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INVESTIGATION OF GEOTHERMAL ENERGY POTENTIAL OF PARTS OF CENTRAL AND NORTH-EASTERN NIGERIA USING SPECTRAL ANALYSIS TECHNIQUE

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ABSTRACT

The current study deals with an estimate of the Curie point depth, heat flow and geothermal gradient from spectral analysis of aeromagnetic data covering an area located approximately between latitude 7.5° N to 11.5° N and longitude 7.5° E to 10.5° E, which corresponds to parts of the Benue trough (lower part of the Upper Benue trough, the entire middle Benue trough, and upper part of the Lower Benue trough), lower part of the Gongola and Yola Basins, the Precambrian Basement, the Jurassic Younger Granites and two prominent hot Springs, Wiki hot spring in Bauchi state (in the north-eastern part) and Akiri hot spring in Nasarawa state (in the south-western part) of central and north-eastern Nigeria. Radially power spectrum was applied to the aeromagnetic data of the study area divided into 48 square blocks and each block analysed 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 values of the curie point depths (Zb), range from 7.6341 km to 34.5158 km, with a mean value of 14.7928 km, geothermal gradient, range from 16.8039 0C km^{-1} to 75.97490C km^{-1}, with mean value of 45.7021 0C km^{-1} and heat flow (q), range from 42.0097 mWm^{-2} to 189.9372 mWm^{-2}, with a mean value of 114.2554 mWm^{-2}. Which reveals that, there might probably be good sources for geothermal and thereby further recommended for detailed geothermal exploration.

Keywords: Aeromagnetic data, Curie point depth, Heat flow, geothermal gradient

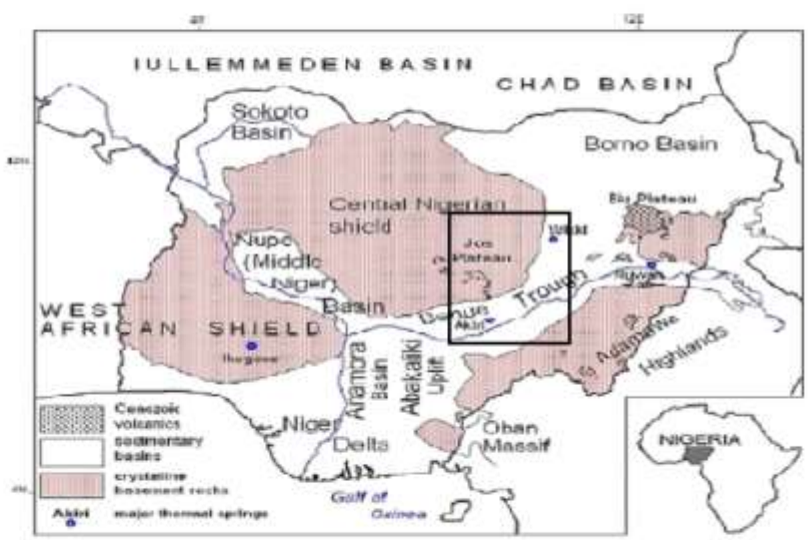
INTRODUCTION

Nigeria is currently facing incessant problem of epileptic power supply, which has affected her Productivity, hence her inability as a Nation to compete socially, politically, economical, and technologically with other nations of the world. Nigeria's over dependence on oil and natural gas has constituted a hindrance towards the harnessing of other sources of power that can contribute immensely to the economic growth of the nation. In other to consistently generate electricity, other sources of power that are widely referred to as renewable energy emerging in the wake of climate change and the depletion of the ozone layer should be explored (Byerly and Stolt, 1977; Connard et al., 1983; Black, 1980; Kebede, 1986; Salem et al., 2000; Glassley, 2010; Shere, 2013). One of which is the geothermal energy. In the light of the above, the Nigeria nation has a lot to benefit from exploring its geothermal potential for the production of electricity in the country. This is the main aim of this study. Radially power spectrum was applied to the aeromagnetic data of the study area divided into 48 square blocks and each block analysed using the spectral centroid method to obtain depth to the top, centroid and bottom of magnetic sources. The estimated values were used to compute the curie point depth, the heat flow and thermal gradient of the area.The study area is bounded by latitudes 7.50'N to 11.50'N and longitudes 7.50'E to 10.50'E located within the central and northeast Nigeria (Fig.1, Fig.2 and Fig.3 & Fig.4). It is approximately 145,200 km^2 and was covered by 48 aeromagnetic maps (Chinwuko et al., 2013; Tildy, 2015; Alexander, 2017). The study area is made up of the cretaceous Benue trough, Precambrian basement Complex, Sedimentary Basins (Gongola and Yola Basins), Jurassic younger Granites, and tertiary – recent sediments of the central and north-eastern Nigeria (Fig.3 and Fig.4). Several works (Salako 2012; Nur et al., 1999; Eletta and Udensi 2012; Abdulsalam et al., 2013; Ikumbur et al., 2013; Igwesi and Umego 2013; Bello et al., 2017; Mohammed et al., 2019; Abdullahi et al., 2019) have been done in parts of the, north central, north eastern Nigeria but they are all restricted or localized to small areas around hot springs and a few on regional scale in the present study area (Fig.1and Fig.2). The geology of the study area is made up of the cretaceous Benue trough, Precambrian basement Complex, Sedimentary Basins (Gongola and Yola Basins), Jurassic younger Granites, and tertiary – recent sediments of the central and north-eastern Nigeria

(Kogbe 1989; Ekwueme, 1987; Reyment, 1965; Carter et al., 1963; Farnbauer and Tietz, 2000; Adelana et al., 2008). (Fig.3 and Fig.4)

Study area

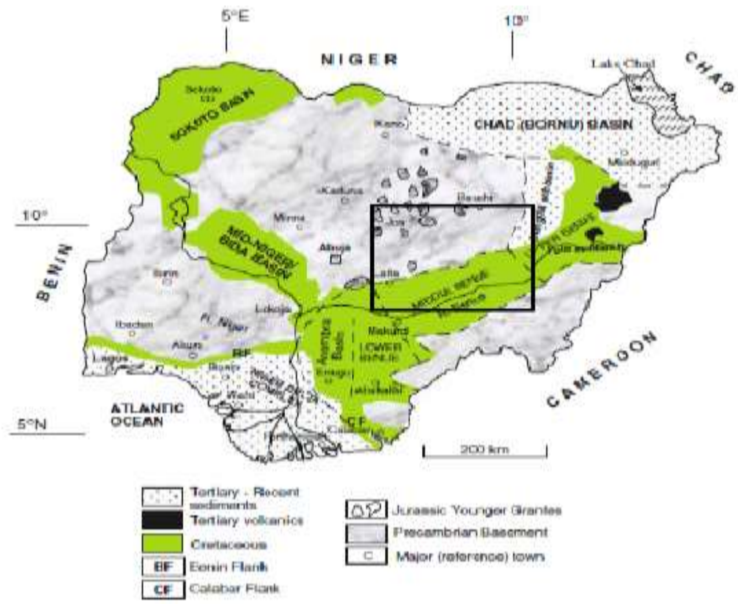
Fig.1: Map of the study area (modified after NGSA, 2010)



Study Area

Surface Geothermal manifestation - Hot springs.

Fig.2: Geological setting and location of areas with major geothermal manifestation (Hot springs) in Nigeria (After Kurowska and Schoeneich, 2010).



Study Area

Fig.3: Geological Map of Nigeria (Modified after Obaje, 2009) showing the study area.

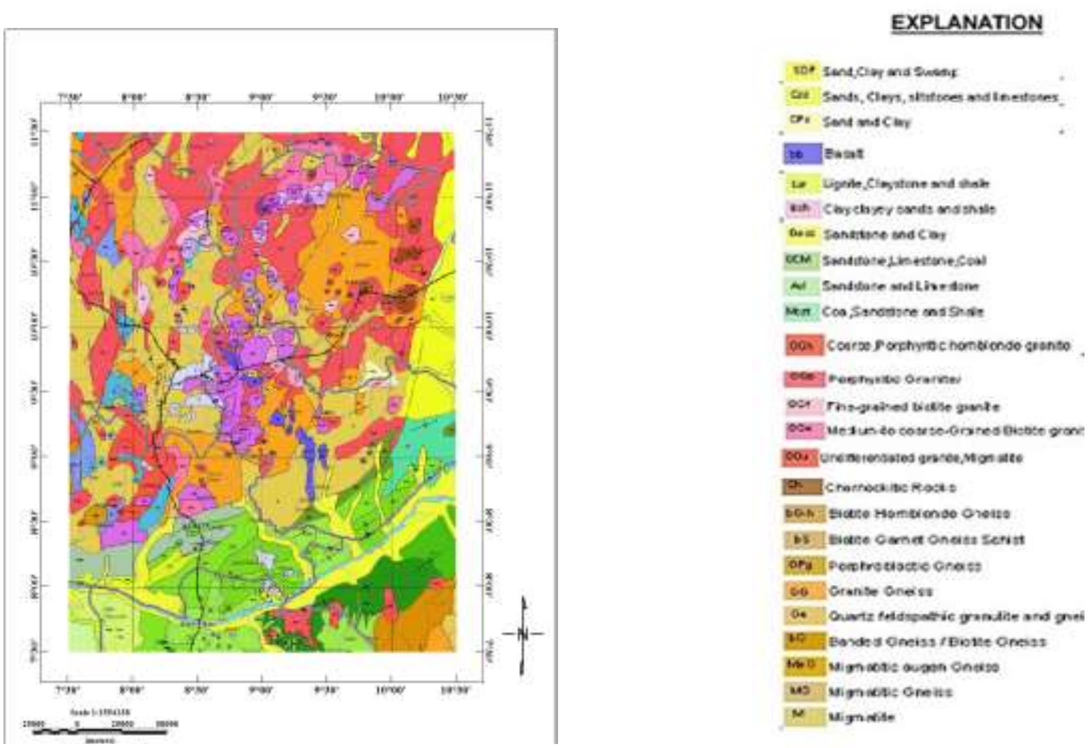


Fig.4: Geological Map of the study area (adapted after NGSA, 2010)

MATERIALS AND METHODS

The high resolution aeromagnetic dataset, which consist of sheet 102 - 107, 124 - 129, 145 - 150, 166 - 171, 187 -192, 208 - 213, 229 – 234 and 249 – 254 utilized for this study was obtained as controlled maps of total magnetic intensity on a scale of 1:100000 compiled by the Nigerian Geological Survey Agency as a part of the nation-wide aeromagnetic survey between 2005 and 2010. The survey was flown in drape mode using real time global positioning system at a sensor mean terrain clearance of 80-100m. Traverse and Tie line spacing were 500m and 2000m respectively in NW-SE and NE-SW directions and the data were recorded at a sampling interval of 100m (NGSA, 2010) and stored in grid form. The study area is covered by forty-eight aeromagnetic maps of total-field intensity in ½º by ½º sheets. The data were initially pre-processed by Fugro Airborne Survey and Consultant teams, pre-processing operation included micro levelling, removal of cultural effects as well as filtering for noise contents. The pre-processed data were quality controlled for isolated spikes and other spurious data which bear no correlation with geology. Butterworth filtering processing was applied to remove any possible cultural noise and other outrageous noise in order to increase the signal to noise ratio while minimizing other noise energies in the data. Total magnetic field intensity maps of the area comprising of the sheets (Fig.5) were plotted using Oasis Montaj software (version 8.4). The composite colour map (Fig.5) effectively displayed both long wavelength and short wavelength features. Fig.5 and Fig.6 are the total magnetic intensity map of the study area and the residual magnetic map of the study area respectively.

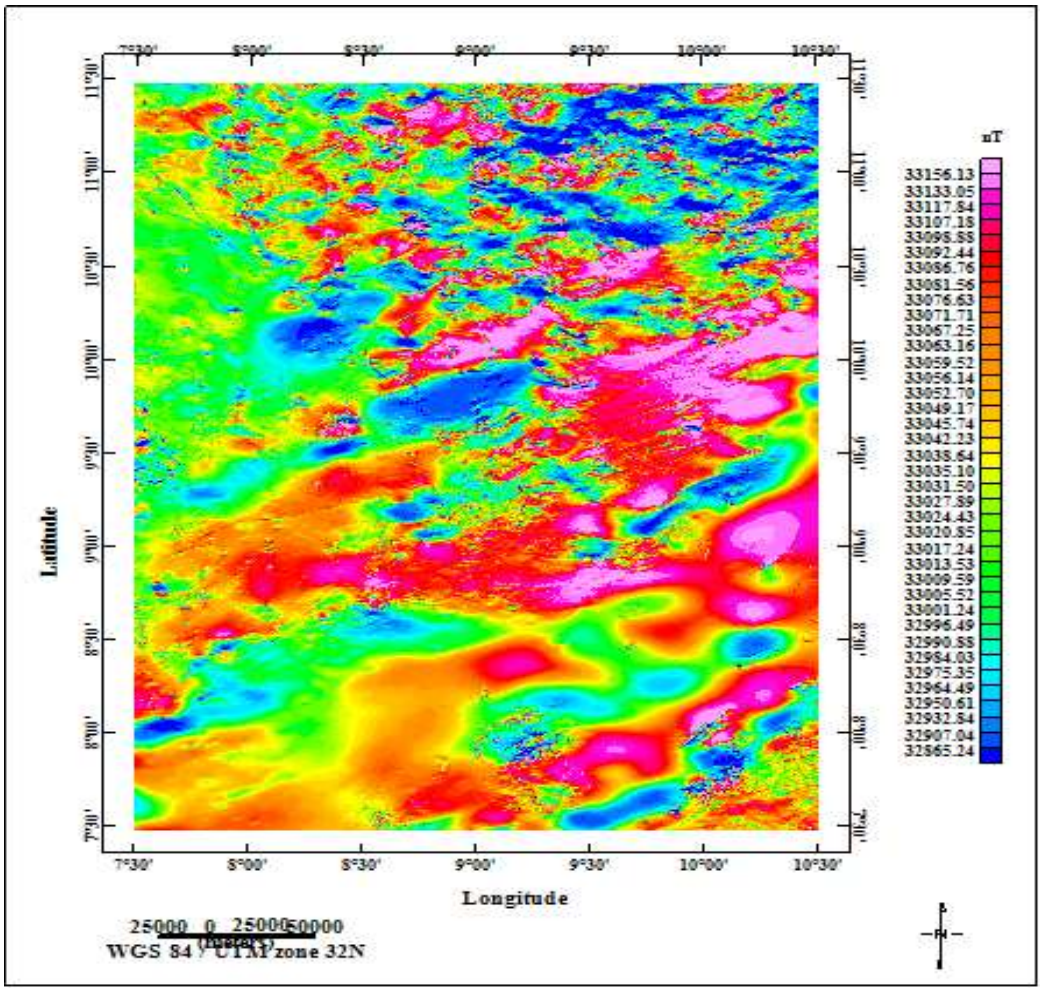


Fig.5: Total magnetic field intensity map of the study area.

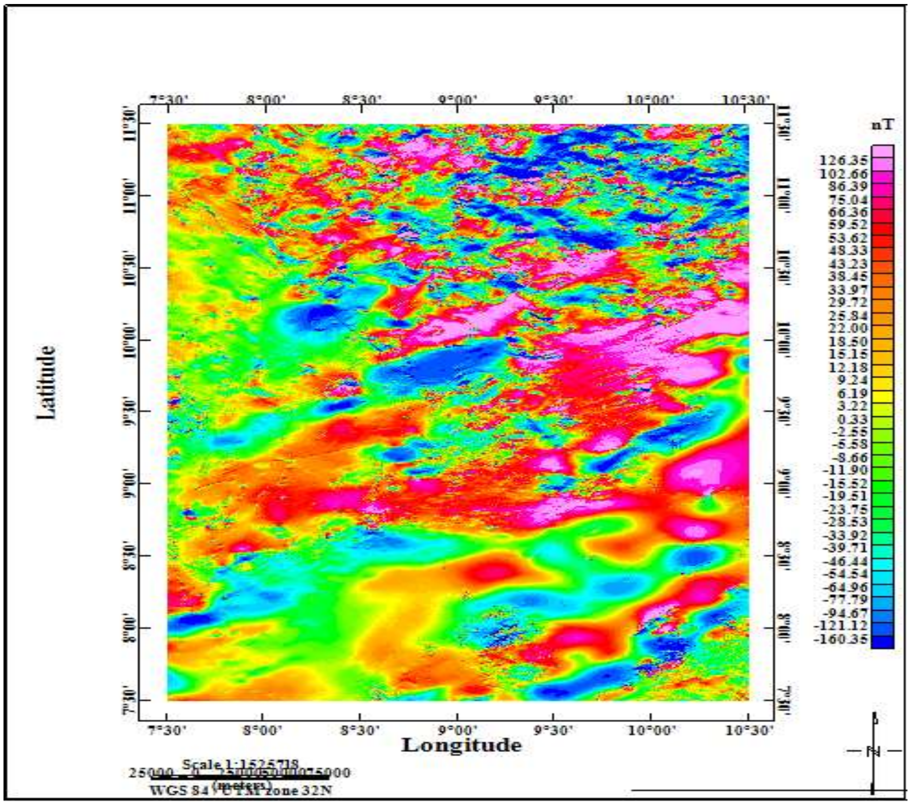


Fig.6: Residual magnetic field intensity map of the study area.

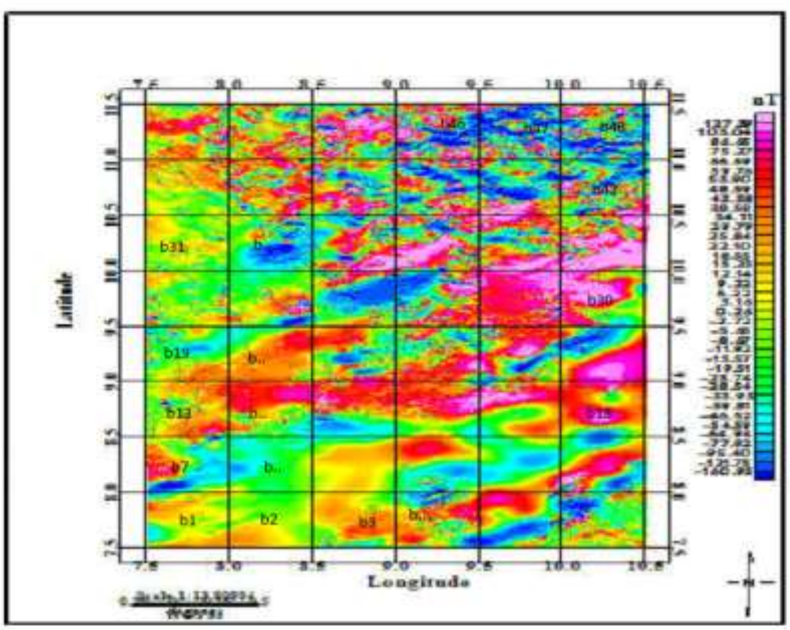


Fig.7: Residual magnetic field intensity divided into forty-eight square windows (55km by 55km each) from b1 to b48.

Curie point depth estimation

The methods for estimating the depth extent of magnetic sources are classified into two; 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-dimensional Fourier transform of the aeromagnetic data has to be performed using Oasis Montaj software (version 8.4). To carry out Spectral analysis, the residual magnetic field intensity map of the study area was divided into forty-eight blocks (**b1 – b48**) (Fig.8), each block covers a square area of 55 by 55km, which represent a square grid of 32 by 32 data points and were padded and cosine tapered before Spectral evaluation for Curie and Heat flow assessments. Graphs of the logarithms of the spectral energies against frequencies were plotted using Grapher 8 software and Surfer 15 software was used to plot Curie point depth, Geothermal gradient and Heat flow graphs.

To perform the analysis, the first step, is to estimate the depth to Centroid (Z_o) of the magnetic source from the slope of the longest wavelength part of the spectrum

$$ln\{[\Phi_{\Delta T}(|k|)^{1/2}]/|k|\} = lnD - |k|Z_o \quad (1)$$

Where $ln\{[\Phi_{\Delta T}(|k|)^{1/2}]/|k|\}$ is the radially averaged power spectrum of the anomaly, /k/ is the wave number, and D 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),

$$ln[\Phi_{\Delta T}(|k|)^{1/2}] = lnB - |k|Z_t \quad (2)$$

Where $ln[\Phi_{\Delta T}(|k|)^{1/2}]$ is the radially averaged power spectrum of the anomaly, /k/ is the wave number, and B is the sum of constants independent of /k/. According to (Okubo *et al.,* 1985; Tanaka *et al.,* 1999), the basal depth (Z_b) of the magnetic source was calculated from the equation below,

$$Z_b = 2Z_o - Z_t \quad (3)$$

The obtained basal depth (Z_b) 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 using the software were obtained from which table 1 was extracted as shown on Fig.9 below.

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 (Fourier 1955) with the following formula.

$$q = \lambda \frac{dT}{dZ} \quad (4)$$

Where q is the heat flow and λ 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 $\frac{dT}{dZ}$ 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 $\frac{dT}{dZ}$ using the following equation;

$$\theta = \{\frac{dT}{dZ}\}Z_b \quad (5)$$

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 $\frac{dT}{dT}$ 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 (Z_b) and the heat flow (q) as follows.

$$q = \lambda \{\frac{\theta}{Z}\} \quad (6)$$

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, Equation (6) was utilised. See Table 1 below.

Fig. 9 and Fig. 10, shows the graphs of the logarithms of the spectral energies for plots of blocks b39, b40, b45 and b46.The determined values of the basal depth or depth to the magnetic source Z_b , for these blocks using their determined Z_o and Z_t values in equation (3) are 11.3km, 8.51km, 7.63km and 11.2km. The Graphs of the logarithms of the spectral energies for the thirty-five blocks (c1 - c35) showing the determined values of Z_o and Z_t. using Grapher 8 software can be found in appendix A. The results of the determined values of Z_o, Z_t and Z_b for the thirty-five blocks are shown in table 1.

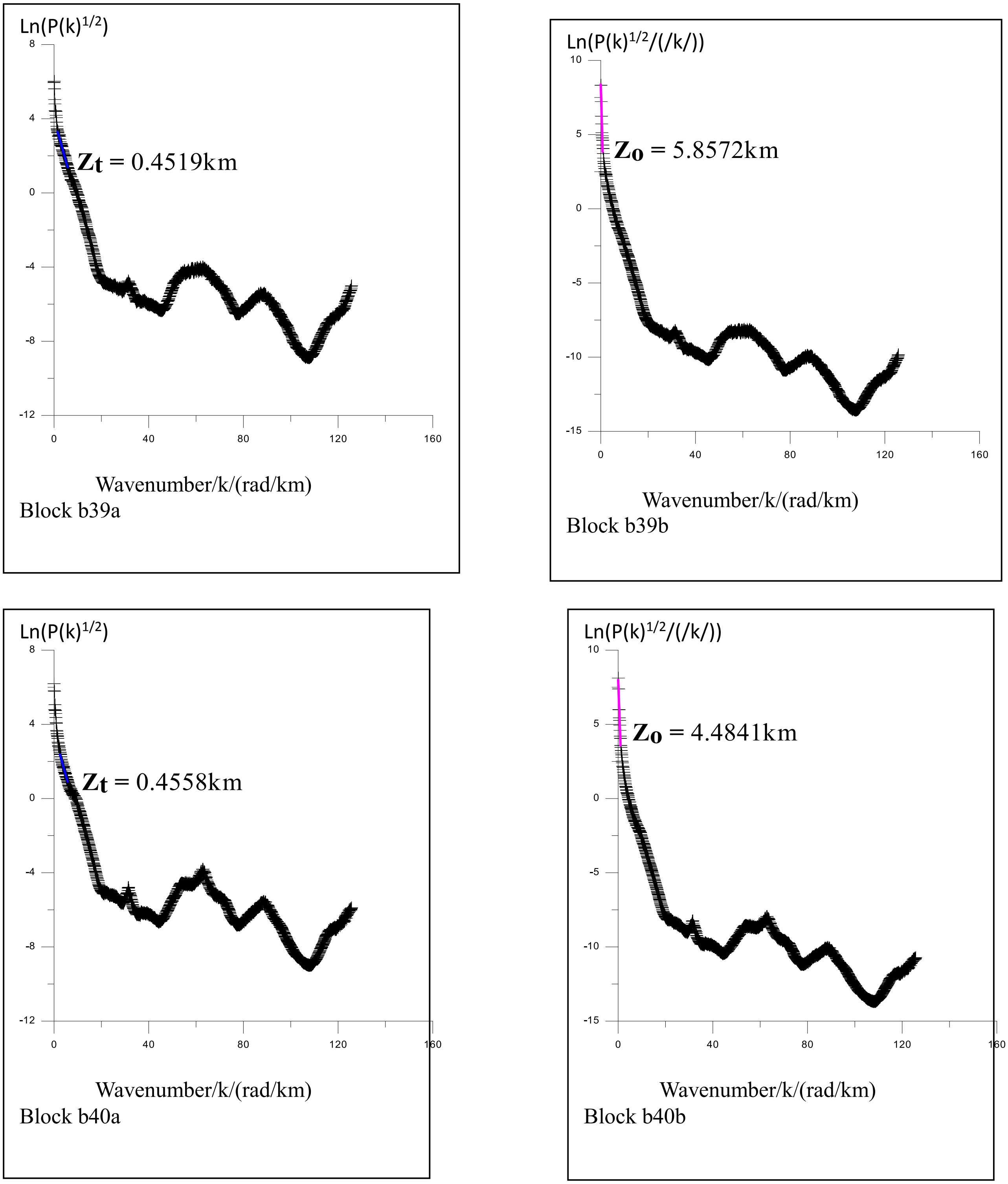


Fig. 9: Graphs of blocks b39, and b40, showing the determined values of Z_o and Z_t using Grapher 8 software.

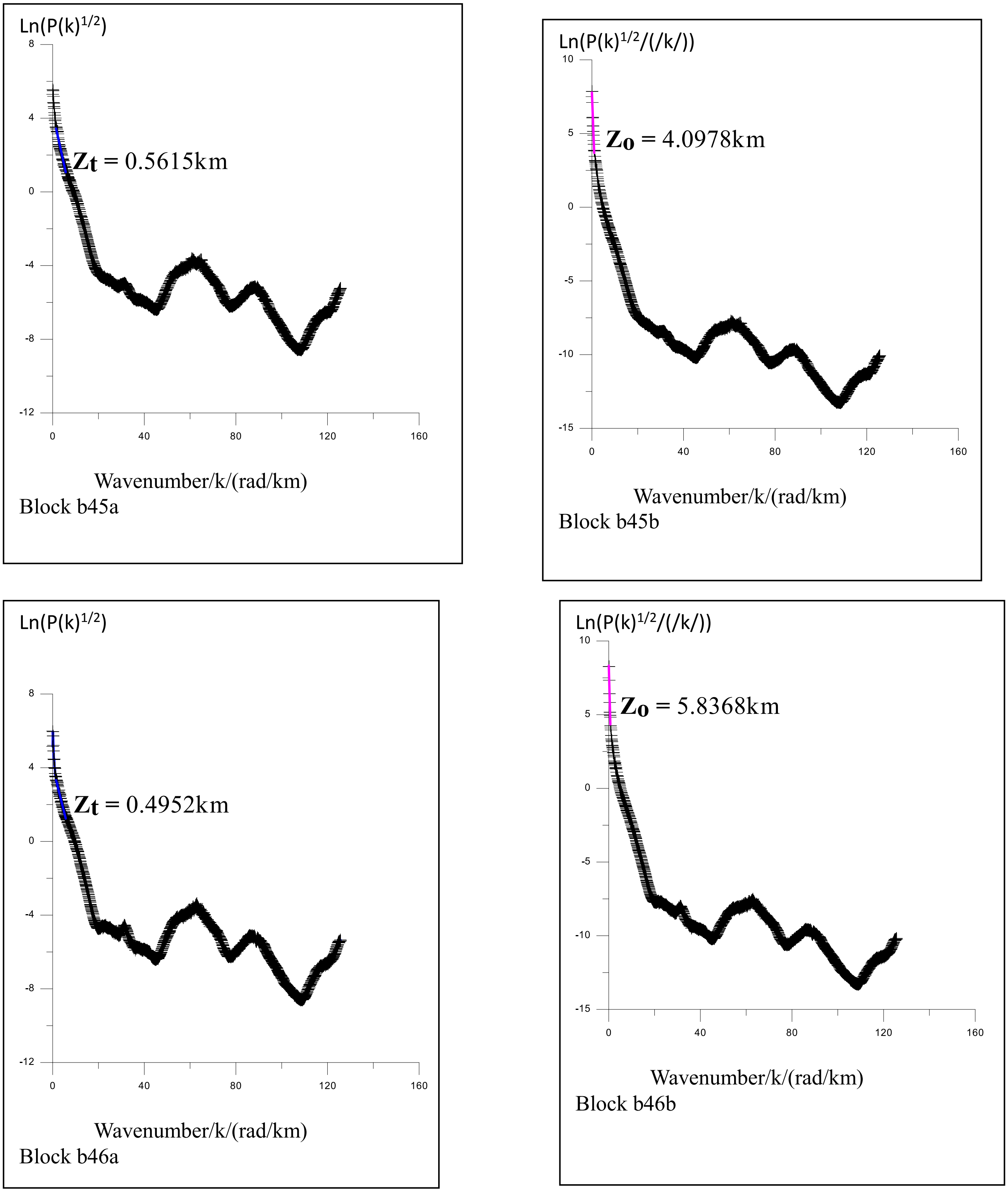


Fig. 10: Graphs of blocks b45, and b46, showing the determined values of Z_o and Z_t using Grapher 8 software

Table.1: Calculated Average Curie point depth, Geothermal gradient and Heat flow from spectral analysis

BLOCK (55km x 55km)	**Depth to Centroid (Z_o) (Km)**	**Depth to top boundary (Z_t)(km)**	**Curie Depth (Z_b) (Km)**	**Geothermal gradient ($\frac{dT}{dZ}$) (°C/km)**	**Heat Flow (q) (mWm^{-2})**
b1	8.0314	0.7377	15.3251	37.846408832569	94.616022081422
b2	7.9964	0.7570	15.2358	38.06823402775	95.170585069376
b3	10.3952	0.3708	20.4196	28.40408235225	71.010205880624
b4	10.0463	0.3647	19.7279	29.399986820696	73.499967051739
b5	9.9044	0.3222	19.4866	29.764042983383	74.410107458459
b6	14.5267	0.4892	28.5642	20.305137199712	50.762842999279
b7	13.7469	0.4316	27.0622	21.432108254318	53.580270635795
b8	14.3662	0.3933	28.3391	20.466422716318	51.166056790794
b9	15.9907	0.4398	31.5416	18.388414030994	45.971035077485
b10	14.7196	0.3024	29.1368	19.9060981302	49.765245325499
b11	17.4091	0.3024	34.5158	16.803898504453	42.009746261133
b12	11.2234	0.2513	22.1955	26.131423036201	65.328557590503
b13	5.2893	0.3285	10.2501	56.584813806695	141.46203451674
b14	7.7869	0.6612	14.9126	38.893284873194	97.233212182986
b15	6.9032	0.4462	13.3602	43.412523764614	108.53130941154
b16	7.7329	0.4477	15.0181	38.62006512142	96.55016280355
b17	6.8137	0.5660	13.0614	44.405653299034	111.01413324758
b18	6.7313	03048	13.1578	44.080317378285	110.20079344571
b19	6.9175	0.4213	13.4137	43.239374669182	108.09843667295
b20	9.9279	0.4890	19.3668	29.948158704587	74.870396761468
b21	5.9267	0.3823	11.4711	50.561846727864	126.40461681966
b22	6.8365	0.3873	13.2857	43.655960920388	109.13990230097
b23	7.2783	0.5645	13.9921	41.451962178658	103.62990544664
b24	7.4277	0.5953	14.2601	40.672926557317	101.68231639329
b25	5.2989	0.4833	10.1145	57.343417865441	143.3585446636
b26	5.9588	0.3386	11.579	50.090681405994	125.22670351498
b27	8.3961	0.3562	16.436	35.288391336092	88.220978340229
b28	5.0396	0.4995	9.5797	60.544693466392	151.36173366598
b29	4.1622	0.3105	8.0139	72.374249741075	180.93562435269
b30	6.5751	0.4687	12.6815	45.735914521153	114.33978630288
b31	4.6539	0.4355	8.8723	65.372000495926	163.43000123981
b32	7.2815	0.4802	14.0828	41.184991620984	102.96247905246
b33	5.9621	0.4723	11.4519	50.646617591841	126.6165439796
b34	6.2039	0.5679	11.8399	48.986900227198	122.46725056799
b35	6.8776	0.4939	13.2613	43.736285281232	109.34071320308
b36	5.8854	0.4095	11.3613	51.050495981974	127.62623995493
b37	4.3036	0.4054	8.2018	70.716184252237	176.79046063059
b38	5.1761	0.4244	9.9278	58.421805435242	146.05451358811
b39	5.8572	0.4519	11.2625	51.49833518313	128.74583795782
b40	4.4841	0.4558	8.5124	68.135895869555	170.33973967389
b41	6.1948	0.4520	11.9376	48.585980431578	121.46495107894
b42	4.9550	0.4959	9.4141	61.60971308994	154.02428272485
b43	4.2503	0.3719	8.1287	71.352122725651	178.38030681413
b44	4.4242	0.4801	8.3683	69.309178686233	173.27294671558
b45	4.0978	0.5615	7.6341	75.97490208407	189.93725521018
b46	5.8368	0.4952	11.1784	51.885779718028	129.71444929507
b47	5.0831	0.4552	9.711	59.726083822469	149.31520955617
b48	4.9580	0.5142	9.4018	61.690314620605	154.22578655151

RESULTS AND DISCUSSION

Radially power spectrum was applied to the aeromagnetic data of the study area divided into

48 square blocks. The curie point depths, range from 7.63km to 34.52km, with a mean value of 14.79km, geothermal gradient, range from 16.80 ^{0}C km^{-1} to 75.97^{0}C km^{-1}, with a mean value of 45.70 ^{0}C km^{-1} and heat flow, range from 42.01 mWm^{-2} to 189.94 mWm^{-2}, with a mean value of 114.26 mWm^{-2}. The curie point depth of the study area compare favourably with what was recorded over Sarti and environs of North-Eastern Nigeria (range from 24 to 28km, Kasidi and Nur (2012)), Jalingo and Environs, North-Eastern part of Nigeria (range from 26 to 28km, Kasidi and Nur (2013)), the eastern Chad basin, Nigeria ((Mafa - Bama and Maiduguri - Gwoza areas) (range from 21 to 32 km , Anakwuba, et al., (2016))), the entire Bida Basin in north-central Nigeria (range from 16 to 30 km, Nwankwo and Sunday (2017)), part of the upper Benue trough corresponding to Kaltungo, Guyok, Lau and Dong areas, north eastern Nigeria (range from 12 to 34 km, Mohammed et al., (2019)) and the Upper Benue Trough (range from 24 to 33km, Nur et al., (1999)).

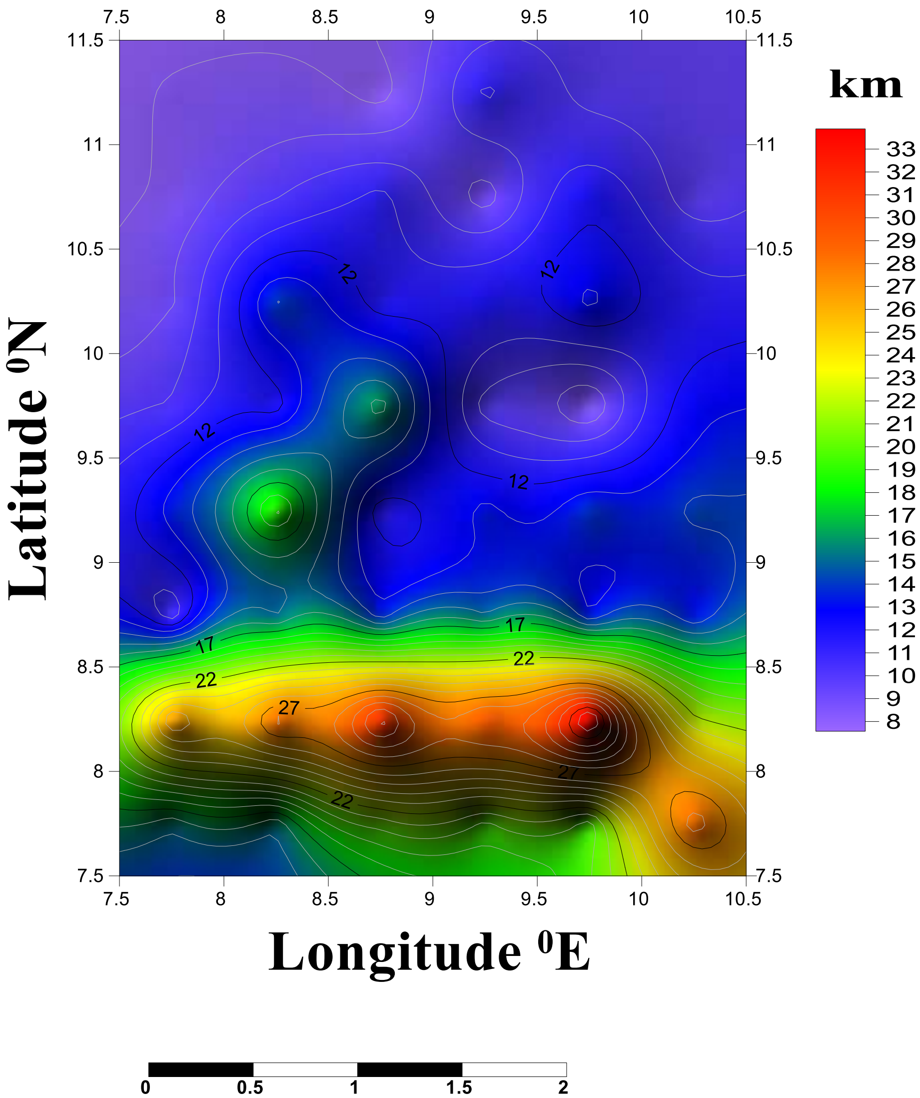


Fig.11: Curie point depth map of the study area using Surfer 8 software.

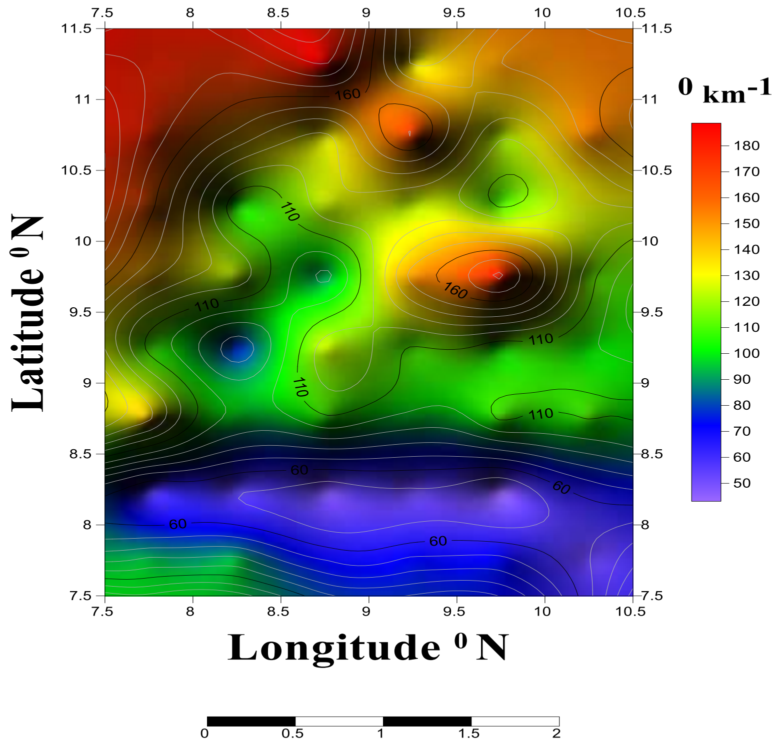


Fig.12: Geothermal gradient map of the study area using Surfer 8 software

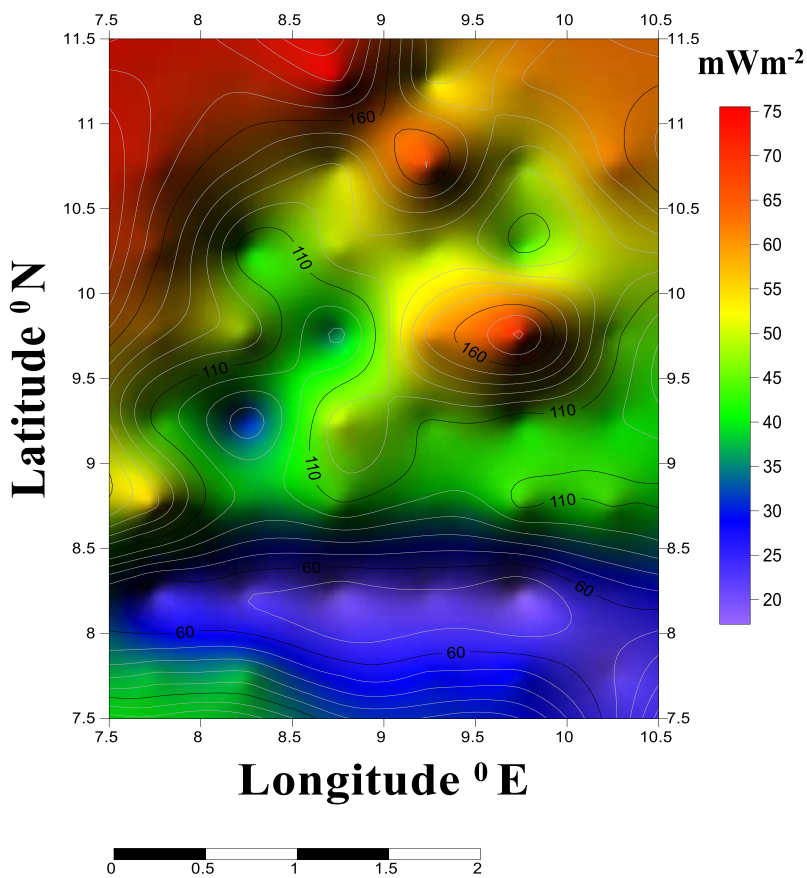


Fig.13: Heat flow map of the study area using Surfer 8 software.

CONCLUSION

In this research, high resolution aeromagnetic data has been used to investigate the present of anomalies and the curie point depth of the study area. The quantitative (Spectral analysis) interpretation technique was chosen to achieve the outlined objectives of this research. The curie point depths has a mean value of 14.79km, a mean geothermal gradient of 45.70^{0}C km^{-1} and heat flow and a mean heat flow of 114.26 mWm^{-2}. Fig. 8, show that, the curie point depth is shallower in the extreme northeast, southeast and part of the west of the study area. Also, Fig. 12, show the thermal gradient tends to be higher mainly in the north, central and extreme southeast of the study area and Fig. 13, show that, the heat flow tends to be higher mainly in the north, central and extreme southeast of the study area. The above characteristics of these areas according to Stein and Stein (1994) and Tanaka et al., (1999), reveals that, there might probably be good sources for geothermal and thereby recommended for both geothermal exploration and exploitation.

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