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Defining the Geometry of Anambra and Afikpo Basins, Southeastern Nigeria, Using High Resolution Aeromagnetic Data

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ABSTRACT: Analysis of high resolution aeromagnetic data was carried out to evaluate the basin geometry of the Southern Benue Trough, Anambra and Afikpo Basins. The total magnetic intensity data covering the area was processed and filtered using Upward Continuation and Source Parameter Imaging. The total magnetic intensity map shows that the field strength values range from ≥ 7891 nT to < 7806.9 nT. The highest field strength values correspond to igneous intrusives and areas with the basement close to the surface; moderate values correspond to Cretaceous sediments and the least values correspond to Tertiary rocks, Alluvial deposits and regions with thick sediment cover. Sedimentary thickness within the study area ranges from 0.2 km within the Southern Benue Trough to 10.0 km within the Anambra Basin. This study established that Afikpo Basin is independent of Anambra Basin with physical barriers separating them in form of basement uplift and therefore be classified as an independent inland sedimentary basin in Nigeria. The basement uplift between the Anambra Basin and Southern Benue Trough stretches from Aguamede through Nkalagu to Udi community with an average depth of 0.65 km. The uplift between Afikpo Basin and Southern Benue Trough stretches from around Uburu to Lekwesi with an average depth of 0.4 km. The edge of Southern Benue Trough is defined to be around Lekwesi down towards Okigwe. The non-continuity of the basin boundary to the surface is as a result of post subsidence due to post depositional processes and post Santonian tectonics within the study area.

KEYWORDS: Southern Benue Trough, Anambra Basin, Afikpo Basin, Airborne Magnetic, Basin Geometry, Basin Boundary, Upward Continuation, Source Parameter Imaging, Physical Barriers, Basement Uplift.

I. INTRODUCTION

The Benue Trough was installed as pull-apart sub-basins generated by sinistral strike-slip displacements inherited from pre-existing transcurrent fault zones in the Pan African mobile belt.[1], [2] It is part of the much larger West and Central African Rift System [3], [4] which originated during the breakup of the Gondwana supercontinent and the opening up of the southern Atlantic and Indian Oceans in the Jurassic.[5], [6], [1], [3] [7] suggests that the southern portion of the Benue Trough was longitudinally faulted with its eastern half subsiding preferentially to become the Abakaliki depression. The thermo-tectonic event during the Santonian created the Afikpo Basin (east) and Anambra Basin (west) of the Anticlinorium.[7], [8], [9] The uplift of the early Cretaceous sediments in the Abakaliki area led to an opening of new depocentres at the western and southeastern parts of the Abakaliki area.[7] The western part is regarded as the Anambra basin while the southern part is regarded as the Afikpo Basin.

There has been a controversy on the status of the Anambra and Afikpo Basins. [7], [9] stated that the basins should be considered independent since they occurred at either flanks of the parent southern Benue Trough. [10] stated that the two basins should be treated as one since they originated from the compressional history/ stage of the Southern Benue Trough. [2] also stated that the Anambra and Afikpo Basins should be considered as one basin called the "Anambra Basin" on the bases that they both resulted from the same Santonian thermo-tectonic event and there is really no

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physical separation or barrier between the two areas, therefore it appears that there is no tectonic definition separating the depression from the area to the northwest of the rift.

The theories on the basins are based on Geology/field mapping and stratigraphic correlation (Figure 1) of the sediments of both basins but occurrences as depressions on both sides of an uplifted area (Abakaliki Anticlinorium) creates doubt on the possibility of both basins being one. It should be noted that field observation cannot independently define the extension and basin geometry without geophysical modelling or core drilling.

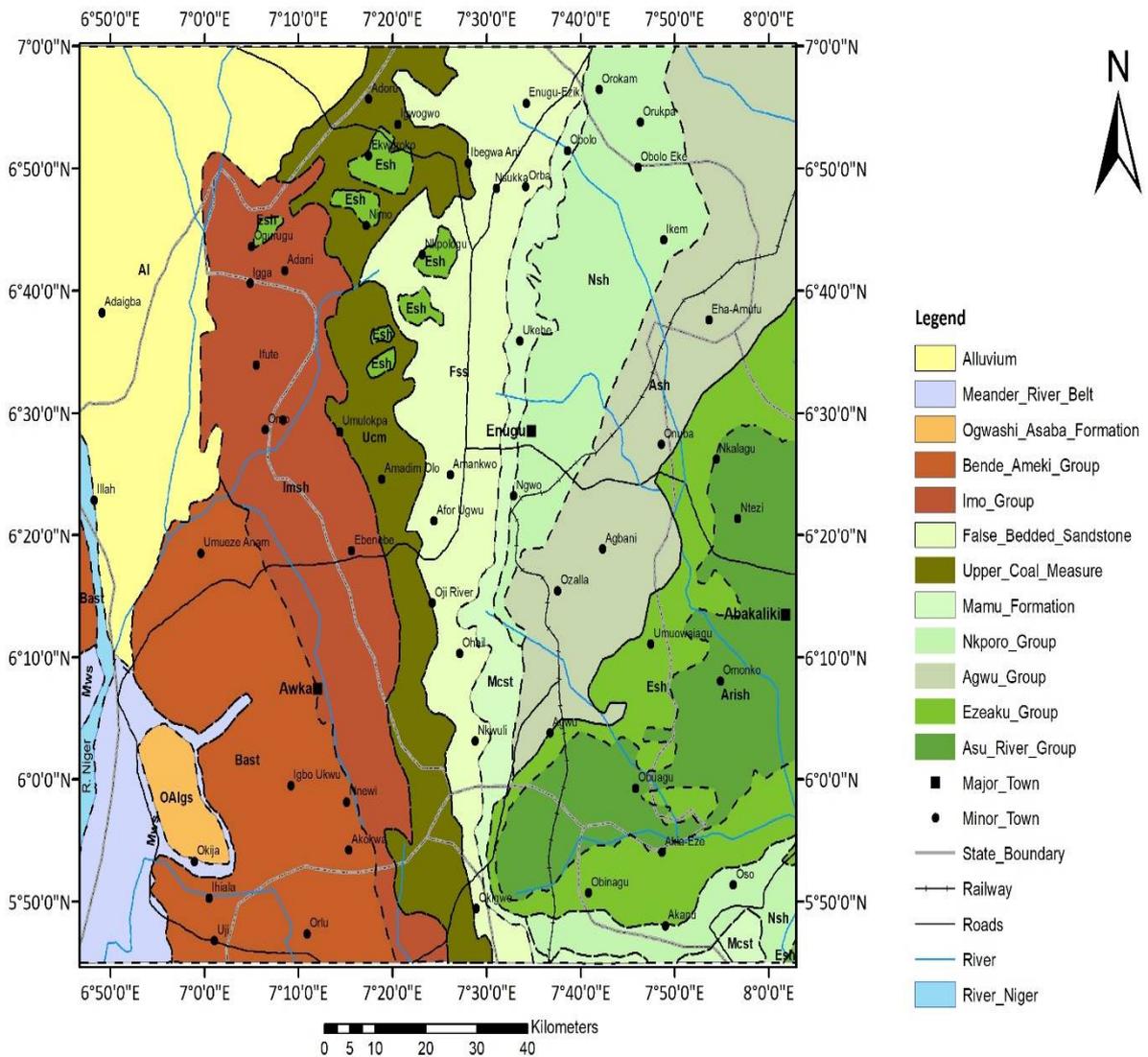


Figure 1: Geology map of the study Area

Previous works on geophysics within the study area [11], [12], [13], [14], [15], [16] dwelt more on the basins' origin, sediment thickness, densities of sedimentary rocks and petroleum potentials of the area. [17] used gravity model to define the relationship of the basins, they concluded that the basins should be regarded as independent basins stating that the Abakaliki Anticlinorium demarcates the Anambra and Afikpo Basins. [17] also suggests that only geophysical

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approach can be used to establish the existence of these boundaries. Therefore, the aim of this research is to define the boundaries of the post Santonian basins (Anambra – Afikpo Basins) around the southern Benue Trough, Southeastern Nigeria, using magnetic method, to obtain a new view of the basins’ relationship. The objectives include qualitative interpretation of the airborne total magnetic intensity map, definition of sediment thickness and its distribution within the study area using advance Source Parameter Imaging (SPI) technique which has been proven to have an accuracy of +/- 20% in tests on real data sets with drillhole control. [18], [19] These objectives would enhance the definition of the geographic positioning of the basement boundaries between the basins.

II. THE STUDY AREA

The area is bounded by longitudes 6°45' 00"E to 8°00' 00"E and latitudes 5°30' 00"N to 6°30' 00"N. The study area covers approximately 6,050 km². It covers parts of Anambra, Ebonyi, Enugu, Imo and Abia states. The area can be accessed through Abakaliki - Afikpo Expressway, Enugu - Onitsha Expressway and Enugu - Nsukka Expressway (Figure 2). It falls within the humid tropical region with two distinct seasons, the rainy season, from March to October, and dry season, from November to March.

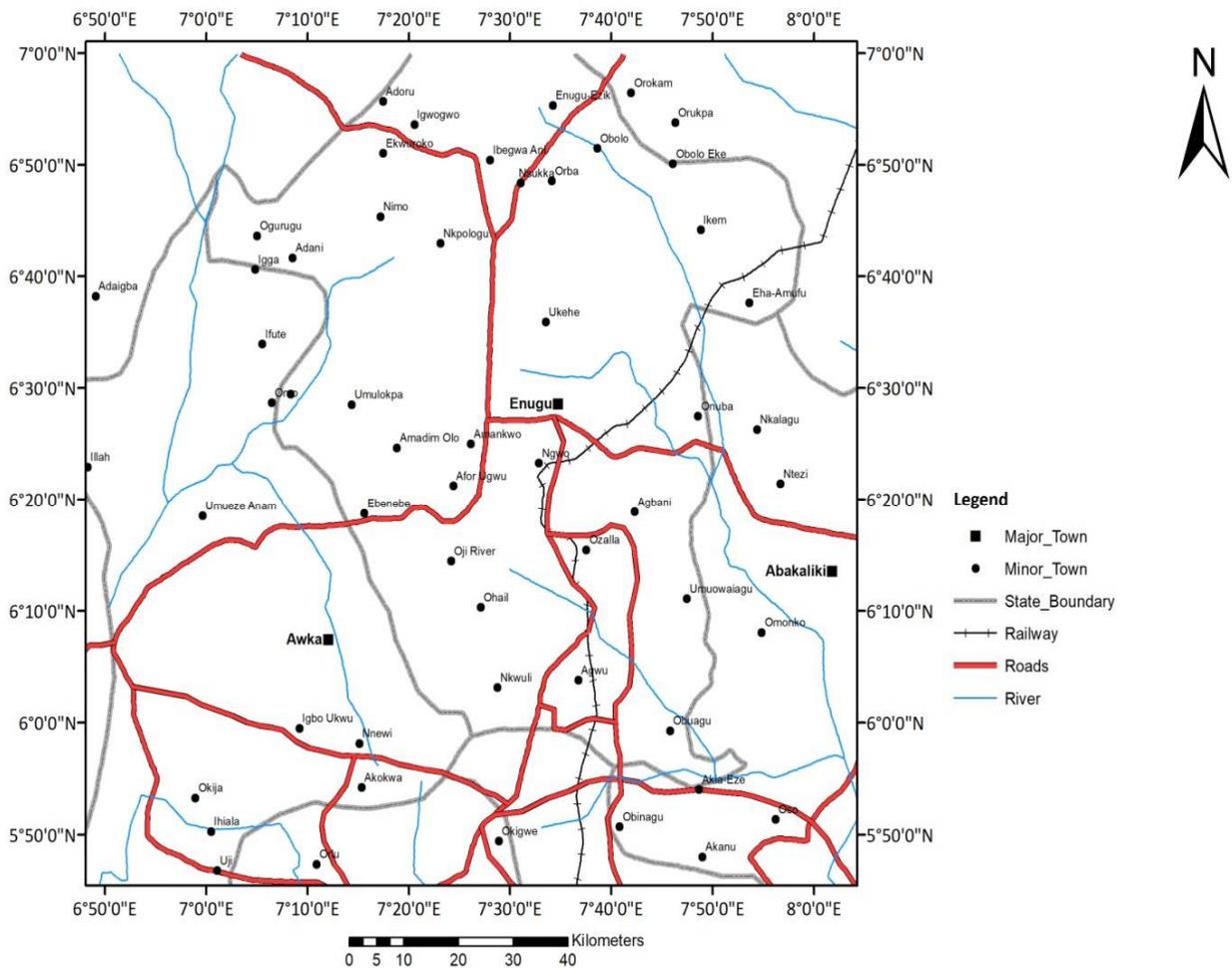


Figure 2: Location map of the study Area

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III. MATERIAL AND METHOD

Data Acquisition

The aeromagnetic dataset used for this study is from the high-resolution airborne survey coverage in Nigeria carried out by Fugro Airborne Survey at 826,000 km along a series of NW – SE flight lines of magnetic and radiometric surveys flown at 500 m line spacing and 80 m terrain clearance in 2009 and was obtained from the Nigerian Geological Survey Agency. The parameter measured was the total magnetic field. It consists of nine square blocks of map sheets (286, 287, 288, 300, 301, 302, 311, 312, and 313) of square block which represents a map on the scale of 1:500,000, covering an area of 27,225 km². The total magnetic intensity grid was generated using a minimum curvature algorithm at a grid cell size of 1,000 m. The digitized data were filtered using a low pass Fourier domain sub-routine filter to eliminate unwanted wavelengths and to pass longer wavelengths. Reduction-to-pole (RTP) transformation was applied to the aeromagnetic data to minimize polarity effects.

Data processing

Upward Continuation

Upward continuation is a filter which transforms the total magnetic field on a surface to a higher level. It is an operation that shifts the data by a constant height level above the surface of the earth (or the plane of measurements). This reduced the effect of shallow bodies, hence eliminating the high frequency bodies and enhancing deeper bodies. It was used to estimate the large scale or regional (low frequency or long wave length) trends of the data; hence the transformation reduces the effect of shallow bodies with respect to deep causative sources. [20] showed the expression for upward continuation from Green's third identity of a potential field (U) measured on a level $z = z_0$ at a point $P = (x, y, z_0 - \Delta z)$;

$$U(x, y, z_0 - \Delta z) = \frac{\Delta z}{2\pi} \tag{1}$$

$$\frac{\Delta z}{2\pi} = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \frac{U(x', y', z_0 - \Delta z)}{[(x-x')^2 + (y-y')^2 + \Delta z^2]^{\frac{3}{2}}} dx' dy', \Delta z > 0 \tag{2}$$

The two dimensional Fourier Transform of a function is given as;

$$F(k_x, k_y) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x, y) e^{-i(xk_x + yk_y)} dx dy \tag{3}$$

Applying the Fourier function (equation 3) to equation 2 gives:

$$F[U_u] = F[U]F[\varphi_u] \tag{4}$$

Where;

$$\varphi_u(x, y, z_0 - \Delta z) = \frac{\Delta z}{2\pi(x^2 + y^2 + \Delta z^2)^{\frac{3}{2}}} \text{ is the analytical expression of } F[\varphi_u] \text{ and } F[U_u] \text{ is the Fourier transform of the}$$

upward continued field.

Upward continuation operator is expressed in the wave number domain

$$F[\varphi_u] = e^{-\Delta z|k|}, \Delta z > 0 \tag{5}$$

Where; $k = \sqrt{k_x^2 + k_y^2}$

A. The filtered grid is transformed from the wave number domain back to the space domain through the following formula:

$$F(k_x, k_y) = \frac{1}{4\pi^2} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} F(k_x, k_y) e^{i(xk_x + yk_y)} dx dy \tag{6}$$

Source Parameter Imaging (SPI)

This technique was developed by [21], [18]. 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 utilizes the relationship between source depth and the local wave number (k) of the observed field, which can be calculated for any point within a grid of data via horizontal and vertical gradients.[21] Hence SPI method requires first- and second-order derivatives and is thus susceptible to both noise in the data and to interference effects. The SPI method [21] estimates the depth from the local wave number of the analytical signal. Figure 3 is a right angle triangle obtained from Argand Diagram and used to simplify the following expressions in SPI method.

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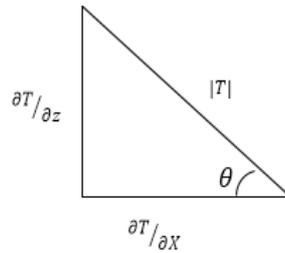


Figure 3: Right Angle Triangle Obtained from Argand Diagram

$$|T| = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2} \quad (7)$$

Where:

$|T|$ = The absolute magnetic wave amplitude. θ is the phase spectrum or phase angle defines by:

$$\theta = \tan^{-1} \left(\frac{\frac{\partial T}{\partial z}}{\frac{\partial T}{\partial x}} \right) \quad (8)$$

In the analysis of potential fields, it is more convenient to use wave number, denoted by k . [21] The wave number concept is used to define the magnetic source.

$$k = \frac{\partial \theta}{\partial x} \quad (9)$$

Substituting equation (8) into (9) we have

$$k = \frac{\partial}{\partial x} \tan^{-1} \left(\frac{\frac{\partial T}{\partial z}}{\frac{\partial T}{\partial x}} \right) \quad (10)$$

Differentiating equation (10), we have

$$k = \frac{1}{|T|^2} \times \left(\frac{\partial T}{\partial x} \frac{\partial^2 T}{\partial x \partial z} - \frac{\partial T}{\partial z} \frac{\partial^2 T}{\partial x^2} \right) \quad (11)$$

By considering a surface, the expressions for the vertical and horizontal components of the magnetic signal are given by [22] as follows;

$$vertical = \frac{\partial T}{\partial z} = 2KFc \sin d \times \frac{x \cos(2I-d-90) - h \sin(2I-d-90)}{h^2+x^2} \quad (12)$$

$$horizontal = \frac{\partial T}{\partial x} = 2KFc \sin d \times \frac{h \cos(2I-d-90) + x \sin(2I-d-90)}{h^2+x^2} \quad (13)$$

Where

K = Susceptibility contrast

F = Magnitude of the ambient field

$c = 1 - \cos^2 I \sin^2 \alpha$ = Ambient field declination

I = Inclination of the ambient field

d = Angle of dip of the body and h is the depth to the top of the magnetic contact.

Substituting equations (11) and (12) into equation (13) and solving accordingly;

$$k = \frac{h}{h^2+x^2} \quad (14)$$

At directly over the edge of the magnetic source, $x = 0$, bearing in mind that the wave number is independent of the magnetization direction; that is, at the maxima of the local wave number, the peaks of the magnetic anomaly outline the magnetic source edges at $x = 0$. [21] defined the depth (h) at this point as

$$h = \frac{1}{k} \quad (15)$$

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IV. RESULTS AND DISCUSSION

The processed data were analyzed both qualitatively and quantitatively. Qualitative interpretation involved visual inspection of the colour spectrum bands and contour maps. From these, inferences were drawn on both the geology of the area and lithologic boundaries. The quantitative interpretation involved the calculation of depth to anomaly sources across the study area using source parameter imaging (SPI) method.

The total magnetic intensity (TMI) map of the area (Figure 4) shows highest field strength values ≥ 7891 nT (corresponding to the pink colours on the map) occurring at the northern, eastern, western and southwestern parts of the study area. They are interpreted as response from igneous rocks associated with Abakaliki, Afikpo, Ishiagu and Okigwe areas. The intermediate field strength values range (7806.9 – 7890) nT, (corresponding to the red colours on the map) represent the lower – middle Cretaceous sedimentary rocks of the study area. The lowest field strength values (< 7806.9 nT) (corresponding to the blue colours on the map) observed at the northern parts of the TMI map of the study area, represent sedimentary deposits of the uppermost Cretaceous – Tertiary ages and Alluvium. The zones of low magnetic intensities are defined as response from deep seated magnetic sources with thick sediments/ sedimentary rocks cover. The zones of intermediate magnetic intensities are interpreted as response from highly consolidated ferruginized sediments or near surface magnetic sources. The zones of high intensities are response from shallow depth or surface magnetic sources of possible igneous rocks/intrusives and intense ferruginized sediments know to be associated with the study area.[23], [2] High frequency bodies are observed at the eastern and southern parts of the study area. The causative body of this high frequency are the igneous intrusives associated with the Southern Benue Trough, Anambra Basin and Afikpo Basin.

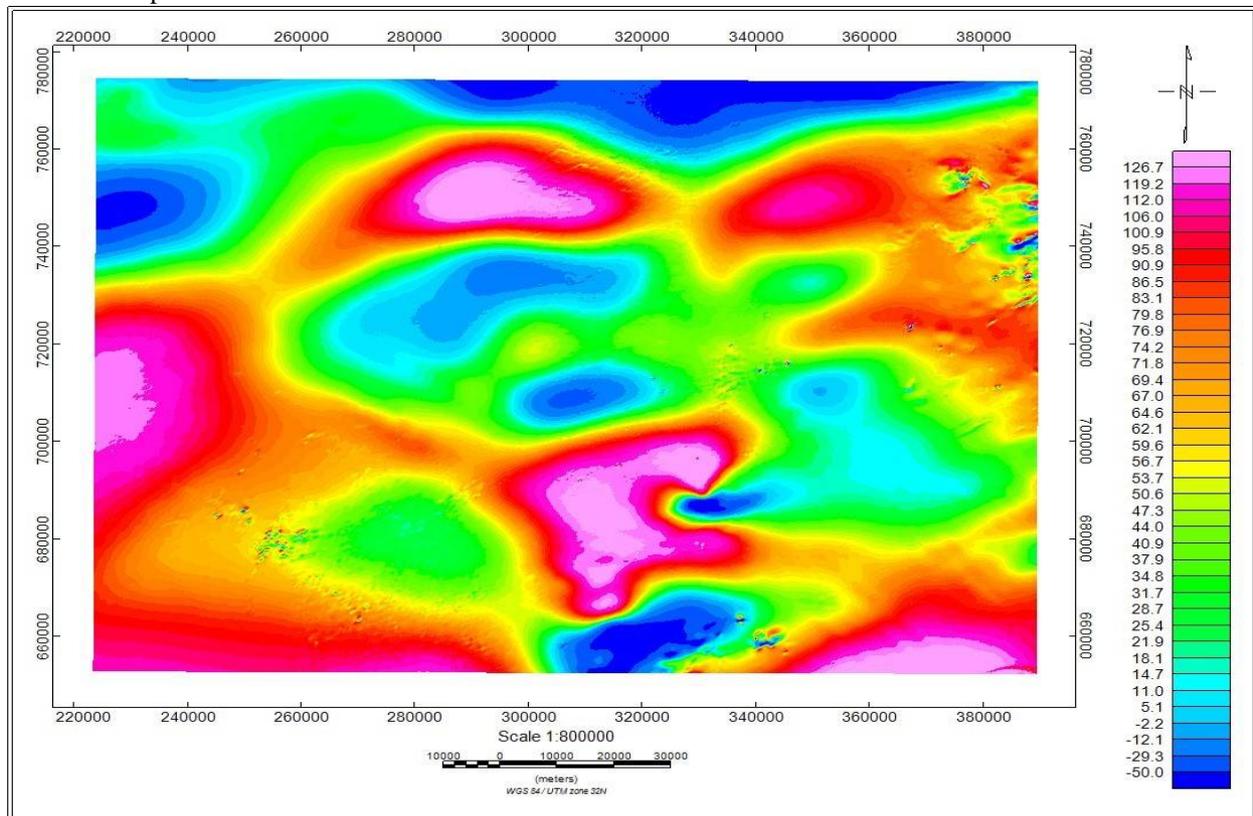


Figure 4: Total Magnetic Intensity (TMI) Map of the Study Area

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The TMI data was upward continued to a height of 400 m to obtain the map in Figure 5. The choice of 400 m for the upward continuation in this study is because the Abakaliki Anticlinorium is regarded as a thin sediment basin with average depth to basement of 500 m. Hence, upward continuing the data above this height will greatly affect the result. The upward continued data greatly enhanced geologic bodies with contrasting magnetic susceptibility; they also reflected the connectivity of bodies with high susceptibility within the area. High frequency bodies were suppressed but few were still observed at the eastern and southern parts of the study area. These bodies were interpreted as intrusives at depths greater than 400.0 m but less than 1.0 km.

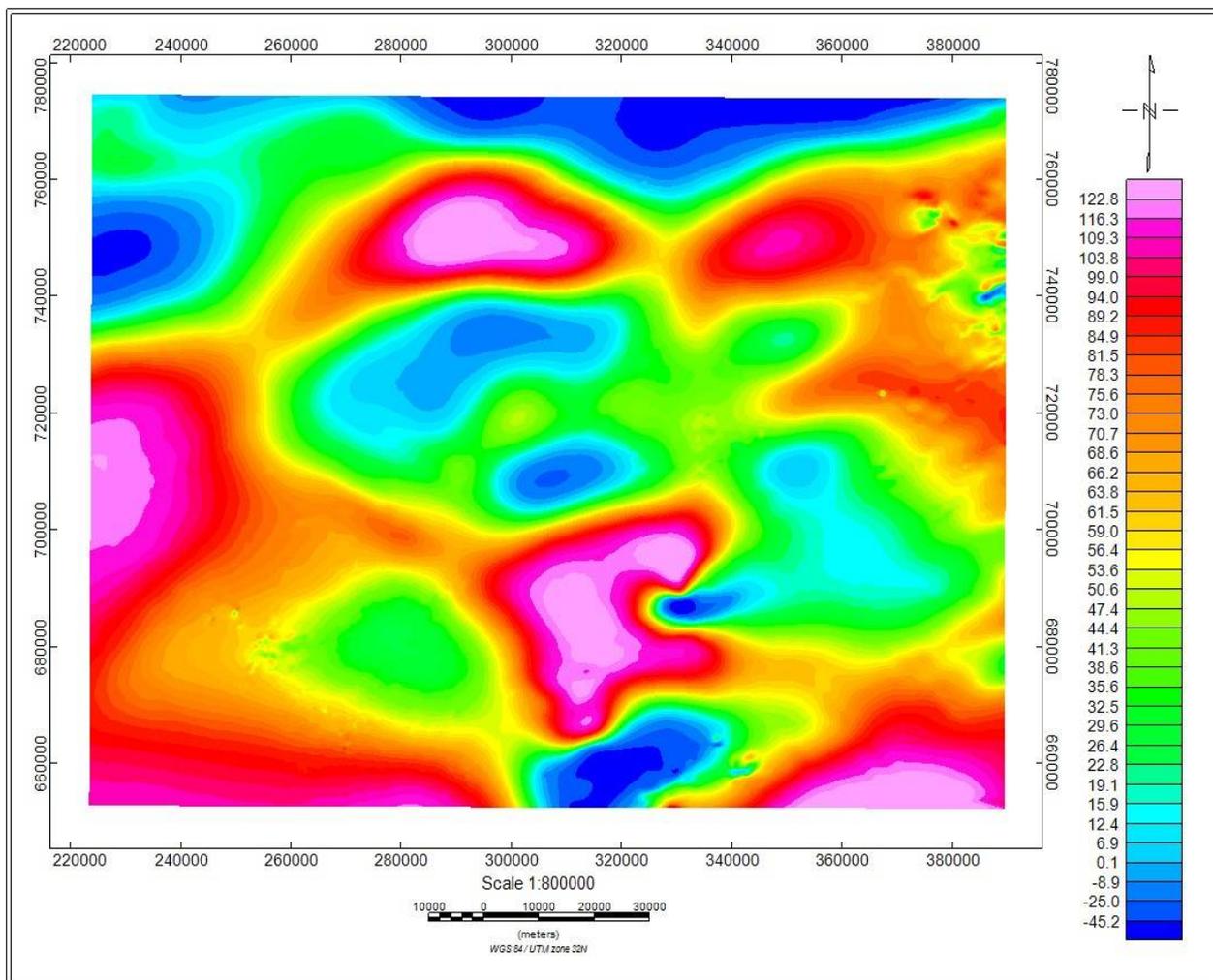


Figure 5: Upward Continued Map of the Study Area

The SPI map (Figure 6) indicates variable depths to basement rocks which is synonymous to thickness of over-burden sediment and this has a very important significance as regards to the hydrocarbon generation potential.[24] Areas with thick sedimentary cover include the northern, western, southwestern and southeastern parts of the study area, corresponding to Anambra and Afikpo Basin sediments. The intermediate sediment thickness is observed at the central part of the study area and it gets thinner eastward; hence, the sediment thickness is observed to get thinner towards Abakaliki Anticlinorium. The shallowest sediment thickness is observed at the Abakaliki Anticlinorium located at the

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eastern part of the study area. The basement of the Abakaliki Anticlinorium looks to be oriented in the NE-SW direction extending from Okigwe at the SW to Abakaliki at the SE.

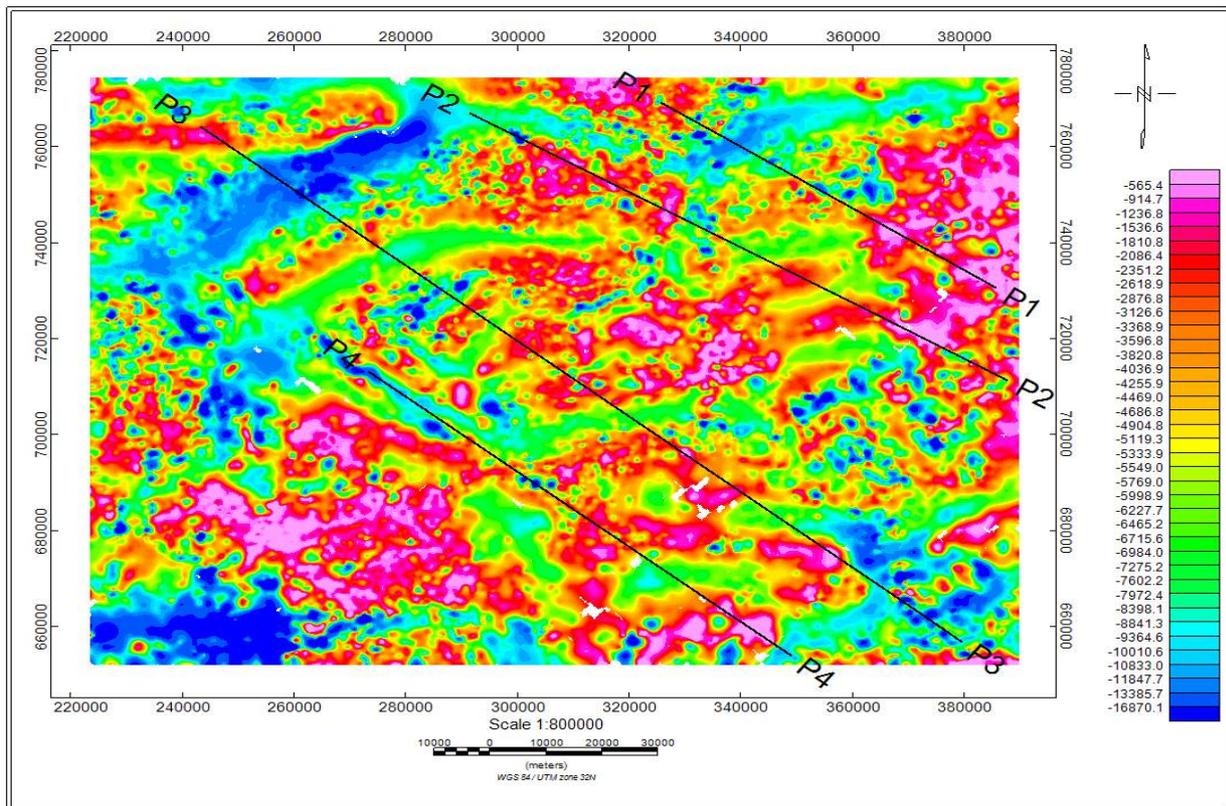


Figure 6: Source Parameter Imaging (SPI) Map of the Study Area

Four profiles P1, P2, P3 and P4 were cut along the study area (Figure 6), in order to evaluate the basins' boundaries within the area. Figure 7 is a cross section for profile 1 (P1) in the study area. The profile reflects the degree of undulation of the basement surface and sediment thickness variation in the area is also reflected. The sediment thickness ranges from 0.2 km to 8.0 km. The profile has the Anambra Basin to the west and the Southern Benue Trough to the east. There is a depression of about 6.0 km before an abrupt high/uplift of about 0.3 km to the surface. This marks the boundary between the Anambra Basin and Southern Benue Trough. The uplift is about 4.0 km wide and separates the two basins. This shows that the tectonic forces that led to the basin formation had some local concentration that resulted in an intense deformation of the basin, in this case, the Abakaliki Anticlinorium which is evidence in this profile. The uplift between the Anambra Basin and Abakaliki Anticlinorium suggests the demarcation of the Anambra Basin and the Benue Trough. This boundary is located around Aguamede in Enugu State with the Anambra Basin to the west of it and Benue Trough to the east.

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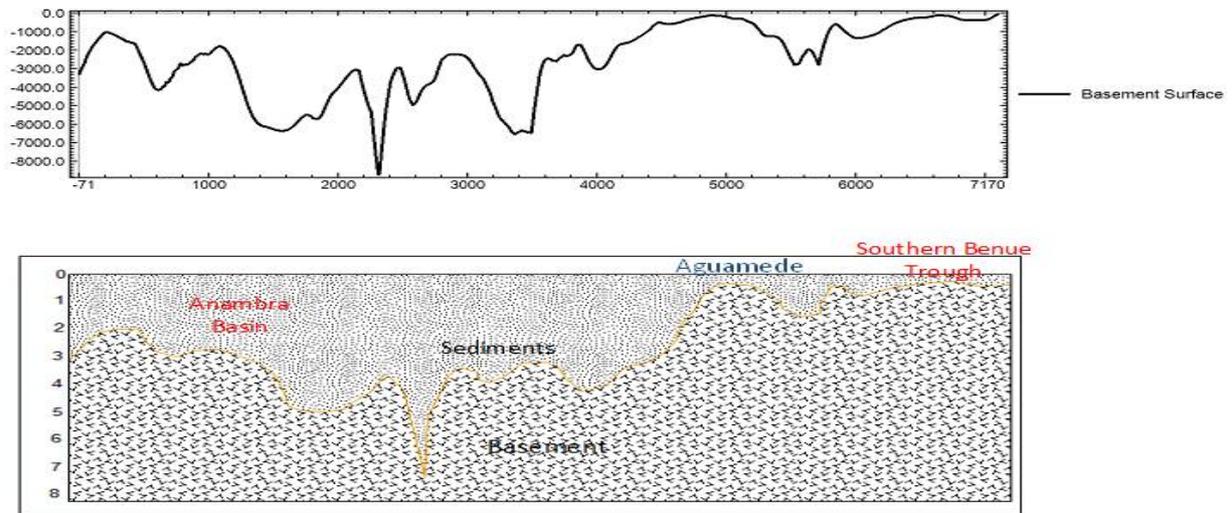


Figure 7: Cross Section of Profile 1

Profile 2 (P2) (Figure 8) shows two basins interpreted as an extension of the Anambra and Abakaliki Anticlinorium of profile 1. The Anambra basin is at the west of the profile while the Abakaliki Anticlinorium is at the east. The boundary uplift is about 0.3 km deep but with a reduced width of 0.8 km. The depression before and after the boundary is also observed. The boundary is located at the north of Nkalagu, Ebonyi State.

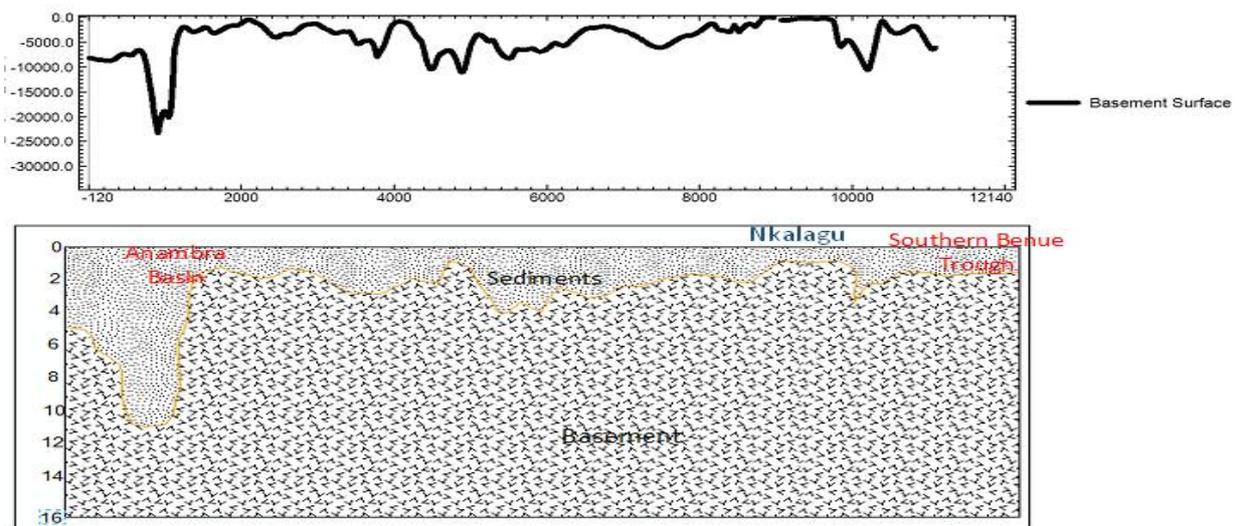


Figure 8: Cross Section of Profile 2

Profile 3 (P3) (Figure 9) shows a separation of three major basins within the study area. The basins include the extension of Anambra and Southern Benue Trough (Abakaliki Anticlinorium), and the Afikpo Basin. The Anambra Basin has average sediment thickness of 7.0 km, the southern Benue trough is deeper along this profile with an average depth of 3.0 km and the Afikpo basin has an average sediment thickness of 5 km. The profile passes through the deepest part of the Anambra Basin at Adaigba (Kogi State) and deepest part of the Southern Benue Trough at Umuekwule (Abia State). The uplift (boundary) separating the Anambra and Southern Benue Trough is located around Udi (Enugu State) with depth of about 0.7 km. Hence, the boundary is deeper when compared with its depth along

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profile 1 and 2. The uplift separating the Southern Benue Trough and Afikpo Basin is defined to be near surface, with a depth of 0.4 km around Uburu (South of Uburu) in Ebonyi State. The profile model shows the separation of the Anambra and Afikpo Basin by the Abakaliki Anticlinorium (Southern Benue Trough).

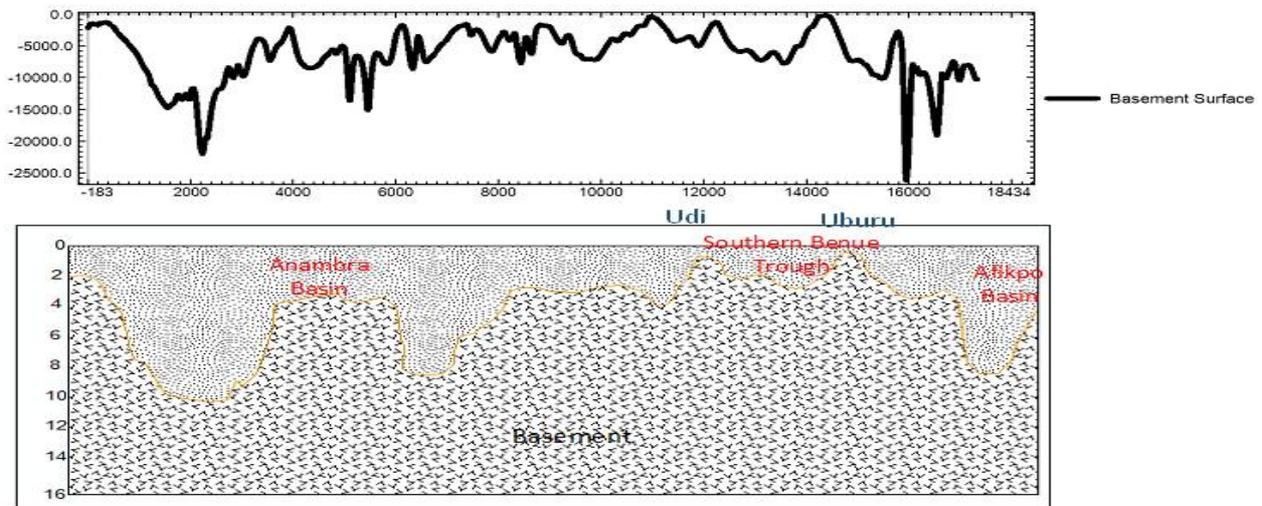


Figure 9: Cross Section of Profile 3

Profile 4 (P4) (Figure 10) also reflect the boundary between the three basins. The depth to the basement uplift (boundary) between the Anambra and Southern Benue Trough (Abakaliki Anticlinorium) is about 0.3 km while that at the boundary between Southern Benue Trough and Afikpo Basin is 0.4m. The Southern Benue Trough within the profile is thin with width of about 1.0 km and sediment thickness of 0.7 km. This indicates that this profile cuts across the edge of Southern Benue Trough at Lekwesi area of Abia State.

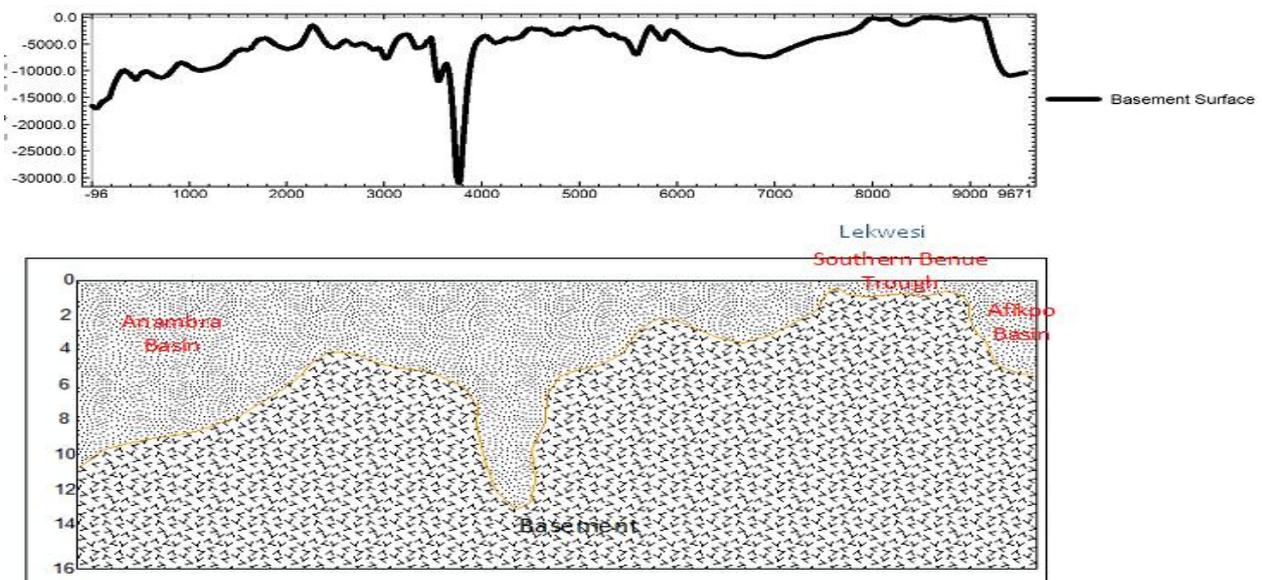


Figure 10: Cross Section of Profile 4

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Afikpo Basin is considered as part of the Anambra Basin on the basis that they are products of the same thermo-tectonic event (Santonian Event).[2] [2] also stated that there is no physical separation or barrier between the two basins and there does not appear to be any tectonic definition of that area into a depression separate from the area to the northwest. Profile 3 (P3) and 4 (P4) which cut across all the three basins have shown that there is a boundary demarcating the basins. The defined basement uplift separating the Anambra Basin and Southern Benue Trough, and separating the Southern Benue Trough and Afikpo Basin is an evidence of the independence of each basin from the other. [7], [25] claimed that the Southern Benue Trough underwent depositional activities such as sediment unloading, reworking and post Santonian tectonics which had pushed the boundaries vertically downward; hence this explains the non-continuity of the basement boundary to the surface. [1] stated that the Benue Trough continued in the southern end, even below the Niger Delta Basin; therefore, it would be inappropriate to say that the Afikpo Basin is not a distinct Basin. The results obtained in this study are in agreement with the work of [17], and both suggest that Afikpo Basin be classified as a major and substantive inland sedimentary basin in Nigeria different from the Anambra Basin.

V. CONCLUSION

The aeromagnetic data covering the southern Benue Trough was processed and filtered using Upward Continuation and Source Parameter Imaging techniques to enhance and define Basin boundaries. The results showed that the areas with high total magnetic field intensity values corresponds to igneous intrusives and areas with the basement closed to the surface, while the moderate to least values corresponds to Cretaceous sediments and Alluvium. It was established that Afikpo Basin is independent of Anambra Basin with physical barriers separating them in form of basement uplift and therefore be classified as an independent inland sedimentary basin in Nigeria. The basement uplift between the Anambra Basin and Southern Benue Trough stretches from Aguamede through Nkalagu to Udi community. The uplift between Afikpo Basin and Southern Benue Trough stretches from around Uburu to Lekwesi. The edge of Southern Benue Trough is defined to be around Lekwesi down to Okigwe. The non-continuity of the basin boundary to the surface is as a result of post subsidence due to post depositional processes and post Santonian tectonics within the study area.

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