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Analysis of Anomalies of the Earth's Magnetic in South-West Cameroon (Central Africa): Estimation of the Depth to the Bottom of Magnetic Sources (DBMS)

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Abstract

In this study, 3 overlapping blocks in South-West Cameroon is used to estimate the depth to the bottom of magnetic sources (DBMS) using Centroid method. The depth to the top of magnetic bodies varies from 2.40 km to 3.37 km in the region. The centroid depth and DBMS varies from 15.57 to 16.22 km and 27.77 to 30.04 km respectively. The geothermal gradient and heat flow are also estimated. The geothermal gradient varies between 19.3 and 20.88°C.km^{-1}, while the few heat flow values range between 48.26 to 52.21 mWm^{-2} based on the constant temperature at the DBMS. Spectral analysis of the data in conjunction with heat flow values revealed an almost inverse linear relationship between heat flow and Curie depths. This study has proved the existence of geothermal resources in the study area. Due to that, the results obtained could be very important for future research and geothermal exploration in the study area.

Keywords: Depth of magnetic sources, Heat flow, Geothermal gradients.

1. Introduction

The study area lies in the Congo Craton between latitudes 2.5° to 4.5°N and longitudes 11° to 13°E. The evolution of this region is constrained by the continental collision between the Congo Craton and the mobile belt (Poidevin, 1983; Nzenti et al., 1984; Penaye et al., 1993; Trompette, 1994; Castaing et al., 1994; Abdelsalam et al., 2002; Basseka, 2002).

The estimation of the depth to the bottom of magnetic sources (DBMS) from the aeromagnetic data is always a challenge. Several studies have shown a correlation between the DBMS and average crustal temperatures in a number of regions around the world: California (Ross et al., 2006), Central Southern Europe (Chiozzi et al., 2005), African – Eurasian convergence zone, SW Turkey (Dolmaz et al., 2005), Island of Kyushu and surrounding area (Okubo et al., 1985), Northeast Japan (Okubo and Matsunaga, 1994), Yellowstone National Park (Bhattacharyya and Leu, 1975). The DBMS is an important parameter to understand the temperature distribution in the crust and the rheology of the Earth's lithosphere (Ravat et al., 2007). Some authors assume that the DBMS is equivalent to the Curie point depth (CPD) of the magnetic minerals, where rocks lose their ferromagnetic properties due to an increase of the temperature in the crust.

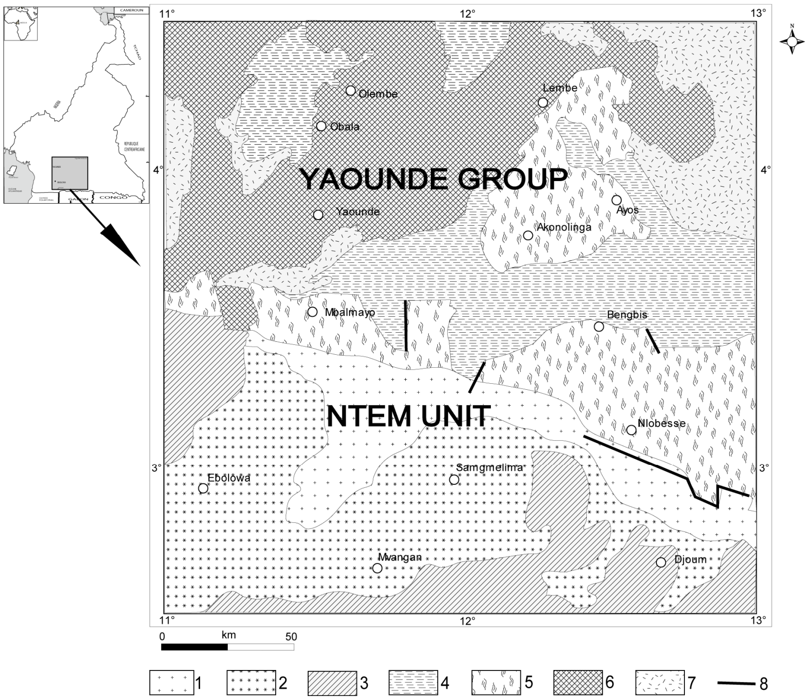
Although results of all the works cited above provided useful information over the study area, none of them gave precise information about the depth to the top and bottom, the heat flow and the geothermal gradient in the study area, which are the objectives of the present study. For this purpose, the basal depth of a magnetic source from aeromagnetic data is considered to be the curie point depth. In this paper, we examined the thermal structure of the crust across the Congo Craton in south-western Cameroon using the centroid method. In addition, details of the basement structure are identified using regional aeromagnetic survey data that is reprocessed to enhance resolution of deep basement structures. These results can provide important evidence for the regional structure within the area in order to better understand the geothermal framework of the region.

2. Geological and Tectonic Setting

The study area lies in South-West Cameroon and is made up of two geo-tectonic units: the Neoproterozoic mobile belt in the northern part that is represented by the Yaoundé group and the Ntem Complex in the southern part, which is the northwestern corner of the Congo craton (Figure 1). The Yaounde group is a huge allochtonous nappe thrust southward on to the Congo craton. It comprises low- to high-grade garnet-bearing schist, gneisses and orthogneisses transformed in medium- to high-pressure granulite facies metamorphism (Toteu et al., 2004). The Ntem complex represents the north-western part of the Congo craton in Central Africa and is very well exposed in Southern Cameroon (Maurizot et al., 1985; Basseka, 2002). It is divided into two main structural units: the Nyong Unit, to the northwest end, and the Ntem Unit, in the south-central area. The Ntem Unit is dominated by massive and banded plutonic rocks of the charnockite suite and by intrusive tonalites, trondhjemites and granodiorites (TTG). Some of these bodies were dated at ca. 2.9 Ga (Delhal and Ledent, 1975; Lasserre and Soba, 1976; Toteu et al., 1994).–Younger metadoleritic dykes are related to the Palaeoproterozoic event. The Yaounde group is a huge allochtonous nappe thrusted southward onto the Congo craton at ca. 620 to 600 Ma (Toteu et al., 1994, 2006). The region has a complex and uneven tectonic structure. The region's tectonic evolution seems to have given rise to the basement's vertical movement, with subsidence to the north and uplift to the south (Manguelle-Dicoum, 1988).

The structural data show a definite deformation on the surface, which is characterized by flat structures gently sloping to the North with a generalized tilting towards the South or South-West, indicating a significant overlap of intermediate formations on the basement of the Ntem complex. This deformation is seen by the presence of folds sloping to the North (Maurizot et al., 1985).

Figure 1: Simplified geological map of southwestern Cameroon (modified from Maurizot et al., 1985).



1. tonalitic;2. charnockitic;3. bonded series;4. micashists; 5. epischists micaschiste;6. gneiss;7. granulites;8. fault.

3. Data and Methods

3.1. Data

The aeromagnetic data were collected by both companies CGG and SURVAIR (contractors) for the BRGM and CIDA (clients) between 1962 and 1970 respectively. Aeromagnetic surveys were flown with a flight height of 200 and 235 m, a nominal flight line spacing of 100 and 750 m in N-S and N103 respectively by CGG and SURVAIR. After correction of the measurements for the temporal variations of the magnetic field, the total magnetic intensity (TMI) anomaly was deduced by subtracting the theoretical geomagnetic field or IGRF (International Geomagnetic Reference Field) at each station. The TMI anomaly data were then upward continued to a height of a mean clearance of 1 km before they were merged into a unified digital grid, which has a cell size of 0.01 degree. This grid enabled us to establish a magnetic anomaly map for the south-western Cameroon.

3.2. Methodology

Calculation of DBMS

The methods for estimating the DBMS (Z_b) are classified into two categories; those that examine the shape of isolated anomalies (Bhattacharyya and Leu, 1975) 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 to magnetic sources by transforming the spatial data into frequency domain. In this research, the method adopted is the later. To obtain the depth to Curie point, Spectral analysis of 2-dimensinal Fourier transformation of the aeromagnetic data has to be performed.

To carry out Spectral analysis, the study area was divided into three overlapping blocks, Each block covers a square area of 111 by 111km, following Okubo et al. (1985), Tsokas et al. (1998).

In doing this, it was ensured that no essential part of the anomaly was cut-off by the blocks, each block was continued upward at 4 km to eliminate shallow source (short wavelength and enhance the deep seated magnetic sources).

The analysis was carried out using computer software FOURPOT, Version 1.1b, Markku (2012). This is a program designed for analysis of potential field data. To perform the analysis, the first step, is to estimate the depth to Centroid (Zo) of the magnetic source from the slope of the longest wavelength part of the spectrum which is given by equation (1)

$$Ln\left(\frac{P\,(k\,)^{1/2}}{k}\right) = A - |k|\,Z_0 \tag{1}$$

Where P (k) is the radially averaged power spectrum of the anomaly, |k| 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) given by equation (2)

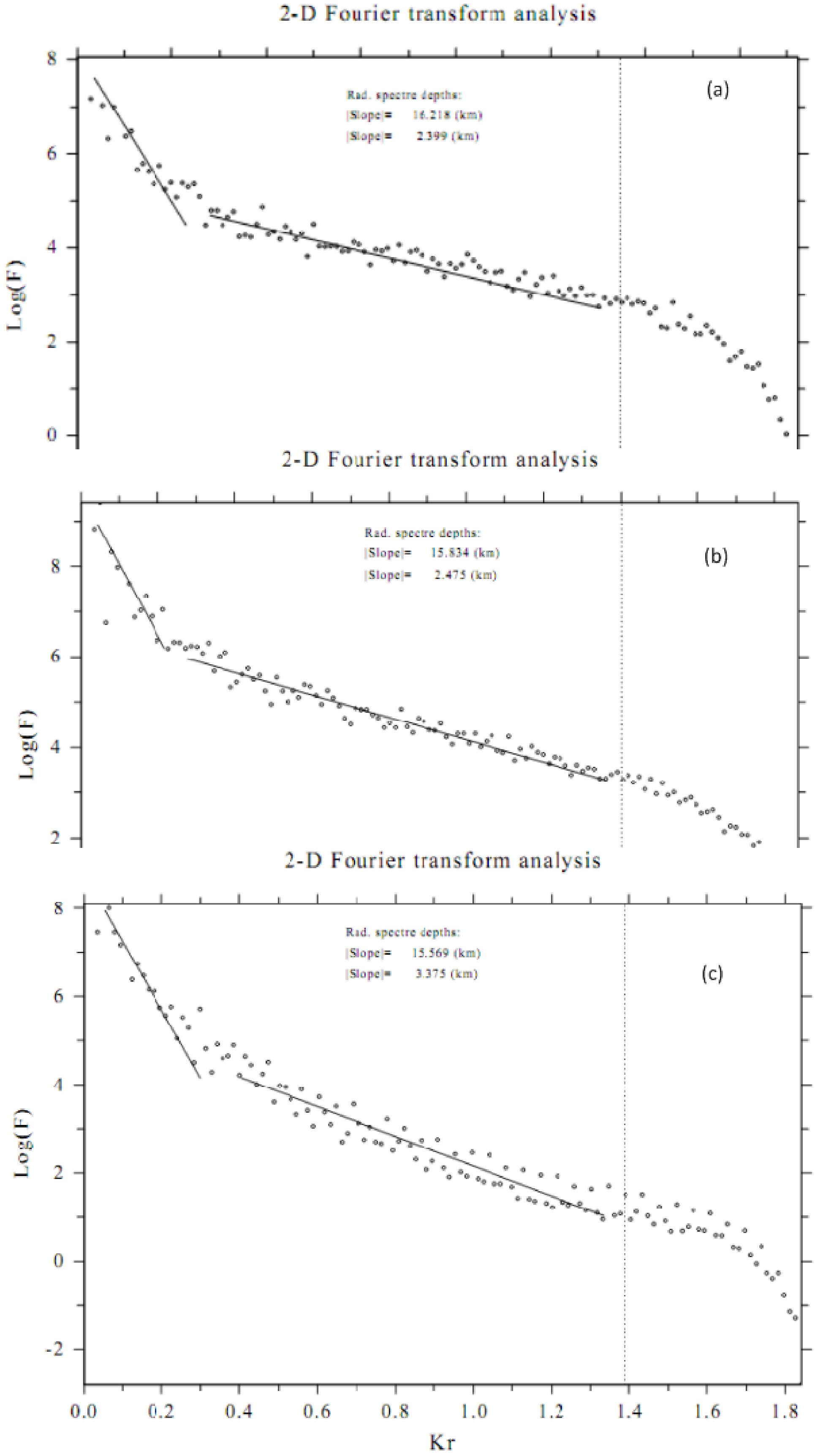
$$Ln\left(P\,(k\,)^{1/2}\right) = B - |k|\,Z_t \tag{2}$$

Where B is a sum of constants independent of |k|. Then the basal depth (Z_b) of the magnetic source is calculated from the equation (3).

$$DBMS = 2Z_0 - Z_t \tag{3}$$

The obtained basal depth (Zb) of magnetic sources in the study area is assumed to be the Curie point depth (Bhattacharyya and Leu, 1975) and Okubo et al, (1985) and the Graphs of the logarithms of the spectral energies for various blocks were obtained from which table 1 was extracted as shown on Figure 2.

Figure 2: Graphs of the logarithms of the spectral energies for various blocks



Estimation of Heat Flow and Thermal Gradient

The heat flow and thermal gradient value was calculated in the study area, the calculation was expressed by Fourier's law with the following formula.

$$Q = k \frac{dT}{dZ} \tag{4}$$

Where Q is the heat flow and K is the coefficient of thermal conductivity. In this equation, it is assumed that the direction of the temperature variation is vertical and the temperature gradient dT/dZ is constant. According to Tanaka, et al, (1999), the Curie temperature (θ) was obtained from the Curie point depth (Z_b) and the thermal gradient dT/dZ using the following equation 5

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

Provided that there are no heat sources or heat sinks between the earth surface and the Curie point depth, the surface temperature is 0°C and dT/dZ is constant. The Curie temperature depends on magnetic mineralogy. Although the Curie temperature of magnetite (Fe_2O_4), in view of that, the curie temperature is approximately 580°C, and an increase in titanium (Ti) content of titanomagnetite (Fe_{2-x} ,Ti_xO_3) causes a reduction in Curie temperature (Nwankwo et al 2011) In addition to that, from Equation (4) and Equation (5) a relationship was determined between the Curie point depth (Zb) and the heat flow (Q) as follows in equation 6.

$$Q = k \left[\frac{\theta}{Z_b} \right] \tag{6}$$

In this equation, the Curie point depth is inversely proportional to the heat flow, Tanaka et al. 1999; Stampolidis, et al. 2005). In this research, the Curie point temperature of 580 °C and thermal conductivity of 2.5Wm-1°C-1 as average for igneous rocks was used as standard (Nwankwo et al 2011) in the study area. In order to compute the thermal gradient and heat flow of the region (Table 1), Equation (6) was utilised.

4. Results and Discussion

Total magnetic intensity (TMI) anomaly map (Figure 3) is characterized by elongated positive magnetic anomalies of NW-SE trending direction which cross the area in the south part and by the NE-SW in the north. Such a contrast in magnetic patterns should undoubtedly correspond to a major regional structure within the basement. The minimum values occurring in the south-west and north-east of the area (- 258 to -20 nT) indicate the presence of slightly magnetic material. The high positive magnetic anomalies reflected in the south-east region indicate the presence of highly magnetic material. This can be interpreted as the presence of intrusive igneous bodies in the southern part of the study area.

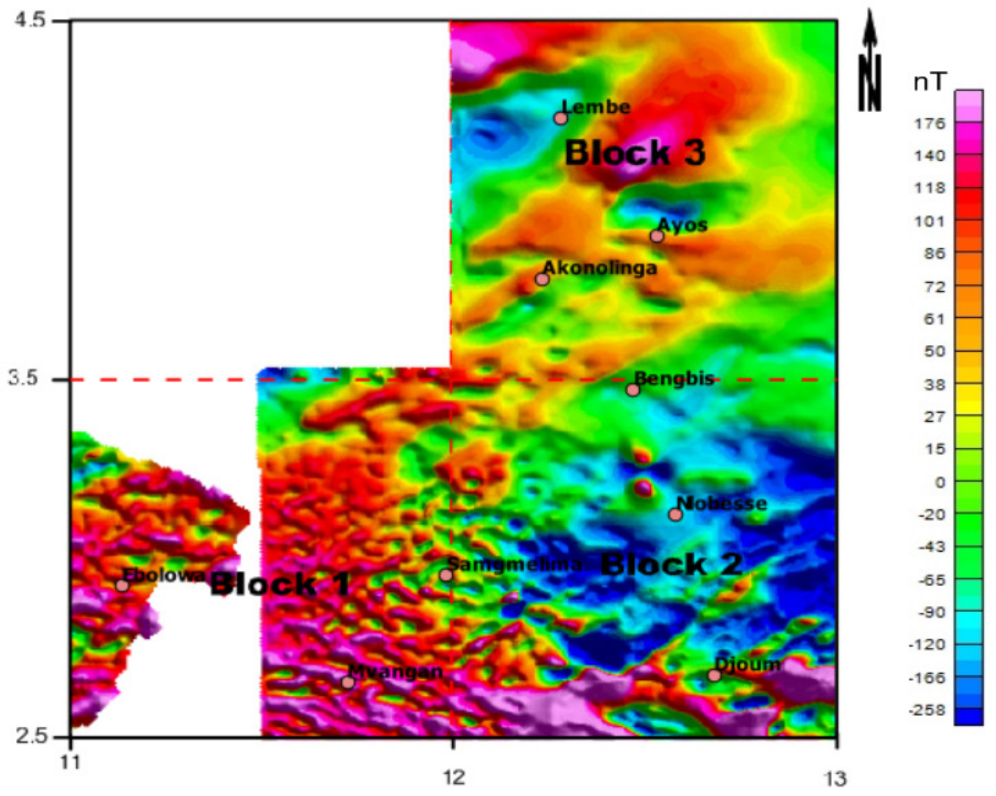
Each block shows graphs of the logarithms of the spectral energies, from which curie isotherm depth was computed. This block denoted by a circle at its center and lies in different geotectonic units on the geological map: blocks 1-2, Ntem Unit and block 3, Yaoundé Group. This process above mentioned was carried out for the three blocks to obtain the depth to shallow (Z_t) and deep (Z_0) causatives. The DBMS for each block was obtained using the formula 3, which showed that the depth to the Centroid (Z_0) ranges from 15.57 km to 16.22 km. On the other hand, the depth to the top boundary (Z_t) of magnetic sources ranges from 2.40 km to 3.37 km (table 1). The result of the investigation of the DBMS of the study area reveals that the Curie isotherm depth varies between 27.77 and 30.04 km. The deeper Curie point in the study area could be as a result of isostatic compensation in the region. Previous studies by Stampolidis, et al. (2005) showed that the Curie point depth is linked to the geological context of an area.

The heat flow and thermal gradient values was calculated in the study area. The thermal gradient of each block is calculated assuming that rocks are dominated by magnetite which has the Curie temperature of 580 °C. The spectral analysis of aeromagnetic data shows that heat flows vary from 48.26 to 52.21 $mW.m^{-2}$. The average heat flow obtained in the study area is 50.04 $mW.m^{-2}$, this may be considered as typical the African crust. The thermal gradient data varies from 19.30 to 20.88 °C/km. This result reveals low vertical temperature gradients in south-western Cameroon.

Table 1: Calculated Average Curie point depth and Heat flow from spectral analysis

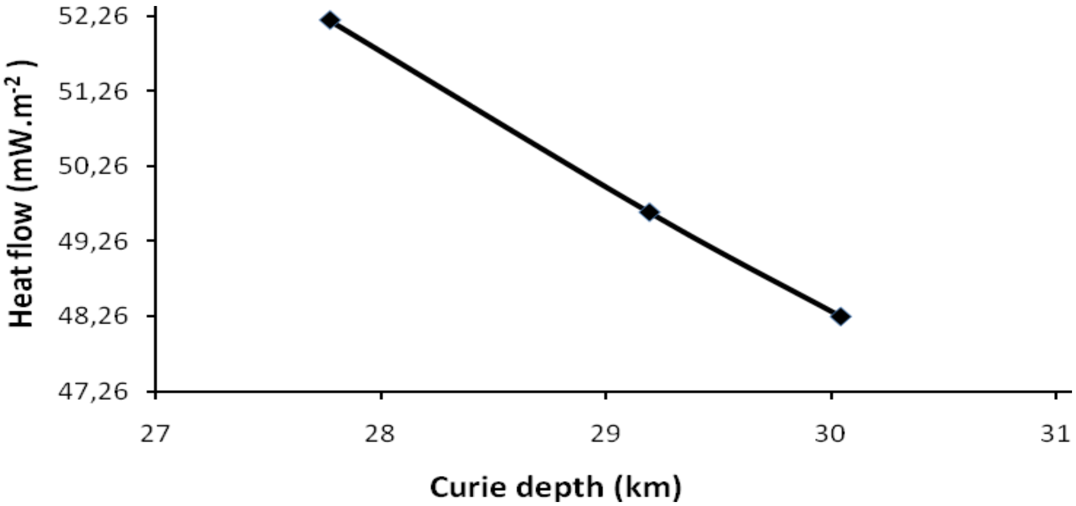
Geotectonic units	Blocks	Z0 (Km)	Zt (Km)	DBMS (Km)	Geothermal gradient (°C/Km)	Heat flow (mW.m-2)
Ntem Unit	1	16.22	2.40	30.04	19.30	48.26
Ntem Unit	2	15.83	2.47	29.19	19.86	49.65
Yaounde Group	3	15.57	3.37	27.77	20.88	52.21

Figure 3: Total magnetic intensity (TMI) anomaly map of the study area, showing each blocks



To investigate any possible relation between heat flow and the obtained Curie depth, we present the current results in Figure 4. Considering Curie depths and heat flow in the study area, Figure 4 shows that, the heat flow decreases with increasing Curie depth. Meaning that, Spectral analysis of aeromagnetic data in conjunction with heat flow information revealed an almost inverse linear relation between heat flow and Curie depths. The blocks of high heat flow correspond to high geothermal gradient.

Figure 4: Heat flow versus DBMS in the study area



5. Conclusion

This study, based on the interpretation of available aeromagnetic data, was to improve the knowledge of the geothermal context of the south-western Cameroon. The depth to the top of magnetic sources varies from 2.40 to 3.37 km for the region. The Centroid depth and the DBMS vary from 15.57 to 16.22 km and 27.77 to 30.04 km, respectively. The deeper DBMS are found in the Southern part of Ntem Unit and shallower in Northern part of the Yaounde Group. The average heat flow obtained is 50.04 mW.m^{-2} which can be utilized for exploration of an alternative source of geothermal energy. The deeper DBMS corresponds to the low heat flow. By considering an average value of 20°C/km in the study area according to table 1, equation (6) shows that the thermal conductivity values in the region varies between 2.41 to 2.61 W.m-1. °C-1 based on the constant temperature at the CPD for whole regions such as Africa. The interpretation of aeromagnetic data to estimate the curie point depth and heat flow over the south-western Cameroon, contributed to better understand geothermal regime and tectonic activities in the area, which shows a possibility for geothermal resources potentials to explore for new and more energy locations in Cameroon.

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