C/km, with an average value of about 46.195 ^{o}C/km. The heat flow in the area ranges from 59.242 to 136.176 mWm^{-2}, with an average value of about 112.364 mWm^{-2} (Table 1). The highest heat flow in the area is observed in the south-western and north-east, the minimum heat flow is observed in the southern part of the map. The results obtained in this work are in agreement with those of other researchers. For instance, the author [9] got a geothermal gradient in the range of 30 to 44 °C/km and an average geothermal gradient of 34°C/km in the Nigerian Chad basin using bore hole temperature logs.

8 CONCLUSION

The average geothermal gradients and heat flow obtained in the area is an indication that the area is suitable for harnessing of geothermal energy, which could be used to generate electricity. This may put to rest the problem of power supply and thus, revamping the nation’s economy.

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