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Investigation of Curie Point Depth Using High Resolution Aeromagnetic of Igumale and Ejekwe Area, Lower Benue Trough Nigeria

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Abstract

Objective: To carryout geophysical investigation in Igumale and Ejekwe area with the aim of estimating the Curie point depth (CPD) and then evaluating the geothermal gradient and heat flow to see if it is viable for geothermal exploration. **Methods:** Spectral analysis method was employed in this research work. **Findings:** The results show that the CPD varies between 1.111 and 17.402km. It is observed that the CPD in the Eastern part of the study area (11 - 12.6km) is shallower when compared to the other parts of the area. The deepest CPD of about 16.6-17.4 km is found in the North-western part of the study area. The geothermal gradient varies between 33 - 52 °C/km. The average heat flow obtained in the study area is 101 - 484mWm^{-2}. It ranges from 83 - 131 mWm^{-2}. The study area is characterized with high heat flow and geothermal gradient. These results indicated that the study area has a good potential for the generation of geothermal energy especially at Ejekwe area. **Novelty:** The study successfully depicted area with good potential for geothermal exploration using spectral analysis method.

Keywords: High Resolution; CPD; Ejekwe; Igumale; Spectral Analysis

1 Introduction

The temperature of the earth's subsurface increases with depth, and at some depth called Curie point depth (CPD), it reaches Curie temperature where ferromagnetic minerals loose their magnetic properties. In other words, material changes from a ferromagnetic to paramagnetic with increase in depth. Different studies have shown that an area with significant geothermal energy is usually characterized with high heat flow and geothermal gradient. The Curie temperature is about 550+-30^{0}C, it is assumed that this point is the depth for magnetic chamber (geothermal source) where heat is trapped into the geothermal reservoirs from the geothermal environment. CPD gives information on both geothermal gradient, local and regional distribution of temperature [(1)]. According to [(2)] CPD gives a better view of the crust's thermal structure using aeromagnetic data as the variation between long wavelength and short wavelength of the anomalies can be considered an indication of CPD.

Developing and developed countries of the world have used geothermal energy in the generation of electricity to meet rapid increase in the demand for electricity to power households and industries. Geothermal energy is not widely known in Nigeria, although several authors[3–8] etc., have carried out research on subsurface temperature across Nigeria. Therefore, delineating specific locations of underground thermal storage structure across Nigeria is important for geothermal energy generation and management.

Among all other sources, earth's geothermal energy originates from the radioactive decay of minerals, formation of the planet, solar energy absorbed at the surface, the effects of the magnetic field and heat released during the tidal force on the earth as it spins and volcanic activity. This energy is cost effective, sustainable, reliable and environmentally friendly.

The use of aeromagnetic data to estimate the CPD, geothermal gradient and heat flow is not new around the world, several authors have utilize that in the past. This present research paper utilizes the method of spectral analysis to estimate the CPD, geothermal grad and heat flow with Igumale and Ejekwe area, lower Benue trough Nigeria. This will help in viewing the thermal structure of the crust.

2 Methodology

2.1 Location And Geology Setting Of The Study Area

The study areas are Igumale and Ejekwe, lower Benue Trough, Nigeria. The geographical coordinates are between latitude 6°30' to 7°30' N and longitude 7°30' to 8°30' E. It is a major tectonic feature in West Africa. It is an elongated rifted depression that trends NE – SW direction and resting uncomfortably upon the Precambrian basement from the South where it merges with the Niger Delta to the North where its sediments are part of the Chad Basin succession. The Benue trough has generally three subdivisions namely; upper Benue trough, middle Benue trough and lower Benue trough[5]. The lower Benue trough which is underlain by a thick sedimentary sequence was formed as a result of series of tectonics and repetitive sedimentation in the cretaceous time[9,10]. The oldest sediment belongs to the Asu River group. Asu River group comprises of bluish black shale with minor sandstone unit. The shale are typically fractured and weathered to needle shaped bodies at the surface. Sandstone horizons are minor in the extreme south but tend to increase northwards[11] of the Abakaliki formation in the Abakaliki area.

2.2 Source of Data

The airborne data of Igumale and Ejekwe used for this study were obtained from the survey conducted by Nigerian Geological Survey Agency (NGSA).

The data was gridded to form the total magnetic intensity (TMI) map and the residual map was separated from the regional map with the aid of Oasis Montaj software. The residual map was subdivided into eighteen (18) equal spectral blocks each in order to accommodate longer wavelength. The fast Fourier transform (FFT) was performed on the 18 spectral aeromagnetic grids (or window). The function of this FFT was to separate the cells of the residual data into energy spectrum and frequency component. The FFT was performed on the residual data for all the cell leading to the discrimination of the anomalies into its energy spectrum and frequency component. This bringing out the energy spectrum and frequency domain (cycle/m). Graphs of the logarithms of the spectral energies against frequencies in cycles per unit distance in radians per unit distance were plotted for the various blocks in MS excel. Two linear segments were drawn from each graph and their gradients (equation 1) were used to calculate the depths to Centroid (Z_0) and to the top boundary (Z_t) using equations 2 and 3 respectively.

The slope of the graph of logarithm of energy against frequency that is given by equation 1;

$$\frac{logE}{Frequency} \tag{1}$$

The estimation of the depth to the top boundary (Z_t) of that distribution from the slope of the line drawn from the low frequency part of the spectral[12],

$$Z_t = -\frac{m_2}{4\pi} \tag{2}$$

The estimation of the depth to the centroid (Z_o) of that distribution from the slope of the line drawn from the high frequency part of the spectral[12] in equation 3

$$Z_o = -\frac{m_2}{4\pi} \tag{3}$$

Where m_1 and m_2 are slopes of the high and low segments of the plots while Z_o and Z_t are depths to the centroid and top of the magnetic body respectively.

The Curie point depth also called the basal depth of the magnetic source was also calculated using equation (4)[13] and[14] in equation 3

$$Z_b = 2Z_o - Z_t \tag{4}$$

The Curie point depth and the geothermal gradient (change in temperature per unit length) are related by equation (5) and the Curie temperature of 580°C was used as a standard for magnetite[13–17] in equation 3

$$\frac{dT}{dZ} = \frac{580^{\circ}\mathrm{C}}{Z_b} \tag{5}$$

Where, $\frac{dT}{dZ}$ =geothermal gradient,

Z_b = basal depth

580°C = the standard Curie point isotherm

Furthermore, the CPD and the geothermal gradient can be related to the heat flow, q as shown in equation 6[14,16] in equation 3

$$\mathrm{q} = \lambda \frac{580^{\circ}\mathrm{C}}{Z_b} = \lambda \frac{dT}{dZ} \tag{6}$$

The thermal conductivity (lambda, λ) with the value of 2.5 $\mathrm{Wm^{-1}\,{}^{\circ}C^{-1}}$ was used as a standard in the study area[16].

These calculated values of Curie point depth, geothermal gradient and heat flow were separately inputted into Surfer software to construct the 2D contour map of CPD (Z_b), geothermal gradient ($\frac{dT}{dZ}$) and the heat flow (q) of the study area.

3 Results and Discussion

The residual map ranges from -124.6 Tn to 54.4 Tn. The colour legend bar indicates that areas of high intensity are marked pink; areas of medium intensity marked from green to yellow while areas of low intensity are marked blue. In computing the Curie point depth, the residual map of the study area was divided into eighteen blocks as shown in Figure 1. The graphs of log of energy against frequency were plotted as shown in Figure 2. The calculated depth to the top boundary ranges from 0,796 to 2.954 m, this is a true reflection of short wavelength while the depth to the centroid ranges from 6.095 to 9.554 m, it depicts Precambrian magnetic basement. These values were used in computing the CPD, geothermal gradient and heat flow as shown in Table 1.

Table 1. Calculated Curie depth, geothermal gradient and Heat flow

BLOCKS	Depth to Centroid(Z_0) in km	Depth to top boundary(Z_t) in km	Curie Depth (Z_b) in km	Geothermal gradient (dT/dZ) °C/km	Heat Flow(q)
1	8.138	0.936	15.340	37.810	94.525
2	7.721	1.486	13.956	41.559	103.898
3	7.962	0.814	15.110	38.385	95.963
4	8.785	1.960	15.609	37.158	92.895
5	8.660	1.486	15.834	36.630	91.575
6	8.730	2.954	14.506	39.983	99.958
7	7.642	2.374	12.910	44.926	112.315
8	7.333	0.991	13.675	42.413	106.033
9	7.695	0.796	14.589	39.756	99.390
10	8.967	1.783	16.151	35.911	89.778
11	6.746	2.381	11.111	52.201	130.501
12	7.483	2.646	12.320	47.078	117.695
13	9.554	1.706	17.402	33.330	83.325
14	7.308	0.995	13.621	42.581	106.453
15	8.236	1.251	15.221	38.105	95.263
16	7.460	0.963	13.957	41.556	103.890
17	6.095	1.716	13.906	41.709	104.273
18	8.295	1.939	14.650	39.590	98.975

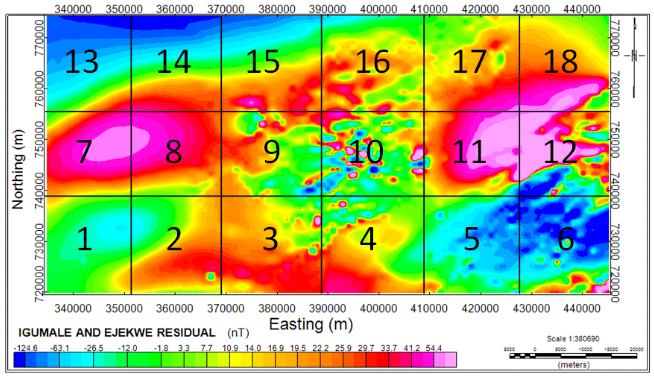

Fig 1. Division into 18 spectral blocks for geothermal analysis

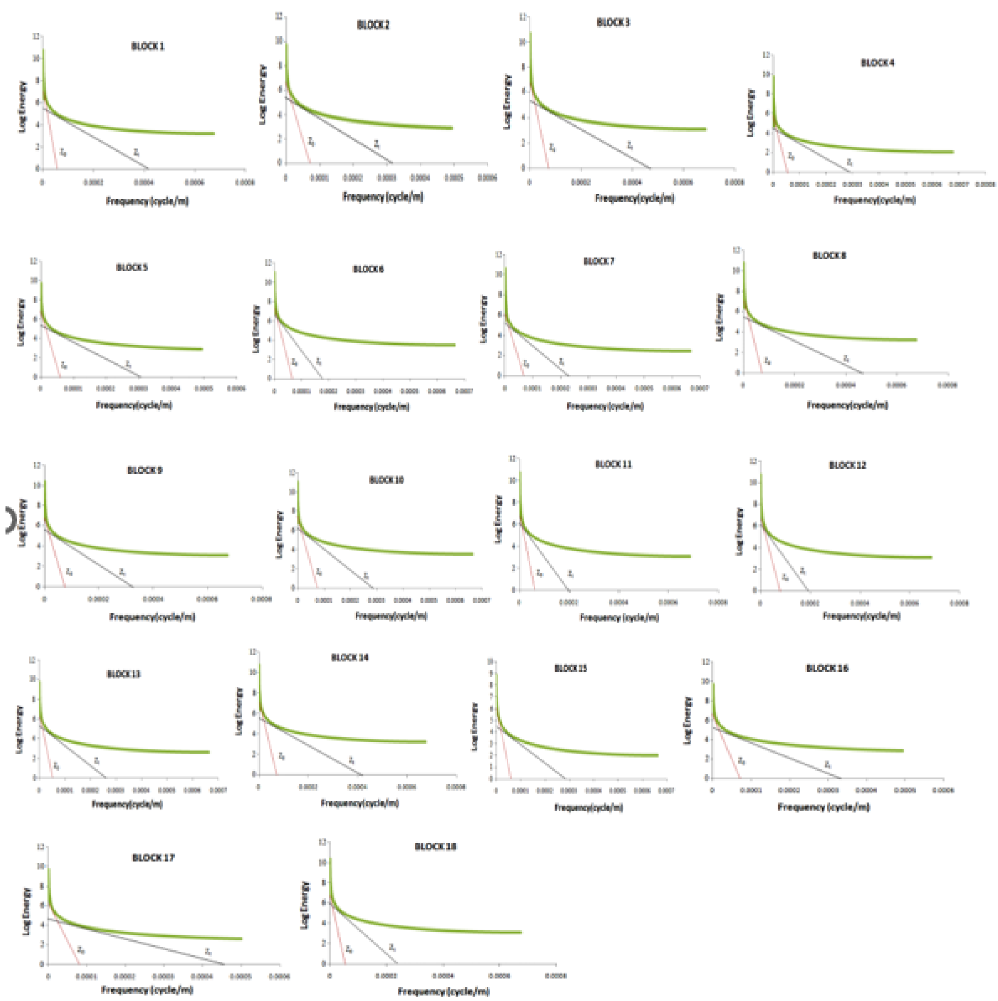

Fig 2. Plots of logarithm of Energy against Frequency (radian per meter) from block 1 to 18

3.1 Curie Point Depth, Geothermal Gradient and Heat Flow

From Table 1, the CPD, geothermal gradient and heat flow map were constructed using Surfer software. The CPD varies between 1.111 and 17.402km. The obtained basal depth (CPD) reflects the average local Curie depth point values beneath each block. It is observed that the Curie depth in the South-western part of the study area (12 - 13km) is shallower when compared to the other parts of the area. These reflect the thinning of the crust under Benue rift. The North-eastern part of the study area has deepest Curie depth (15 - 16km) while the other parts of the area have a deeper Curie depth as shown in Figure 3. The average heat flow obtained in the study area is 101.484mWm^{-2}. It ranges from 83.325 to 130.501 mWm^{-2}. The lowest heat flow range is found in south-western part of the study area while the highest value of 130.501mWm^{-2} is found in south-western part. The central part of the study area has heat flow values of 93 to 98 mWm^{-1}. The quantitative change in curie depth observed in Figure 3 infers that the heat flow values vary in study area. These are clearly displayed on the heat flow contour map in Figure 5. The calculated geothermal gradient in the study area varies between 33.330 and 52.201C/km with an average value of 40.593C/km. These results compared favourable well with other researchers (4) (17), who carried out their studies in the lower Benue trough. Measurements have also shown that anomalous high temperature and heat flow are attributed to the region with significant geothermal energy. It is expected that active geothermal areas will be associated with shallow Curie point. This relationship is clearly demonstrated by the heat flow contour map (Figure 5) and geothermal gradient map (Figure 4).

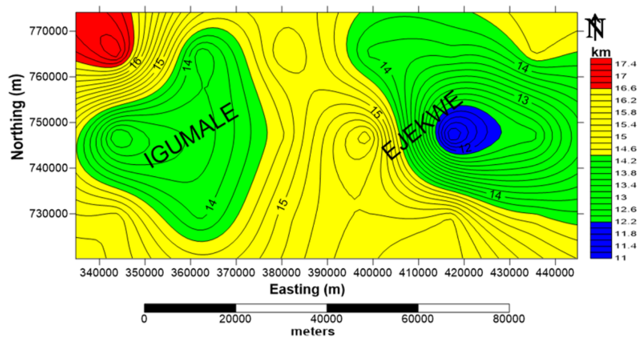

Fig 3. Curie depth map of the study area (contour interval of 0.2km)

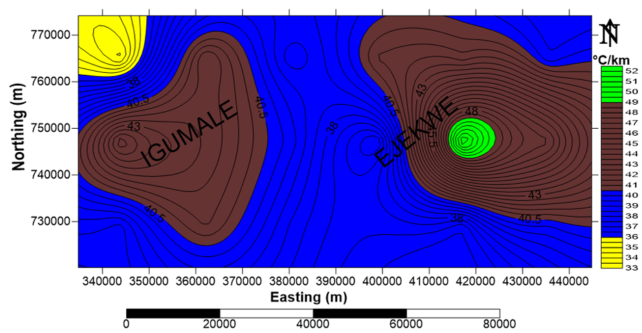

Fig 4. Geothermal gradient contour map of the studyarea (Contour interval of 0.5°C/km)

4 Conclusion

The aeromagnetic data of Igumale and Ejekwe area of lower Benue trough have been interpreted quantitatively and qualitatively. We have examined the Curie point depth and geothermal gradient by employing spectral analysis on the aeromagnetic data within study area. The study area is characterized with high heat flow and geothermal gradient. These results indicated that the study area has a good potential for the generation of geothermal energy especially at Ejekwe area. The high heat flow and geothermal gradient observed in the area maybe as a result of rifting and magmatism induced tectonically during Pan-African

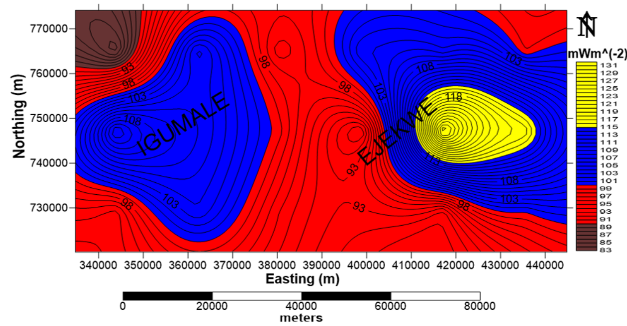

Fig 5. Heat flow contour map of the study area (Contourinterval of 1)

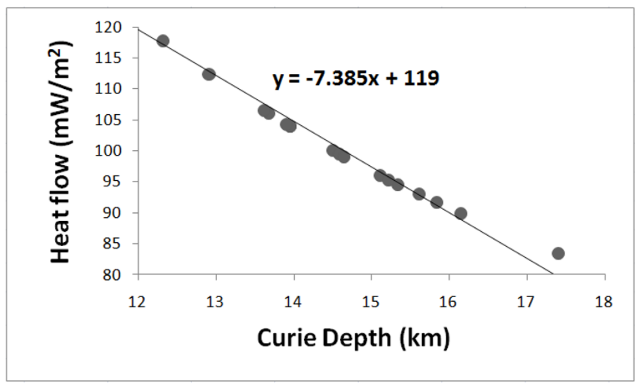

Fig 6. Plot of Heat flow against Curie point depth

Orogeny.

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