Evaluation Of The Magnetic Basement Depth Over Parts Of Middle Benue Trough Nigeria By Empirical Depth Rule Based On Slope Techniques Using The HRAM

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Abstract: The new High resolution aeromagnetic data (HRAM) of parts of the middle Benue trough Nigeria have been interpreted to determine the magnetic basement depth and appraise its hydrocarbon accumulation potential through the empirical depth rule methods employing the maximum and half slope techniques. The regional field was modeled with a first order polynomial and the residual field regarded as an error between the model and the data using the polifit program. The residual data was contoured into a map and the preliminary qualitative analysis on it revealed areas of low frequency anomaly probably related to deep seated bodies which are areas of thicker sediment; and areas of high frequency anomaly for shallow seated bodies. Then profiles were then taken along these most prominent anomaly closures of the map and labeled profile OO', NN', WW',BB' and AA' respectively for the purpose of depth determination. The Maximum slope techniques employed using an empirical constant of 1.82 estimated an average depth of 3.66km for the deep magnetic basement and an average of 0.80km for the shallow depth. The half slope technique also employed using an empirical constant of 0.63 estimated an average depth of 3.74km for the deep magnetic source. The results obtained with this method compares favorably with that obtained through spectra analysis for the area. Predominant NE-SWtrend in the orientation of the magnetic contour closures were equally found within the study area which is an attribute of the Pan – African Orogeny trends. The significance of this result is that, this study area with an average depth to basement of 3.70km and the oldest geological formation being marine sediment of Albian age, may be promising for hydrocarbon accumulation if other conditions are met.

Key words: Middle Benue Trough, Magnetic anomaly, high resolution aeromagnetic data (HRAM), magnetic basement depth, Maximum slope technique, half slope technique, high frequency and low frequency anomaly source.

1.0 Introduction:

Anomalous magnetization of parts of the solid earth's surface might be associated with local mineralization or be due to subsurface structures that have a bearing on the location of the oil deposit. Magnetic and gravity survey data have been used to provide information on the nature and form of the crystalline basement.Determination ofmagnetic basement depth beneath sedimentary cover has been known as one of the key functions of aeromagnetic survey and its interpretation. This study appraised the hydrocarbon accumulation potential of some parts of the middle Benue trough through the analysis of its aeromagnetic data by determining the sedimentary thicknesses in the study area using the new high resolution aeromagnetic data (HRAM). The new high- resolution airborne survey in Nigeria was flown in 2009 by Fugro airborne services for the Nigerian Geological Survey Agency. It is termed higher resolution and quality data than that of 1970s because of its flight parameters of 500m line spacing and 80m terrain clearance and in digital form, as against flight line spacing of 2km, average terrain clearance of 150m, and a nominal tie line spacing of 20km of the old 1970s aeromagnetic data which is map form only. The method employed here is empirical and can serve as a validation to more modern automatic source depth methods like spectral analysis that is commonly employed. The method is a pre-computer hand method developed out of enormous experience in magnetic interpretation. It is quicker and can be employed in remote region of the earth that cannot easily have access to costly OASIA MONTAJ and other costly softwares. It is equally a way of keeping alive the works of the pioneers of this method while showing that they can compare favorably with the new computer heavily based automatic depth determination techniques like Spectral, SPI techniques, Werner deconvolution etc. The uniqueness of this work lies in its use of the new 2009 HRAM as against the commonly used 1970s old data {Ofoegbu, (1984, 1985, 1986); Ahmed, (1991); Nwachukwu (1985); Ofoegbu and Onuoha (1991); Onwuemesi, (1996)}; and its use of pre-computer technique to compare the new technique.

2.0 The Location and Geology of the Study area.

The study area is shown in Fig. 1a below, it is located in the Middle Benue Trough Nigeria within Latitude 7000'N to 8000'N and Longitude 8050'E to 9050'E. In the aeromagnetic map it is represented by sheet numbers 251, 252, 271, 272. The Benue trough is part of the long stretch arm of the Central African rift system originating from the early Cretaceous rifting of the central West African basement uplift (Obaje, 2004). The tectonic evolution of

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Benue trough originated from the separation of the African Continent from the South American continent in the Aptian (Grant, 1971). This trough is divided into the Lower Benue Trough at the southern part, the Middle Benue Trough at the centre while the Upper Benue Trough is at the Northern part Samuel et.al, (2011).

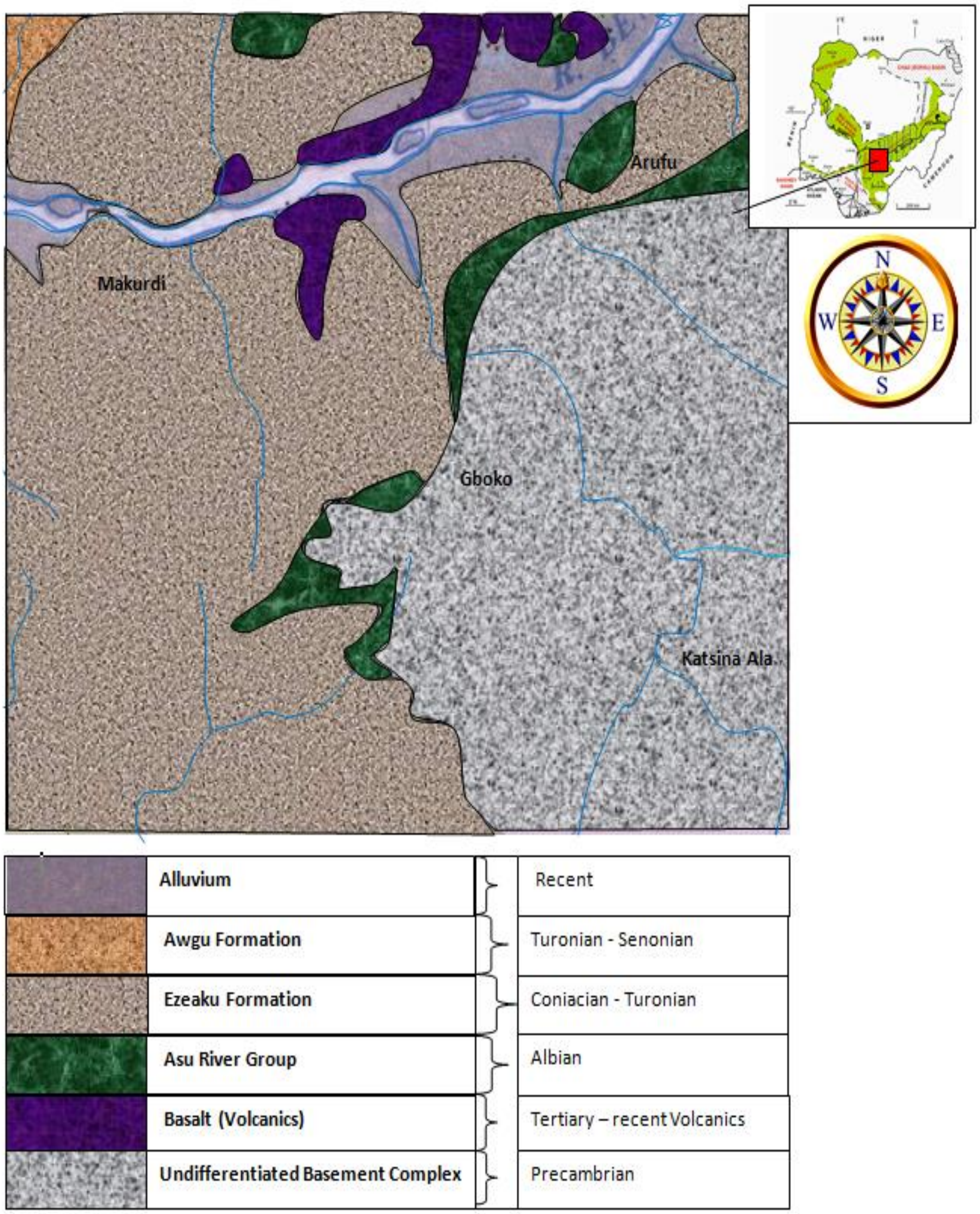

Fig.1 Geological map of part of the Middle Benue Trough (Modified

The work of (Olade, 1975) Cratchley and Jones, (1965), Burke et al (1970); Offodile, (1976); Osazuwa et al (1981) and Offoegbu (1985) have more on the geology of the Benue Trough. The study area is characterized by the presence of thick sedimentary cover of varied composition whose age ranges from Albian to Maastrichtian, with the earliest sedimentation being the marine Asu-River group of Abian age (Obaje, 2004). Stratigraphically, the Cretaceous sedimentary succession in the study area is shown on fig 1(b & c).the Asu-River Group of marine origin is the oldest deposited sediment in the Middle Benue Trough followed by Ezeaku Formation, keana/Awe Formation, Awgu Formation and Lafia Sandstone as the youngest sediment (Obaje, 2004).

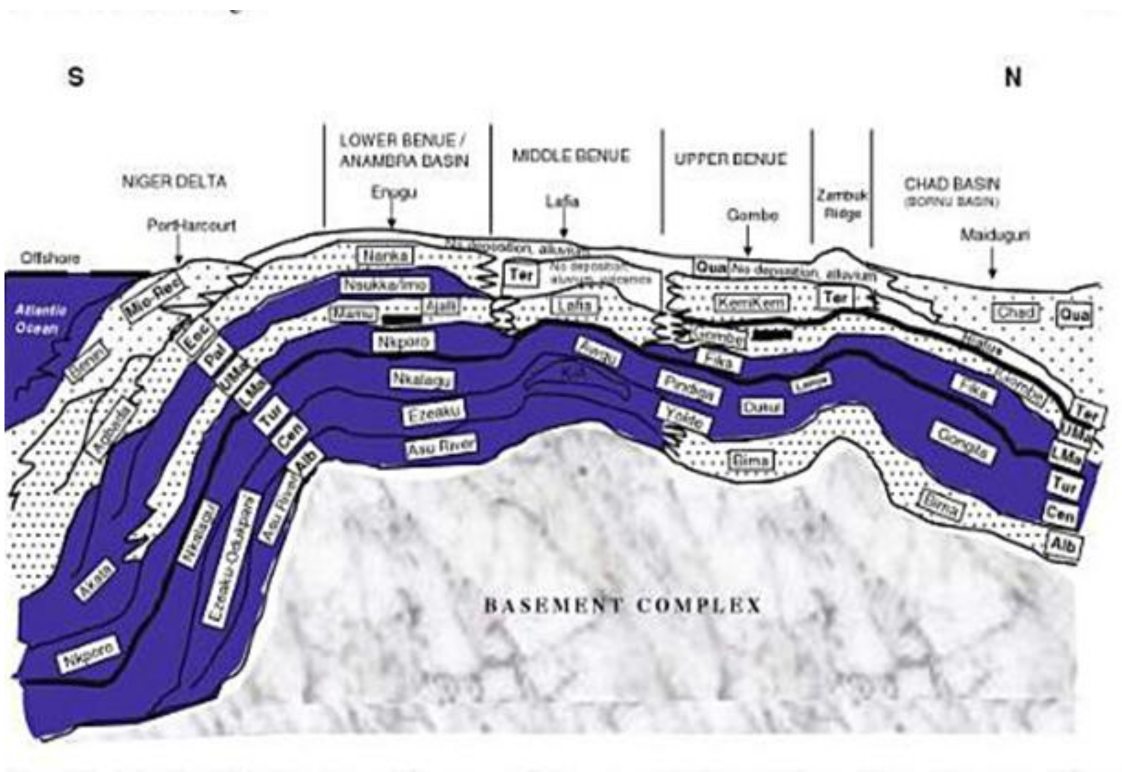

Fig1b *Stratigraphic succession in the Benue trough (Obaje,2004)*

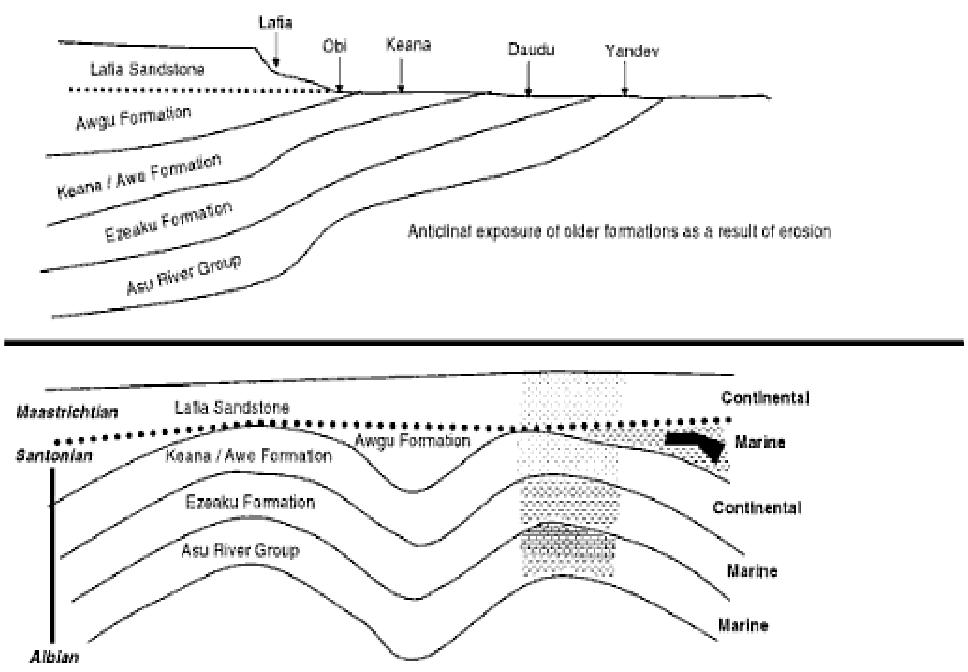

Fig1c. Stratigraphic succession in the middle Benue trough (Obaje,2004)

3.0 Materials and Data source

The aeromagnetic map of the digitized data used in this work is shown on fig 2. It was purchased from the Nigerian Geological Survey agency from the most recent survey of 2009 by Fugro Airborne service. It is of higher resolution than those of 1970s. This data was used to recalculate the basement depth of some parts the Middle Benue trough using the empirical depth rule techniques.

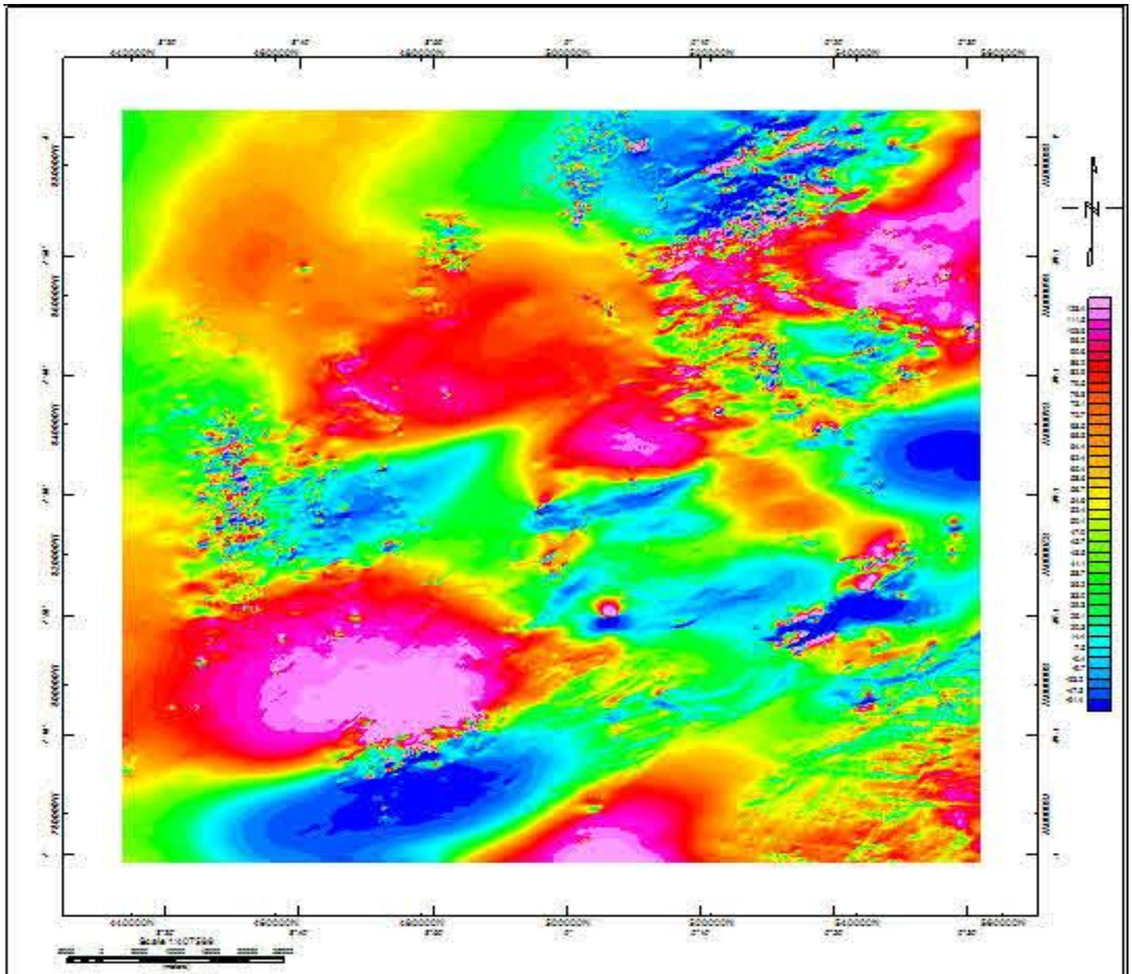

Fig. 2: Magnetic anommaly map of Makurdi-Gboko Axis of the Middle Benue Trough Nigeria

Each square block of fig 2 represents a map on the scale of 1:100,000. Each square block is (55x55) km^2 covering an area of 3,025km^2, hence the study area is 12,100km^2

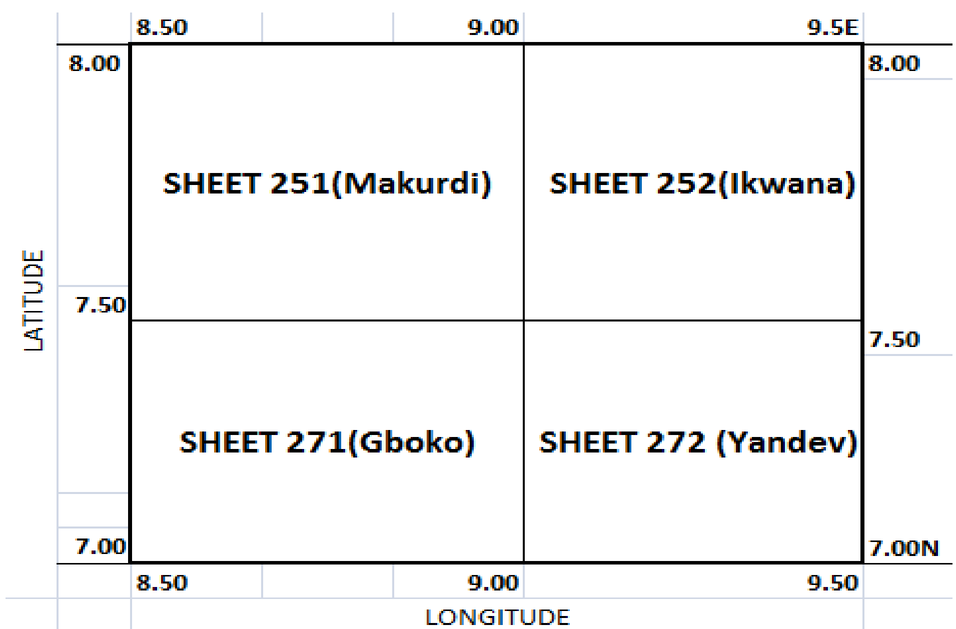

Fig2b *the geographical coordinates of the map sheets for the study area .*

4.0 Method and theory of study.

This depth estimation by empirical depth rule employed the maximum slope and half slope technique using certain empirical constants developed out of enormous experience over the years in magnetic interpretations.Peters, 1949 was probably the first to relate depth of magnetic source to the horizontal extent of the portion of sloping flanks of his profile curves. Graphical techniques make use of the sloping flanks of profile as illustrated in (fig 3) to estimate depth (Nettleton, 1971; Telford et.al 1990)

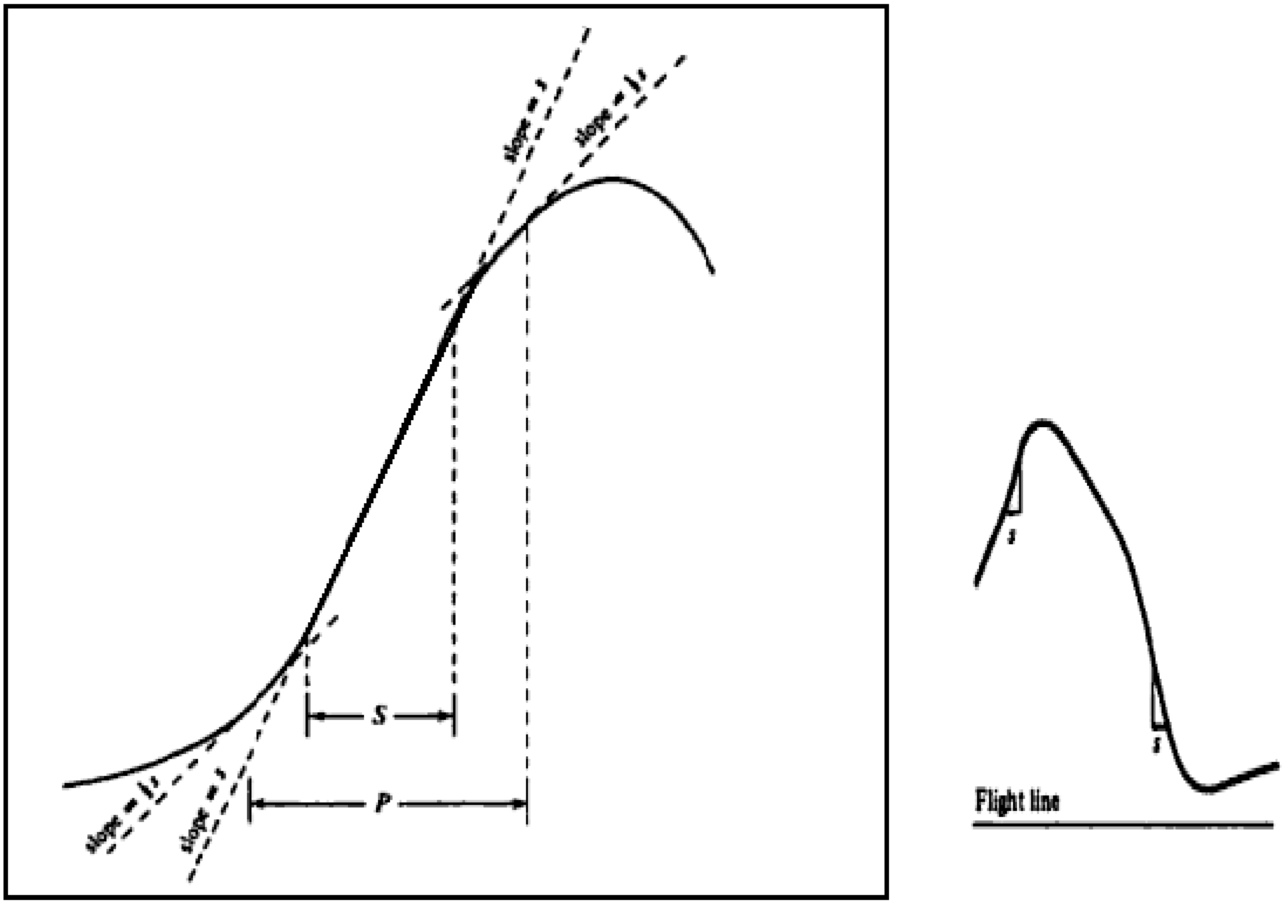

Figure 3: Determining anomaly depth from the slope of magnetic profile. Maximum slope(S); Peters Half-slope (P) (Nettleton, 1971; Spector and Paker 1979; Telford et.al,1990)

To estimate magnetic depth, the horizontal extent of the portion of the profile curve that is nearly linear at the maximum slope (S) is measured, or the distance between the two points of tangency (half slope, {P}) is measured. The depth (Z) beneath the portion of the curve is calculated using equation 1.1 and 1.2

$Z = K_1S$; $1.67 \leq K1 \leq 1.82$ (empirical constant K_1 1.82)....1.1

$Z = K_2P$ (empirical constant $K2 = 0.63$) ………..1.2

5.0 Preliminary analysis (Qualitative)

The acquired data is composed of the effect of all underground magnetic sources, hence regional-residual separation was performed. The quantitative analysis to determine depth is based on the residual map

5.1 Regional- Residual separation:

The regional field was modeled with a first order polynomial and the residual field regarded as an error between the model and the data using polifit program. The obtained regional map is displayed of fig 4a

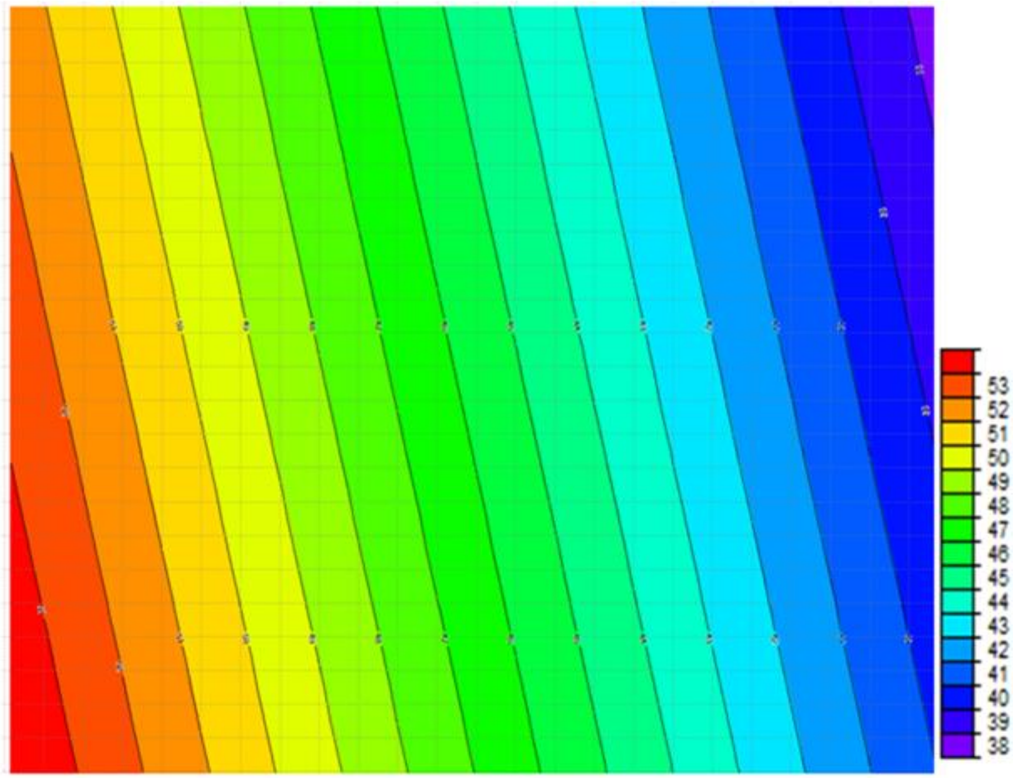

Fig4a. The Regional magnetic field anomaly map of the study area (add 32000nT to every value)

This regional trend represented by parallel evenly spaced contours could be seen to have appeared in the NW-SE directions which have been attributed to deeper heterogeneity of the earth crust during the sequence of events at opening up of South American and African plate. The regional magnetic field intensity ranges between 53nT to 38nT from the Southeastern part towards the Northwestern part of the study area dipping gently and uniformly with a regional gradient of 205gammas/km. The 2-D residual map on of the study area is shown on fig4b, the prominent anomalies have been numbered.

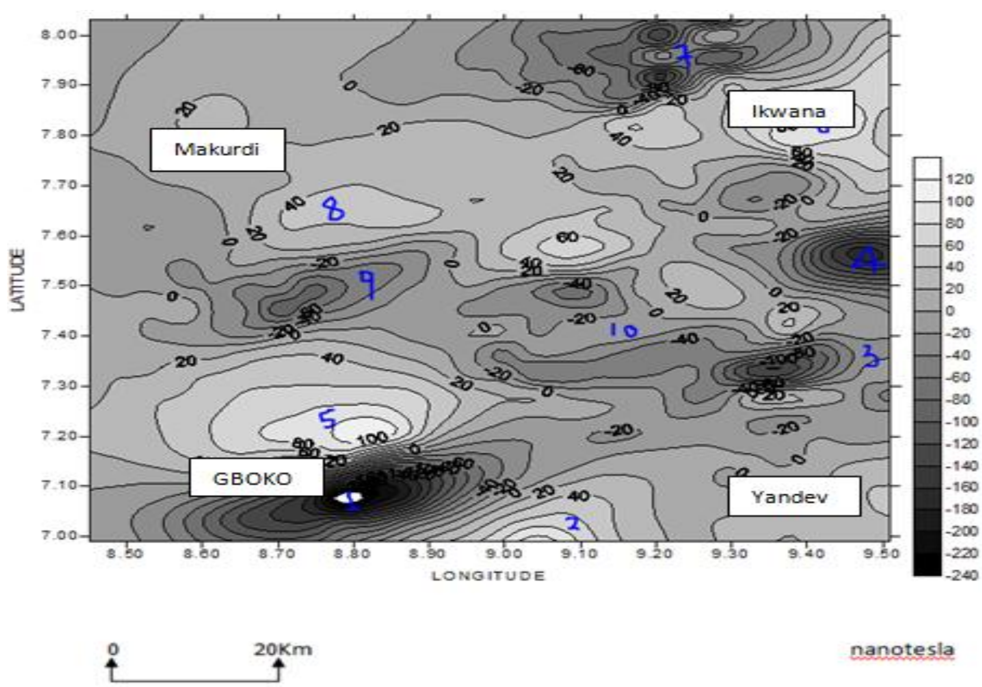

Fig 4b: The 2-D residual contour map of the study area.

This could be observed to be made up of low frequency anomalies (1,3,4,7,9) which are related to deep-seated bodies which is probably an area of thicker sediment and could be taken as the magnetic basement depth; and high frequency anomalies (2,5,6,8) related to near-surface bodies which are areas of the shallower sediment. This could be properly understood with the 3-D residual map of the study area on fig4c

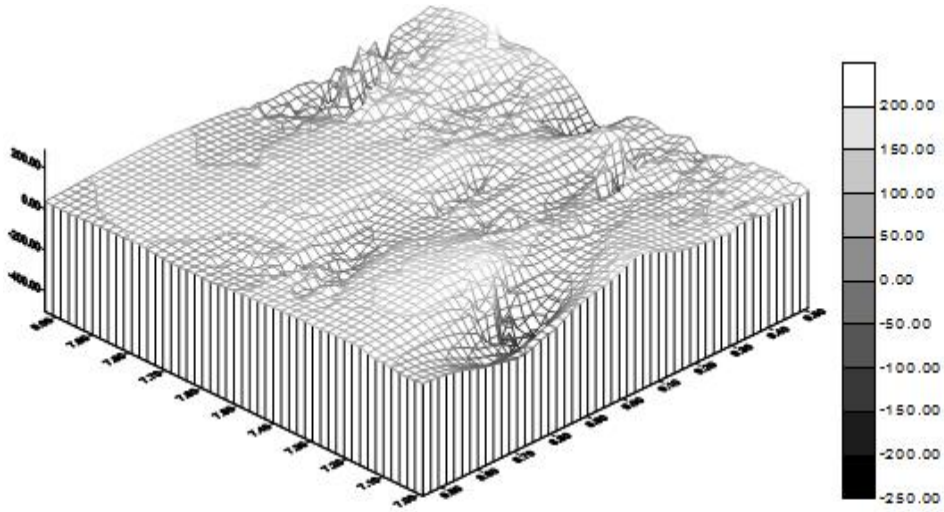

Fig4c. The 3-D view of the residual contour map of 4b

Profiles were then taken on these suspected areas of thicker and shallower sediment as have been revealed above using the slope techniques to quantitatively determine its depth. The Gboko and Ikwana area have more geologic features and Markudi almost featureless. The general trends in the orientation of these magnetic contour closures could also be observed to be in the NE-SW direction with subordinate E-W orientation.

6.0 The quantitative analysis by slope techniques (the maximum Slope technique and Half slope technique).

The residual contour map of fig4b above was profiled NN^{I}, BB^{I},AA^{I}, OO^{I} and WW^{I} along the most prominent anomaly zones within the study area as shown on the profile map of fig5 for the purpose of magnetic basement depth estimation.

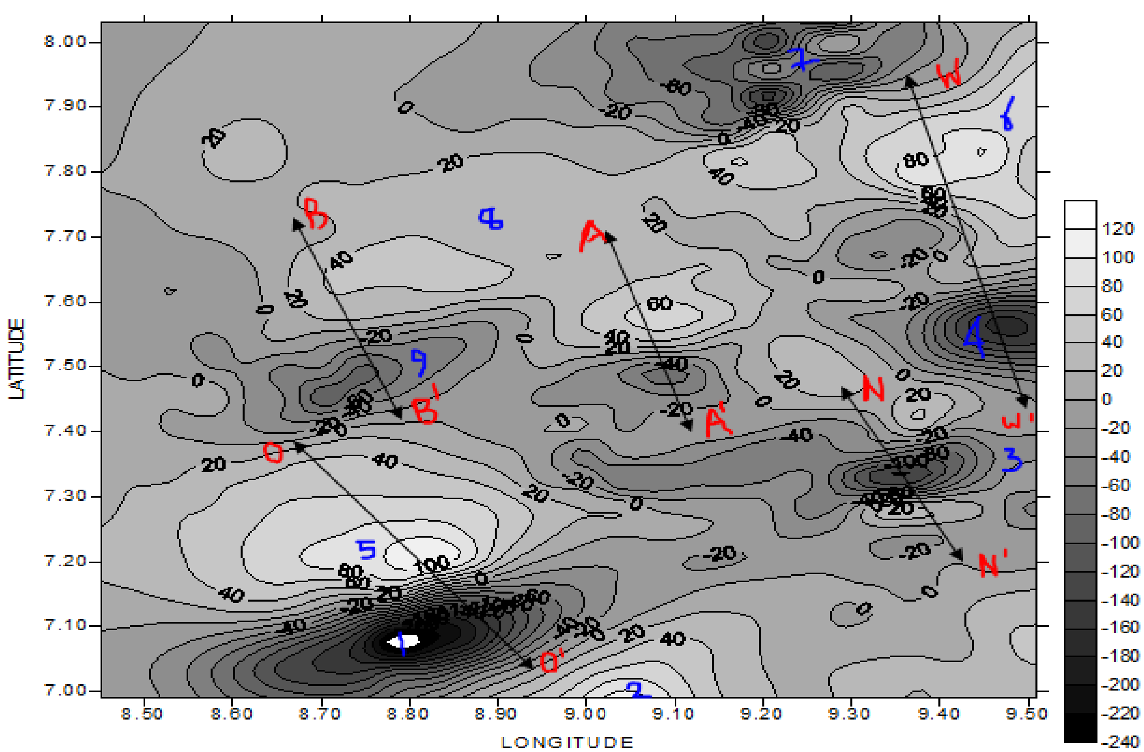

Fig5 residual field contour map showing the profiles used for depth estimation

The plots of the contour values against the distance produced the smooth picked graphs shown on fig6 which are replica of the theoretical curves of fig3.

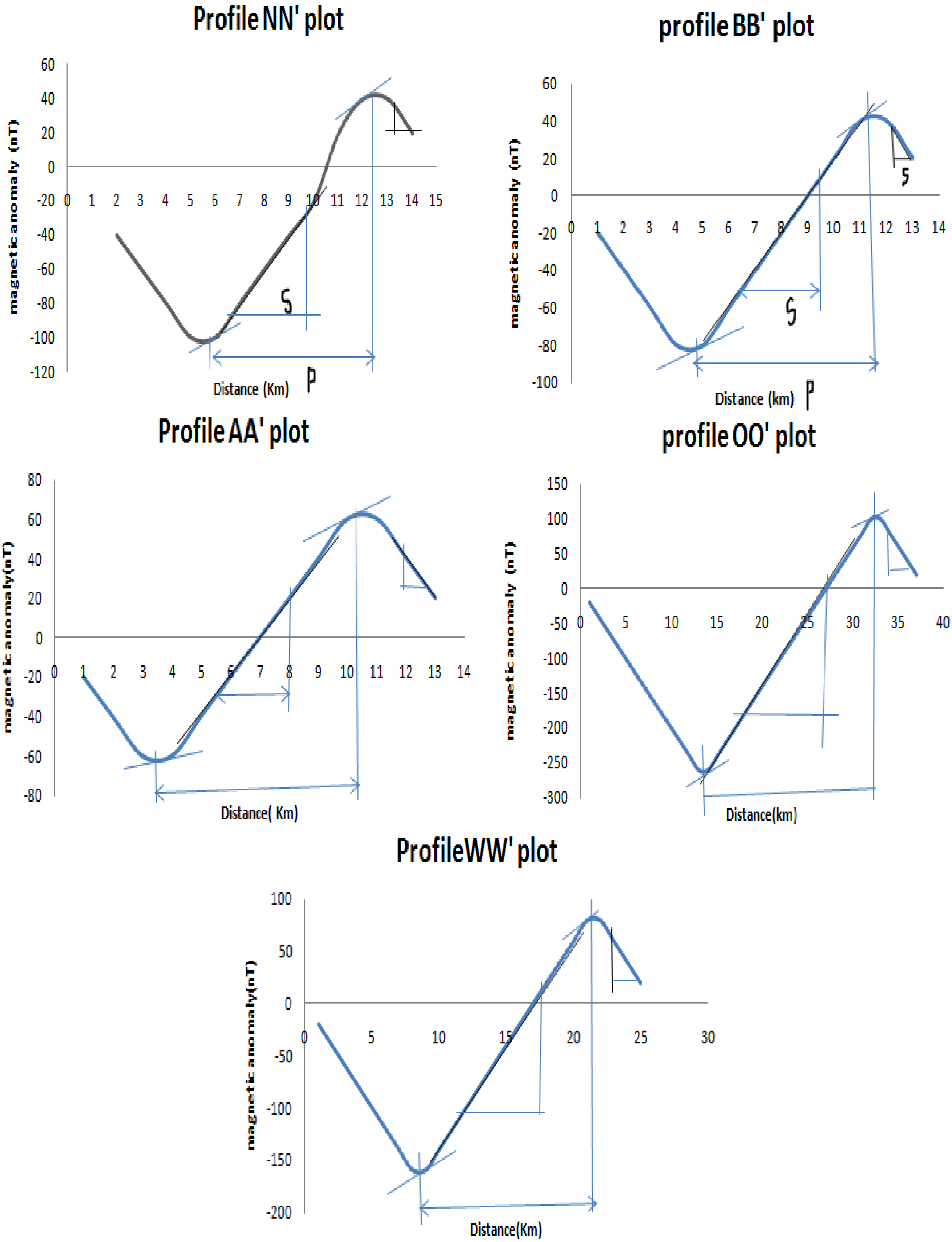

Fig6 Depth estimations from the sloping flanks of the profile plot.

S is the measured horizontal extent of the portion of the curve that is nearly linear at the maximum slope and ***P*** is the horizontal distance between the points of tangency. Employing the theoretical equations of 1.1 and 1.2, the summary of the estimated depth for the five profiles taken are shown on table1 using the maximum and half slope technique

Table1. Summary of depth estimate from the slope techniques

PROFILES	MAXIMUM SLOPE TECHNIQUE(for the deep and shallow source)					HALF SLOPE TECHNIQUE(deep source)		
	DEEP	SHALLOW	Depth(Z)=K1S			Depth(Z) = K2P		
	S (Km)	S (km)	Constant (K1)	Deep (Km)	Shallow(Km)	DEEP: P(km)	Constant(K2)	Depth(km)
NN'	2.0	0.3	1.82	3.64	0.36	6.6	0.63	4.16
BB'	2.0	0.3	1.82	3.64	0.36	6.6	0.63	4.16
AA'	1.8	0.8	1.82	3.23	1.46	5.2	0.63	3.28
OO'	2.4	0.5	1.82	4.36	0.91	6.8	0.63	4.28
WW'	1.9	0.5	1.82	3.45	0.91	4.5	0.63	2.83
average depth from each slope technique				3.66	0.80			3.74
Estimated magnetic basement depth from the slope method = 3.70Km								

Additional advantages of these graphs of fig6 is that besides using the quick slope method to estimate depth we could also read off other parameters from the graph and apply host of other graphical methods like: Rambabu and Rao,1983; Rao and Rambabu,1981; Bean,1966; Stanley,1977.

7.0 Result discussion:

The qualitative interpretations of the residual map revealed conjugate pair of NE-SW and NW-SE fracture in the Benue. More importantly it has identified two magnetic source depth; the low frequency anomaly source depth for deep seated body and the high frequency anomaly for the shallow seated bodies. The areas of deep seated bodies in the map are possibly the magnetic basement depth; while the shallower are possibly magmatic intrusions into the sedimentary basins which are possibly responsible for the mineralization found in the area. Offoegbu and Odigi (1989) have confirmed the close association between magmatic activities and mineralization. Slope techniques have therefore been employed to quantitatively determine the depth of these high and low frequency anomaly sources. The calculations on table 1 have revealed depth estimates averaging 3.70km as the magnetic basement depth, and 0.8km as the shallow depth source. A very important significance of the magnetic basement depth of 3.70km is with regards to the hydrocarbon accumulation potential of the area. Wright et al, 1985 reported that when all other conditions for hydrocarbon accumulation are favorable, that the minimum thickness of the sediment required to achieve the threshold temperature of 115^{o}C for the commencement of oil formation from marine organic remains would be 2.3km deep. Therefore with the calculated magnetic basement depth of 3.70km, and the marine Albian Asu River group commencing the sedimentation, the study area could be looked upon as an area which may be favorable for oil accumulation if other conditions are met Figure4c have equally revealed something like a favorable trap for accumulation. Offoegbu (1984) and other works have equally shown that this area have favorable geological features and traps for this purpose. More attention should be paid to the Gboko and Ikwana area because they have more favorable geologic features and sediments. Quantitative automatic source depth techniques using the 1970s data employed by other researchers have equally yielded comparable results to this notwithstanding that this method is based on empirical figures merely developed out of long term interpretation experience. Ahmed, (1991) in the middle Benue using the 1970s data showed the magnetic basement depth to vary from 1.513km and 4.936km. The study area has been considered to be the most prospective area for hydrocarbon within the trough according to Nwachukwu, (1985), because depths to the mature zones are moderate; (2-4 km). The 2-D spectral analysis and Landsat Imagery of the adjacent lower Benue trough by Onyewuchi, et.al, (2012) equally revealed a two layer depth model and predominant NE-SW lineament trend. The shallow magnetic source (d1) has an average depth of 1.041km while the deeper magnetic source bodies (d2) have an average depth of 3.574km. Osazuwa *et al*, 1981 estimated the thickness of sediments in the upper Benue Trough to vary between0.9km and 4.6km. The NE-SW direction of magnetic contour trend observed from the study agrees with that made by others like and Ajakaiye*et al,* 1981 for the area which was attributed to the events at the possible opening up of South American and African plate or Pan – African Orogeny trends.

8.0 Conclusions:

The slope method though empirical but has given results which compared favorably with the more modern computer based automatic spectral depth method of analysis obtained by other researchers. The geology of the Benue Trough offers promises to prospective investors and science in general as confirmed by this work and others. This result obtained using the new 2009 survey data will be more precise because of the high resolution nature of the data due to technological improvements since 1970. The likely error and task through digitization has also been eliminated because the 2009 data is in digitized form obtained through high profile software and good error correcting softwares.

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