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Structural Evaluation of Bouguer Gravity Data Covering Parts of Southern Niger Delta, Nigeria

C. C. Ofoha[1*], G. Emujakporue[1] and A. S. Ekine[1]

[1]Department of Physics, University of Port Harcourt, Choba, Rivers State, Nigeria.

Authors' contributions

This work was carried out in collaboration between all authors. Author CCO designed the study, performed the statistical analysis and wrote the first draft of the manuscript. Author GE wrote the protocol of the study. Author ASE managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Qualitative and quantitative methods of data analysis and interpretation were employed on the bouguer gravity data obtained from the Nigerian Geological Survey Agency (NGSA) in Geo soft grid file format. The datasets cover Degema and Oloibiri area of southern Niger Delta. The study is aimed at evaluating those structures that could serve as conduits and entrapments for hydrocarbon and other earth resources like water and minerals. Regional-Residual separation was applied on the bouguer gravity data by means of polynomial fitting of degree one. This art gave rise to the residual and regional maps. Further filtering actions like the first vertical and horizontal derivatives and the second vertical and horizontal derivatives were applied on the residual data in order to accentuate the subtlest anomalies peculiar with the study area. The qualitative analysis and interpretation of the data expressed in grids reveal ENE-WSW, N-S, E-W and WNW- ESE structural features. These trends are regarded as the litho-tectonic domains. Spectral depth analysis was carried on the residual by dividing the residual into overlapping windows. The analysis revealed two depth quantitative models, D_1 and D_2. D_1 represents depths within the basement and its environs while the

*Corresponding author: E-mail: williamscharles333@yahoo.com;

D_2 is associated with shallow related gravity sources. D_1 varies from 6.5 km to 21.09 km with an average value of 12.56 km. Conversely, D_2 obtained from the less steep section of the energy curve varies between 3.15 km and 7.19 km with an average value of 4.35 km. The average or true sedimentary thickness of 12.56 km suggests that the area will be plausible for hydrocarbon exploration.

Keywords: Minibasin; oloibiri; gravity zones; crustal structure; gravity high; gravity low.

1. INTRODUCTION

Sparse literatures exist in the structural evaluation of the Niger Delta region using bouguer gravity data. This is partly due to the reliability of the seismic and borehole techniques which are capable of producing more detailed resolution of the earth's subsurface structures [1]. Recent acquisition of high resolution data by the Nigerian Geological Survey Agency (NGSA) has really upturned the case as geoscientists are finding the technique to be more utilitarian in delineating structures associated with area of interest. When compared to other methods, the gravity method penetrates greater depth, has fewer crews and also covers inaccessible areas [1]. In view of this [1] stated that the gravity method can be used where target area underlie high velocity zones like salt provinces, overthrust and foothills belts and underexplored basins.

This method, like the magnetic method, is non destructive and it depends on measuring differences in the earth's gravitational field within area of interest. These differences termed anomalies are as a result of lateral variation in the density of subsurface rocks/structures. The gravity method can be used to delineate structural trends as well as estimating depth to basement rocks in a particular study area.

[2] delineated basement fracture and fault zones expressed as lineaments and then inferred the influence of such lineaments on the tectonic history and oil and gas bearing potential of some parts of offshore Niger Delta through aeromagnetic studies. To achieve the purpose, the aeromagnetic data was analysed qualitatively using Wing Link software. Their result showed northeast-southwest (NE-SW), northwest-southeast (NW-SE), north-south (N-S) and south-west (S-W) trends which probably was the result of faulting, fracturing, down warp and epeirogenic warping within the study area.

[3] in another separate research investigated the depth of magnetic sources using two dimensional spectral depth analyses within the Niger Delta province. Two depth models representing the deeply and shallow seated bodies were proposed in an attempt to determine the sedimentary thickness. 9466 m and 2467 m sedimentary thickness values were obtained for the deeply and shallow seated magnetic bodies.

[4] discriminated the regional from residual structures within the study area through aeromagnetic study. This was done in order to define thicker sedimentary section by subjecting the data into various geophysical techniques like tilt depth, Euler Deconvolution, Analytic signal, derivatives and 2D derivatives. Tectonic trends with strike direction of NE-SW, NW-SE and E-W directions were observed.

In order to examine the relationship between deep basement shape and size and the hydrocarbon target, [5] used airborne magnetic data covering Niger Delta area to investigate the relationship between deep basement architecture and hydrocarbon target. Varying basement structures which would have significant control on oil and gas within the Tertiary strata of the Niger Delta were established.

Aeromagnetic data covering parts of Imo River was used by [6] in identifying basement features associated within the basin and then deduced the influence of the basement features in hydrocarbon exploration by subjecting the data to various filtering actions. This art revealed tectonic features trending in the NE-SW direction.

For the purpose of this research, structural evaluation was carried out by integrating qualitative and quantitative analyses and interpretation of the residual bouguer gravity data.

1.1 Theoretical Background of the Gravity Method

The gravity method is dependent on two laws derived by Newton, namely his universal law of gravitation, and his second law of Motion. The universal law of gravitation states that the force of attraction between two bodies of known mass is directly proportional to the product of the two masses and inversely proportional to the square of the distance between their centers of mass [7] while his second law of motion states that the rate of change of momentum of a body, is directly proportional to the force applied and this change in momentum takes place in the direction of the applied force. In other words, Newton's second law can be stated as: In an inertial reference frame, the vector sum of the forces F, on an object is equal to the mass *m* of that object multiplied by the acceleration, a, of the object [7]:

Newton's second law can be expressed mathematically as:

$$F = Ma \quad (1)$$

$$F = Mg \quad (2)$$

Where

F is the force of attraction between bodies
M is the mass of the body
g is the acceleration due to gravity
In differential form, Newton's second law can be stated as

$$F = \frac{dP}{dt}, \quad (3)$$

Therefore

$$F = \frac{d(mv)}{dt} \quad (4)$$

Where

F = the applied force,
dP = change in momentum
dt = change in time
The universal gravitational law, according to Newton, can be expressed as

$$F = \frac{G \times M \times m}{R^2} \quad (5)$$

Where

F = the force of attraction between two of the masses
G = Universal gravitation constant
M and m = masses of particle 1 and 2 respectively
R = distance between the two masses

Nevertheless, the essential characteristics of the gravity method can be explained in terms of mass and acceleration as illustrated in Newton's second law. The mass distribution and shape of an object are linked by the objects center of mass (8).

Equating 2 and 5

$$F = \frac{G \times M \times m}{R^2} = M \times g; \quad (6)$$

$$thus\ g = \frac{G \times m}{R^2} \quad (7)$$

The gravitational potential (Fig. 1a) at a point in a given field is defined as the work done by the attractive force of M on m as it moves from 0 to infinity. The concept of the potential helps in simplifying and analyzing certain kinds of force fields like gravity, magnetic and electric fields. Equation 7 a represents the force per unit mass, or acceleration, at a distance r from P, and the work necessary to move the unit mass a distance (ds) having a component dr in the direction is given as (8)

$$\text{v} = Gm \int_{\infty}^{R} \frac{dr}{r^2} \quad (8)$$

$$\text{v} = Gm \frac{1}{r} \Big|_{\infty}^{R} \quad (9)$$

$$\text{v} = \frac{\boldsymbol{G}\text{M}}{\boldsymbol{r}} \quad (10)$$

where

v = the work used in moving a unit mass from infinity to the point in question
m = A unit mass at point P
r = Distance covered by the masses

1.2 Location and Geology of the Study Area

The study area (Fig 1) is bounded eastwards by Port Harcourt, westwards by the Penington River, southwards by Bille and Bonny and Northwards by Patani and Ahoada. Geographically, the study area spans 6º0'0" E - 7º0'0" E and 4º30' N - 5º0'0' N. Basically, the area under review is about 6050 km^2. The geologic map, (Fig 2), which falls within Oloibiri and Degema, reveals the area to be swampy and shows the Creeks, with the Benin Formation and Sombreiro Warri Deltaic Plain sands.

The Niger Delta is situated in the apex of the Gulf of Guinea on the West Coast Africa. The stratigraphic and structural disposition of the Niger Delta has been documented by several workers [9]. The Niger Delta was formed by the buildup of sediments over a crustal tract developed by rift faulting during the Precambrian with outlines controlled by deep seated faults associated with rifting [10]. Rifting diminished in the late Cretaceous and gravity tectonism became the primary deformational process after the rifting phase in the Niger Delta. Gravity tectonism which became the major deformational process after the rifting process gave rise to the development of various types of structures within the region. The Niger Delta started as two different depocenters in the Bende- Ameki area, east of the Delta and in the Anambra Shelve, West of the delta in the mid to late Eocene. These two depocenters later formed a single deltaic sedimentary basin in the late Miocene to date [11]

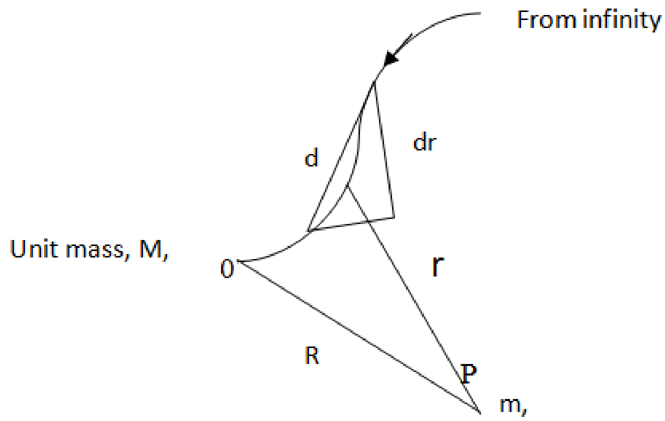


Fig. 1a. Gravitational field potential (8)

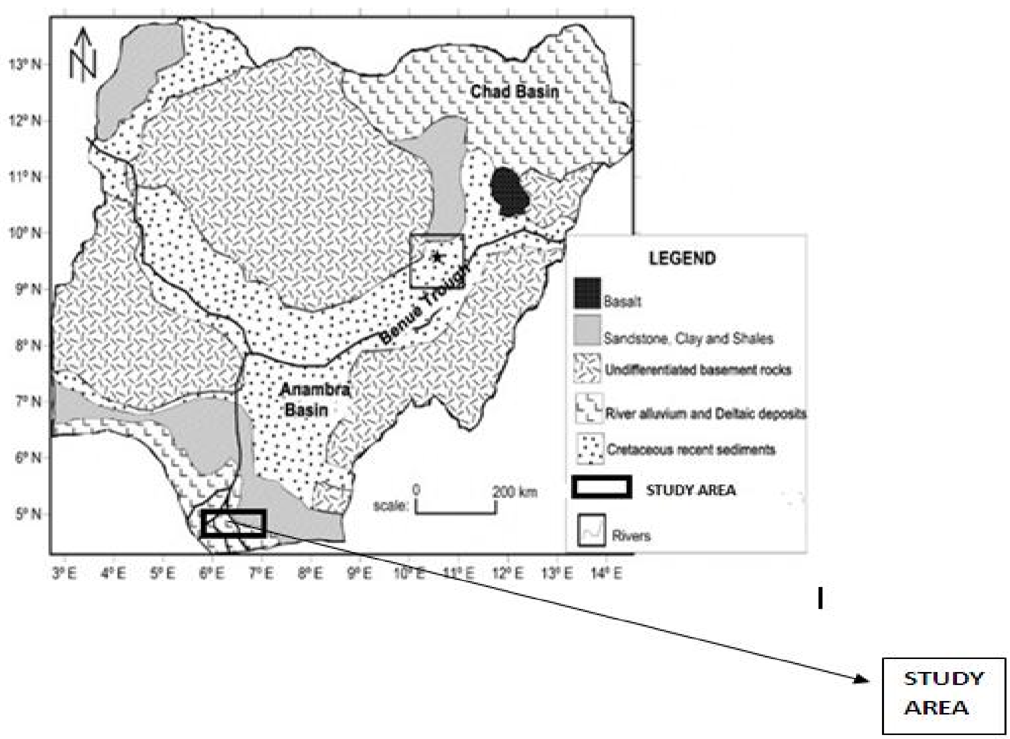


Fig. 1. Map showing the study area (8)

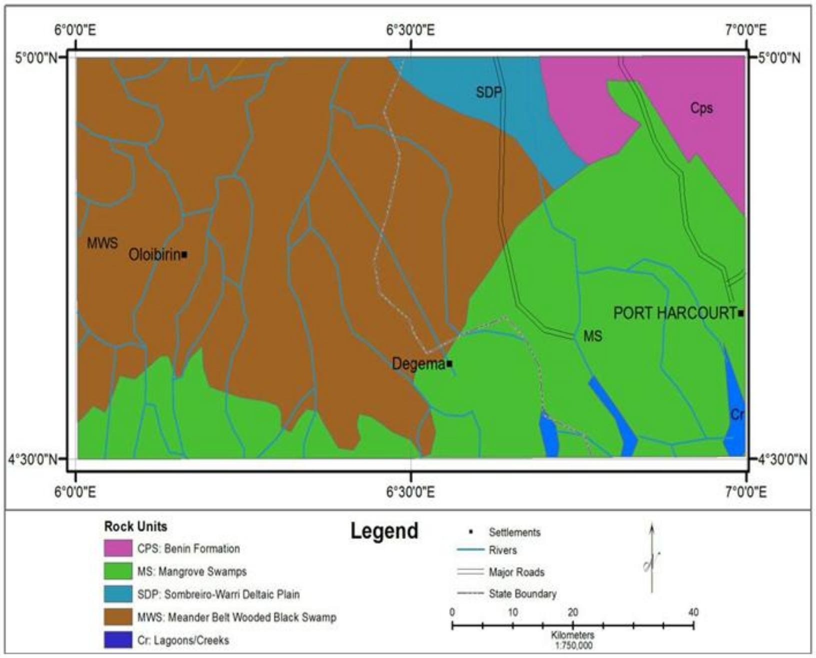


Fig. 2. Geological map of the study area (Courtsey: The Nigerian geological survey agency, NGSA, Abuja)

2. MATERIALS AND METHODS

Digitized bouguer gravity data (Fig. 3) was used for this research. The bouguer datasets were acquired in 2009 by Fugro Airborne Service on behalf of the Nigerian Geological Survey Agency. The two half degree sheets of aero or bouguer gravity were obtained from the Nigerian Geological Survey Agency, NGSA and in Geosoft file format. The agency applied some sorts of reductions/corrections like latitude, elevation, terrain/topography, bouguer, free air and Eotvos. The Bouguer gravity datasets are of high resolution in that they were acquired at a terrain clearance of about 100 m, flight line pattern of NE-SW and tie line spacing of 500 m. The Oasis Montaj Modeling and Surfer software were used for the processing, analysis and interpretation of the bouguer datasets.

For the purpose of this research, two basic methods of data analysis and interpretation were adopted, namely: the qualitative and the quantitative method of data analysis and interpretation. Qualitative data analysis and interpretation were implemented first on the acquired Bouguer gravity data with the aid of Oasis Montaj Software by digitizing the geosoft grid file formats into X, Y and Z channels using the utility module of the gridding tool. For the coordinate channels (X, Y) and the principal channel (Z) to be created, the gridded gravity datasets were saved to a database which was created before the importation of the datasets. Filtering actions like regional-residual separation using X utility module was then performed on the principal Z channel and consequently the regional and residual channels were created by means of polynomial fitting of degree one. On the regional-residual channels further filtering like the first vertical derivative, second vertical derivative, first horizontal derivative and the second horizontal derivative actions were undertaken and thus other qualitative filtering channels generated. Thereafter, maps were generated for each of the channels and then visual inspection of the raster (image) maps done before they are then transformed into its contour formats. Tectonics of the study area was examined by analyzing the structural trends of the contoured maps. Analysis was performed on the contoured maps on the basis of amplitude, shape and size of the anomalies and identification of anomalous boundaries, volcanic zones, lineaments, folds, faults, dykes, seals, and other regional structures that, perhaps, assist in hydrocarbon and other mineralized fluid migration and entrapment. Quantitative analysis and interpretation was applied on the bouguer gravity datasets by windowing the residual bouguer map into eighteen overlapping windows. On each of the windows Fast Fourier Transform was performed and the anomalies decomposed into its energy and wavenumber components. Log of energy against wave number was plotted thereafter. This aided the computation of the depth parameters which were imported into surfer for the depth to basement morphology to be delineated.

The first vertical derivative map transformational technique was applied to the residual data so as to make more apparent the shallow related magnetic bodies. This filtering or transformational technique accentuated the high wavenumber component at the expense of the low wave number component. According to [12] this technique is based on the expression:

$$F\left[\frac{d^n Ø}{dZ^n}\right] = K^n F(Ø) \quad (11)$$

Where,

- n = 1, the nth order vertical derivative
- Ø = the potential of the magnetic field
- F = the Fourier transform of the magnetic field

Like the first vertical derivative, the second vertical derivative highlights near surface anomalous effect at the expense of the effects that are of deep origin. This study necessitated the application of the second vertical derivative (SVD) on the residual data so as to make conspicuous some shallow effects that were not accentuated by the first vertical derivative. The second vertical derivative filtering method is based on equation 11 with n = 2

First horizontal derivative which enhances low frequency component of underground causative sources was applied to the residual data. This technique has the capability of producing anomaly peaks located over the edges of wide bodies. Thus by applying this filtering technique, there is an increase in the definition of body edges located at a shallower depth.

[11] believes that, in Fourier domain, the horizontal derivatives of a smoothly scalar quantity Ø(x, y), in x and y directions are given by:

$$F\left[\frac{d^n Ø}{dx^n}\right] = (ik_x)^n F(Ø) \quad (12)$$

and

$$F\left[\frac{d^n Ø}{dy^n}\right] = (ik_y)^n F(Ø) \quad (13)$$

Where the factors $(\boldsymbol{ik_x})^{\boldsymbol{n}}$ and $(\boldsymbol{ik_y})^{\boldsymbol{n}}$ are operators which transforms a function into nth order derivatives with respect to x and y, respectively [12]

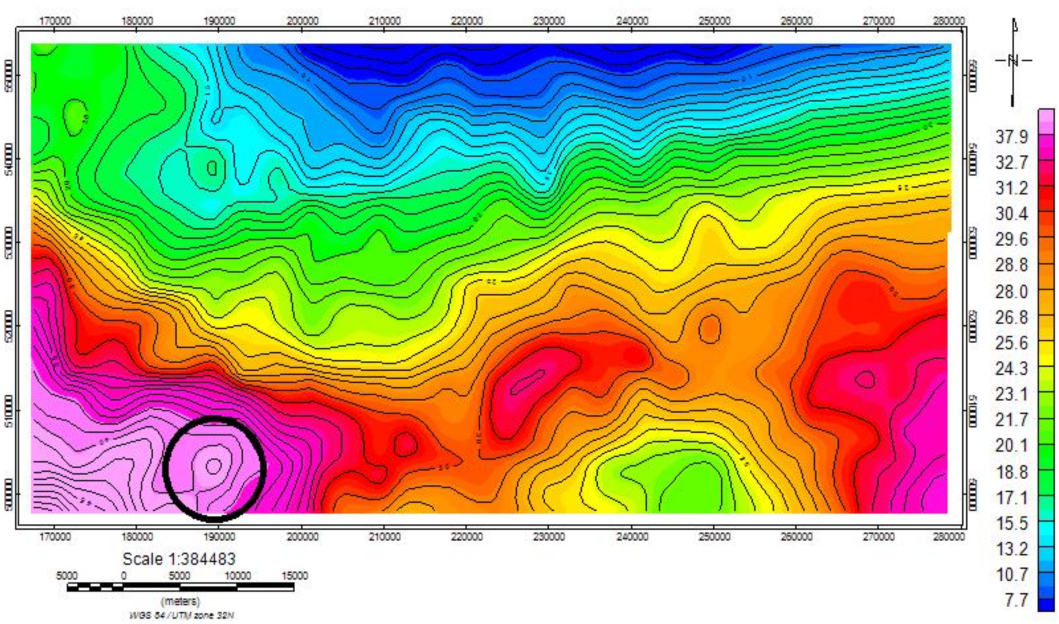


Fig. 3. Bouguer gravity map of the study area (mgal)

3. RESULTS

To have first hand information on significant local anomalies, regional-residual separation was carried out on the contoured bouguer gravity data and this resulted in the generation of the residual and regional data (Fig 4 and Fig 5). On the residual data further processing like the first vertical derivative, second vertical derivative, first horizontal derivative and the second horizontal derivative were undertaken and consequently their respective grid maps (Fig. 6, Fig 7, Fig 8 and Fig 9.) generated. The qualitative grid anomalous maps represented in contour formats assisted in characterizing the subsurface structures through the analysis of its anomalies.

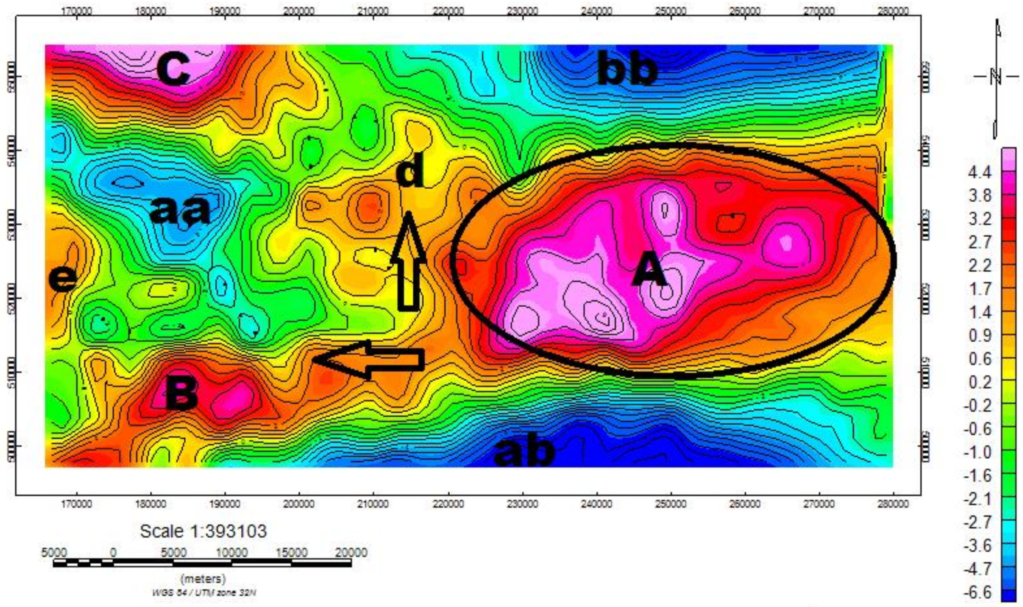


Fig. 4. Residual bouguer gravity map (mgal)

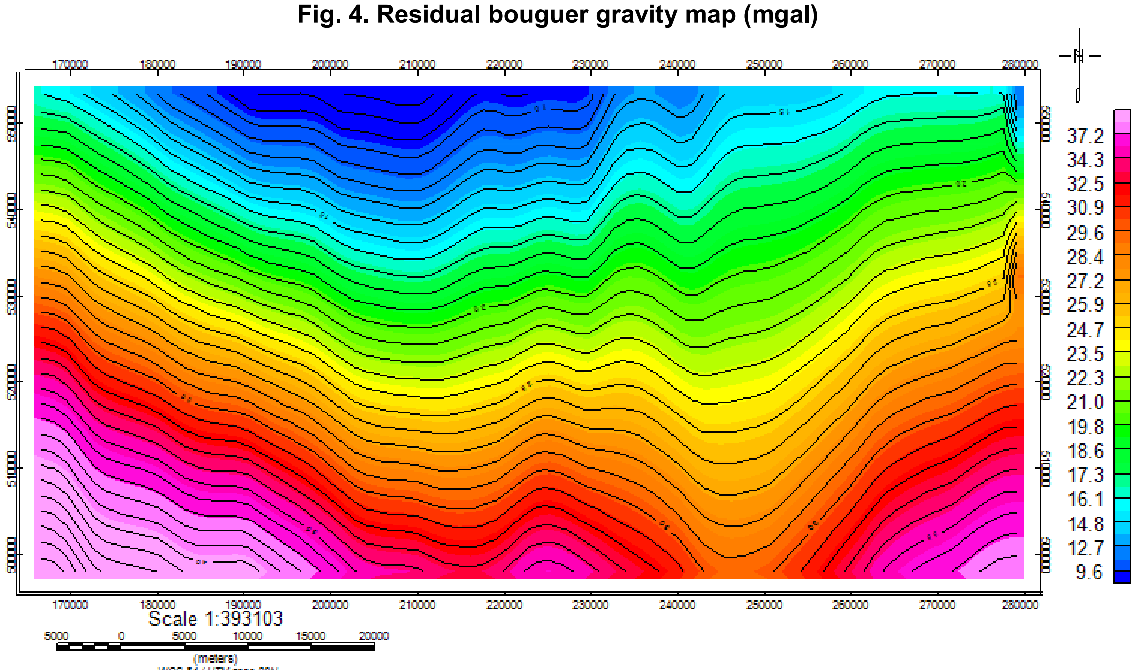


Fig. 5. Regional bouguer gravity map of the study area (mgal)

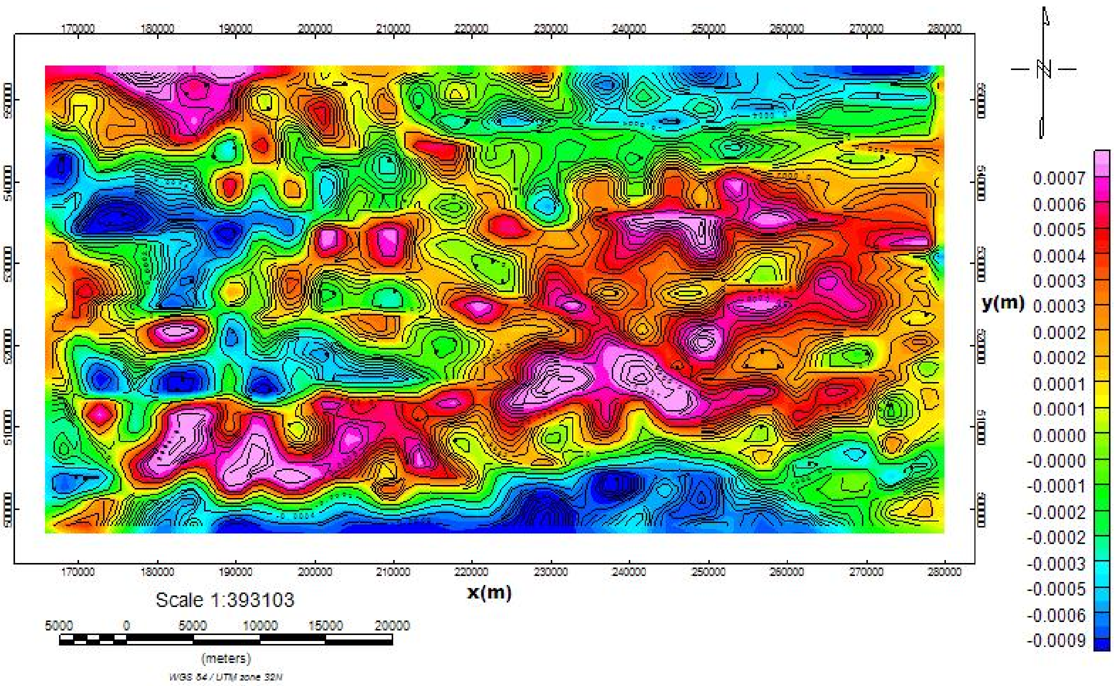


Fig. 6. First vertical derivative bouguer map (mgal/m)

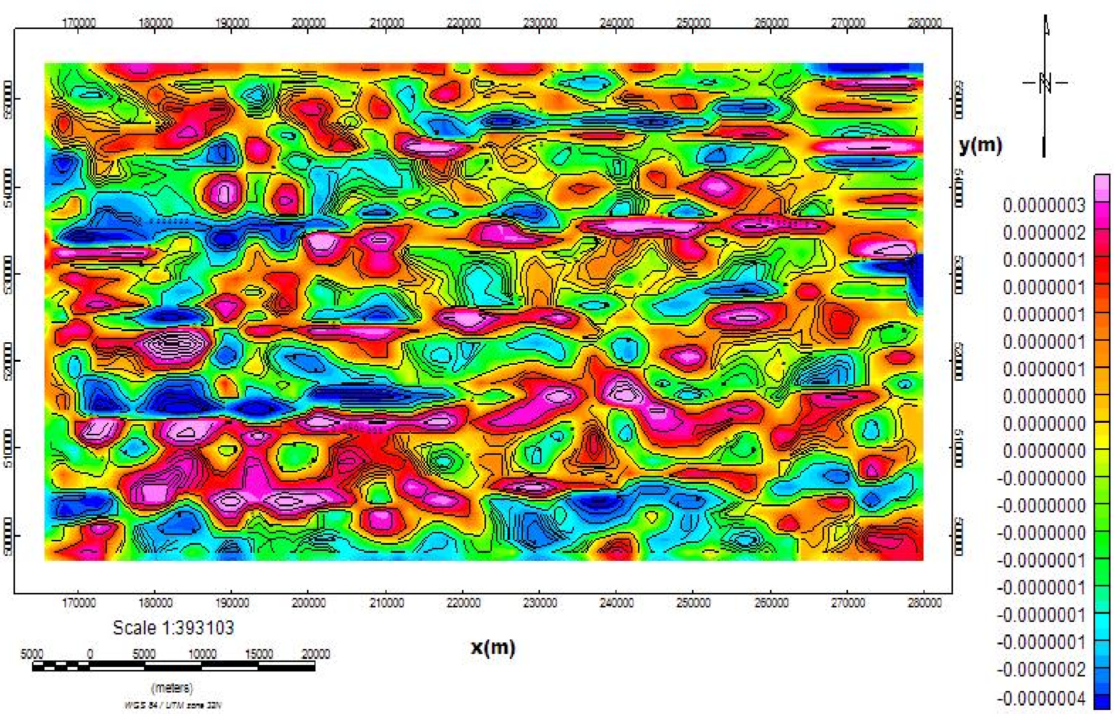


Fig. 7. Second vertical derivative bouguer map (mgal/m)

Some of the results of Fast Fourier Transform performed on each of the windows found in the windowed residual bouguer map (Fig. 10) are shown in Fig 11. Fig. 11 served as prerequisite for the generation of Table 1.

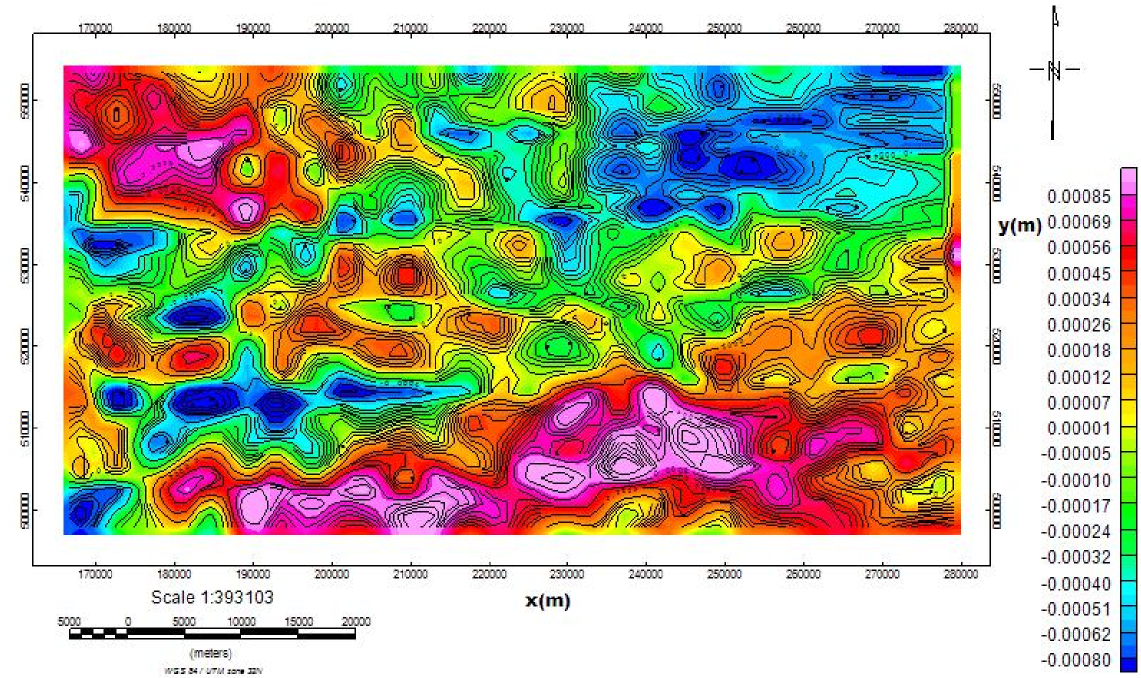


Fig. 8. First horizontal bouguer gravity map (mg al)

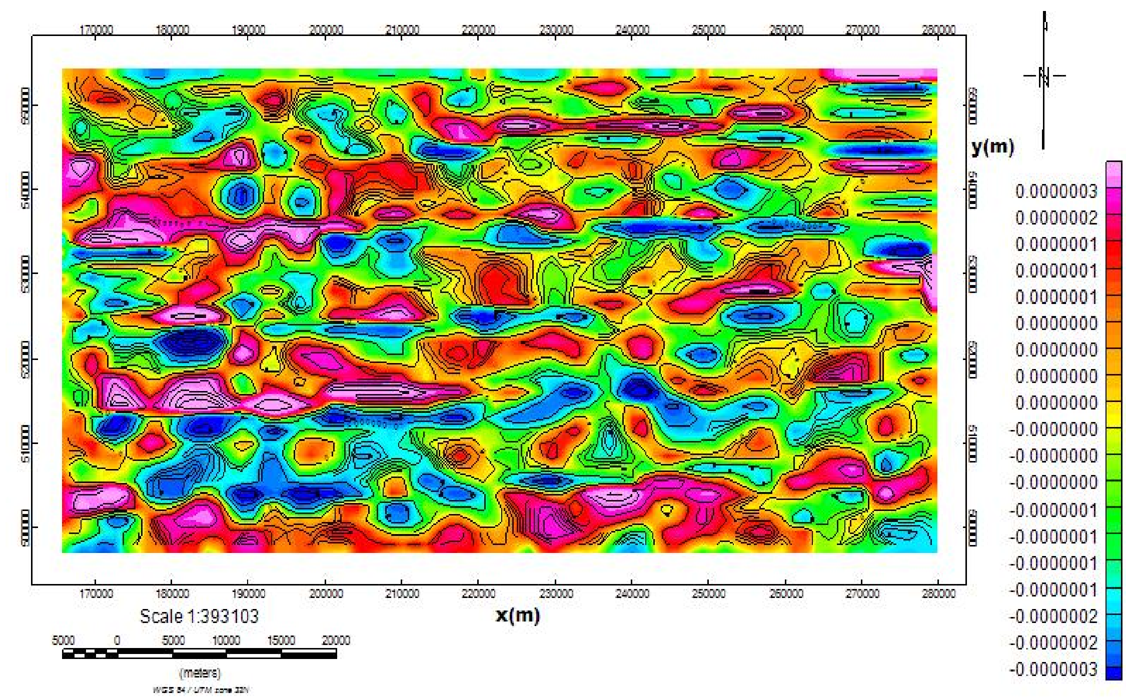


Fig. 9. Second horizontal bouguer gravity map (mg al)

Fig. 12 and Fig. 13 depict the depths to deeply seated and shallow related gravity sources while Fig 14 and Fig 15 show surface 3D maps for shallow and deeply seated anomalous sources respectively.

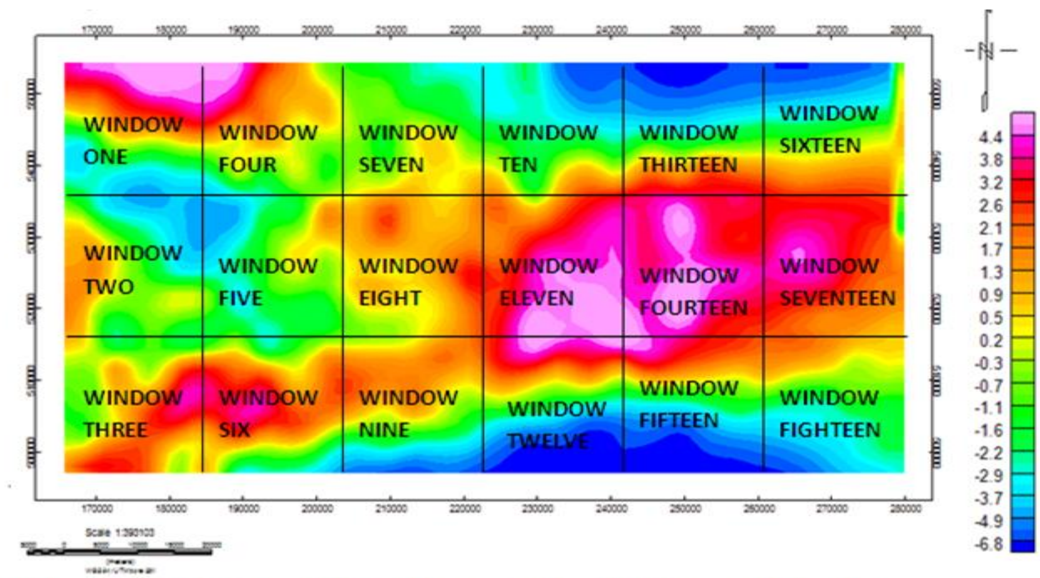


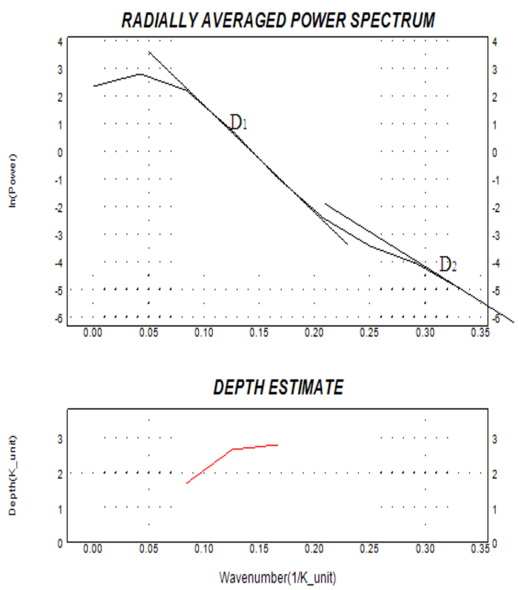
Fig.10: The residual divided into eighteen overlapping spectral windows

Table 1. Depth parameters obtained via spectral depth analysis

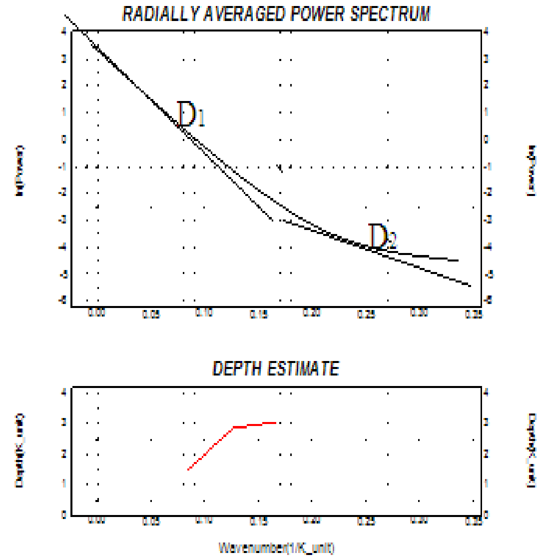
X	Y	Slope		Depth(km)		True depth
		S1	S2	D2	D1	Da
54500	176250	-20	-6.3	-3.15	-10	-6.6
290000	176250	-28.6	-14.6	-7.3	-14.3	-10.8
508750	176250	-40	-14.3	-7.15	-20	-13.6
196250	176250	-19	-10	-5	-9.5	-7.25
527500	196250	-13	-	-	-6.5	-3.25
507500	196250	-13	-6.67	-3.33	-6.5	-4.9
301000	215000	-14.19	-10.5	-5.25	-7.1	-6.2
525000	215000	-40	14.26	-7.13	-20	-13.6
510000	117000	-26.6	-11.14	-5.57	-13.33	-9.5
547500	232500	-42.18	-15.8	-7.9	-21.09	-14.5
527500	235000	-30	-		-15	-7.5
507500	230000	-13.33	-6.4	-3.2	-6.67	-5.9
552500	252500	-20	-12.6	-6.3	-10	-8.15
527500	252500	-20	-10.5	-5.25	-10	-7.6
507500	252500	-31.2	-	-	-15.6	-7.8
507500	252500	-25.6	-	-	-12.75	-6.4
548000	272500	-25.5	-10.5	-5.25	-12.75	-9
527500	272500	-30.1	-13.37	-6.69	-15.05	-10.89

4. DISCUSSION

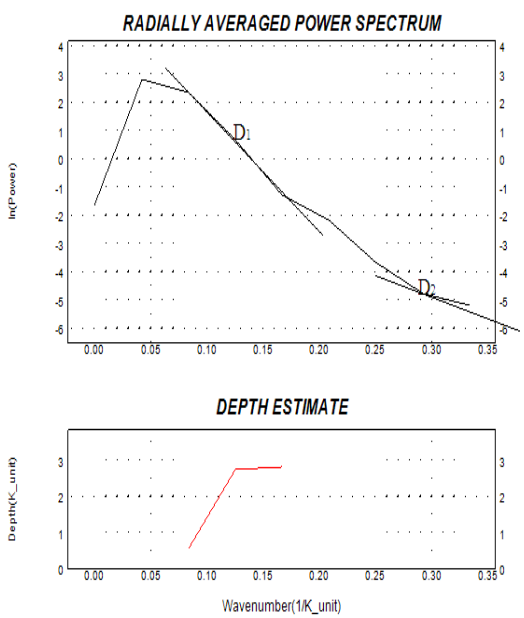
The Bouguer gravity anomaly map covering the study area was produced on a scale of 1:393103 by the Nigerian Geological Survey Agency (NGSA). Colour variations depicting low and high amplitude gravity anomalies are apparent on the bouguer gravity raster map. The map shows two distinguishable areas: a) predominant gravity lows trending ENE-WSW, N-S and NW-SE around the northeastern, northwestern and northern areas and b) ostensible trending ENE-WSW to E-W gravity highs found in the southern, southeastern and southwestern side of the map. The gravity high is found to be located within Port Harcourt and Degema regions while the gravity low is observed within Oloibiri area of the geologic map. Beside the map is a label which accentuates the gravimetric values of, perhaps, distinct lithology and structures with the aid of colour differences. This difference in colours (Fig. 3) partition the study area into gravity high (yellow, red and mangenta colours) and gravity low (green and blue colours). Maximum and minimum gravity values revealed by the label are 37.9 mg al and 7.7 mg al respectively. The colours on the map varies from blue and green at the northern end of the map to yellow, red and magenta at the southern end of the map. The colour contrast reflects summation of gravitational effect of all subsurface rocks within the study area and as such horizontal variations of rock densities are revealed. Close inspection of the bouguer gravity raster map reveals sharp gradients found within geological domain of Oloibiri and Degema area of Niger Delta, Nigeria. As evidenced by the label, gravitational field generally increases from the northern end to the southern end of the map. The blue and green colours found at the north are associated with



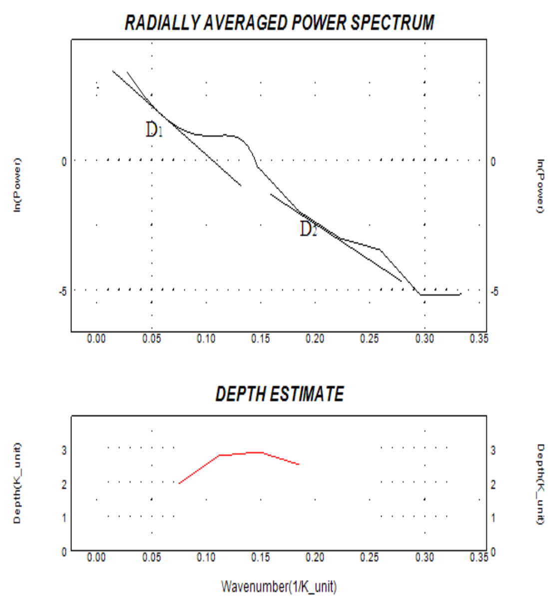
SPECTRAL ANALYSIS ON WINDOW ONE



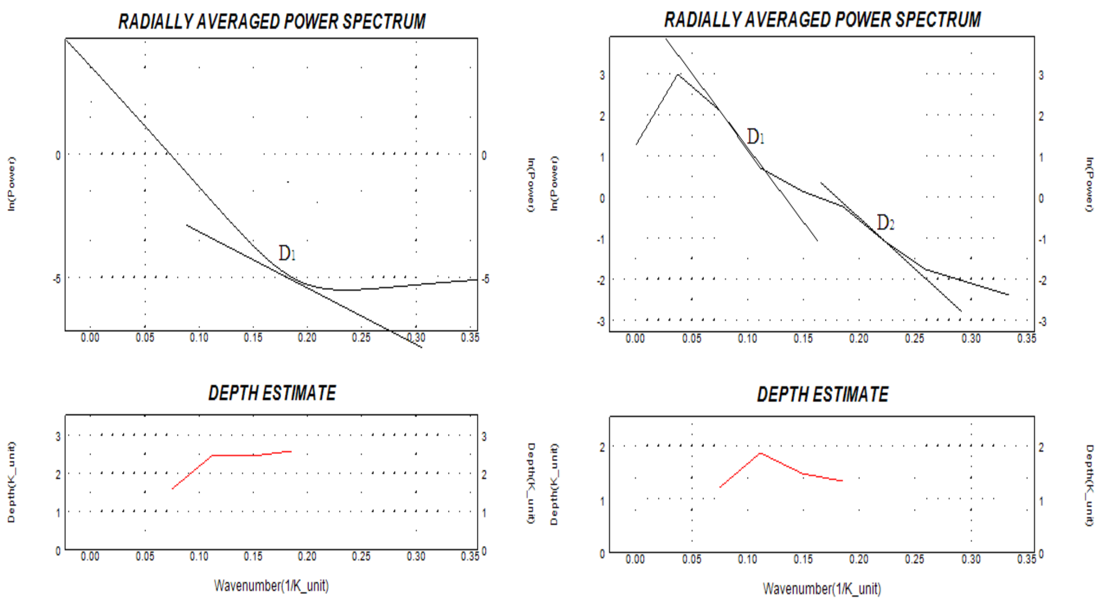
SPECTRAL ANALYSIS FOR WINDOW TWO



SPECTRAL ANALYSIS ON WINDOW THREE



SPECTRAL ANALYSIS ON WINDOW FOUR



SPECTRAL ANALYSIS ON WINDOW FIVE **SPECTRAL ANALYSIS ON WINDOW SIX**

Fig. 11. Spectral analysis on some of the windows

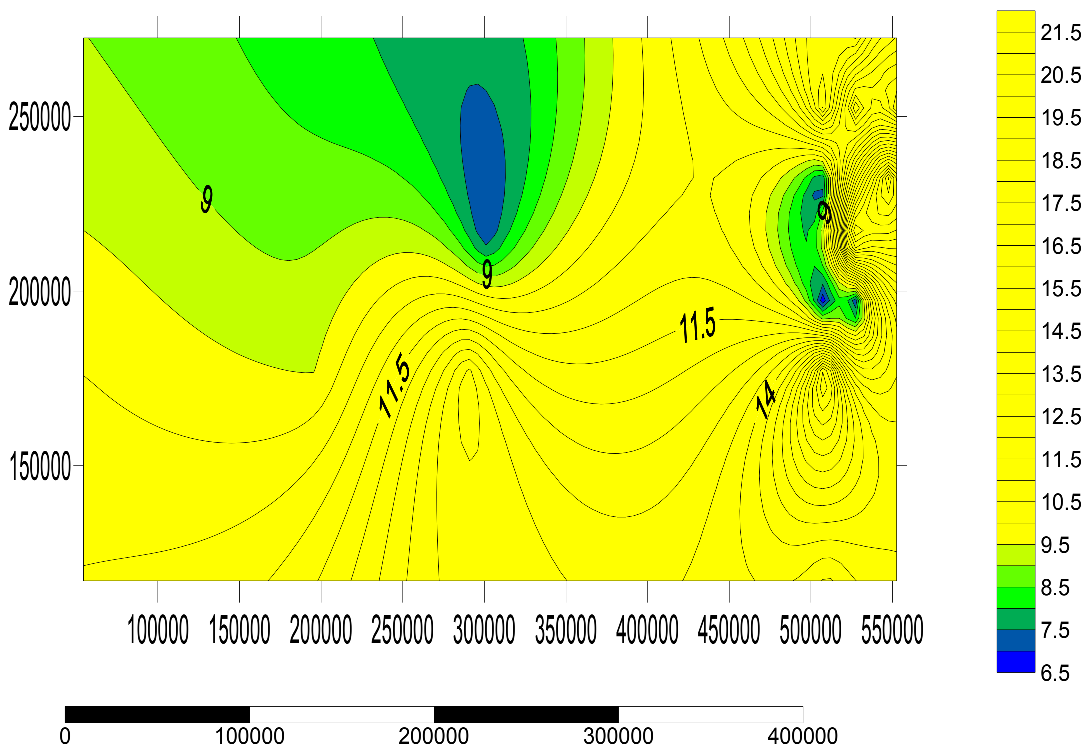


Fig. 12. Depth to gravity source map depicting deeply seated causative sources

possible rocks with low gravity values. On the other hand, high gravity values obviously dominate the southern end of the map. It can therefore be deduced that higher density causative sources occur at the southern portion of the study area while low density causative sources are seen at the northern end of the map. Thus, there is a northwards decrease of rock density towards the north. [12] observed a southward decrease of rock density within Qaltara depression area of western Egypt. They stated that the southwards decrease of causative sources may indicate that the crust-mantle boundary is deeper within the southwest than the center and northern part of their study area. [13] suggested that such decrease in gravity represents increasing thickness of the continental crust. According to [14] gravity high regions are associated with basement rocks while gravity low regions are associated with sedimentary rocks. Nevertheless, gravity high within the study area ranges between 23.1 mgal to 37.9 mgal while gravity low varies from 21.7 mgal to 7.7 mgal.

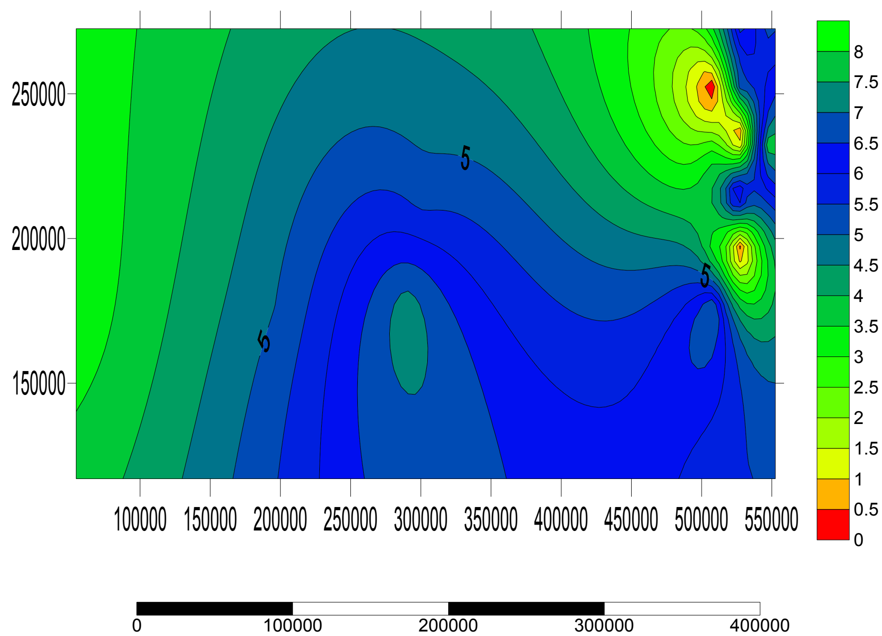


Fig. 13. Depth to gravity source map depicting shallow related causative sources

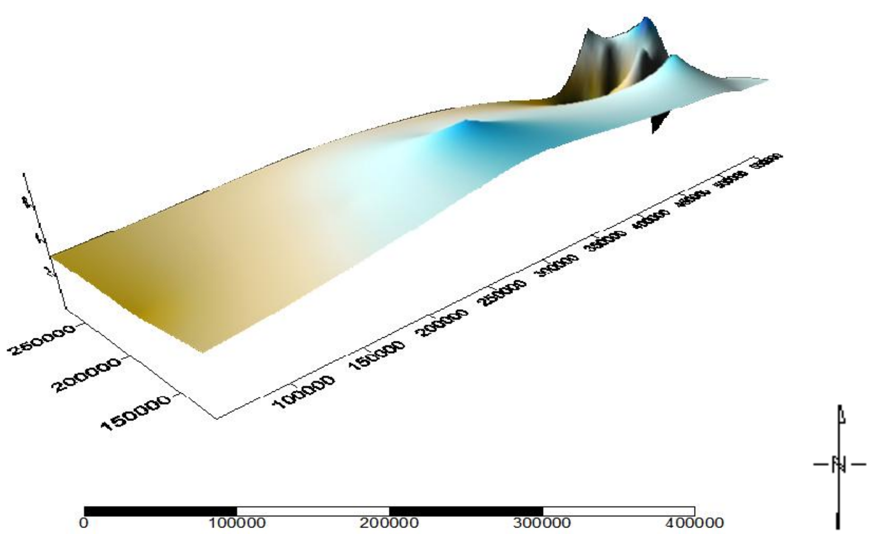


Fig. 14. Surface depth map depicting shallow seated gravity sources

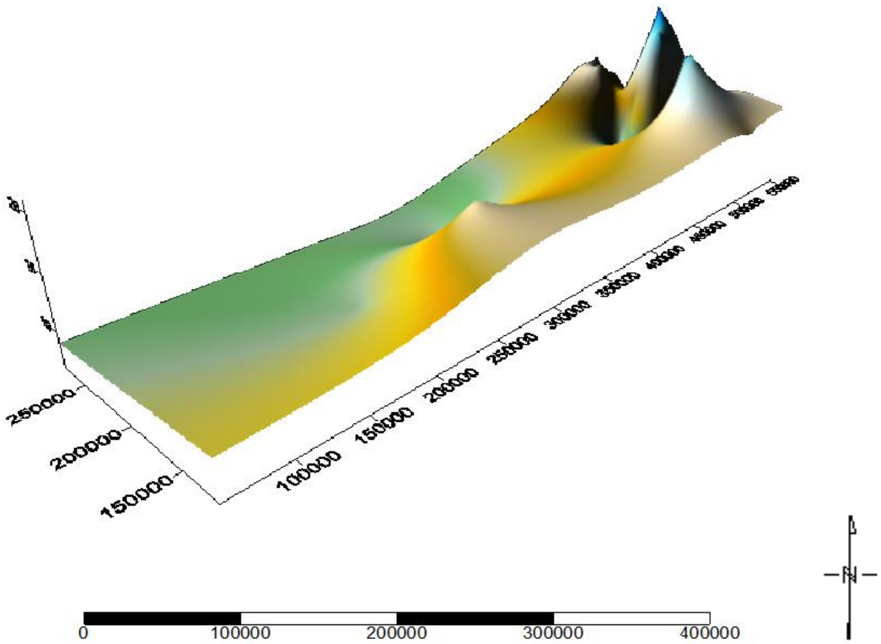


Fig. 15. Surface depth map depicting deeply seated gravity sources

To further interpret the crustal structure of the study area, the need to transform the bouguer raster map into contoured bouguer gravity map. The contoured bouguer gravity map (Fig. 3) is contoured at a stable 1.2 mgal contour interval. Distinct positive contour configurations are evident on the map. Strong positive gravity anomalies with contours trending in the E-W and ENE-WSW direction are observed at the southern portion. However, little NE-SW directional contour trends can be seen at the south eastern end of the map. These strong positive anomalies whose gravimetric values range from 23.1 mgal to 37.9 mgal are irregular and spaced. The irregularity observed could be attributed to high differentiation of the basement while the observed spacing pattern between the contours is an indication that the anomalies are of deeper origin. It is apparent that maximum gravity high with a tectonic trend of NW-SE direction occurs at the south western portion and slightly at the south eastern portion. Within the NW-SE region, an anomalous structure circled with a thick line is visible. This circled causative source could have intruded vertically into surrounding strata. Hemispheric shape like structure with a contour value of 3.0 mgal is noticeable at the southern part. At the northern end is gravity low with ENE-WSW trending contours. Subtle gravity low with contour value of 2.4 mg al is also observable at the southern part of the map The tectonic trends found within the gravity low region are relatively close except for the trends at the North western part. The closeness of the tectonic trends is an indication that the gravity low regions are shallower unlike the gravity high region. As shown by the gravity values in the label, sharp but little gravity changes can be seen with contours having 1.6, 1.8, 2.0 and 2.2 mgal contour values. Sharp gradient is also noticed within the south western portion of the map. [15] stated clearly that these type of sharp gravity gradients are possibly due to upwelling of the mantle associated with high temperature. Thus, it can be extrapolated that melting of the basement rocks had occurred in the lower crust of the study area. The E-W and ENE-WSW tectonic trends indicate sets of faults induced possibly by gravity tectonism within the study area. Attenuated trends expressing Charcot and oceanic fault zones can be seen within the study area. These trends are subtle and they trend in the NW-SE direction.

The bouguer gravity sourced from the Nigeria Geological Survey Agency (NGSA) is the sum of all gravitational effect of underground sources. The Bouguer map consists of the effect due to deeply and shallow seated gravity sources but with the deeply seated or the regional superimposed on the shallow seated or the residuals. To give a better interpretation of the desired feature, highlight some salient features and hidden tectonics, regional-residual separation was carried out by using polynomial fitting technique of degree one. The choice of polynomial degree is, however, arbitrary. The regional-residual separation is based on the subtraction of the regional from the Bouguer. The resultant effect is the anomaly of interest which is called residual anomaly.

The residual map reveals linear, irregular and smoothened gravity anomalies with gravimetric values ranging from -6.8 mg al to 0.2 mg al for low gravity regions and 0.5 mg al to 4.43 mg al for high gravity regions. Two distinct gravity lows exist within the study area, namely the gravity low with blue colouration and that with green colouration. Gravity low indicated by the blue colours is located within the north eastern, western and southern portions of the map while the gravity low expressed by the green colour is evenly distributed within the study area. Gravity anomalies labeled aa, ab and bb are the gravity lows. At the edges of these gravity low anomalies, the blue colouration faints to light blue. The change in colour could be as a result of weathering of gravimetric rock units involved. Anomalies with high gravity values are noticeable at the eastern, central, south western and north western portion of the map. These anomalies with high gravity values are labeled A,B,C, d and e. The principal gravity high, A, found at the eastern region of the map has protruding edges that connects with high gravity anomalies labeled B and C. These anomalies B and C are found within the south western and north western region while the magnetic high d and e, can be located towards the northern part and the western edge of the map. These anomalies labeled aa, ab, bb, A, B, C, d and e are lineaments and possible fault zones within the area under review. [16] opined that the gravity highs are associated with Meta sedimentary rocks while the gravity lows are due to sedimentary rocks like shale, sandstone and/or limestone. The contoured residual map highlights varying degrees of contours that are closely packed. The closeness of the contour can be related to shallow gravity bodies. These contours vary from being circular, elliptical to being elongated linear contours. At the southeastern portion of the map, closely packed and elongated linear contours with low relief are conspicuous. These linear elongated contours forms fault belt zone. [17] believe that this anomalous pattern results from subsurface faulting that have displaced gravimetric rocks. The elongation of the contour depicts faults that serve as conduit for economic deposits while the closeness of the contours shows that the faults are of shallow origin. Hence, faults of shallow origin exist within the study area. Nevertheless, the contour architecture found in the residual is quite different from the contours observed in the bouguer gravity. This is attributed to the regional-residual separation performed on the bouguer map. The circled anomaly found on the bouguer map shows anomaly similar to that of a salt dome. This anomaly is unrelated to anomalies of interest as the anomaly is no longer discernible on the residual map. This is an indication that such anomaly is of deeper origin. Emplaced at the eastern portion of the map are high gravity anomalies indicated with a thick circle. These anomalies lie within the Port Harcourt region of the geologic map. However, this region is underlain by the Mangrove swamps. Within the anomalies indicated with a thick circle, are higher anomalies of high gravity values labeled A. The anomalies are of short wavelength. These anomalies are of wide areal extent. The anomalies consist of edges protruding towards the northern and south western portion of the map. The direction of protruding anomalies is indicated with the arrows. Towards the western side of the map, high gravity values can be seen. The western part of the bouguer residual map falls within Oloibiri town of Bayelsa state, Nigeria. This region is predominated by the Meander Belt Wooded black swamp. Similar colour of the anomalies labeled A can be noticed at the north western and south western portion. Moving northwards (which is occupied by the Meander Belt Wooded black swamp) and immediately above the circled anomaly is an extended linear anomalies with a relatively high relief. These gravity signatures are almost synonymous to the signatures found immediately below the circled anomalies. At the southern part of the bouguer residual map falls the degema region and within such region low gravity signatures that are closed and linear can be seen. However, similar type of feature can be seen within the eastern, northern part of the map. These signatures are marked aa, ab and bb. The gravity signatures generally trend in the ENE-WSW, N-S, E-W and WNW- ESE directions but with the ENE-WSW tectonic trend dominating.

Smoothened long wavelength effect known as regional trends was subtracted from the bouguer anomaly data. These longer wavelength effects are due to the deeply seated gravity sources. The deeply seated gravity effect obscures the shallow seated anomalies of interest known as the residual. The long wavelength regional effect therefore makes it difficult to interpret the short wavelength residuals. Manifested on the regional map are parallel and linear elongated regional trends running from east to west. These extended linear trends are curvy in the eastern, northern, southern and south western portion of the map. [18] enunciated that the parallel and curved anomalies are due to large tectonic feature of ancient geosynclines. The map shows a southwards increase in the density of gravimetric sources within the area. The gravity values of the deep seated sources vary from 9.6 mg al to 37.2 mg al.

Colour variations highlighting shallow seated gravity bodies are illustrated in the first vertical derivative map. Unlike the residual gravimetric sources, the gravity values are very small. However, anomalous bodies with high and low density are still distinguishable. Sources with high gravity values ranging from 0.0001 mg al to 0.0007 mg al can be seen occurring at the eastern, north western and western side of the map while low values ranging from -0.0001 mg al to -0.0009 mg al are observed to appear within the southern, northeastern and western portion of the map. The 0.000 mg al value is a zone with no vertical gravity contrast. The high gravity anomaly existing at the eastern portion is similar to the high gravity anomaly which occurred at the same region in the same bouguer residual map. The anomaly runs towards the southwestern and northern portions of the area. Gravity lows appearing apparently on the bouguer residual map are inconspicuous on the first vertical derivative map. This is owned to the fact that the one dimensional fast Fourier transform - the first vertical derivative filter- recognizes some of the low gravity values as artifact. Unlike the bouguer residual map, localized and shorter wavelengths contours are observable. Dominating on the map are closed gravity contours. Little linear contours that are apparent exist at the southern region. The shorter wavelength contours is an indication that shallower gravity sources are accentuated using the first vertical derivative filter. Embedded inside high gravity contours occurring across the map are contours of higher gravity values. According to [19] the higher gravitational values that are embedded are distinct litho logy from the surrounding. Existing on the map are contours having E-W, N-S, ENE-WSW and WNW- ESE tectonic strike direction.

In contrast to the residual and first vertical derivative map, lateral orientation of anomalies is obvious in the second vertical derivative map. However, few anomalies with vertical orientation can be seen. The label beside the second vertical derivative map indicates little or no changes vertically within the map. Gravity values ranging between -0.0000004 mg al and 0.0000003 mg al exist within the map. The gravity anomalies emplaced laterally are noise. This is because the second vertical derivative identifies and visualizes anomalous changes in the vertical direction. Close inspection of the map, reveals gravity bodies with sharp edges. Regions with no vertical gravity contrast are obvious as indicated by the 0.000 mg al values attached to the label. Irregular, circular, localized and short wavelength gravity contours can be seen on the map. The contours have a general trend of E-W, N-S, NE-SW and NW-SE. The E-W trends, however, persist within the study area.

The first horizontal derivative map shows acute predominate high gravity field changes. Gravity sources with large areal extent are visible running from the south eastern side of the map to the southern portion. [20] stated that sources with such large area extent can be attributed to the homogeneity of the source. They also stated that such anomalous feature is produced by large density contrast. Gravity lows can be seen more at the north eastern portion of the map. Minor circular gravity lows are also noticeable towards the western zone of the map. E-W and N-S tectonic trends are visible on the map but with the former occurring frequently. Gravity anomalies within the map have values ranging from 0.00080 mg al to - 0.00085 mg al.

Spatially distributed on the second horizontal derivative map are structural highs. The structural highs are anomalies with high gravity values. The anomalous gravity values vary between --0.0000003 mg al and 0.0000003 mg al. Structural or gravity lows can be observed within edges of the map. Close examination of the contours reveals contours that are of longer wavelength laterally. The anomalous gravity trends are in the E-W direction. However, minor N-S trend are discernible at the edges of the map.

The quantitative analysis performed on the residual bouguer data by means of spectral analysis reveals two depth source models representing the causative sources. These sources are of deeper and shallow origin. The deeply seated anomalous sources (D_1) are positioned within and beyond the basement while the shallow causative sources are found within the sedimentary section. The slope of the energy curves are negative, hence the corresponding depth values are all negative values. D_1 which was obtained from the steepest part of the energy curve ranges from 6.5 km to 21.09 km with an average value of 12.56 km. Depth value of 21.09 km implies that measured parameter of interest goes behold the basement. This is because it is believed that the depth to basement falls within 12 km within the Niger Delta region. On the other hand, D_2 obtained from the less steep section of the energy curve varies between 3.15 km and 7.19 km with an average value of 4.35 km. Depth values for window 5, 11, 15 and 16 were not computed due to the effect of noise. This is evidenced by the non linear nature of the spectral energy curve. The depth value obtained in this research is comparable to those obtained by previous researchers who employed the old and new bouguer gravity data sets. [19] discriminated the depth of gravity sources using Euler deconvolution and source parameter imaging techniques. They obtained depth to anomalous sources to be between 2,000 m to 9,300 m for structural index of one, and 3,200 m to 10,600 m for structural index of two while the source parameter imaging technique reveals depth to gravity sources ranging between 1,700 m and 10,600 m. [20] estimated the depth to gravity and magnetic data using least square method. It was obtained that depths of between 1,000 m to 3, 500 m from the gravity data and depths of 2,183 m to 4,385 m from the magnetic data exist within the area.

Regions of magnetic highs and lows are replicated as folded basement gravity surface on the depth to gravity contour and surface maps. The maps highlight the highs and lows of the basement as well as its relief. The depth to basement contour maps relating the deeply seated and shallow causative sources reveal structural highs and lows. On the depth map relating to the shallow sources, structural low zones are expressed in green and blue colour and this is evenly distributed seen on the map whereas few structural highs are depicted on the map with red and yellow colours. On the depth contour map showing deeply seated anomalous sources, structural highs which are evenly distributed are evident on the map with yellow colour. However, structural low with green colouration are discernible on the map.

For the surface depth map showing shallow causative gravity sources, structural low zones can be found at the southwestern portion of the map while structural high zone is found within the central portion of the map. Structural high and low zones are also observed on the surface depth map showing deeply seated causative gravity sources. Structural high zones are found within the north western side of the map while structural low zones are observed at the northern and eastern portion. Observed within the zones of structural are spiky surface which are believed to be intruding unto the sedimentary section. Nevertheless, spiky structures are located at the north eastern portion of the maps. Sorrounding the spikes are synclines which can serve as generating depocenters for hydrocarbon.

This study, hence, identified that basement highs and lows play major role in sediment and hydrocarbon distribution in the Niger Delta. This factor appears to have controlled the trapping of hydrocarbon within the study area. The depth to surface map relating to deeply seated sources reveals a minibasin which serve as an entrapment for hydrocarbon and perhaps other earth resources. . This minibus in found northeast ward is the focal point for oil and gas and therefore is the preferred target for hydrocarbon exploration in the study area.

5. CONCLUSION

Subsurface structures having strike direction of ENE-WSW, N-S, E-W and WNW- ESE were observed qualitatively within the study area. These structures have rectilinear, curvelinear, circular and elliptical shapes. Quantitatively, a true sedimentary value of 12.56 km was revealed using spectral depth analysis. Syclines expressed as minibasins were revealed and these are regarded as the generating depocenters as the oil and gas generated in such regional lows will migrate up dip. These results show that the area will be geologically significant as the area will be viable for hydrocarbon exploration.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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