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Full Length Article

Estimation of Curie-point depths, geothermal gradients and near-surface heat flow from spectral analysis of aeromagnetic data in the Loum – Minta area (Centre-East Cameroon)

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ABSTRACT

The current study deals with an estimate the Curie point depth, Heat flow and geothermal gradient from spectral analysis of aeromagnetic data in the Loum – Minta area, Centre-East Cameroun. Aeromagnetic data reduce to equator was divided into 5 blocks. All of the blocks overlapped with adjoining blocks by 50 percent and each block analyzed using the spectral centroid method to obtain depth to the top, centroid and bottom of magnetic sources. The depth values were subsequently used to evaluate the Curie-point depth (CPD), geothermal gradient and near-surface heat flow in the study area. The result shows that the CPD varies between 5.22 and 14.35 km with an average of 9.09 km, the geothermal gradient varies between 40.42 and 111.11 °C/km with an average of 72.24 °C/km, and the resulting heat flow varies between 101.05 and 277.77 mW m^{-2} with an average of 180.59 mW m^{-2}. Such heat flow values are suggestive of anomalous geothermal conditions and are recommended for detailed geothermal exploration.

1. Introduction

The study area lies in the northern part edge of the Congo Craton (CC), in the central-east area of Cameroon (Central African fold belt zone). It extends from latitudes 4° 00′ to 5° 00′N and longitudes 12° 00′ to 13° 00′E (Fig. 1). The surface area of the study region covers approximately 9259.07 km^2. In Cameroon, extensive geophysical investigations have been largely confined to regional and local geological structures study, oil–gas exploration, and mineral surveys. Geothermal investigations have not received enough attention across the Cameroon landscape. There is a missing gap in crustal temperature information of Cameroon. Hence, this study can be a significant contribution for the exploration of geothermal fields in the future.

The objective of this investigation is to apply spectral analysis on aeromagnetic data over the Loum-Minta area in order to estimate the CPD and to deduce the geothermal gradient and heat flow in order to explore the geothermal potential. Furthermore, the geothermal gradient using Curie-point has never been applied in the studied area before.

2. Geological and tectonic setting

The study area is at the limit of the granite formations, which occupies the greater part of Adamaoua and the Yaoundé domain. The Yaoundé Domain consists of an extensive tectonic nappe that was thrusted onto the Congo Craton (CC) during the Pan-African collision [1]. Thrust slices of metasedimentary rocks with poorly constrained ages of ~626 Ma [2] are common in the Yaoundé Domain [1]. The geological maps of [3] (Fig. 1) show the granite-covered area and the ancient metamorphic series of Nanga-Eboko that is mainly composed of ectinites and migmatics. The more recent and less metamorphosed series of Akonolinga consists mainly of chlorite-schist and quartzite occurs the southern part of the study area. The tectonic facts revealed that, the area of study is characterized by four phases of deformations D_1-D_4 [4]. A D_1-early tectonic event, responsible of the E–W foliation which has been progressively transposed by a D_2 tectonic event. A D_2 event has developed heterogeneous simple shear in a dextral transpressive

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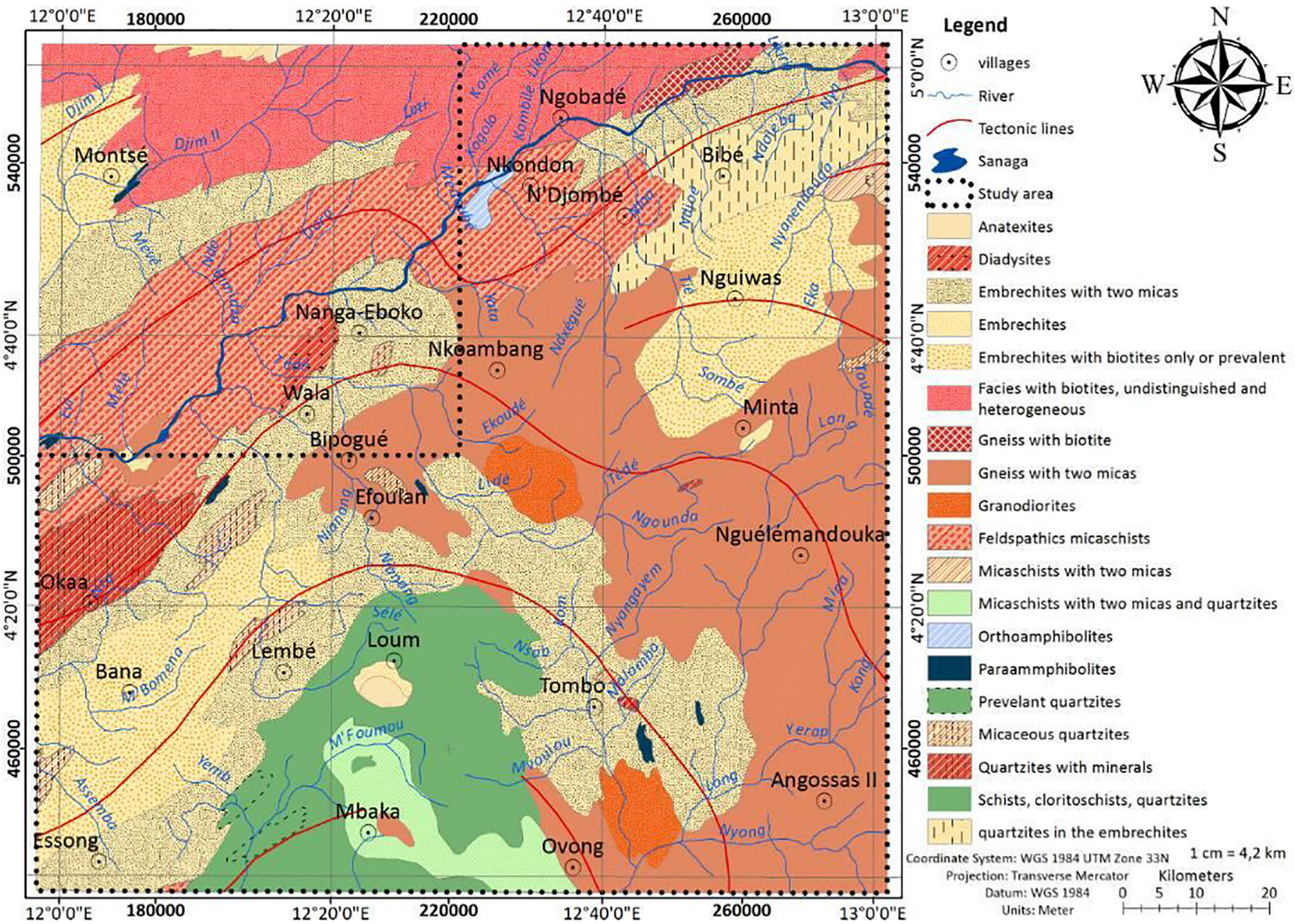

Fig. 1. Geology map of the study area [3].

context with moderate to strong dipping NE–SW striking foliation; a D_3 tectonic event has lead to a sinistral N–S ductile shear characterized by N- to ENE-striking foliation and E–W strike-slip shear corridors and a D_4 tectonic event that developed N–S dextral ductile strike-slip deformation.

3. Materials and method

3.1. Aeromagnetic data

The data set use in the present study is from an aeromagnetic survey covering some parts of Cameroon territory. This aeromagnetic survey was conducted in 1970 by Survair Limited (Ottawa) as part of a cooperative agreement between the Canadian and the Cameroon governments. The flying height was 235 m, flight lines had an N-S direction with 750 m interlines space. After correction of the measurements for the temporal variations of the magnetic field, the total magnetic intensity (TMI) anomaly (Fig. 2) was deduced by subtracting the theoretical geomagnetic field or IRGF (International Geomagnetic Reference Field) at each station. The TMI was reduced to the equator (RTE) (Fig. 3) to correct the shape and the peak of the magnetic anomalies over their causative bodies. The RTE correction applied assumed a declination of −5.73° and an inclination of −15.92° utilizing the FFTFIL (Fast Fourier Transform Transform Filtering) program (Geosoft Oasis Montaj 8.3).

3.2. Method

One of the methods of examining thermal structure of the crust is the estimation of the CPD, using aeromagnetic data [5]. Various studies have shown correlations between Curie temperature depths and average crustal temperatures, leading to viable conclusions regarding lithospheric thermal conditions in a number of regions around the world [6]. Diverse methods have been described by several Authors [7–10] for estimating the Curie depth. The method adopted to estimate CPDs from the aeromagnetic anomaly data by [9] and [10] was used in this study. This method is based on the calculation of the depth of a magnetic source from the power spectrum of magnetic anomalies after transformation of data into frequency domain. The top and centroid depths of the magnetic sources are given as Z_t and Z_0 by Okubo et al. (1985), respectively. The CPD (Z_b) after [9] is then obtained from:

$$Z_b = 2Z_0 - Z_t \tag{1}$$

The geothermal gradient (dT/dz) between the Earth's surface and the Curie point depth (Z_b) can be defined by Eq. (8) [9,10]:

$$\frac{dT}{dz} = \frac{\theta_c}{Z_b} \tag{2}$$

where θ_c is the curie temperature.

In addition, the geothermal gradient can be associated to the heat flow Q by using Eq. (3):

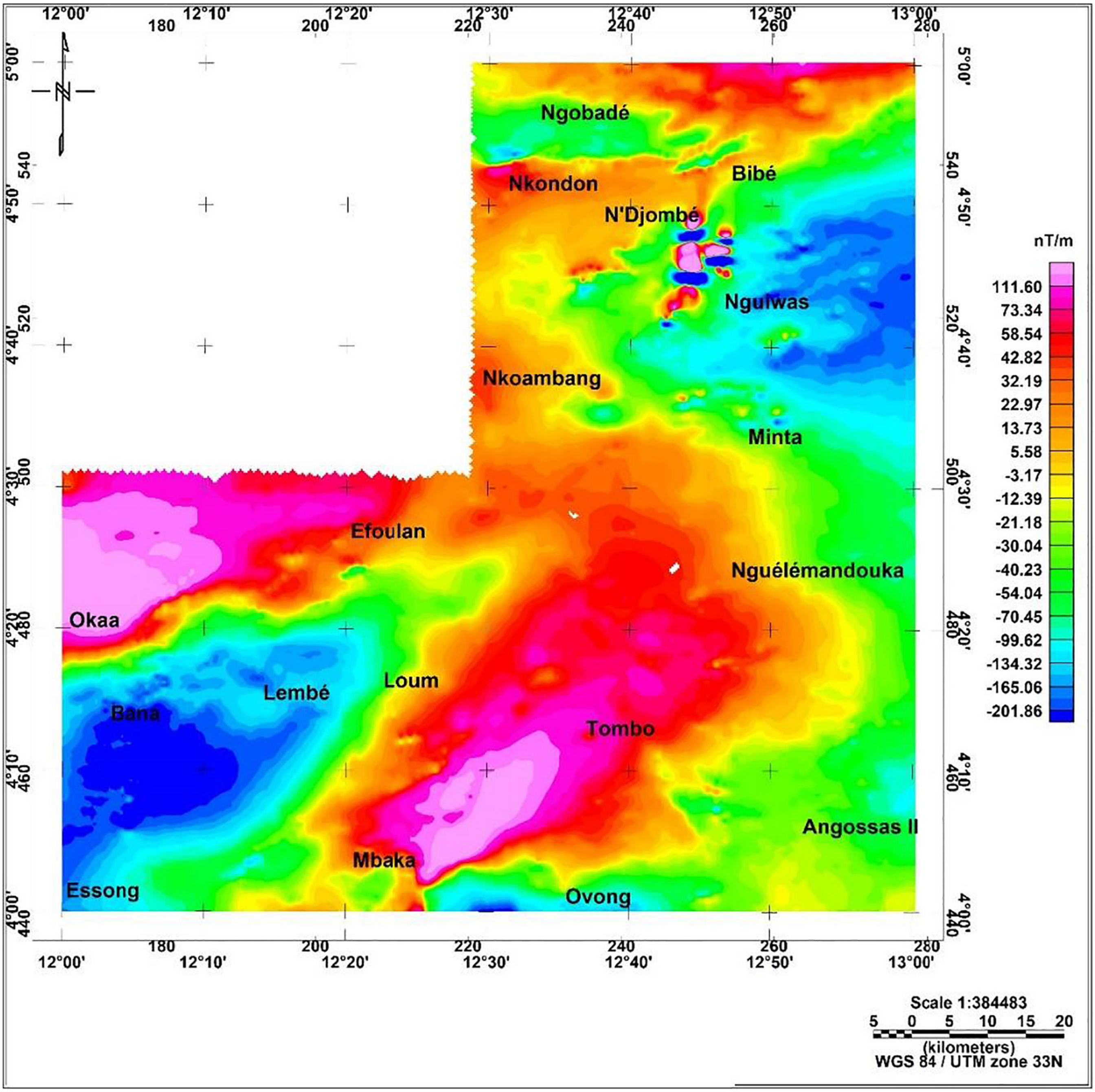

Fig. 2. Total magnetic intensity (TMI) anomaly map of the area.

$$Q = \lambda \frac{\theta_c}{Z_b} \tag{3}$$

where λ is the coefficient of thermal conductivity.

4. Result and discussion

Researchers have preferred several window sizes to estimate CPD in literature ([9,11–13]). In this study, TMI-RTE map was divided into five overlapping (overlapped 50% with the adjacent blocks) square blocks having the size of $0.5° \times 0.5°$ (shown as the block numbers of 1, 2, 3 4 and 5 in Fig. 4) where the centers of the blocks are marked with a black circle. In each block, power spectrum was applied using Oasis Montaj 8.3 software in order to calculate the depth to top (Z_t) and centroid (Z_0) depths of magnetic sources. Fig. 5 shows two examples of power spectrum of the aeromagnetic data from two blocks: block 4 and block 5. From the relation of $Z_b = 2Z_0 - Z_t$, the CPD (Z_b) was computed, following the [9] procedure. The geothermal gradient (*dT/dZ*) was calculated using the formula of Eq. (2) and the Eq. (3) was finally applied to estimate the heat flow of the study area. In this calculation, the Curie point temperature was assumed to be 580C and thermal conductivity 2.5 $Wm^{-1}°C^{-1}$ as an average value for the igneous rocks over basement. The results of the estimated depths, geothermal gradient and heat flow for the 5 blocks are shown in Table 1.

According to the Table 1, the depth to top of magnetic source ranges between 5.16 and 3.16 km with an average value of 4.45 km, the centroid depth ranges between 4.19 and 9.61 km with

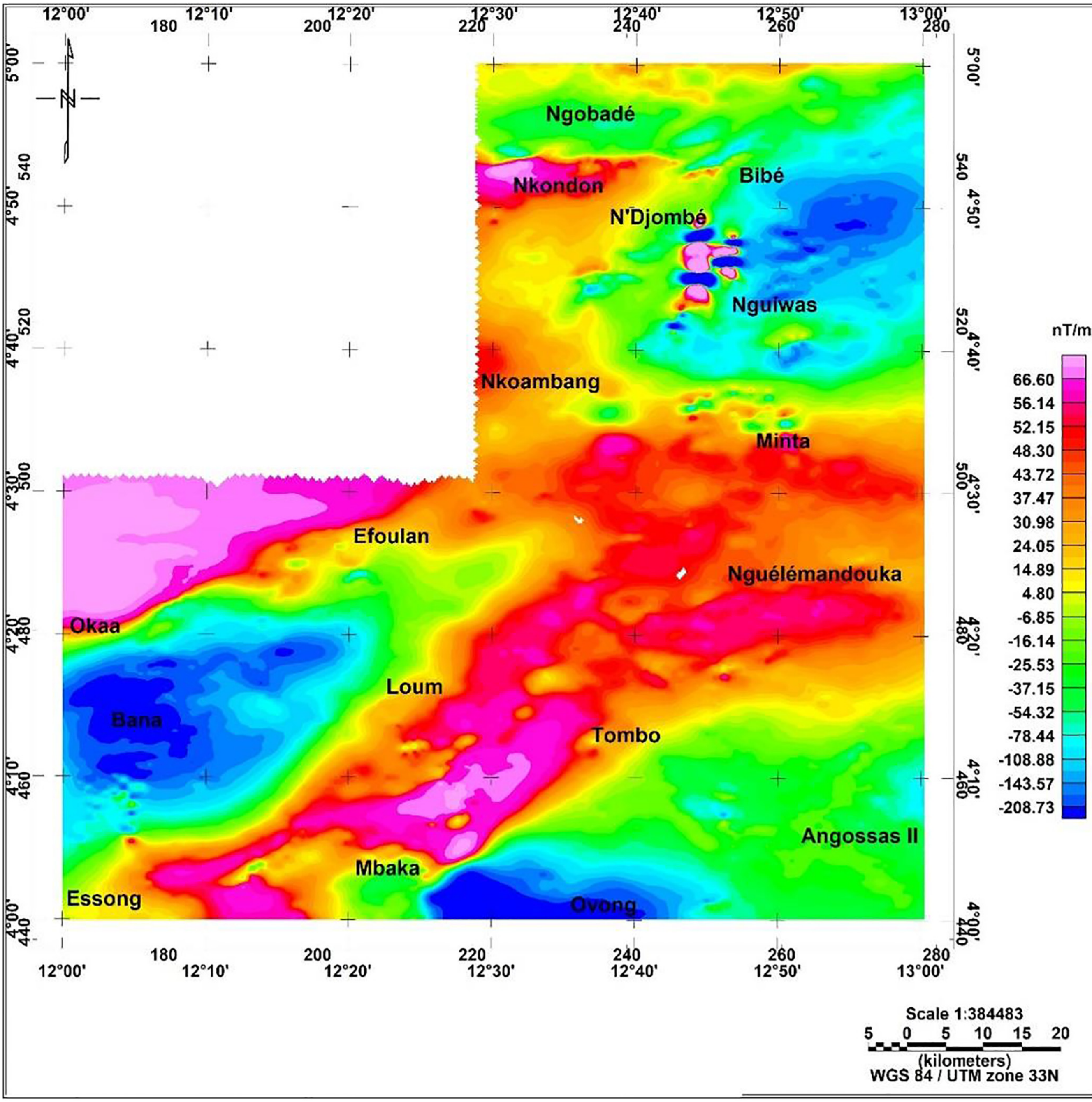

Fig. 3. Total magnetic intensity Reduced to equator of (TMI-RTE) map of the area.

an average value of 6.77 km, and the CPD values vary between 5.22 and 14.35 km with an average value of 9.09 km. Fig. 6 shows the CPD values variation in the Loum-Minta area with the shallowest parts (less than 8 km) in the north-eastern and south-eastern; whereas the maximum value is located in the western part. The CPD estimates the average bottom depth of magnetic sources and it is believed they reflect the thermal structure of the region. [10] showed that Curie point depths are shallower than about 10 km in volcanic and geothermal areas, 15–25 km at island arcs and ridges, deeper than 20 km at plateaus, and deeper than 30 km at trenches.

Table 1 similarly discloses that geothermal gradient vary between 40.42 and 111.11 °C/km with an average value of 72.24 °C/km, while heat flow parameters vary between 101.05 and 277.77 mW/m^2 with an average value of 180.59 mW/m^2, respectively. Figs. 7 and 8 show the contour maps for the geothermal gradient and heat flow, respectively. Fig. 9 and Fig. 10 give the variation of geothermal gradient and heat flow with the estimated CPD respectively. In the study area, the geothermal gradient and heat flow values decrease significantly with the deepening of Curie point depth as it shown in Figs. 9 and 10 below.

All the current literature states that the Curie point depth and of course heat flows are greatly dependent upon geological conditions. Heat flow is the primary observable parameter in geothermal exploration. Generally, the units that comprise high heat flow values correspond to volcanic and metamorphic regions since these two units have high heat conductivities. Additionally, tectonically active regions affect heat flow significantly. The average heat flow

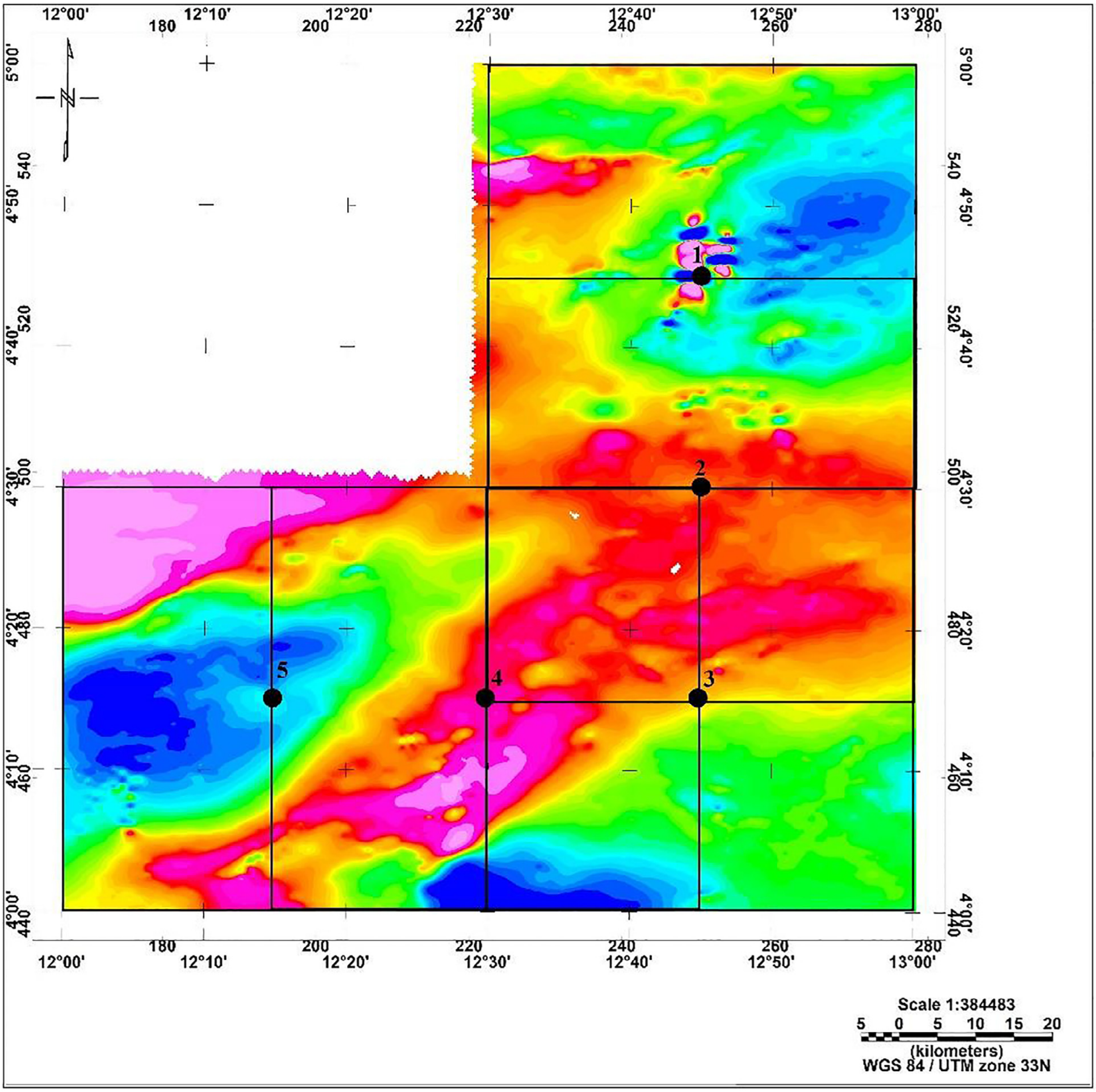

Fig. 4. Map showing the four overlapping blocks used for power spectral analysis. Each 0.5° by 0.5° blocks is denoted by a number at its center.

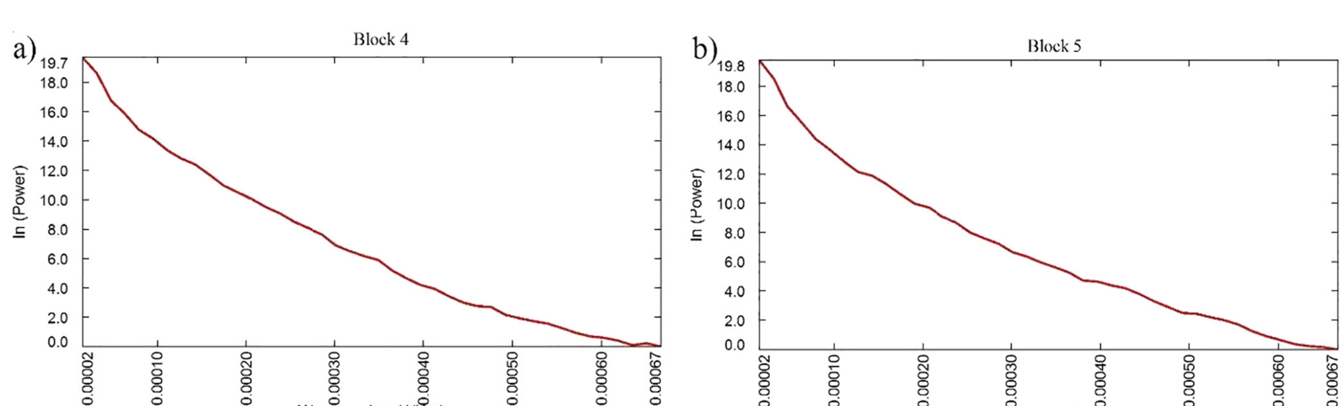

Fig. 5. Radial power spectrum for two blocs: block 4 in (a): the depth of the top Z_t = 3.16 km, the depth to centroid Z_0 = 4.19 km, the Curie point depth $Z_b = 2Z_0 - Z_t$ = 5.22 km; block 5 in (b): the depth of the top Z_t = 4.87 km, the depth to centroid Z_0 = 9.61 km, the curie point depth $Z_b = 2Z_0 - Z_t$ = 14.35 km.

Table 1
Estimated CPD, geothermal gradients and heat flow by applying the centroid method for the 4 blocks in the study area.

Block number	Coordinates (UTM)		Depth to top (km)	Depth to centroid (km)	DCP (km)	Geothermal Gradient (°C/km)	Heat flow (mW/m^2)
	Easting (km)	Northing (km)					
1	250.34952	525.56929	4.56	5.99	7.42	78.17	195.42
2	250.28806	498.02745	5.16	8.2	11.24	51.6	129.00
3	249.88565	470.46194	4.48	5.87	7.26	79.89	199.72
4	222.11893	470.46194	3.16	4.19	5.22	111.11	277.77
5	194.35221	470.46194	4.87	9.61	14.35	40.42	101.05

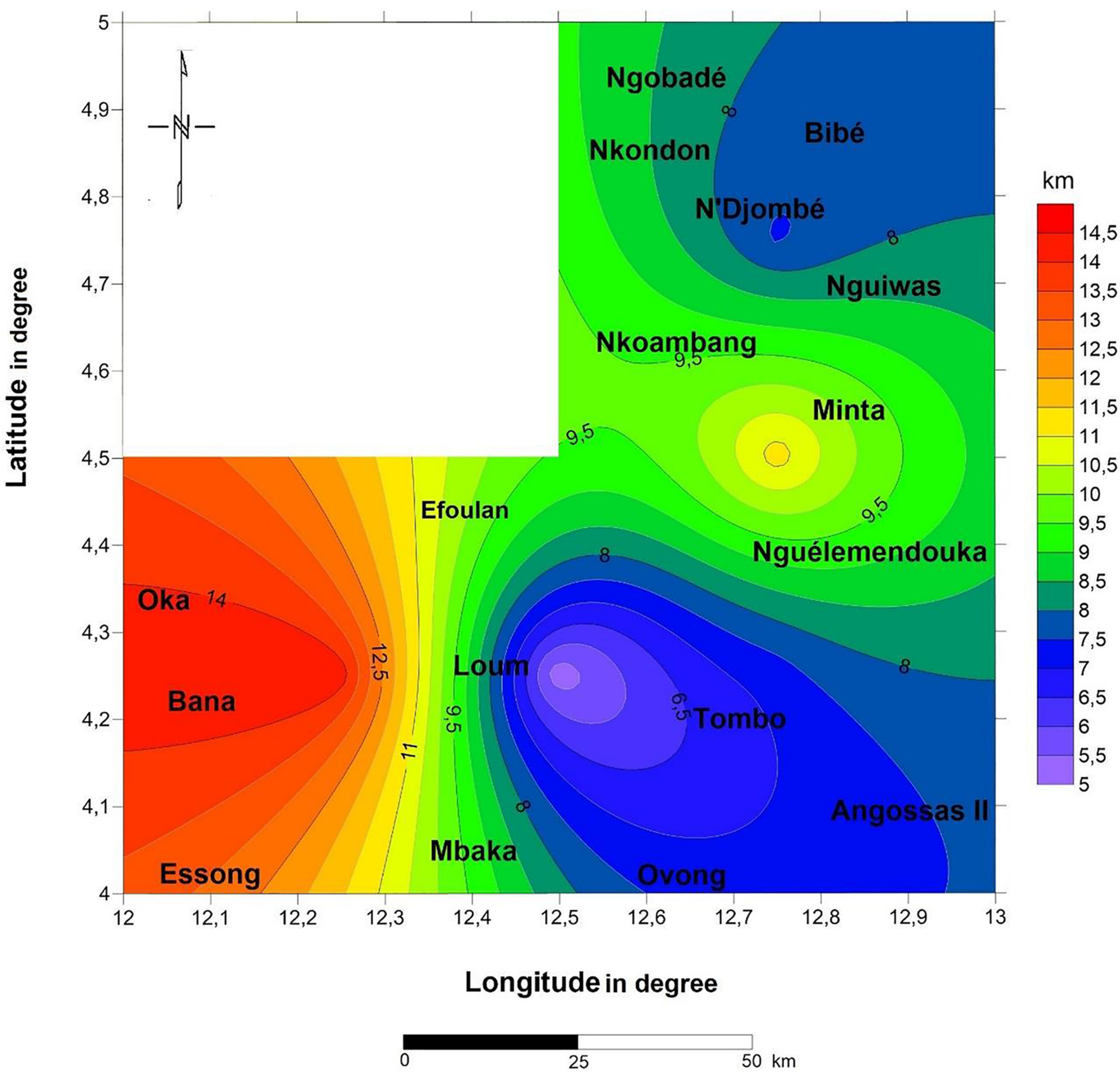

Fig. 6. CPD map of the study area.

in thermally normal continental regions is reported to be above 60 mW m^{-2}. Values in excess of about in 80–100 mWm^{-2} indicate anomalous geothermal conditions [14]. Anomalous high heat flow values above 100 mW m^{-2} have been observed in the study area.

5. Conclusion

The Curie point depth for the study area was estimated using surface magnetic data through spectral analysis. The result reveals that, the Curie point depth varies inversely with heat flow; this shows that heat flow in the study area decreases with increase in Curie depth. The inferred Curie point depth obtained ranges from 5.22 km to 14.35 km. On the other hand, the heat flow in the study area varies between 101.05 and 277.77 mWm^{-2} with an average of 180. 59 mWm^{-2}, and the geothermal gradient varies between 40.42 and 111.11 °C.km^{-1} with an average of 72.24 °C.km^{-1}. The interpretation of aeromagnetic data to estimate the depth to Curie point and heat flow over in Loum-Minta area, contributed to the better understanding of geothermal regime in this area, the study has shown that a possibility of geothermal resource exists in this area. Therefore, the anomalous heat flow areas observed in this study maybe recommended for further investigation.

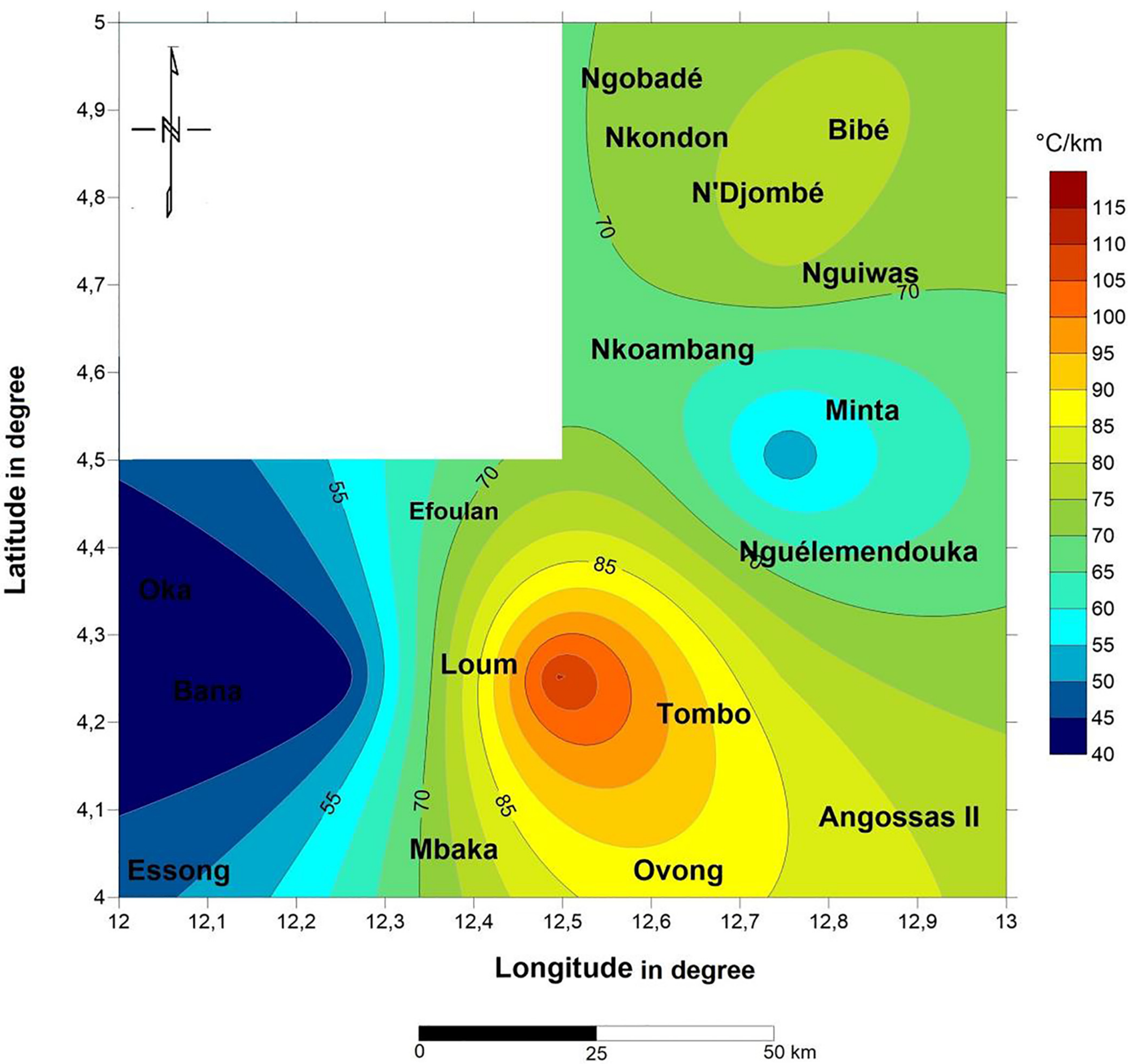

Fig. 7. Geothermal gradient map of the study area.

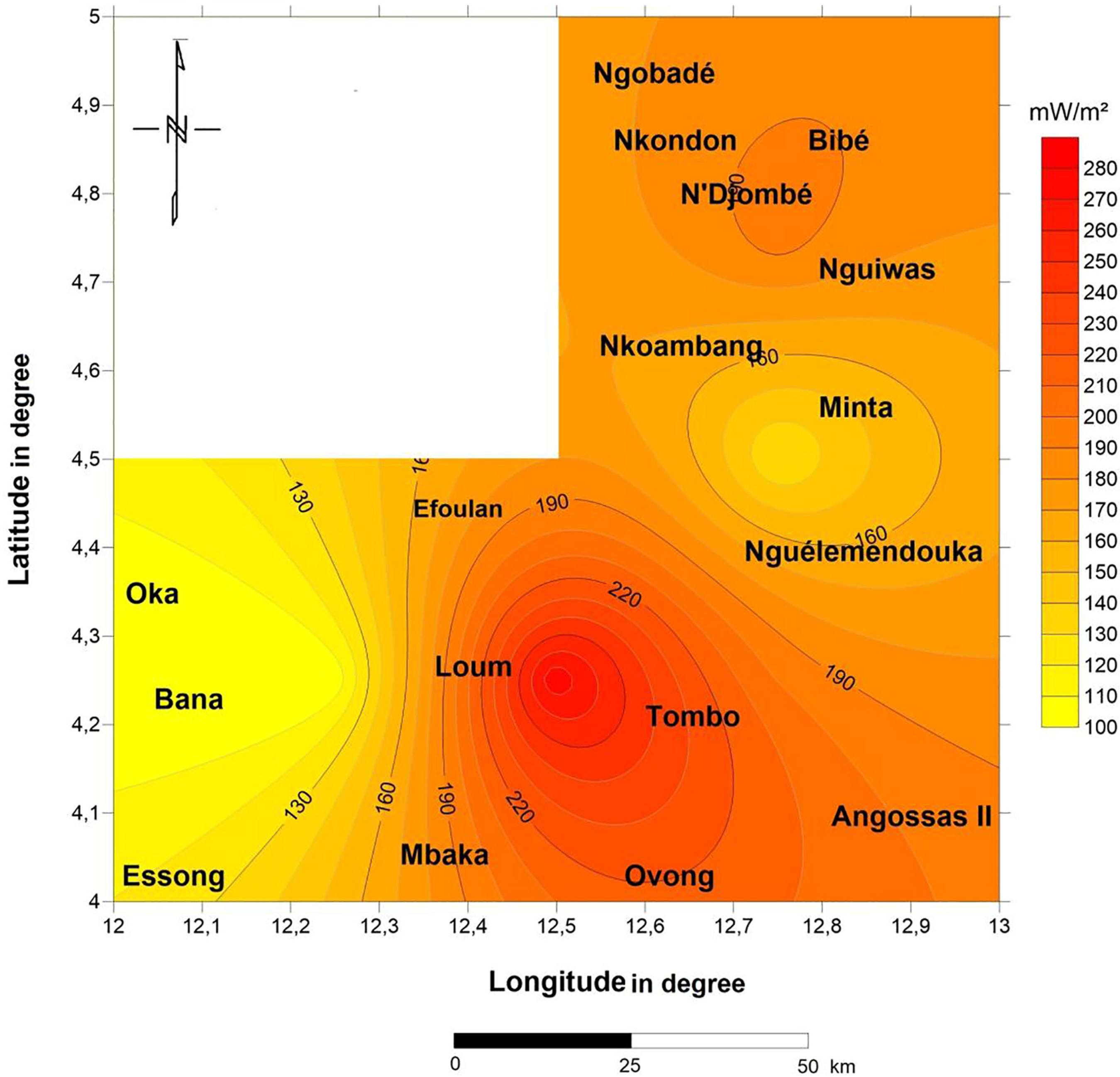

Fig. 8. Heat flow map of the study area.

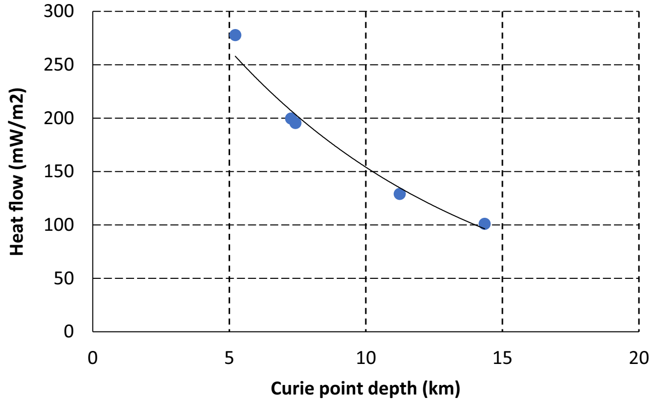

Fig. 9. The variation of heat flow with the estimated Curie point depth.

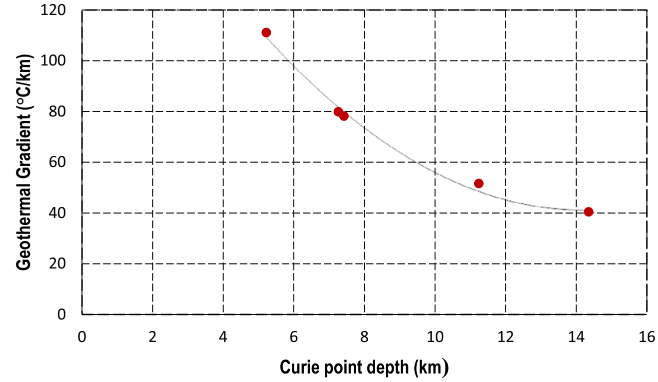

Fig. 10. The variation of geothermal gradient with the estimated Curie point depth.

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