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Interpretation of High Resolution Aeromagnetic Data over Numan and Its Environs Adamawa State North Eastern Nigeria

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Abstract: *Interpretation of High Resolution of Aeromagnetic Data over Numan and its environs was carried out to determine depth to the centroid (Z_o)km, depth to the top boundaries, Curie Point Depth geothermal gradient (dt/dz) ^{0}C/km and heat flow (q) mW/m^2 of the area under study. High Resolution of Aeromagnetic Data with sheet number 173,174,175, 194,195 and 196 of Kaltungo, Guyuk, Shelleng, Lau, Dong and Numan respectively. Aeromagnetic data were divided into six blocks and subjected to spectral analysis via the Oasis Montaj Software with upward continuation techniques to get the magnetic anomalies over the area. The following parameters were estimated; Depth to the centroid (Z_o) which vary from 12.5km to 16.4km , Depth to the top boundary (Z_t) range from 7.01km to 9.65km, Curie Point Depth (Z_b) vary from 17.99km to 25.99km, Geothermal Gradient (dt/dz) range from 22.32^{0}C/km to 32.24km and Heat flow (q) vary from 55.80mW/m^2 to 80.60m/Wm^2. The estimated average value of Depth to the centroid (Z_o), Depth to the top boundary (Z_t), Curie Point Depth (Z_b), Geothermal Gradient (dt/dz) and Heat flow (q) were 15.03km, 8.35km, 21.71km, 27.01^{0}C/km and 67.54m/Wm^2 respectively. There is possibility of geothermal energy exploitation and exploration around Guyuk since it has the highest heat flow of 80.60m/Wm^2 and the Curie Point Depth (CPD) of 17.99km. For further research there should be application of integrated geophysical techniques in order to locate more potential zones for geothermal energy exploitation and exploration within the study area.*

Keywords*:* geothermal, energy, centroid, curie point depth, geothermal gradient, heat flow, exploitation and exploration

INTRODUCTION

Geothermal energy originates from heat produced in the Earth's core during the planet's formation by radioactive decay of various minerals. One potential renewable energy source is the thermal energy stored by rocks and fluids at the Earth's center. One renewable energy source that can be explored, captured, and used for both residential and commercial applications is geothermal energy. There are currently 21 nations in the globe where geothermal steam production is used to generate electricity. In Europe, 4300 Gwh/y of power is produced by geothermal means. Virtually entirely concentrated in Turkey, Iceland, and Italy (Blue Book on Geothermal Resources, 1999).

Through the interpretation of aeromagnetic data sets, such as magnetic, radiometric, and gravity data, geophysicists have been using geophysical methods to carry out the exploration of solid minerals, hydrocarbon deposits, geothermal energy, and other minerals in various parts of the world. Some of these research endeavors have resulted in pathways for the exploration of solid minerals, geothermal energy, and hydrocarbon deposits (oil and gas) (Dziadek *et al.*, 2021; Ani *et al.*, 2023; Akin and Ciftci, (2011); Abraham *et al.*, 2018; Adewumi *et al.*, 2023; Elbarbary *et al.*, 2022; Aboud *et al.*, 2022; Ezeh *et al.*, 2020; Nnaemeka *et al.*, 2023; Nwosu and Onuba (2013) ; Abraham *et al.*, 2015; Wang *et al.*, 2023; Ebelehulu *et al.*, 2021; Elbarbary *et al.*, 2018 and Odidi *et al.*, 2020). Numerous applications exist for the study of aeromagnetic data, including the detection of buried metallic structures such as dykes, faults, contacts, lineaments, and sills (Obira *et al.*, 2020; Ohal, 2016). In certain areas of the Upper, Middle, and Lower Benue Troughs as well as the Chad Basin in Northeastern Nigeria, magnetic data sets have been utilized for purposes related to economics, geological mapping, estimation of depth to basement, hydrocarbon exploration, groundwater potential zone investigation, delineation of crustal structures, structural lineaments, identification of magnetic sources, mineral deposits, estimation of geothermal gradients, Curie Point Depth, Heat flow, and Point to the Centroids. (Kasidi, 2019; Ezeh *et al.*, 2020; Ayuba and Nur, 2019; Chinekeokwu *et al.*, 2023; Bensen *et al.*, 2023 and Chukwunoso *et al.*, 2012).

For the sake of the country's industrial and economic development, Nigeria must maintain energy sustainability in the energy sector and raise the rate at which energy is supplied. Due to the lack of power, disputes involving renewable energy sources including geothermal, solar, and wind power became necessary. The focus of this study is geothermal energy; investigating renewable energy sources can truly lessen power outages and increase energy sustainability (Ayigun *et al.*, 2022 and Abraham *et al.*, 2018).

Based on prior research, Nigeria is among the African nations endowed with geothermal energy. This is evidenced by the presence of warm springs, radiogenic heat formations, and elevated concentrations of radioactive elements, including uranium U^{234} and thorium, in certain regions of the country (Udochukwu, 2019; Abdulwahab *et al.*, 2019; Onyejuwuka and Iduma, 2020; Ezekiel, 2019; Maman and Lawal, 2019, Badamasi *et al.*, 2022; Hussaini *et al.*, 2023; Eldosonky *et al.*, 2023 and Kasidi, 2019).

In North-Central Nigeria, Anudu *et al.* (2012) examined aeromagnetic data over Wamba and its surrounding regions. In addition to charting the deposits of metalliferous minerals in the basement rocks, the research's objectives included defining structural lineament and trend and determining the depth to magnetic sources. To create a residual aeromagnetic intensity contour map, regional residual separation was applied to a total aeromagnetic intensity contour map. The depth to magnetic sources was estimated using Peter's hod, which revealed two depth source models. The deeper sources had a magnetic intensity ranging from -225Nt to 3.15km, while the shallower sources had a magnetic intensity ranging from -10nT to 20nT, and they were located between 0.23km and 0.76km. Based on the findings, hydrocarbon exploration in the studied area may be possible because deeper sources exist because of basic intrusive bodies underlying the sediment-covered marginal areas of the Benue Trough.

Research on Curie-temperature Depth and Heat flow inferred from spectral analysis of aeromagnetic data over the southern Bida Basin, west central Nigeria, was conducted by Bensen et al. in 2019. The study was conducted to estimate heat flow and Curie Temperature Depths in the southern Bida basin. Using spectral analysis of aeromagnetic data, the Curie Point Depths (CPD) of the region were estimated in light of the findings. Zt 1.388km was the magnetic source at the top boundaries, and 13.188km was the average depth to the centroid (Z_o). The Curie Point Depth (CPD) average was 24,987 km. According to the researcher, Gulu and Kirri have a shallow Curie Point Depth (CPD) which result to high value of heat flow obtained to be 59.751Mw/m^2. The area under study is good for geothermal energy exploration base on the researcher’s recommendations.

This research is therefore aimed at interpretation of aeromagnetic data over some parts of Numan and its environs with the following objectives (i) estimate geothermal gradients and Curie Depth Point (ii) to determine heat flow and points to the centroids (iii) to determine potential zones for geothermal energy exploration.

The study Area

The area of the study is Numan and its environs, lie within latitude 9^0 00N -10 00N and longitude 11 00^{0}E – 12 30^{0}E in Adamawa State North Eastern Nigeria. The area is bounded to the east by the Ngurore town to the north Benue River, Zuwai, Kushi, Demsa, Jimeta, Zandi, Mutum Daya, Manga and Pupule just to mention a few, the geology map of the area shows the entire towns in the study area.

Geology of the Area

The geology formation of the area comprises of Alluvium, New Basalt, Older Basalt, Kerrikeri formation, Gombe formation, Pindiga formation,Yoldeformation, Bima formation, Pan-African older granitoids, Meta- Sediments/Volcanic series and Migmatite- Gneiss complex.
The Bima Formation, which lies at the base of the stratigraphic sequence in the Yola Arm and is now the most extensively researched geological formation underlies the study region, along with Alluvium, New Basalt, Older Basalt, Kerrikeri Formation, Gombe Formation, and Gombe Formation. Two sedimentary units make up the majority of it. Both the Quaternary River course alluvium and the Albian Bima Formation, which are mostly located in the southern

portion of the region, predominate. Sand deposits have been lost in areas where the Bima Sandstone has deteriorated. (Obiefuna *et al.*, 2010) Sands, clays, silty-clay, and pebbly sands are the main types of alluvial deposits found in river courses.

The Gombe and Bambam areas' and the study area's Yolde Formations are thought to be continuous. A fossiliferous and severely fragmented limestone component of the Yolde Formation. With clays, silts, and shales intercalated in between, the Formation is made up of a series of alternating flaggy fine- to coarse-grained sands and sandstone. Beneath younger rocks, the beds naturally tilt westward. The limestone-siltstone and sandstone units that make up the Yolde Formation in the Numan area are bedded shale units. Each cycle starts with base shale and moves upward through siltstone and sandstone. In the sampled Numan boreholes, where the unit of sandstone and shales is most developed, the overall thickness reached roughly 210 meters. The lower 25 meters are made up of poorly sorted, coarse- to medium-grained Bima Sandstone, which is covered in cyclically bedded shale, siltstone, lime stone, and sandstone facies of the Yolde Formation (Obiefuna *et al.*, 2010).

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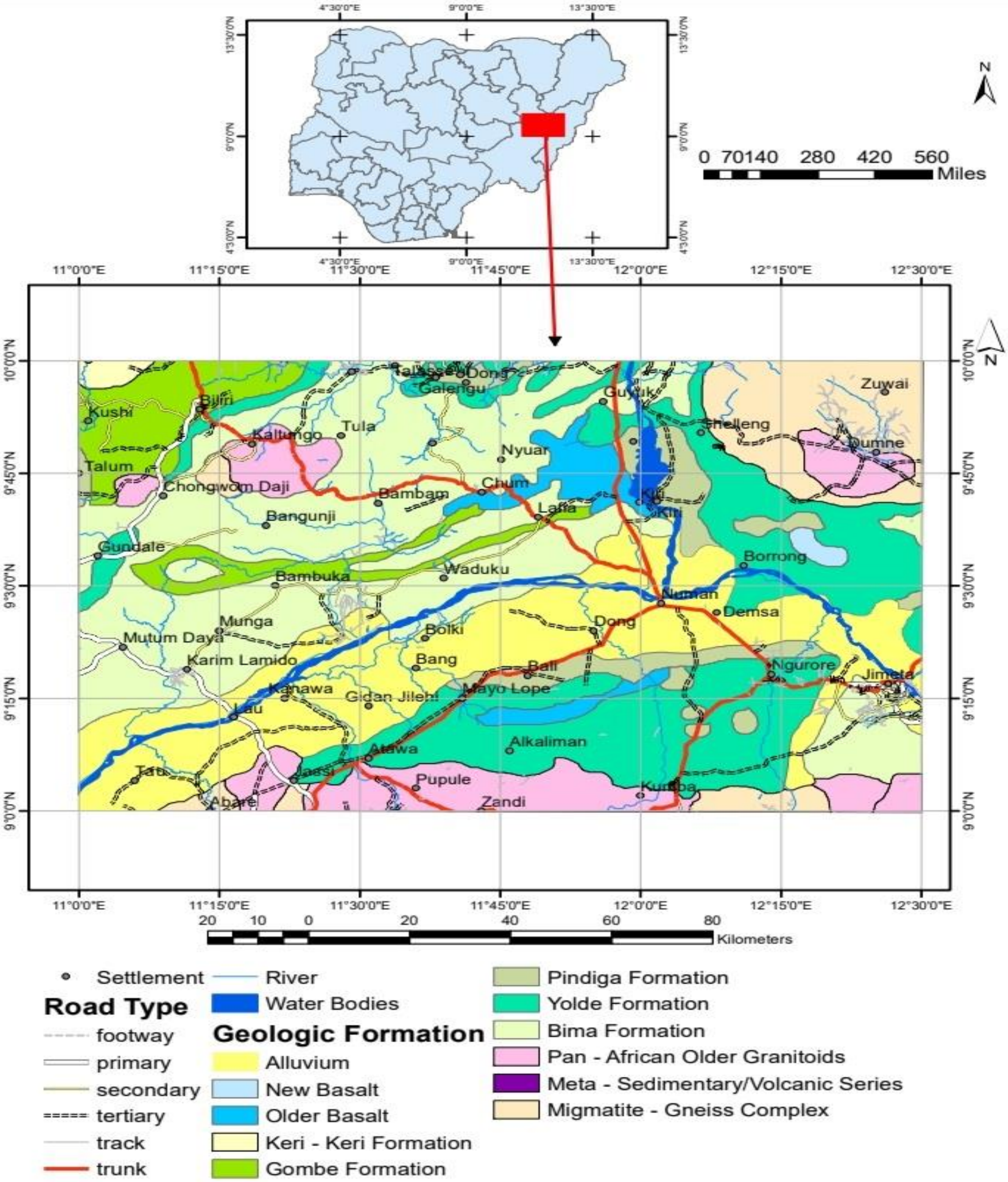
Geology map of the study area. Digitized from Nigeria Geological Survey 2006



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Materials and Method

High resolution aeromagnetic data sheets (173,174,175, 194, 195, and 196) covering parts of the Numan surroundings (katungo, Guyuk, Numan, Shelleng, Lau, and Numan) were obtained from the Nigeria Geological Survey Agency (NGSA). Between 2004 and 2009, Fugro conducted aerial surveys across Nigeria on behalf of the NGSA. The Aeromagnetic Survey was carried out along NE-SE flight lines with a 2-kilometer line spacing, using nominal flying heights of 80 meters and 500-meter spacing.

Using the Oasis Montaj software package, the entire magnetic field data were then gridded and plotted following the coordinate conversion (degrees to meters) in order to prepare for the upward continuation (Abubakar & Muhammed, 2022). The upward continuation is a legitimate regional field for the area because it is derived from a relatively deep structure. When interpreting magnetic anomalies across regions with a high concentration of near-surface magnetic sources, including dykes and other intrusions, the approach can be helpful (Keary *et al.*, 2002 and Hayatudeen *et al.*, 2021).

$$F(x,y,-h) = \frac{h}{2\pi}\iint \frac{f(x,y,0)\partial x \partial y}{(x-x')^2+(y-y')^2+h^2)^{1/2}} \qquad \ldots\ldots 1$$

Where $F(x,y,-h) = total\ field\ at\ a\ point\ \ F(x',y',-h)\ above\ the\ surface$

$on\ which\ F(x',y',-0)\ is\ known.\ h = continuation\ height.$

Spectral Analysis

Six square grids, measuring 30' x 30' of 54.9 kilometers by 54.9 kilometers of 2 x 3 blocks, were created using the aeromagnetic data, for a total of six (6) data points. To determine the depth to the Centroid (Zo) and Top Boundary (Zt), respectively, spectral analysis was employed on the data sheets upward continuation techniques performed on the data. Utilizing the MAGMAP package within the Oasis Montaj setting. Each block's spectral data was windowed and Fast Fourier transformed. After being imported into Microsoft Excel, the radial SPC files were transformed into a format that MATLAB could process. The depth to each block's centroid (Zo) and upper limit (Zt) was then calculated.

Curie-point depth

The estimation of Curie point depth requires two phases (Manea & Manea, 2011). To begin the study, determine the depth to the centroid (Zo) of the magnetic source by calculating the slope of the longest component of the wave length spectrum.

$$In[\frac{p(s)^{½}}{/s/}] = InA - 2\pi/s/Z_o \quad \text{..........2}$$

where A is a constant, /s/ is the wave number, and p(s) is the anomaly's radially average power spectrum. The slope of the second longest wave length special segment is used to estimate the depth to the top boundary (Z_t) of that distribution in the second step.

$$Inp[(s)^{½}] = InB - 2\pi/s/Z_t \quad \text{..........3}$$

where B is the sum of the constant, the basal depth independent of $/s/$.

In calculating Curie point depth the basal depth (Z_b) of the magnetic source in the area is assumed to be the Curie point depth (Manea & Manea, 2011). The basal depth (Z_b) of the magnetic source is calculated as follows:

$$Z_b = 2Z_o - Z_t \quad \text{..........4}$$

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Heat flow and geothermal gradient

Using Fourier's Law and the following formula, the estimate of heat flow and thermal gradient will be computed:

$$q = \lambda[\frac{\partial T}{\partial Z}] \quad \ldots\ldots 5$$

In order to relate the Curie point depth (Z_b) to Curie point temperature variation, the vertical direction of temperature variation and the constant thermal gradient was assumed. The geothermal gradient $\left(\frac{\partial T}{\partial Z}\right)$ between the earth and the Curie point depth (Z_b) was defined by the equation:

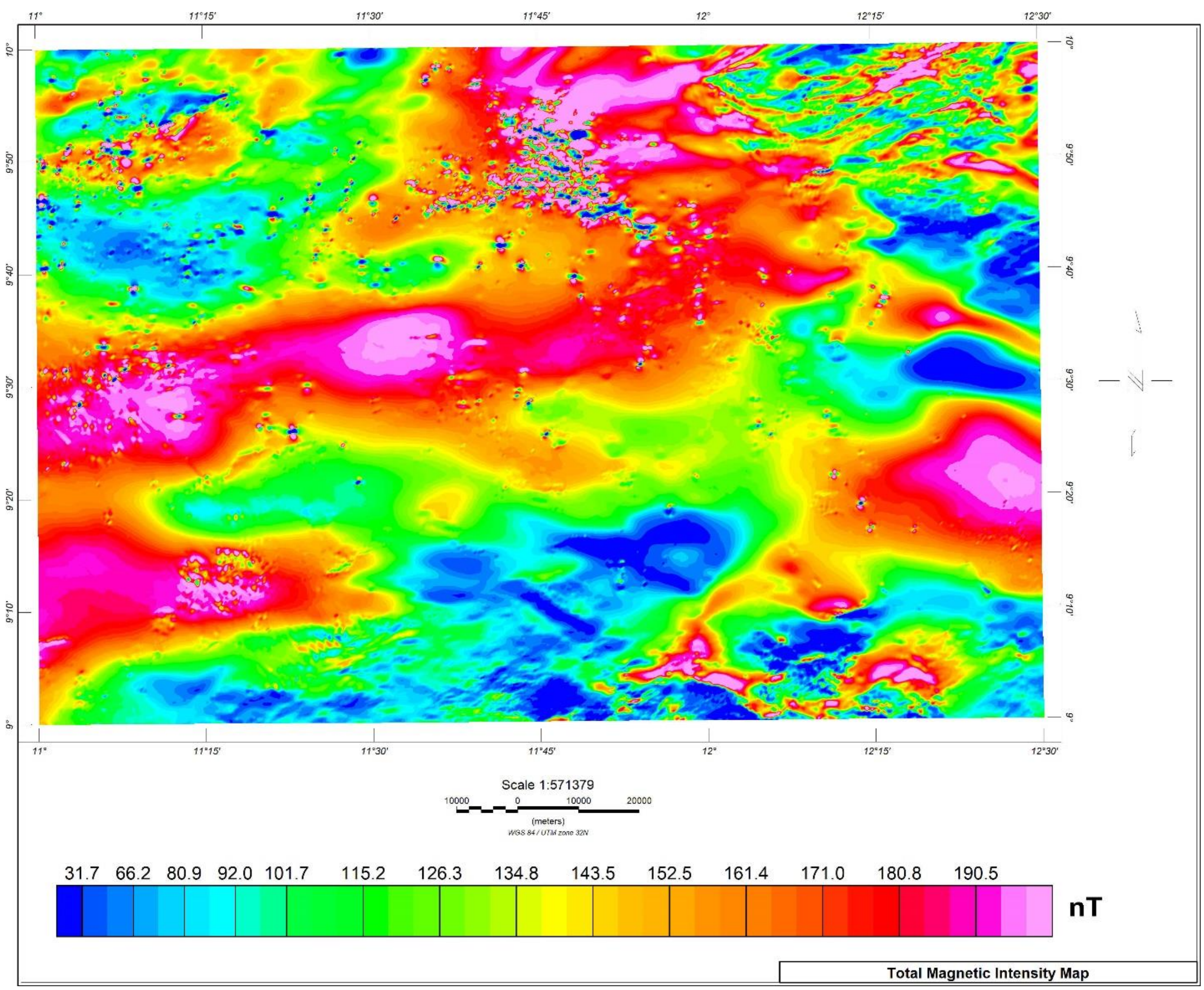
$$\frac{\partial T}{\partial Z} = \frac{580℃}{Z_b} \quad \ldots\ldots 6$$

where 580^0C is the Curie temperature at which ferromagnetic minerals are converted to paramagnetic minerals. Furthermore, the geothermal gradient was related to heat flow (q) using the formula:

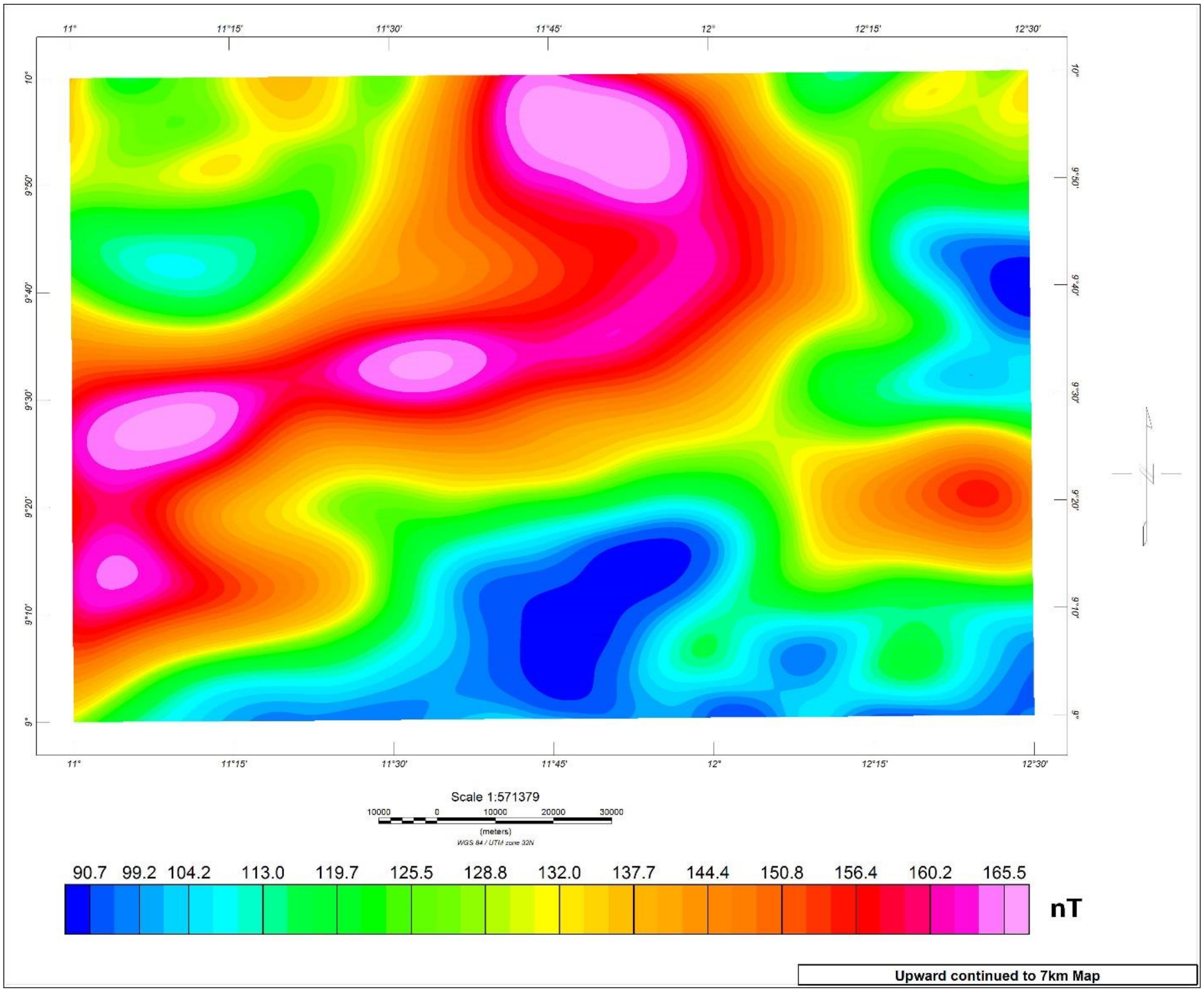
$$q = \lambda(\frac{\partial T}{\partial Z}) = \lambda(\frac{580℃}{Z_b}) \ldots\ldots 7$$

where λ is the coefficient of thermal conductivity.

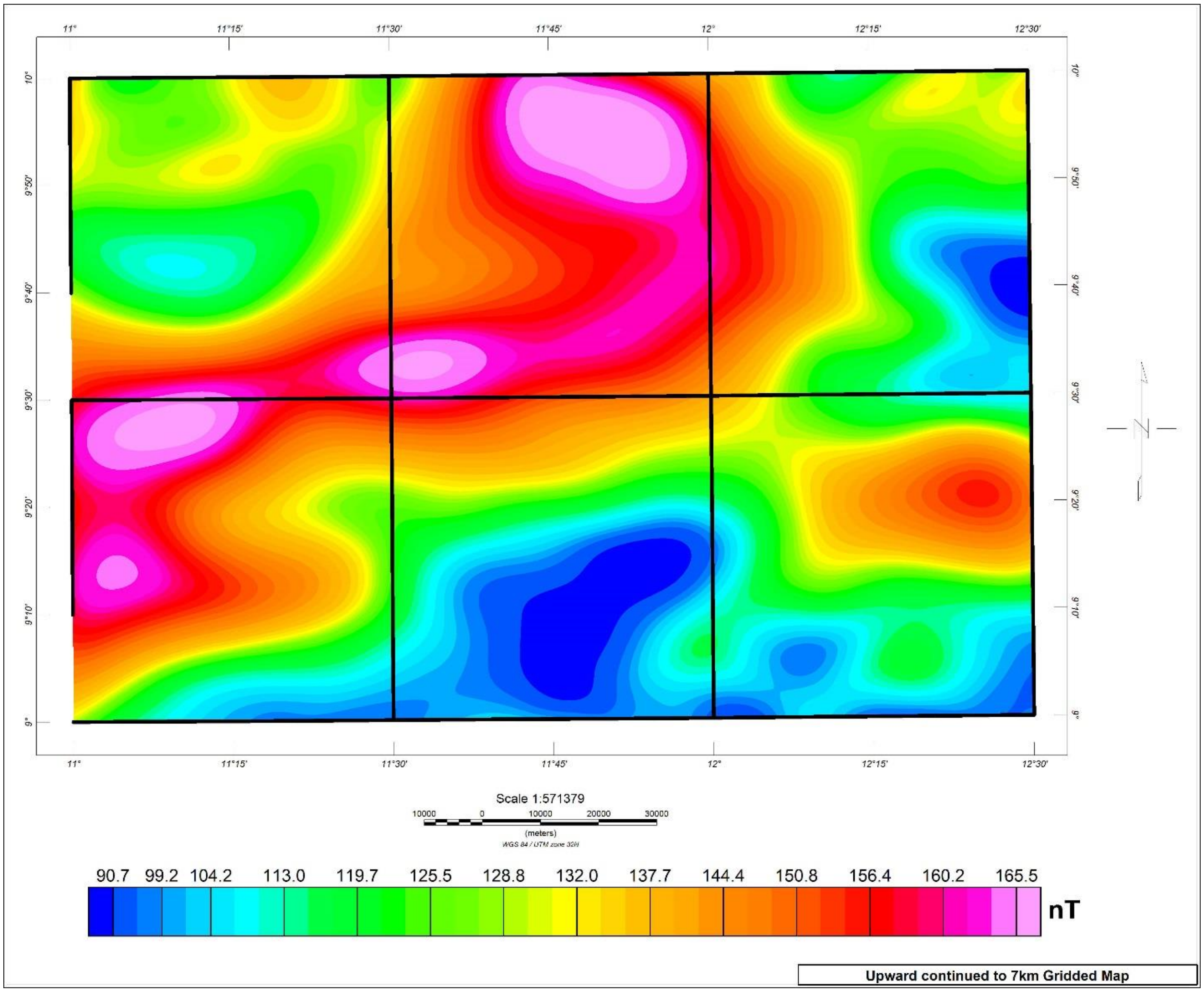
A thermal conductivity of 2.5 $Wm^{-1o}C^{-1}$ was used to compute the subsurface heat flow (Anyadiegwu & Aigbogun, 2021).



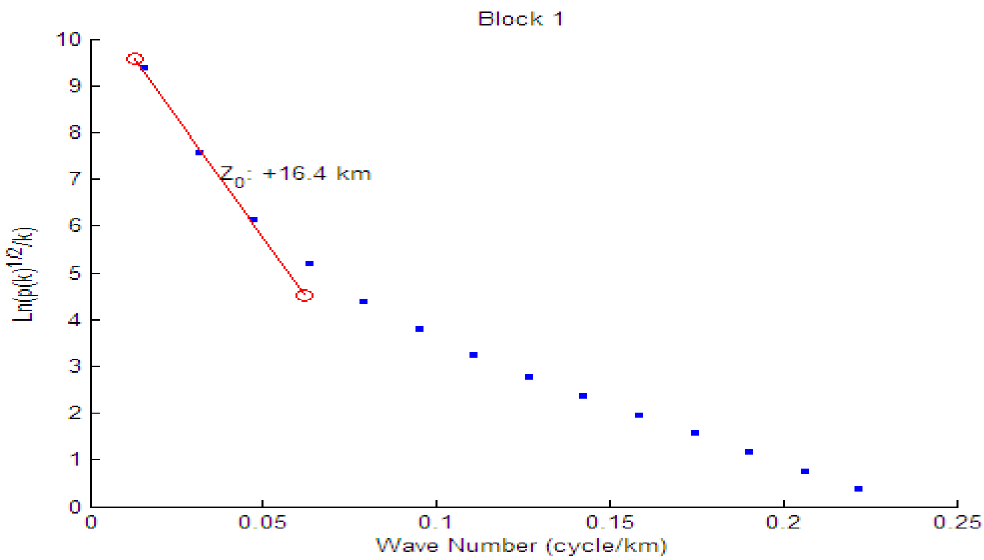
Total Magnetic Intensity Map of the area.

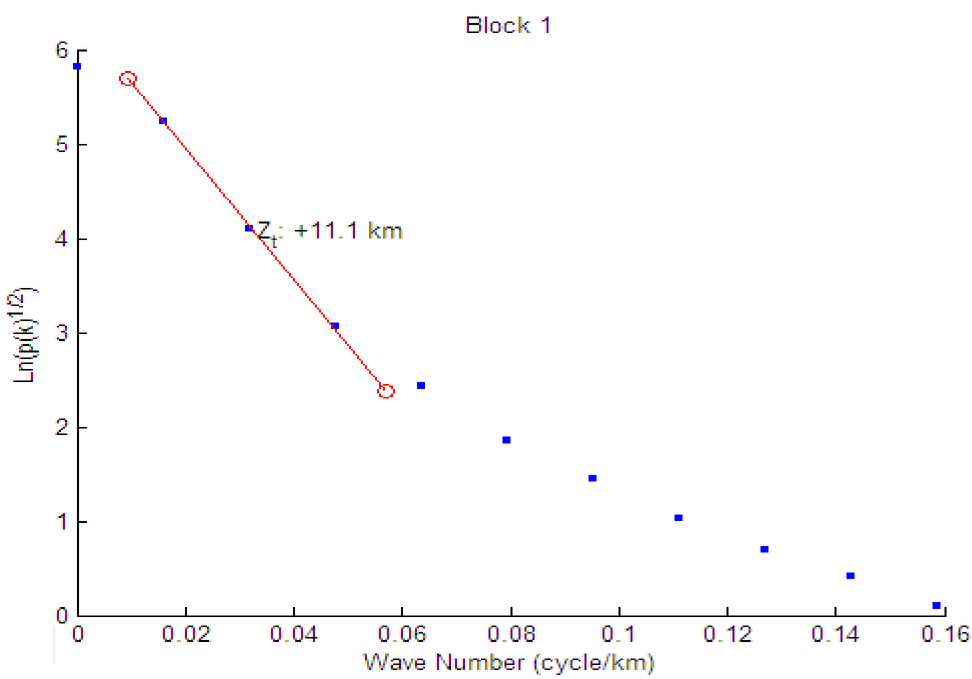


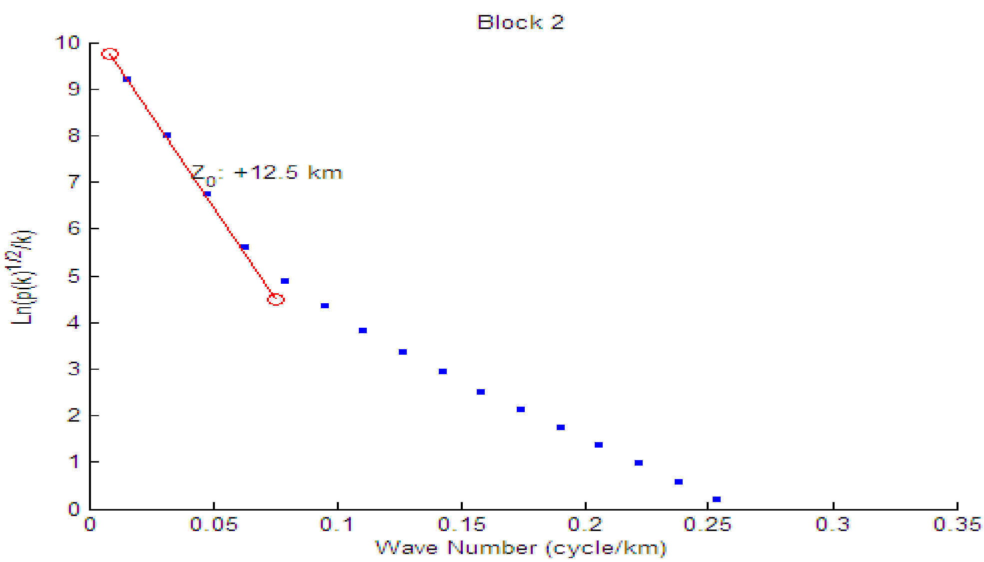
Upward continued to 7km Map

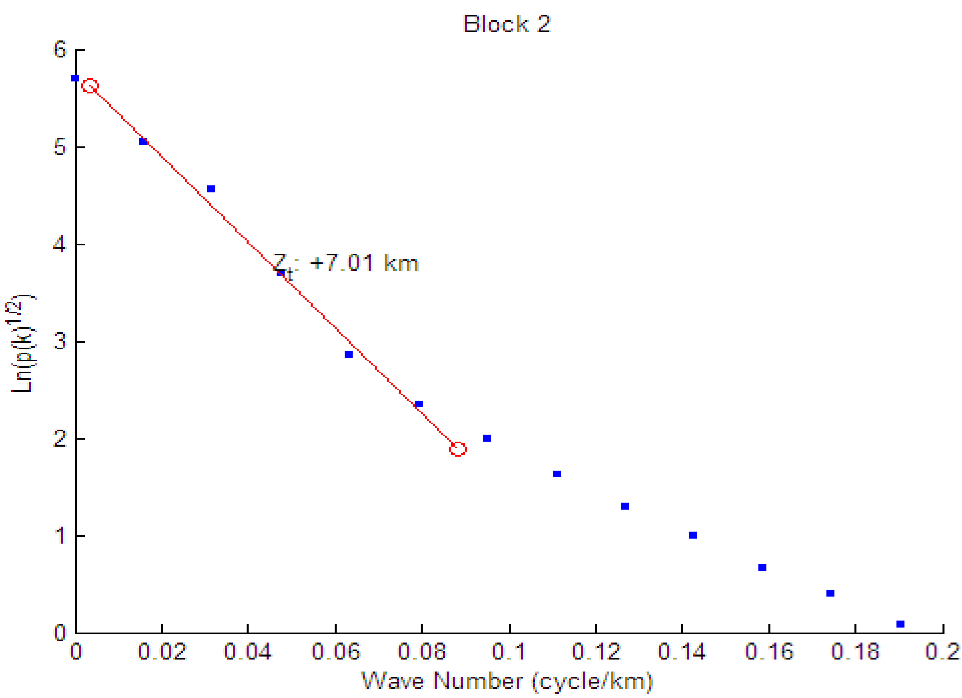


Gridded Map representing Kaltungo (173) Block 1, Guyuk (174) Block 2, Shelleng (175) Block 3, Lau (194) Block 4, Dong (195) Block 5 and Numan (196) Block 6.


Block 1
Z0: +16.4 km
Ln(p(k)1/2/k)
Wave Number (cycle/km)
0
0.05
0.1
0.15
0.2
0.25
0
1
2
3
4
5
6
7
8
9
10


Block 1
Zt: +11.1 km
Ln(p(k)1/2)
Wave Number (cycle/km)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0
1
2
3
4
5
6


Block 2
Z0: +12.5 km
Ln(p(k)^1/2/k)
Wave Number (cycle/km)


Block 2
Zt: +7.01 km
Ln(p(k)^1/2)
Wave Number (cycle/km)

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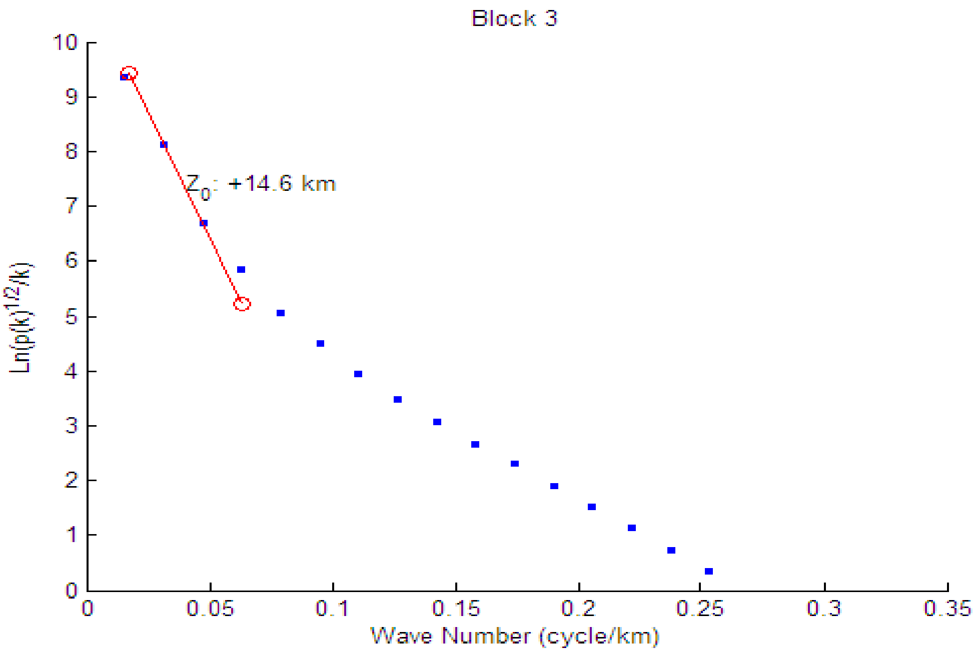
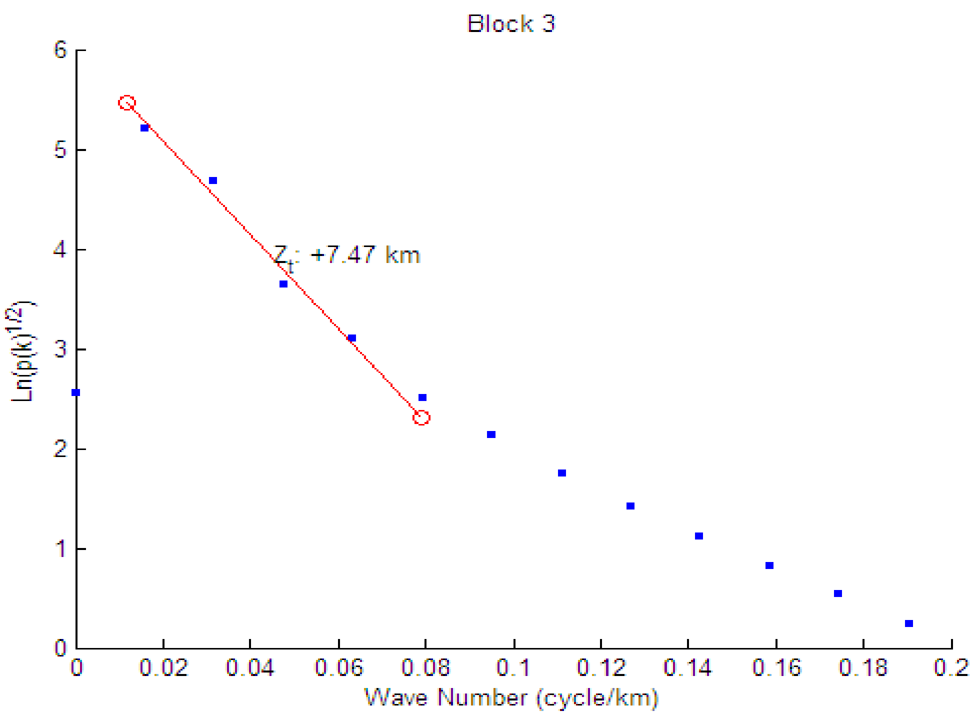
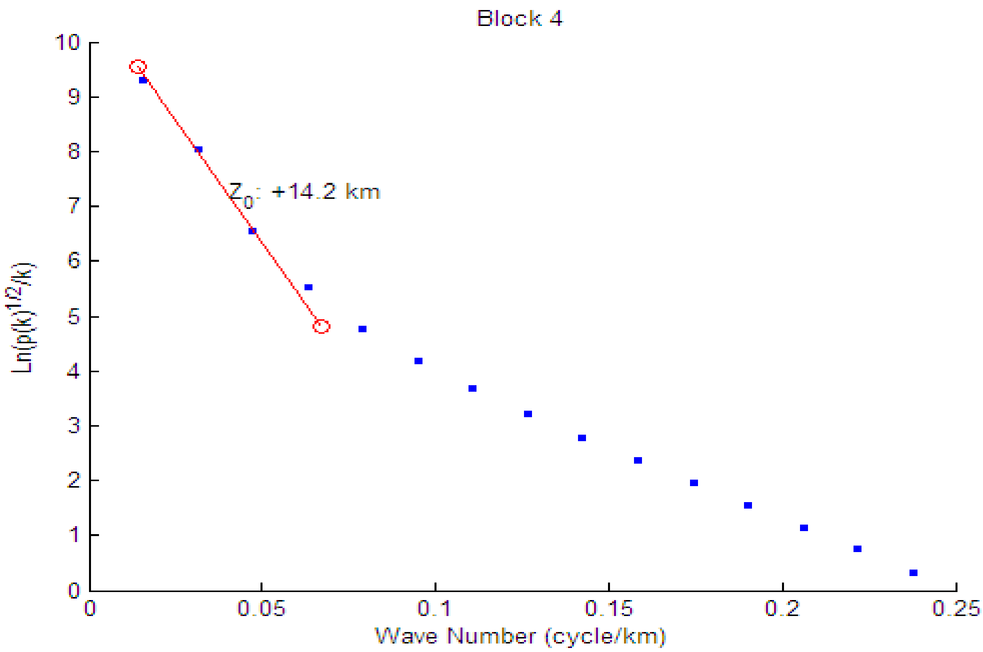
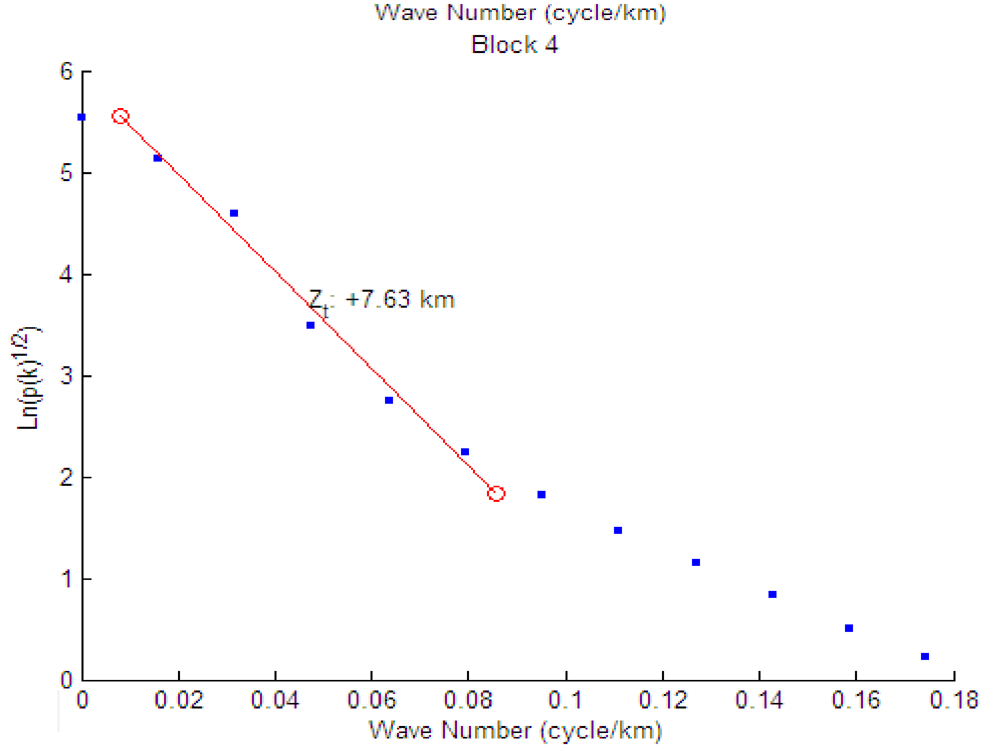
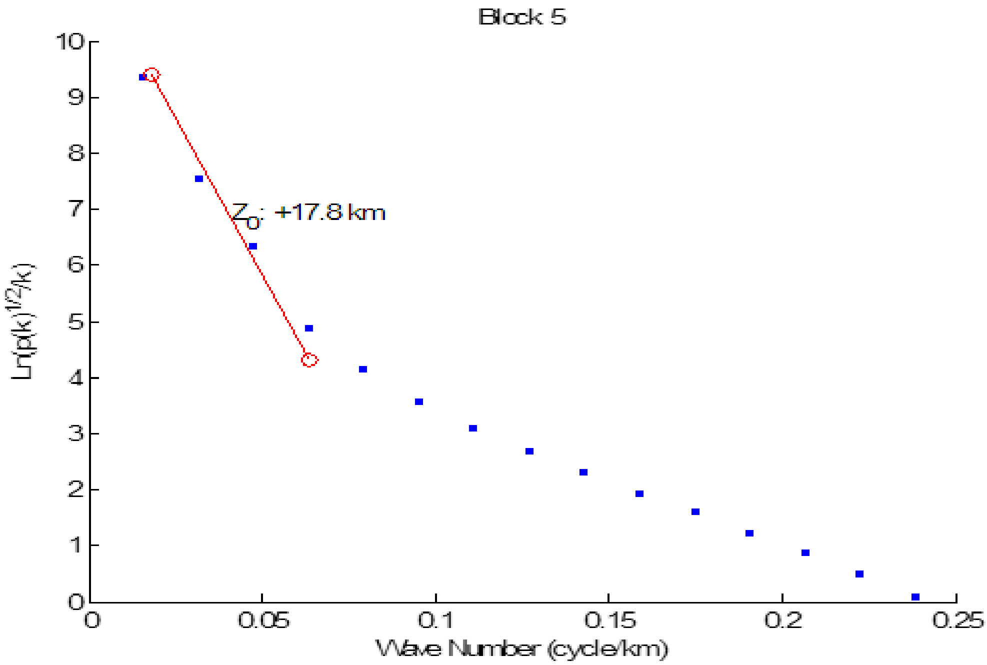
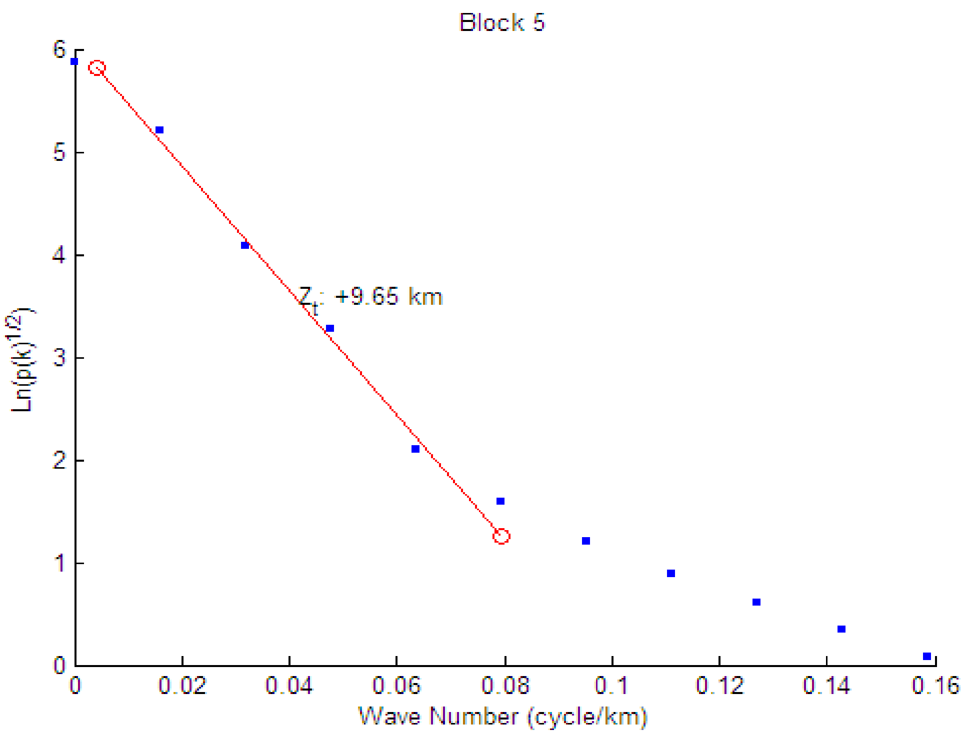


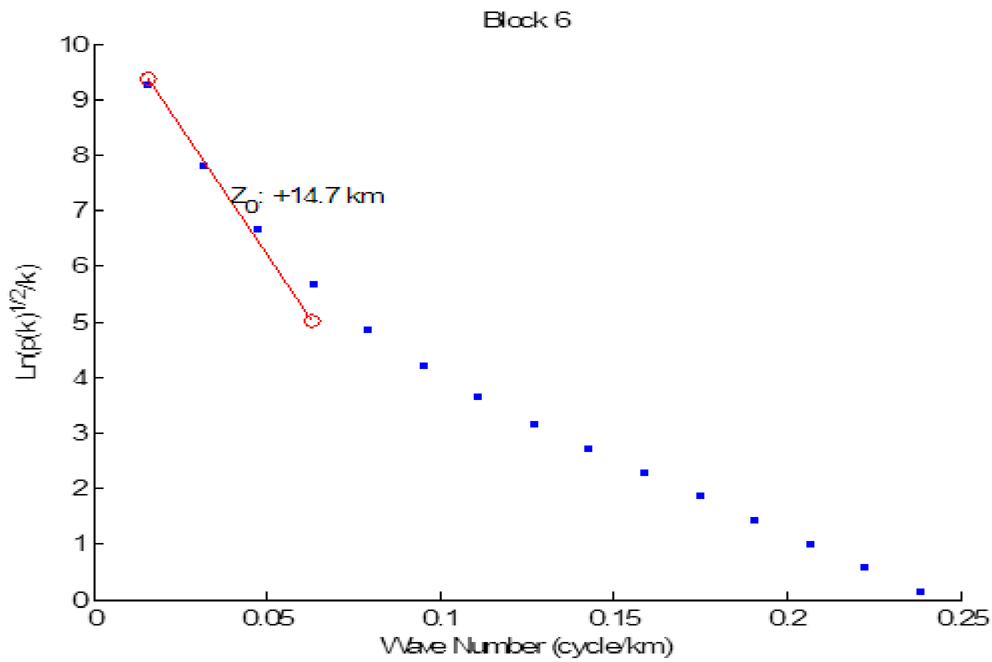



Block 4
Z0: +14.2 km
Ln(p(k)1/2/k)
Wave Number (cycle/km)


Block 4
Zt: +7.63 km
Ln(p(k)1/2)
Wave Number (cycle/km)


Block 5
Zo: +17.8 km
Ln(p(k)^1/2/k)
Wave Number (cycle/km)


Block 5
Zt: +9.65 km
Ln(p(k)^1/2)
Wave Number (cycle/km)


Block 6
Z0: +14.7 km
Ln(p(k)1/2/k)
Wave Number (cycle/km)
0
0.05
0.1
0.15
0.2
0.25
0
1
2
3
4
5
6
7
8
9
10

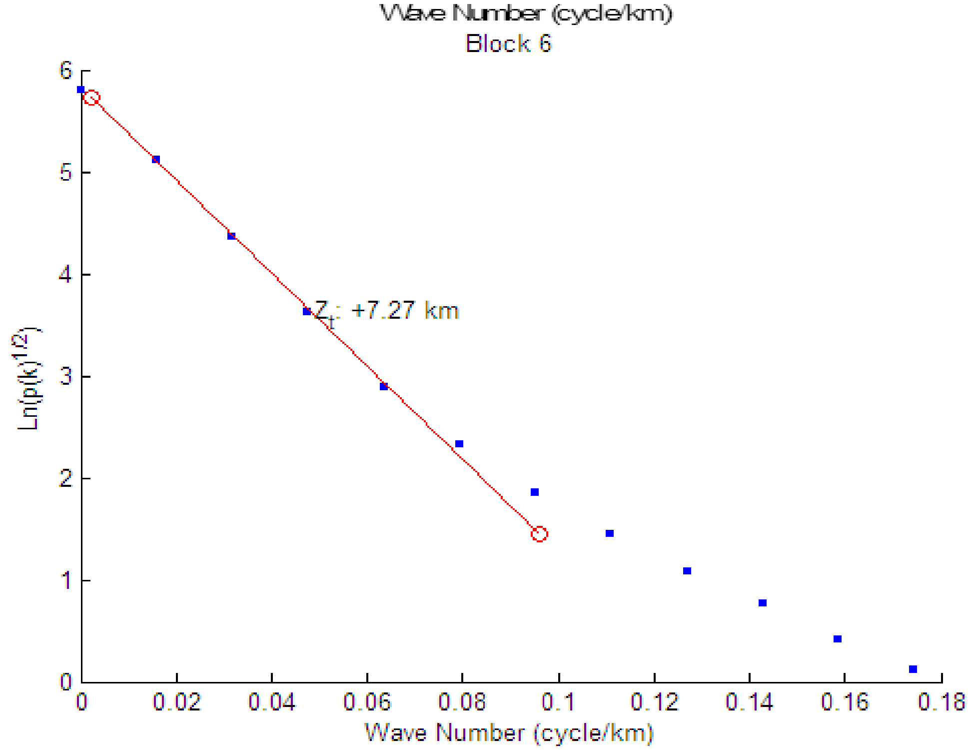

Block 6
Zt: +7.27 km
Ln(p(k)1/2)
Wave Number (cycle/km)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0
1
2
3
4
5
6

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Table 1:

Block S/N	Depth to the centroid (Z_O)km	Depth to the top boundary (Z_t) km	Curie Point Depth (Z_b)km	Geothermal Gradient (dt/dz) ^{0}C/km	Heat flow (q) mW/m^2
1	16.4	11.1	21.70	26.73	66.83
2	12.5	7.01	17.99	32.24	80.60
3	14.6	7.47	21.73	26.70	66.75
4	14.2	7.63	20.77	27.92	69.80
5	17.8	9.65	25.99	22.32	55.80
6	14.7	7.24	22.13	26.20	65.50
Average	15.03	8.35	21.71	27.01	67.54

Table 1 Showing the Results of Block 1-Block 6.

DISCUSSION OF RESULT

Base on the table of result the parameters in block1 are Depth to centroid (Z_O) = 16.4km, Depth to the top boundary (Z_t) = 11.1km, Curie Point Depth (Z_b) = 21.7 km, Geothermal Gradient (dt/dz) = 26.73 ^{0}C/km and Heat flow (q) = 66.83 mW/m^2.

In block 2, Depth to the centroid (Z_O) = 12.5km, Depth to the top boundary (Z_t) = 7.01 km, Curie Point Depth (Z_b) = 17.99km, Curie Point Depth (Z_b) = 32.24km and Heat flow (q) = 80.60mW/m^2

Block 3 reveals Depth to the centroid (Z_O) = 14.6 km, Depth to the top boundary (Z_t) = 7.47 km, Curie Point Depth (Z_b) = 21.73km, Curie Point Depth (Z_b) = 26.70km and Heat flow (q) = 66.75mW/m^2.

In block 4, Depth to the centroid (Z_O) = 14.2km, Depth to the top boundary (Z_t) = 7.63km, Curie Point Depth (Z_b) = 20.77km, Curie Point Depth (Z_b) = 27.92km and Heat flow (q) = 69.80mW/m^2.

In block 5, Depth to the centroid (Z_O) = 17.8km, Depth to the top boundary (Z_t) = 9.65km, Curie Point Depth (Z_b) = 25.99km, Curie Point Depth (Z_b) = 22.32km and Heat flow (q) = 55.80mW/m^2.

In block 6, Depth to the centroid (Z_O) = 14.7km, Depth to the top boundary (Z_t) = 7.27 km, Curie Point Depth (Z_b) = 22.13km, Curie Point Depth (Z_b) = 26.20km and Heat flow (q) = 65.50mW/m^2.

These are the average values of the analyzed parameters; Depth to the Centroid (Z_O) = 15.03km, Depth to the top boundary (Z_t) = 8.35km, Curie Point Depth (Z_b) = 21.71km, Geothermal Gradient (dt/dz) = 27.01 ^{0}C/km, Heat flow (q) = 67.54 mW/m^2 of Block 1- Block 6 that represent the area under study. The result obtained is in conformity with the earlier research outcomes within the study area (Yassah *et al.*, 2023 and Mohammed *et al.*, 2019).

CONCLUSION

Interpretation of high resolution of aeromagnetic data over some parts of Numan and its environs was carried out the following parameters were estimated; the Curie Depth range from 17.99km to 25.99km with average value of 21.71km and the heat flow vary from 55.80 m/Wm^2 to 80.60 m/Wm^2 with the average value of 67.54 m/Wm^2. The Curie Point Depth of the study area shows that it's varies inversely with heat flow. This revealed the heat flow in the study location decrease with increase in Curie Point Depth, this shows that Curie Point Depth is an indication of thermal structure of the study area.

Further Research

Researchers in the area of geology and geophysics in Nigeria need to intensify efforts through the application of integrated geophysical techniques in order to locate more potential zones for geothermal energy exploitation and exploration within the study area.

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