Estimation of Depth to Magnetic Basement in Ekiti State, Southwestern Nigeria from Aeromagnetic Data Using Spectral Analysis Technique

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Abstract: **Magnetic method is one of the oldest geophysical techniques used to delineate subsurface structure and determine the source of specific anomalies present in a particular area. An estimate of depths to magnetic basement of Ekiti State in Nigeria was carried out using spectral analysis of composite aeromagnetic map of the state. Regional anomaly was removed from the total magnetic intensity data by fitting a plane surface polynomial using Surfer software. The resulting residual was subjected to reduction to equator (RTE) filtering with the aid of Oasis montajsoftware to remove the asymmetry associated with the low latitude anomalies. Results of the 2-D spectral analysis revealed a two layer depth source model. The depths of shallower magnetic sources vary from 55.9 to 190.4 m, while the depths of deeper magnetic sources vary from 547.2 to 1244 m. The eastern part of the study area has low magnetic relief while the central part of the state has high magnetic relief; hence the overburden thickness towards the east is relatively high as evident from the configuration of the basement topography in the area.Depth estimation of the magnetic basement in Ekiti State indicates the maximum overburden thickness of about 1.2 km which is not sufficient for accumulation of hydrocarbon; therefore, the state can only be explored for solid mineral resources and not petroleum resources.**

Keywords: **basement topography, contour map, magnetic relief, spectral analysis, total magnetic intensity.**

I. INTRODUCTION

The study presented in this research concerns the estimation of depth to magnetic basement in Ekiti State from the spectral analysis of aeromagnetic data.The study area is underlain by Precambrian crystalline basement rocks mostly of igneous-metamorphic origin. The prominent rock units in the state include porphyritic granite, fine-medium grained granite, granite gneiss, schist/quartz schist, migmatites and charnockite [1].Magnetic survey explores the subsurface geology on the basis of anomalies in the Earth's magnetic field resulting from the magnetic properties of the underlying rocks. It gives information which helps in the determination of depth to basement rocks and mapping of the topographic features on the basement surface. Hence, basement structures and depths areaccurately delineated and mapped using magnetic data. Aeromagnetic data are routinely interpreted by estimating source depths or locations; consequently, many processing algorithms have been proposed to assist the estimation [2]. The application of 2-D spectral inversion to the interpretation of potential field data is one method that has been used to determine the basement depth, and is now sufficiently well established [3]. Spectral analysis of magnetic data has been used extensively in the past two decades to derive the depth to magnetic basement [4].

In this paper, spectral analysis was carried out on the aeromagnetic data of Ekiti State in order to estimate the depths to magnetic basement rocks by dividing the composite aeromagnetic map of the state into 35 overlapping cells. The results show that depth of shallower magnetic sources ranges from 55.9 to 190.4 m with an average depth value of 81.7 m, while the depth of deeper magnetic sources vary from 547.2 to 1244 m with an average depth value of 903.9 m. The eastern part of Ekiti State is majorly characterized by low magnetic relief. This is an indication that the average thickness of the sediment over the basement in that area is relatively high. On the order hand, high magnetic reliefs are observed around the central region and southern part of the study area, indicating dominance of shallow basement.

II. LOCATION OF THE STUDY AREA, GEOMORPHOLOGY AND GEOLOGY

Ekiti State is located between longitude4°5' and 5°45' Eastof the Greenwich meridian and between latitude 7°15' and 8°5' northoftheequator. The state is mainly an upland zone, rising over 250 meters above the mean sea level. Generally, it has an undulating land surface with a characteristic landscape that consists of old plains broken by steep-sided out-cropping dome rocks that may occur singularly or in groups or ridges. Ekiti State enjoys a tropical climate with two distinct seasons, which are the wet season (April - October) and the dry season (November - March). Itis underlain entirely by crystalline Precambrian rocks, which form part of the basement complex of western Nigeria (Fig. 1). The geologic setting of the area is typical of the migmatite gneiss complex rocks of the Precambrian Basement Complex of southwestern Nigeria [5], comprising of undifferentiated granite, charnockitic rocks, medium to coarse granite and migmatite gneiss rocks.

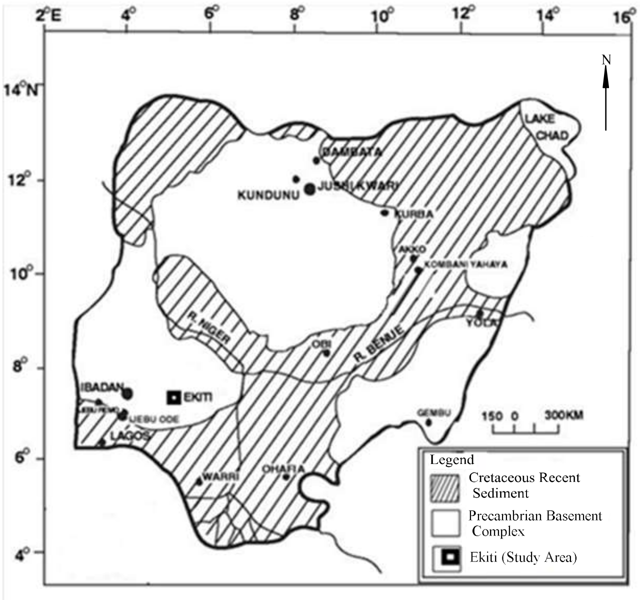

Figure 1: Location of Ekiti State in the Basement Complex of Nigeria (modified after [6]

III. MATERIALS AND METHODS

As part of a nationwide high resolution airborne geophysical survey aimed at assisting and promoting mineral exploration in Nigeria, aeromagnetic data were acquired between 2004 and 2008 by Fugro Airborne Survey Limited for the Nigerian Geological Survey Agency (NGSA). The survey was carried out by fixed wing Cessna Caravan aircraft with a flight spacing of 500 meters and a terrain clearance of 80 meters. The flight direction was NW-SE with tie-line spacing of 5000 meters and tie-line direction of NE-SW. In the survey program, the high resolution aeromagnetic survey over Ekiti State was conducted in 2007 and published by the Nigerian Geological Survey Agency (NGSA). The study area is covered by the aeromagnetic map sheet 224 (Osi), 225 (Isanlu), 243 (Ilesha), 244 (Ado-Ekiti), 245 (Ikole), 263 (Ondo), 264 (Akure) and 265 (Owo). The data, in grid format were given in the Universal Transverse Mercator (UTM) projection of coordinate system WGS84/UTM Zone 32N and were extracted using GEOSOFT Oasis Montaj software as the data were in GEOSOFT grid file format. The coordinates of the total magnetic intensity data were re-projected from the UTM zone 32N to UTM zone 31N of the Greenwich Mercator since Ekiti State is located within UTM zone 31N for the coordinates of the data to correspond to their actual locations.The aeromagnetic data had the regional geomagnetic field and the effects of diurnal magnetic variations removed during the on-board processing. The total magnetic intensity map of the Ekiti State shows the magnetic intensity distribution over the area characterized by low/negative and high/positive magnetic anomalies ranging from -126.78nT to 168.34nT (Fig. 2).

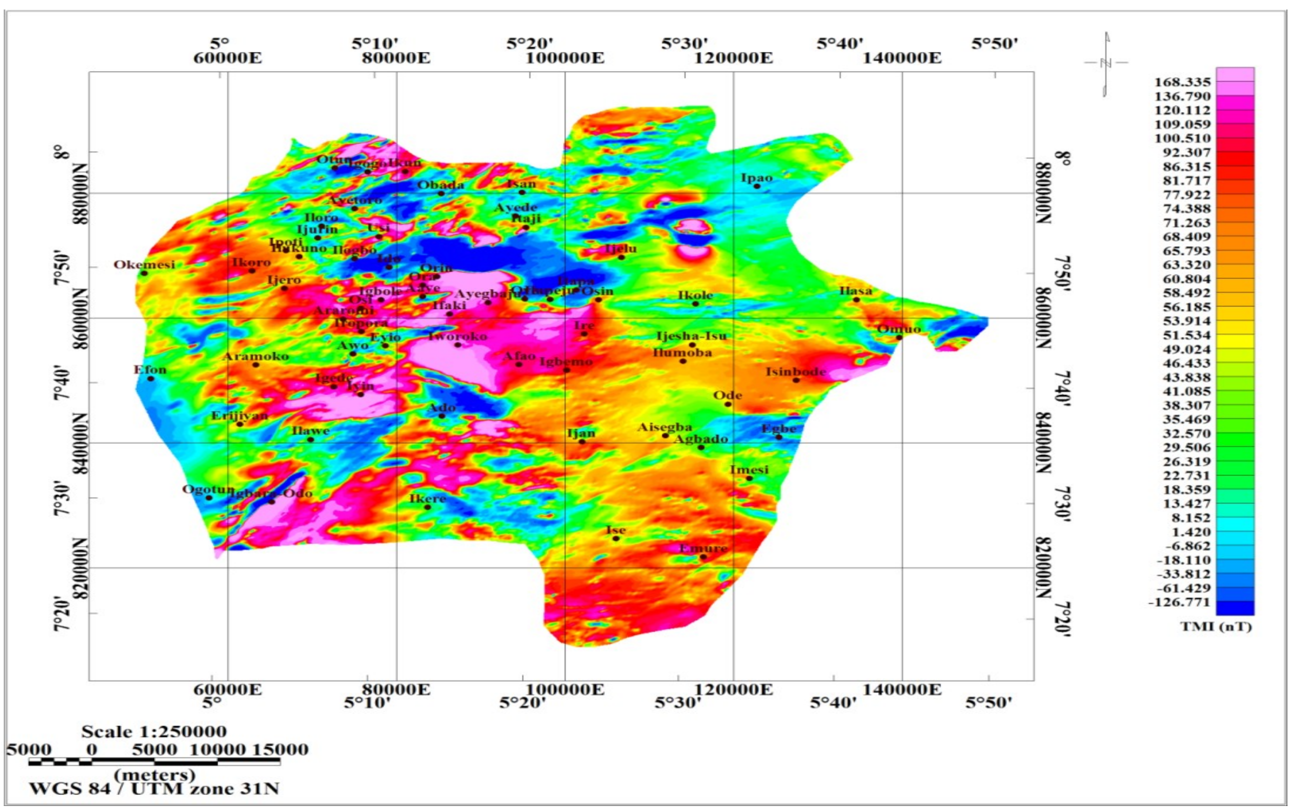

Figure 2: Total magnetic intensity map of Ekiti State.

IV. SPECTRAL ANALYSIS

Spectral analysis technique is one of the automated techniques for determining depth to magnetic basement. It uses the 2-D Fast Fourier Transform to transform magnetic data from space domain to frequency domain. The major advantage of this technique is its ability to filter almost all the noise from the data whilst still making sure no information is lost in the process of interpretation by overlapping data. The application of the power spectrum method to potential field data was proposed by Bhattacharyya, [7]; and the determination of the depth to magnetic body was given by Spector and Grant, [8].

The expression for the energy spectrum of the total magnetic field intensity anomaly over a single rectangular block, in polar coordinates (r, θ) is given as follows [8]:

If, $r = (u^2 + v^2)^2$ and $\theta = \arctan(u/v)$

then energy spectrum E (r, θ) is given by:

$$E(r, \theta) = 4\pi^2 K^2 e^{-2hr} (1 - e^{-tr}) S^2(r, \theta) R_T^2(\theta) R_k^2(\theta) \quad \ldots\ldots (1)$$

Where,

$$S(r, \theta) = \frac{\sin(arcos\theta)}{arcos\theta} \cdot \frac{\sin(brcos\theta)}{brcs\theta}$$

$$R_T^2(\theta) = [\, n^2 + (\, l\cos\theta + m \sin\theta\,)^2]$$

$$R_k^2(\theta) = [N^2 + (\, L\cos\theta + M \sin\theta\,)^2]$$

K = magnetic moment per unit depth

l, m, n = directions of cosines of the geomagnetic field vector

L, M, N = direction of cosines of the magnetization

R_T = factor for the geomagnetic field direction

R_K = factor for the magnetization field direction

u, v = horizontal wave numbers along x, y direction

h = depth to the top of prism

r = magnitude of the frequency vector

t = thickness of the prism

a, b = horizontal dimension of the prism along x, y direction

S = factor for the horizontal size of the prism

Spector and Grant [8] made further assumption that for a moderately large number of bodies, the average values of inclination and declination of the magnetic vector will not differ appreciably from the inclination and declination of the geomagnetic field. They obtained the expression for the ensemble average of the radial spectrum as:

$$\langle E(r)\rangle E(r) = 4\pi^2 K^2 \langle e^{-2hr}\rangle \langle (1 - e^{-tr})^2\rangle \langle S^2(r)\rangle \quad \ldots\ldots\ldots (2)$$

$$\langle S^2(r)\rangle = \frac{1}{\pi}\int_0^{\pi} \langle S(r, \theta)\rangle d\theta$$

The average ensemble depth h is observed in the factor e^{-2hr}

Thus, the scaling factor (depth factor) can therefore be expressed as:

$$\langle e^{-2hr}\rangle = \frac{e^{-2hr}\sinh(2r\Delta h)}{4r\Delta h} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The depth computations of magnetic field data can be approximated to exp(-2hr. The exp(-2hr) term is the dominant factor in the power spectrum. Hence, the depth estimate could be made using the equation [9]:

$$E(r) = e^{-2hr} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where, *E (r), h* and *r* are the spectral energy, depth and frequency respectively.

If *h* and *r* are replaced with *Z* and *f* respectively, then,

$$Log\, E = -2Zf \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Thus the logarithmic plot of the radial spectrum would give a straight line whose slope is *-2Z*. The mean depth of burial, *Z* of the magnetic body when the frequency unit is in radians per kilometer is given as:

$$Z = -\frac{m}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where *m* is the slope of the best fitting straight line.

If the frequency unit is in cycles per kilometer, equation vi can be expressed as:

$$Z = -\frac{m}{4\pi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

V. RESULTS AND DISCUSSION

5.1 Regional and Residual Fields

The regional magnetic fields correspond to low frequencies of observed fields, while the residual field is the difference between the observed field and the regional field, and correspond to high frequencies of the observed field. The residual effects can be described as the wanted effects (anomaly of interest) and is usually the subject of analysis and interpretation. The anomaly separation procedure may consist of removal of a smooth regional field from the observed or measured field, leaving the irregular residual field.The Regional fields associated with deep masses were removed to produce the Residual data for the study area by fitting a two – dimensional, first order polynomial (trend surface) to the total magnetic field intensity using least-square technique.Figure 3 shows the residual magnetic intensity (RMI) map of Ekiti state having field values ranging from -162.0 to 126.1 nT.

The NE – SW and NW – SE trending lineaments are observed in the southern and central parts of the study area respectively (Fig. 4); E – W and N – S orientations of lineaments are also observed in the northern part of the study area. Each lineament is made up of nearly concentric elongated magnetic contours which may be described as dike structures striking along their directions of elongation [10]. Further visual inspection of the residual magnetic intensity contour map of the study area reveals that the eastern part of Ekiti State is majorly characterized by low magnetic relief. This is an indication that the average thickness of the sediment over the basement in that area is relatively high. On the order hand, high magnetic reliefs are observed around the central region and southern part of the study area, indicating dominance of shallow basement.

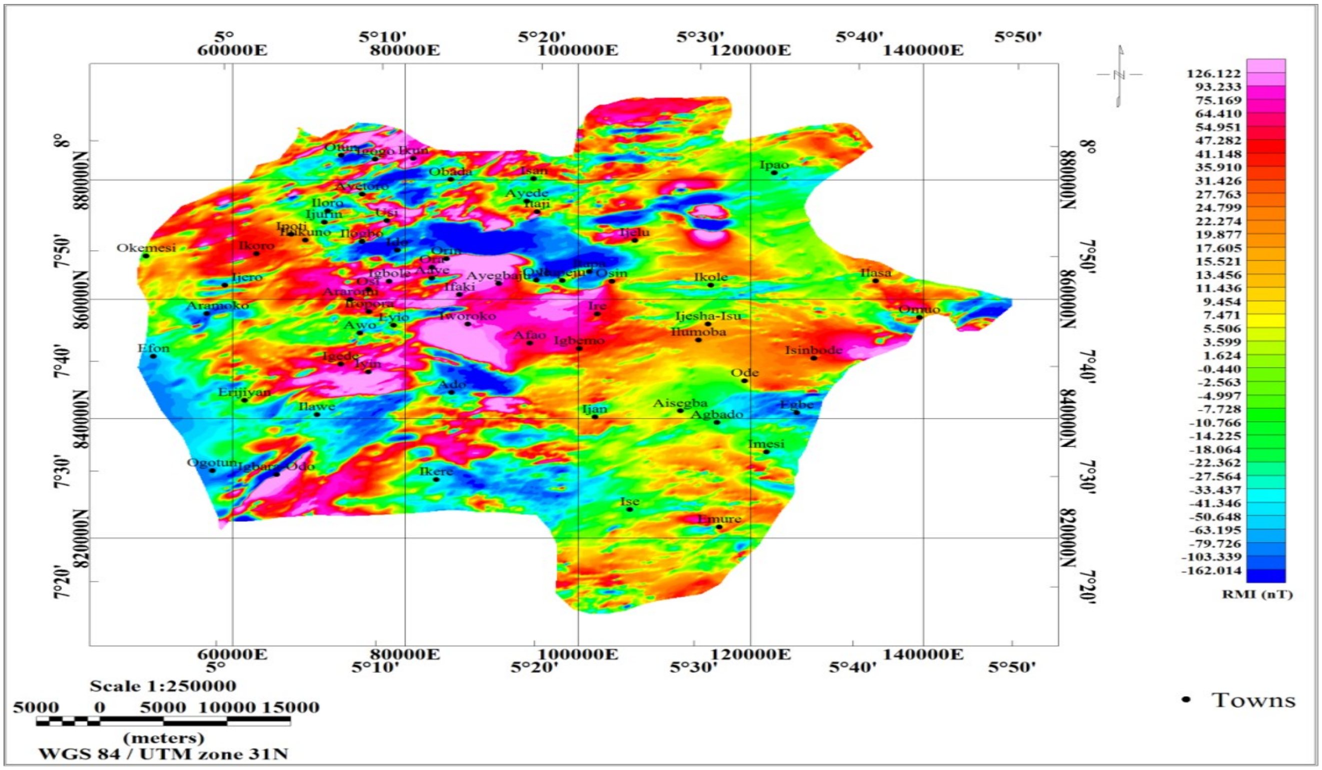

Figure 3: Residual magnetic intensity map of Ekiti State

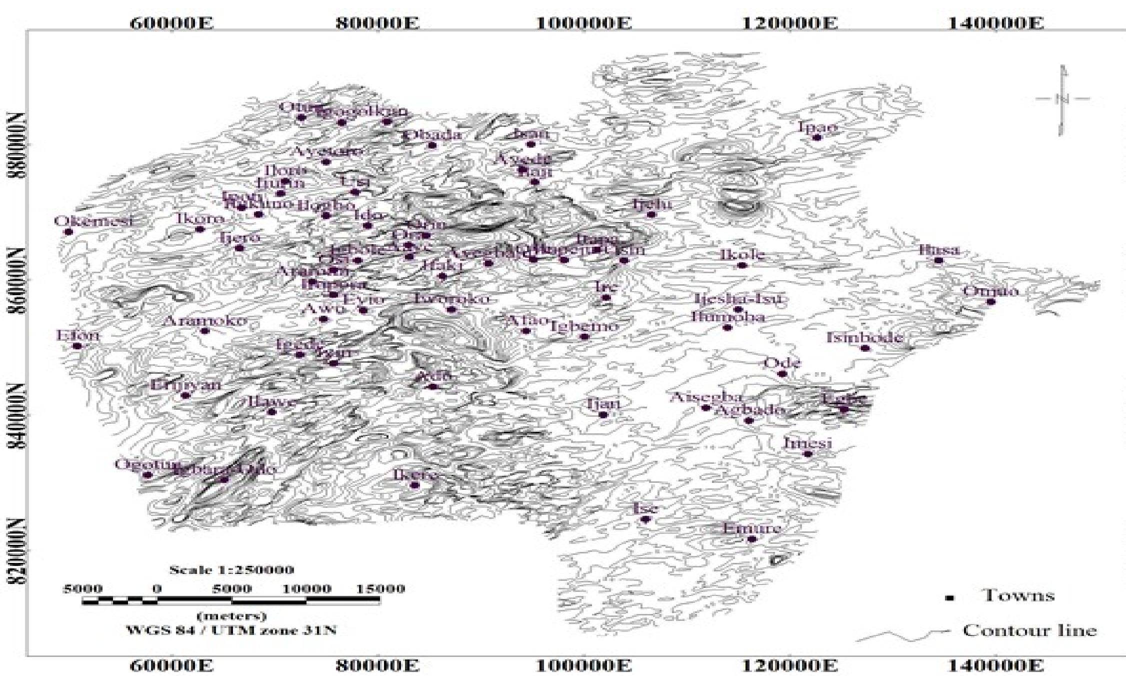

Figure 4: Residual magnetic intensity contour map of Ekiti State (contour interval in 10nT)

5.2 Reduction to Magnetic Equator (RTE)

Reduction to the magnetic equator (RTE) is used in the low magnetic latitudes to centre the peaks of magnetic anomalies over their sources. RTE transformation filter was applied with the aid of GEOSOFT Oasis Montaj software to the residual magnetic intensity data with -10.484^0 and -1.443^0 representing the inclination and declination respectively of the geomagnetic field parameters of the central location of the study area (fig. 5).This became necessary to correct for the effect of latitude and realign the anomalies in order to have their peaks symmetrically centered over their corresponding sources since the study area is located within the magnetic low latitude region.

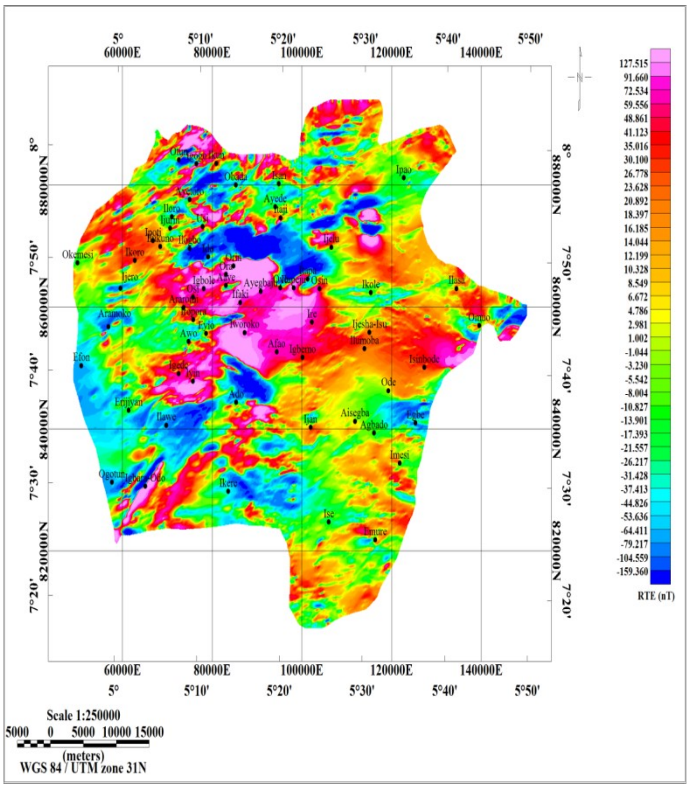

Figure 5: Reduction to equator map of ekiti state

5.3 Map division into overlapping sub-regions

Spectral analysis was carried out on the aeromagnetic data of Ekiti State in order to estimate the depths to magnetic basement rocks by dividing the composite aeromagnetic map of the state into 35 overlapping cells (Fig. 6). The overlapping operation was obtained by sliding a sub-region dimension of 20 x 20 km across the entire magnetic map and 35 overlapping blocks each being 20 x 20 km in length were obtained. The radially average log power spectrum of each block was computed using MAGMAP filtering program of Oasis Montaj software and produced as radially average power spectrum graphs, which were plots of log of energy spectral against frequencies in cycles per kilometer (fig. 7). Usually, the line segment in the higher frequency range on the graph is from the shallow magnetic source while the one in the lower frequency range is from deep seated magnetic source. So, the slopes of the straight line segments in the higher and lower portions of the graphs were determined and used to estimate the depths to magnetic basement for shallow and deeper sources respectively. The depth of shallower magnetic sources ranges from 55.9 to 190.4 m with an average depth value of 81.7 m, while the depth of deeper magnetic sources vary from 547.2 to 1244 m with an average depth value of 903.9 m (TABLE 1). These depth values were used to generate basement surface topographic map of the study area, which show the undulating nature of the basement surface(Fig. 8). The surface plot of the magnetic layershows the variations in the depth of the magnetic source rocks. The valleys indicate areas where the sediments are thicker than the orders.

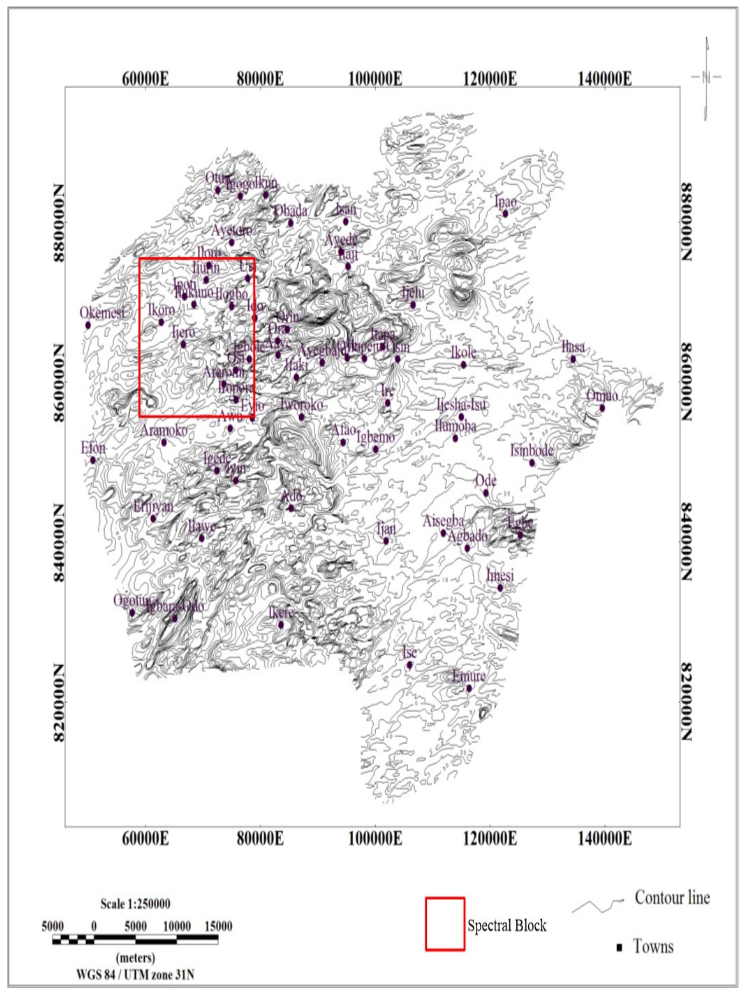

Figure 6: Aeromagnetic map showing spectral block

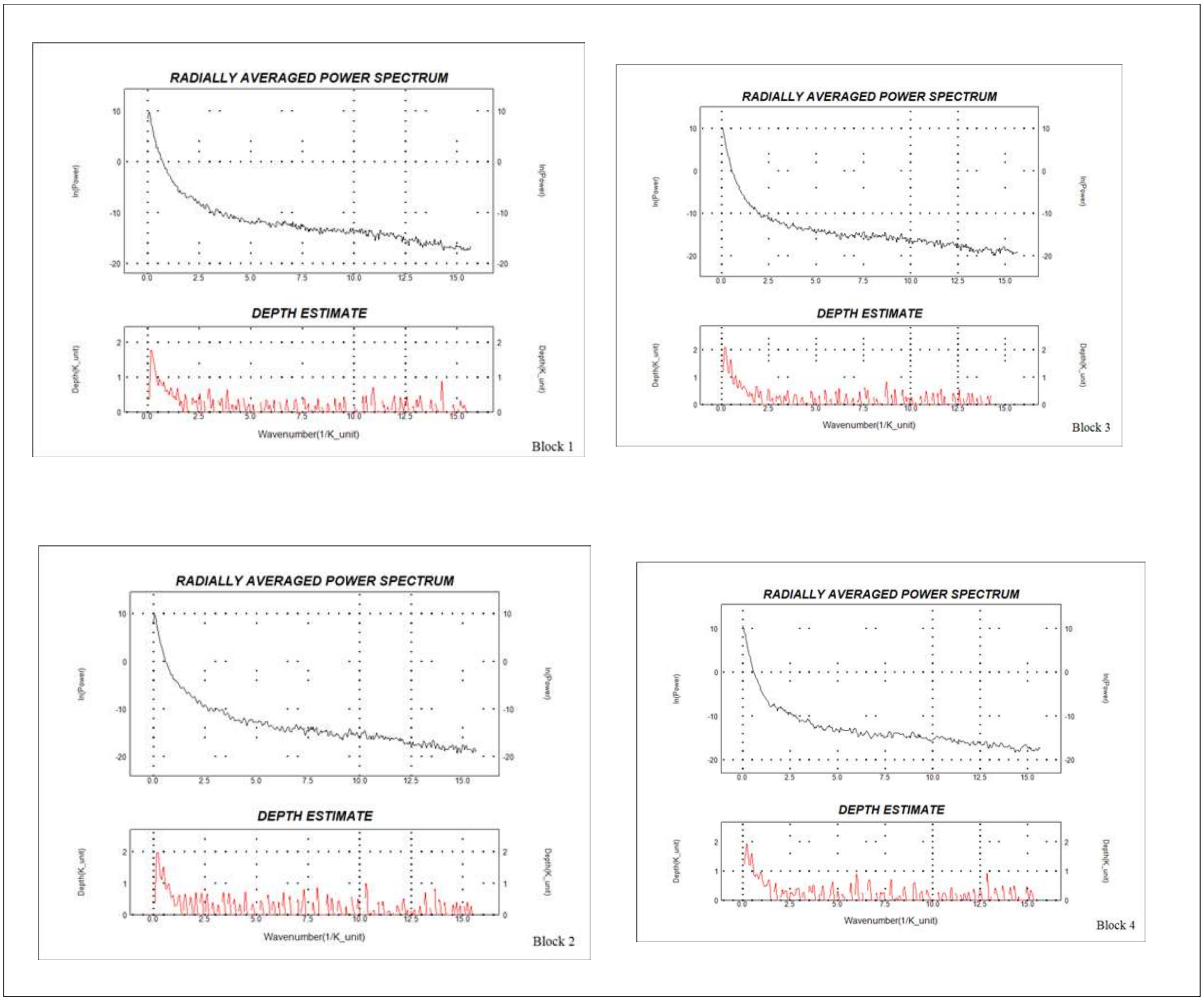

Figure 7: Power spectral plot of selected blocks

Table 1: Depth to magnetic sources from spectral analysis

Block	Easting (X)	Northing(Y)	Depths to magnetic basement	
			Deep depth (km)	Shallow depth (km)
1	70000	870000	0.856877	0.1904
2	80000	870000	0.5472	0.06903
3	90000	870000	0.7691	0.05596
4	100000	870000	0.7674	0.1061
5	110000	870000	0.5897	0.08619
6	115000	870000	0.8854	0.08045
7	60000	860000	0.8569	0.104
8	70000	860000	0.9283	0.07426
9	80000	860000	0.7426	0.07187
10	90000	860000	0.6883	0.099
11	100000	860000	0.8283	0.06436
12	110000	860000	0.7956	0.0675
13	115000	860000	0.8283	0.06483
14	60000	850000	0.9997	0.06233
15	70000	850000	0.73965	0.0682
16	80000	850000	0.9862	0.06326
17	90000	850000	0.92457	0.06072
18	100000	850000	0.88155	0.07966
19	110000	850000	0.9314	0.07292
20	115000	850000	0.7156	0.06624
21	70000	840000	0.9862	0.06724
22	80000	840000	0.8218	0.07512
23	90000	840000	0.8819	0.06868
24	100000	840000	1.1898	0.08843
25	110000	840000	0.9957	0.07175
26	115000	840000	0.825007	0.06356
27	70000	835000	1.01703	0.09414
28	80000	835000	1.093414	0.07397
29	90000	835000	1.1095	0.07285

30	100000	835000	0.88495	0.08013
31	110000	835000	0.84533	0.08585
32	110000	830000	1.2272	0.088055
33	120000	855000	1.07587	0.10877
34	115000	835000	1.1767	0.11642
35	110000	825000	1.24398	0.09824

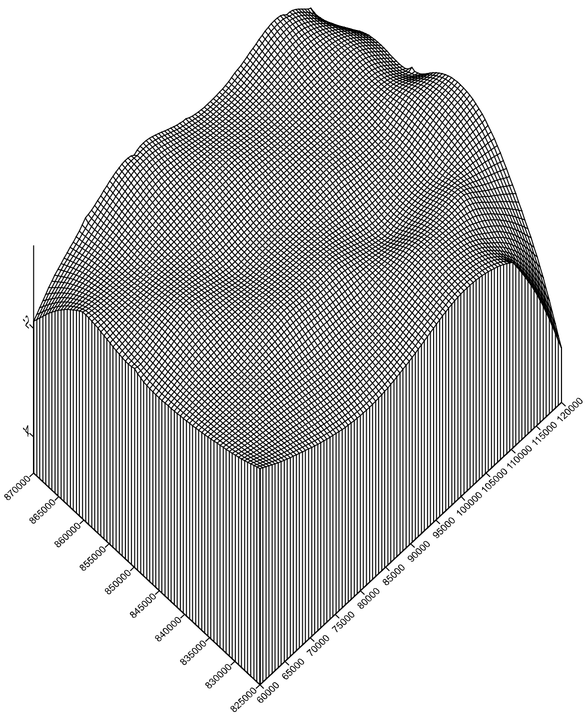

Figure 8: Basement Topography of the study area

VI. CONCLUSION

Power spectral analysis was performed on aeromagnetic data of Ekiti State for the purpose of estimating the depth to magnetic basement in the area. The results of this analysis show clearly the variation along the profiles in the surface of the magnetic basement across the study area. The depth of the deeper sources varies from 547.2 to 1244 m with an average depth value of 903.9 m and is believed to correspond to the surface of the magnetic basement in the study area. The depth of shallower magnetic sources ranges from 55.9 to 190.4 m with an average depth value of 81.7 m. This might refer to some major magnetic units, to uplifted basement surface or to some local magnetic features. The eastern part of the study area which is predominantly migmatite has low magnetic relief while the central part of the state has high magnetic relief; hence the overburden thickness towards the east is relatively high as evident from the configuration of the basement topography in the area.Depth estimation of the magnetic basement in Ekiti State indicates the maximum overburden thickness of about 1.2 km which is not sufficient for accumulation of hydrocarbon. So, the state can only be explored for solid mineral resources and not petroleum resources. These results therefore demonstrate the applicability of the spectral method of magnetic interpretation in estimating the depth to the surface of the magnetic basement in a basement complex.

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