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Depth Estimates Deduced From Source Parameter Imaging of High Resolution Aeromagnetic Data over Part of Nasarawa and Environs, North-Central Nigeria

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***Abstract*— Source Parameter Imaging (SPI) of high resolution aeromagnetic data over Nasarawa and environs was carried out to determine depth to the magnetic basement for hydrocarbon deposit. The technique is a profile or grid-based method for estimating magnetic source depths, source geometries, dip and susceptibility contrast. It is a procedure for automatic calculation of source depths from gridded magnetic data where the depth solutions are saved in a database. These depth results are independent of the magnetic inclination and declination.The result of the analysis has its highest sedimentary thickness of about 5.297 km and 4.752 km around Akwanaand Adadu areas.The shallow sedimentary thickness occur at basement complex around Kogum River, Pankshin andNasarawaEggonareas at northern fringes.Detailed seismic survey and testdrilling be carried out around Akwana and Adadu areas, withsedimentary thickness of about 5.0 km.**

***Index Terms*— Aeromagnetic data, Polynomial fitting, and Source Parameter Imaging.**

I. Introduction

Recent interest in the inland basins in Nigeria for petroleum and mineral deposits necessitated the need to study one of the prominent basins which has received little attention from researchers, for some time now exploration work have been going on in the inland basins of Nigeria with the aim to expanding the national exploration and production base and thereby add to the proven reserves asset, even though it has been frustrated because of the poor knowledge of their geology. In view of increased efforts to explore for new reserve, the high resolution aeromagnetic data was used to evaluate the subsurface structure in the study area for possible hydrocarbon accumulation, it is believed that this will contribute to a better understanding of the geology of the area.

II. Location of the Study Area

The study area is located between longitudes 8^0 00`E and $10^0$ 00`E and latitudes 7^0 30`N and $9^0$ 30`N in north central Nigeria (Fig. 1). The area is part of the Middle Benue Trough that is noted for hosting economic minerals, it covers an approximate area of 48,400 km^2, and covers farmlands, villages, towns, game reserves, natural reserves etc. The area lies northeast of the federal capital Abuja.Topographically, the study area is hilly at the northern fringes and drained mainly by river Benue and its tributaries in the southern part, it is characterized by moderate relief with high granitic hills generally extending several kilometers, having the NE – SW direction and forms several peaks of relatively higher elevation than the surrounding rocks.The prominent peaks are Pankshin (1610ft), Wase (1479ft), Kagoro hills (694ft) and Eggon hills (775ft).(Geological Survey of Nigeria,(GSN)) bulletin No.5 and19.The area is in general undulating. Despite the hilly nature of some part of the study area, there are still good road networks, foot-paths and tracks in the area. Major roads found in this area provide access road to the southeastern part of Nigeria and some other communities in the study area such as Akwanga, Nasarawa-Eggon, Lafia, Keana, Awe, Doma, Shendam, Pankshin to mention few. There are other minor roads that provide access to smaller settlements, farms, rivers and streams.

The area is marked by two distinct climatic conditions, temperatures in this area range from 20°C - 27°C, while at night, temperatures could be as low as 10°C, Months of March to June experienced increasing temperatures as the rainy season set in, sometimes daily temperature could be above 35°C. The rainy season lasts usually from May/June to September/October depending on the rainfall pattern for the particular year, with mean annual rainfall of 1560mm. The dry season is usually heralded annually by the dry, cold Harmattan winds and occurs between November and March. After the departure of the Harmattan and in the absence of rain, the hot sunny season with temperatures exceeding 27 ^oC sets in (Balogun, 2003). The mean annual temperature of the area is 20^oC.

This paper utilizes the Source Parameter Imagingto determine the depth to magnetic sources in the study area, the Source Parameter Imaging is a useful technique because it give automatic calculation of source depths from gridded magnetic data.

III. Geology of the study area

The study area is located within the Basement complex of North-central Nigeria and the Cretaceous sediment of the Middle Benue Trough. It consists of various rock units which have been reported to occur in this area (figure.2). It is underlain by Precambrian basement rocks, remobilised by the pan African episode (600-500,ma) and uplifted relative to the surrounding areas (Nnange*et al* 2001).These include the

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Precambrian basement complex rocks, mainly granulitic gneisses, migmatite, older granite, younger granite, porphyries and rhyolites which outcrop in the northern portion of the study area.

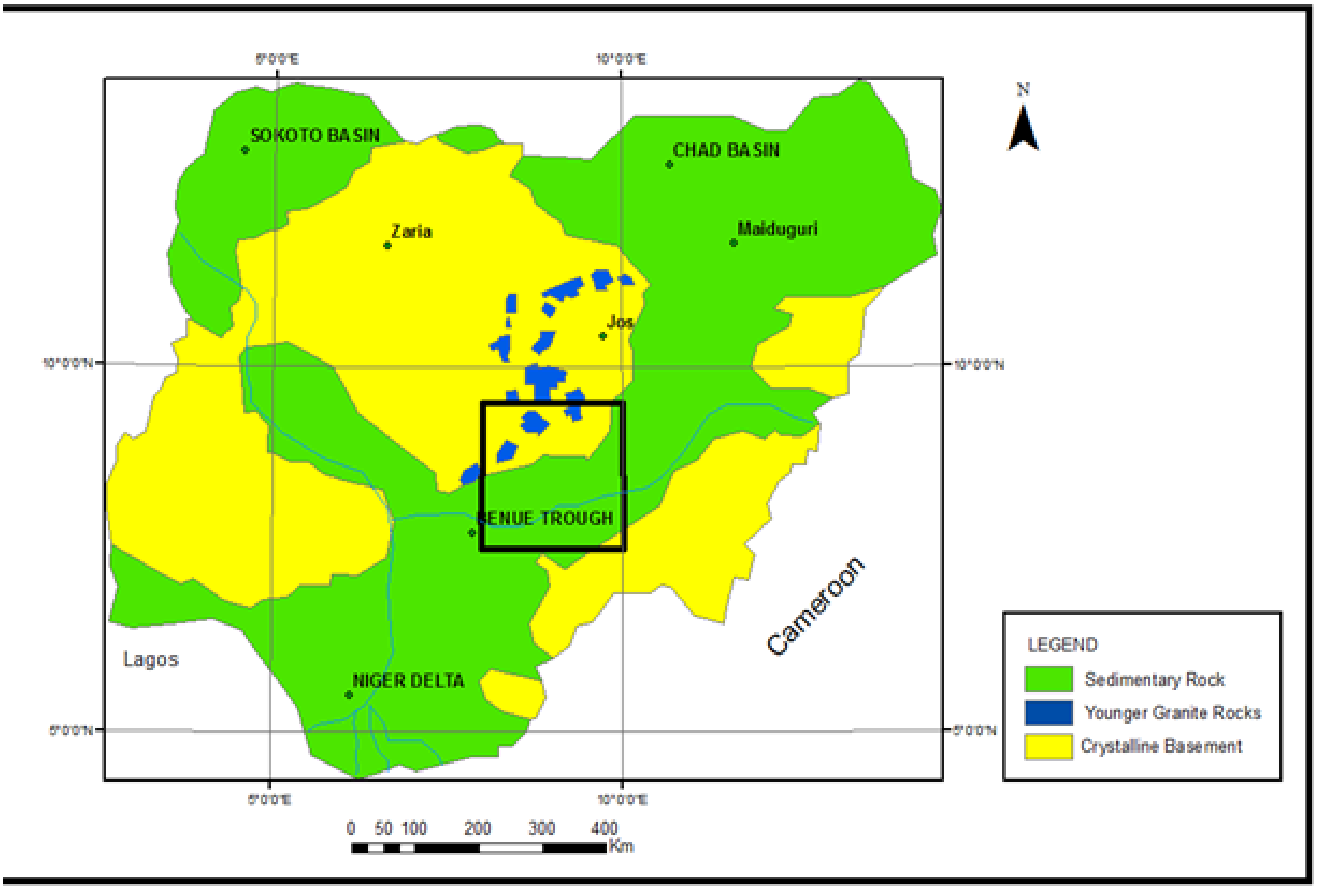

Figure 1. Map of Nigeria Showing the Study Area

The cretaceous rock units include;

(a) Asu River Group, which consist of mixture of lava-flows, dykes and sills representing the first middle Albian episode into the Benue Trough. This group, which is believed to be about 3000m thick, lies unconformably on an older basement complex. Rock units belonging to the Asu River Group outcrop along axis of the Keana (Offodile, 1976).

(b) Awe Formation, which consists of flaggy, whitish, medium to coarse – grained sandstones interbedded with carbonaceous shales or clays from which brine springs issue continuously (Ford, 1981; Offodile, 1980). The Awe Formation marks the beginning of the regressive phase of the Albian Sea.

(c) Keana Formation consists of continentialfluviatlile sand and shale.

(d) Ezeaku formation comprises essentially of calcareous shale, micaceous fine to medium – grained friable sandstones,with occasional beds of limestone.

(e) ConicianAgwu formation consists mainly of black shale, sandstones and local coal seams.

(f) Lafia Formation is the youngest formation reported in the Middle Benue Trough and consists of coarse-grain ferruginous sandstones, red loose sand, flaggy mudstones and clays (Offodile, 1976).

The Tertiary- Recent volcanic rocks which consist of the Basalts, Trachyte, Rhyolite, and newer basalts of Sura volcanic line also occur in the area.

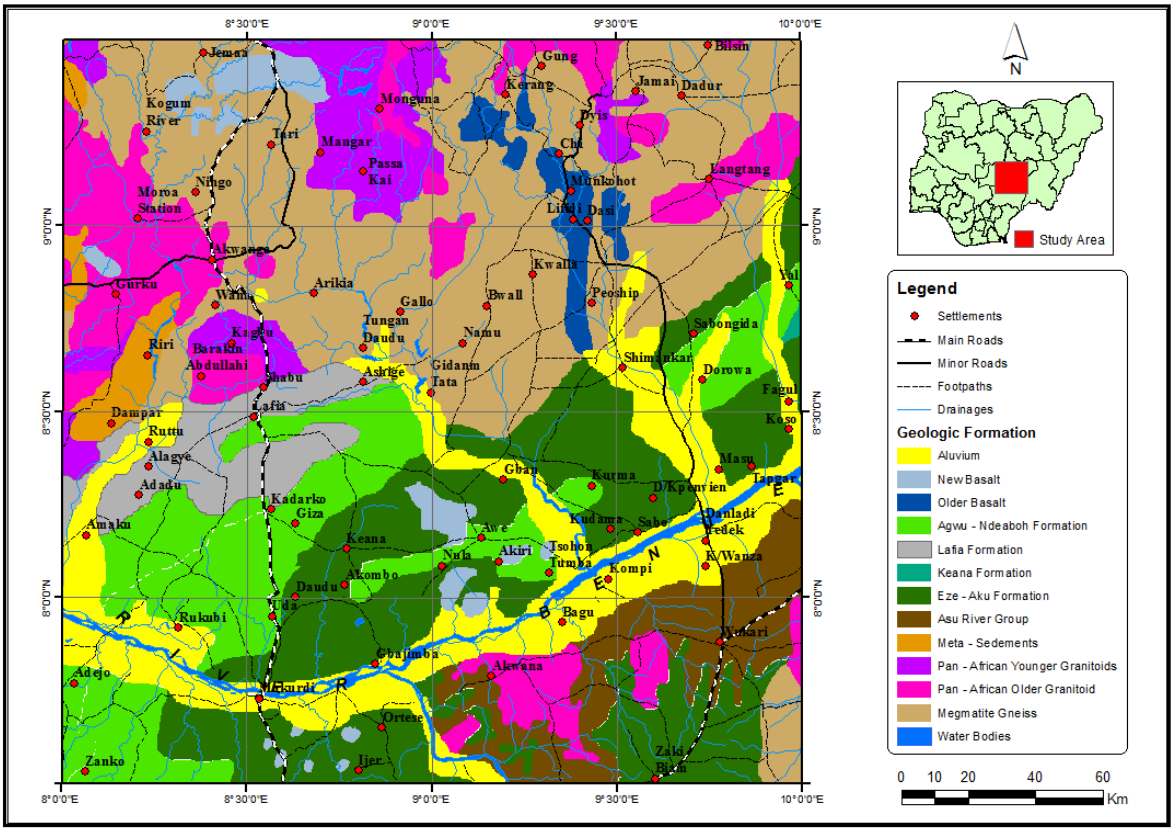

Figure 2.Geological map of the study area (Adapted from the Geologic Map of 2006).

IV. Material and Methods

The new high resolution aeromagnetic data (HRAM) used for this present work was obtained from the Nigerian Geological survey agency Abuja, which had acquire digital data for the entire country between 2005 and 2009, The airborne survey was carried out for the Nigerian Geological Survey Agency by Fugro airways services, the surveys was flown at 500m line spacing and at an average flight elevation of 80 m along NW – SE direction, and published in form of grid (digital form) on 30` by 30` sheets. The IGRF has been removed from the data. This work covers sheets 188, 189, 190, 191, 209, 210, 211, 212, 230, 231, 233, 250, 251, 252, 253 and 254, sixteen sheets were assembled for this work with each square block representing a map in the scale of 1:100,000. Each square block is about 55 x 55 km^2 covering an area of 3,025km^2 hence the total area studied is about 48,400km^2, the digital data was acquired as merged unified block from which the sixteen sheets are windowed after a polygon had been created by means of a computer program Oasis montage version 7.5.

The total intensity magnetic map of the study area (Fig. 3) shows anomalies of high and low magnetic intensity values with dominant NE – SW and E-W trends, and steep gradients which are distributed throughout the area. The anomalies in the magnetic field of the earth may be considered to arise from three principal sources (Bird, 1997). These are lithologic variation, basement structures and sedimentary sources. The magnetic intensity values range from 32,936 nT to 33,129 nT and the mean 33033nT. The maximum intensity value of 33,129 nT is observed in the Northeastern region while the minimum value of 32,936 nT is recorded at the Southwestern part the study area. Thus the magnetic relief of 351 nT in the area is attributed to differences in magnetic mineral content between various lithologies and to variation in the depth to the magnetized rocks. Bird, (1997) viewed anomalies with amplitudes in the order of 100 nT to be related to variations in basement lithologies. Magnetic data observed in geophysical surveys are the sum of magnetic fields produced by all underground sources, the grid map also shows the local magnetic anomalies super imposed on the regional field,

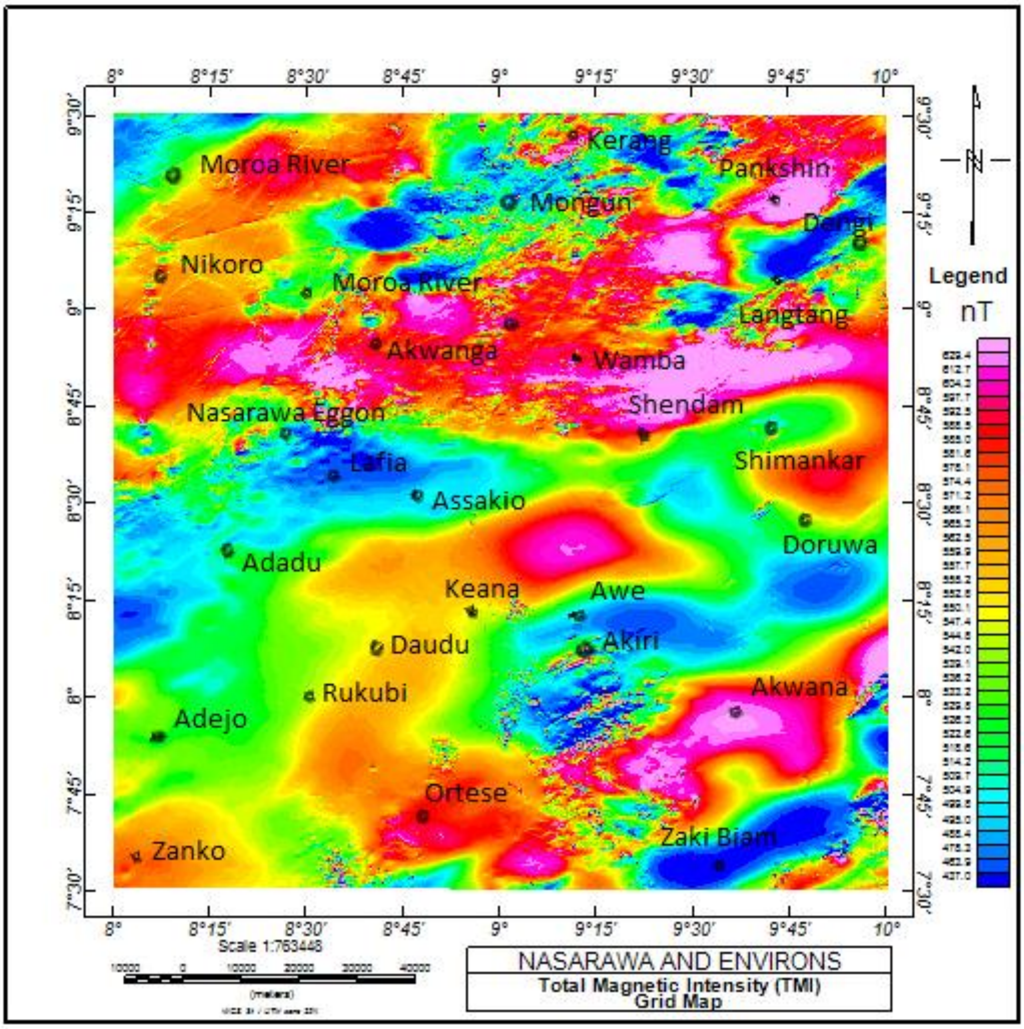

Figure 3.Total Magnetic Intensity Grid Map of the Study Area (To obtain the actual total magnetic field value, add 32,500 nT to the values shown in the key).

To remove the regional magnetic field, which is the anomalies associated with low frequency components, a plane surface was fitted to the digital data by polynomial fitting least square analysis using Oasis Montage version 7.5. In this method, the matching of regional by a polynomial surface of low order exposed the residual features as a random error, the treatment is based on statistical theory. The observed data are used to compute, usually by least squares, the mathematically describable surface giving the closest fit to the magnetic field that can be obtained within a specified degree of detail (Skeels, 1967; Johnson, 1969 and Dobrin, 1988). This surface is considered to be the regional and the residual is the difference between the magnetic field value as actually mapped and the regional field value, thus determined (Udensi, 2000).

The residual map shows striking similarity with the total magnetic intensity map,though few features are missing, suggesting that the residual map is overwhelmingly sourced from the basement. The map shows colour ranges like the total magnetic intensity anomaly grid map, with red as high and blue as low and steep gradients which are distributed throughout the area, the maximum intensity value of 70nT is observed in the northeastern region while the minimum value of -92nT is recorded at the southeasternpart the study area. The general trending fabric of the residual magnetic intensity anomalies is the NE-SW direction.The long wavelength anomalies which are certainly due to deep seated basement, dominate the central and southern part of the study area, while the short wavelength anomalies dominate the northern fringes.

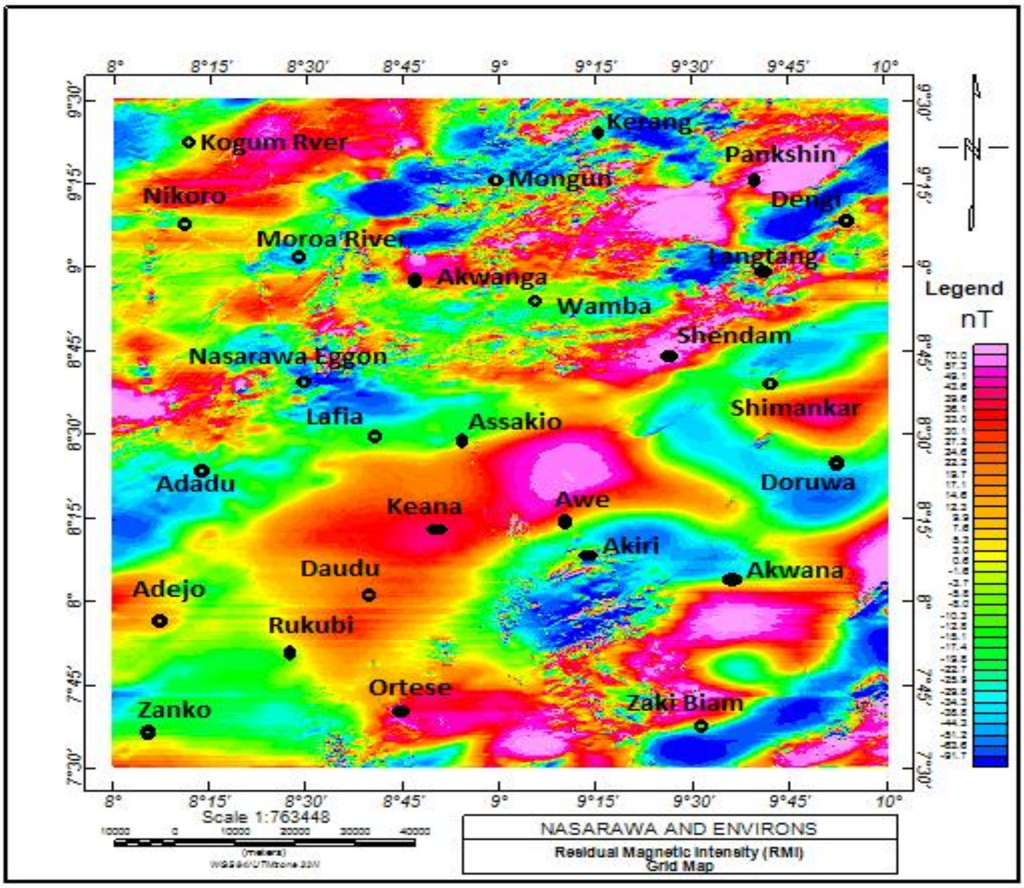

Figure 4.Residual Magnetic Intensity Grid Map of the Study Area.

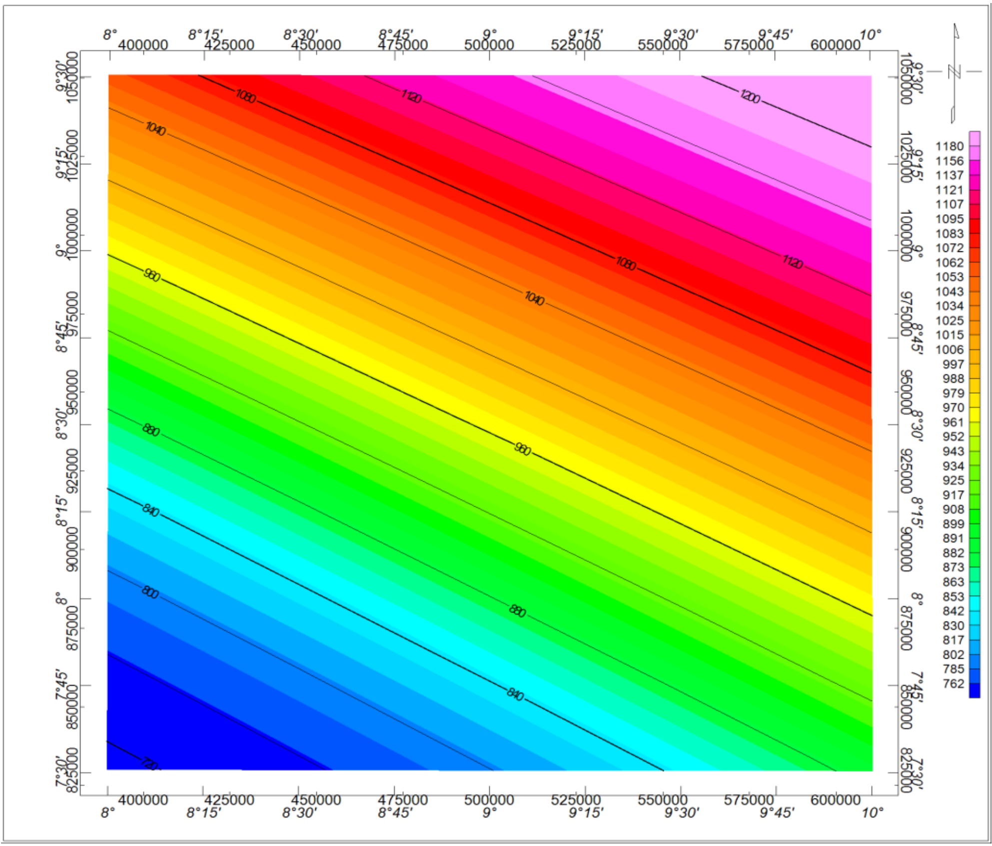

Figure 5.Regional magnetic grid map of the study area. (To obtain the actual total magnetic field value, add 32,500 nT to the values shown in the key)

The regional magnetic field values range from 32528 nT to 33487 nT and occur in the NW-SE direction,the values increase from southwest to the northeast, the maximum intensity value is observed in the northeastern region while the minimum value is recorded at the southwestern region, the long wavelength anomalies with spatial scales of several kilometers are certainly due to deep seated basement. The term regional represent anomalies arising from larger and deeper features, the targets for specific surveys are often small scale structures buried at shallow depths and the magnetic responses of these targets are embedded in a regional field that arise from magnetic sources that are usually larger and deeper than the targets or located farther away.

V. SOURCE PARAMETER IMAGING(SPI)

The use of Source Parameter Imaging or SPI technique in the determination of depth to magnetic sources is known, the method has been used extensively by Blakely and Simpson, (1986),Thurston and Smith, (1997) and Salako and Udensi (2014). It is a profile or grid-based method for estimating magnetic source depths, and for some source geometries the dip and susceptibility contrast. The method utilises the relationship between source depth and the local wavenumber (*k*) of the observed field, which can be calculated for any point within a grid of data via horizontal and vertical gradients. At peaks in the local wavenumber grid, the source depth is equal to n/*k*, where n depends on the assumed source geometry (analogous to the structural index in Euler deconvolution). Peaks in the wavenumber grid are identified using a peak tracking algorithm and valid depth estimates isolated (Blakely and Simpson, 1986). The advantages of the SPI method over Euler deconvolution or spectral depths are that no moving data window is involved and the computation time is relatively short. On the other hand, errors due to noise can be reduced by careful filtering of the data before depths are calculated. (- for example n=1 for a contact, n=2 for a dyke.)

According to Thurston and Smith, 1997 SPI™ is a procedure for automatic calculation of source depths from gridded magnetic data where the depth solutions are saved in a database. These depth results are independent of the magnetic inclination and declination, so it is not necessary to use a pole-reduced input grid. The Source Parameter Imaging (SPI™) function is a quick, easy, and powerful method for calculating the depth of magnetic sources. Its accuracy has been shown to be +/- 20% in tests on real data sets with drill hole control. This accuracy is similar to that of Euler deconvolution, however SPI has the advantage of producing a more complete set of coherent solution points and it is easier to use.A stated goal of the SPI method according to Thurston and Smith, (1997) is that the resulting images can be easily interpreted by someone who is an expert in the local geology. The SPI method estimates the depth from the local wave number of the analytical signal. The analytical signal A1(x, z) is defined by Nabighian (1972) as:

$$A_1(x,z) = \frac{\partial M(x,z)}{\partial x} - j\frac{\partial M(x,z)}{\partial z} \quad \ldots\ldots(1)$$

Where M(x,z) is the magnitude of the anomalous total magnetic field, j is the imaginary number, z and x are Cartesian coordinates for the vertical direction and the horizontal direction respectively. From the work of Nabighian (1972), he shows that the horizontal and vertical derivatives comprising the real and imaginary parts of the 2D analytical signal are related as follows:

$$\frac{\partial M(x,z)}{\partial x} \leftrightarrow -\frac{\partial M(x,z)}{\partial z} \quad \ldots\ldots(2)$$

Where ↔ denotes a Hilbert transformation pair. The local wave number K_1 is defined by Thurston and Smith (1997) to be

$$K_1 = \frac{\partial}{\partial x}\tan^{-1}$$

The concept of an analytic signal comprising second-order derivatives of the total field, if used in a manner similar to that used by Hsu *et al.* (1996), the Hilbert transform and the vertical-derivatives operators are linear, so the vertical derivative of (2) will give the Hilbert transform pair,

$$\frac{a^2M(x,z)}{\partial z\partial x} \Leftrightarrow -\frac{a^2M(x,z)}{\partial^2 z} \quad \ldots\ldots(4)$$

Thus the analytic signal could be defined based on second-order derivatives, A_2 (x,z), where

$$A_2(x,z) = \frac{a^2M(x,z)}{\partial z\partial x} - j\frac{a^2M(x,z)}{\partial^2 z} \quad \ldots\ldots(5)$$

This gives rise to a second-order local wave number k_2, where

The first and second-order local wave numbers are used to determine the most appropriate model and a depth estimate independent of any assumption about a model.

Nabighian (1972) gives the expression for the vertical and horizontal gradient of a sloping contact model as:

$$\frac{\partial M}{\partial x} = 2KFc \sin d \frac{h_c\cos(21-d-90)+x\sin(21-d-90)}{h_c^2+x^2} \quad \ldots\ldots(7)$$

$$\frac{\partial M}{\partial z} = 2KFc \sin d \frac{x\cos(21-d-90)+h_c\sin(21-d-90)}{h_c^2+x^2} \quad \ldots\ldots(8)$$

Where K is the susceptibility contrast at the contact, F is the magnitude of the earth's magnetic field (the inducing field), c = 1 – $\cos^2 i\sin^2\alpha$, α is the angle between the positive x-axis and magnetic north, *i* is the ambient-field inclination, tan1 = sini/cosα, d is the dip (measured from the positive x-axis), h_c is the depth to the top of the contact and all trigonometric arguments are in degrees. The coordinate system has been defined such that the origin of the profile line (x=0) is directly over the edge.

The expression for the magnetic field anomaly due to a dipping thin sheet is

$$M(x,z) = 2KF_{cw}\frac{h_1 \sin(21-d) - x\cos(21-d)}{h_c^2+x^2} \quad \ldots\ldots(9)$$

Reford (1964), where w is the thickness and h_1 the depth to the top of the thin sheet. The expression for the magnetic-field anomaly due to a long horizontal cylinder is

$$M(x,z) = 2KFS\,\frac{\sin i}{\sin I}\,\frac{(h_h^2 - x^2)\cos(21-180) + 2xh_h \sin(21-180)}{h_c^2+x^2} \quad \ldots\ldots(10)$$

Murthy and Mishra, S is the cross-sectional area and h_h is the depth to the centre of the horizontal cylinder.
Substituting (7), (8), (9) and (10) into the expression for the first-and second-order (i.e. (3) and (6) respectively) local wave numbers, we obtain, after some simplification, a remarkable result as:

$$K_1 = \frac{(n_k+1)h_k}{h_k^2+x^2} \quad \ldots\ldots(11)$$

and

$$K_2 = \frac{(n_k+1)h_k}{h_k^2+x^2} \quad \ldots\ldots(12)$$

Where n_k is the SPI structural index (subscript k = x, t or h), and $n_c = 0$, $n_t = 1$ and $n_h = 2$ for the contact, thin sheet and horizontal cylinder models, respectively. From (11) and (12) above, it is evident that the first- and second-order local wave numbers are independent of the susceptibility contrast, the dip of the source and the inclination, declination, and the strength of the earth's magnetic field.

The contact, thin sheet and horizontal cylinder are all two-dimensional models (infinite strike extent), so it is an implicit assumption of the SPI method that the geology is two dimensional. If the body is two-dimensional and there is no interference from nearby bodies, the depth estimate will be reasonable and the structural index should be constant over the entire area for which the response is anomalous.

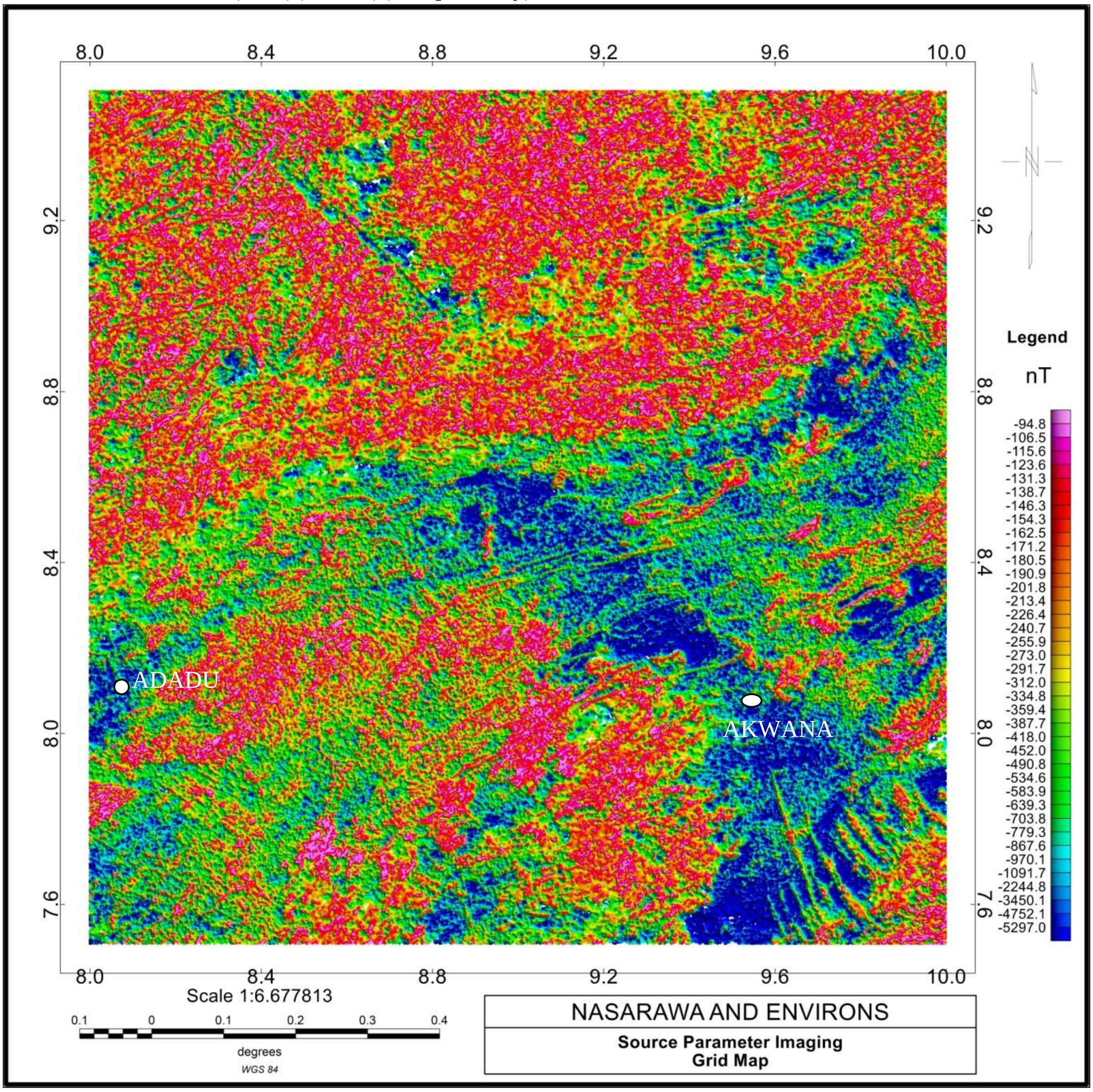

Figure 6. Source Parameter Image Grid Map of the Study Area

The source parameter imaging is a complex technique that require two or three operationsthrough several mathematical processing from various grids. To performed this transform the magnetic residual data was used as input data into the Oasis montaj software version 7.5 anddx, dy and dz were processed. Furthermore, the output grids from dx, dy and dz were later used as input grids into the SPI processing tool in the menu bar of the Oasis montaj software and it produces the source parameter imaging grid map. It is necessary to mention that first order derivative was adhered to, as the (SPI) method is sensitive to noise at higher derivative order. Therefore, the data was carefully filtered to ensure good estimate of the local wave number, hence the depthwere performed on the acquired digitized aeromagnetic data leading to the quantitative determination of depth to magnetic sources.

VI. Discussion of the Result

Aeromagnetic anomalies over Nasarawa area consist of slow to fast varying types, the former occupy a broader part of the area and is coincident with the sedimentary cover, while the latter is a concentrated sequence almost restricted to the northern zone of the area and coincident with the suit of Mesozoic alkaline and pre-alkaline granites and volcanic which include rocks such as rhyolites, granites, subordinate syenites, gabbro, dolerites and basalt that have been emplaced along pre-existing basement lineaments, including ring fractures.

The Source Parameter Imaging interpretation method was applied to the magnetic residual anomaly with the goal of deducing depth to magnetic sources in the study area, the method included regional residual separation and analytical signal. This technique is useful for quick determination of sediment thickness to shed more light to the geology of the area. Much insight into the sediment thickness depth of the area come to bear as comparisons to terrain provide information about magnetic sources at depth that can be compared directly to geologic map.

The result of the Source Parameter Imaging emphasize the effect of near surface anomaly sources and also calculated the depth to magnetic basement, Smith *et al.* (1998). The SPI grid map overNasarawa and environscan be divided into main three sections, areas of shallow, medium and deeper depths, though minor depressions also exist in some areas. The northern part of the study area is characterized by high magnetic intensity values represented by red colour. Whereas the southern part is dominated by low magnetic intensity values represented by dark-green-blue colour. The two sections are separated by a zone characterized by medium magnetic intensity values area depicted by yellow-orange colour. The white portion of SPI grid map are the areas where the structural index cannot be reliably estimated, due to small local wave number. The model independent local wave number had been set to zero in that portion.

These high magnetic intensity values, which dominate the northern part of areaare probably caused by near surface igneous rocks of high magnetic susceptibilities. The low magnetic intensity at the southern partcould be due tosediment thicknessand other non-magnetic sources. It can be observed from Figure 5that, the depth to the basement ranges between 0.094 km and 5.297 km. The highest sediment thicknessoccur at the south-central and the south-eastern parts. However, relatively higher depth scattered around eastern and southwestern parts. The sedimentary thickness of the study area in general, appears to increases from south to north. This collaborates well with earlier findings of the spectral analysis of the area by Nur (1994).

Results of depth estimate obtained from SPI method agreed largely with other published works in the study area. The numeric values are also in agreement, but the areas delineated as highest depth differs from both method. The shallowest region however agrees both in location and values. According to Nwosu*et al*. (2013) that thickness of over 5km was obtained around Makurdi area, Nwachukwu, (1985) using geochemical technique considered the Middle Benue Trough to have high prospects for hydrocarbon within the Trough, Nur, *et al* (1994) obtained 1.6km to 5km for deeper source around middle Benue, while 60m to 1.2km was obtained for shallow magnetic source; Other workers whom this present work had largely corroborated include: Likkasson, *et al* (2005), (Ofoegbu (1984a) and Ofoegbu 1986.

VII. Conclusion and Recommendations

Source Parameter Imaging (SPI) over parts of Nasarawa and environs was carried out to determine the sedimentary thickness for hydrocarbon potential. The result show that highest sedimentary thickness of about 5.297 km and 4.11km was obtained around Akwana and Adaduareas. Shallow sedimentary thickness could be found around basement complex and volcanic areas at the northern fringes, the results agreed with the results obtained from spectral depth determination of the area. Hydrocarbon potential is enhanced by the thickness of the sediments of a basin, and by the type of geological structures existing within the subsurface, which include source rock, reservoir rock, paleotemperature and traps. The deeper sections of the sedimentary basin identified in this study could be the potential sites for hydrocarbon deposits and is therefore recommended for further investigation.

Exploration of the Nigerian inland basins is worth given a push due to youth restiveness in the Niger Delta region. Hydrocarbons if discovered and harnessed will increase the country's reserve and boost productivity. All these will have economic and strategic benefits for the country.

VIII. Acknowlegements

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References

[1] Balogun, O. Y., 2003. Senior Secondary Atlas.2nd Ed.Longman Nigeria.

[2] Bird, D. E. (1997): Primer: Interpreting Magnetic data. America Association of Petroleum Geologist Explorer. 18(5), pp 18-21.

[3] Blakely, R.J., and Simpson, R.W., (1986). Approximating edges of source bodies from magnetic or gravity anomalies: Geophysics, v. 51, p. 1,494-1,498.

[4] Dobrin, M., and Savit, C. (1988).*Introduction To Geophysical Prospecting* (Fourth Edition ed.). Singapore: McGraw-Hill.

[5] Ford, S.O. (1981): The Economic Mineral Resources of the Benue Trough. Earth Evolution Sciences Vol. 1, No. 2, pp154-163.

[6] Geological Survey Nigeria Bulletin 5 and 19.

[7] Hsu, N. C., Herman, J. R., Bhartia, P. K., Seftor, C. J., Torres, O., Thompson, A. M., Gleason, J. F., Eck, T. F., &Holben, B. N. (1996). Detection of biomass burning smoke from TOMS measurements.*Geophys. Res. Lett.*, *23*, 745- 748.

[8] Johnson, W. W. (1969). A least - Squares method of interpreting magnetic anomalies caused by Two- Dimensional structures. Geophysics, Vol.34, pp65 -74.

[9] Jones, H.A.(1965): The Geology of Benue Trough. Annual Report Geological Survey Nigeria 1965: 32-37.

[10] Likkasson, O.K., Ajayi, C.O. and Shemang, E.M. (2005): Some Structural Features of the Middle Benue Trough, Nigeria, Modeled from Aeromagnetic Anomaly Data. Science Forum: Journal of Pure and Applied Science 8: 100-125

[11] Nabighan, M.N. (1972). The analystic signal of two dimensional magnetic bodies with polygonal cross – section; its properties and use or automatic interpretation.*Geophysics.*37:507 – 517.

[12] Nnange, J. M, Poudjom D.Y.H, Fairhead, J.D, Ebinger, C (2001).Determination of the Isostatic Compensation mechanism of theregion of Adamawa dome west central Africa Using the AdmittanceTechnique of Gravity data. Afri.J. Sci. Technol. Science andEngineering series. 1(4): 29-35.

[13] Nigerian geological Survey Agency. (2006). Geological Map of Nigeria, scale: 1:2, 000, 000.

[14] Nigerian Geological Survey Agency Abuja. 2009. High Resolution Airborne Geophysical Series-Magnometer Survey Grid Map of Total Intensity (16 sheets). Scale 1: 100,000.

[15] Nur, M.A., Onuoha, K.M. and Ofeogbu, C.O. (1994).Spectral analysis of aeromagnetic data over the middle Benue trough, Nigeria.*Jour. Min. Geol.* 30(2):211 – 217.

[16] Nwachukwu, J.I. (1985) Petroleum Prospects of Benue Trough, Nigeria, *Am Assoc. Pet. Geol., Bull.,* 69 (4), 601-609Mishra, D. C. and Naidu, P.S; 1974. Two-dimentional Power spectral analysis of aeromagnetic fields, Geophysics Prop, 22, 345 – 534.

[17] Nwosu O.B, Umego M.N, Onuba L.N., (2013). Spectral Re-Evaluation Of The Magnetic Basement Depth Over Parts Of Middle Benue Trough Nigeria Using HRAM International Journal Of Scientific and Technology Research Volume 2, Issue 10, Issn 2277-8616.

[18] Offodile. M. E. (1976). The Geology of the Middle Benue, Nigeria.Palaentological Institute, University Uppsala, Special Publication, **,** 4:pp 1-166.

[19] Offodile M.E. (1980). A mineral survey of the Cretaceous of the Benue Valley, Nigeria. CretaceousRes 1:101–124.

[20] Ofoegbu, C.O. 1984a Aeromagnetic anomalies over the lower and middle Benue Trough Nigeria; Nigeria Journal of mining and geology Vol.21,pp. 103- 108,

[21] Ofoegbu, C. O.(1986). A preliminary result of a pseudogravity study of the Benue Trough, Nigeria.J. Afr. Earth Sci; 5: 187- 192.

[22] Ofeogbu, C.O. (1988). An aeromagnetc study of part of the study of the Upper Benue Trough, Nigeria. Jour. Afr. Earth Sci. Vol.7, pp. 77-90

[23] Reford, M. S. (1964). Magnetic anomalies over thin sheets. *Geophysics, 29,* 532 - 536.

[24] Salako, K. A., (2014). Depth to Basement determination using Source Parameter Imaging (SPI) of Aeromagnetic Data: An application to upper Benue Trough and Borno Basin, Northeast, Nigeria. Academic Research International (AR Int.) 5(3): 74-80.

[25] Smith, R.S., Thurston, J.B., Dai, Ting-fan, and MacLeod, L.N. (1998). The Improved Source Parameter Imaging Method: Geophysical Prospecting, Vol. 46, pp. 141-151.

[26] Skeels, D.C. (1967): What is Residual Gravity? Geophysics, 32: 872 -876.

[27] Thurston, JB and Smith, R.S. (1997). Automatic Conversion of Magnetic Data to Depth, Dip, and Susceptibility Contrast using the SPI Method: Geophysics Vol. 62, No. 33, pp807 – 813

[28] Udensi E.E. (2000): Interpretation of Total Magnetic Field Over the Nupe Basin in West Central Nigeria Using Aeromagnetic Data Ph.D thesis A.B.U. Zaria Nigeria.