Regional Magnetic Field Trend and Depth to Magnetic Source Determination from Aeromagnetic Data of Maijuju Area, North Central, Nigeria.

ABSTRACT

Aim: The aim of this study is to estimate regional magnetic field trend and depth to magnetic rocks within Maijuju area, North-Central, Nigeria.

Methodology: The Total Magnetic Intensity (TMI) map was gridded, contoured and interpreted for trends, closures and dislocations. The TMI map was reduced to the equator; Upward continuation to depth 1, 2, 3, km was carried out; the magnetic residual field map was divided into 4 blocks of area each 27m $\times$ 27m for 2-D spectral analysis of the magnetic anomalies over the area. All resultant maps were interpreted.

Results: The TMI map revealed anomalies observed in the study area to trend largely in the NE-SW and E-W directions. Low magnetic intensities values were observed at Jos-Bukuru, Jarawa, Shere, and Kofai and Rop Complexes. Intermediate negative magnetic values (-54.5 to -5.3 nT/m) were observed at the Sara-Fier Complex. Positive magnetic intensity range of 72.9 to 270.7nT/m was seen to dominate the Older Granite region, the Basement Complex and part of Sara-Fier Complex, Magnetic Discontinuities which could represent geologic fractures were also observed. The TMI reduced to equator map was used to centre the peaks of magnetic anomalies over their sources. The upward continuation maps revealed that TMI continued upward to elevations of 1km, 2km and 3km permits a clearer view of the deeper anomaly sources and showed the regional magnetic field trend to be in the NE-SW direction. The spectral depth analysis result showed that the deeper magnetic sources have an average depth of 1.47km while the shallow magnetic sources have an average depth of 360m (0.36km).

Conclusion: The regional magnetic field trend as observed from the upward continuation process is NE-SW trend while the spectral depth analysis result revealed that the deeper sources have an average depth of 1.47km while the shallow sources have an average depth of 360m (0.36km).

Keywords: [Magnetic, Anomalies, Spectral, Sources, Trend]

1. INTRODUCTION (ARIAL, BOLD, 11 FONT, LEFT ALIGNED, CAPS)

Maijuju, the study area of this research, is found in Plateau State, North Central Nigeria. It lies between longitude $9^{\circ}00'$E - $9^{\circ}30'$E and latitude $9^{\circ}30'$N - $10^{\circ}00'$N. The study area covers approximately 2970km^2. The towns in the study area include Kayarda, Bukuru, Shere, Girim, Fusa, and Gwodong. Accessibility to the area is mainly by road and foot paths.

Geologically, the study area is an area of Younger Granite Complexes, forming distinctive groups of intrusive and volcanic rocks bounded by ring dykes or fault [1]. Volcanic activities which occurred several years ago, created vast Basaltic plateau and volcanoes, producing regions of mainly narrow and deep valleys, and sediment from the middle of rounded hills with shear facies. Younger Granite Complexes in the study area are Jarawa, Sara Fier, Shere, Jos-Bukuru, Shona, Kofai and Rop. Other rocks found in the area are Basic Rocks (Gabbro and Dolerite) and Basement Rock such as Migmatite which are resistant to erosion. The phases of volcanic activities involved in the formation of Plateau State, have made it one of the mineral rich states in Nigeria. Minerals found in this area are Biotite, Hornblende, Quartz, Feldspar etc. Due to the presence of Younger Granite intrusions in the study area, Tin and Columbite potential in the area is high. The geology map of the study area is shown in Figure 1.

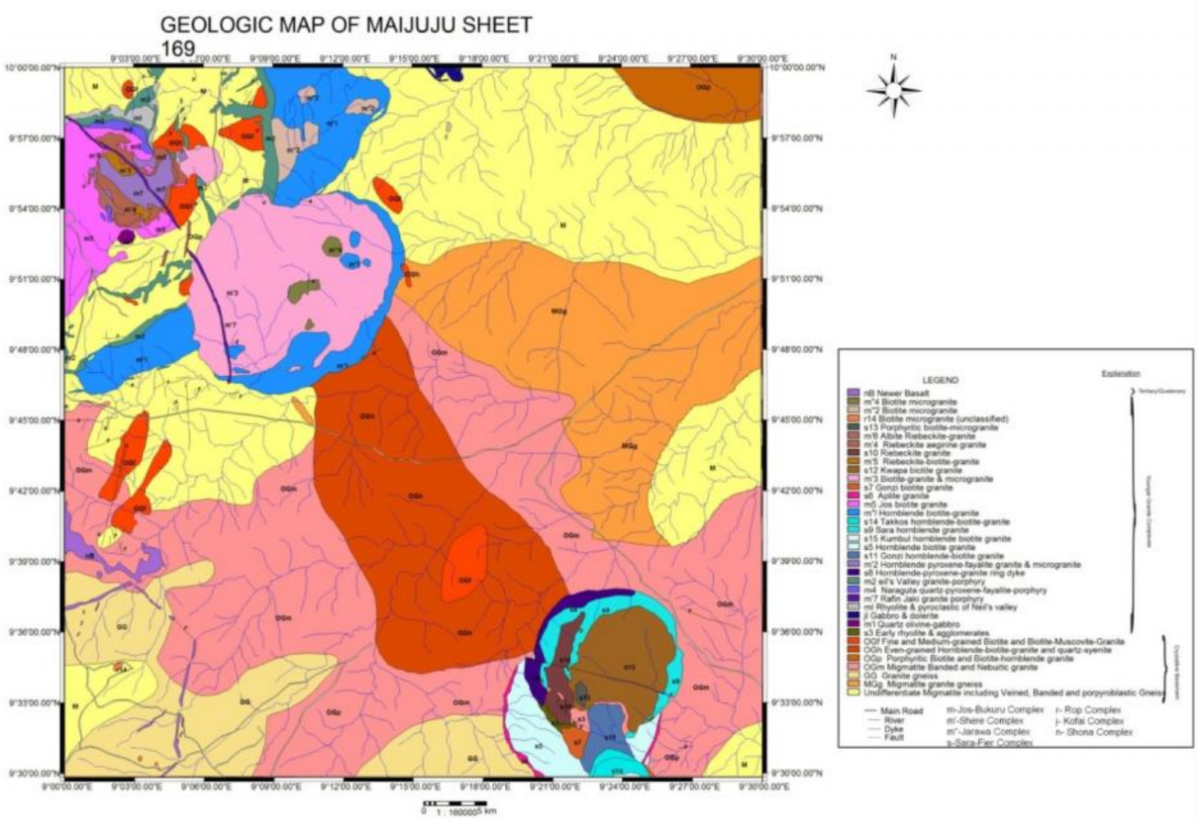


Fig.1. Digitised Geology map of Maijuju sheet 169. (After Geological Survey of Nigeria, 1962).

The aim of a magnetic survey is to investigate subsurface geology on the basis of magnetic anomalies in the Earth's magnetic field resulting from the magnetic properties of the underlying rocks. Magnetic surveys can be performed on land, at sea and in air. The speed of operation and cost make airborne magnetic surveys very attractive, where the principal objective has been to assist in mineral and groundwater development through improved geologic mapping. In addition, aeromagnetic surveys have traditionally been applied at the early stage of petroleum exploration to determine depth and major structure of crystalline basement rocks underlying sedimentary basins. The methodology for acquiring and compiling data appears to be keeping pace with modern technology so that presently the magnetic method is by far the most widely used of all geophysical survey; both in terms of line-kilometres surveyed annually and in total line-kilometres [2]. Thus, compared to other geophysical methods, the aeromagnetic data are always readily available and so it is important to exploit the potentialities of these data.

The largest airborne geophysical survey ever carried out in Nigeria, was conducetd in three phases between 2005 and 2010 in other to position the country as an exciting destination for explorers. This survey was partly financed by the Nigerian Federal Government and the

World Bank as part of a major project known as the Sustainable Management for Mineral Resources Project. All the airborne geophysical work, data acquisition processing and compilation, was carried out by Fugro Airborne Surveys; the survey acquired both magnetic and radiometric data compilation. The recent survey has a Tie-line spacing of 500m, light line spacing of 100m, and Terrain clearance of 100m using TEMPEST system compared with the survey carried out in the 1970s which had a Tie-line spacing of 20 km, light line spacing of 2 km, and lying altitude of 200m. Aeromagnetic data covering Maijuju Area, sheet 169 was acquired from the Nigerian Geological Survey Agency, 31, Shetima Mangono Crescent Utako District, Garki, Abuja.

Several studies have been carried out using upward continuation and spectral depth analysis techniques as method for enhancing magnetic data in different part of the world and Nigeria. Some include that of [3], [4], [5], [6], [7], [8], [9] and [10].

The aim of this study is to carry out Upward Continuation and to determine the depth to magnetic rocks within Maijuju area, North-Central, Nigeria. Specifically, the study seeks to

i. Qualitatively interpret the Total Magnetic Intensity (TMI) map.
ii. Reduce the TMI data to equator and interpret the result.
iii. Carry out Upward continuation of TMI data to 1km, 2km and 3km elevation
iv. Carry out Spectral analysis of TMI data

2. MATERIALS AND METHOD

2.1 Materials

The materials include: soft copy of Total Magnetic Intensity map (Aeromagnetic map) covering Maijuju sheet 169 (1:100 000), Hard copy of Geologic map covering Maijuju sheet 169 (1: 100 000) and Geologic report covering Maijuju area [1].

2.2 Software

The software include: Oasis Montaj and MATLAB

2.3 Method

i. The Total Magnetic Intensity map was gridded, contoured using Oasis Montaj software by Geosoft. The map was qualitatively interpreted for highs, low and anomaly trends.
ii. The TMI map was reduced to the equator. To reduce the magnetic data to equator Equation 1 [11] was applied to the data

$$(\theta) = \frac{[\sin(I) - i.\cos(I).\cos(D-\theta)]^2 X \left(-\cos^2(D-\theta)\right)}{[\sin^2(I_a) + \cos^2(I_a).\cos^2(D-\theta)] X [\sin^2(I) + \cos^2](I).\cos^2(D-\theta)]}, \text{if } (|I_a|) < (|I|), I_a = I \quad (1)$$

Where:
I = geomagnetic inclination
I_a = inclination for amplitude correction
D= geomagnetic declination
Sin (I) is the amplitude component while icos(I)cos(D-θ) is the phase component. The inclination, declination and inclination for amplitude correction used here were 3.6°, 1.6° and 86.1°. The resultant map was interpreted.

iii. Upward continuation to depth 1, 2, 3, km was carried out. Equation 2 [12] below can be used for the calculation of the upward continuation

$$F(x, y, -h) = \frac{h}{2\pi} \iint \frac{F(x, y, 0)\partial x \partial y}{\sqrt{(x - x^{i})^2 + (y - y^{i})^2 + h^2}} \quad (2)$$

Where F (x´, y´,-h) is the total field at the point P (x´, y´,-h) above the surface on which F(x, y, 0) is known, h = elevation above surface. The resultant maps were interpreted.

iv. The magnetic residual field map was divided into 4 blocks of area each 27m × 27m. As described by [13], the criteria used for choosing the dimensions of blocks for spectral analysis were that each block should contain more than one maximum or minimum and the square's sides should not cut through the essential parts of the anomalies.

v. The grid for each section was Fast Fourier transformed and radial average spectrum was run for each section; this produces a column for logs of spectral energy and the corresponding frequencies. These logs of spectral energies were plotted against the corresponding frequencies, and two trend lines were imposed on linear segment [14] and [15]. If the frequency unit is in radians per kilometre the mean depth of burial of the ensemble is given by Equation 3.

$$Z = -\frac{m}{2} \quad (3)$$

Where m is the slope of the best fitting straight line. If, however, the frequency unit is in cycles per kilometre, the corresponding relation can be expressed as

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

vi. Steps ii-v was carried out using MAGMAP Filtering extension of Oasis Montaj. Plot of log of spectral energy against the frequency was carried out with MATLAB.

3. RESULTS AND DISCUSSION

3.1 Interpretation of the Total Magnetic Intensity (TMI) map for trends and closures

From the TMI map (Fig. 2), most of the magnetic anomalies between longitude 9°00'-9°15'E and latitude 9°45'-9°55'N; 9°00'-9°10'E and 9°30'-9°40'N (Jos-Bukuru, Jarawa and Shere Younger Granite Complexes), trend mainly in the NE-SW direction. Magnetic anomalies between longitude 9°15'-9°30'E and latitude 9°45'-10°00'N; 9°15'-9°30'E and 9°30'-9°40'N (Basement Complex), trend largely in the East-West direction. Low negative magnetic intensity values (624.5 to -54.5 nT/m) where observed at the Jos-Bukuru, Shere, Jarawa and Kofai and Rop Complexes. This result agrees with the result of [16] and [6] that biotite granites which form the plutons in the ring complexes are associated with the lowest negative anomalies in the Younger Granite Province.

Intermediate negative magnetic values (-54.5 to -5.3 nT/m) are observed at the Sara-Fier Complex. Positive magnetic intensity values range of 72.9 to 270.7nT/m is seen to dominate the part of the Sara-Fier Complex, Older Granite region and Basement Complex. Several Magnetic highs and lows were observed as closures on Fig.2. Circular to near circular closures are probably caused by circular to near circular ore bodies or intrusions while elongated closures represent almost linear anomalies caused by long ore bodies or dykes. Some dislocations represented by lines are seen in the gridded TMI map which could be geological fractures. On magnetic maps dislocations are observed when one part of an anomaly pattern is displaced with respect to the other part.

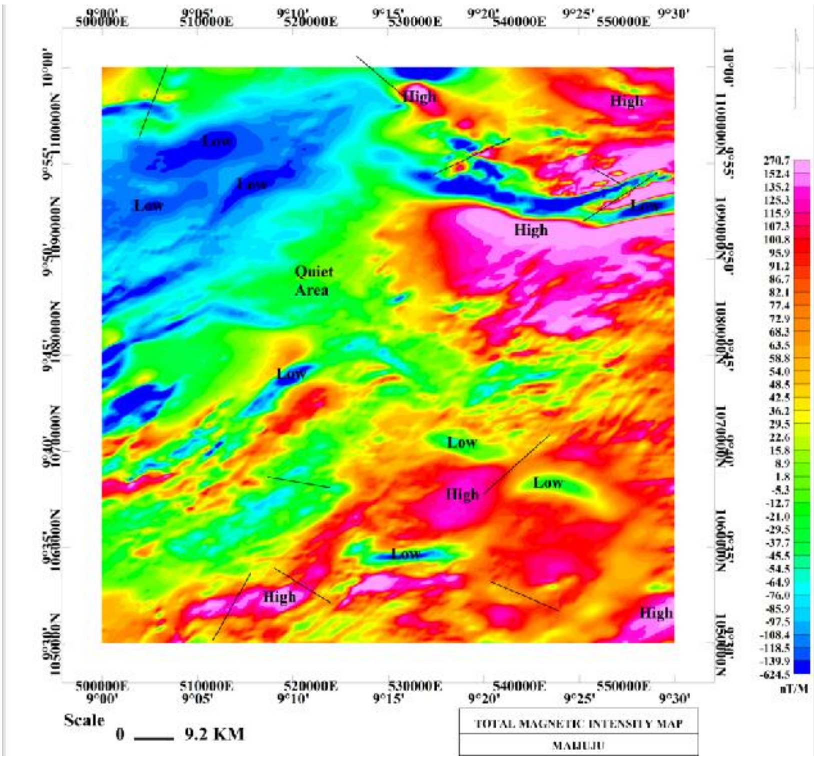


Fig. 2. Total magnetic intensity (TMI) map of Maijuju sheet 169, with lines representing dislocations

3.2 Interpretation of the TMI Reduced to Equator (TMI-RTE)

The TMI data was reduced to the equator (Fig.3) to realign the anomalies and have their peaks centred over their sources. This gives a better result without losing any geophysical meaning. The low magnetic intensities observed around the Younger Granite complex is thought to be as a result of the underlying rocks (Jos biotite granite, Albite-riebeckite granite, hornblende-biotite granite etc) found at this region. The Younger Granite rocks are thought to have the largest number of intrusions (Obaje, 2009) in the study area. Similarly, high magnetic intensities observed around the basement are due to basement rocks such as Older Granite and migmatite.

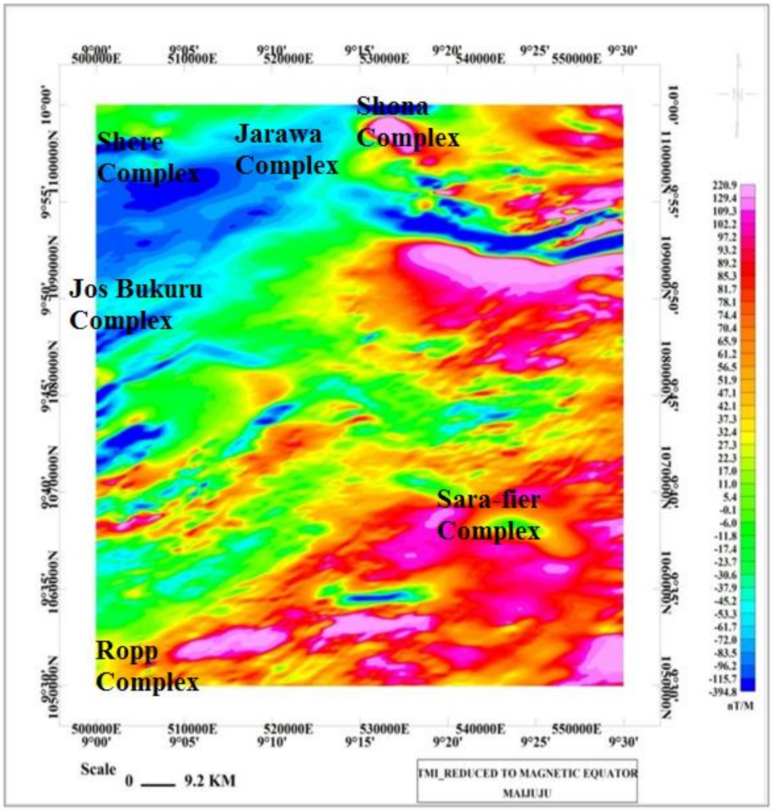


Fig. 3. Total magnetic intensity reduced to equator (TMI-RTE) map

3.3 Interpretation TMI Upward Continued Maps

Upward continuation method is used in magnetic interpretation to determine the form of regional magnetic variation over a survey area, since the regional field is assumed to originate from relatively deep-seated structures. The upward continued field must result from relatively deep structures and consequently represents a valid regional field for the area. Upward continuation is also useful in the interpretation of magnetic anomaly fields over areas containing many near-surface magnetic sources such as dykes and other intrusions (Keary et al., 2002). Upward continuation attenuates the high wavenumber anomalies associated with such features and enhances, relatively, the anomalies of the deeper seated sources.

Figures 4, 5, and 6 show the TMI continued upward to elevations of 1km, 2km and 3km respectively. Comparison of the three figures clearly illustrates that the high - wavenumber components of the TMI have been effectively removed by the continuation process. It is apparent that the attenuation of the shallow sources in the upward continuation process permits a clearer view of the deeper anomaly sources and also provides information of the regional anomaly trend. These upward continued maps illustrate the change in the anomaly character with increasing observation to magnetic source distance, and are also useful as a low filter as such, the 3km upward continued data provides an excellent view of the study area undistorted by local, high amplitude, high gradient anomalies of the magnetic sources in the shallow portion of the study area. Here the regional anomaly trends largely in a NE-SW direction. This implies that the deep seated structures trend largely in a NE-SW direction.

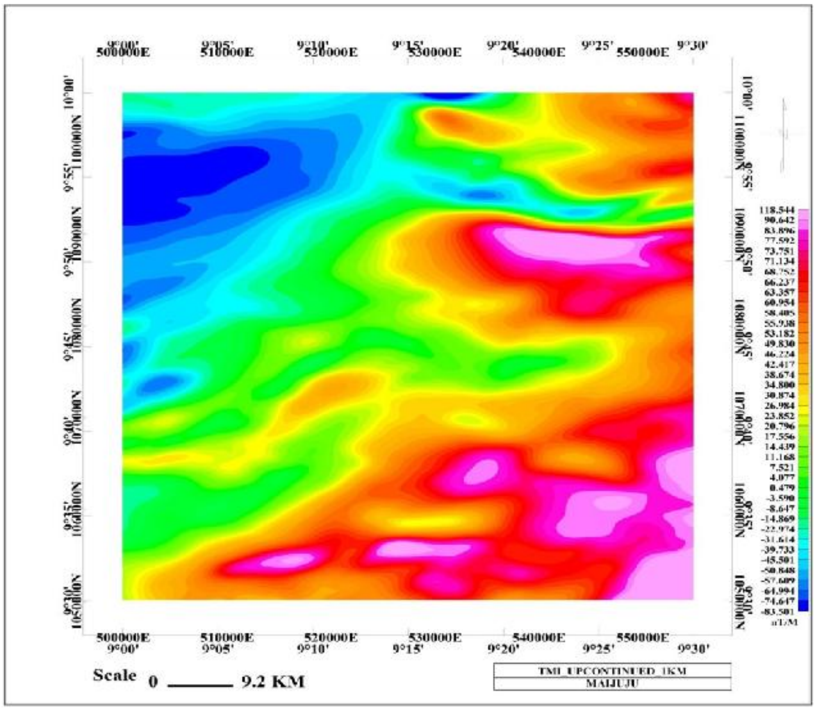


Fig. 4. TMI data continued upward to 1km elevation.

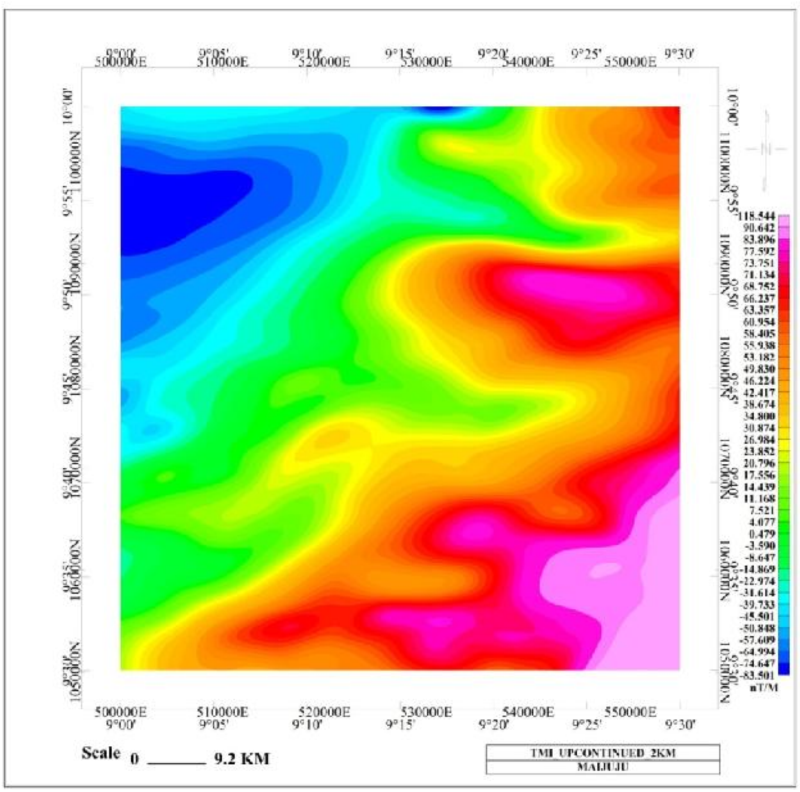


Fig. 5: TMI data continued upward to 2km elevation.

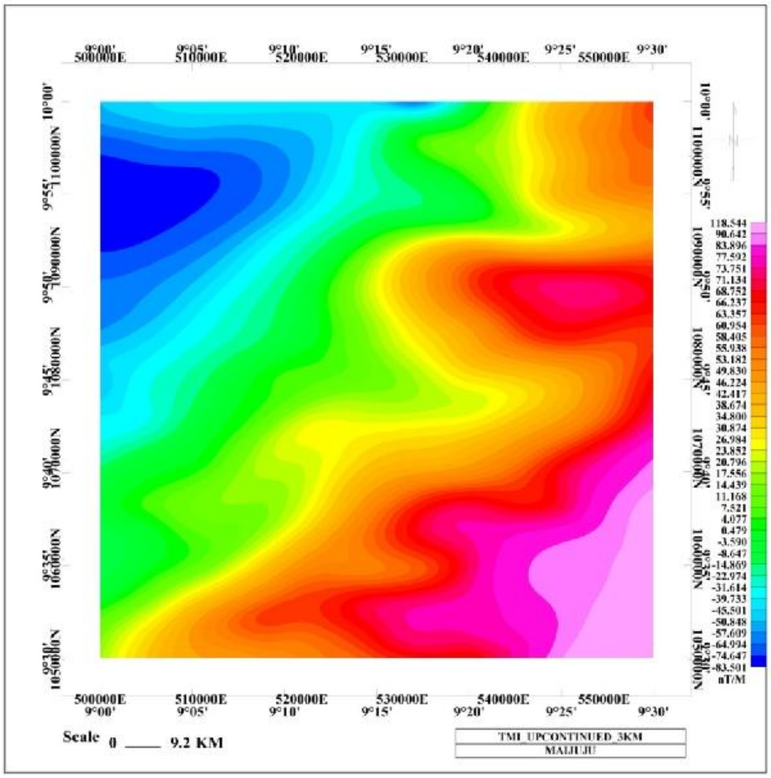


Fig.6. TMI data continued upward to 3km elevation.

3.4 Spectral Depth Analysis of TMI.

Fig. 7 show sections selected for Spectral Depth Analysis from the TMI map. Plots of energy spectrum for each block are shown in Figs 8-11. A typical energy spectrum for magnetic data may exhibit a deep source component, a shallow source component and a noise component. The spectra showed two straight line segments in two frequency ranges. While the straight line segment in the higher frequency range is from the shallower source components, the one in the lower frequency range is from the deeper source components. The depths to magnetic sources calculated from Equation 4, since frequency is expressed in cycles per kilometer is summarised in Table 1. The Table shows the depths to deeper sources ranging from 1.05km to 2.01km and the depth to the shallower sources ranging from 0.34km to 0.39km.

The source that account for the shallow source depth derived from the statistical spectral analysis could be the effect of outcropping basement rocks of the study area which consists of migmatites, gneisses, and Older Granite. Also exposed Younger Granite intrusions also account for this source. It could also be due to the rhyolitic rocks that directly overlie the metamorphic basement; Pleistocene cassiterite bearing alluvium and/or Quaternary to Recent basalt lava flows have filled the broad Pleistocene valleys [6]. The deep sources could be attributed to the magnetic rocks that intrude the basement. Intra basement features like fractures and faults are other deeper sources. The spectral depth result shows that the deeper sources have an average depth of 1.47km while the shallow sources have an average depth of 360m (0.36km).

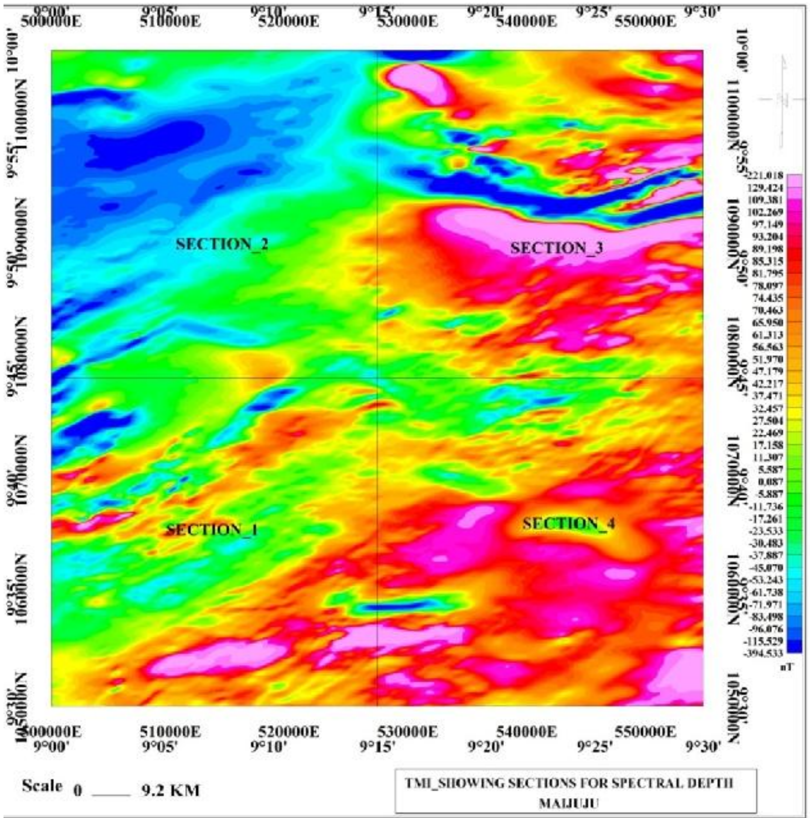
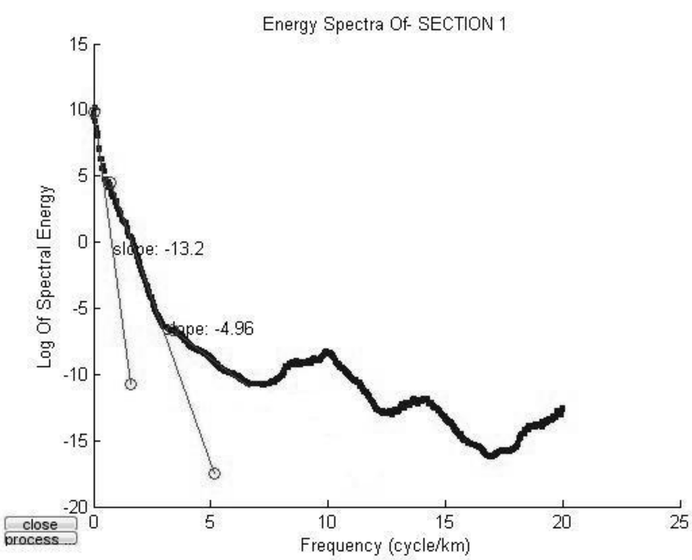


Fig. 7: TMI showing sections selected for Spectral Depth



Analysis

Fig. 8. Plot of log of Spectral Energy against Frequency for section 1.

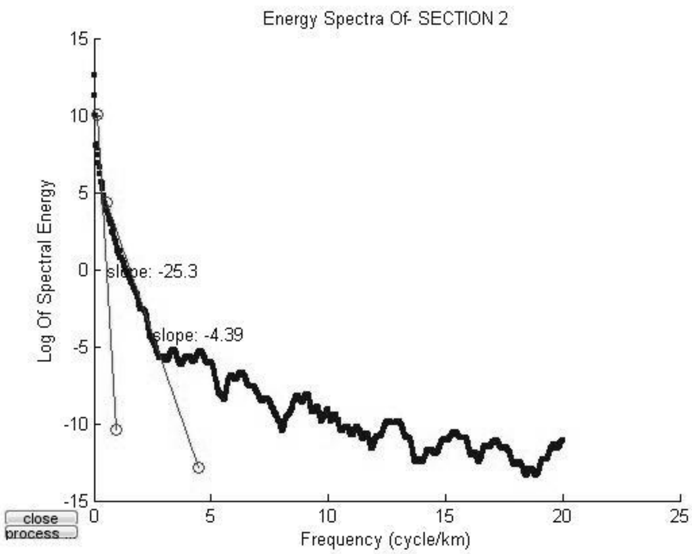


Fig. 9. Plot of log of Spectral Energy against Frequency for section 2.

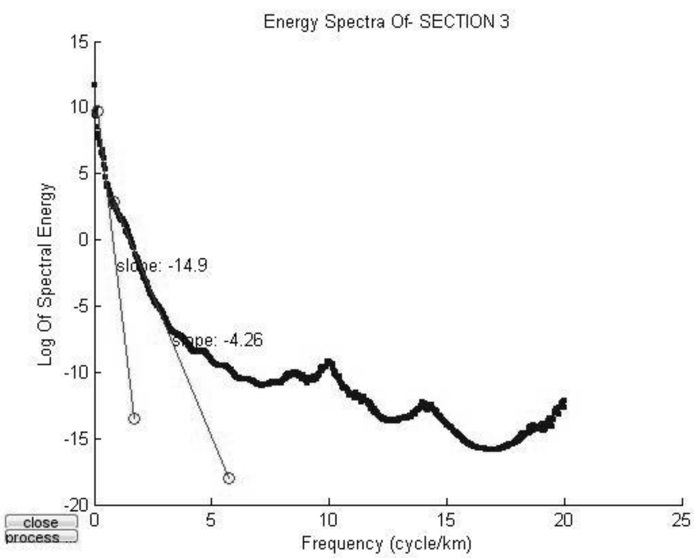


Fig. 10. Plot of log of Spectral Energy against Frequency for section 3.

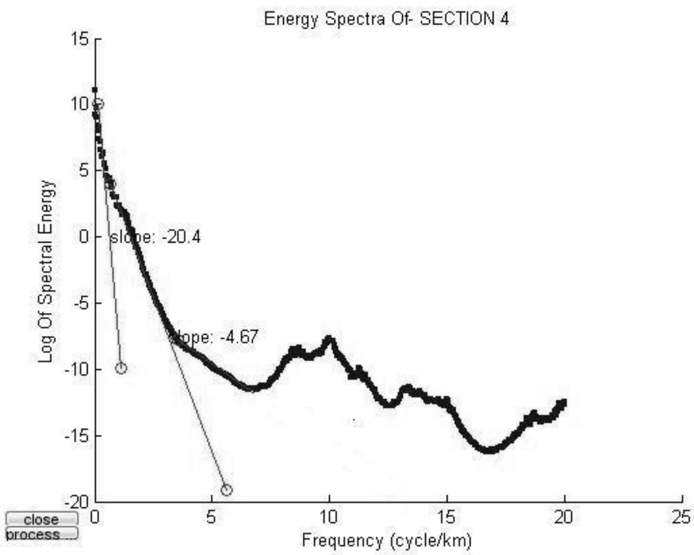


Fig. 11. Plot of log of Spectral Energy against Frequency for section 4.

Table 1. Spectral depth for each section of TMI.

SECTION N0.	Block	1st Layer Gradient	2nd Layer Gradient	Depth to Deeper Sources(km)	Depth to Shallower Sources(km)
1	SW	-13.2	-4.96	-1.05	-0.39
2	NW	-25.3	-4.39	-2.01	-0.35
3	NE	-14.9	-4.26	-1.19	-0.34
4	SE	-20.4	-4.67	-1.62	-0.37

4. CONCLUSION

The TMI data of the Maijuju Area North Central Nigeria has been interpreted for the trend of the regional magnetic field and the depth to the magnetic sources present in the study area. The regional magnetic field trend as observed from the upward continuation process is NE-SW trend while the spectral depth analysis result revealed that the deeper sources have an average depth of 1.47km while the shallow sources have an average depth of 360m (0.36km).

REFERENCES

1. Macleod WN, Turner DC, Wright EP. The Geology of the Jos Plateau. Geological Survey of Nigeria, 1971; Bulletin 32.

2. Paterson NR, Reeves CV. Applications of gravity and magnetic: The state- of-the-art in 1985. Geophysics. 1985; 50(12): 2558-2594

3. Ofoegbu CO, Hein K. Analysis of Magnetic Data over Part of the Younger Granite Province of Nigeria. Pure and Applied Geophysics. 1991;136:173-189.

4. Cowan DR, Cowan S. Separation Filtering Applied to Aeromagnetic Data. Exploration Geophysics. 1993; 24:429-436

5. Akanbi ES, Udensi EE. Structural trends and spectral depth analysis of the residual field of Pategi area, Nigeria, using Aeromagnetic Data. Nigerian Journal of Physics. 2006; 18(2), 271-276.

6. Akanbi ES, Mangset, WE. Structural trends and spectral depth analysis of the residual magnetic field of Naraguta area, North central, Nigeria. Indian Journal of Science and Technology. 2011; 4(11): 1410-1415.

7. Nwankwo LI, Olasehinde PI, Akoshile CO. Heat flow anomalies from Spectral Analysis of Airborne Magnetic Data of Nupe Basin, Nigeria. Asian Journal of Earth Sciences. 2011; 4(1): 20-28.

8. Abdulsalam NN, Mallam A, Likkason KO. Identification of Linear Feature using continuation Filters over Koton Karifi area, Nigeria, from Aeromagnetic Data. World Rural Observations. 2011; 3(1): 1-8.

9. Ganiyu SA, Badmus BS, Awoyemi MO, Akinyemi, OD, Olurin OT. Upward Continuation and Reduction to Pole Process on Aeromagnetic Data of Ibadan Area, South-Western Nigeria. Earth Science Research. 2013; 2(1): 66-73. URL: http://dx.doi.org/10.5539/esr.v2n1p66

10. Ofor NP, Adam KD, Udensi EE. Spectral Analysis of the Residual Magnetic Anomalies over Pategi and Egbako Area of the Middle Niger Basin, Nigeria. Journal of Natural Sciences Research. 2014; **4**(9): 44-49.

11. Leu LK. Use of reduction-to-equator process for magnetic data interpretation: Presented at the 51st Ann. Internat. Mtg., Sot. Exnl. Geonhv.: Geophysics. 1981; 47,445 (Abstract).

12. Telford WM, Geldart LP, Sheriff RE, Keys DA. Applied Geophysics. Cambridge University Press. 1990.

13. Hahn A, Kind EG, Mashira DC. Depth estimation of magnetic sources by means of Fourier amplitude spectra. Geophysical Prospecting. 1976; 24: 287-308.

14. Bhattacharyya BK. Continuous spectrum of the total magnetic field anomaly due to a rectangular prismatic body. Geophysics. 1966; 31(1): 97–121.

15. Spector A, Grant FS. Statistical models for interpreting Aeromagnetic data. Geophysics. 1970; 35(2): 293-302.

16. Ajakaiye DE. Aeromagnetic anomalies across the Nigerian Younger Granite province. 20^{TH} anniversary Proce. Nigerian Mining & Geosci. soc., edited by Oluyide PO, Mbonu WC and Onuugu SA. 1982; 19(1): 266.

17. Keary P, Brooks M, Hill, I. An Introduction to Geophysical Exploration. Blackwell Publishing Ltd. 3^{rd} Edition. 2002.

18. Obaje NG. Geology and Mineral Resources of Nigeria. Lecture Notes in Earth sciences 120, DOI 10.1007/978-3-540-92685-6 3, Springer-Verlag Berlin Heidelberg. 2009.