Determination Of Magnetic Basement Depth Over Parts Of Middle Benue Trough By Source Parameter Imaging (SPI) Technique Using HRAM

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Abstract: The new high resolution aeromagnetic data of parts of the middle Benue trough Nigeria have been analysed to appraise its hydrocarbon accumulation potential using Source Parameter Imaging (SPITM) technique. The regional-residual separation was done with a first order polynomial using POLIFIT program and this lead to the residual field data that corresponds to the target sources for further processing. The preliminary qualitative interpretation revealed that the area is made up of low frequency anomaly and high frequency anomaly sources, related to deep and shallow seated bodies which are possibly areas of deeper and shallower sediments. The general trend in the orientation of the magnetic contour closures are found to be predominantly in the NE-SW direction, an attribute of the Pan – African Orogeny trends. Quantitative analysis of the study area using SPI revealed two main magnetic anomaly sources depth represented by the long spikes (deep blue coloured) and the short spikes (light green and orange colored). The long blue spikes are areas of deeper lying magnetic bodies hence with thicker sedimentary cover and ranges from 2000m to 6291.5m with an average depth of 3245m and could be viewed as the magnetic basement depth of the studied area. The short spikes are areas of shallow seated magnetic bodies hence are areas of thinner sediment ranging from 159.067m to 2000m with an average depth 1079.5m. They may be regarded as magmatic intrusions into the sedimentary basins and these may be responsible for the Lead-Zinc mineralization found in the area. Several undulations found on the basement surface may likely act as trap. The significance of these results indicate that the marine sedimentary layer of the Albian Age, Coniacian – Turonian Age, and Turonian – Senonian Age have the potential to generate hydrocarbon if other conditions are met.

Keywords: Source parameter imaging (SPI), high resolution aeromagnetic data (HRAM), Middle Benue Trough, magnetic basement depth, Magnetic anomaly.

1.0 Introduction:

Several automatic source depth determination techniques like the spectral analysis, the Werner deconvolution, Euler deconvolution the SPI can all be employed to quantitatively map the magnetic basement depth beneath sedimentary cover. This is one of the key functions of aeromagnetic survey and interpretation. However, this study determined the magnetic basement depth beneath the study area through source parameter imaging (SPI) technique in order to appraise its hydrocarbon potential. 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. The Source Parameter Imaging (SPI^{TM}) method computes source parameters from gridded magnetic data (Thurston and Smith, 1997). Amongst the notable researchers who have worked in this area but with the old data of 1970s employing techniques other than SPI includes. Nwachukwu (1985), Ofoegbu (1984, 1985, 1986); Ahmed (1991); Osazuwa et al(1981) etc. This work wants to re-evaluate this area determining the sedimentary thicknesses in the study area, depths to different magnetic source layers within the study area, and basement topography displaying the spatial variation in sedimentary thickness within the study using the 2009 HRAM data and SPI technique. Image processing of the source-parameter grids enhances details and provides maps that facilitate interpretation by even non-specialists. The method assumes either a 2-D sloping contact or a 2-D dipping thin-sheet model and is based on the complex analytic signal.

2.0 The study area:

The study area is in the middle Benue trough Nigeria. The middle Benue trough (the hatched area) links the upper and lower arms of the Benue trough sedimentary basin in Nigeria. It is part of a long stretch arm of the Central African rift system and one of about seven inland sedimentary basins in Nigeria (fig1a) originating from the early Cretaceous rifling of the central West African basement uplift

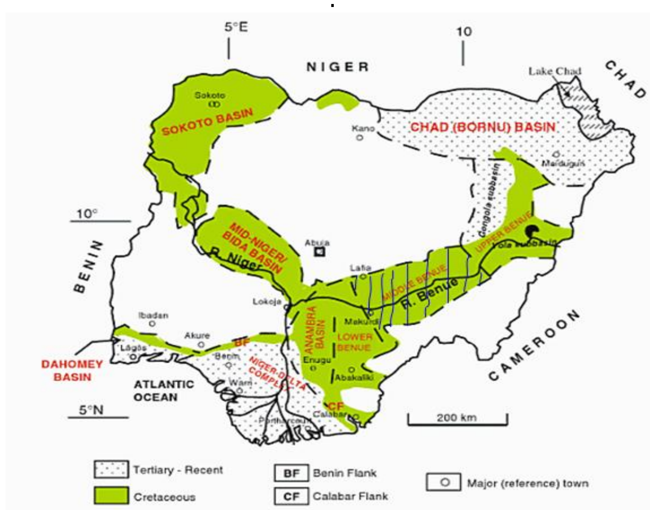

Fig.1a Map of Nigerian Basins showing the position of the study area (the hatched portion) (Obaja,2004).

The Benue trough is a unique rift feature on the African continent. It occupies an intracontinental position and has a thick compressionally folded Cretacious suprscrustal fill, and divisible into upper, middle and lower Benue (Samuel et.al, 2011). The area is characterized by the presence of thick sedimentary cover of varied composition whose age ranges from Albian to Maastrichtian (Obaje,2004). The geologic map of the study area is shown on fig1b.

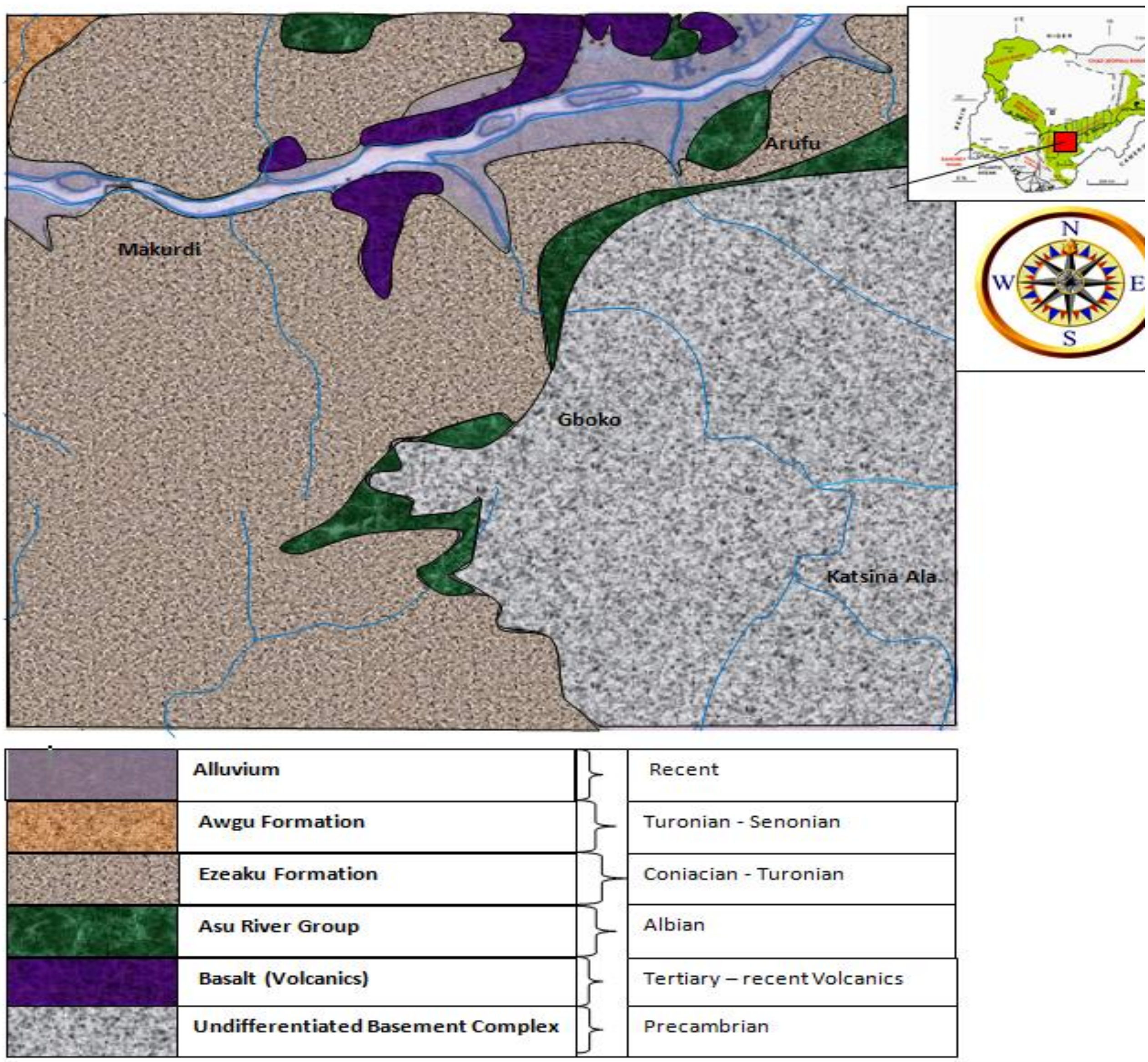

Fig.1b Geological map of part of the Middle Benue Trough (Modified from NGSA, 2003)

The Cretaceous sedimentary succession in the middle Benue trough (beginning from the oldest to the youngest) consists of the Asu River Group, the Awe, Keana, Eze-Aku, Awgu and Lafia Formations. The marine Asu-River group of Abian age commenced the sedimentation in the The Cretaceous sedimentary succession in the middle Benue trough above the basement (beginning from the oldest to the youngest) consists of the Asu River Group, the Awe, Keana, Eze-Aku, Awgu and Lafia Formations (fig1c). The marine Asu-River group of Abian age commenced the sedimentation in the middle Benue trough. (Obaje et al, 2004).

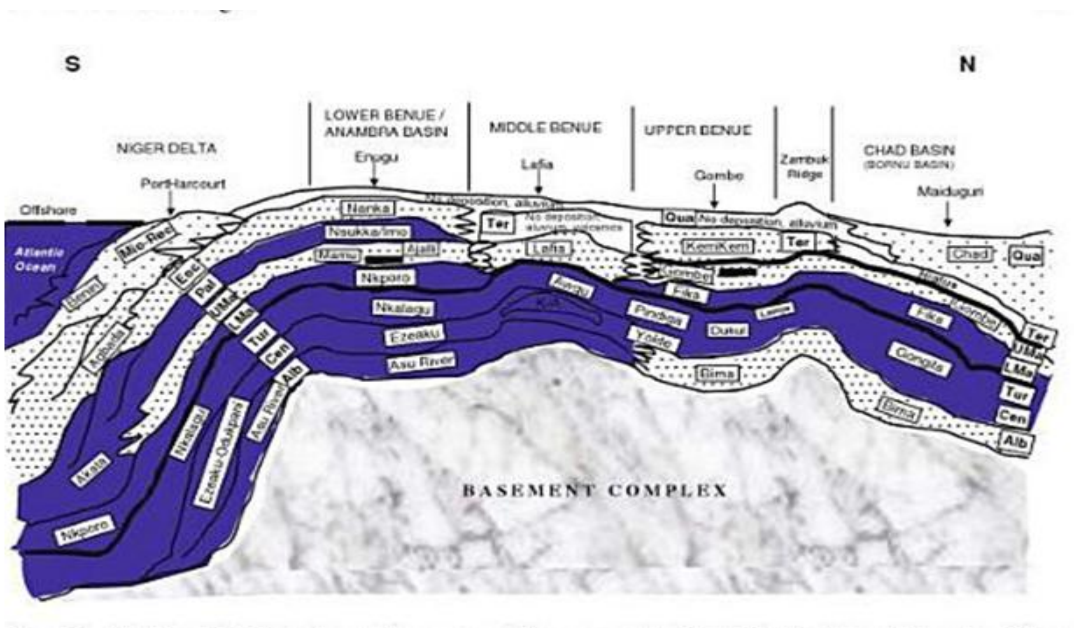

Fig1c Stratigraphic succession in the Benue trough (Obaje, 2004)

Extensive report on the geology of Benue trough have been reported widely in the works of Cratchley and Jones, (1965); Burke et al,(1970); Offodile, (1976); Ofoegbu (1985); Grant, (1971) and Olade, (1975).

3.0 Data source/ compilation.

Aeromagnetic surveys in Nigeria flown in the 1970s at a flight line spacing of 2km, average terrain clearance of 150m, and a nominal tie line spacing of 20km have played a key role in understanding the country's regional geology, but due to their low resolution have become of limited use. New dataset from Nigerian Geological Survey Agency was used for this work, it's from the new high-resolution airborne survey coverage in Nigeria carried out by Fugro airborne survey at 826,000 line-km of magnetic and radiometric surveys flown at 500 m line spacing and 80m terrain clearance in 2009. It's of higher quality than the 1970s and in digitized form as well (fig2a).

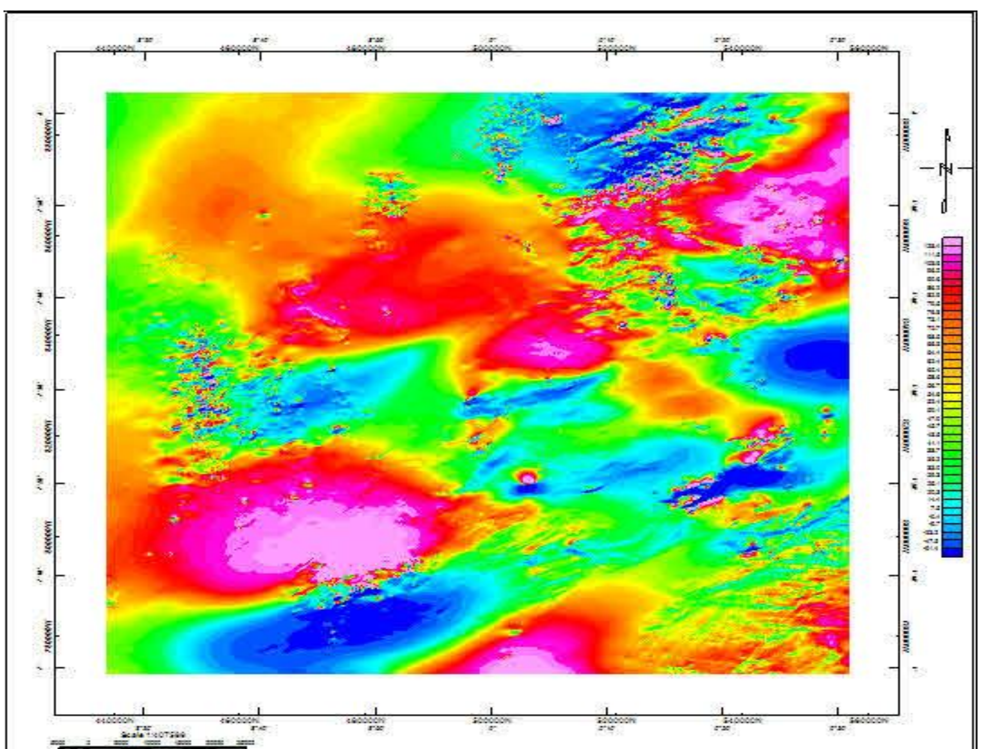

Fig. 2: Magnetic anommaly map of Makurdi-Gboko Axis of the Middle Benue Trough Nigeria

It consists of four square blocks of map sheet (251,252, 271,272) (fig2b). Each square block represents a map on the scale of 1:100,000 and is (55x55) km^2 covering an area of 3,025km^2, hence the study area is 12,100km^2

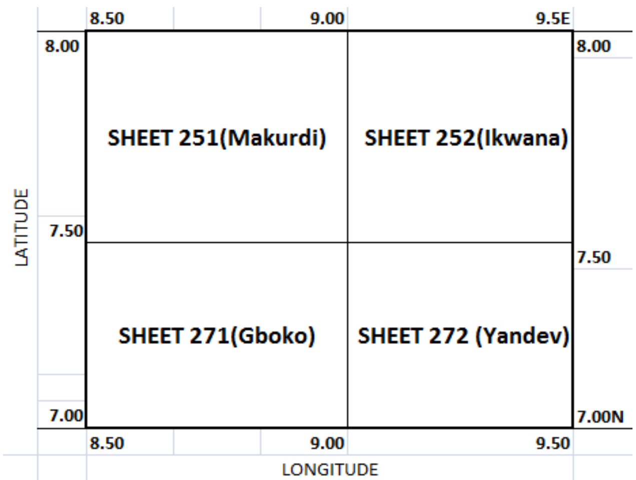

Fig2b the map sheet number for the study area and their geographical coordinates.

4.0 Preliminary analysis: Qualitative interpretation

The brief preliminary analysis done on the acquired data are qualitative, they include production of composite anomaly map, the regional-residual separation and their interpretation. They provided the first hand information about the study area before quantitative interpretation with SPI.

4.1 Production of the composite aeromagnetic contour map

The unified composite dataset of the study area was imported into a new worksheet in surfer32 software environment and saved. This dataset was then gridded in the Surfer environment using the Kriging method and the composite contour map of the study area in Fig 3 was produced giving us the first view and the idea of the basement topography in the study area before regional-residual separation.

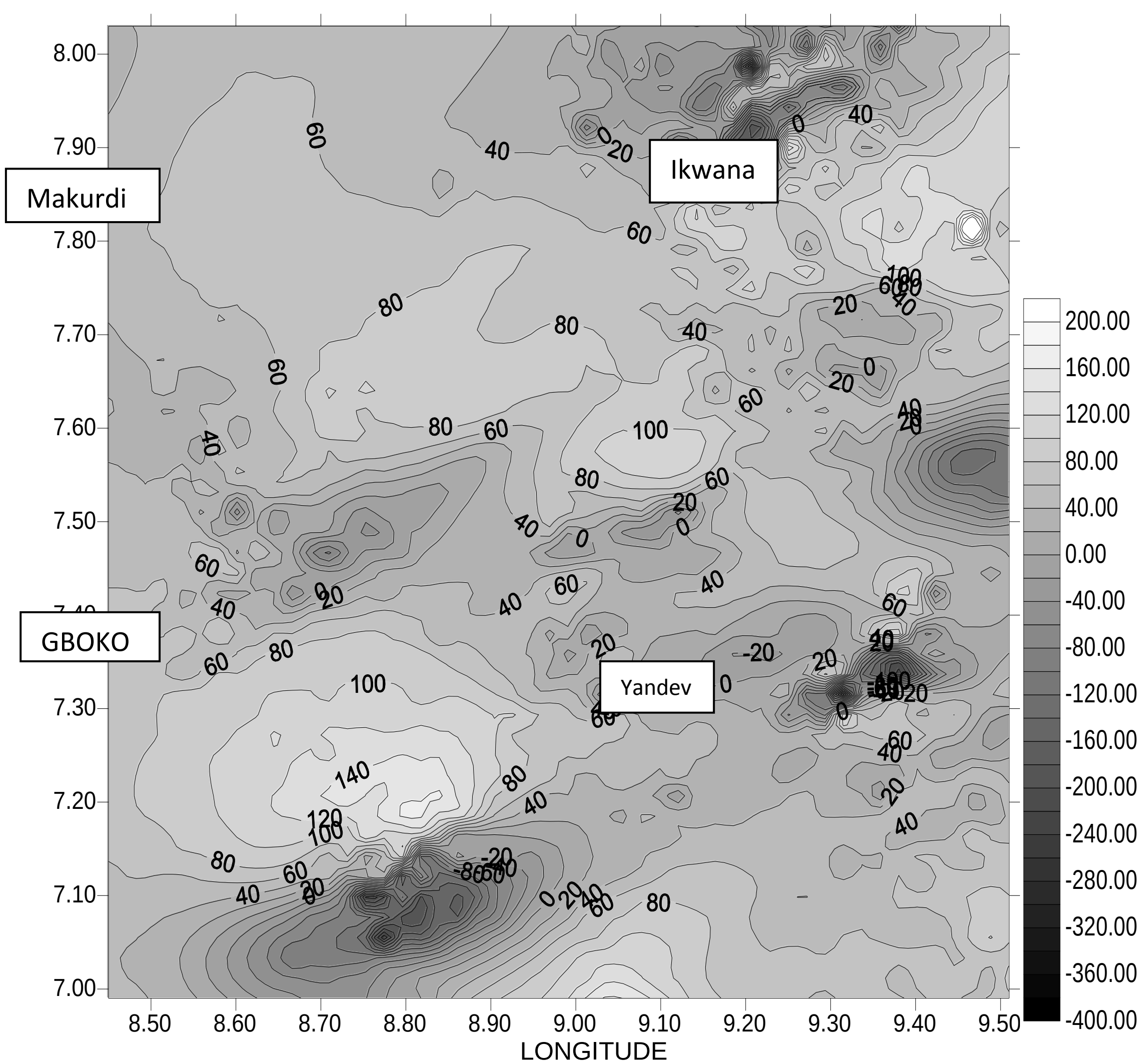

Fig3. Composite aeromagnetic anomaly contour map of the study area (add a background value of 32000nT to each value)

4.2 Regional- Residual separation

The regional-residual separation was done with least square method using Polifit program. The regional and residual field is shown on fig4a&b

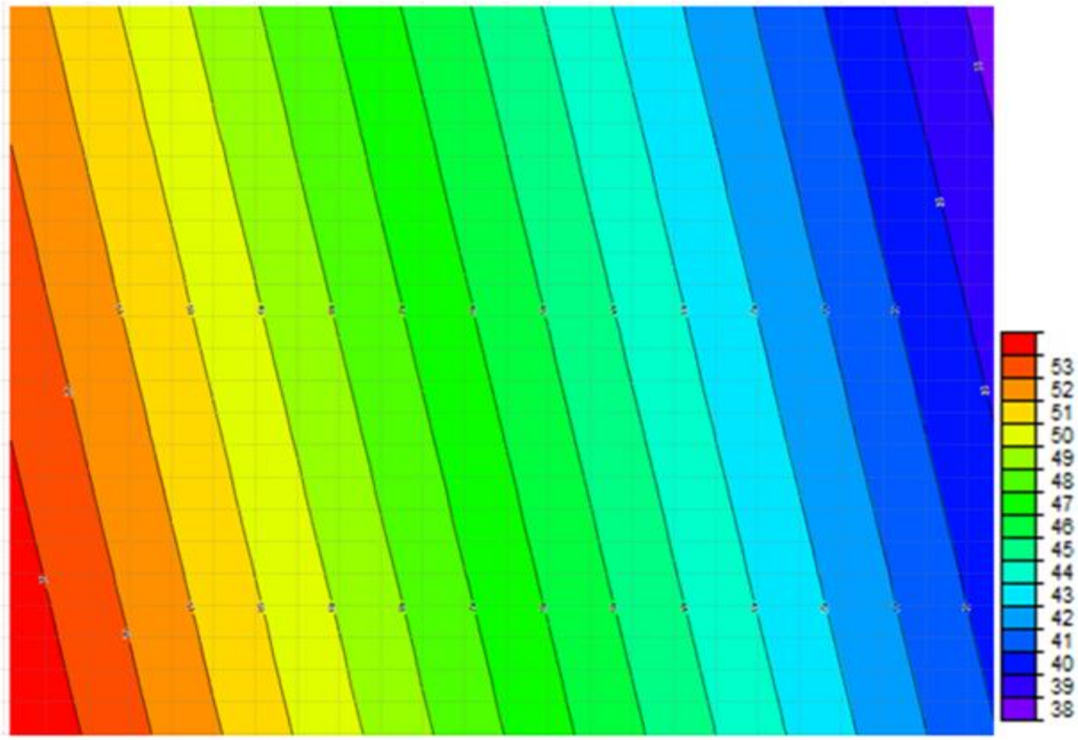

Fig4a The Regional magnetic field anomaly map of the study area (add 32000nT to every value)

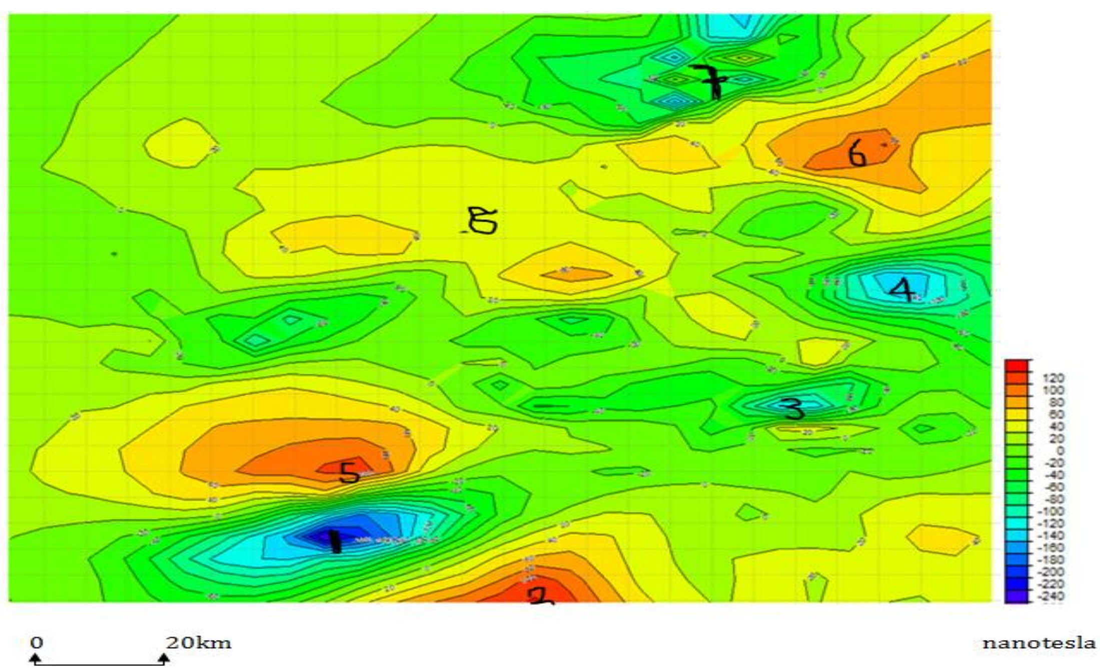

Fig4b the residual anomaly contours map.

Prominent magnetic anomalies numbered (1-8) could be observed on the residual map of the study area. It is separated into low frequency anomalies (1,3,4,7) which are related to deep-seated bodies and high frequency anomalies (2,5,6,8) related to near-surface bodies. About one third of the map can be seen to be featureless which may correspond to undifferentiated basement in the south-eastern part of the study area. The general trends in the orientation of these magnetic contour closures could be observed to be in the NE-SW with subordinate E-W trend. Prominent closures and undulations are more noticeable in the basement surface of Gboko part followed by Ikwana and Yandev. Ajakaiye et al (1980) had earlier identified a conjugate pair of NE-SW and NW-SE fracture in the Benue trough which is attributed to deeper heterogeneity of the earth crust during the sequence of events at possible opening up of South American and African plate. SPI technique was then used to calculate the depth value of the shallow and deep seated bodied which are suspected to be areas of deeper and shallower sediments.

5.0 Determination of depth to magnetic sources by The SPI™ (local wavenumber) method

The Source Parameter Imaging (SPI ™) is a technique using an extension of the complex analytical signal to estimate magnetic depths. This technique developed by Thurston and Smith (1997) and Thurston et al. (1999, 2002) sometimes referred to as the local wavenumber method is a profile or grid-based method for estimating magnetic source depths, and for some source geometries the dip and susceptibility contrast. The method utilizes 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 Thurston and Smith, (1997). The depth is displayed as an image. The original SPI™ method (Thurston and Smith, 1997) works for two models: a dipping thin dike and a sloping contact. The local wavenumber has maxima located over isolated contacts, and depths can be estimated without assumptions about the thickness of the source bodies (Smith et al., 1998). Solution grids using the SPI technique show the edge locations, depths, dips and susceptibility contrasts. The local wavenumber map more closely resembles geology than either the magnetic map or its derivatives. The SPI method requires first- and second-order derivatives and is thus susceptible to both noise in the data and to interference effects.

6.0 Theory and Result.

The SPI method (Thurston and Smith, 1997) estimated the depth from the local wavenumber of the analytic signal. The analytic signal $A_1(x,z)$ is defined by Nabighian (1972) as

$$A_1(x,z) = \frac{\partial M(x,z)}{\partial x} - j\frac{\partial M(x,z)}{\partial z}, \qquad \text{………………1.0}$$

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

$$\frac{\partial M(x,z)}{\partial x} \Leftrightarrow -j\frac{\partial M(x,z)}{\partial z}, \qquad \text{…………………………..2.0}$$

Where $\Leftrightarrow$ denotes a Hilberts transform pair. The Local wavenumber k_1 is defined by Thurston and Smith (1972) to be

$$k_1 = \frac{\partial}{\partial x}\tan^{-1}\left[\frac{\partial M}{\partial z}\bigg/\frac{\partial M}{\partial x}\right] \qquad \text{…………………………..3.0}$$

The analytical signal defined by Nabighan (1972) uses the Hilbert transform pair in equation 2.0. The Hilbert transform and the vertical derivative operators are linear, so the vertical derivative of (2.0) will give the Hilbert transform pair,

$$\frac{\partial^2 M(x,z)}{\partial z \partial x} \Leftrightarrow -\frac{\partial^2 M(x,z)}{\partial^2 z}, \qquad \text{…………………………..4.0}$$

This enables us to define an analytic signal based on second- order derivatives, $A_2(x,z)$ where

$$A_2(x,z) = \frac{\partial^2 M(x,z)}{\partial z \partial x} \Leftrightarrow -j\frac{\partial^2 M(x,z)}{\partial^2 z}, \qquad \text{………. 5.0}$$

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

$$k_2 = \frac{\partial}{\partial x}\tan^{-1}\left[\frac{\partial^2 M}{\partial^2 z}\bigg/\frac{\partial^2 M}{\partial z \partial x}\right] \qquad \text{……………………....6.0}$$

This first and second – order local wavenumbers are used to determine the most appropriate model and depth estimate of any assumption about a model.

6.1 Magnetic anomalies

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

$$\frac{\partial M}{\partial x} = 2KFc\sin d\,\frac{h_c\cos(2I-d-90) + x\sin(2I-d-90)}{h_c^{\,2} + x^2}$$

…………………………………7.0

$$\frac{\partial M}{\partial z} = 2KFc\sin d\,\frac{x\cos(2I-d-90) - h_c\sin(2I-d-90)}{h_c^{\,2} + x^2}$$

…………………………………..8.0

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 the magnetic north, I is the ambient- field inclination, tan I = tani/ 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 argument 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

$$M(x,z) = 2KFcw\,\frac{h_t\sin(2I-d) - x\cos(2I-d)}{h_t^{\,2} + x^2}$$

……………………………………...9.0

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

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

……………………..10.0

where S is the cross – sectional area and h_h is the depth to the expression for the centre of the horizontal cylinder.

6.2 First and second order local wave numbers

Substituting (7.0),(8.0),(9.0),(10.0) into the expression for the first- and second order local wavenumbers, we obtain after some simplification, a remarkable result:

$$k_1 = \frac{(n_k\ \ +1)h_k}{h_k^{\ 2}\ \ + x^2}$$ ………………………………..11.0

$$k_2 = \frac{(n_k\ \ +2)h_k}{h_k^{\ 2}\ \ + x^2}$$ ……………………………..….12.0

Where n_k is the SPI structural index (subscript k=c, t or h), and n_c =1 and n_h =2 for the contact, thin sheet and horizontal cylinder models, respectively.

6.3 SPI images and interpretations

OASIS MONTAJ software was employed to compute the SPI image and depth. SPI method makes the task of interpreting magnetic data significantly easier as shown by the SP images generated from residual field data of the studied area (5a, b&c). This model can be displayed on an image and the correct depth estimate for each anomaly can also be determined (fig5b &c).

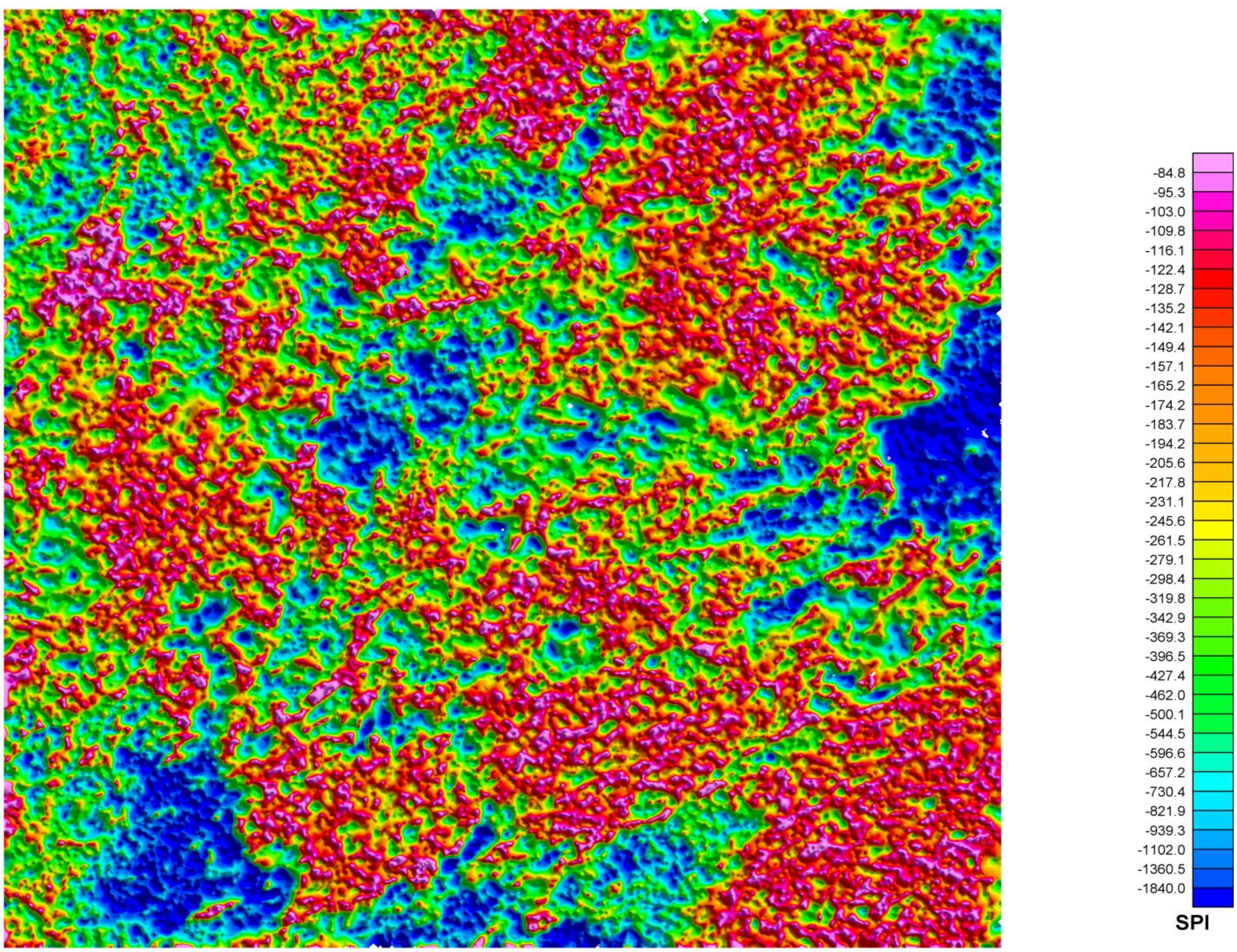

Fig 5a: SPI grid; and SPI legend

The above generated SPI grid image and SPI legends shows varied colours supposedly showing different magnetic susceptibilities contrast within the studied area, and could also portraying the undulations in the basement surface. The negatives in the numbers on the legend signify depth. The light blue to deep blue colors at the end of the legends shows areas of thicker sediments or deep lying magnetic bodies. The upper colours (purple and orange) at the other end of the SPI legends shows areas of shallower sediment or near surface lying magnetic bodies. These are clearly portrayed in 3-D views on fig5b&c in different tilt positions.

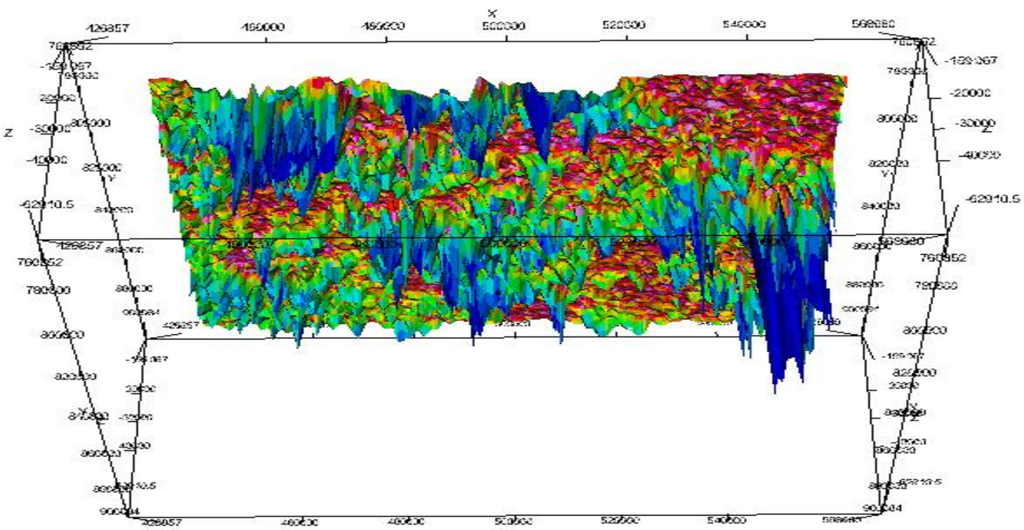

Fig5c. The 3-D SPI view of the study area

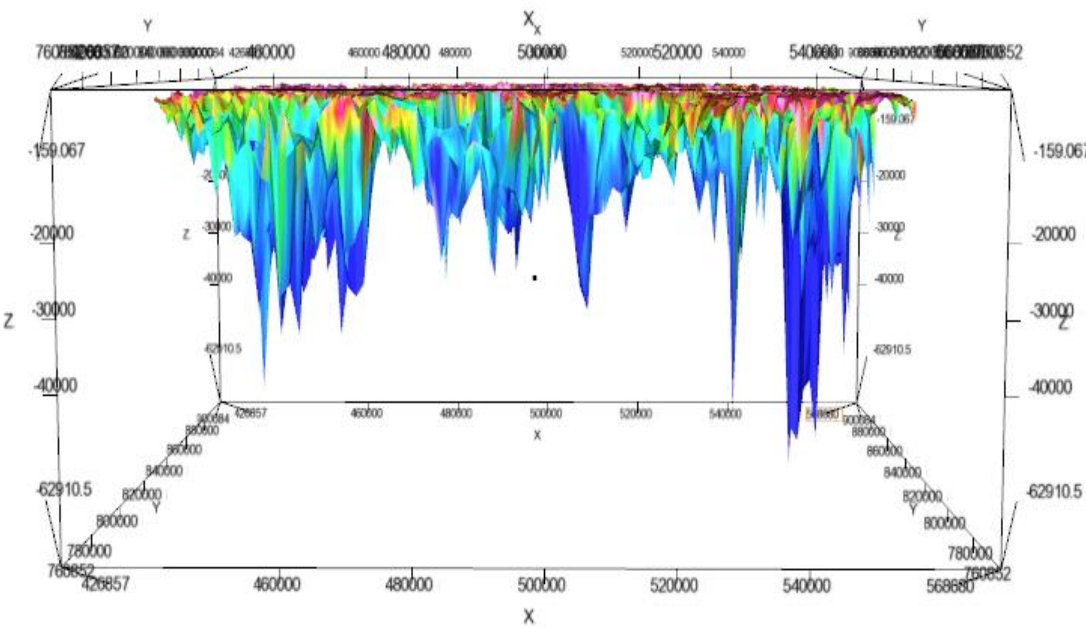

Fig5b: 3-D SPI view of the study area (showing variously colored downward spikes whose depths z could also be read from the z axis of the plot)

7.0 Result and discussions

SPI of the aeromagnetic data of the study area in the middle Benue trough has revealed two main magnetic anomaly sources depth represented by the long spikes (deep blue colored) and the short spikes (light green and orange colored). The long blue spikes represent areas with deep lying magnetic bodies hence with thicker sedimentary cover and ranges from 2000 to 6291.5m with an average depth of 3245m and could be viewed as the magnetic basement depth of the studied area. The magnetic basement depth gotten from this SPI has been validated using spectral analysis and slope techniques each yielding 3.65km and 3.70km respectively. This magnetic basement depth is synonymous to depth of over-burden sediment which has a very important significance as regards to the hydrocarbon generation potential. The work of Wright et al, (1985) reported that the minimum thickness of the sediment required to achieve the threshold temperature of 115oC for the commencement of oil formation from marine organic remains would be 2.3km deep when all other conditions for hydrocarbon accumulation are favourable and the average temperature gradient of 1oC for 30m obtainable in oil rich Niger Delta is applicable. Previous study showed the geology of the area to be associated with the marine Albian Asu River Group which commenced sedimentation in the middle Benue Trough, therefore the calculated average depth of 3.25km from the study area is sufficient for oil to generate if other conditions are met. The short spikes show areas of shallower sediment ranging from 159.067m to 2000m with an average depth 1079.5m and may be regarded as magmatic intrusions into the sedimentary basins and these may be responsible for the Lead-Zinc mineralization found in the area. Active magmatisms have been reported in the Benue Trough with Ofoegbu and Odigi, (1989) confirming the close associations between magmatisms, mineralization and fractures in the area. The varied lengths of the spikes are an indication of undulations in the topography of the basement surface within the study area. This fact can be seen clearly by comparing fig 5b or 5c above with the 3-D plot of the residual data of study area (fig6)

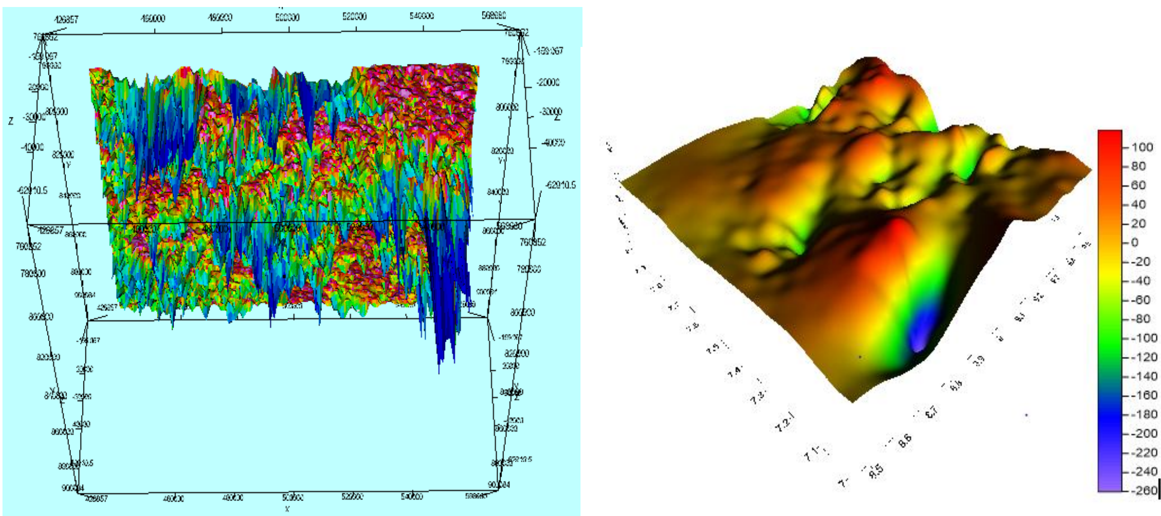

Fig 6: The 3-D SPI image of the study area juxtaposed with 3-D residual map of the study area to show the undulations and likely traps in the basement topography

More attention should be paid to the Gboko and Araufu area because it has more favourable geologic features/sediments. Ofoegbu,(1984,1985,1986) in his geological and geophysical studies carried out in the Benue trough have shown that the area possessed favourable geological and geophysical features like thick sedimentary sequence, marine source bed, block faulting and suitable traps notable with oil producing regions of the country. In comparison with other works; Ahmed, (1991) one - dimensional Spectral calculation in the area using the 1970s data showed the magnetic basement depth to vary from 1.513km and 4.936km. Osazuwa et al, (1981) estimated the thickness of sediments in the upper Benue Trough to vary between 0.9km and 4.6km; Onyewuchi, et.al, (2012) employing 2-D spectral analysis and Landsat Imagery of the adjacent lower Benue trough equally revealed a two layer depth model and predominant NE-SW lineament trend, his shallower magnetic source (d1) has an average depth of 1.041km while the deeper magnetic source bodies (d2) have an average depth of 3.574km. Nwachukwu, (1985) with his estimated depths to the mature zones of (2-4) km in The middle Benue trough has considered it to be the most prospective area for hydrocarbon within the trough.

8.0 Conclusion:

Though the findings from the qualitative and quantitative interpretation obtained from this work have shown some similarities favourable with those of the other researchers using the previous old data, however, this could be more dependable and exacts owing to the high resolution nature of the 2009 data over than the 1970s data in terms of terrain clearance, and line spacing. The old map requires digitization which is stressful and could introduce error unlike the 2009 data that is in digitized form, different errors have been corrected using improved software and technique. The SPI have estimated depth comparable with that from spectral and other technique and this depth values over part of the Middle Benue is an indication that hydrocarbon prospecting should be intensified in this area since the sediment over the area are sufficient to generate hydrocarbon and the are.

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