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RESEARCH ARTICLE

ANALYSIS OF AEROMAGNETIC ANOMALIES OVER PART OF THE UPPER BENUE TROUGH (*SHEET NUMBERS 171,172,192, AND 193*), NIGERIA

Rahmat S. Tukur[a], Olatunji S. Ayanninuola[a], Etim D. Uko[b*], Charles O. Ofoegbu[a]

[a] Department of Physics, Nassarawa State University, PMB 1022, Keffi, Nigeria.
[b] Department of Physics, Rivers State University, PMB 5080, Port Harcourt, Nigeria.
****Corresponding Author Email: e_uko@yahoo.com***

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ABSTRACT

A total of four Aeromagnetic Sheets of 1:100,000 scale comprising of Sheets Yuli-171, Futuk-172, Bashar-192 and Muri-193 which covers part of the Upper Benue trough were subjected to both qualitative and quantitative analysis and interpretation in order to understand the magnetic signature, intrusive magmatic activities, basement structural orientation, basement geomorphology, sedimentary thickness and the relationship between the anomalies to the mineralization potential of the study area. To achieve this, various techniques such as filtering, reduction-to-the-Pole, reduction to the Equator (RTE), spectral analysis were applied to the residual magnetic intensity (RMI) using Geosoft Oasis Montaj softwares. The analysis results shows the variation in depth of the various magnetic anomalies observed with different wavelength which is an indication of their sources depth, the structural trends of the rock in the areas are in the NNE-SSW, ENE-WSW and E-W respectively, and a lot of positive signals from several places in the analytical signal map which is an indication an intense igneous activity occurring as near surface intrusion within the sediments of the upper Benue trough and some part of the bounding basement section which are Sabon Gari, Raramai, Dan, Yuli, Garua, Bashar, Boswas Tukur and the southern part of Futuk which area predominantly basement and the areas such as part of Zurak, part of Wase, Near Ligri, Senge, Pindiga which are predominantly underlain by the thick sediments. The spectral analysis depth for both the shallow 0.23km to 0.43km and deep magnetic sources ranges 3.3km to 5.7km below the surface. The results show that the aeromagnetic anomalies can be attributed to the presence of different lithological units, structural features such as faults and shear zones, and hydrothermal alteration zones. This study provides valuable information for future geological and mineral exploration activities in the Upper Benue Trough and highlights the potential of aeromagnetic surveys in understanding the subsurface geology of the region.

KEYWORDS

Upper Benue Trough, Nigeria, Vertical Derivatives, depth to Magnetic Structures

1. INTRODUCTION

The magnetic data provide insight into mapping basement surfaces and delineating shallower volcanic and in some cases shale or salt diapers. Aeromagnetic survey maps the variation of the geomagnetic field, which occurs due to changes in the percentage of magnetite in the rock and reflects the variations in the distribution and type of magnetic minerals below the earth surface and measure variations in basement susceptibility (Sunmonu and Alagbe, 2014). According to Aryamanesh, the applications of aeromagnetic play an important role in tracing lithological contacts and to recognize the structures like faults, lineaments, dykes, and layered complexes (Aryamanesh, 2009). Therefore, this research consists of determining/estimating the locations and depths of the magnetic sources as well as delimiting logical mineralization zones in the research area. The aim of this Study is to Analyze the Aeromagnetic Anomalies over Part of the Upper Benue Trough with sheet numbers 171, 172, 192, 193.

The significance of the Study are that airborne magnetic analyses are relatively valuable in mapping magnetic well bodies and thus in mineral examination, particularly when labouring over a large area in preparation for a larger ground survey. The use of enhancement filters that amplify shallow radiofrequency anomalies will allow the delineation of favourable zones of mineralization as most mineralization is restricted to those structures that are within the top kilometres of the earth's crust with high mineral potential and this study will serve to add knowledge about to expand the mineral potential in the region through the application of these techniques. The aim of this paper is therefore to investigate aeromagnetic anomalies over part of the Upper Benue Trough (Sheet Numbers 171,172,192,193).

2. AREA OF STUDY AND ITS GEOLOGY

The area covers part of the Upper Benue Trough. It covers widths 9.00N to 10.00N and lengths 11.00E to 12.00E which corresponds with sheet numbers 171, 172, 192, 193 and their respective locations, Yuli, Futuk, Bashar and Muri (Figure 1). The Benue Trough is an intra-cratonic rift structure that extends from the northern border of the Niger Delta to the southern edges of the Chad Basin. The Benue Trough is a significant geological pattern that lies under the Nigeria and extends roughly 1,000 km northeast from the Bay of Benin to Lake Chad. It is part of the broader West and Central African rift system. The trough has its southern border at the northern border of the Niger Delta, where it slopes down and is covered with tertiary and newer sediments. It extends in a north-easterly direction to the Chad Basin and is about 150 km wide. The trough is arbitrarily divided into the lower, middle, and upper regions, and the upper region is further divided into the Gondola and Yola arms.

The Anambra Basin to the west of the lower region is younger than the rest of the trough and was formed during a later period of compression but is

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considered part of the formation (Obaje, 2009). The Benue Trough was formed by rifting the central West African basement at the beginning of the Cretaceous Period. Initially, sediments that were deposited by rivers and lakes were collected in the trough. During the late early to mid-Cretaceous period, the basin sank rapidly and was covered by the sea. Seabed sediments mainly accumulated in the southern Abakaliki Rift under low-oxygen soil conditions. In the Upper Cretaceous, the Benue trough probably formed the main connection between the Gulf of Guinea and the Tethys Ocean (predecessor of the Mediterranean) via the Chad and Iullemmeden basins (Wright, 1985).

Towards the end of this interval, the basin rose above sea level and comprehensive coal-forming swamps developed, particularly in the Anambra Basin (Adighije, 1981). A common explanation for the trough formation is that it is an aulacogen, an abandoned arm of a three-armed radial rift system. The other two arms continued to expand during the collapse of Gondwana when South America separated from Africa (Peters, 1978). The two continents appear to split apart at their present-day southern tips, with the rift extending along the modern coastline to the Benue Trough and later dividing along the present-day south coast of West Africa and the northeast coast of South America. When the continents were wedged apart, the trough opened. When the separation was complete, the southern part of Africa swung back a little, compressing and crumplingng the sediments in the Benue trough (Wright, 1968).

During the Santonian age, over 84 million years ago, the basin underwent intense compression and folding, forming over 100 anticlines and synclines. The deposits in the Benue Trough were displaced westwards at this time, causing subsidence of the Anambra Basin (Obaje, 2009). A refinement to the model involves the rise of a mantle plume, where abnormal heat leads to melting of the upper mantle, thinning and stretching the ((crust, followed by rifting of the weakened crust. This may have been repeated several times, with the Benue Trough deformed between rifting episodes (Ofoegbu, 1984). The same plume may be responsible for the line of volcanoes in Cameroon along the Central African Shear Zone and the volcanic island of St. Helena in the Atlantic Ocean (Coulon et al., 1996).

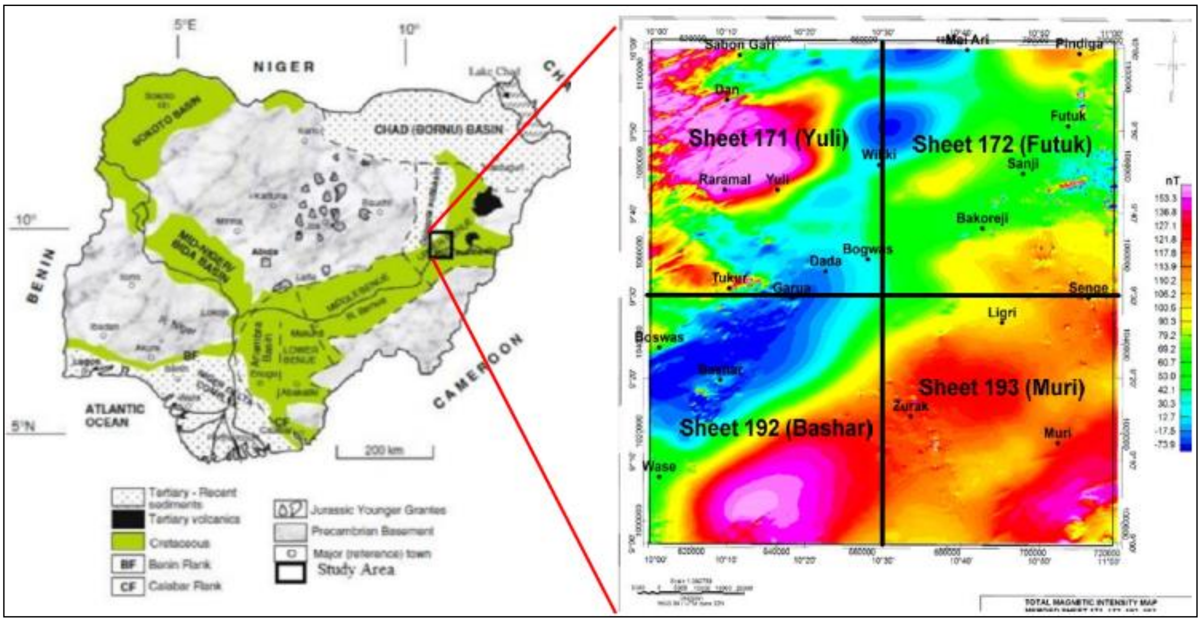

Figure 1: General Geology Map of Nigeria Showing the Location of Area (Obaje, 2009)

3. Materials and Methods

3.1 Data Source

The airborne data was acquired as a secondary data from the Nigerian Geological Survey Agency (NGSA). The aeromagnetic data used for this work is a secondary data acquired was acquired and processed by Fugro A.S. PTY for the Nigerian geological survey Agency. The study area is covered by a total of four Aeromagnetic sheets of 1: 100,000 sheet 171 Yuli, Sheet 172 Futuk, 192 Bashar and Sheet 193 Muri.

3.2 Material Used

The Total Magnetic field Intensity value Z was stripped of 33,000nT by the NGSA after the data was acquired, a series of filtering and reductions are applied to the 2D gridded data in both wave number and Fourier domains to achieve Reduction to magnetic equator, upward continuation, Regional/Residual separation, horizontal gradient magnitude, Analytic signal, First/Second/Third vertical derivatives (1VD), second vertical derivatives (2VD), Spectral analysis, heat flow and geothermal gradient using the Geosoft Oasis Montaj software and the other analysis and interpretation such as ArcGis, Forplot, Golden, Surfer and Rockworks softwares.

4. Results and Discussion

4.1 Reduction to Magnetic Equator

Because the area within the region is closer to the equator than the pole, the raw total magnetic intensity map of the study area was reduced to the magnetic equator. This was done to avoid elongation and data distortion that could occur if it was reduced to the pole, which is almost at 90 degrees from the data point. The Total magnetic intensity map spans in value from -73.9nT to 153.5nT and ranges in the variance of magnetic strength across the area, as illustrated in Figure 2. The total magnetic intensity decreases to the Equator, and the RTE map differs only slightly from the TMI map since Nigeria is closer to the equator, resulting in a lower angle of inclination and declination, thus the similarity.

The RTE map (Figure 2b) is a representation of both the regional and residual anomalies within the area, with intensity values ranging from -57.0nT to 151.5nT. The magnetic susceptibility of an RTE map is inversely proportional to the magnetic intensity over the area, which means that areas with high magnetic intensity in pink coloration have low magnetic susceptibility, and areas with low magnetic susceptibility according to the map have high magnetic susceptibility. The variation observed is due to the different responses of different rock materials to magnetism, which is as a result of the different response of different rock materials to magnetism. Most natural materials have a very low susceptibility, which can be either negative (diamagnetism) or positive (ferromagnetism) (paramagnetic).

The fields produced by diamagnetic and paramagnetic materials are normally too tiny to effect survey magnetometers, but modern high-sensitivity magnetometers are changing that. The majority of magnetic anomalies are caused by the tiny number of ferro- or ferri-magnetic substances in which intermolecular exchange forces hold the molecular magnets parallel. The magnetic intensity distribution across the map reveals that the areas surrounding many crustal magnetization patterns are magnetically intense. The long wavelength regional magnetic sources arose from deep seated magnetic sources, whereas the short wavelength residual magnetic sources are those of residual origin.

4.2 Residual and Regional Anomaly

The residual anomaly map was created from the RTE using Gaussian traditional regional-residual separation methods. The residual anomaly map emphasizes the near-surface (short wavelength)/ remnant anomaly

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from the research area more than the deep-seated anomaly. They emphasize the remnant magnetisation that is caused by the intrinsic rock in the research region. The research area's residual magnetic intensity level ranges from -30.2 to 16.9 nT, with a mean value of 1.0 nT. Negative intensities are from rocks with high magnetic susceptibility such as granite, rhyolite, and other granitic intrusions; other factors influencing magnetic susceptibility include weathering intensity and resistance to weathering; the prominent residual magnetic signals from the study area are more predominantly occurs within the Western, North western and North-eastern part covering the communities like Bashar, Tukur, Raramal, Dan, Sabon gari some part of Zurak, Futuk, Bakoreji and Senge as seen in Figure 3.

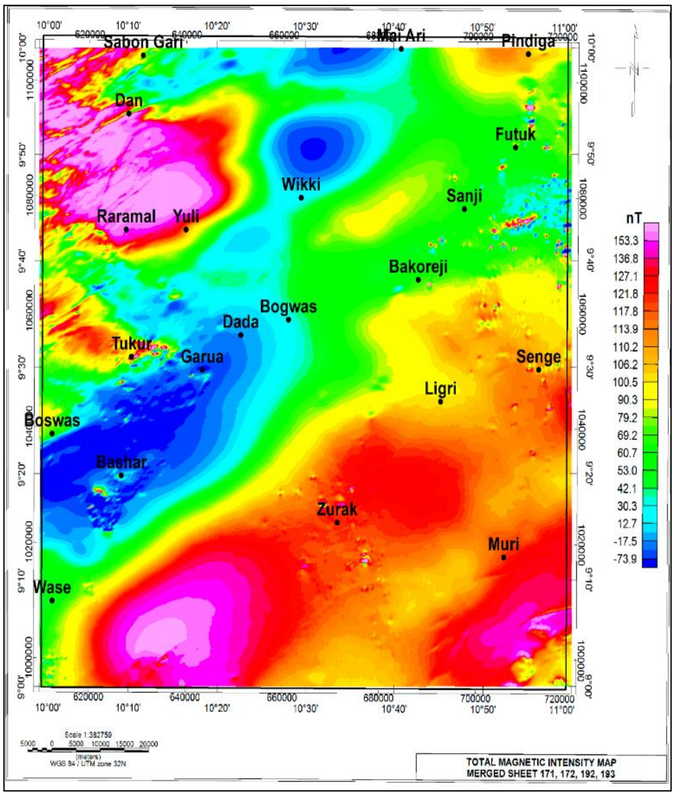

Figure 2a: The Total magnetic intensity (TMI) map of the study area.

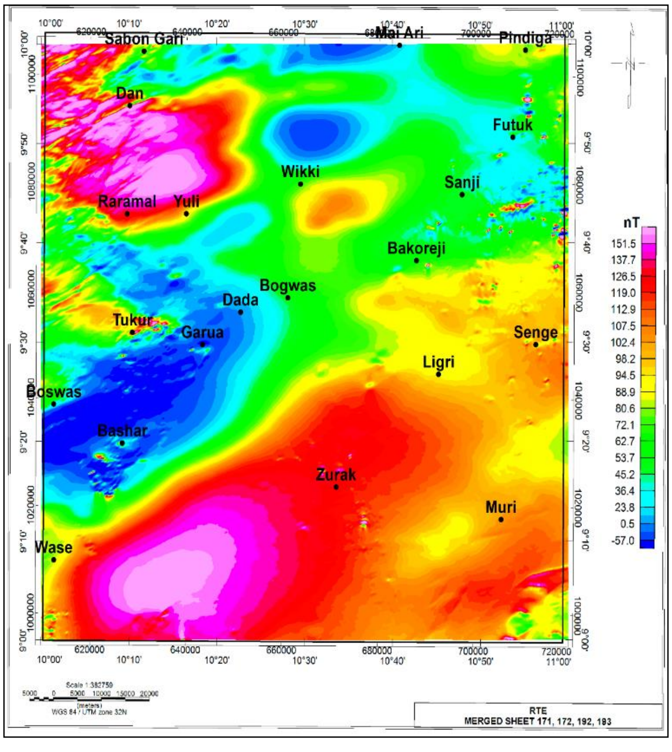

Figure 2b: The Total magnetic intensity Reduced to the Magnetic equator (RTE).

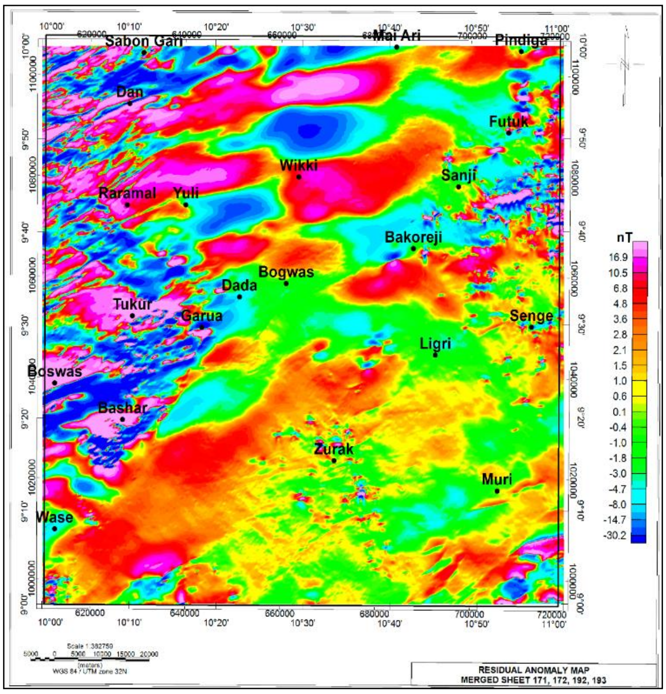

Figure 3: The residual anomaly map of the study area with locations superimposed, showing the showing the regional trend of the magnetic anomaly

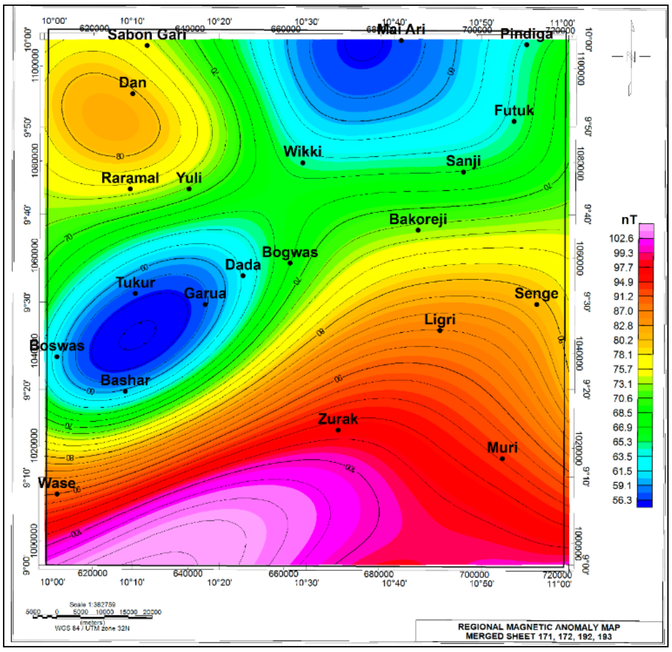

Figure 4: The Regional anomaly map of the study area variation and distributions of remnant magnetic anomaly within the area.

The residual magnetic field intensity data was gridded using the minimum curvature method to give a perfect representation of the localised/remanent/intrinsic magnetization pattern of the rock within the area, which is usually near surface granitic intrusions which might be likely accompanied by mineralization in some cases. As seen on the map, most of the residual magnetic signatures have preferred orientation in the appear NE-SW direction, the remanent magnetisation is characterised by short wavelength and sharp magnetic gradations. Other areas within the map such as Ligri, Muri, Southern and northern part of Zurak, Bogwas Wikki and the Eastern part of Wase and the Southern part of Senge as seen on the map have low to no intrusive activities this is due to the areas being predominantly sedimentary and the basement response will be at considerable depth from the surface hence the occurrences of more long wavelength magnetic signature within these areas which are regional and deep seated in nature. The regional anomaly map of the area emphasizes the area's deep-seated anomaly sources; the regional anomaly map is shown in Figure 4 and ranges in intensity from 56.3 to 102.6nT, with a trend in the NW-SE direction.

4.3 First Vertical and Second Vertical Derivatives

First vertical derivatives (1VD) are a type of vertical derivative that emphasizes shallower anomalies and can be calculated in either the space or frequency domain. Nabighian proposed employing 3D Hilbert transforms in the X and Y directions to calculate the first vertical derivative in a stable manner (Nabighian, 1984). Horizontal and vertical derivatives are used in several recent algorithms for edge recognition and depth-to-source estimates. Vertical gradients of order 1.5 were proposed (Gunn et al., 1975). The first vertical derivative map emphasizes residual near-surface anomalies, while the first vertical derivative (Figure 5) revealed near-surface source magnetic characteristics linked to geological formations. Pink coloration was used to clearly identify lithological connections, which can be observed all throughout the map area. The 1VD filter reduced wide, regional anomalies while enhancing local magnetic responses that are interpreted as structures in the area.

Figure 6 shows a second vertical derivative map of the area that shows even shallower anomaly sources than the first vertical derivative map, indicating that most of the residual anomalies seen in the area are very close to the surface, and some of them may even occur as outcrop in the study area, implying that the mineral being hosted by them will be of shallow depth and thus economical for exploration processes. The legitimacy of the presence of a surface vein harbouring mineralization can be confirmed by ground research. The majority of the structures identified in the area corresponded to structures already delineated in the geological map of the area, therefore the structures were extracted, their trend estimated, and plotted with a rose diagram, as shown in figures 7 and 8.

Structures appear to fill a bigger portion of the map, which is due to the basement and the intensity of geologic activity within the area, both of which could lead to mineralization. As shown in figure 6, the basic structural tendency in the area is NNE-SSW, ENE-WSW, and E-W. The structural patterns seen are similar to those seen on the residual map, the numerous structural trends offer us a sense of the area's deformational phase and orogeny processes, and structures also function as conduits or possible hosts for mineralization within the terrain, especially in the areas where localised/remanent mineralization was observed on the residual map.

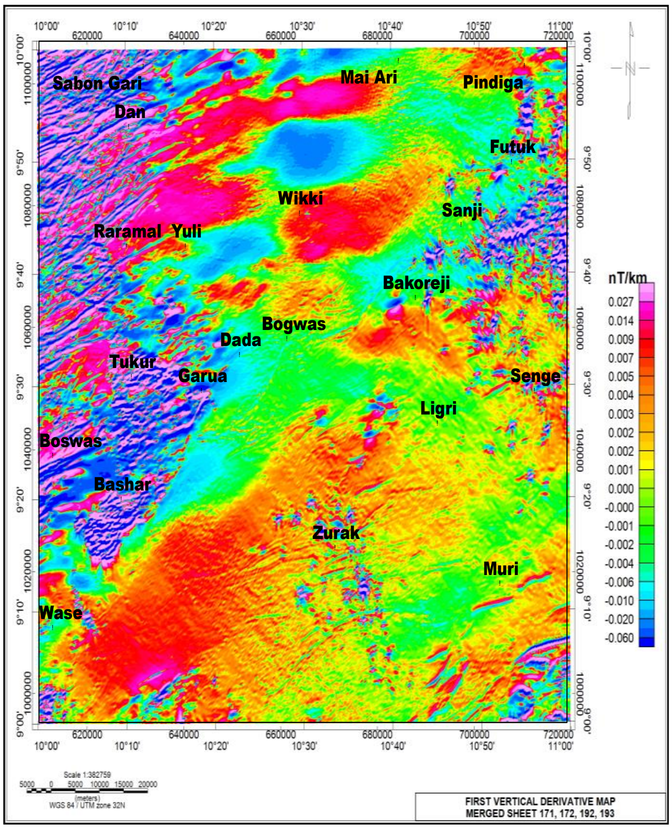

Figure 5: First vertical Derivative map of the study area, emphasises the near surface anomaly sources.

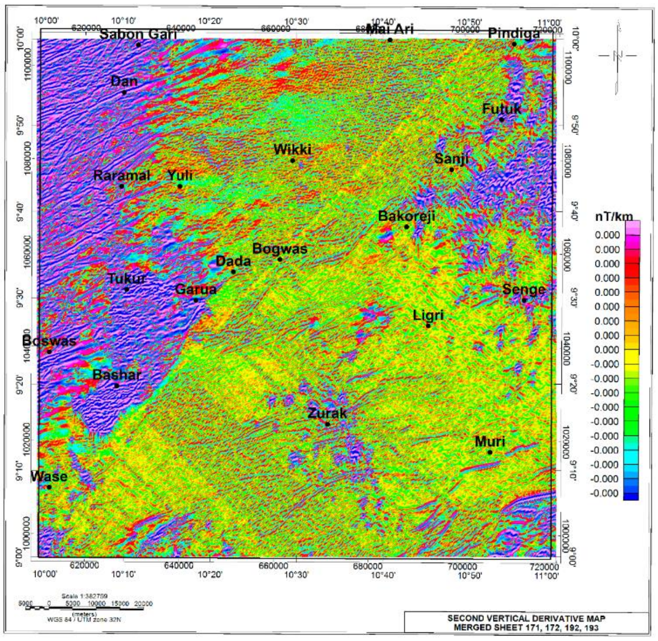

Figure 6: The second vertical derivative map of the area emphasises nearer surface anomaly than the first vertical derivative

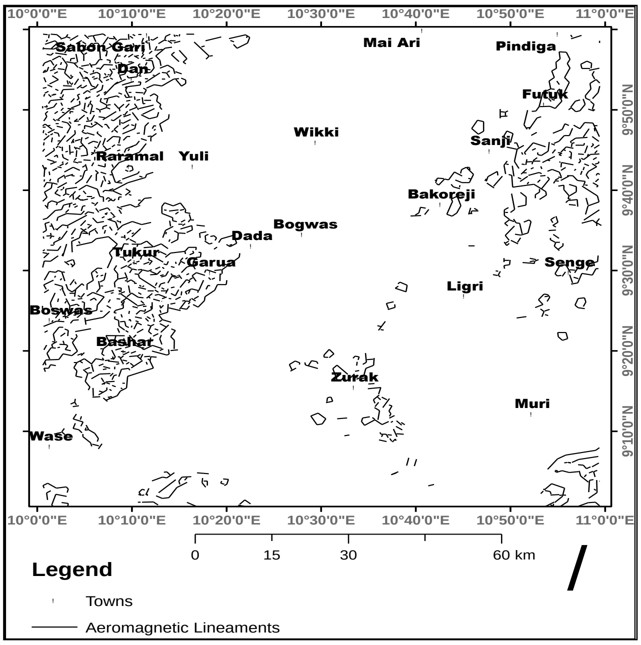

Figure 7: Extracted structures from the vertical derivatives map which are potential of the structures within the area.

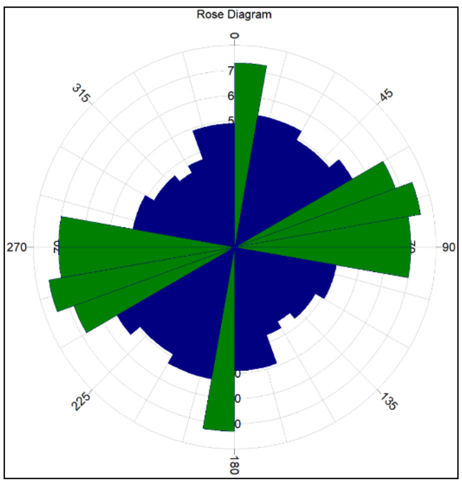

Figure 8: The Rose diagram for trend analysis host for mineralization The deformational trend in the area can be observed from the diagram.

4.4 Structural Density/Intensity

The Structural density map (Figure 9) which shows the spatial variational distribution and intensity of structural deformation from place to place over the areas, the range of distribution ranges fro High structural intensity to low structural intensity, the area with most prominent residual magnetic anomaly typically have equal structural intensity response, areas with high structural density are in red, moderate in yellow coloration and low areas are in blue coloration, the blue zone are more of the background intensity values over the area. The observed high intensity are distributed over area such as Sabon gari, Raramai, Yuli, Bashar, Tukur and the southern part of Futuk, the areas with moderate structural intensity are Northern part of Zurak, Eastern part of Wase, Futuk, Garau as seen on the map while the remaining areas falls within the low structural intensity zones.

4.5 Analytical Signal

Nabighian proposed the analytic signal as a tool for magnetic interpretation, demonstrating that its amplitude generates a bell-shaped function at each corner of a two-dimensional body with a polygonal cross section (Nabighian, 1972; 1974). Furthermore, the analytical signal of total magnetic intensity is vertically independent of the magnetic inclination of magnetization and is a better control tool for interpretation of magnetic anomalies in the middle and low altitudes than reduction to pole, allowing for more precise location of the causative bodies (Ellis et al., 2012; Lin et al., 2016). The study region's analytical signal shaded image (Figure 10) shows comparable tendencies to the residual anomaly map and the Vertical derivative map, the areas with amplitude of analytical signal are shown in dark red to pink coloration as found in areas within the Eastern, Northeastern, Northwestern of the study area also near Zurak, are implication of near surface magnetic intrusions or basement occurrences prominent within those regions. The vast range in susceptibility of rock-units in zones of fracturing/shearing/faulting or superposition by later granitic events can also be attributed to occurred within those closures in general. The trends visible in the analytic signal (amplitudes) are identical to those traced by the first vertical derivatives in Figure 5.

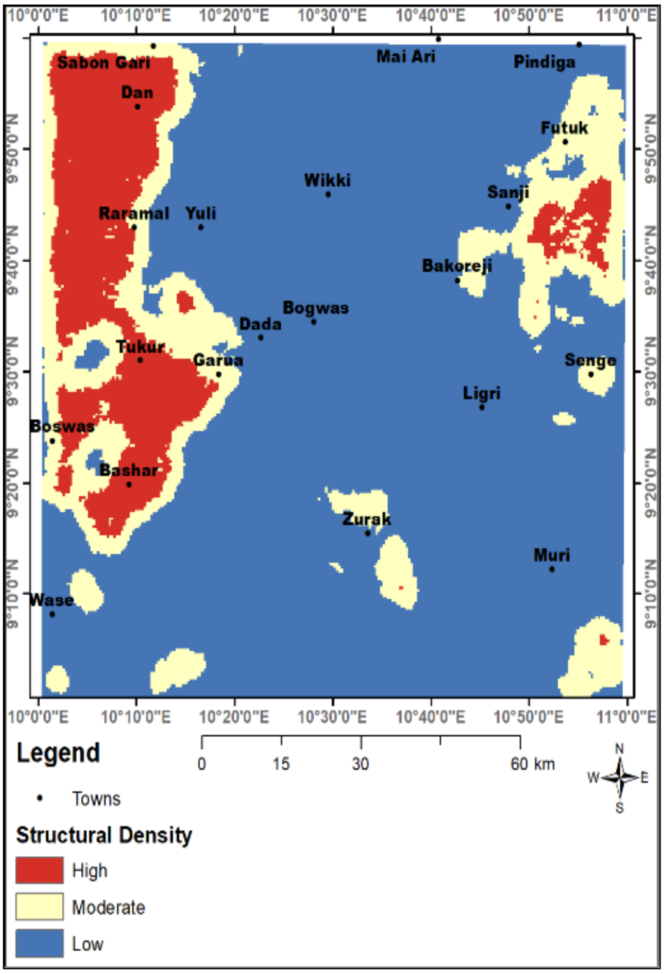

Figure 9: The Structural density map of the study area showing the various rock responses.

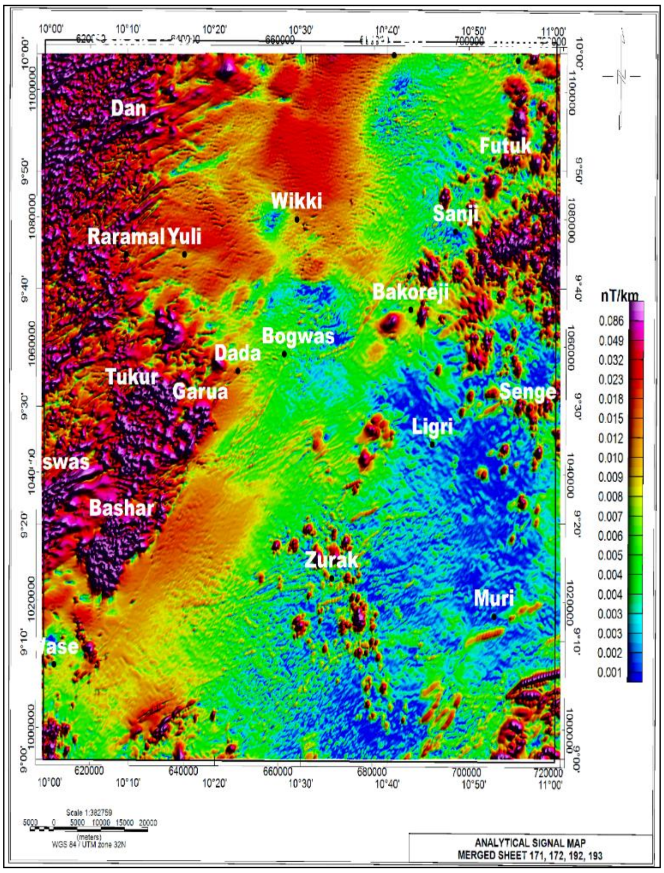

Figure 10: The analytical signal map showing the spatial distribution of extracted structures over the study area.

4.6 Spectral Analysis

Spectral analysis is a depth approach used to estimate depth to anomaly sources within a region, and it was developed by Spector and Grant's understanding of the power spectrum. If the slope of the log power spectrum shows the depth to the source, then a section with a constant slope defines a spectral band of potential field emanating from equal depth sources (Figure 11) (Spector and Grant's, 1970). As a result, it appears that band-pass filtering can isolate the contribution of these specific sources from the rest of the field (Spector and Grant, 1970; Jacobsen 1987; Cowan and Cowan 1993; Pawlowski, 1994; 1995). Because the low-wavenumber (long-wavelength) section of the power spectrum is typically steep, long-wavelength anomalies must arise from deep-seated sources.

The spectral depth analysis was carried out on the filtered map of the region by separating it into 25 spectral blocks of $37km^2$ each and labelling them block 1 to 25 (Figure 12). The average energy spectrum plot was used for each block, and a total of two depths were generated. The first is the deep magnetic depth source (Z_1) and the second is the shallow depth magnetic sources (Z_2), which are residual in nature and are caused by near surface rocks or intrusions within the area, and are also the point of interest in the exploration for near surface mineral deposits occurring within veins within veins. The first depth source is the deep magnetic depth sources which resulted from the deep basement occurring within the sedimentary zones within the study area, the deep magnetic depth (Z_1) have a depth value range from 3300m to about 5800m below the surface, as seen in Figure 13, the 3 dimensional depth model was produced, and the areas with deeper source within the deep magnetic zone are seen in light blue coloration on the map at the Senge, Futuk, Pindiga, Bashar, Boswas, Mai Ari, and Uzo-Uwani, other areas such as Zurak, Murl, Bogwas, Dada, Wikki, Sabon Gari, Dan and Bakoreji are the areas with shallower depth to magnetic source (reddish-brown) within the composite sheet of the area. The remaining area falls within the average depth within the deep magnetic source estimates, the reasons why the deeper depth appear to occurs from areas with underlying basement in this case is that the magnetic signals giving these signals has there sources from deeper part of the crust up to the surface.

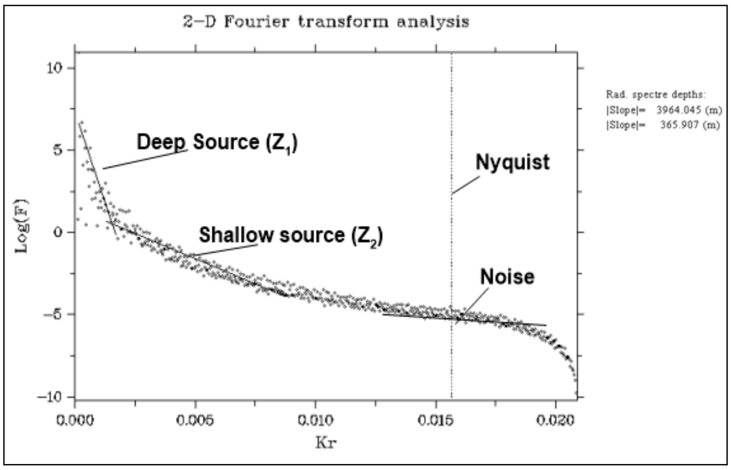

Figure 11: The average radial power spectrum was amplitude versus frequency for block 1, example was divided into 25 blocks each of 37km².

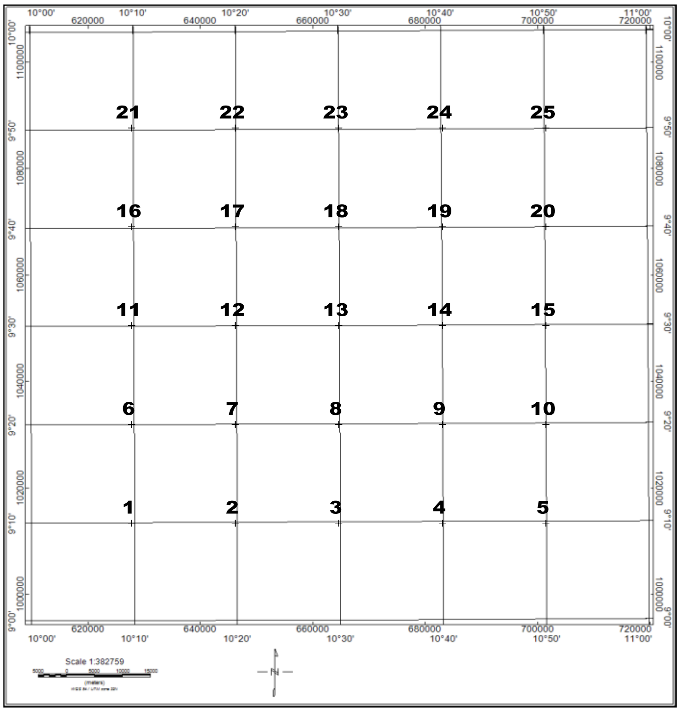

Figure 12: The spectral block schematics, the calculated and displayed in a semi-log figure of filter spectral aeromagnetic data of the area

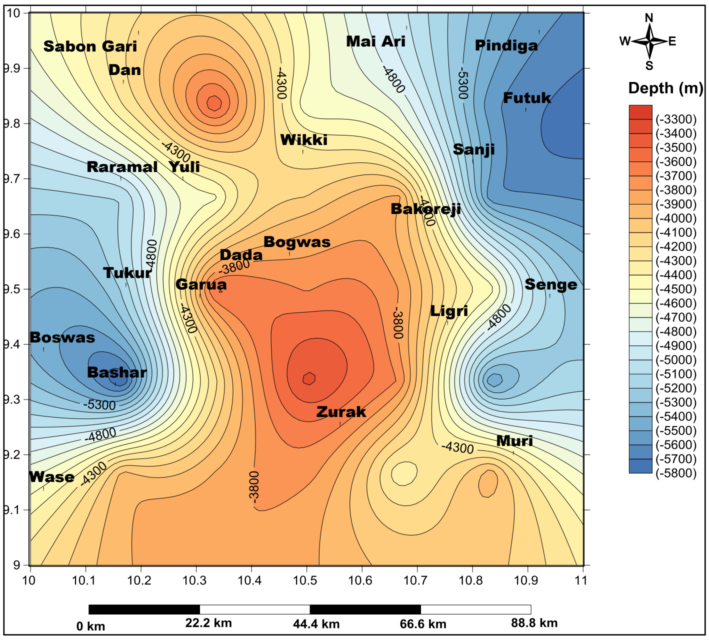

Figure 13a: The Depth estimation map of the deep magnetic basement sources (regional depth) (Z_1) of the deep magnetic basement sources (residual depth) calculated from the average energy spectrum of the area

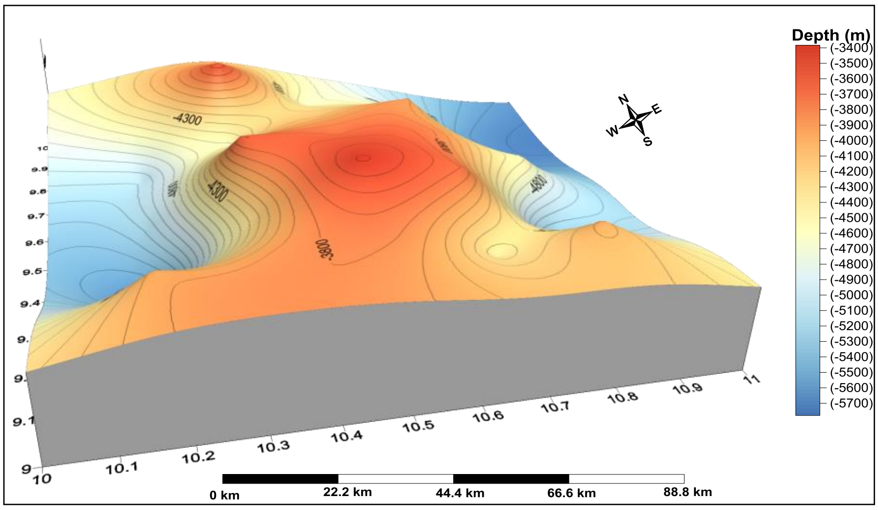

Figure 13b: The 3-dimensional Depth estimation map (Z_1) across the area calculated from the average energy depth sources across the area.

The shallow depth (Z_2) to the magnetic source ranges from 0.23km (230m) to less than 0.44km (440m) below the surface, as shown in Figure 14. The magnetic signal depth observed from the shallow depth source are from the near surface magmatic intrusions occurring within the sedimentary zone and evidences of basement outcrops within the basement zones within the area of study and these depths are apparently shallower in areas with underlying basement complex in comparison to areas underlain by sedimentary rocks, as seen in Raramal Yuli, Dan, Tukur, Futuk Muri, Sabon Gari. The depth estimates show that the areas with shallower depths within the two depth estimates for the deep and shallow magnetic source depths (Z_1 and Z_2) are those with high levels of near-surface magnetic intrusion. The thickness of the sedimentary within the upper part of the Benue trough can therefore be estimated from this analysis to be on the average of 4.2km, the sedimentary thickness and basemen depth vary from place to place, and thus the sedimentary cover is thick in some areas and thin in others within, however, the overall depth to the basement over the upper Benue is greater than 2km and this is average depth for hydrocarbon formation as the temperature requirement for Hydrocarbon formation can only be attained a this depth.

Table 1: The two depths estimation for the 25 spectral blocks Z_1 is shallow depth and Z_2 is deep source (Negative depth values is an indication of depth below the ground surface)

BLOCKS	Longitude (Deg.dec)	Latitude (deg.dec)	Deep depth Z_1 (m)	Shallow depth Z_2 (m)
1	10.16666	9.16666	-3964.05	-365.907
2	10.33333	9.16666	-3894.45	-297.414
3	10.5000	9.16666	-3762.38	-385.351
4	10.6666	9.16666	-4375.16	-394.031
5	10.83333	9.16666	-3942.39	-293.887
6	10.16666	9.33333	-5803.66	-304.363
7	10.33333	9.33333	-4230.69	-407.412
8	10.50000	9.33333	-3374.07	-334.405
9	10.6666	9.33333	-3710.84	-289.608
10	10.83333	9.33333	-5495.61	-277.990
11	10.16666	9.50000	-5176.91	-383.855
12	10.33333	9.50000	-3578.70	-363.653
13	10.50000	9.50000	-3713.44	-302.128
14	10.6666	9.50000	-3801.56	-372.772
15	10.83333	9.50000	-4456.60	-328.674
16	10.16666	9.66667	-5089.55	-233.331
17	10.33333	9.66667	-4519.10	-227.326
18	10.50000	9.66667	-4098.05	-422.275
19	10.6666	9.66667	-3878.83	-305.891
20	10.83333	9.66667	-5571.19	-347.560
21	10.16666	9.83333	-4300.12	-431.388
22	10.33333	9.83333	-3513.55	-343.316
23	10.50000	9.83333	-4576.54	-270.984
24	10.6666	9.83333	-4707.32	-421.092
25	10.83333	9.83333	-5562.43	-267.267
	Maximum		-5803.66	-431.388
	Minimum		-3374.07	-227.326
	Average		-4363.89	-334.875

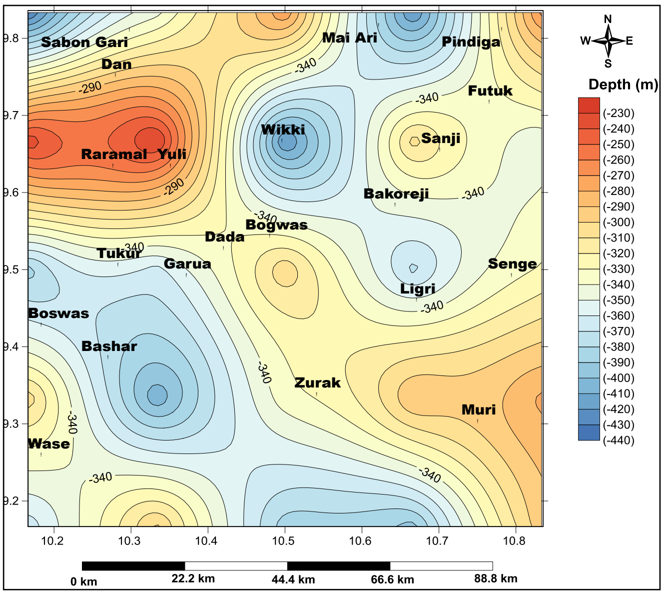

Figure 14a: The Depth estimation map of the shallow magnetic basement sources (residual depth) (Z_2) across the area calculated from the average energy spectrum of the area, showing the variation in basement depth sources across the area.

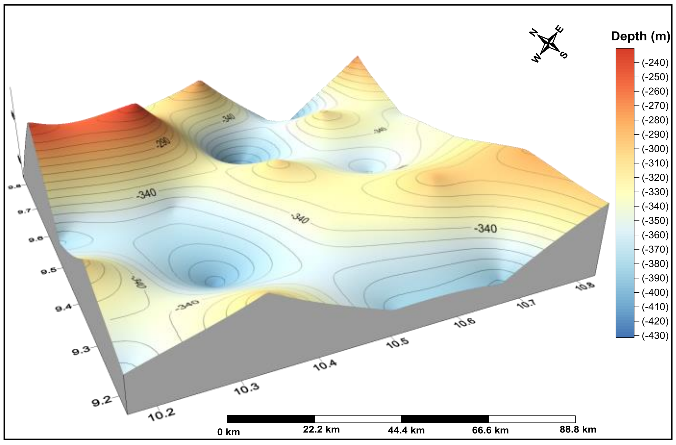

Figure 14b: The 3-dimensional Depth estimation map of the shallow magnetic basement sources (residual depth) (Z_2) across the area calculated from the average energy spectrum of the area, showing the variation in basement depth sources across the area.

5. Conclusion

Most of the delineated structures found within the basement occurring region and some part of the sedimentary region where the occurrences of sandstone are prominent as seen in the areas around Sabon gari, Raramai, Dan, Yuli, Garua, Bashar, Boswas Tukur and the southern part of Futuk which area predominantly basement and the areas such as part of Zurak, part of Wase, Near Ligri, Senge, Pindiga (NE part of the composite sheet) and Southern part of Muri which resulted from latter near surface magmatic intrusive giving rise to the observed high magnetic signature which are due to the presence of high composition of magnetic minerals of magnetite components with possible occurrences of mineral rich magmatic deposit emplaced as fracture/faults filling mineralization as the prominent Zurak lead deposits occurring within the sedimentary rock region , the preferred orientation of the structural features are in the NNE-SSW, ENE-WSW and E-W direction.

The depth to the basement over the study area covering part of the upper Benue trough estimated using the spectral method gave a two depth to basement type consists of the source intensity from shallow depth (Z_2) and the deep (Z_1) magnetic from deep basement region, the deep magnetic intensity depth (Z_1) ranges in values from 3.3km to 5.7km and average of 4.2km and a depth range of 0.23km to 0.43km for the shallow depth intensity of magnetic source (Z_2), which is within the recommended depth range for the standard depth of formation of Hydrocarbon publications which ascribed an average depth of 2km as required for the right sediments to reach the right geothermal gradients requited for Hydrocarbon formation also considering work on Niger deltas where the relationship of geothermal gradient with the hydrodynamics of the basin was critically considered a direct correlation of the temperature of formation of hydrocarbon to the depth of oil formation to be between 2300m and 6860m and the temperature interval of 65 °C to 150°C obtainable within such depth ranges.

Hydrocarbon formation temperature is largely influenced by factors such as lithology, geothermal conductivity, fluid flow, sedimentary digenesis, depth to basement, sedimentary thickness or even heat distribution, source rock availability, right organic matter components, reservoir rock, seal, trap rock, migration and Timing required are very vital role in the petroleum system of a basin should be given critical consideration, other factor such as the presence of high-level magmatic intrusion activities which is more prominent within this part of the Upper Benue trough can also lead to the high deviation from that which was obtainable in term of petroleum prospects and yields prevalence within the Niger delta basin which has all the complete petroleum play system in place and also characteristic low magmatic intrusive activities.

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