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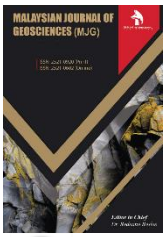

RESEARCH ARTICLE

GEOPHYSICAL INVESTIGATION TO ESTIMATE THE CURIE POINT DEPTH, HEAT FLOW AND GEOTHERMAL GRADIENT IN SOKO AND ANKPA, BENUE TROUGH NIGERIA

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ABSTRACT

This work presents the interpretation of the aeromagnetic data over Soko and Ankpa area using spectral analysis method. The study area was divided into eight (8) equal spectral blocks in order to estimate the depth to the top boundary, centroid, Curie point depth, heat flow and geothermal gradient of the study area. The result of the analysis shows the range of the depths to the top boundary and centroid varies between 1.085 to 1.984 km and 6.151 to 8.730 km respectively. The Curie temperature isotherm ranges between 11.112 km and 15.476 km and the geothermal gradients associated with it ranges from 39.967 and 52.196 $^{0}C/km$. The corresponding values of heat flow ranges from 93.697 mWm^2 and 130. 490 mWm^2. From this analysis, it was observed that areas with high geothermal gradient correspond to high heat flow and an inverse relationship exists between the heat flow and the Curie point depth. With the high geothermal gradient especially at the southeastern part of the study area, there is a possibility of enough geothermal energy for exploration in order to boost and generate clean energy for electricity.

KEYWORDS

Ankpa, Soko, depth to the centroid, depth to the top and geothermal energy.

1. INTRODUCTION

Developed and developing countries have successfully used geothermal energy in generation of electricity to meet the rapid growth in demand for electricity to power industries and households across the world. In power generation, geothermal energy is consider to be one of the most clean energy source and has appealed the growing attention worldwide (Okorie et al., 2019). It has several advantages over fossil fuels of having clean, large reserves and environmentally friendly (Croteau and Gosselin, 2015). There will be a reduction in the emission of harmful gases and particulate matter resulting from the combustion of fossil fuels if there is an increase in global utilization of geothermal resources.

According to power base line in 2015, Nigeria has one of the lowest rate of consumption of electricity per capita in Africa. Nigeria generated about 4,000 MW of electricity for her population of over 170 million in which 80% of the total electricity produced is consumed on demand by residential and commercial sectors in Nigeria (Abraham and Nkitnam, 2017). As a result of these challenges, there is need to emphasize the exploration of various energy resources available particularly the geothermal energy to aid the new energy map for the country. In long term vision for providing reliable and renewable environmental-friendly sources of energy for Nigeria, the importance of geothermal energy can never be over emphasize.

In Nigeria, geothermal energy has been given little or no attention in the past. Several researchers have carried out work within the Benue trough using aeromagnetic data for the purpose of determining the presence of mineral and geothermal investigation (Obiora et al., 2016; Ekwueme et al., 2018; Yakubu et al., 2020). This paper focuses on Ankpa and Soko area for the purpose of investigating the geothermal potential of the study area

2. LOCATION AND GEOLOGY OF THE STUDY AREA

The area of study is located within the lower Benue Trough, Nigeria and is comprised of Soko and Dekina areas. The Benue Trough of Nigeria is one of the most prominent geologic features in West Africa. It extends over a distance of 800km trending in the NNE-SSW direction starting from the Niger-Delta to the South-West of the lake Chad and it ranges from about 130 to 250 km in width (Obaje et al., 2006). Because of the large regional area, the studies in the Benue Trough are usually separated geographically into the lower, middle and upper Benue Trough. The depocenters of the lower Benue Trough is made up of the area around Anambra basin and Abakaliki Anticlinorium (Uplift) whereas Middle Benue Trough comprise the area around Makurdi through Yandev, Lafia, Awe, Akiri, Keana, Wukari to Jangwa. In the Upper Benue Trough, the depocenter comprise Gombe, Nafada (Gongola arm) and Bambam, Jessus, Lakun and Numan (Yola arm) (Fatoye et al., 2014).

3. DATA SOURCE AND METHODOLOGY

The data of the study area (Soko and Ankpa) was obtained from the Nigeria geological survey agency (NGSA) Abuja. The airborne geophysical work was carried out by Fugro Airborne survey, in which an aircraft was flown at 80 m terrain clearance and 500 m line spacing. The digitized data by FURGRO airborne surveys was obtained from the Nigeria geological

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survey agency in XYZ format. X is the latitude, Y is the longitude and the Z is the magnetic field intensity.

The data was gridded to form the total magnetic intensity (TMI) map. The TMI of the study area was subdivided into eight (8) equal blocks each in order to accommodate longer wavelength. The obtained magnetic data was transformed into radial energy spectrum for each block using microsoft excel and Fourpot software. The graphs of log of energy against frequency was plotted. Two linear segments were identified, which indicates the presence of two magnetic source layers in the study area. The slope of the deep and shallow line segments were calculated for each block, then depth to centroid Z_o and depth to top boundary, Z_t were also evaluated using equations 2 and 3 respectively.

In performing the spectral analysis, the first stage is to estimate the depth to the centroid (Z_o) and depth to the top boundary (Z_t) of the magnetic source from the gradient of the graph of logarithm of energy against frequency that is given by equation 1;

$$\frac{logE}{Frequency} \quad (1)$$

Where frequency is measured in cycle/metre
From the graph, linear segments were drawn from the high frequency portion of the spectral, from which the slopes were estimated for the calculation of the depth to the centroid (Z_o) using the equation (2):

$$Z_o = -\frac{m_1}{4\pi} \quad (2)$$

Also, the depth to the top boundary (Z_t) was estimated from the low frequency portion from the gradient of the line drawn from the low frequency part of the spectral (Okubo et al., 1985).

$$Z_t = -\frac{m_2}{4\pi} \quad (3)$$

where, m_1 and m_2 slopes of the high and low segments of the plots while Z_o and Z_t are depths to centroid Z_o and depth to top boundary, Z_t respectively. The Curie point dephth (basal depth of the magnetic source) was evaluated using equation (4) as (Tanaka et al., 1999; Okubo et al., 1985);

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

The geothermal gradient (change in temperature per unit length) and the Curie point depth are related by equation (5) and the Curie temperature with value 580°C was used standard for magnetite (Maden, 2010; Stampolidis et al., 2005; Tanaka et al., 1999; Frost and Shive, 1986).

$$\frac{dT}{dZ} = \frac{580^oC}{Z_b} \quad (5)$$

Furthermore, the Curie point depth and the geothermal gradient are related to the heat flow (q) as shown in equation 6 (Tanaka et al., 1999; Turcotte and Schubert, 1982):

$$q = \lambda\frac{580^oC}{Z_b} = \lambda\frac{dT}{dZ} \quad (6)$$

The thermal conductivity (lambda, λ) of 2.5 $Wm^{-1}C^{-1}$ was used as a standard in the study area (Nwankwo et al., 2011). These calculated values of the geothermal gradient, Curie point depth and heat flow were inputted separately into Suffer software to construct the 2D contour map of geothermal gradient, Curie point depth and heat flow of the study area.

4. Presentation of Results and Discussion

The total magnetic intensity of Soko and Ankpa area, after gridding showed that the magnetic intensity varies between -124.6 and 112.2nT as shown in Figure 1. These variations in the magnetic signatures may be due to either difference in lithology, faults, depth to the magnetic source, susceptibility contrast or degree of geologic strike in the study area.

The areas of low magnetic anomaly likely indicate lower concentration of magnetically susceptible minerals, while areas with high positive magnetic anomaly will likely indicate higher concentration of magnetically susceptible minerals.

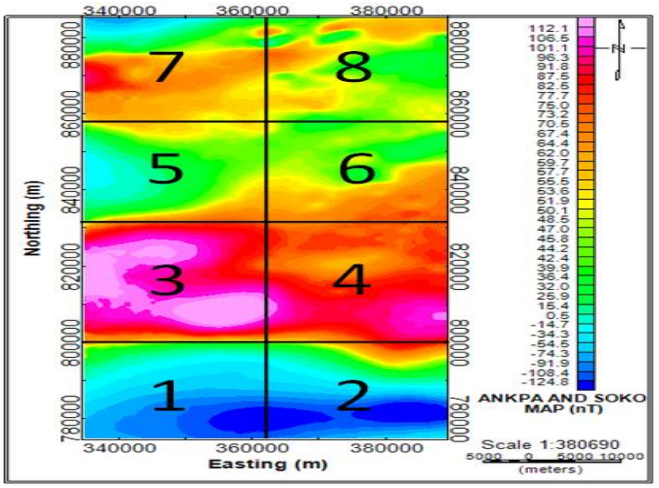
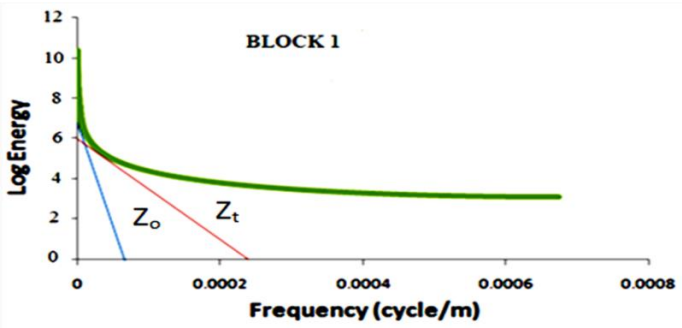
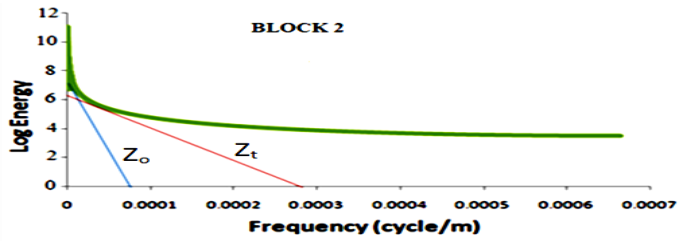
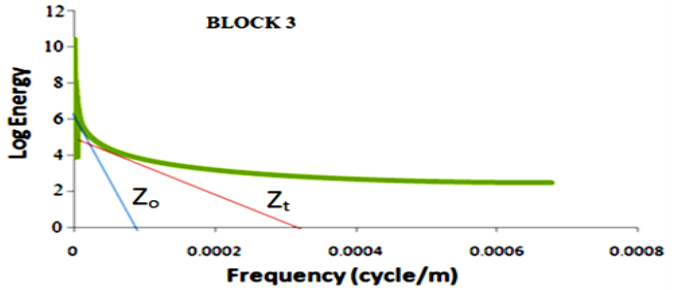


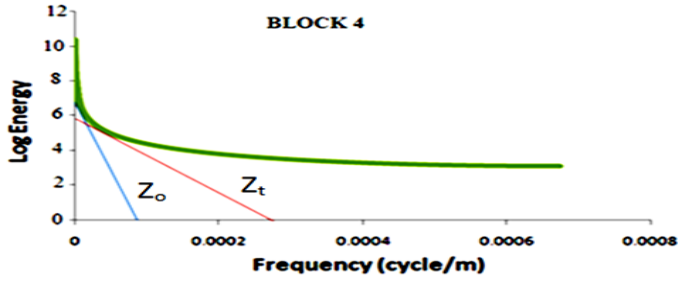
Figure 1: Division of TMI grid into 8 spectral blocks for geothermal analysis

In computing the Curie point depth, the TMI map of the study area was divided into eight (8) equal spectral blocks as shown in Figure 1. FOURPOT and Excel computer software was used in carrying out the analysis. The graphs of logarithms of energy versus frequency were plotted for each of the spectral blocks shown in Figure 2. The results of the depth to the centroid, top, geothermal gradient, Curie point depth and heat flow are shown in Table 1.









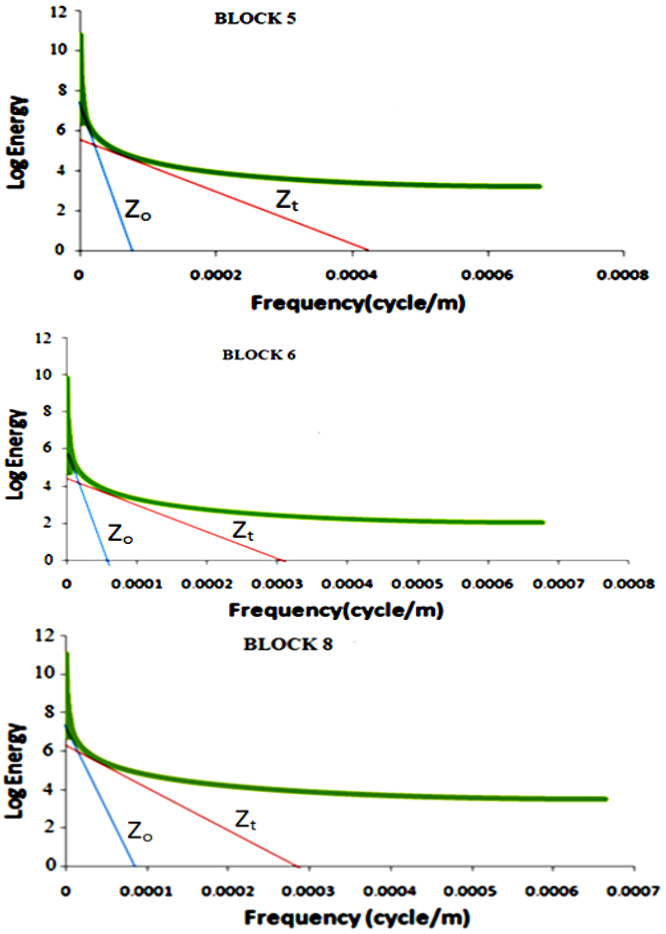


Figure 2: The graphs of logarithms of energy versus frequency

Table 1: The calculated Curie point depth, Geothermal gradient and Heat flow

Blocks	Depth to centroid (Z_0) in km	Depth to top boundary (Z_t) in km	Curie point depth (Z_b) in km	Geothermal gradient ($\frac{dT}{dZ}$) in °C/km	Heat flow (q) in mWm^{-2}
1	8.730	1.984	15.476	37.477	93.693
2	8.163	1.814	14.512	39.967	99.9173
3	6.151	1.190	11.112	52.196	130.490
4	6.548	1.705	11.391	50.917	127.293
5	7.540	1.058	14.022	41.364	103.409
6	7.407	1.178	13.636	42.534	106.336
7	6.548	1.389	11.707	49.543	123.858
8	7.341	1.752	12.930	44.857	112.142

From table 1, the contour map of geothermal gradient, Curie point depth and heat flow was constructed with the aid of Surfer 13 software. The Curie point depth varies between 11.112km and 15.47km. The south western portion of the study area is having relatively high value of 15.47km Curie point depth. The shallowest region is at the south east and south west central portion of the study area which ranges from 11km-11.4km as shown in Figure 3. In figure 4, the map defines a region of high geothermal gradient of $51.1^0\,C/km$ which is in the southwestern and around the southwestern parts of the study area and a low value of geothermal gradient of $36.5^0\,C/km$ occurred at the southern (Ankpa) part of thestudy area. it was observed that area of high heat flow corresponds with the area of high geothermal gradient and vice versa. The heat flow varies between 93.697 and 130.490mWm^{-2}. The highest heat flow value is 130mWm^{-2} and it is observed in the southwestern and southeastern part of the area while the lowest value of heat flow of about 92mwm^{-2} occurred at the southern part of the study area as shown in Figure 5.

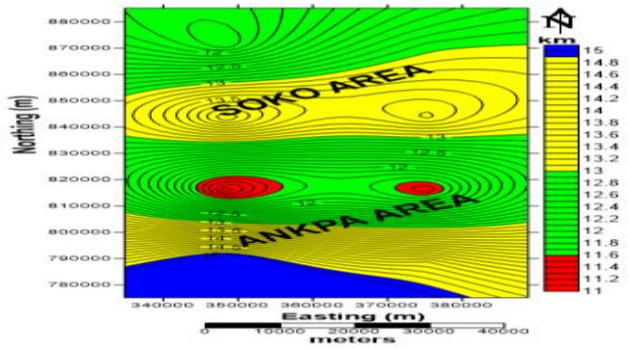


Figure 3: The Curie point depth map of the study area.

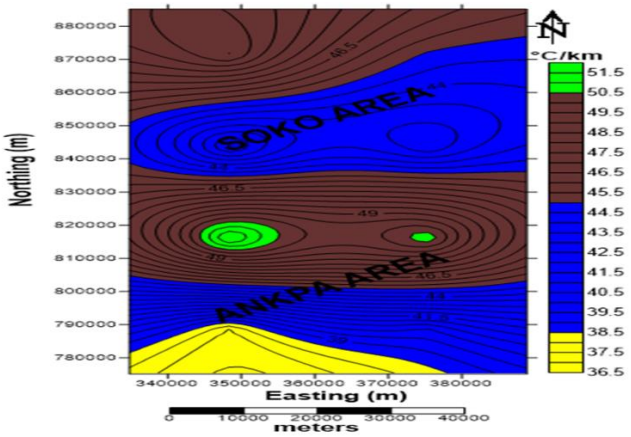


Figure 4: The geothermal gradient map of the study area.

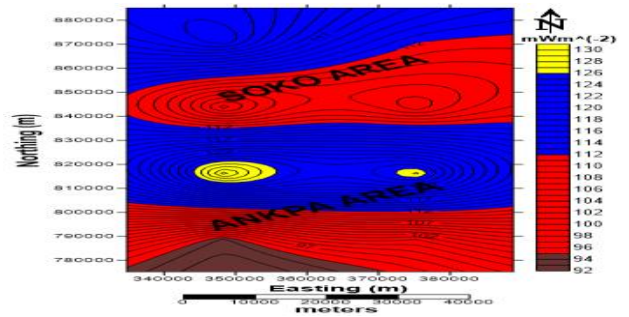


Figure 5: The heat flow contour map of the study area (Contour interval of 1 *mWm-2).*

Measurements have shown that, a typical high value of heat flow and geothermal gradient are attributed to the region with significant geothermal energy potential. In view of this, the area of study with high value of geothermal gradient has a good potential for the generation of geothermal energy (Barbier et al., 2011). Usually, shallow Curie point depth is linked to area of active geothermal gradient and heat flow. This assertion is clearly revealed by the contoured map of geothermal gradient (Figure 4) and that of heat flow (Figure 5). The result of Curie point depth deduced from the analysis of aeromagnetic data using spectral method in combination with the calculated values of heat flow values showed an inverse correlation between Curie point depth and heat flow as shown in Figure 6.

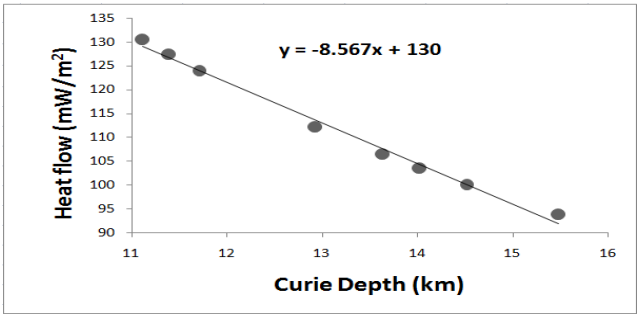


Figure 6: The graph of heat flow against Curie point depth.

5. Conclusion

The Curie point depth, heat flow and geothermal gradient of the area of study has been determined by employing spectral analysis. The results have thrown more light on the understanding of contributions of Curie point depth, heat flow and geothermal gradient, particularly to geophysicists and other geoscientists. Furthermore, with the high geothermal gradient especially at the southeastern part of the study area, there is a possibility of enough geothermal energy potential geothermal for exploration.

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