Determination of Depth to Magnetic Basement Using Spectral Analysis of Aeromagnetic Data over Biu Plateau Basalt and Yola Sub - basin, North East Nigeria

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Abstract: ***Quantitative analysis of aeromagnetic data covering total area of 48,000 km^2 on latitude 11.00^0 N to 13.00^0 N and Longitude 9.00^0 E to 11.00^{0}E, which corresponds to Basement Complex part of upper Benue trough northeastern, Nigeria was carried out with the aim of estimating the sedimentary thickness using Spectral analysis. Two dimensional spectral analyses of aeromagnetic data using Oasis Montaj was carried out to determine the average depths of magnetic basement over Biu Plateau Basalt and Yola Sub - basin, north east Nigeria. The results reveal the presence of two source depths that is the deeper and shallow source depth. The deeper magnetic sources vary between 900 to 3810 m and the shallower magnetic sources; vary between 340 to 810 m. The deeper sources correspond to the basement topography underlying the area, while the shallower magnetic sources are associated with basic intrusive within the Middle Benue Trough and the adjoining basement formed by the Cameroon Volcanic line. Areas of deeper magnetic basement are potential sites for hydrocarbon exploration within the Benue rift and groundwater exploration on the basement area.***

Keywords: Spectral analysis, aeromagnetic data, Biu plateau basalt, Yola sub - basin

1. Introduction

The subsurface structure of the earth crust is conceals with lot of different natural resources that when discovered and harnessed, could be of economic and scientific importance. Different economic minerals, oil, gas, and groundwater lie beneath the earth crust and the presence and magnitude of these resources can be revealed by geophysical investigations of the subsurface geologic structures in the area. Several geophysical methods exist and for each, there exist physical property to which the method is sensitive. The type of physical property to which a method responds clearly determines its range of application. Several geophysical works have been carried out in different geological formations across the globe using gravity, magnetic, seismic, electrical, and other geophysical methods.

Magnetic method of geophysical prospecting is very vital in investigating subsurface geology and identifying anomaly resulting from the magnetic properties of the underlying rocks. It is found to be very successful in delineating various subsurface formations due to relatively high susceptibility contrast between basement rock and sedimentary unit (Emujakporue *et al*., 2017). Several works were carried out for the purpose of delineating basement structural pattern and topology using aeromagnetic data (Osinowo *et al*., 2013; Emujakporue *et al*., 2017 etc). Information about subsurface geometry, depth, thickness and lateral extent of the basement is very crucial for accurate characterization of certain target of a given formation.

Udensi, and Osazuwa (2004) estimated the average depth to basement to be 3.39 km with a maximum depth of 4.5 km. In the spectral determination of depths to magnetic rocks in the Bida Basin, Udensi and Osazuwa (2004) were able to corroborate the interpretations of Ojo (1984) and Ojo and Ajakaiye (1989) that outlined the basin as being bounded by a system of linear faults. Kasidi, and Ndatuwong, (2008) interpreted aeromagnetic data over Longuda plateau and its environs, northeast Nigeria using spectral analysis, and found the mean depth of the shallow sources was 0.591 and 2.26 km was the depth to deeper magnetic sources. Nur *et al.*, (2010) analysed the aeromagnetic data over Garkida and environs, north-eastern Nigeria, and the spectral result revealed the depth to basement indicate two source depths which vary from 750 m to 2285 m for deeper sources and 150 m to 744 m for shallower sources. Salako and Udensi (2013) interpreted aeromagnetic data over parts of upper Benue Trough and southern Borno Basin, northeast, Nigeria and the result of the study revealed that the shallow depth was estimated to have ranged from 0.268 km to about 1.08 km while the deepest depth was estimated to have ranged from 2.06 km to about 3.35 km.

Spectral analysis however has the advantage of estimating the depth of anomaly source approximated by a prismatic block based on the logarithmic radial energy spectrum of the total magnetic intensity. The spectrum consists of a straight line whose gradient is related to the average depth to the tops of the prisms. Thus by dividing the study area into rectangular tiles, the mean depth to the top of the source at each point will be estimated with resolution relative to the number of the tiles. The method has the advantage of giving an estimate of the numerical value of the depth at each point (Chiozzi *et al*., 2005).

The spectral analysis of aeromagnetic fields over the area would differentiate and characterize regions of sedimentary thickness from those of uplifted or shallow basement and also to determine the depth to the magnetic sources. The results could be used to suggest whether or not the study area has the potential for oil/gas and mineral deposits concentration.

2. Geology and Tectonics of the Area

The geology of the area is made up of the Precambrian basement complex rocks which are considered to be undifferentiated basement complex (McCurry 1979 and Bassey *et al.*, 1999), mainly gneisses, migmatite and granites outcropping in different parts of the study area which include, Garkida, Shani, Zumo, Chibok and even in Girei. Cretaceous sediment belonging to Bima sandstone and Yolde formation outcrops at the northern part of the study area (Figure 2). The tertiary to recent Volcanics (Biu basalt) are third most widespread rocks in the study area belonging to northern arm of Cameroon volcanic line. The Volcanics vary in composition from basalt to trachyte and rhyolite.

The keri-keri Formation is composed of sandstones, siltstones and shale underlying the Gombe sand stone. The formation which outcrops in this part of the study area is Palaeocene in age. The Yolde Formation is considered to be transitional between the continental Bima and marine Gongola formations. This formation shows lateral variation of Sandstone and Calcareous shale. The Bima unit varies in thickness between (100-300m).

The Pan-African older granites are the second wide-spread group of rocks in the study area. They intruded into the Gneiss-migmatite complex. The gneiss-migmatite complex is the most widespread and occupies more than half of the area and is the oldest rock here. They are heterogeneous rock group, which is composed gneiss migmatite of various origin and series of metamorphosed basic and ultra basic rocks (Grant 1971).

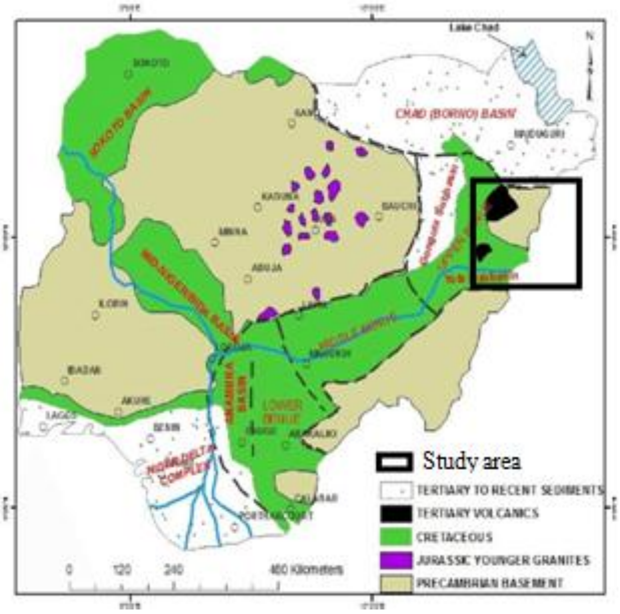

Figure 1: Geology map of Nigeria showing study area

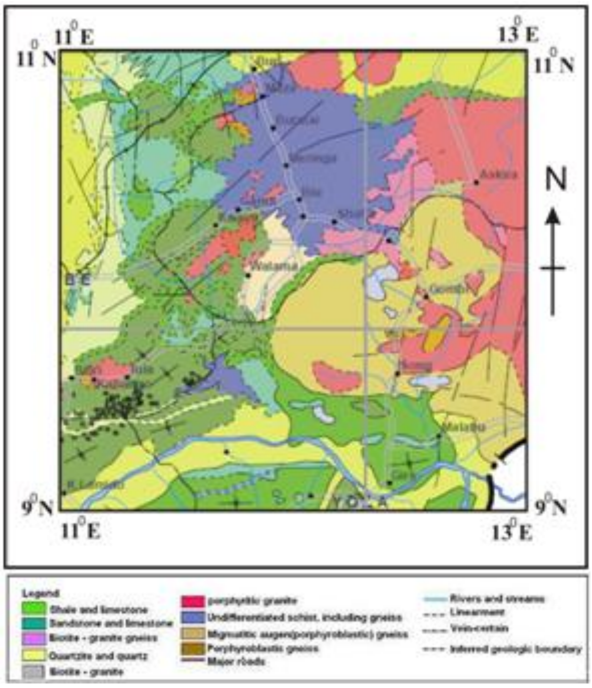

Figure 2: Geology of the study area

Pindiga formation is a sequence of Marine shale with a number of limestone beds towards the base of the Formation. The Tertiary- Recent volcanic rocks in the study area consist of the Basalts, Trachyte, Rhyolite, and newer basalts of eastern arm of Cameroon volcanic line.

3. Materials and Method

The study area comprise 131, 132, 133, 134, 152, 153, 154, 155; 173, 174, 175, 176; 194, 195, 196 and 197 total magnetic intensity (TMI) grids. The total field aeromagnetic field intensity for the study area comprises 16 half-degree grids and in scale of 1:100,000 acquired from NGSA and is used for the purpose of the present study.

The aeromagnetic survey was conducted by Fugro Airborne Surveys, on behalf of the Nigerian Geological Survey Agency (NGSA) between 2003 and 2009. The main purpose of these surveys has been to assist in mineral and groundwater development through improved geological mapping. The magnetometer system used for the aeromagnetic data survey is 3 scintrex CS-2 Cesium vapour. The output from the magnetometer was sampled at 0.2 s to a resolution of 0.01 nT with noise envelope of 0.1 nT

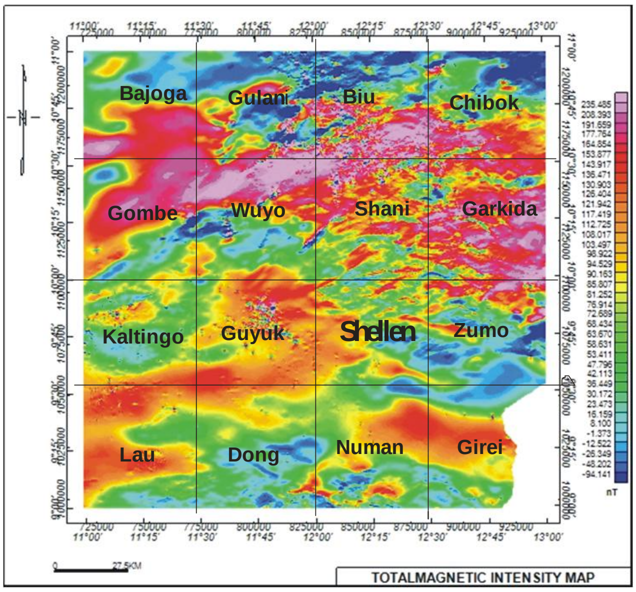

Figure 3: Total Magnetic Intensity Map of the Study Area

A correction based on the international Geomagnetic Reference Field, IGRF, and epoch date January 1, 1974 was included in all the maps. Thus, the magnetic feature that can be defined by the digitised data has a narrowest width of 3.0 km. This gridding system was supported by previous studies with crustal magnetic anomalies (Ajakaiye *et al.*, (1985), Udensi (2001) and Udensi and Osazuwa (2002), which shows that the spacing is suitable for the portrayal and interpretation of magnetic anomalies arising from regional crustal structures. The actual magnetic intensity value was reduced by 33,000 nT for handling before the contour map was plotted. As a result, 33,000 nT must be added to the data so as to get the actual magnetic intensity at a given point. The total magnetic intensity was contoured and colour filled to show the high and low total magnetic intensity of the study area (Figure 3).

Polynomial fitting (order one) method was used for the regional-residual separation, Figures. 5 and 6 shows the colour filled regional map and residual map respectively. The magnetic values found on Figure. 5 trend northeast-southwest and the lines observed indicate faults. Figures 4 and 6 are the total magnetic intensity map reduced to equator and the residual magnetic map of the study area respectively.

Reduction to Magnetic Equator (RTE)

The Reduction to Magnetic Equator (RTE) filter was used to produce the RTE_TMI image (Figure 4) in order to centre structures and anomalous bodies over their exact positions. To produce anomalies depend on the inclination and declination of the body's magnetization, inclination, and declination of the local earth's field and orientation of the body with respect to the magnetic north (Baranov, 1957). The RTE_TMI gridded data (Figure 4) was adopted as our new processed data for other images to be produced.

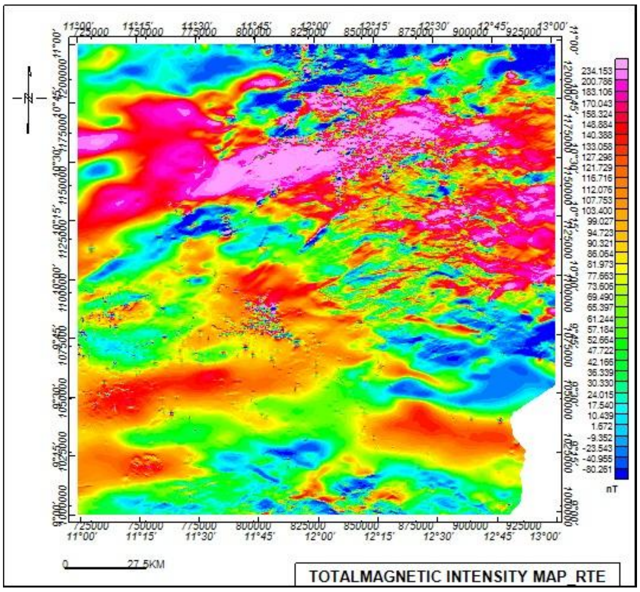

Figure 4: Total Magnetic Intensity Map_RTE of the Study Area

$$L(\theta)=\frac{[\sin(I)-i.\cos(I).\cos(D-\theta)]^2 *(-\cos^2(D-\theta))}{[\sin^2(I_a)+\cos^2(I_a).\cos^2(D-\theta)] * [\sin^2(I)+\cos^2(I).\cos^2(D-\theta)]} \quad (1)$$

If $(|I_a|\langle|I|)$, $I_a = I$

Where $L(\theta)$ is the TMI reduction to equator (RTE), I is the geomagnetic inclination, I_a is the inclination for amplitude correction and D is the geomagnetic declination.

Spectral Analysis Method

The depth estimate of the residual field data were estimated using the procedures developed by Spector and Grant (1970) that examines the statistical nature of magnetic anomaly patterns to obtain the average depths to the top of magnetised bodies using quantitative technique, based on the properties of the energy spectrum of large and complex aeromagnetic data set. This method provides a relationship between the magnetic anomaly spectrum and the depth of magnetic sources in the wave-number/frequency domain. The data from space domain to the wave number domain was converted by using Fourier transform. These depth values of magnetic sources were determined from the slope of the log of power spectrum of the magnetic anomaly data. The principles underlying the use of spectrum in determining the average depths to the top of the anomaly outlined by Spector and Grants (1970), and it is achieved by transformation of the grid to two-dimensional spectra in the wave-number domain, where many physically meaningful functions can be calculated analytically.

The Fourier transforms of the potential field due to a prismatic body has a broad spectrum whose peak location is a function of the depth to the top and bottom surface and whose amplitude is determined by its magnetization.
For a bottomless prism, the spectrum peak at the zero wave number according to the expression:

$$F(\omega)=e^{-h\omega} \quad (2)$$

Where ω is the angular wave number measured in radian/ground – unit and h is the depth to the top of the prism. For a prism with top and bottom surface, the spectrum is:

$$F(\omega)=e^{-h_t\omega}-e^{-h_b\omega} \qquad (3)$$

Where h_t and h_b are the depths to the top and bottom surface respectively. As the prism bottom moves closer to the observation point at surface, the peak moves to a higher wave number. The effect of increasing the depth is to shift the peak to a lower wave number Spectra and Grant, (1970).

Because of these characteristics, there is no way to separate the effect of deep sources from shallow sources of the same type by using wave number filters. The sources can only be separated if the deep sources have greater amplitude or if the shallow sources have less depth extent Salako and Udensi, (2013). When considering a line that is long enough to include many sources, the log spectrum of this data can be used to obtain the depth to the top of statistical ensembles of sources using the expression:

$$LogE(k)=4\pi hk \qquad (4)$$

Where h is the depth in ground – unit and k is the wave number in cycles/ground- unit. The depth of an ensemble of sources can be determined by measuring the slope of the energy (power) spectrum and dividing by 4π ,

Computer software was used to generate the energy frequency plots and the slopes. From the slopes of the plot, the first and the second magnetic sources depth was respectively estimated using the expression:

$$Z_1=-\frac{m_1}{4\pi} \qquad (5)$$

$$Z_2=-\frac{m_2}{4\pi} \qquad (6)$$

Where m_1 and m_2 are slopes of the first and second segments of the plots while Z_1 and Z_2 are first and second depths respectively (Table 1). Contour maps and surface plots of the first layer magnetic source (Z_1) and second layer magnetic sources (Z_2) were also obtained using sufer 8 computer software.

4. Results and Discussion

The TMI_RTE map show slight modification of the original magnetic anomalies on total magnetic intensity (TMI) map (Figure 3), as positive and negative anomalies respectively. The amplitude of anomalies range from – 80.261 nT to 234.153 nT (Figure 4) which were consistent in pattern, trend and amplitude of the total magnetic anomalies (Figure 3) within – 96.14 nT to 235.49 nT shows that the data has been filtered.

The northeast, northwestern and some part southern regions of the RTE map is characterized by positive (high) magnetic intensity value range between 127.296 nT to 234.153 nT. The southwest, southeast and some extend north east regions host intermediate magnetic value range within 30.330 to 121.726 nT while the edge of the northern, southeast, south and western regions have negative anomalies range between - 80.261 nT to 24.015 nT.

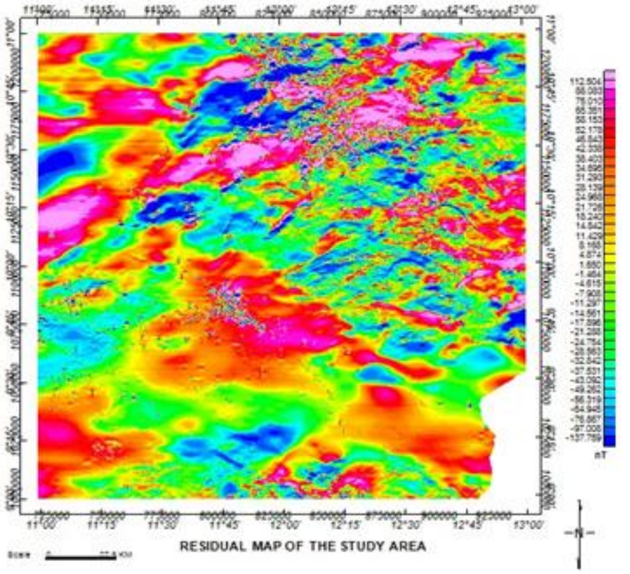

Figure 5: Residual aeromagnetic map

The anomalies in the residual magnetic map of Fig. 5 have short wavelength and are more or less circular in the underlying basement surface. There are high magnetic values around NE and WS of the study area. The structural trends revealed from the first degree polynomial surfaces have a dominant of NE-SW and NW-SW directions. This qualitative interpretations of the residual map also revealed the it is trending in NE-SW and NW-SE fracture in the Benue trough as have been predicted earlier by the works of Ajakaiye, (1981) which was attributed to the event at possible opening up of African and South American plates. These suggest regions where the basements are shallow or exposure. A fairly discontinuities and lineament exists in the study area trending NE-SW and NW-SE direction. This is an indication of possible faults zones within the basement complex of the basin.

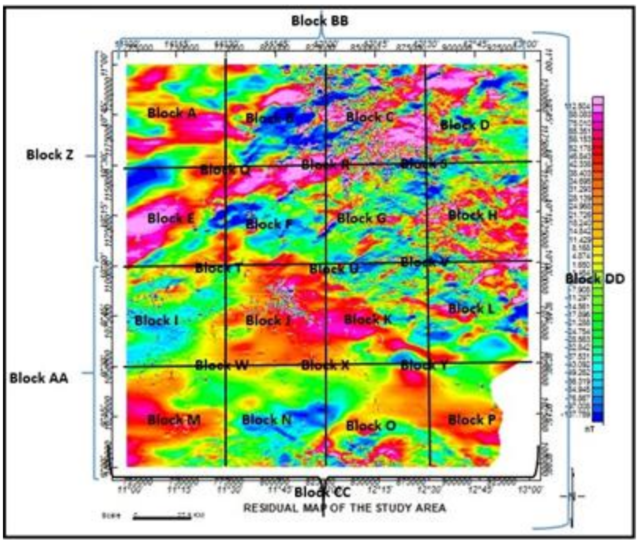

Figure 6: Total Magnetic Intensity Map of the Study Area.

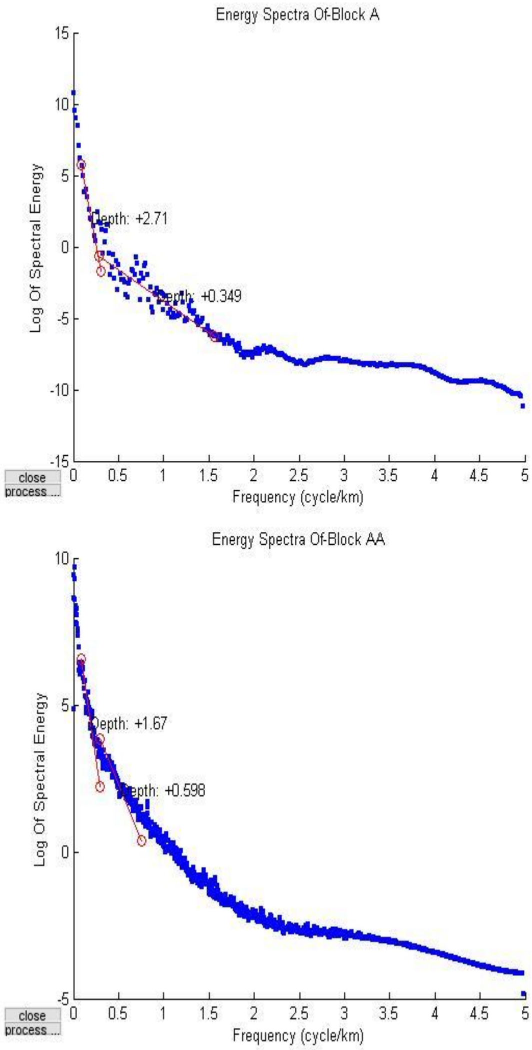

Figure 7: A plot of energy spectrum against frequency for block AA and BB

The depth to magnetic basement determined using spectral analysis suggest 100% two source depths beneath the study area as revealed by the spectral blocks in figure 6 and these values are summarized in Table 1 for the 30 blocks making up the study area. The results suggest the existence of two main source depths under the study area, the deeper and the shallower source. The deeper sources represented by the steep segment of the spectra of the blocks reflect the Precambrian basement. The shallow magnetic horizons represented by the second segment of the spectra of the spectral blocks reflect magnetic sources shallower than the basement. The deeper magnetic source (sedimentary thickness) varies between 900 to 3810 m and the shallower sources vary between 340 to 810 m. The thicker sedimentary cover in the southern part and some areas in the north western part of the area correspond with the upper Benue Trough and the Gongola basin within the Gombe sandstone (Fig.6).

Table 1: Estimated depth to the shallow (Z_2) magnetic sources and deep (Z_1) magnetic sources in km

Section	Long (deg)	Lat (deg)	Z_1 (km)	Z_2 (km)
A	11.25	10.75	2.71	0.34
B	11.75	10.75	1.72	0.49
C	12.25	10.75	1.21	0.35
D	12.75	10.75	1.44	0.56
E	11,25	10.25	2.60	0.67
F	11.75	10.25	1.51	0.49
G	12.25	10.25	1.19	0.36
H	12.75	10.25	1.09	0.43
I	11.25	9.75	3.14	0.85
J	11.75	9.75	3.30	0.35
K	12.25	9.75	1.45	0.81
L	12.75	9.75	1.36	0.57
M	11.25	9.25	2.14	0.52
N	11.75	9.25	2.19	0.51
O	12.25	9.25	0.90	0.45
P	12.75	9.25	1.56	0.54
Q	11.50	10.50	1.76	0.55
R	12.50	10.50	1.20	0.54
S	11.50	9.50	3.01	0.39
T	12.50	9.50	2.95	0.65
U	12.00	10.75	1.68	0.56
V	12.00	10.25	3.81	0.69
W	12.00	9.75	3.03	0.65
X	12.00	9.25	2.83	0.56
Y	11.25	10.00	2.10	0.46
Z	11.75	10.00	1.28	0.52
AA	12.25	10.00	1.61	0.59
BB	12.75	10.00	1.13	0.49
CC	11.50	10.00	1.56	0.47
DD	12.00	10.00	1.55	0,43
Average			**1.97**	**0.53**

In this work, the deeper models, Z_1 was proposed. Z_1 was imported into surfer software environment and then 3D depth to basement map (Fig 7 b) depicting the undulating nature of the magnetic basement was generated. $Z_1$and Z_2, represent the deep and shallow seated magnetic sources respectively. The deeper magnetic sources regarded as the low frequency component is represented by the steep gradient of the spectral energy curve while the shallow magnetic bodies seen as the high frequency component is represented by the less steep gradient of the energy curve. The deeper magnetic sources are attributable to magnetic bodies on the basement surface and the shallow sources probably regarded as magnetic intrusions.

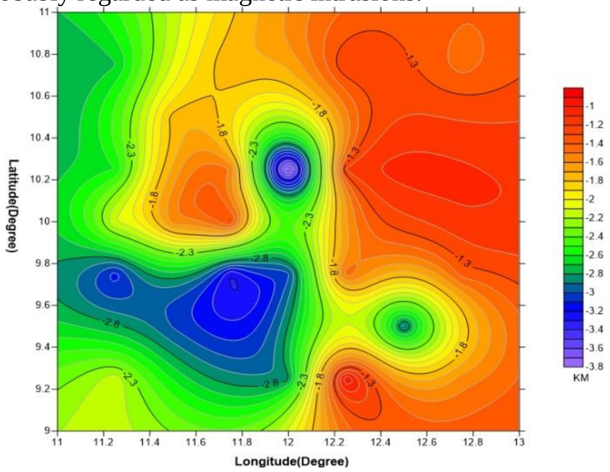

Figure 8: Contour map of deeper depth to basement magnetic source (contour interval 0.02km).

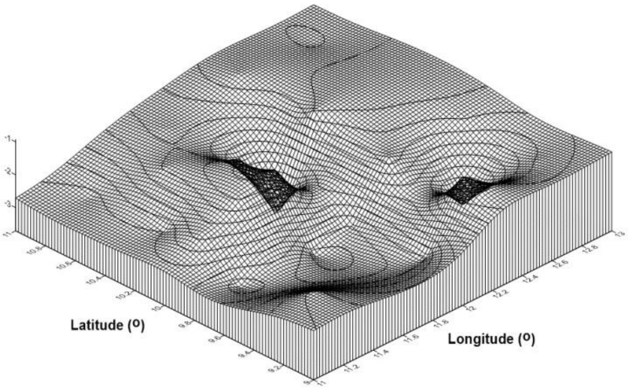

Figure 9: 3D Wire frame of the Basement Map within the Study Area

5. Conclusion

The qualitative interpretation of the anomalies in the residual map revealed areas of high frequency anomaly sources related to deep seated bodies and areas of low frequency anomaly related to shallow seated bodies. Several undulation and likely traps is noticeable on the basement surface. Dominant NE-SW trending is attribute to the Pan – African Orogeny trends was equally found.

The aeromagnetic data is used to delineate the subsurface structure that controls the anomalous mineralisation zones of the studied area. Spectral Depth Analysis method was applied to interprete aeromagnetic data with the purpose of estimating depth to the basement (sedimentary thickness) in the area. The results of this interpretation show the variation in the surface of the magnetic basement across the study area. The depth of the deeper sources ranges from 0.90 to 3.81 km and is believed to correspond to the surface of the magnetic basement in the study area. The shallower depth, ranging from 0.34 to 0.81 km, might refer to some major magnetic units, to uplifted basement surface or to some local magnetic features. These results therefore demonstrate the aeromagnetic data interpretation using Spectral Depth Analysis method has successfully delineated the depths to magnetic sources within the surface of the magnetic basement in a basement complex. The highest sedimentary thickness obtained in the area with spectral analysis is 3.81km. This highest sedimentary thickness was found at the south west and south east all within the upper Benue trough part of the study area. This area of high sedimentary thickness should be the target for further exploration.

References

[1] Ajakaiye D. E (1981) Geophysical investigation of Benue Trough; A review. Earth Earth Sci 1: 126-136.

[2] Ajakaiye, D. E., Hall, D. H., & Millar, T. W. (1985).Interpretation of Aeromagnetic data across the central crystalline shield areas of Nigeria. *Geophysics J. R. Astron Society*, *83*, 503-517.

[3] Baranov, V. (1957). A new method for interpretation of aeromagnetic maps: pseudo-gravimetric anomalies. *Geophysics*.22.359-383.

[4] Bassey, N.E. Ezeigbo, H.I. and Kwache, J.B., (1999). Hydrogeological study of Duhu area (Sheet 135)N.E. Nigeria on the basis of Aeromagnetic data. *Water resources Journal of National association of Hydrogeologist.* 10: 26-30.

[5] Chiozzi, P., Matsushima, J., Okubo, Y., Pasquale, V., & Verdoya, M. (2005). Curie-point depth from spectral analysis of magnetic data in central–southern Europe. *Phys. Earth Planet. Inter.*, *152*, 267-276. https://doi.org/10.1016/j.pepi.2005.04.005

[6] Emujakporue, G., Ofoha, C., & Kiani, I. (2017). Investigation into the basement morphology and tectonic lineament using aeromagnetic anomalies of Parts of Sokoto Basin, North Western, Nigeria. *Egyptian Journal of Petroleum.* https://doi.org/10.1016/j.ejpe.2017.10.003

[7] Grant, N. K., 1971. A Compilation of radiometric ages from Nigeria, *Journal of Mining and Geology*, 6: 37-54.

[8] Kasidi, S. and Ndatuwong, L.G. (2008): Spectral Analysis of Aeromagnetic Data over Longuda Plateau and Environs, North-Eastern Nigeria. *Continental Journal Earth Sciences;* 3, 28–32.

[9] McCurry, P., (1979). The geology of the Precambrian to lower Palaeozoic rocks of northern Nigeria a review in C.A. Kogbe (ed.): Geology of Nigeria Elizabethan press Lagos. 15-39pp.

[10] Nur A., Kamurena E. and Kasidi S. (2010): Analysis of aeromagnetic data over Garkida and environs, north-eastern Nigeria. *Global journal of pure and applied sciences* VOL. 17, NO.2, 2011: 209-214

[11] Ojo, S. B. (1984). Middle Niger Basin revisited magnetic constraints on gravity interpretations. A paper presented at the 20th Nigeria Mining and Geosciences Society Conference, Nsukka, Nigeria, *Conference proceedings*, 52–53.

[12] Ojo, S. B. and Ajakaiye, D. E. (1989). Preliminary interpretation of gravity measurements in the middle Niger Basin area, Nigeria. In: Kogbe, C.A. (Ed.), Geology of Nigeria, second ed. Elizabethan Publishing Co., Lagos, 347–358p.

[13] Osinowo O, Akanji, A., & Olayinka A. (2013). Application of high resolution aeromagnetic data for basement topography mapping of Siluko and environs, southwestern Nigeria. *Journal of African Earth Sciences*. https://doi.org/10.1016/j.jafrearsci.2013.11.005.

[14] Salako, K. A. and Udensi E. E., (2013): Spectral Depth Analysis of Parts of Upper Benue Trough and Borno Basin, North-East Nigeria, Using Aeromagnetic Data. *International Journal of Science and Research (IJSR), India Online ISSN:* 2319-7064

[15] Spector, A., and Grant, F.S. (1970), Statistical Models for interpreting aeromagnetic data. *Geophysics* Vol. (35), 293-302.

[16] Udensi, E. E. (2001). Interpretation of total magnetic field over the Nupe Basin in west central Nigeria using aeromagnetic data. Ph.D thesis A.B.U. Zaria Nigeria.

[17] Udensi, E. E., & Osazuwa, I. B. (2002). Two and Half Dimensional Modelling of the Major Structures Underlying the Nupe Basin, Nigeria using Aeromagnetic Data. *Nigerian Journal of Physics (NJP)*, 14(1), 55 – 61.

[18] Udensi, E. E. and Osazuwa, I. B. (2004). Spectra determination of depths to magnetic rocks under the Nupe basin, Nigeria. Nigeria Association of Petroleum Explorationists (NAPE) Bulletin 17, 22–27.