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Investigation of Nsukka Area, South-Eastern Nigeria for Mineral Exploration Using Gravity Method

Igwe, Emmanuel Awucha, Yakubu, John Akor And Idike Julius Igboji
Department of Physics and Astronomy, University of Nigeria, Nsukka
Corresponding Author: Igwe, Emmanuel Awucha

Abstract: *Gravity method was used in this work to map the survey area and to obtain the causes of the observed anomalies in the area. Digitized airborne gravity data were obtained over Nsukka area from Nigeria Geological Survey Agency (NGSA). The data were processed and reduced to a format suitable for interpretation by the following methods: vertical derivative, upward continuation and analytic signal. Some portions of the survey area were modelled. From the models, the densities of the anomalous bodies were 1.635, 2.643, 2.420, 4.127, and 3.707g/cm^3 located at depth of about 564, 822, 407, 815, and 1893m respectively. The densities indicate clay, sandstone and ironstone located at those various depths. Density of 1498kg/m^3 corresponds to clay material located at depth of about 923m from the surface. The densities of 3523, 4127 and 3707kg/m^3 correspond to that of ironstone located at depths of about 604, 815 and 1893m respectively from the surface. The density of 2420kg/m^3 corresponds to sandstone located at the depth of about 407m below the surface; this represents the most prolific aquifer in the study area. The depth estimated using Euler method ranged between -407m and 1713m for SI =1, 1792m and 9664m for SI = 2 and 2000m and 9664m for SI =3 respectively. This shows that some parts of the study area may have possible potential for hydrocarbon accumulation.*

Keyword: *Gravity anomaly, Euler 3D deconvolution, forward and inverse modelling, vertical derivatives, analytic signal*

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I. Introduction

Geophysical techniques are used to assess the physical and chemical properties of soil, rocks and ground water based on their response to either various parts of the electromagnetic (EM) spectrum, including gamma rays, visible light, radar, microwave, and radio waves or acoustic and/or seismic energy, or other potential fields, such as gravity and the earth's magnetic field.

In gravity surveying method, the subsurface geology is investigated with regard to earth's gravitational field. Although referred to as the 'gravity method', it is actually the difference in acceleration due to gravity that is measured. The variation arises from differences of density between subsurface rocks. The causative body anomaly has different density other than that of the surrounding rocks and represents a subsurface zone of anomalous mass responsible for gravity anomalies. The primary goal of studying detailed gravity data is to provide a better understanding of the subsurface geology. The gravity method is a relatively cheap, non-invasive, non-destructive remote sensing method. It is also passive – that is, no energy needs to be put into the ground in order to acquire data; thus, the method is well suited to a populated setting. The small portable instrument used also permits walking traverses. Measurements of gravity provide information about densities of rocks underground. There is a wide range in density among rock types, and therefore geologists can make inferences about the distribution of strata. The gravity method involves measuring the gravitational attraction exerted by the earth at a measurement station on the surface. The strength of the gravitational field is directly proportional to the mass and therefore the density of subsurface materials. Anomalies in the earth's gravitational field result from lateral variations in the density of subsurface materials and the distance to these bodies from the measuring equipment, Mariita (2007).

The gravity method has found wide applications in geothermal energy investigations as well as the monitoring of geothermal reservoirs under exploitation. This is because it is fairly cheap, and fast in data collection with minimum logistics preparation. The method can infer location of faults, permeable areas for hydrothermal movement, intrusive bodies, hydrocarbon etc. It is however, more commonly used in determining the location and geometry of heat sources. In this study, gravity method will be used to investigate the following: identify anomalies and the possible cause of the anomalies, estimate the depths to the causative bodies and estimate the mass of the anomalous bodies.

II. Location And Geology Of The Study Area

Nsukka area is situated in Enugu state, south-eastern Nigeria. South-eastern Nigeria is presently called the southeast geopolitical zone courtesy of dividing Nigeria into six geopolitical zones in 1999. Nsukka area also constitutes one of the components of the cultural zones into which Enugu State is divided, the other being Enugu zone. The area comprises seven local government areas, namely: Nsukka; Igbo Etiti; Igbo-Eze South; Igbo-Eze North; Isi-Uzo; Udenu and Uzo-Uwani.

Ofomata (1978) holds that the land surface of the Nsukka environment lies between Latitudes 6^0 18’ and 7^0 06’ north and longitude 6^0 52' and 7^0 53 ' east, and covers a total surface area of approximately 3,961 square kilometers. Nsukka area shares common boundaries with Kogi and Benue states to the north, Enugu zone and Anambra state to the South, Ebonyi State and Enugu Zone to the East, and Kogi and Anambra states to the West. The study area consists of three major geologic formations. These are Mamu, Ajali and Nsukka formations (Fig. 1.3). The Mamu formation, previously known as lower coal measures (Reyment, 1965), consists of fine-medium grained, white to grey sandstones, shaly sandstones, sandy shales, grey mudstones, shales and coal seams. The thickness is about 450m and it conformably underlies the Ajali formation. The Ajali formation, also known as false bedded sandstone, consist of thick friable, poorly sorted sandstones, typically white in colour but sometimes iron-stained. The thickness averages 300 m and is often overlain by considerable thickness of red earth, which consists of red, earthy sands, formed by the weathering and ferruginisation of the formation. The Nsukka formation, previously known as the upper coal measures (Reyment, 1965), lies conformably on the Ajali sandstone. The lithology is very similar to that of Mamu formation and consists of an alternating succession of sandstone, dark shale and sandy shale, with thin coal seams at various horizons. Eroded remnants of this formation constitute outliers and its thickness averages 250 m.

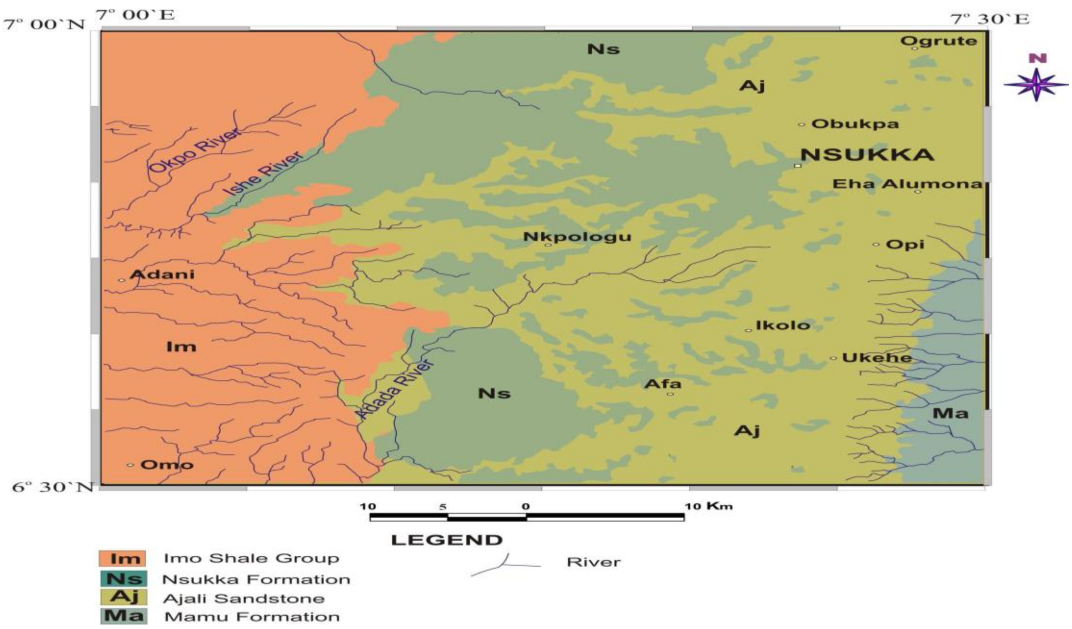

Fig. 1: Geological map of the study area (Obiora, et al., 2016)

Source of data

Airborne Bouguer anomaly data were obtained from 2008 survey by Nigeria Geophysical Survey Agency (NGSA). The data were obtained in XYZ format. X and Y are distance in meters measured along east and north direction respectively, while Z is the Bouguer anomaly values measured in miligal.

III. Materials And Methods

Once gravity data are reduced to the form of gravity anomalies, the next step usually involves gridding the data in order to produce a map. Then filters are applied to facilitate three-dimensional interpretation. Because gravity data can be collected both along profiles such as ship tracks or roads and as scattered points, the standard gridding algorithm used is minimum curvature (Briggs, 1974). Here an algorithm with some degree of trend enhancement such as anisotropic kriging (Hansen, 1993) or gradient-enhanced minimum curvature (O’Connell et al., 2005) should be used. The gravity data used in this work were gridded using Oasis Montaj software in the X and Y directions, employing minimum curvature method. Data were saved as grid files (GRD format). Contour map constructed using Oasis Montaj software, shows simple gravity data as gathered in the field (Fig 2). The Bouguer anomaly map with a contour interval of 0.5 mgal and a maximum of about 33 mgal and a minimum of about -4 mgal were drawn. A 3D view of the Bouguer anomaly map of the study area is shown in Fig. 2b. First vertical derivative was applied to the Bouguer anomaly map using Oasis Montaj software. First vertical derivative is commonly computed from gravity data to emphasize high -frequency anomalies due to shallow sources. It can be calculated both in space and frequency domain using standard operators. A stable calculation of the first vertical derivative was proposed by Nabighian (1984) using 3D Hilbert transforms in the X and Y directions. This was employed in this work. A second vertical derivative (SVD) map of gravity data was also calculated using the Fast Fourier Transform (FFT).The result is an enhanced anomaly or residual map related to the input gravity (Fig 3c). The SVD map emphasized local anomalies and isolates them from the regional background. The SVD enhances near surface effects at the expense of deeper anomalies. The quantity '0 mgal/m^2' in Figs 3 and 4 indicates the edges of local geological features. In most cases gravity anomaly data are interpreted on (or near) the original observation surface. In some situations, however, it is useful to move (or continue) the data to another surface for interpretation or for comparison with another data set. The effect of the deeper mass is relatively enhanced by upward continuation of the field whereas downward continuation will achieve the opposite effect that is to enhance the shallower mass. Upward continuation was computed using Oasis montaj software. FVD and SVD were continued upwardly too 500m, (Fig. 2b & 2d), showed enhancement in the maps. The analytic signal method, also known as the total gradient method, produces a particular type of calculated gravity anomaly enhancement map used for defining, in a map sense, the edges (boundaries) of geologically anomalous density distributions. Mapped maxima (ridges and peaks) in the calculated analytic signal of a gravity anomaly map locate the anomalous source body edges and corners (e.g., basement fault block boundaries, basement lithology contacts, fault/shear zones, igneous and salt diapirs, etc.). Analytic signal maxima have the useful property that they occur directly over faults and contacts, regardless of the structural dip present. In 2D, the local wave number K is defined as the derivative of the phase of the analytic signal (θ) with respect to distance x, (Bracewell, 1965; Nabighian, 1972) given as

$$K = \frac{\partial \theta}{\partial x}, \qquad 1.$$

where

$$\theta = \tan^{-1}\left[\frac{\partial f(x,z)/\partial z}{\partial f(x,z)/\partial x}\right]. \qquad 2.$$

The analytical signal of the potential field, A(x, z), is given by

$$A(x,z) = \frac{\partial f(x,z)}{\partial x} - j\frac{\partial f(x,z)}{\partial z} \qquad 3.$$

where, f is the potential field.

Depth to the source of anomaly was obtained using two different methods: Euler depth estimation method and forward and inverse modelling. Euler 3D processing routine automatically locates and determines depth for gridded magnetic and gravity data. Euler 3D automates 3D geologic interpretation by delineating magnetic and gravimetric boundaries and calculating source depths. The Euler 3D deconvolution method does not assume any particular geologic model; the deconvolution can be applied and interpreted even when particular models, such as prisms or dykes, cannot properly represent the geology. This method was applied in this work to estimate the depths of the anomalous bodies. The vertical component of gravity anomalous field Tz, which must satisfy the Euler's homogeneity equation (Hood, 1965) is given by:

(x-xo)Tz x + (y-yo)Tzy + (z-zo)Tzz = N(Bz-Tz) , 4.

where, Tz is the gravity anomalous field (vertical component) of a body having a homogeneous gravity field. xo, yo and zo are the unknown coordinates of the source body centres or edges to be estimated and x, y and z are the known coordinates of the observation point of the gravity and the gradients. The values Tzx, Tzy and Tzz are the measured gravity gradients along the x, y and z directions. N is the structural index, which is a measure of the rate of change with distance of a field (Thompson, 1982) and Bz is the regional value of the gravity. This was computed using Oasis Montaj Geosoft Software. Forward and inverse modelling was done using PotentQ 3D modelling software which is an Oasis Montaj Geosoft software extension. Forward and inverse modelling involves iterative trial and error method where the observed data is fitted to a particular source body until a match is found. The software enabled us to obtain the sought parameters of the anomalous bodies in the study area. Figures 7 a – e show the models obtained and the sought parameters for each of the areas, while Table 1 summarized the result.

Figure 6, shows the areas selected for modelling. The selection was motivated by two reasons: information from the Bouguer anomaly map and the residual maps (analytic signal and derivative maps), the selected areas show either high positive or negative anomalies in the Bouguer map, while residual maps show the distribution of causative bodies which fall within the areas selected.

IV. Results And Discussion

Qualitative and Quantitative interpretation procedure was employed in this work. Qualitatively, Bouguer anomaly map (Fig. 2a) shows positive and negative anomalies with the negative anomalies around the eastern part indicating that the eastern part is covered with a very low density material. The high positive anomalies are mostly in the SS and SW an indication of dense material beneath the southern part of the study area, consequently high density contrast. While the green and yellow coloured areas have little or no density contrast.

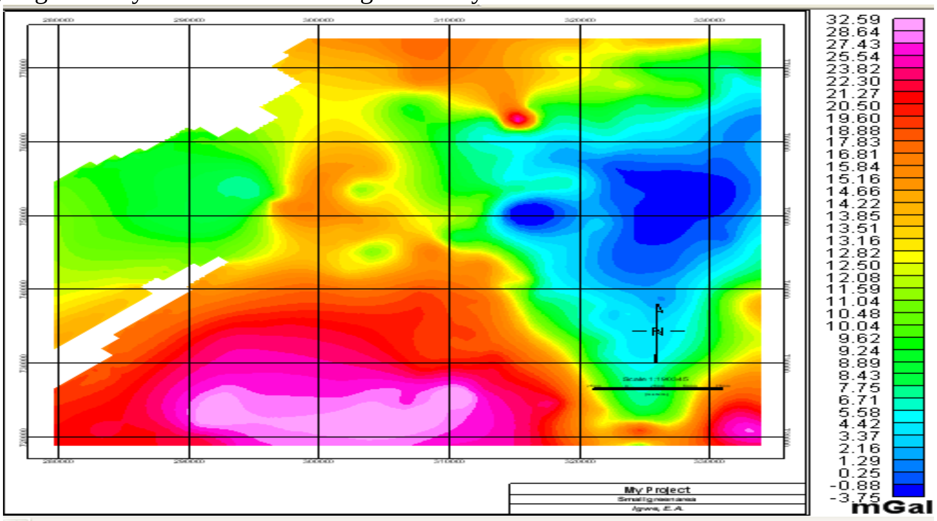

Fig 2a: shows the Bouguer anomaly map of the study area.

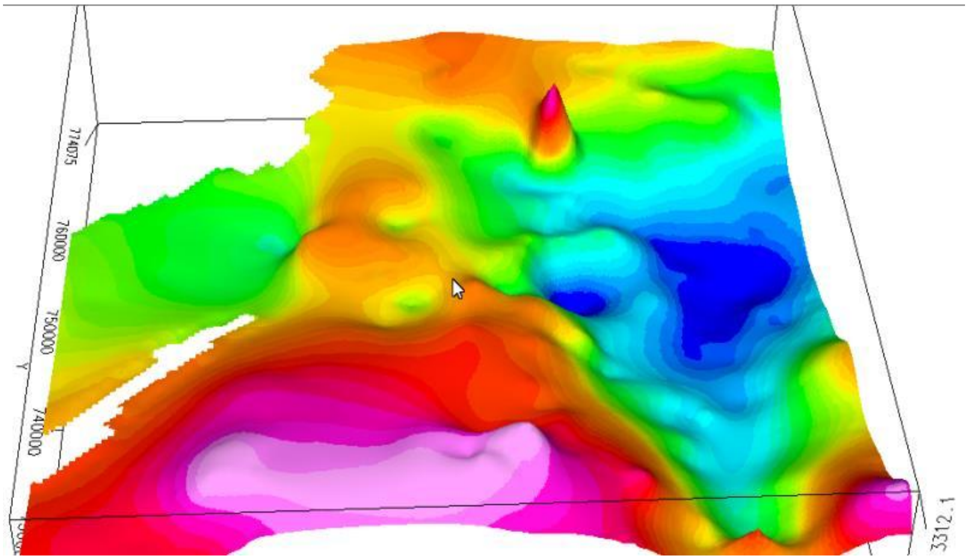

Fig 2b: A 3D view of the Bouguer anomaly

The Bouguer anomaly map was also produced in 3D form to show clearly the distribution of the anomalies (Fig. 2b). Vertical derivative was applied in order to gain deeper understanding of the distribution of the causative bodies. From the result of first vertical derivative, the causative bodies can be seen scattered around the centre, northern, eastern and southern parts, while the western part still shows little or no density contrast (Fig. 3a). Second vertical derivative was also applied and this enabled us to locate the boundaries of the causative bodies. From Fig. 3c, the yellow colour shows the edges of the anomalous bodies. The result of upward continuation enhanced this effect. Analytic signal method for source identification was also applied and the result agreed with that obtained using SVD i.e. showed clearly the edges of the anomalous bodies (Fig. 4). Quantitatively, the sought parameters of the source bodies were obtained from Euler depth estimation method and 3D forward and inverse modeling (Table 3.1). The depth estimated using Euler method for SI = 1 ranged between – 407.7m and 1713m (Fig. 5a). The negative sign in the depth signifies elevation. The colour aggregate as seen in Fig. 5a shows that the North-Eastern part and the central part of the study area have Dyke-like bodies (Reid, 2002) with a shallower depth beneath it. The deepest part with SI = 1 occurs mostly around the Western part, South-Eastern part and the Northern part. This result agreed with the result obtained from the modeling which ranged between 268 and 1893m for the areas modeled.

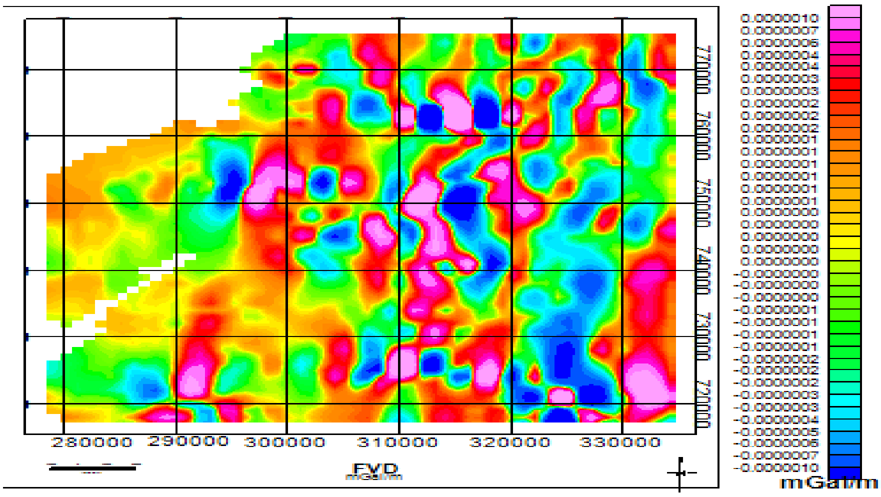

Fig 3a: First vertical derivative

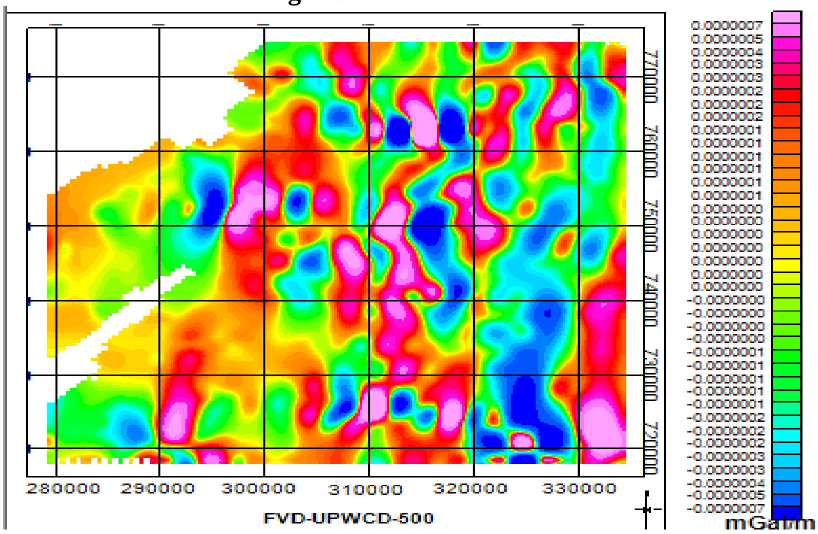

Fig. 3b: FVD Upward continued to 500m

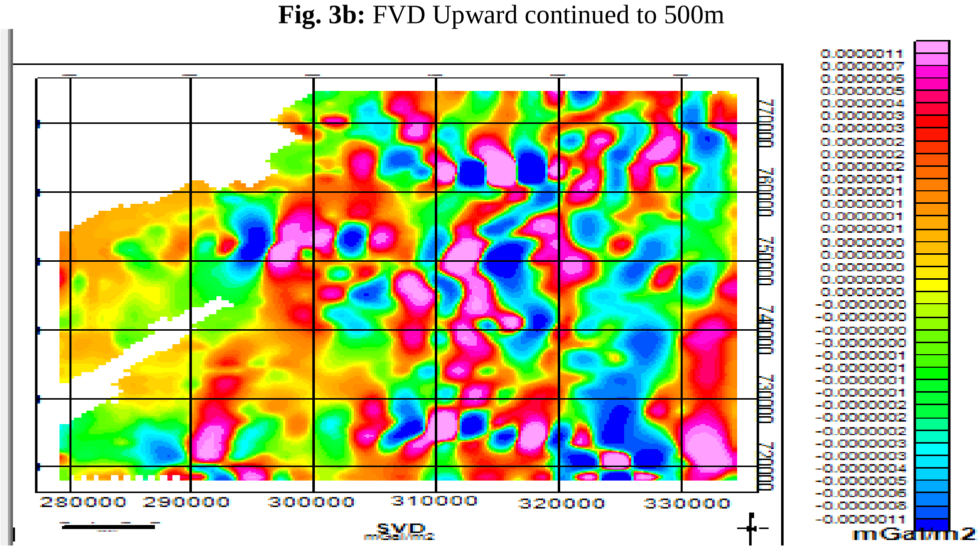

Fig 3c: SVD map of the study area

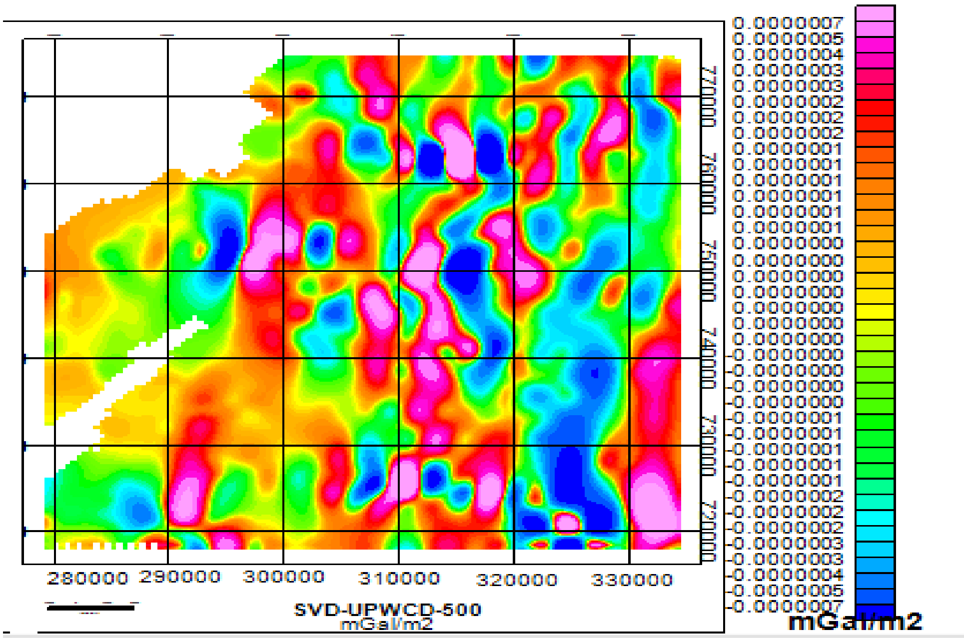

Fig. 3d: SVD upward continued to 500m

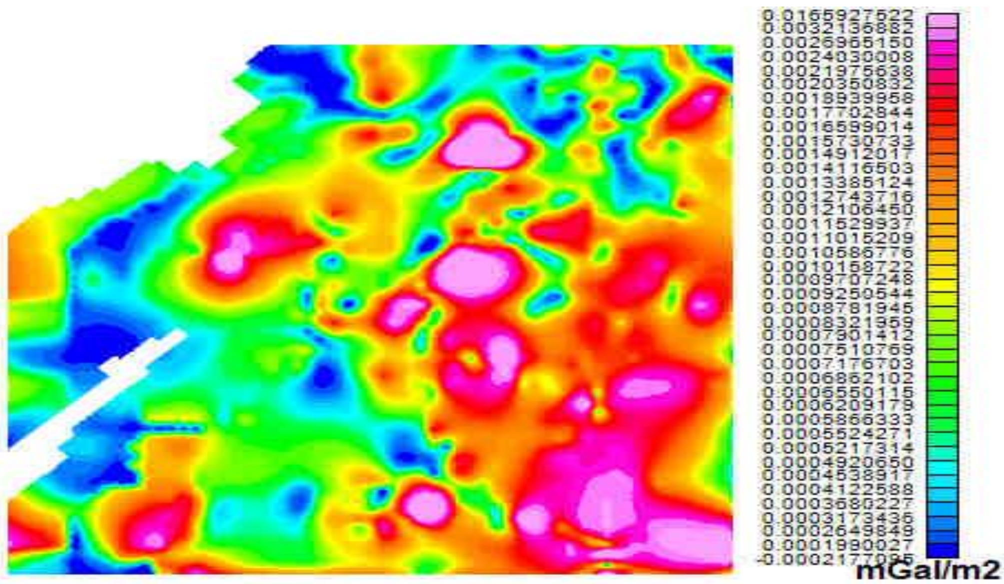

Fig 4: Analytic Signal of Bouguer Anomaly

For SI = 2, the depth ranged between 1792.6m and 9664.8m which could be interpreted as the depth to the basement. The red – pink coloured areas indicate areas with deepest depths, blue colour indicates shallow depth, while yellow and green colours indicate areas with moderate depths. From Fig. 5b, the blue colour occupies the central part indicating a shallow body/depth. The yellow and green colours surrounded the blue part and covered the Eastern part. This indicates that the blue part (the central portion of the map) is an intrusion into the yellow and green coloured area. The Western part is covered with a deep lying body. For SI = 3, the depth ranged between 2006.0m and 9664.7m (Fig. 5c). The same scenario observed in SI = 2 is repeated with SI = 3 (Figs. 4b&c). This shows that, there is an intrusion in the central part of the study area which was interpreted as Dyke – like body in Fig. 4a which is in line with the result obtain by Ugbor and Okeke (2010) in the neighbouring Akata town in Abakaliki. This results show that some parts of the study area are favourable for hydrocarbon generation (depth of about 2.2km), if other conditions are met, which agreed with the results obtained from other works in Benue Trough (Abdullahi et al., 2014).

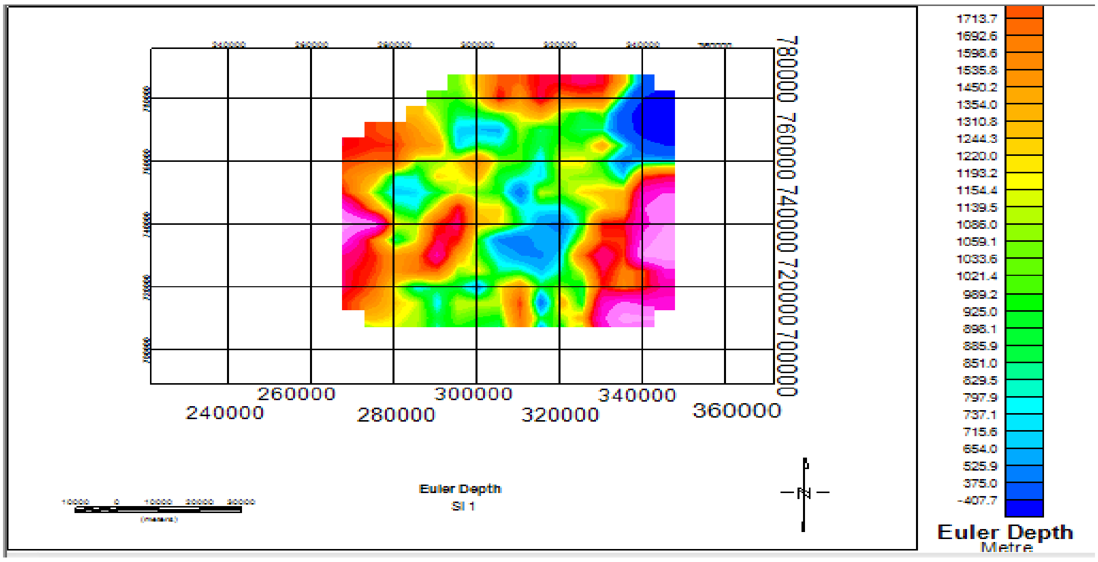

Fig. 5a: Euler 3D depth for SI = 1

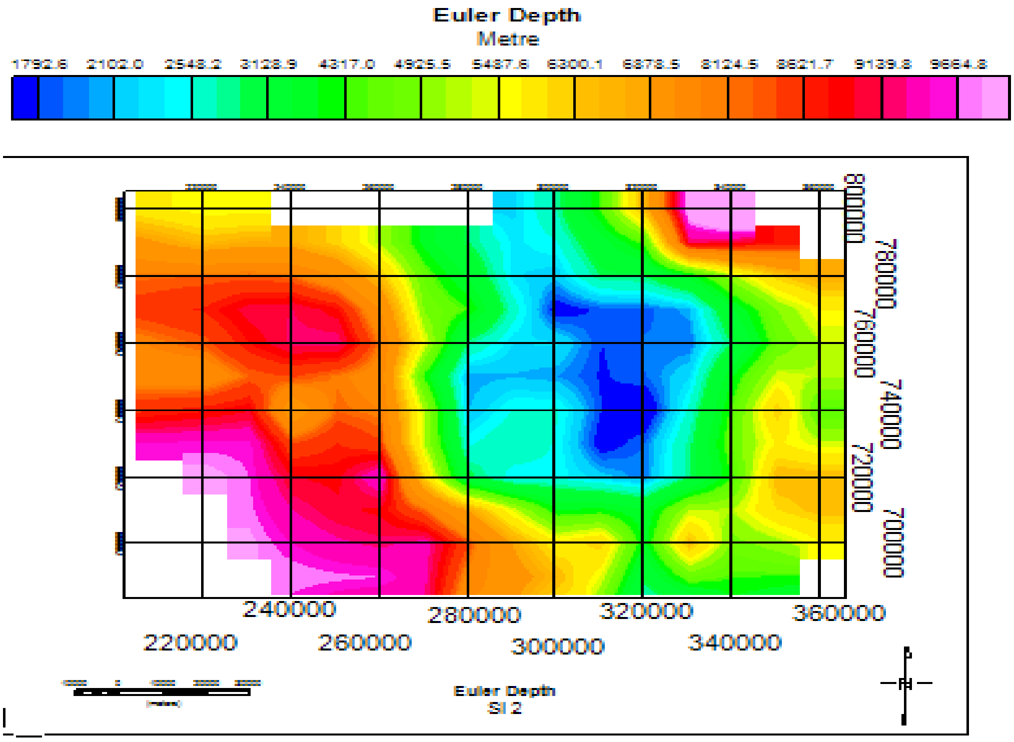

Fig. 5b: Euler 3D depth for SI = 2

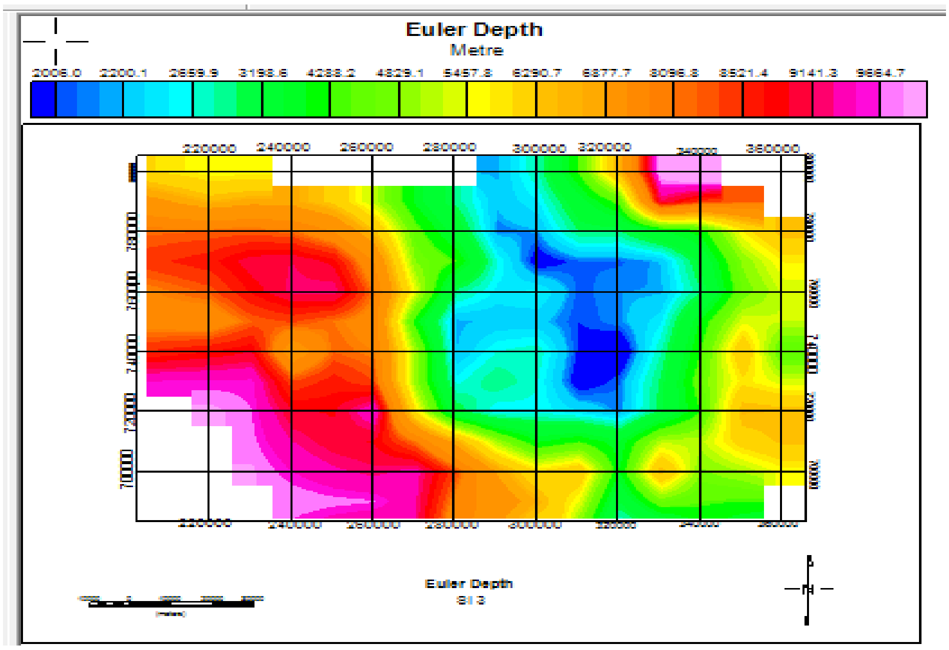

Fig. 5c: Euler 3D depth for SI = 3

The result of the modelling is as follows. Profile 1 is located at the central part of the study area towards east (319741.5m longitude, 748132.3m latitude). The density of the causative body obtained was 1635kg/m^3 which indicates clayey material and the depth was about 564m from the surface. The Geologic structure beneath profile 1 indicates a syncline structure (Dobrin and Savit, 1988). Profile 2 is located at the South-eastern part of the study area with coordinates 333038.7m longitude, 719195.3m latitude, density of 2.643kg/m^3 and depth of 822m which is interpreted as Kaolinite. Profile 4 is located at the Southern part at 309957.8m longitude and 725362.7m latitude. And profile 5 is located at the Southern west at 291728.3m longitude and 724099.3m latitude. Profiles four and five have anticline geologic formations (Dobrin and Savit, 1988) with densities of about 4127 and 3707kg/m^3 respectively. The depths to the surface were about 815 and 1893m respectively. These density ranges correspond to that of ironstone. These layers are as the result of weathering and feruginization activities in the study area (Ofomata, 1978). Nsukka area has long rainy season of about seven (7) months (April to October). A reasonable quantity of the rain water infiltrates into the underlying geologic formations and is responsible for the weathering to great depth of these formations to produce a thick mantle of weathered materials. This weathering activities lead to precipitation of iron oxides, the absolute and/or relative accumulation of which leads to the formation of highly resistant ironstone concretion (Ofomata, 1978).

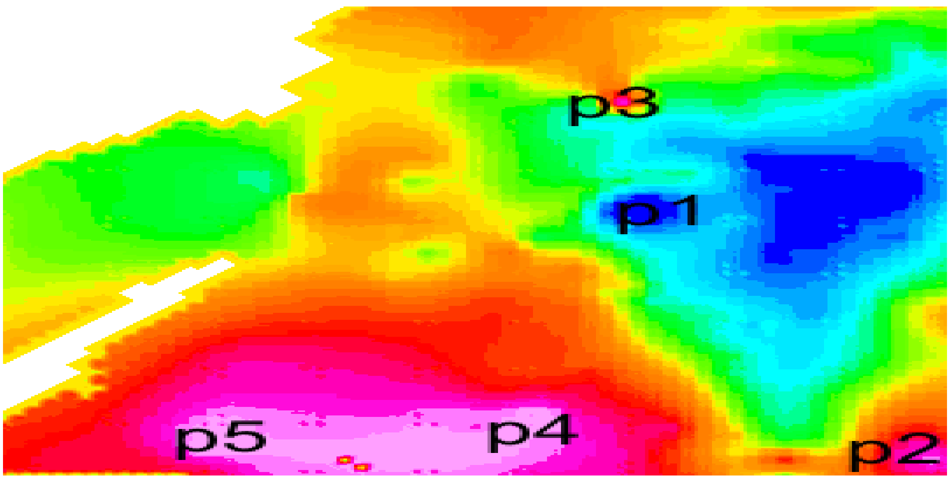

Fig. 6: Bouguer Anomaly Map showing the profiles

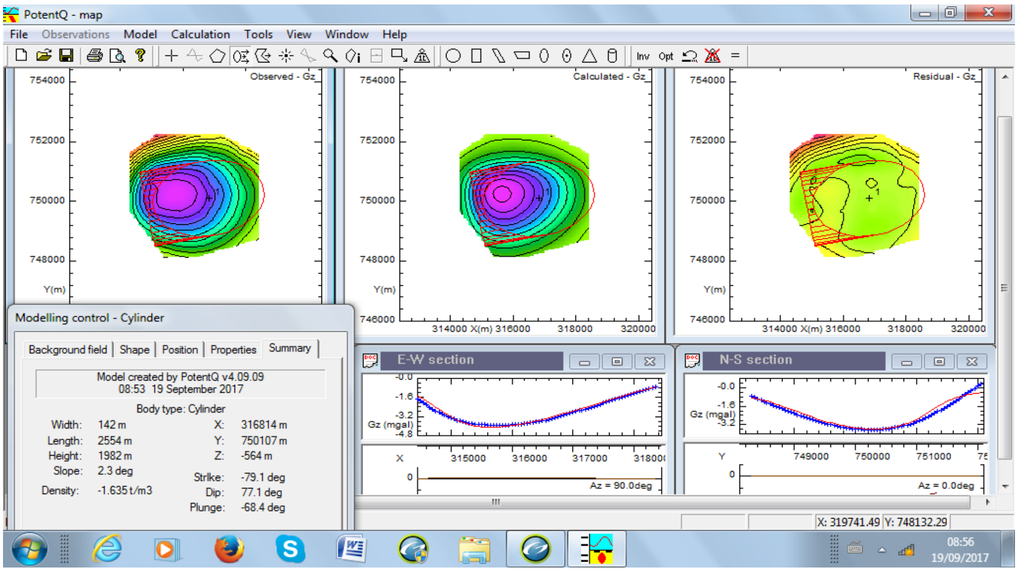

Fig. 7a: Profile 1

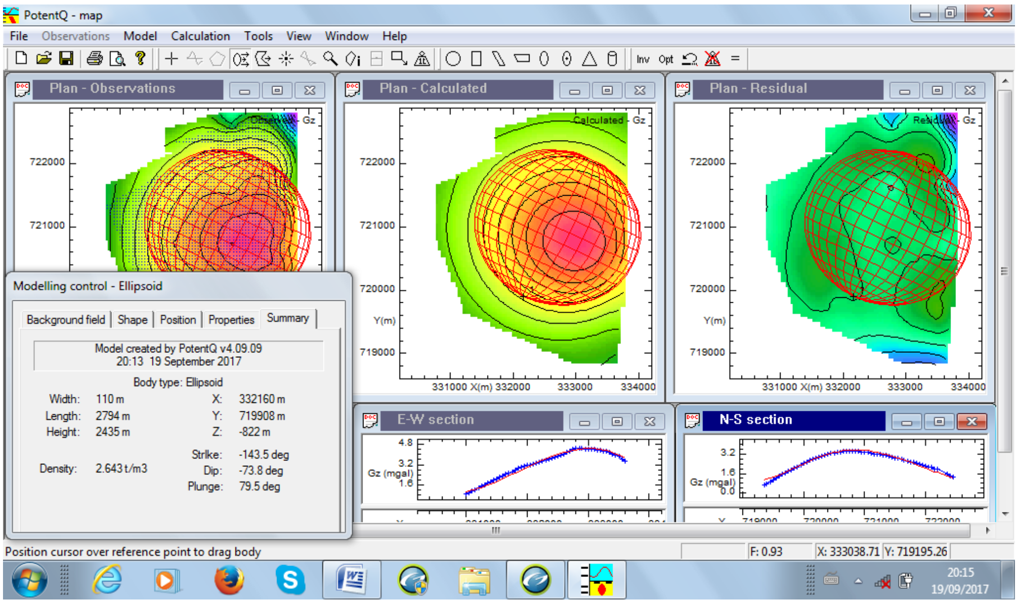

Fig. 7b: Profile 2

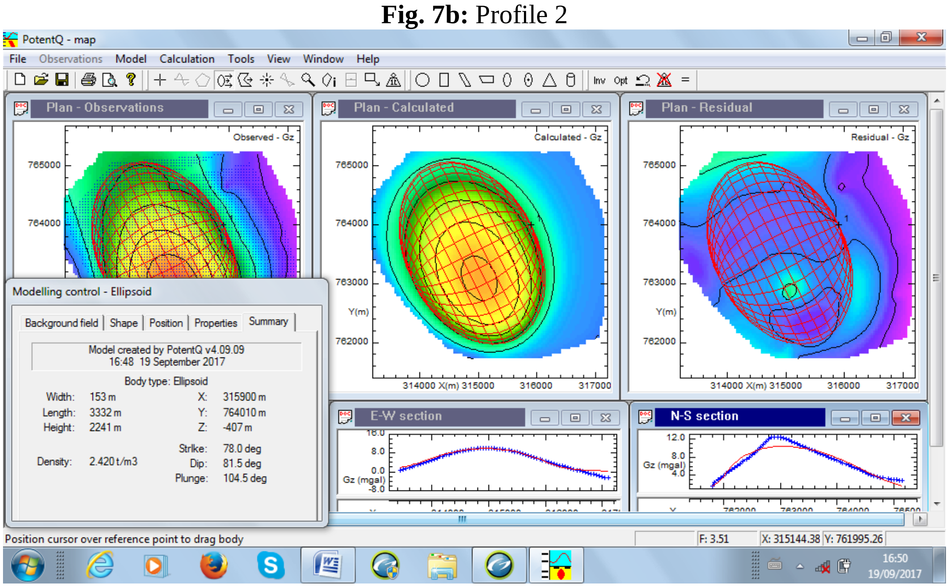

Fig. 7c: Profile 3

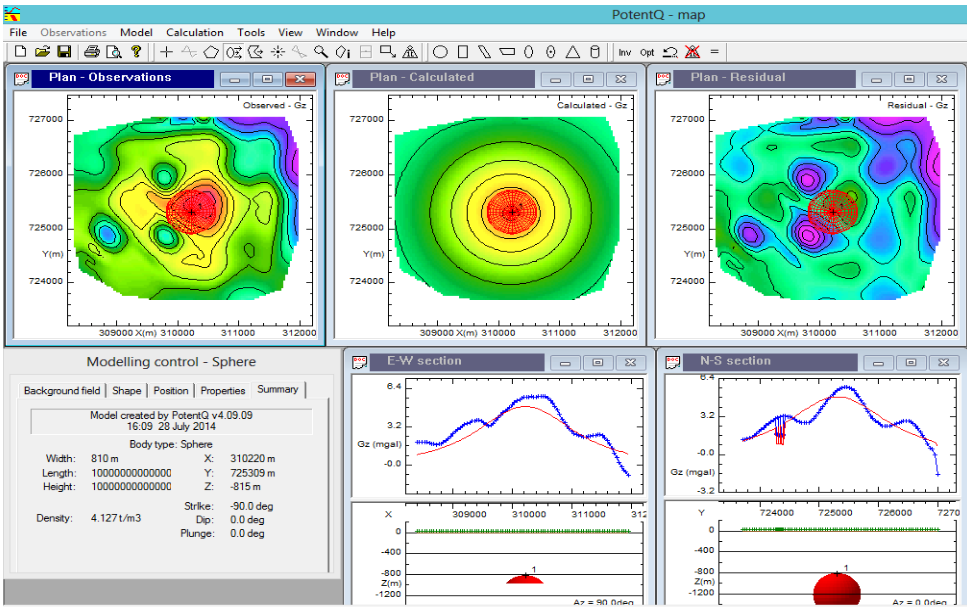

Fig. 7d: Profile 4

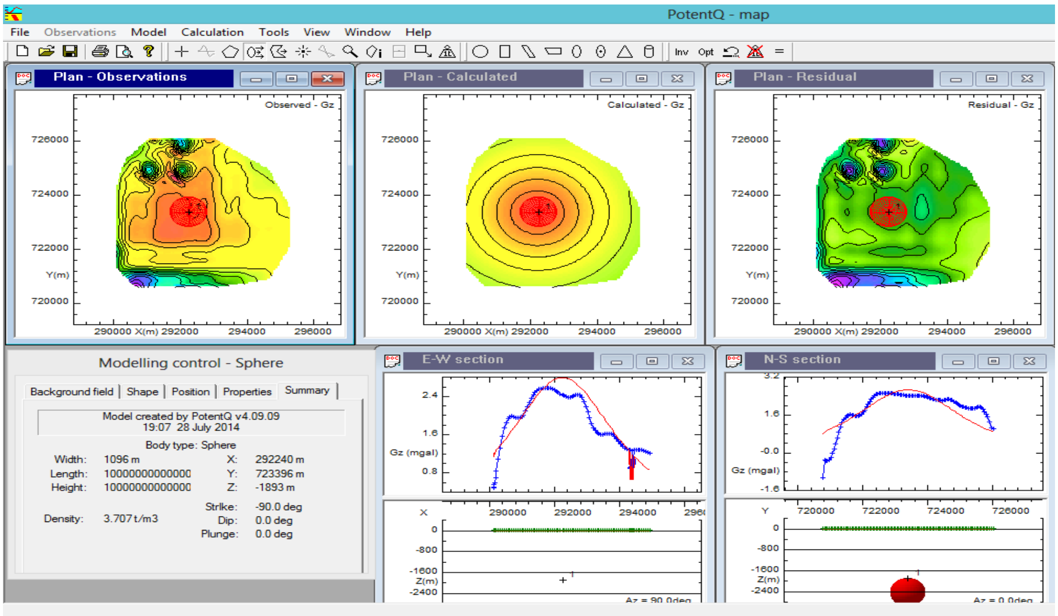

Fig. 7e: Profile 5

Table 3.1: Summary of model result

Profile	Body Type	Width (m)	Length (m)	Height (m)	Depth to surface of body (m)	Density of the body (g/cm^3)	Possible cause of anomaly
One	Cylinder	142.0	2554.0	1982.0	564.0	1.635	Clay
Two	Ellipsoid	110.0	2794.0	2435.0	822.0	2.643	Kaolinite
Three	Ellipsoid	153.0	3332.5	2241.0	407.0	2.402	Sandstone
Four	Sphere	-----	405.5	-----	815.0	4.127	Ironstone(Limonite)
Five	Sphere	-----	548.0	-----	1893.0	3.707	Ironstone(Limonite/Siderite)

Finally, profile three has anticlinorium geologic formation located at the Northern part with coordinates 315144.4m longitude and 761995.3m latitude. The density of about 2420kg/m^3 (sandstone) was obtained as the density of the causative body in the area, located at a depth of about 407m below the surface. This represents the most prolific aquifer in the study area. Its depth agreed with some of the depths obtained in UNN environs (Ofomata, 1978) where borne holes are located.

V. Conclusion

Gravity data of Nsukka area has been interpreted; we have been able to identify the cause of the observed anomaly in the study area. The analysis shows that the causative bodies trend N-S and that the bodies are concentrated at the central area according to Fig 3.5. Euler depth estimation shows that the depth to anomalous bodies ranged from – 407 to 1713m for SI =1, 1792 to 9664m for SI = 2 and 2000 to 9664m for SI = 3 respectively. Selected areas were also modeled. The densities of the causative bodies obtained ranged 1635kg/m^3 to 4127kg/m^3, while depths to the surface ranged from 407m to 1893m. This work has also shown that, Nsukka area has exploitable minerals like clay, sandstone and ironstone that are suitable for ceramic production. The depth range in the area suggests that the area is also suitable for hydrocarbon generation if other conditions for hydrocarbon accumulation are favourable.

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