

Magnetic Basement Depth Re-evaluation over the Yola Arm of the Upper Benue Trough, Nigeria from 3-D Euler Deconvolution and Spectral inversion of HRAM data.

Abstract:The High Resolution Aeromagnetic (HRAM) data have been used to re-evaluate the basement depth in parts of the Upper Benue Trough, Nigeria using 3-D Euler deconvolution and spectral inversion methods. The strong regional magnetic field was separated from the residual magnetic field with a first order polynomial using Polifit program. Several clusters of circular magnetic anomaly closures with different amplitudes which occur especially in the southeastern and central parts of the area were interpreted to be lithological variations of mafic-ultramafic inclusions within granodioritic batholiths. Lineament interpretation of the aeromagnetic data revealed several linear and structural features with dominant trends in the N-S and NE-SW directions. For the purpose of depth estimation, the residual magnetic data was subdivided into twenty four (24) overlapping spectral blocks using the Power spectrum module in Oasis Montaj 7.2HJ software program. Two prominent magnetic depth source layers (magnetic basement depth) were identified with the deeper sources ranging from 1.56km to 2.92km with a mean depth of 2.37km, while for the shallower sources, the basement depth values ranges from -1.17km to 0.98km with an average depth of 0.55km. Results of the 3-D Standard Euler deconvolution revealed the presence of several geologic bodies which includes contacts, sills/dikes, pipes/cylinders and spheres. These geobodies are located at a depth range of 500m to 2000m(2km) within the study area. The shallow depth sources are attributed to intrusive bodies resulting from basement uplift. From the economic point of view, the basement depth in the Upper Benue Trough proper and the series of tectonic events associated with the basin do not favour the accumulation and entrapment of hydrocarbons. However, mineral ores are believed to be prevalent in the study area because of the several shallow magnetic bodies that intruded into the sediments.

Keywords: Magnetic basement depth, Spectral analysis, 3-D Standard Euler deconvolution, Magnetic structural Index, Lineaments, Intrusives, Upper Benue Trough

1 INTRODUCTION

Several studies have been carried out on the sedimentology, structural geology, petroleum geology, petrology and hydrogeology of the Benue Trough. Notable among these studies include [1-6]. Nwachukwu [7] using geochemical techniques revealed that the Benue Trough have high prospects for hydrocarbon prospectivity. Mapping of magnetic basement depth beneath sedimentary cover is one of the key functions of aeromagnetic survey and its interpretations. The Benue trough is part of the long stretched arm of the Central African rift system originating from the early Cretaceous rifting of the Central/West African basement uplift [8]. The trough has been categorized into three different zones which includes the Lower Benue Trough at the southern part, the Middle Benue Trough at the center while the Upper Benue Trough is at the Northern part.

Depth to basement, faults in the basement surface, and the relief of the basement surface have direct relevance to the depositional and structural history of an area [9]. The trend of basement faults and structure is frequently the main determinant of the primary fractures that develop to accommodate basin extension. In many sedimentary basins, magnetic anomalies arise from secondary mineralization along fault planes, which are often revealed on aeromagnetic maps as surface linear features. Most mineral deposits are therefore related to some type of deformation of the lithosphere, and most theories of ore formation and concentration embody tectonic or deformational concepts [10]. Aeromagnetic data therefore can be employed in mapping of fracture and fault system of the basement rock which possibly controls the mineralization of any area. Basement structures and depth can be delineated and mapped using magnetic data. Definition of the various basin and sub-basin geometries of an area is very important for mapping the regional hydrocarbon and mineral fetch areas [9]. Systematic offset of magnetic anomalies may indicate strike-slip faults; which have displaced basement rocks and possibly affected the sediment section. A magnetic basement interpretation can, to a certain extent, lead to a better understanding of the structures of the overlying sedimentary rocks. Some mineral deposits are associated with an increase in the abundance of magnetic minerals, and occasionally the sought after commodity may itself be magnetic (e.g. iron ore deposits), but often the elucidation of the subsurface structure of the upper crust is the most valuable contribution of aeromagnetic

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data. Magnetic surveys are effective in determining geometry of sedimentary basins and in defining major masses of extrusive and intrusive igneous rocks[9]. It is possible for example to use the geometry of an intrusive mass inferred from magnetic data to infer the spatial stress patterns produced by the forceful intrusion of the mass. The relationship between intrusive masses is often apparent from regional magnetic surveys[9].

A sedimentary basin is any depression that has accumulated sediments from basement rocks. If it contains numerous magnetic rock units such as igneous intrusions or extrusive, magnetic sediments or magnetic metamorphic units, these can provide information on the morphology of the sedimentary basin and its structure. However, if the magnetic units occur at the basement surface, then the depth determinations for these will map the basin floor morphology. This approach has been used for several decades to locate sedimentary basins with significant thicknesses of sediment [9]. In general, igneous rocks have higher content of magnetic minerals especially magnetite than sedimentary rocks and can be identified and mapped in the sedimentary basin from the magnetic data. Igneous features such as intrusive plugs, dykes, sills, lava flows and volcanic centres can occur at any stage of a basin's evolution and therefore be preserved at any level in the sedimentary section. Such features are significant in understanding the history of a basin and assessing its petroleum or mineral prospective. The thermal effects of igneous intrusion can cause maturation of hydrocarbon source material without associated changes in vitrinitic reflectance[11] and thus it is important to be aware of the existence of igneous units that may cause such effects. Kimberlites and lamproites, diatreme may penetrate sedimentary section and magnetic expressions of many of these can be recognized as small sub-circular anomalies with amplitudes of the order of a few nano-teslas. Such intrusions which are normally only few hundred metres across, can often be distinguished from classical volcanic vent by their sizes and isolation however, not all such features have magnetic responses[9].

Several of the previous studies carried out in the study area were done using the old aeromagnetic data acquired by the Nigeria Geological Survey Agency (NGSA) in 1976. This study therefore aims at re-appraising the basement depth (sedimentary thickness) of the study area using spectral inversion and 3-D Euler deconvolution. This will have a serious implication on the hydrocarbon and mineral potentials of the study area.

2.0 LOCATION, PHYSIOGRAPHY AND GEOLOGY

The Benue Trough originated from Early Cretaceous rifting of the central West African basement uplift. It forms a regional structure which is exposed from the northern frame of the Niger delta and runs north-eastwards for about 1000 km to underneath Lake Chad, where it terminates. Regionally, the Benue Trough is part of an Early Cretaceous rift complex known as the West and Central African Rift System. Figure 1 is the digital elevation map of the study area showing the elevation

while figure 2 is the geology map of the study area. The Basement Complex upon which the Benue Trough is lying consists of migmatite-gneiss complex, which has been extensively intruded by the granitic and charnockitic rocks of Pan-African age[12]. The migmatite-gneiss complex is composed predominantly of migmatite and banded gneisses. Relics of meta-sedimentary and meta-volcanic rocks are widely distributed in the migmatite-gneiss complex and they form part of the succession[13]. The Biotite granite forms the inlier of the Gombe Hill and a portion of it was seen in the southern part of the study area. The basaltic plugs were also seen scattered around quite a few part of the study area while in the southern part they intruded the older sedimentary rock (Bima Sandstone Formation) of the area. The Upper Benue Trough includes an E-W trending Yola arm and a N-S trending Gongola arm or Gongola Basin. These two branches are separated by an area structurally dominated by four major NE-SW trending sinistral strike-slip faults. A series of N-S to NNE-SSW trending faults controls the trend of the Gongola Basin [15] while deep-seated E-W trending fractures appear to characterize the Yola Arm [16-18].

The study area is located within the Upper Benue Trough. The Benue Trough generally is defined as an intercontinental Cretaceous basin about 1000 km in length stretching in a NE-SW direction and resting unconformably upon the Pre-Cambrian Basement. In the Yola arm, the oldest sediments belong to the Bima sandstone and Yolde Formation which outcrop in major parts of the study area. Ezeaku Shale Group and Yola Formation are also present in the various parts of study area. The Bima Sandstone and Yolde Formation are variable sequence of sandstones and shale which mark the transition from Continental to Marine sedimentation. The Upper part of the formation (Bima sandstone and Yolde Formation) contain blue-black shales [19]. From the map of the study area (Fig. 2), it is observed that on the southern part of the area, the basement complex outcrops on the surface. The basement rocks are mainly quartz, feldspathic rocks, biotite, hornblende, gneisses, quartzites, marbles and calc-silicate rocks.

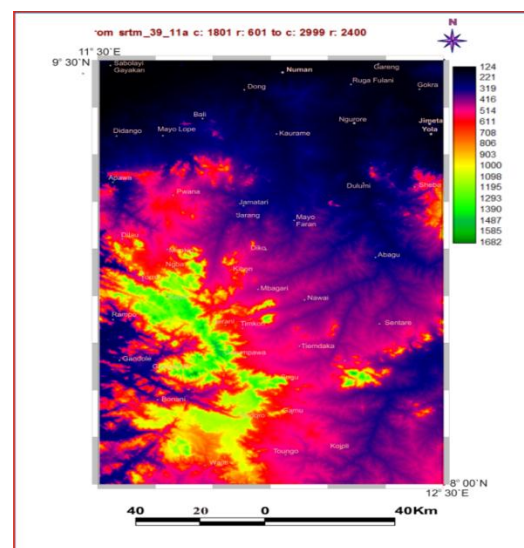


Fig. 1. Digital Elevation Model (DEM) of part of the Yola Arm

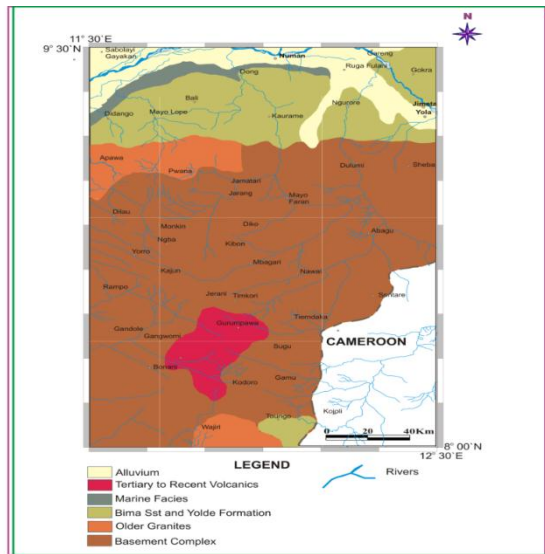


Fig. 2. Geological Map of part of the Yola Arm

3.0 MATERIALS AND METHODS

The data used for the present study are part of the High Resolution Aeromagnetic Map flown by the Nigerian Geological Survey Agency (NGSA) and completed in 2011. Flight line direction was NNW-SSE at station spacing of 2km with flight line spacing of 500m at an altitude of about 150m. However, the flight and tie line direction are 150°/330° 60°/240° respectively. Regional correction of the magnetic data was based on the IGRF (epoch date1 of January, 1974). For this study, aeromagnetic sheets of Numan (sheet 196), Dong (sheet 195), Jada (sheet 217), Kiri (sheet 237), Monkin (sheet 216) and Toungo (sheet 236), each on a scale of 1:100,000 were used. Digital filtering using non linear filters (NLF) was used to separate signals of different wavelengths and to isolate and enhance anomalous features of interest within a certain wavelength band. Digital image enhancement for the purpose of highlighting linear features or edges – faults, fractures and joints and other geological boundaries were carried out on the data. The very strong regional gradients were removed from the residual magnetic fields using the regional-residual separation technique. This was done using the Profit Software by fitting to the total field data a polynomial of degree one leading to the generation of first degree residual field intensity data.

Furthermore, the application of spectral analysis to the evaluation of the depth of aeromagnetic anomalies is now sufficiently documented and well established [20-24]. The power spectrum of potential field data computes the thickness of sedimentary basins and that of the crustal mohodepth[22]. The spectral depth method is based on the principle that a magnetic field measured at the surface can therefore be considered the integral of magnetic signatures from all depths. The power spectrum of the surface field can be used to identify average depths of source ensembles [22]. This same technique can be

used to attempt identification of the characteristic depth of the magnetic basement, on a moving data window basis, merely by selecting the steepest and therefore deepest straight-line segment of the power spectrum. A depth solution is calculated for the power spectrum derived from each grid sub-set, and is located at the centre of the window. Overlapping the windows creates a regular, comprehensive set of depth estimates[5,20,22,25-26]. Given a residual magnetic anomaly map of dimension L×L digitized at equal intervals, the residual total intensity anomaly values can be expressed in terms of double Fourier series expansion given in equation 1 below:

$$T(x, y) = \sum_{n=1}^N \sum_{m=1}^M P_m^n \cos\left\{\left(\frac{2\pi}{l}\right)(nx + my)\right\} + Q_m^n \sin\left\{\left(\frac{2\pi}{l}\right)(nx - my)\right\} \dots\dots\dots(1)$$

Where L is the dimension of the block, Pnm and Qnm are Fourier amplitudes and N, M are the number of grid points along the x and y directions respectively.

Depth results are generated for the entire dataset using different wave number ranges and window sizes. A potential field grid may be considered to represent a series of components of different wavelength and direction. The logarithm of the power of the signal at each wavelength can be plotted against wavelength, regardless of direction, to produce a power spectrum. The power spectrum is often observed to be broken up into a series of straight line segments. Each line segment represents the cumulative response of a discrete ensemble of sources at a given depth. The method allows an estimate of depth of magnetized blocks of varying depth, width, thickness and magnetization. Most approaches used involve Fourier transformation of the digitized aeromagnetic data to compute the energy (or amplitude) spectrum. This is plotted on the logarithmic scale against frequency. The plot shows the straight line segments which decrease in slope with increasing frequency. The slopes of the segments yield estimates of depths to magnetic sources.

Similarly, the objectives of the 3-D Euler deconvolution process is to produce a map showing the locations and the corresponding depth estimates of geologic sources of magnetic or gravimetric anomalies in a two-dimensional grid (Reid, 1990). The Standard 3-D Euler method is based on Euler's homogeneity equation, which relates the potential field (magnetic or gravity) and its gradient components to the location of the sources, by the degree of homogeneity (N), which can be interpreted as a structural index[27]. The method makes use of a structural index in addition to producing depth estimates. In combination, the structural index and the depth estimates have the potential to identify and calculate depth estimates for a variety of geologic structures such as faults, magnetic contacts, dykes, sills, etc. Thompson [27] showed that for any homogenous, three-dimensional function f(x, y, z) of degree n, it can be shown that, the Euler's homogeneity relation can be satisfied:

$$nf = x \partial f / \partial x + y \partial f / \partial y + z \partial f / \partial z \dots\dots\dots(2)$$

Considering potential field data, Euler's equation can be written as:

$$N(B - T) = (x - x_0) \frac{\partial T}{\partial x} + (y - y_0) \frac{\partial T}{\partial y} + (z - z_0) \frac{\partial T}{\partial z} \dots \dots \dots (3)$$

where B is the regional value of the total magnetic field and (x₀, y₀ & z₀) the position of the magnetic source, which produces the total magnetic field (T) measured at (x, y & z).Thompson[27] showed that simple magnetic and gravimetric models are consistent with Euler's homogeneity equation. Thus Euler Deconvolution provides an excellent tool for providing good depth estimations and locations of various sources in a given area, assuming that appropriate parameter selections are made.

4.0. PRESENTATION OF RESULTS, INTERPRETATION AND DISCUSSION

The total magnetic field intensity (TMI) of the study area is shown as a contour map and a 3-D surface map in figure 3&4 respectively. Several magnetic closures (mainly magnetic highs) with magnetic intensity values varying from 7900 - 8300gammas were observed in the study area. These magnetic closures which are circular in shape and mostly with strikes in the NE-SW direction formed several clusters and represented the linear and structural trends of the study area. These clusters of circular magnetic anomaly closures with different amplitudes which occur especially in the southeastern and central parts of the area are interpreted to be lithological variations of mafic/ultramafic inclusions within grano-dioritic batholiths [28]. Similarly, the strong regional magnetic fields were separated from the weaker residual magnetic fields of the study area by fitting a polynomial of low degree to the TMI data. This was done using the Polifit program. Figure 5&6 shows the first degree regional and residual magnetic fields of the study area respectively. The regional magnetic field values varies from about 7818-7868gammas and showed a NW-SE regional trend while the residual magnetic field intensity values varies from very low values of -134.6 to 137.7gammas.

For the purpose of the spectral inversion, the residual data was divided into sixteen (16) spectral blocks allowing spectral probe of 12.5km by 12.5km area for 15minute by 15minute windowing. For the purpose of easier handling of the large data involved, the four residual blocks of the study area was sub-divided into 24 spectral cells of 12.5km by 12.5km in order to accommodate longer wavelengths so that depth up to about 12km could be investigated. Each signal was then widowed 15 minutes by 15 minutes. The power spectrum module in Oasis Montaj 7.2HJ version software that employs the fast Fourier transform technique was used to transform the residual magnetic data into the radial energy spectrum for each block. The average radial power spectrum was calculated and displayed in a semi-log figure of amplitude versus frequency. Spector and Grant[22] have shown that the log-power spectrum of the source have a linear gradient whose magnitude is dependent upon the depth of the source.

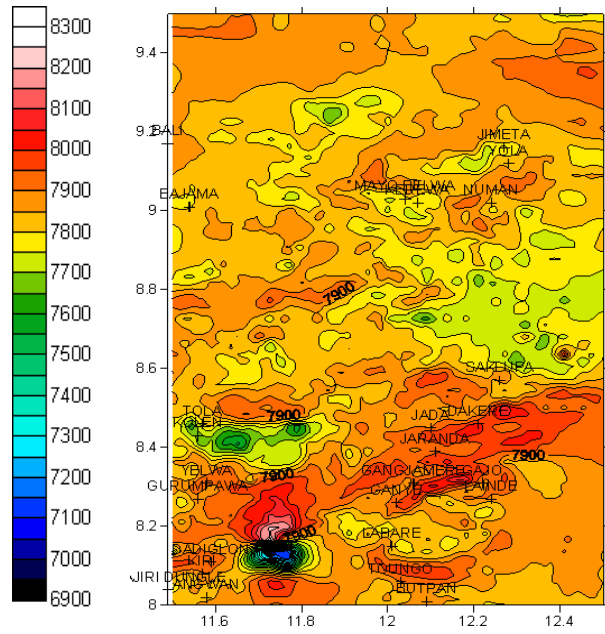


Fig. 3.Total magnetic field intensity map of the study area

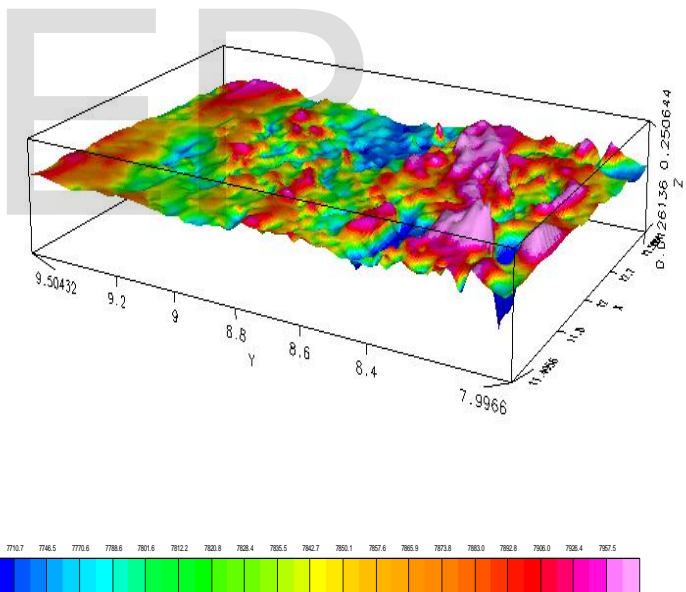


Fig. 4. 3-D map of the total magnetic intensity of the study area

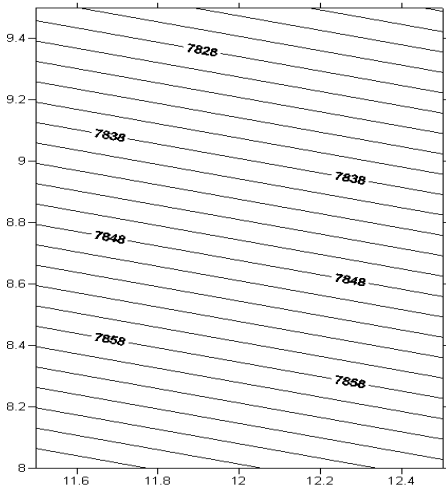


Figure 5. First degree regional magnetic field of the study area

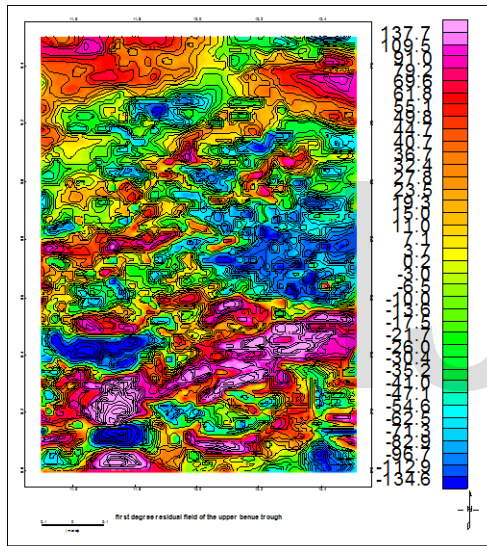


Figure 6. First degree residual magnetic field of the study area

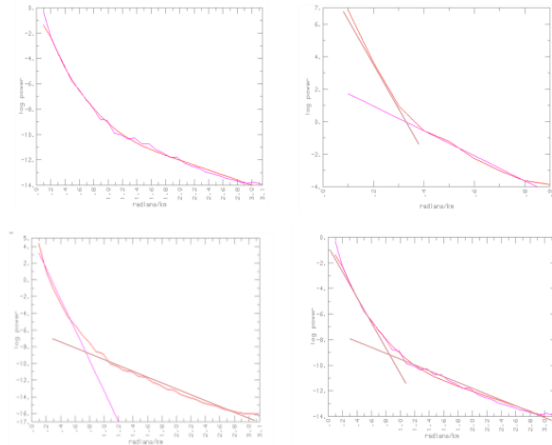


Figure 7b. Power spectrum plots of Log power (E) against Frequency (rad/sec) over Numan Sheet

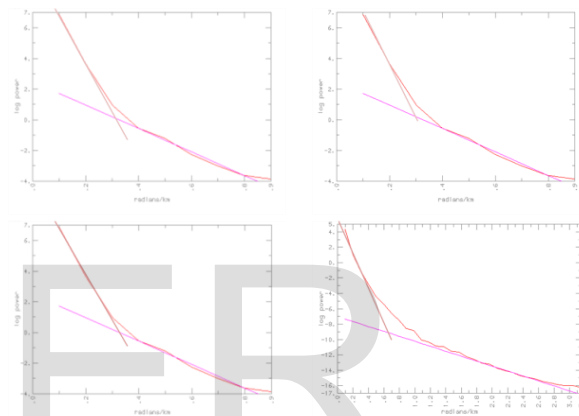


Figure 7c. Power spectrum plots of Log power (E) against Frequency (rad/sec) over Jada Sheet

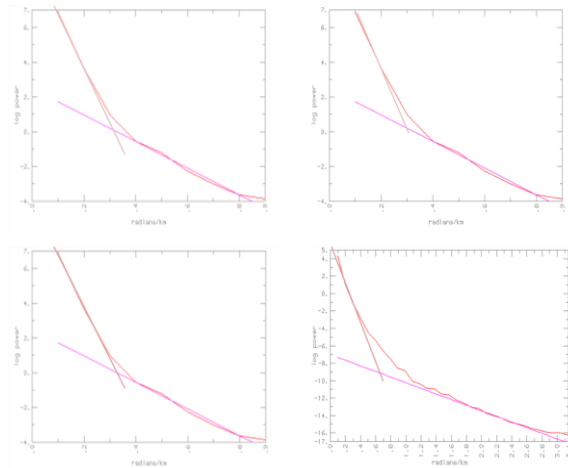


Figure 7d. Power spectrum plots of Log power (E) against Frequency (rad/sec) over Tongo Sheet

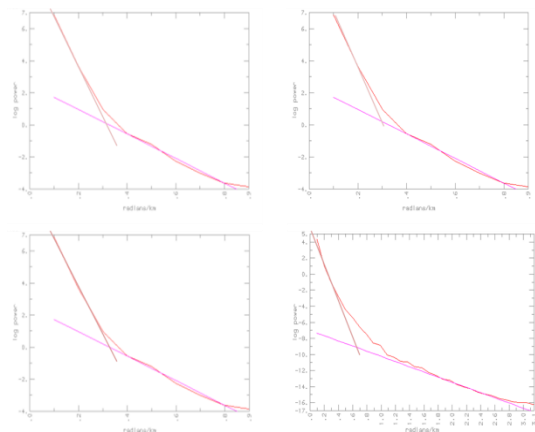


Figure 7a. Power spectrum plots of Dong Sheet and environs

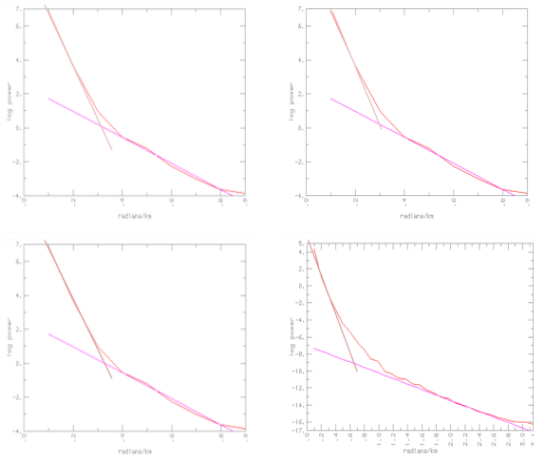


Figure 7e. Power spectrum plots of Log power (E) against Frequency (rad/sec) over Monkin Sheet

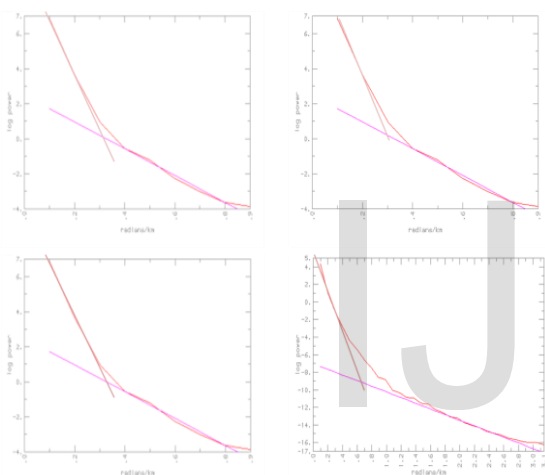


Figure 7f. Power spectrum plots of Log power (E) against Frequency (Rad/sec) over Kiri Sheet

Graphs of logarithm of the spectral energy against the frequencies for the 24 spectral cells were plotted as shown on figures 7a-7f below. For each cells two linear segments could be identified which implies that there are two magnetic source layers in the study area. Each linear segment group points are due to anomalies caused by bodies occurring within a particular depth range. The line segment in the higher frequency range is from the shallow sources and the lower harmonics are indicative of sources from deep - seated bodies. Spectral analysis of the aeromagnetic data of the study area revealed two main magnetic anomaly source depths as shown in table 1and. The deep magnetic source varies from 1.575km to 2.92km with an average depth of 2.37km and thus represents the magnetic basement surface. The basement depth contour map of the study area is shown in figure 8 below. The shallow magnetic sources which vary from -1.17km to 0.98km with an average depth of 0.55km may be regarded as the magnetic intrusions into the sediment, probably as the result of magmatic activities. Active magmatism have been reported in the

Benue Trough with [29] confirming the close association between magmatism, mineralization and fractures in the area. The estimated sedimentary thickness of the study area is therefore not sufficient for hydrocarbon accumulation. The Middle Benue trough with an estimated sediment thickness of 2-4km was considered to be the most prospective area of the Benue Trough for hydrocarbon exploration within the trough by [30]. Ofoegbu [1-3] maintained that the area possesses a fairly good petroleum system capable of hydrocarbon accumulation. One dimensional spectral estimates done in the area by Ahmed[4] using the old magnetic data revealed a magnetic basement depth range of 1.513km and 4.936km. Osazuwa et al[31] estimated the thickness of sediments in the Upper Benue Trough to vary between 0.9km and 4.6km. Similarly, results of the 2-D spectral analysis of the adjacent Lower Benue trough by [32] equally revealed an average basement depth of 3.574km.

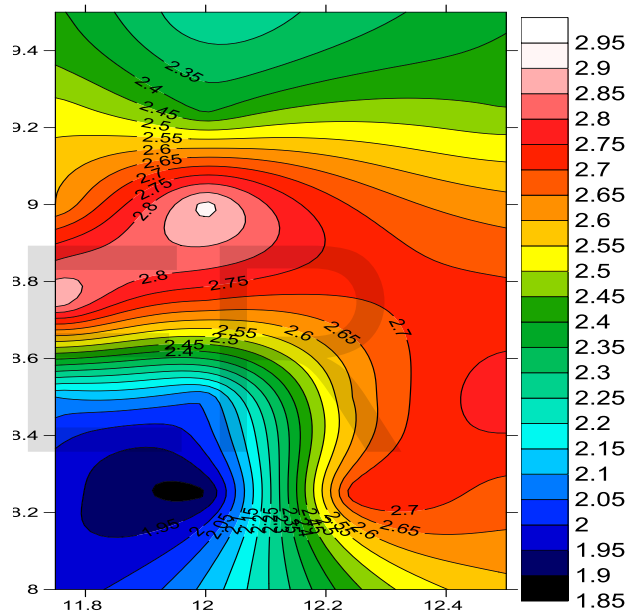


Figure 8. Basement contour map of the study area in kilometers

Figure 9 is the contour map of 3-D Standard Euler deconvolution of the study area. For a better comparison of the obtained solution, only solutions in the depth range between 0m to 2000 m were kept, which entailed an elimination of a few spurious solutions. 3-D Euler deconvolution of the aeromagnetic data of the study area using different scenarios based on structural indices (structural index 0 for contacts, structural index 1 for sills and dikes, structural index 2 for horizontal cylinders and pipes, and structural index 3 for spheres), revealed standard euler solutions. The structural interpretation of the study area is therefore very complex with variable geologic features, typically dikes, sills, contacts, and spheres. Thus structural indices of 0 to 3 were assigned to the different geological models. Thus the Standard Euler deconvolution of the study area suggests a depth range to the source of magnetization to be between 0 m to a little above 3000m. Comparing these depth estimates with the information gotten from the spectral analysis, there is a positive correlation between the results from both depth estimation methods. Similarly, the presence of

numerous lineaments in the study area and the correlation and alignment of the major intrusions into the basin with both the strike and trend of the basin is enough reason to believe that rifting and wrench faulting are possible origins of the basin. Regional extension enhances brittle deformation to the degree that the style is commonly dominated by fractures. Protracted or episodic deformation involving two or more major wrench faults can be considerably more complex leading to a variety of trends. This variety of trends probably resulted from the interaction of two factors: pre-deformational anisotropies and external rotation and reactivation of the fractures.

5.0 SUMMARY AND CONCLUSION

The results obtained from the use of the HRAM data have shown some similarities with those from the previous old data but with resolution highly improved. The study area has a mean sedimentary thickness of 2.289km. The average basement depth values estimated from spectral analysis and the abundance of intrusives shows that the area may not be viable for hydrocarbon exploration as the shallow basement depth is not conducive for hydrocarbon generation and accumulation. Some of these linear features corresponded to the strike and direction of some paleo-structures, faults, and tectonically related joints with dominant trend direction of NW-SE. The pre-

sent study is therefore in agreement with previous studies which suggested that Nigeria has a complex network of fractures and lineaments with dominant trends of NW-SE, NE-SW, N-S and E-W directions. These linear structures running NW-SE observed from the study are suggested as the continental extension of the known pre-cretaceous oceanic fracture zones which run along the trough axis beneath the sedimentary cover [33]. Finally, the correlation of these lineaments with mineralization in the area has been ascertained by previous authors[10,34-36].

In conclusion, the deep anomaly source depth averaging 2.373km deep could possibly represent the magnetic basement surface of the study area while the other depth averaging 0.554km could possibly represent the shallow source. From the estimated sediment thickness of the area and the occurrence of numerous intrusive bodies in addition to the deformational history of the sedimentary rock sequences in the study area, the possibility of hydrocarbon accumulation in the study area is very low. The possibility of other minerals such as lead, anhydrides, asphalt-impregnated sand stones, carbonaceous shales and quartz arenites, etc., in the study area is very high.

Table 1. Spectral Depth Estimates of the study area

Spectral Blocks	Longitude		Latitude		Estimated Basement Depth (km)	
	X ₁	X ₂	Y ₁	Y ₂	D ₁	D ₂
Kiri A	11.5	11.75	8	8.25	0.6	1.98
Kiri B	11.5	11.75	8.25	8.5	0.9	2.1
Kiri C	11.75	12	8	8.25	0.8	1.89
Kiri D	11.75	12	8.25	8.5	0.92	2.06
Monkin A	11.5	11.75	8.5	8.75	0.57	2.9
Monkin B	11.5	11.75	8.75	9	0.66	2.6
Monkin C	11.75	12	8.5	8.75	0.11	2.7
Monkin D	11.75	12	8.75	9	0.94	2.92
Jada A	12	12.25	8	8.25	0.67	2.75
Jada B	12	12.25	8.25	8.5	0.598	2.61
Jada C	12.25	12.5	8	8.25	-1.174	2.67
Jada D	12.25	12.5	8.25	8.5	0.88	2.78
Dong A	11.5	11.75	9	9.25	0.35	2.52
Dong B	11.5	11.75	9.25	9.5	0.2	2.41
Dong C	11.75	12	9	9.25	0.98	2.38
Dong D	11.75	12	9.25	9.5	0.67	2.255
Toungo A	12.25	12.5	8	8.25	0.54	2.06
Toungo B	12.25	12.5	8.25	8.5	0.98	2.05
Toungo C	11.5	11.75	8	8.25	0.62	1.98
Toungo D	11.5	11.75	8.25	8.5	0.28	1.575
Numan A	12.25	12.5	9.0	9.25	0.2	2.45
Numan B	12.25	12.5	9.25	9.5	0.9	2.39
Numan C	11.5	11.75	9.0	9.25	0.2	2.58
Numan D	11.5	11.75	9.25	9.5	0.9	2.34
Average Depth					0.5539	2.3729

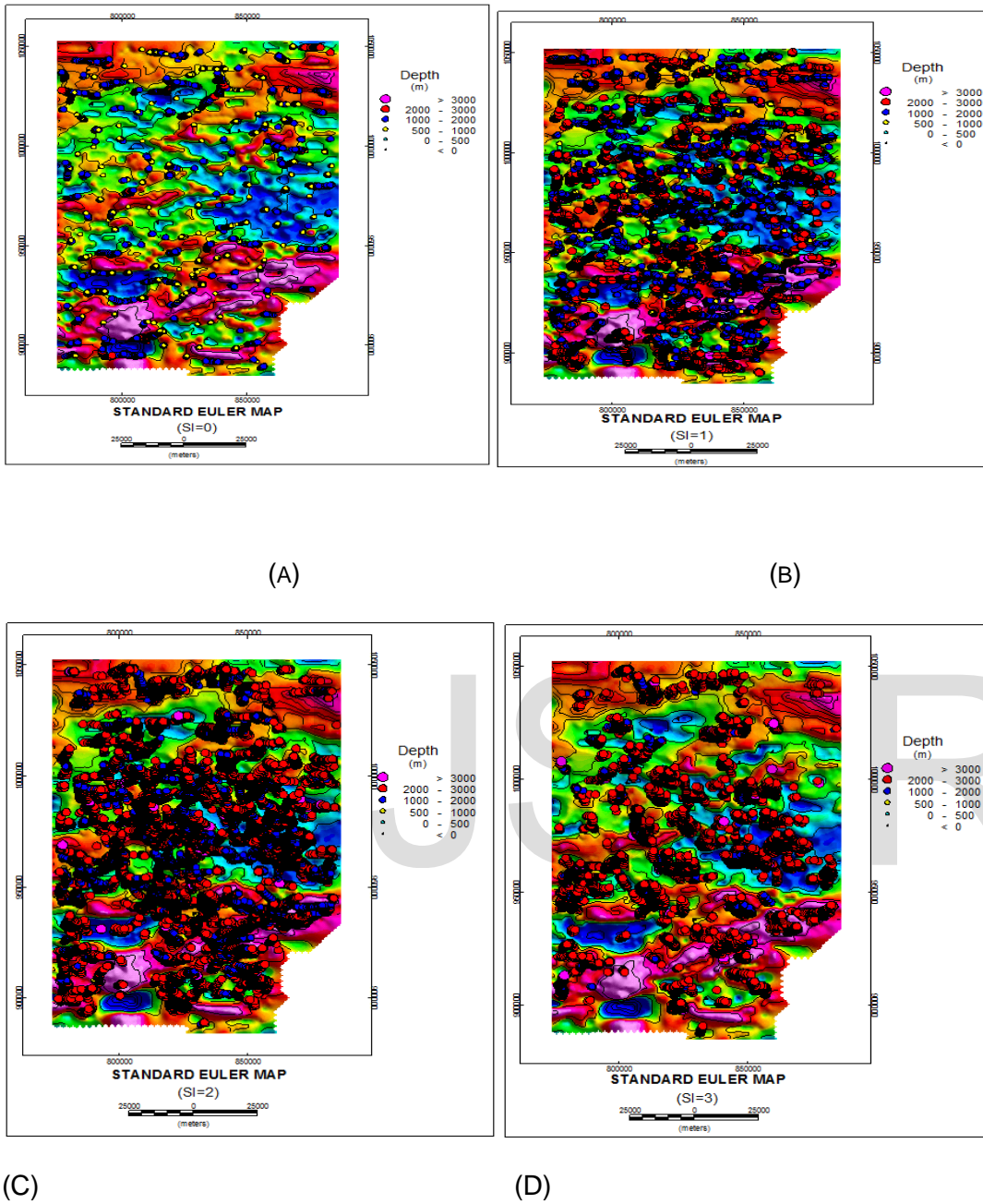


Fig. 9. Standard Euler Deconvolution Depth Solution Contour map of the stuy area showing various geologic models at various structural indices(SI) :(a) Structural index one (SI = 1) (b) Structural index two (SI = 2) (c) Structural index Three (SI = 3) (d) Structural index four (SI= 4)

6.0 REFERENCES

- [1] C.O.Ofoegbu.,1984a. Aeromagnetic anomalies over the lower and middle Benue Trough Nigeria; Nigeria Journal of mining and geology Vol.21,pp. 103-108.
- [2] C.O.Ofoegbu., 1984b.A model for the tectonic evolution of the Benue Trough of Nigeria. GeologischeRundschau, 73, 1007-1018.
- [3] C.O.Ofoegbu., 1985a. A review of the geology of the Benue Trough of the Nigeria;Journal of African Sciences, Vol.3, pp.285-291.
- [4] N.M. Ahmed., 1991. Spectral Analysis of Aeromagnetic Data Over the Middle Benue Trough, Nigeria; research publication; M.Sc. thesis University of Nigeria Nsukka,95pp
- [5] C.O.Ofoegbu and K. M. Onuoha.,1991.Analysis of magnetic data over the Abakaliki Anticlinorium of the Lower Benue Trough, Nigeria. Marine and Petr.Geolo, Vol. 8, pp. 174-183.
- [6] A.G.Onwuemesi., 1996.One-Dimensional Spectral Analysis of Aeromagnetic Anomalies and Curie Depth Isotherm In The Anambra Basin Of Nigeria; J. Geodynamics Vol. 23, No. 2, pp. 95-107.
- [7]Nwachukwu JI (1985). Petroleum prospects of Benue Trough, Nigeria. Am AssocPetrGeol B 69: 601-609.
- [8]O.A .Samuel, Olusola, J.O, and Olabisi, A.A., 2011. Stratigraphic Evolution and Petroleum Potential of Middle Cretaceous Sediments intheLower and Middle Benue Trough, Nigeria: Insights from New Source Rock Facies Evaluation. Petrol. Technol. Devel. J. 1.
- [9] P.J. Gunn., 1997. Application of Aeromagnetic Survey to Sedimentary Basin Studies. AGSO Journal of Australian Geology and Geophysics Vol. 17, No. 2, pp.133-144.
- [10] S.E.Ananaba and D.E.Ajakaiye.,1987. Evidence of tectonic control of mineralization of Nigeria from lineament density analysis: A Landsat study; Int. Jour. Rem. Sensing; vol.1, No.10, pp. 1445-1453.
- [11] S.A.Reeckmann and Mebberson, A.J. 1984. Igneous intrusions in the North-West Canning Basin and their impact on oil exploration. In: The Canning Basin, WA, Purcell, P.G., editor, GSA/PESA Canning Basin Symposium, Perth: 389-399.
- [12] N.G.Obaje., 2009. Geology and Mineral Resources of Nigeria. Springer-Verlag Berlin Heidelberg, pp. 219.
- [13] Ajibade, A.C., Woakes, M., and Rahaman, M.A. 1989. Proterozoic crustal development in the Pan-African regime of Nigeria. In: Geology of Nigeria (2nd revised edition), Edited by Kogbe, C.A. Rock view Nigeria Ltd, Jos, Nigeria. 57-69
- [14] J.Benkheilil., 1988. Structure. Centres Rech., Explor. Prod. Elf and Geodynamic Evolution of the Intracontinental Benue Basin (Nigeria) Bull Aquitaine in 1207, 29-128.
- [15] P.M. Zaborski.,1998. A review of the Cretaceous system in Nigeria. African Geoscience review vol.5, No. 4, pp 385-400. Printed in France.
- [16] J.C. Maurin, and R. Guiraud, 1989. Relations entre tectonique et sédimentation dans les bassins barrémo-aptiens du Nord Cameroun. C.R. Acad. Sci. Paris, 308: 787-792.
- [17] J.C. Maurin, and R. Guiraud, 1990. Relationships between tectonics and sedimentation in the Barrémo-Aptian intracontinental basins of Northern Cameroon. J. Afr. Earth Sci., 10: 331-340. DOI: 10.1016/0899-5362(90)90064-L
- [18] Braide SP (1992a) Geologic development, origin and energy mineral resource potential of the Lokoja Formation in the Southern Bida Basin. J Mining Geol., Vol. 28; pp.33-44
- [19] Carter, J.D, Harber W, and Tait, F.A., 1963. The geology of parts of Adamawa, Bauchi and Borno provinces in northeastern Nigeria. Bull Geol Surv Nigeria 30: 1-108.
- [20] Bhattacharyya, B.K.1966. Continuous Spectrum of the total magnetic field anomaly due to rectangular prismatic body, Geophysics, Vol.31, pp.97 - 121.
- [21] Bhattacharyya, B.K, Leu L. K., 1975. Spectral analysis of gravity and magnetic anomalies due to two-dimensional structures. Geophysics 40: 993-1013.
- [22] Spector, A. and F.S. Grant.,1970. Statistical models for interpreting aeromagnetic Data; Geophysics; vol.25; pp. 293-302.
- [23] Mishra, D.C. and Naidu, P.S; 1974. Two-dimensional Power spectral analysis of aeromagnetic fields, Geophysics Prop, 22, 345-534
- [24] Hahn, A., Kind, E. G. and Mishra, D. C., (1976): Depth estimation of Magnetic sources by means of Fourier amplitude spectra, Geophysical. Prospecting, 24, 287-308.
- [25] Bath, M., (1974). Spectral Analysis in Geophysics, Elsevier Scientific Publishing company Amsterdam
- [26] Oppenheim, A.V., and Schafer, R.W., 1975. Digital Signal Processing .Prentice Hall International, Inc., N.J.
- [27] Thompson, D. T., 1982. EULDPH: A new technique for making computer-assisted depth estimates from magnetic data, Geophysics, 47, 31-37.
- [28] Gazala, H.H., 1993. Geological and structural interpretation of airborne surveys and its Significance for mineralization, South Eastern Desert Egypt. Journal of African Earth Sciences, 16(3), 273-285.
- [29] Ofoegbu, C. O. and Odigi, M.I., 1989. Basement structures and ore mineralization in the Benue Trough, In the Benue Trough: Structure and Evolution (ed. Ofoegbu, C.O) Earth Evol, Sci, 239-248.
- [30] Ofoegbu, C.O., 1985b. Long Wavelength anomalies and the crustal structure underneath the Benue Trough and surrounding regions, Nig, J, Ming, Geol. 22, 45 - 50
- [31] Osazuwa, I.B, Ajakaiye, D.E, and Verheijen, P.J.T., 1981. Analysis of the structure of part of the Upper Benue Rift Valley on the basis of new geophysical data. Earth Evolution Sciences 2: 126-133.
- [32] Onyewuchi, R.A., Opara, A.I., Ahirakwem, C.A., & Okoh, F.U. (2012). Geological Interpretations Inferred From Airborne Magnetic and Landsat Data: Case Study of Nkalagu Area, Southeastern Nigeria. Int. Journ. of Sci. and Tech., 2 (4), 178-19.
- [33] Ananaba, S. E., (1991). Dam sites and Crustal Mega-lineaments in Nigeria. ITC Journal Vol. 1, pp. 26-29.
- [34] Chukwu-Ike, I.M and J.W. Norman. 1997. Mineralized Crustal Fractures shown on Satellite Imagery of Nigeria, Inst. of Min. and Meta-transactions. 86:55-67.
- [35] Onyedim, G. C., Awoyemi, M. O., Ariyibi, E. A. and Arubayi, J. B., (2006). Aeromagnetic imaging of the basement morphology in part of the Middle Benue Trough, Nigeria, Journal of Mining And Geology, vol.42 (2), pp.157-163.
- [36] Udoh, A. N., (1988). Remote sensing imageries of Nigeria, north of 70401: In: Oluyide, P.O., et. al., (eds). Precambrian Geology. Geological Survey of Nigeria, Publ., pp.99- 102.

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