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Investigation of Curie Point Depth, Using Aeromagnetic Data From Eastern Niger Delta, Nigeria

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ABSTRACT

The research investigated the depth to magnetic sources in parts of Eastern Niger Delta which included Akwa Ibom State, Rivers State and small fringe of Abia state. The portion is enclosed by the coordinates, (Lat. 4.50 N to Lat. 5.00 N) and (Long. 7.50 E to Long. 8.00 E). The Aeromagnetic data was processed with the method of Spectral analysis which generated Curie point depth. Geothermal gradient and heat flow maps of the location. The geothermal gradient observed are of values 7.5 0C/km (lowest) and 21.50C/km (highest) in the Southwest and central section respectively, though it reduces towards the Northeast, Northwest and Southeast. Logically, this trend is repeated for the observed heat flow as the lowest (22 mW/m2) and highest (54 mW/m2) in the Southwest and centre respectively. From the contour maps generated, variations between (7.22km -12.6km) and an average of 10.06km, for the depth to the top, and (28km - 60km) with an average of 43.73km, from surface to the end of magnetic sources in the subsurface, were deduced. It can be observed that the deepest point (60km) to the bottom occurs in the southwestern area and decreases generally towards the northeast. The increase inTotal magnetic intensity (TMI) values between 7473.4nT and 7582.6nT, with high magnetic anomalies located in the northern end, southwest and southeast end and low anomalies in the central are consistent with thicker sedimentary deposits.

KEYWORDS

Curie point, Spectral analysis, Niger Delta, Aeromagnetic.

INTRODUCTION

Magnetic methods has been of the earliest methods used for the determination of underneath structures of the Earth, the forms and the contents for economic, security and educational purposes. The method is nondestructive as it makes use of potential field that exists naturally within the Earth. The internal structure of the Earth contains lot of different natural resources, with distinct properties that can be used for its exploration.

Variations in the Earth's magnetic field often correspond to differences in lithology, faulting, or intrusions within the basement. Mapping these variations helps infer the depth, geometry, and tectonic framework of underlying rocks (Olorogun, et al, 2026). (Abeki,et al.; 2025, Olorogun et al., 2026) have separately estimated, in central and western parts of Niger Delta,, the depth-to-basement to be from about 5 km to 12 km, signifying thick sedimentary sequences favourable for petroleum generation. This study investigated the Curie point in the Eastern Niger Delta making use of Spectral analysis method on the Aeromagnetic data from the region and calculation based on statistical method of depth determination.

GEOLOGICAL SETTING

The Niger Delta region (Figure 1) lies within Lat. 40 to 60 N and Long. 50 to 80 N, while the research section is situated within Lat. 4.50 to 5.00 N and Long. 7.50 to 8.00 E. Generally, the Niger Delta sedimentary basin was formed in the Tertiary period due to inter play of subsidence and deposition of sediments arising from a succession of regressions and transgressions of the Atlantic Ocean (Short and Stauble, 1967). This cyclic event resulted in the deposition of three litho-stratigraphic units in the Niger Delta basin. These three units are arranged in this order from the top Benin Formation, the underlying Agbada Formation and at the base, Akata Formation, and also in order of increasing age (Reyment, 1965).

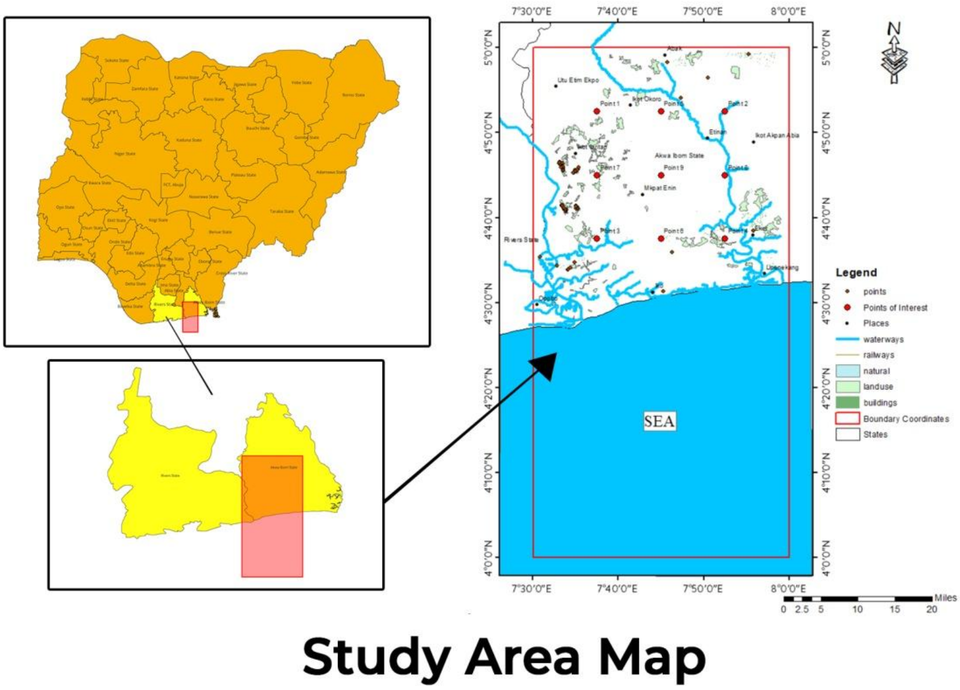


Figure 1: Map of Eastern Niger Delta

METHODOLOGY

Aeromagnetic data of Eastern Niger Delta were procured from Geological Survey Agency of Nigeria (GSAN). Other necessary items and equipment used for this work are: Geosoft Oasis Montaj, Golden Surfer software, Computer and Microsoft excel.

By Spectral analysis method, the Total Magnetic Intensity (TMI) was sectioned into nine blocks. From each block was obtained, energy and wave number components and then spectral energy versus frequency (cycle/km) graph. The depth to the top and bottom of magnetic sources were calculated from the plot of each block and recorded as shown in Figures 2- 10. From this two depth source models, shallow point depth (Figure 12) and Curie point depth (Figure 13) were obtained. Equations (3), (4) and (5) were, respectively, applied to determine bottom depth of magnetizing body, geothermal heat flow and geothermal gradient.

Determination of Depth to Base of Magnetic Sources (DBMS) has been carried out using statistical method of depth evaluation due to (Spector and Grant, 1970; Bhattacharryya and Leu, 1975; Okubo et al., 1985, Blakely, 1995; Tanaka and Matlsubayashi, 1999; Ross et al., 2006; Trifonoya et al.,2009; Bensal et al.,2011; Bensal et al.,2013).

Let k be the wave number (2π/km), lnP(k) the natural logarithm of the power spectral density, the centroid depth $Z0$ can be calculated from

$$ln\ ((K)^{1/2}\ /K) = [k]\ Z_0 \quad (1)$$

where lnP(k) is the natural logarithm of radially average power spectrum, k is the wave number (2π/km).

From similarly expression, the depth Z_t to the top of magnetic sources is also determined from the equation:

$$ln\ (P(K)^{1/2}\ /K) = [k] Z_t \quad (2)$$

The depth of the bottom of magnetization Z_b, known as Curie point depth (DBMS), is:

$$Z_b = 2Z_0 - Z \quad (3)$$

The expression of the Geothermal gradient can be obtained from heat flow equation,

$$q = k(\phi/d) \quad (4)$$

where ϕ is the Curie point (in ^{0}C). Substituting ϕ = 500^{0}C, k =2.5Wm^{-1}°C the thermal conductivity (Nwankwo *et al.,*2009, 2011; Tanaka *et al*., 1999). Then the geothermal gradient, in ^{0}C/km, becomes

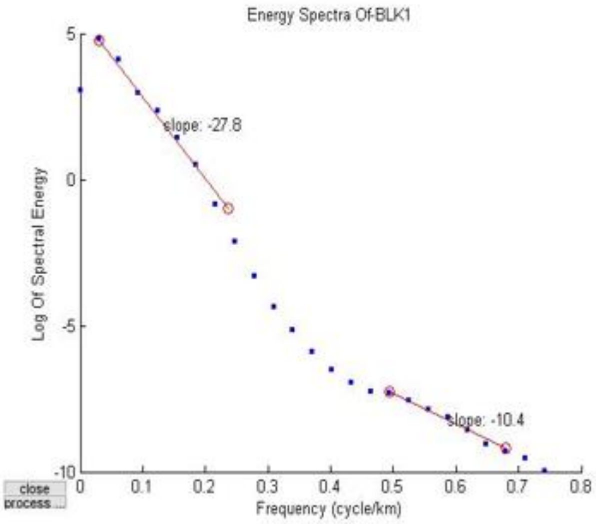
$$\frac{\Delta T}{\Delta Z} = {}^{580}/_{d} \quad (5)$$

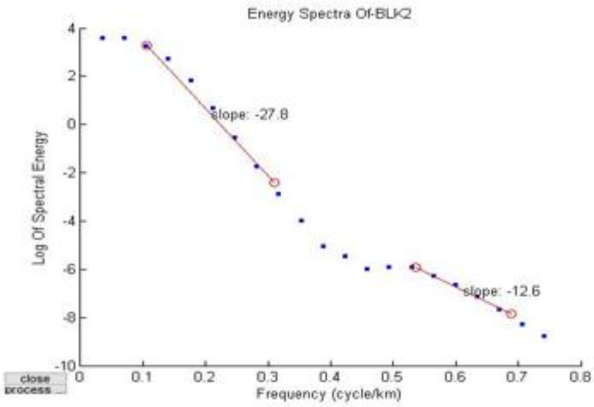
where, ΔT and Δz are the increase temperature and increase in vertical depth respectively.

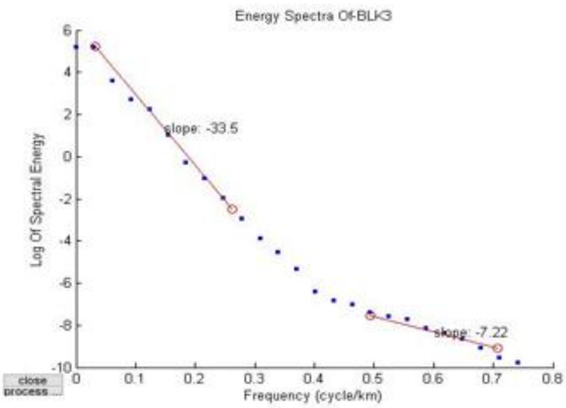
RESULTS

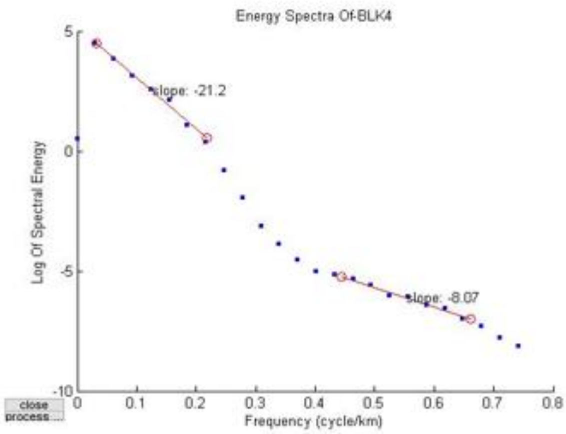
Table 1: Calculated values of Depth to the top of the magnetic source, Z_t , the Depth Z_o to the centroid of magnetic source and Depth to the base of magnetic source, Z_b.

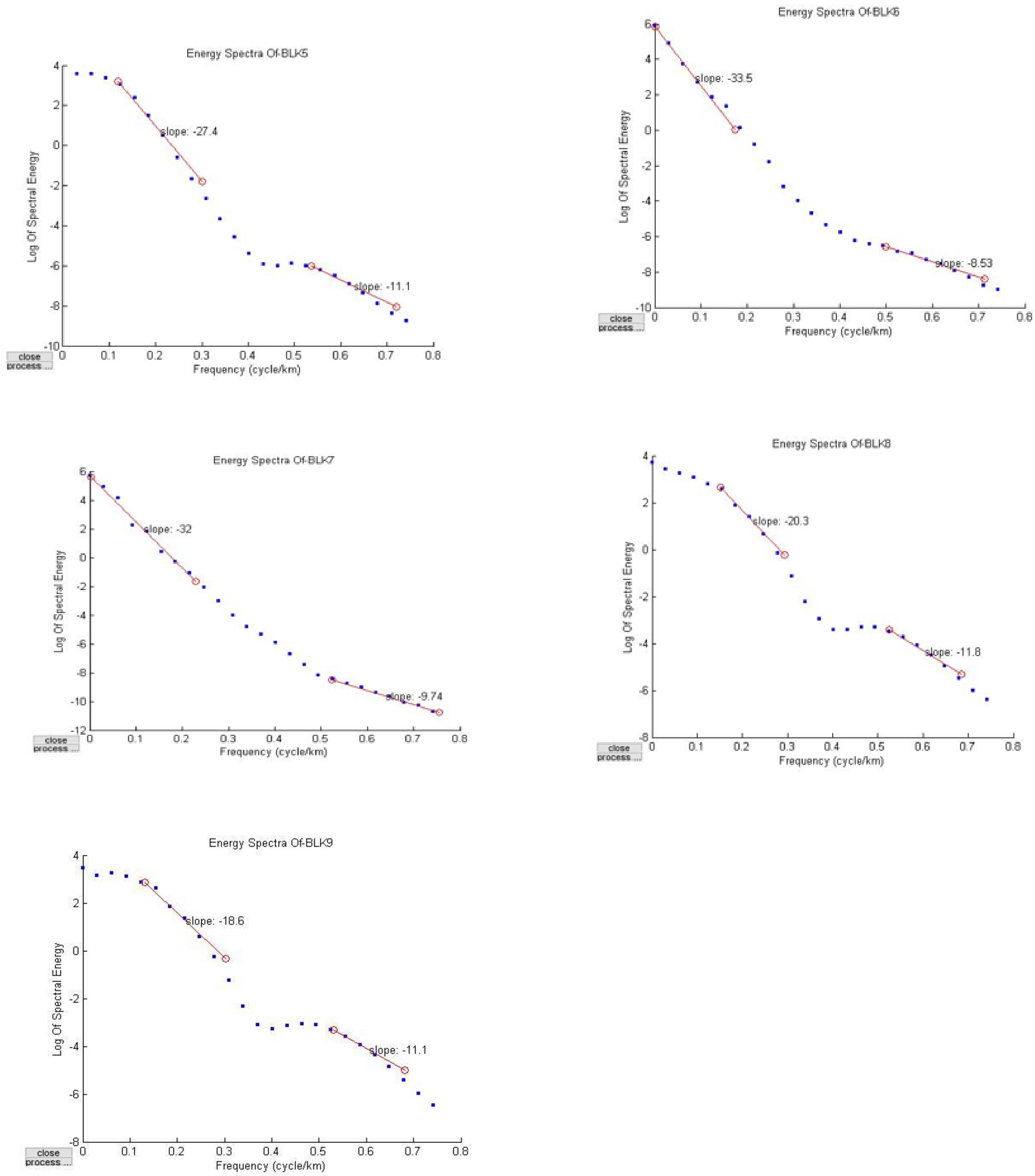
S/No.	Z_t (Km)	Z_o (Km)	$2Z_o$ (Km)	Z_b = ($2Z_o$ - Z_t) /Km	Geothermal gradient ^{0}C/Km	Heat flow (mW/m^2)
1	10.4	27.8	55.6	45.20	12.832	32.080
2	12.6	27.8	55.6	43.00	13.488	33.721
3	7.22	33.5	67.0	59.78	9.702	24.256
4	8.07	21.2	42.4	34.33	16.895	42.237
5	11.1	27.4	54.8	43.70	13.272	33.181
6	8.53	33.5	67.0	58.47	9.920	24.799
7	9.74	32.0	64.0	54.26	10.689	26.723
8	11.8	20.3	40.6	28.80	20.139	50.347
9	11.1	18.6	37.2	26.10	22.222	55.556


Energy Spectra Of-BLK1
slope: -27.8
slope: -10.4
Log Of Spectral Energy
Frequency (cycle/km)
close
process ...


Energy Spectra Of-BLK2
slope: -27.8
slope: -12.6
Log Of Spectral Energy
Frequency (cycle/km)
close
process ...


Energy Spectra Of-BLK3
slope: -33.5
slope: -7.22
Log Of Spectral Energy
Frequency (cycle/km)
close
process ...


Energy Spectra Of-BLK4
slope: -21.2
slope: -8.07
Log Of Spectral Energy
Frequency (cycle/km)
close
process ...



Figures 2- 10: Plots of the log of spectral energy against frequency (blocks 1- 9)

Results

The Total magnetic intensity (TMI) of the area ranges from 7473.4nT to 7582.6nT with higher values in the Northwestern and Southeastern parts, Figure 11. The relatively lower values (7473.4nT -7515.1nT) generally lie in the Northeast- Southwest trend. High magnetic intensity dominates the Northern part of the area between (7534.8 - 7582.8nT). The higher magnetic anomalies, generally, is due to shallow basement while relatively lower values are attributed to thick sedimentation.

The distance Zt below the surface of the shallow causative body lies at 7.22km to 12.6km. From the Table1, an average of 10.06km has been calculated. The decrease in depth is in the Southwest –Northeast trend as seen from Figure 12. The bottom depth Zb, as observed from (Figure 13) is also at varying values of 28.0km to 60.0km, giving an average of

43.74km. The depth decreases from Southwest down to the centre (26km) and then increases in the Northeast trend to 44km depth. From Table 1, an average value of 43.7km is calculated for Zb.

From figure 14, the heat flow has values range from 22mWm-2, in the Southwestern area, to 54mWm-2, at the centre. From the Table 1, the average is 35.88mWm-2. Then the heat flow decreases towards the Northeast up to 34mWm-2 and 32mWm-2 in the Northern section. The same low heat flow between 26 and 32 mWm-2 could be observed along the Northwest-Southeast trend indicating stable thick sedimentary.

The geothermal gradient reveals values that range between 7.5 and 21.5 0C/km where the lowest and the highest exist in Southwest and central portion respectively, Figure 15. An average of 14.350C/km has been calculation for geothermal gradient (Table 1). From the centre, Figure 15, the geothermal gradient decreases all round. It reduces down to (12,5 – 15.50C/km) in the Northeast, (11- 130C/km) in Northwest, (13.5 - 17.5 0C/km) in the Southeast and the lowest (7.5 – 10.50C/km) in the Southwest. The low to relatively high geothermal gradient is an indication of prevalent lateral heterogeneity in the subsurface.

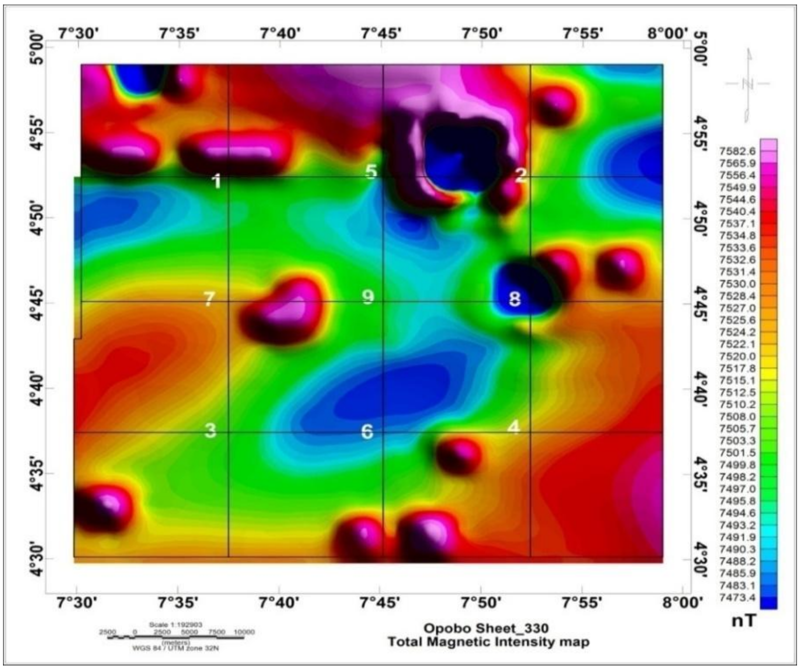


Figure 11: Total Magnetic Intensity for the area

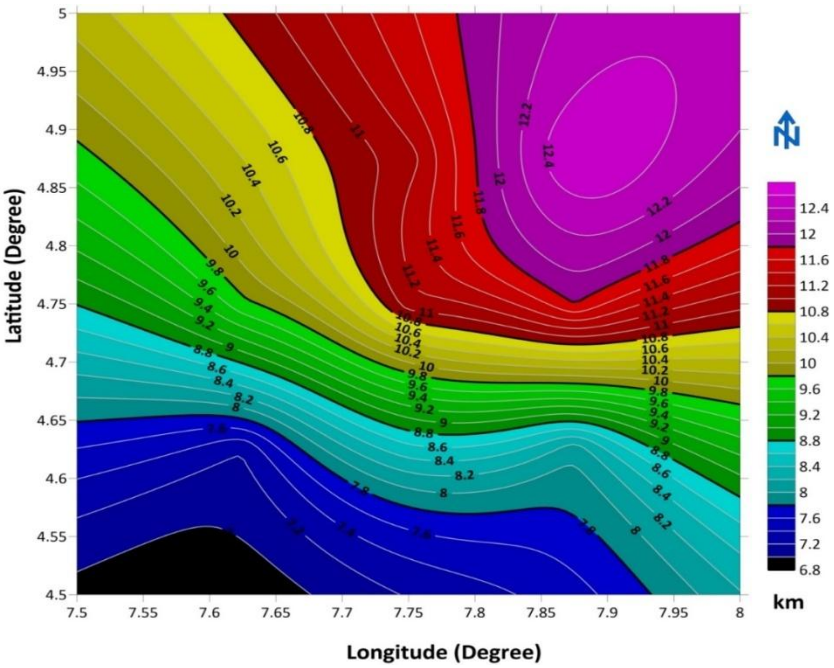


Figure 12 : Shallow depth map

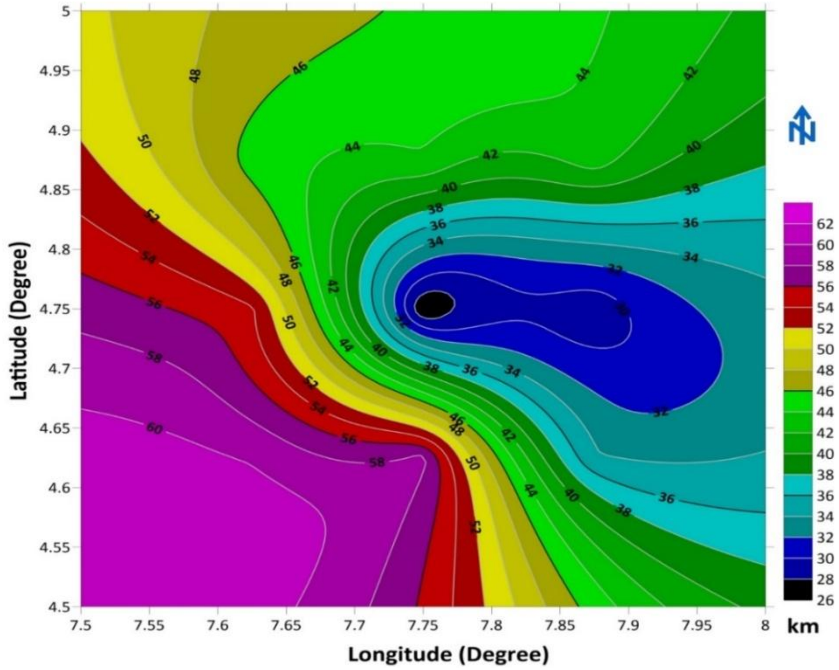


Figure 13: Curie point dept map

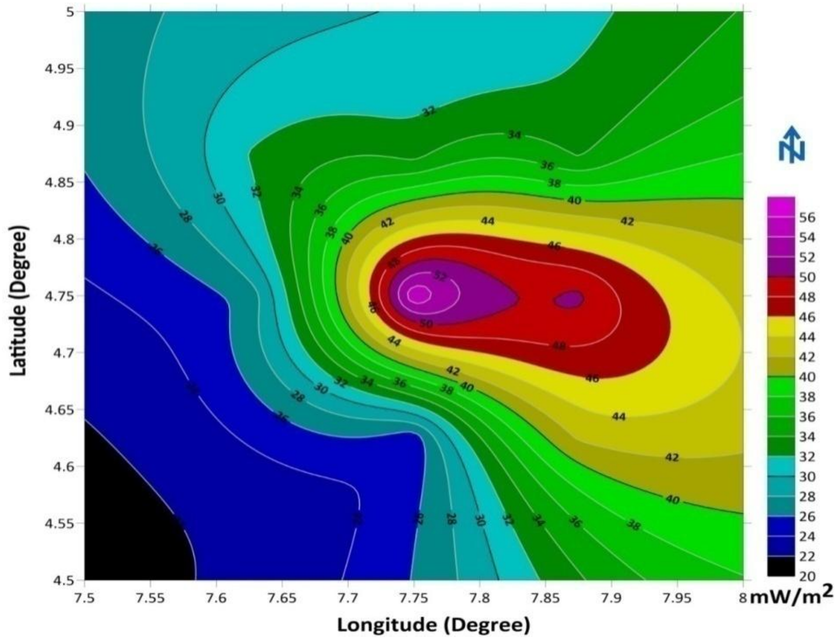


Figure14 Heat flow contour map

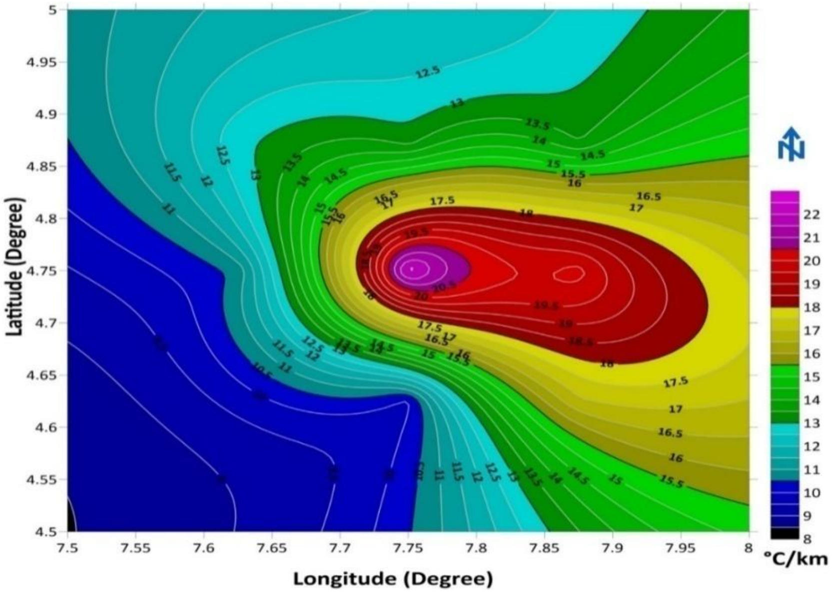


Figure 15: Geothermal gradient contour map

CONCLUSION

From Spectral analysis method employed for the aeromagnetic data it reveals the depth for the shallow magnetic source ranges between 7.22 to12.6km with an average of 10.06km. For the deeper Curie point depth magnetic sources, the variation in depth lies between 28.0 and 60.0km while the calculated average is 43.74km. The geothermal heat flow ranges from 22 to 54mW/m2 and an average of 35.88mW/m2 in which the lowest and highest heat flow are located at the Southeast and central sections of the area of research. Geothermal gradient has the lowest and the highest values of 7.5 and 21.5 0C/km respectively with an average of 14.350C/km. Like for the heat flow, the lowest and the highest geothermal gradient locations are in the Southeast and the central respectively.

The Total magnetic intensity values varied from 7473.4nT to 7582.6nT, with high magnetic anomalies (entirely positive) located in the northern, southwestern and extreme end of the southwestern regions. and low anomalies in the central and part of the southwestern zones, are consistent with thicker sedimentary deposits. These findings demonstrate the effectiveness of aeromagnetic method for regional subsurface mapping and resource potential assessment, especially for geothermal and hydrocarbon exploration in sedimentary basins.

This work can be improved upon when one or two other geophysical methods, like Seismic and Resistivity methods are combined with Aeromagnetic data in the investigation.

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