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IMPROVING THE GEOLOGICAL UNDERSTANDING OF THE NIGER DELTA BASIN OF NIGERIA USING AIRBORNE GRAVITY DATA

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ABSTRACT

Airborne gravity anomaly over parts of Niger delta basin of Nigeria has been interpreted qualitatively and quantitatively. The residual anomaly was obtained from the observed field data through a second order polynomial method and then enhanced by a filtering process. The qualitative interpretation of the gridded data reveals NS, EW and NE-SW trending subsurface structures. The inverse and forward modeling results show spherical and dyke-like anomaly structures at depths of between 1,090 m to 3,538 m, while the density contrast of formations identifies areas of possible hydrocarbon occupation. The Euler deconvolution windowed solutions reveal depth to anomalous sources of between 2,000 m to 9,300 m for structural index of one, and depths of between 3,200 m to 10,600 m for structural index of two. The source parameter imaging reveals depth ranges of between 1,700 m to 10,600 m. The work reveals that the maximum depth to basement in the study area is 10,600 m.

Keywords: Airborne gravity data, Anomalous bodies, Niger delta, Inverse and forward modeling, Euler deconvolution, Source parameter imaging, Density contrast, Basement, Stratigraphy, Residual anomaly

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Contribution/ Originality

This study contributes to the existing literature on the structure, stratigraphy and depths to basement information of parts of the southern Niger delta of Nigeria using airborne gravity data. The papers primary contribution is in determining the maximum depths to basement in this region as lying between 9,300 m to 10, 600 m.

1. INTRODUCTION

Majority of the regional studies in the Niger delta have focused on the use of seismic and borehole methods for interpretation of the stratigraphic, petroleum and structural geology of the region. Although, the seismic and borehole methods are capable of producing a more detailed and better resolved picture of a subsurface, they have limitations in terms of depth of penetration, cost and coverage. On the other hand, the gravity method has the advantages of providing information on earth properties at grater depths with simple logistics and coverage of inaccessible areas (Hinze, 1990). Despite these advantages the gravity method, as evident from literature, has scarcely been employed in the geologic study of the Niger delta with the most notable work being that of Hospers (1965). However, this trend has gradually improved with the acquisition of high resolution airborne data by the Nigerian Geological Survey Agency.

Density contrast is basically the fundamental parameter of gravity survey and has found wide application in regional geological studies, mineral exploration and other subsurface investigations (Reynolds, 1997). The Bouguer

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gravity anomaly can be analysed and interpreted to get useful information as structural trends, sedimentary thickness, and depth to basement rocks, location of hydrocarbon or other minerals in a region.

In order to improve the geological understanding of the Niger delta which is a prolific region with high occurrence of hydrocarbon, a combination of forward and inverse modeling, Euler Deconvolution and source parameter imaging methods were employed in this work to evaluate the structural trends and depth to anomalous gravity sources within the southern part of the region.

2. LOCATION AND GEOLOGY OF STUDY AREA

The study area (Fig.1) lies within longitudes 6°00' to 7° 00'E and latitudes 4°30' to 5°30'N south of the Niger delta with an area of about 13, 000 km². The major cities and towns in the study area include Patani, Ahoada, Oloibiri and Degema. The Niger Delta is located approximately between longitudes 5°00' to 8°00'E and latitudes 4°00' to 8°00'N, with depobelt area of 300,000 km² and an average elevation of 92 m above sea level Opufunso (2007). According to Reijers (2011) it was developed during the breakup of the South American and African plates in the late Jurassic. This led to the development of the massive continental margins of West Africa and the Benue Trough. Marine sedimentation started to evolve in the early Tertiary times (Doust and Ommatsola, 1990) and over the years has praded a distance of more than 250 km from the Benin and Calabar flanks to the present delta front (Evamy *et al.*, 1978). According to Merki (1972) the progradation of the Niger Delta sequence has been controlled by synsedimentary faults, folding and interplays between subsidence and sediment supply. The sediment supply was mainly from the Niger, Benue and Cross Rivers.

The stratigraphy of the Tertiary Niger Delta is divided into three formations (Fig.2), representing prograding depositional facies that are distinguished mostly on the basis of sand-shale ratios and these are the Akata Formation, the Agbada Formation and the Benin Formation (Evamy *et al.*, 1978; Tuttle *et al.*, 1999; Reijers, 2011). The Akata Formation is the base of the delta. It is of marine origin and is composed of thick shale sequences (potential source rocks) and turbidite sands (potential reservoirs) with minor amounts of clay and silt. It was formed from the beginning of the Palaeocene to the Recent. The Agbada Formation is the major petroleum-bearing unit of the Niger Delta. Deposition began from the Eocene to the Pleistocene. The Formation consists of paralicsiliciclastics over 3700 m thick. The Benin Formation is a continental latest Eocene to Recent deposit of alluvial and upper coastal plain sands (30% - 70%) that are up to 2000 m thick.

Fig-1. The study area (modified from (modified from Obaje (2009)).

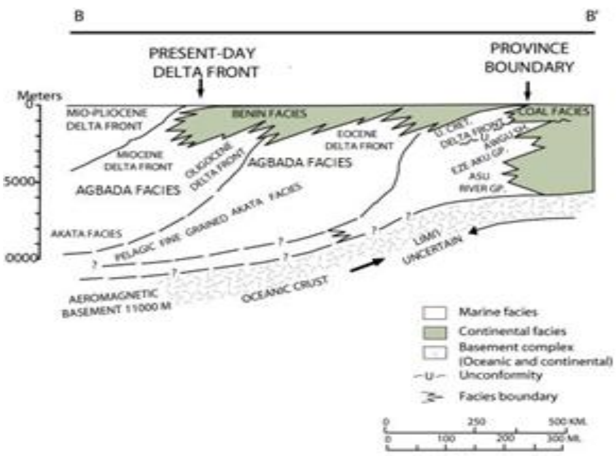

Fig-2. Stratigraphy of the Niger delta (Obaje, 2009).

3. MATERIALS AND METHODS

The data used for this study are airborne gravity data obtained from the Nigerian Geological Survey Agency (NGSA) Abuja. The data were collected by Fugro Airborne Survey Limited for the agency in 2010. The area under study consists of: Patani sheet (319); Ahoada sheet (320); Oloibiri sheet (327) and Degema sheet (328). The data were collected at 4 km line spacing and terrain clearance of 80 m. To achieve the purpose of this study aimed at interpreting the gravity anomaly and to identify the subsurface structures of the study area, the following approach was adopted guided by the geology of the area. First, the regional anomaly was separated from the residual anomaly where the regional field was obtained by applying a second order polynomial approximation to the observed field. By applying a least squares method, a trend of order two was obtained and subtracted from the observed field data to get the residual anomaly (Hinze, 1990). The residual anomaly was enhanced by applying a high pass filter of order zero and downward continued to a depth equivalent to the grid size of 500 m. To enhance the geologic boundaries, a first order derivative filter was applied. This resultant residual field was gridded using a random gridding method (Briggs, 1974) since the data were sparsely and continuously sampled between points. A grid size of 500m was used to avoid over or under sampling and thereafter a base map was produced. All these were done using Oasis montaj™software. The depths to anomalous bodies were obtained using forward and inverse modeling (Saltus and Blackely, 1983). Selected portions (Fig.3b) of the gridded residual field data were chosen for modeling. The selection was based on qualitative information from the field anomaly base maps. The areas were modeled using the PotentQ-3D modeling software which is an extension in the Oasis Montaj™ software.

Euler Deconvolution method (Thompson, 1982; Reid *et al.*, 1990) was used to locate and estimate the depths of anomalous sources and depth to basement. This was achieved using structural index values of 1 and 2 based on models of dykes and spheres as derived from the inverse and forward modeling. The derived solutions were windowed to reduce uncertainty to the minimum by constraining the obtained Euler Deconvolution solutions to accept depth (dz) tolerance of 10% and horizontal (dy) tolerance of 20%. Thereafter the solutions were gridded to estimate the depths. Also the source parameter imaging method (Abbass and Mallam, 2013) was applied to locate and estimate the depths of anomalous sources and depths to basement by calculating the horizontal grids, applying a cut off depth consistent with geology of area and then obtaining the SPI grid. All these were archived using Oasis Montaj™ software.

4. RESULTS

Figures 3(a) and (b) shows the residual Bouguer gravity map and contoured map respectively. The points P1, P2, P3 and P4 were the points modeled with results as shown Figures 4(a), (b), (c) and (d).

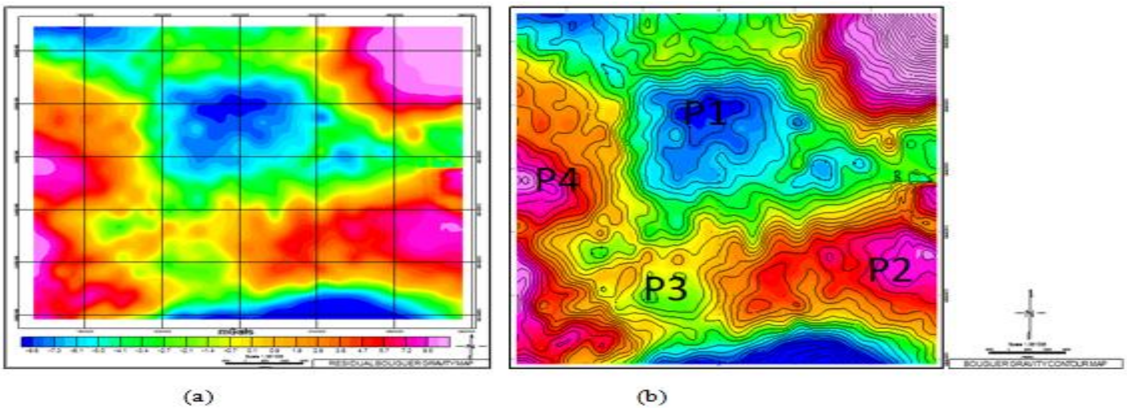

Fig-3. (a) Residual Bouguer gravity map and (b) contour map of the study area (Eke, 2015)

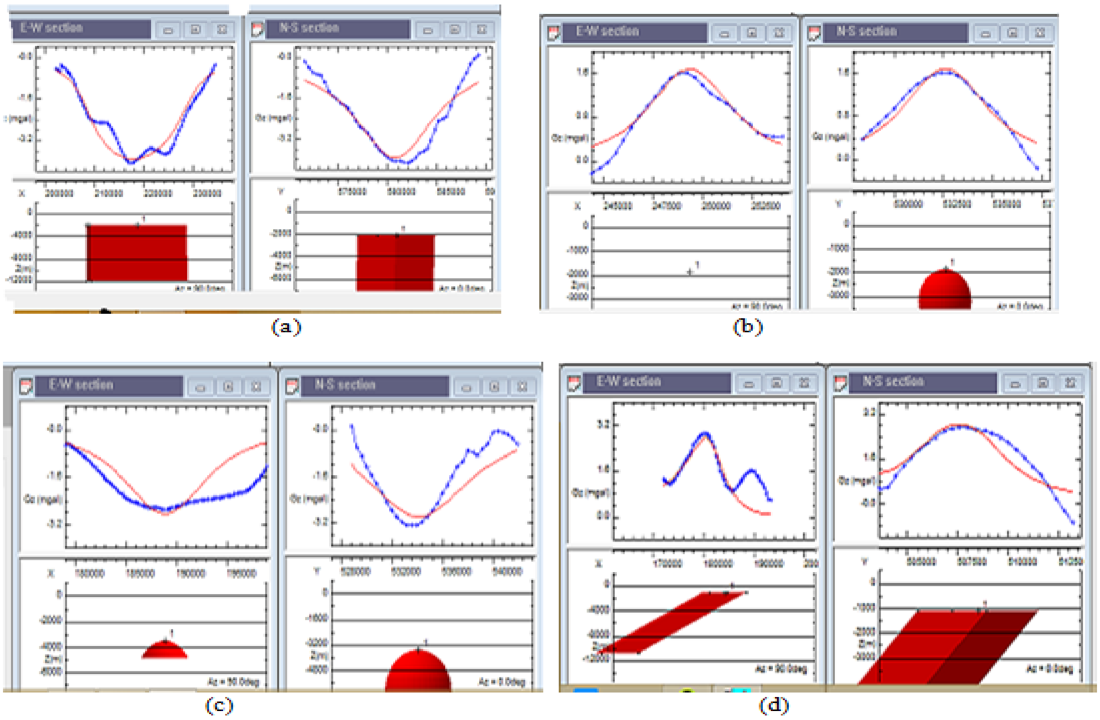

Fig-4. Models for profile points (a) P1, (b) P2, (c) P3 and (d) P4 (Eke, 2015)

Figures 4(a), (b), (c) and (d) shows the profile model results obtained for points P1, P2, P3, and P4.

The summary of the model results are shown in Table 1. It shows the models, depth to anomalous sources and their densities.

Table-1. Summary of inverse and forward modeling results for Bouguer gravity profile points (Eke, 2015)

Model	Model shape	Anomalous depth/m	Density of anomalous Body/gcm^{-3}
P1	Dyke	2,083	0.062
P2	Sphere	1,855	0.259
P3	Sphere	3,538	0.223
P4	Dyke	1,094	0.076

The windowed Euler 3D colour legend bar solutions for structural index of 1 and 2 respectively are shown in figures 5(a) and (b), while Table 2 shows the summary of the depth results.

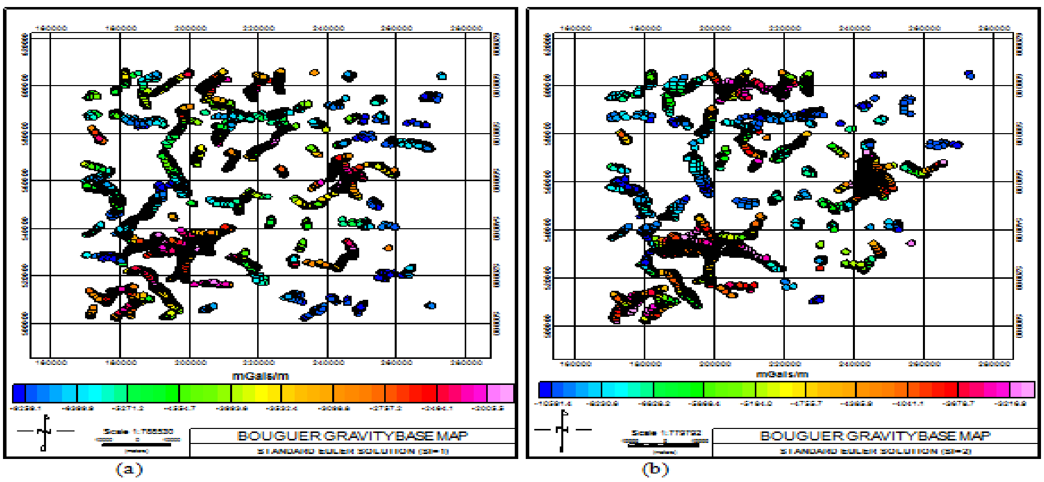

Fig-5. Euler 3D colour legend bar solutions for (a) SI=1 and (b) SI=2 (Eke, 2015)

Table-2 .Summary of windowed Euler 3D solutions (Eke, 2015)

Structural index	Approximate depth ranges/m
1	2,000 – 9,300
2	3,200 – 10,600

Figure 5 shows the source parameter imaging grid map and the colour legend bar that shows the depth ranges as between 1,700m and 10,600m.

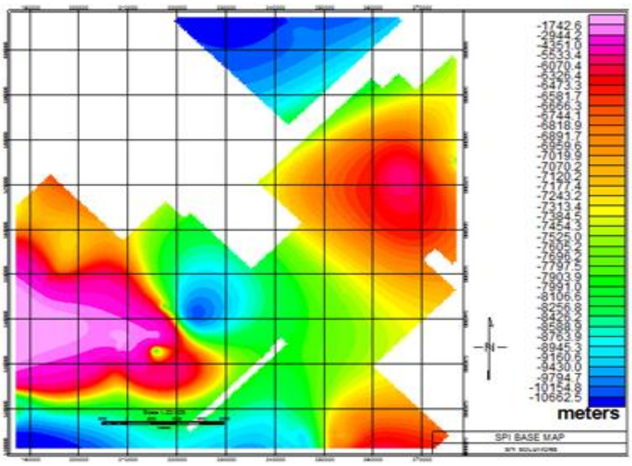

Fig-6. SPI base map and legend bar for study area (Eke, 2015).

5. DISCUSSIONS

The residual Bouguer gravity values ranges from -9.6mGal to 9.6mGal. These values are indicative of coastal-oceanic regions where the Bouguer gravity values drops to zero as we move close to the coast (Robinson and Coruh, 1988). The colour legend bar indentifies regions of gravity high (red and pink colours) that correspond to regions with high density contrast beneath the surface; intermediate values (green and yellow) and gravity lows (blue colour) that correspond to regions of low density contrast. Figure 3(b) is the contoured Bouguer gravity anomaly map drawn at 5 mGal interval. It shows the type of structural trends in the study area. The circular contours are indicative of spherical anomalies attributed to synclines and anticlines bodies; while the long narrow patterns are indicative of dyke related modeled bodies. We can also infer NS, EW and NE-SW trending features.

The forward and inverse modeling (Figs.4a, b, c and d) show the fit of the field values (blue) and the theoretical values (red). The modeled results show that the profiles fit with spheres and dykes. These are indicative of stratigraphic structures such as anticlines, diapers, and faults (Prieto, 1998). The summary of the result (Table 1) shows that profile P1 is a dyke-like structure trending in a north-east direction at a depth of 2,083 m. Profile P2 modeled as a sphere shows an anticline anomalous body trending in the north-east direction at a depth of 1,855 m. Similarly profiles P3 and P4 modeled as a sphere and dyke respectively show syncline and anticline anomalous bodies trending in a north-east and southwest-northeast directions respectively. Their depths of occurrence are 3,538 m and 1,094 m respectively. From the modeled results, their depths of occurrence and their density contrasts, we may conclude that these are probable potential hydrocarbon zones.

The Euler 3D windowed depth grid maps for structural index of 1 and 2 solutions (Table 2) show that the depth ranges are 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. These are in agreement with the works of Evamy *et al.* (1978); Merki (1972) and Oladele and Ojo (2013).

The generated SPI grid image and legends (Fig.6) shows varying colours indicating the different density contrast within the study area. These variations are indications of the subsurface undulations as the blue areas indicate deep lying gravity bodies (probably the basement) while the other colours (purple, orange and red) show areas of shallower sediments or near surface gravity bodies. The depths range from 1,700 m to 10, 600 m. The SPI result fairly agrees with the depth ranges from the Euler 3D method.

6. CONCLUSION

From the result of the quantitative interpretations, the maximum depth to basement in the region is about 10,600 m while the major intrusive and structures in the area are synclines and anticlines occurring as diapers and faults at depths of about 1,000 m to 3,500 m.

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Competing Interests: The authors declare that they have no competing interests.

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