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Interpretation of High Resolution Aeromagnetic Data to Estimate the Curie Point Depth Isotherm of Parts of Middle Benue Trough, North-East, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author AA wrote the first draft of the manuscript and performed the statistical analysis. Author KAS design the study and appraised data quality. Author TA check the protocol, and managed the literature searches. Author AM check grammar and language. All authors read and approved the final manuscript.

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ABSTRACT

This research work deals with estimation of Curie point depth isotherm using aeromagnetic data of part of middle Benue Trough, North-East, Nigeria. The study area lies within the Longitude 9°E – 10°E and Latitude 8°N – 9.50°N with an estimated total area of 18150km^2. Regional/Residual separation was performed on the total magnetic intensity using polynomial fitting. The residual map was divided into fourteen spectral blocks and the log of spectral energies were plotted against frequency. Centroid depth and depth to top boundary obtained were used to estimate the Curie point depth isotherm which is the depth at which the crust and uppermost mantle magnetic materials cease to be magnetic as a result of increase in temperature as depth increases. The result shows that the Curie isotherm depth varies between 17.04km to 27.40 km with an average value of 22.5 km. Based on previous research works, the Curie point depth isotherm obtained from this study is a good source of geothermal potential.

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1. INTRODUCTION

The bottom of a magnetic source indicate the thermal boundary at which magnetic mineral in the crust loss their magnetic properties as a result of increase in temperature as depth increase down the crust [1,2]. This thermal boundary is referred to as Curie point depth and it is the nethermost part of the crust to have material which develops discernible mark in a magnetic anomaly map [3]. This point is assumed to be the depth for the geothermal source (magmatic chamber), where most geothermal reservoir tapped their heat from in a geothermal environment [4].

This Curie point has a Temperature 0f 550^0C± 30^0C. For temperature above curie-point, magnetic materials loose there magnetic ordering and both induced and remnant magnetisation disappears, and for temperature greater than 580°C those materials will begin to encounter ductile deformation [1].

Literatures such as [2,4,5,6,7,8,9] have shown that spectral analytical method can be regarded as a proxy for an estimate of Curie-point depth(CPD). Records have shown that there is minimal record of geophysical studies on regional geothermal structure in the middle Benue trough.

In an effort to boost the power sector of Nigeria, it is of necessity to carry out this present research work which is aimed at estimating the Curie point depth isotherm of part of middle Benue trough using high resolution aeromagnetic data for geothermal potential source.

2. LOCATION AND GEOLOGY OF THE STUDY AREA

The study area (Fig. 1) located in the northeastern part of Nigeria and lying between Latitude 8^0N and 9.5^0 N and longitudes 9^0 E and 10^0 E with estimated total area of *18,150km^2*. It is bounded by middle Benue trough (Fig. 2). The Benue Trough comprises of a progression of rift basins that model a portion of the Central West African Rift System of the Niger, Cameroon, Chad and Benin Basement fracture, subsidence, block faulting and cracking [10].

[11] pointed out that the Benue Trough generally has been geographically and structurally subdivided into three parts erroneously termed as "lower Benue Trough", "middle Benue Trough" and an "Upper Benue Trough". The area is housed by middle Benue trough, the study conducted by [12] distinguishes six sedimentary Formations in the middle Benue trough which are Asu River Group, Keana Formation, Awe Formation, Ezeaku Formation, Awgu Formation, Lafia Formation.

The oldest, Asu River Formation being middle to Albian and the youngest, Lafia Formation is of the Maestrichtian age. The lithologic composition of the Asu River Group comprises limestones, shales, micacous siltstones, mudstones and clays [12,13].

The deposition of the Awgu Formation marks the end of marine sedimentation in this part of the Benue Trough. The formation is made up of bluish-grey to dark-black carbonaceous shales, calcareous shales, shaley limestones, limestones, sandstones, siltones, and coal seams [12].

The deposition of the Ezeaku Formation is attributed to the beginning of marine transgression in the Late Cenomanian. The sediments are made up mainly of calcareous shales, micaceous fine to medium friable sandstones and beds of limestones which are in places shelly.

The Awe Formation was deposited as passage (transitional) beds during the Late Albian Early Cenomanism regression. The formation consists of flagy, whitish, medium to coarse grained calcareous sandstones, carbonaceous shales and clays.

The Keana Formation resulted from the Cenomanian regression which deposited fluviodeltaic sediments. The formation consists of cross-bedded, coarse grained feldsparthic sandstones, occasional conglomerates, and bands of shales and limestones towards the top [13].

The Lafia Formation is the youngest formation in this area. The formation was deposited under continental condition (fluviatile) in the Maastrichtian and lies unconformably on the Awgu Formation. It is lithologically characterized by ferrug- inized sandstones, red, loose sands, flaggy mudstones, clays and claystones. [14].

The work of [15], Burke et al. [12,16] and [17] and [18] have more on the geology of the Benue Trough.

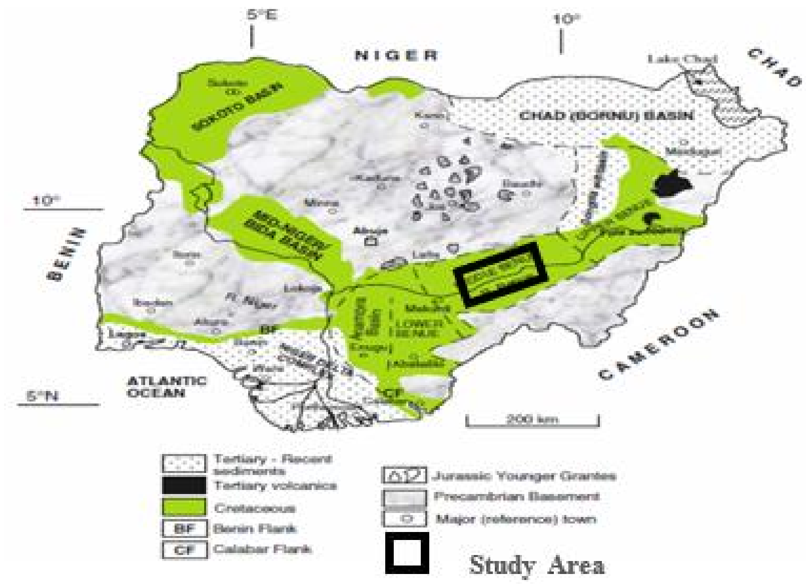

Fig. 1. Geological Map of Nigeria showing the study area in black outline [10]

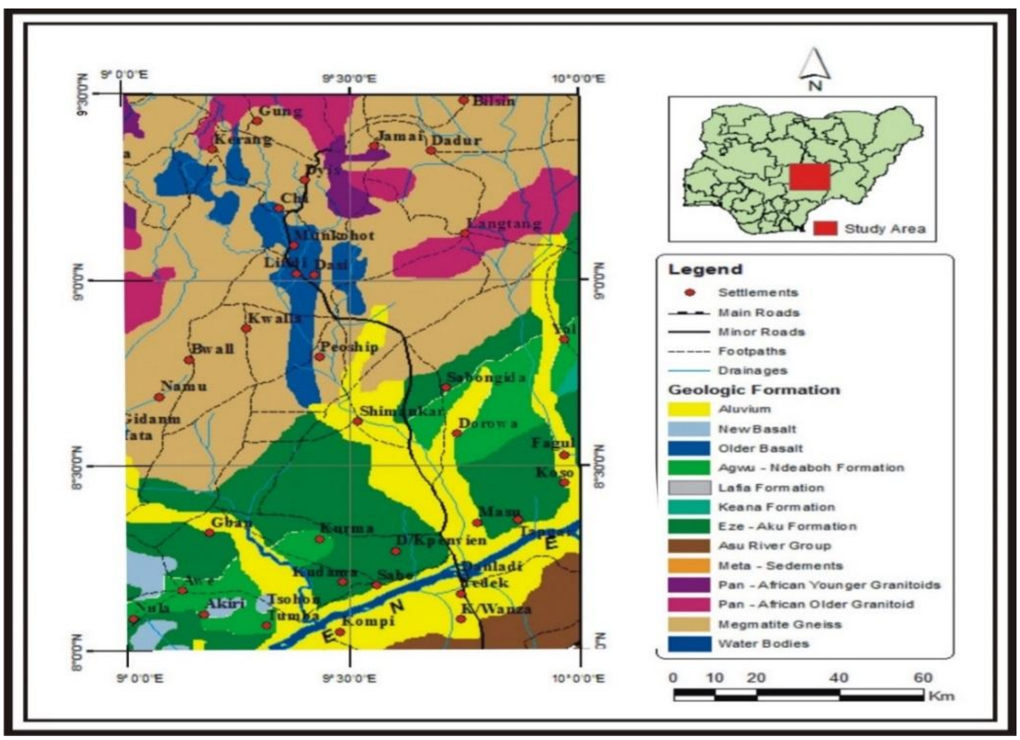

Fig. 2. Geological map of the middle Benue trough [19]

3. MATERIALS AND METHODS

For this work, six aeromagnetic maps with sheets numbers 190, 191, 211, 212, 231 and 232 covering the study area was acquired from the Nigerian Geological Survey Agency (NGSA) Abuja as a part of the across the nation aeromagnetic study carried out in 2009 by Fugro Airborne survey. The data was acquired using magnetometers. 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 2km 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. Each 1:100,000 topographical sheet covers an area of about 3025 km^2 (i.e. 55 km x 55 km) totalling a superficial area of 18150 km^2.

The six total field aeromagnetic sheets were assemble, merge into Oasiss montaj 6.42v software to produce the map of the total magnetic intensity, TMI (Fig. 3) of the area. This total magnetic intensity map was then subjected to polynomial fitting of order two to derive the residual magnetic values by subtracting values of the regional fields from the total magnetic intensity values, the residual component formed the basis for further analysis an interpretation.

3.1 Spectral Method

It is a depth estimating method pioneered by [20] and later developed by [21]. It has been utilized widely in the analysis of magnetic anomalies as in the determination of average depth to the top of magnetic basement, computation of crustal thickness, thermal framework of the earth: [3,22,23,24,4,25,26,6,27,28]. The techniques permits an estimate of depth of magnetized blocks of varying depth, width, thickness and magnetisation. Most approaches used include Fourier transformation of the aeromagnetic data to estimate the energy (or amplitude) spectrum by transforming the spatial data into frequency domain.

3.2 Curie Point Depth Estimation

The methods of Curie Point Depth determination utilize spectrum analysis techniques to separate influences of the different body parameters in the observed magnetic anomaly field. Fundamentally, the method of [21] estimates the average depth to the top boundary of the magnetized layer from the slope of the log power spectrum while the method of [3] obtains the depth to the centroid (effects from the bottom)of the causa-tive body using a single anomaly interpretation. [29] effec-tively combined and expanded both methods to propose an algorithm for regional geomagnetic interpretation oriented to the purposes of geothermal exploration.

The Curie point depth is evaluated in two stages as proposed by; The first stage is the estimation of depth to centroid $h_{0,}$ of magnetic source from the slope of the longest wavelength part of the spectrum, using equation [29,30,4].

$$\ln\left[\frac{\sqrt{p(s)}}{|s|}\right] = \ln A - 2\pi|s|h_0 \qquad (1)$$

where

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

The second stage is the estimation of the depth to the top boundary h_1 from the slope of the second longest wavelength part of the spectrum [29] and [31,30,4].

$$\ln\sqrt{[p(s)]} = \ln B - 2\pi|s|h_1 \qquad (2)$$

where B, is the sum of constant independent of |s|.

The basal depth h_b also known as Curie point depth was calculated from the equation below. [29] and [31]; [4].

$$h_b = 2h_0 - h_1 \qquad (3)$$

where h_0= centroid depth, h_1 = depth to the to the top boundary.

4. RESULTS AND DISCUSSION

The total magnetic intensity map, TMI (Fig. 3) and the residual magnetic intensity map (Fig. 4) shows variation of highs and lows in magnetic signature. About one third of the map can be seen to be greenish (featureless) which may correspond to alluvium deposition in the southern part of the study area, the pink colouration depicts high magnetic signature while blue depicts low magnetic signature and yellow indicates intermediary.

The negative values imply areas that are magnetically subdued or quiet while the positive values are magnetically responsive. The magnetically subdued areas are the magnetic lows of the study area and this is typical of a sedimentary terrain while the magnetic responsive areas are the magnetic highs regions which are assumed to be due to the likely presence of outcrops of crystalline igneous or metamorphic rocks, deep seated volcanic rocks or even crustal boundaries. From (Fig. 3) the high magnetic anomaly (denoted with **H**) which can probably be attributed to igneous intrusion and shallower sediment is well pronounced in the central part trending approximately East-West similar to the one in residual map (Fig. 4). The high magnetic signature can also be found in the North-Eastern part trending North-West while the low magnetic anomalies associated with the sedimentary region was well pronounced in North-Western, North-Eastern, while other scattered at the edges of North-Eastern part of the study area. The low magnetic signature denoted with **L** is well pronounced in the northern part of the study area, though few could also be found at Southern part of the study area trending NE-SW.

The varying amplitude of these magnetic anomalies is an indication of different sedimentary thickness in the study area. These variations in the anomaly amplitude may also indicate possibly the occurrences of basement complex rocks containing varying amounts of magnetic minerals.

The traced line on the map is probably a fracture (fault line). At some places on the southern part of the residual map (Fig. 4) there is a break in the NE-SW trending magnetic low present on the total magnetic map (Fig. 3). These anomalies may be due to magnetic source of shallow origin.

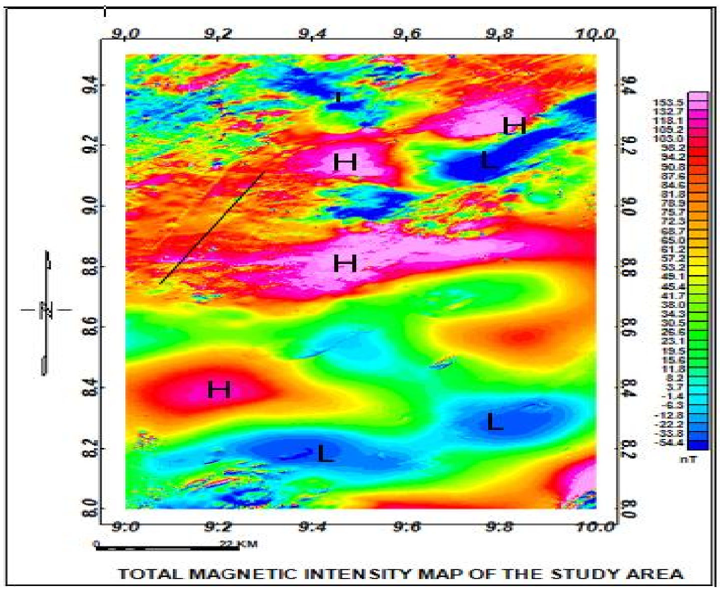

Fig. 3. Total magnetic intensity map of the study area (33000nT must be added to the data so as to get the actual value at any point)

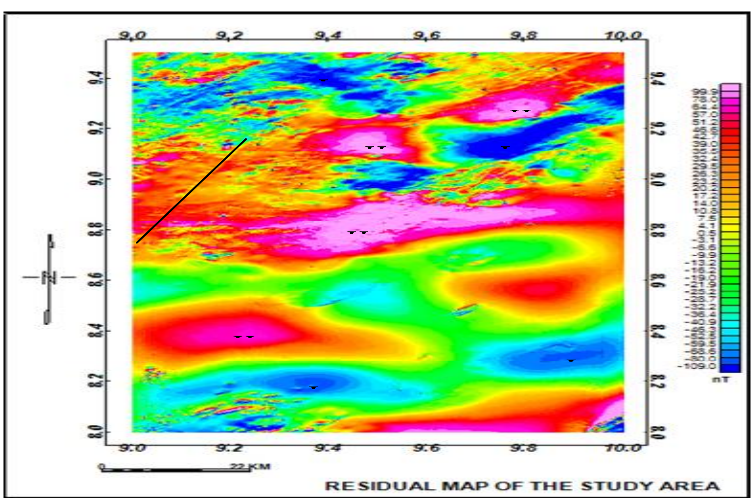

Fig. 4. Residual map of the study area

4.1 Spectral Analysis

The residual map (Fig. 4) of the study area was divided into fourteen (Blocks A - N) overlapping magnetic sections in which six (Blocks A - F) covered 55 km by 55 km data points, three other division (Block G,H and I) covered 110 km by 55 km data points, J, K and L covered 110 km by 110 km and Block M and N covered the remaining 165 km by 55 km part of the study area. In doing this division we ensured that essential parts of anomaly were not cut by the blocks.

The divisions of residual map into spectral sections or blocks were done with Oasis Montaj. The analysis was carried out using a spectral program plot (SPP) developed with MATLAB. Graph of the logarithm of spectral energies against frequencies obtained for blocks A, B, C and D are shown in Fig. 5. The estimated value for centroid depth and depth to the top boundary, Z_0 and Z_1 respectively are shown in Table 1.

From the graphs of the Logarithm of spectral energies versus frequencies plotted for each block, there were spectral peaks which were easily noticeable and the significance of this is the indication of the fact that Curie point depths are detectable as it defines the source bottoms.

4.2 Curie Point Depth (CPD)

The results of the spectral analysis of aeromagnetic anomalies over the area shows that the Curie point depth estimates (using equation 3) range between 17.04 km and 27.4 km (Table 1) with an average value of 26.62 km. Literatures such as [3,22,28,4] indicates that CPD is greatly dependent on the geologic conditions of an area under consideration, the CPD are shallower in volcanic and geothermal field.

Subsequently, contour map (Fig. 6) of the Curie point depth was generated. It shows that high values of 21 km to 27.5 km are located at the central region (Wamba and Kwalla) to the north-eastern part (Pankshin) and lower values of 17 km to 19.5 km can be located at the central southern part (Ibi and Akwana) and the north western part (Wase), this low value might be as a result of igneous intrusion or the dominance of Ezeaku formation (sandstone and limestone) in the area.

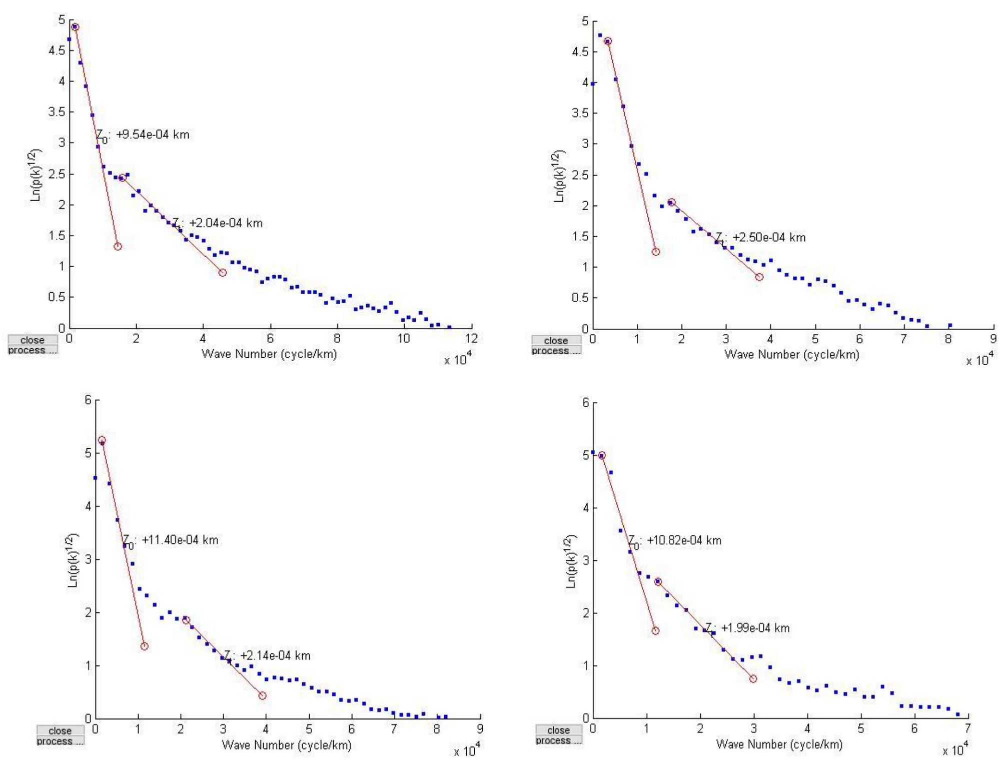

Fig. 5. Typical plots of the logarithm of spectral energies against frequencies obtained for block A, B, C, and D

Table 1. Location and depth estimation of centroid depth (Z_0), depth to basement (Z_t) and CPD (Z_b)

Blocks	Longitude (degree)	Latitude (degree)	Depth to centroid, Z_o(km)	Depth to the top boundary Z_t(km)	Curie point depth, Z_b(km)
A	9.25	9.25	9.54	2.04	17.04
B	9.75	9.25	13.30	2.50	24.1
C	9.25	8.75	11.40	2.14	20.66
D	9.75	8.75	10.82	1.98	19.66
E	9.25	8.25	9.56	1.20	17.92
F	9.75	8.25	9.36	1.40	17.32
G	9.5	9.25	10.60	2.00	19.20
H	9.5	8.75	15.40	3.20	27.40
I	9.5	8.25	10.44	1.70	19.18
J	9.5	9.0	11.04	1.50	20.58
K	9.5	8.0	12.98	1.84	24.12
L	9.25	8.25	14.70	2.08	27.32
M	9.75	8.25	11.32	1.86	20.78
N	9.5	8.25	12.42	1.65	23.19
Average			11.63	1.94	21.32

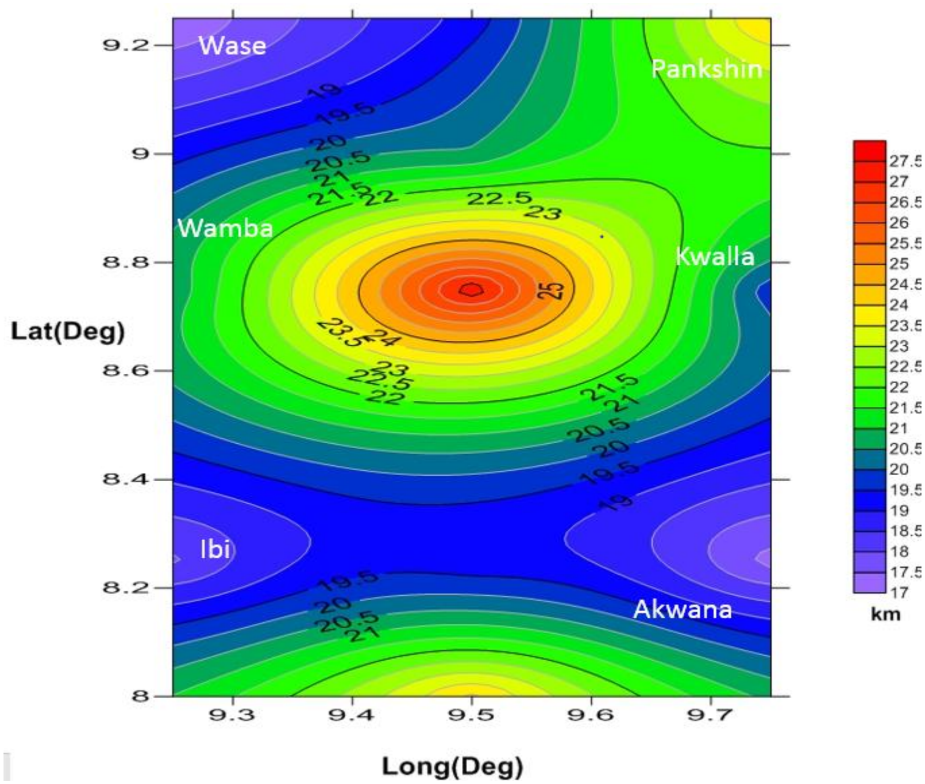

Fig. 6. Contour map of the Curie point depth Contour interval is 0.5 km

5. CONCLUSION

The Curie point isotherm has been determined in the north eastern part of the middle Benue trough and it is found to range between 17.04 km and 27.4 km with an average value of 26.62 km. In the central part of the study area, bounding Wamba, Kwalla and Pankshin, the Curie point depth was found to attain its highest estimate of 21 km to 27.5 km while it was found at depths between 21 km to 27.5 km around Ibi, Akwana and Wase.

The result largely agreed with [6] that estimate the immediate Eastern part of the study area Curie point depth to vary between 24 km and 28 km.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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