Asian Journal of Applied Science and Technology (AJAST)
(Quarterly International Journal) Volume 4, Issue 1, Pages 112-119, January-March 2020

Structural Trends from Airborne Gravity Data of Delta State, Nigeria

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Article Received: 30 October 2019 Article Accepted: 29 December 2019 Article Published: 25 February 2020

ABSTRACT

Airborne gravity anomaly over Delta State in the Niger delta basin of Nigeria has been interpreted to obtain the structural trends/types and depth to basement in the state. The residual gravity anomaly obtained from a second order polynomial operation on the observed field data was enhanced by a first order filtering operation based on the regional geology. This was converted to a gridded data and analyzed qualitatively to reveal NS and EW trending subsurface structures. Inverse and forward modeling using Oasis Montaj software were applied to selected portions using geological models of sphere and dyke to reveal syncline and anticline structures at depths of between 2005 m to 7372 m, with density contrast of between 1.12 gcm^{-3} and 2.70 gcm^{-3}. The Euler deconvolution operation with a structural index of one, reveal depths between 124.2 to 16,000 m. The results show that the maximum depth to basement in the area occurs in the northern part of the state with maximum depth of 16,000 m.

Keywords: Airborne gravity data, Niger delta, Inverse and forward modeling, Euler deconvolution, Residual anomaly.

1. INTRODUCTION

Measurement of variations in gravity values over the earth can be used for several interpretations [1]. For example, large scale measurements can be used for studies of the earth's shape, rotation and isostatic compensations. Medium scale measurements can be used for regional geological studies while microgravity surveys can be used for subsurface information as buried relics, factures and fault information and others. The measured vertical component of gravity in a field survey is a function of depth, geometric dimension and density contrast of the formations and the variations from point to point is as a result of the shape and rotation of the earth, elevations, excess mass-effects, topography, geological effects and other time variant changes [2]. These theoretical measured values can be corrected to the earth's ellipsoid to obtain a Bouguer gravity anomaly for interpretation of the subsurface. This anomaly can be applied in several ways as in detecting subsurface cavities [3], water flood surveillance [4], locating unexploded ordinance [5], mapping bedrocks for civil engineering works [6] and regional and residual structural analysis [7]. Airborne gravity measures can help us to determine subsurface structures and infer information about the earth's interior because lateral variations in gravity anomalies, over a wide region, associated with density contrast in formations can be obtained from measured gravity values over these regions. Although, airborne data are affected by aircraft height above land surface and the terrain, an accuracy of a few milligrams is guaranteed and they can be used for geological structural studies of sedimentary basins, hydrocarbon traps, ore-bodies and others [1].

Delta State is one of the major oil and gas producing states in the south-south Niger delta of Nigeria. It is blessed with other minerals as industrial clay, lignite, limestone, kaolin and silica [8]. The presence and exploration of oil and gas especially and the other minerals require adequate information of the subsurface. Most structural and stratigraphic works in the region are done with seismic data [7] with little input from other geophysical methods. Hence there is the need for input from other geophysical methods, of which the gravity method is suitable. According to [7] the advantages of the gravity method make it an ideal method to investigate the subsurface of this region because of the terrain. The State is a part of the Niger Delta Structural Basin with identified three major sedimentary cycles that occurred in the early Cretaceous resulting in three sub-surface stratigraphic units of; the Benin, the Agbada and the Akata Formations [9].

The Benin formation is composed of loose and unconsolidated sands of about 1800 m thickness in some regions [10, 11]. The underlying Agbada Formation consists of sandstone and shales with thickness of about 3000 m and rich in hydrocarbons. It is underlain by the Akata Formation that extends to the basement. The Ogwashi Asaba Formation consists of an alternation of lignite seams and clay. The surface rock throughout the state consists of the Ogwashi Uku formation.

Several gravity interpretation methods exist to infer subsurface information. For the purpose of this study, spectral analysis technique that will involve Euler deconvolution and modeling will be used with the objectives of obtaining; the thickness of sediments, structures and structural trends in this area. This will contribute to the existing knowledge on the structure, stratigraphy and depths to basement information using airborne gravity data in this region.

2. THE STUDY AREA

Delta State lies approximately between Longitude 5°00 and 6°.45' East and Latitude 5°00 and 6°.30' North (Fig.1). The State is within the region built up by sedimentation and called the Niger Delta of Nigeria [8]. According to [8] four major physiographic units have been identified within the state, namely; the active freshwater swamp located close to the River Niger, where annual flooding and deposition occurs up to 45 km from the river's course, the mangrove swamp area in an intermediate delta stage, the upland and swamp also called the coastal plain and the upland Niger valley. The vegetation varies from the mangrove swamp along the coast, to the evergreen forest in the middle, and the savannah in the north east.

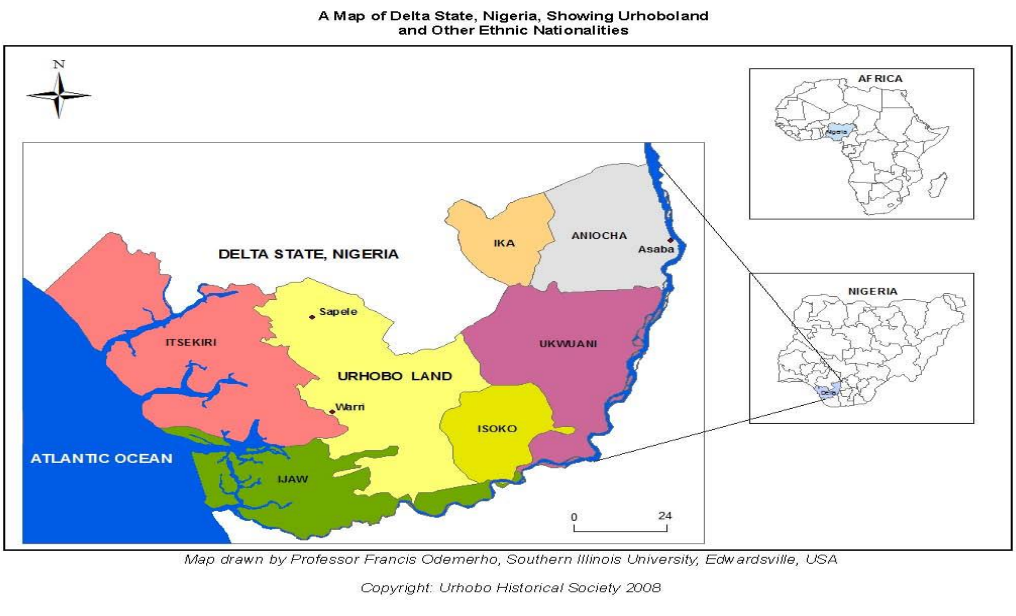

Fig.1: Map of Delta State, Nigeria [12]

The eastern part of the state is drained by the River Niger that discharges into the sea through distributaries that includes the Forcados, Escravos and Warri rivers and creeks such as the Bomadi creeks, amongst others. In the north and northeast, Rivers Jamieson and Ethiope join to form the Benin River, which eventually discharges into the sea in the West.

Three types of soils are identified in the state. These are alluvial soils on the marine deposits along the coast; alluvial and hydromorphic soils on marine and lacustrine deposits found in the area closest to the Niger and Benin rivers; and the feral soils on loose sandy sediments in the dry land areas of the north and northeast. Large deposits of silica sand are found in different lithological formations and along the beds of rivers and streams in the state [8].

3. MATERIALS AND METHODS

The airborne gravity data for this work were obtained from Bureau Gravimetrique International (BGI). The data in zipped format were first converted to text format and sorted out into the required longitudes and latitudes of the study area, and later translated into the x – latitude and y-longitude coordinate using a projected scale factor of 1^o = 110574. A grid cell size of 300 m was used to obtain the Bouguer gravity anomaly map. Based on prior knowledge of the depth to basement in the region a best polynomial fittings based on [13] was used to focus on the local and regional anomalies respectively with the regional gravity, g_R obtained from the a second polynomial of the equation

$$g_R = a_0 + a_1 x + a_2 x^2 + ... + a_n x^n \qquad 1$$

To properly enhance the local anomalies and infer structural features, a high pass filter was applied to the anomalies from which a contour base map of the area was plotted to reveal the structural trending in the region. Inverse and forward modeling using a normalized root mean square error of 10% obtained as,

$$\text{Fit} = [1- (\frac{| y_o - y_p |}{| y - y_m |})] \; x \; 100\% \qquad 2$$

where y_o is the measured or observed output, y_p, the simulated or predicted output and y_m, the mean output, were applied to selected regions of the base map to obtain the structural types, depth and density contrast.

Sediment thickness and depths to basement in the area were obtained utilizing Euler method [14; 15].

$$(x - x_0)\frac{\partial g_T}{\partial z} + (y - y_0)\frac{\partial g_T}{\partial z} + (z - z_0)\frac{\partial g_T}{\partial z} = \eta(g_T - g_R) \qquad 3$$

where; g_T is the total gravity field from source points (x_0, y_0, z_0) and measured points (x, y, z) with structural index of η =1 utilized for the operation. All these were achieved using Oasis Montaj 6.4.2 software.

4. RESULTS AND DISCUSSION

Figure 2 is the Bouguer gravity anomaly contour map of the study area, Fig.3 is the base map indicating points that were modeled. Figures 4 to 7 are the model results that are summarized in Table 1, while Fig. 8 is the Euler depth map of the state.

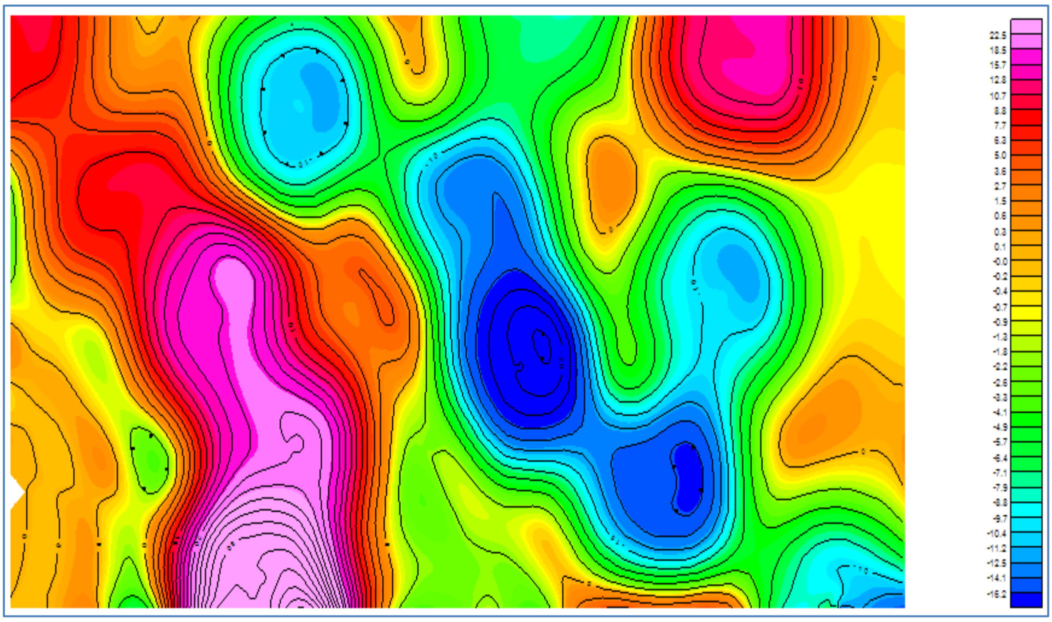

Fig.2: Contour map of study area

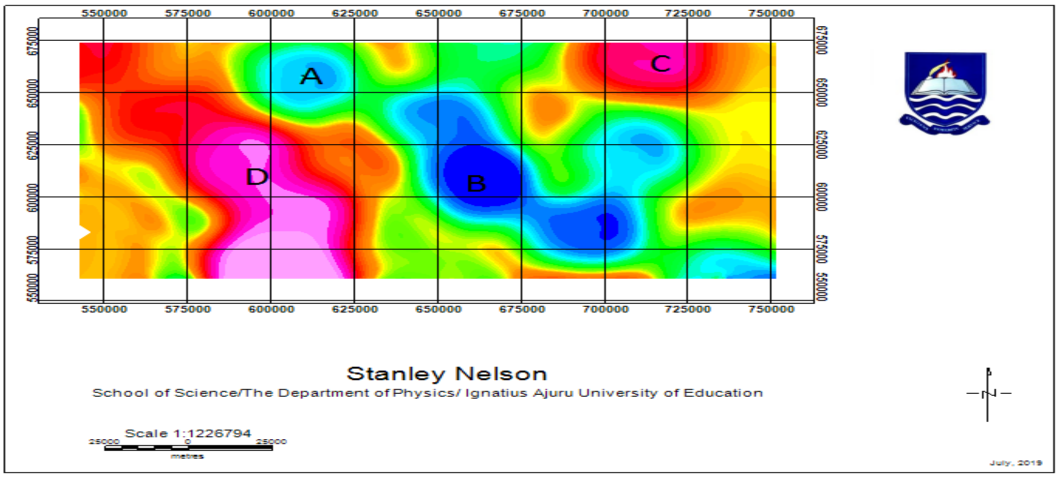

Fig.3: Base map of study indicating the points that were modeled

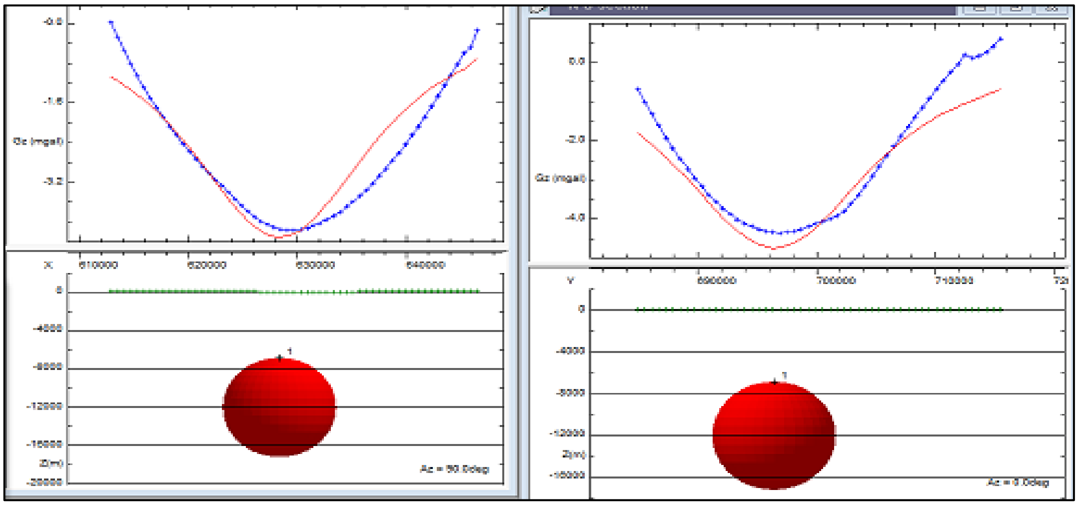

Fig.4: Model results for point A using a sphere model

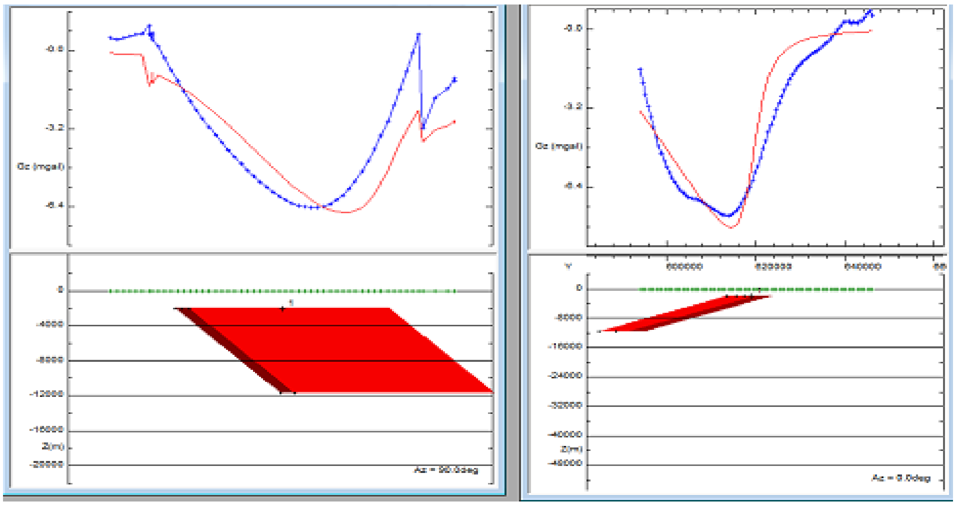

Fig.5: Model result of point B using a dyke model

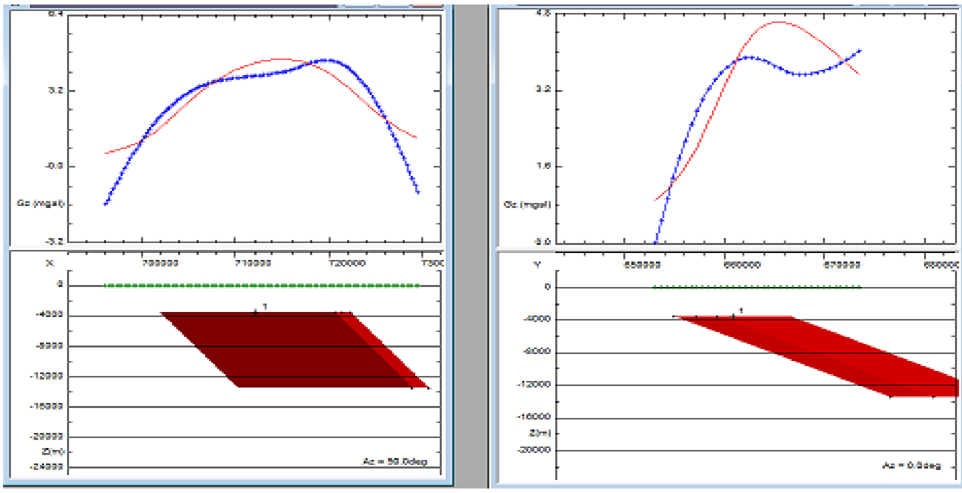

Fig.6: Model result for point C using a dyke model

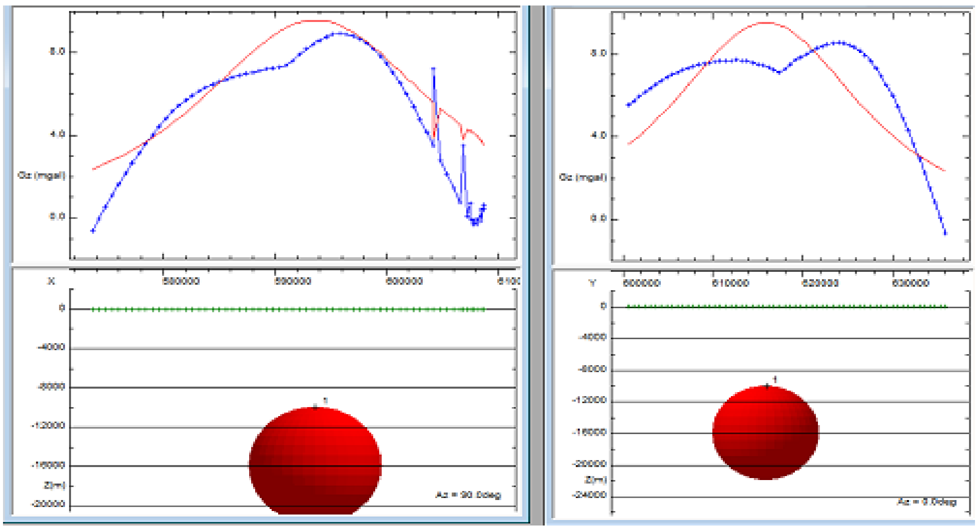

Fig.7: Result of model Point D from a sphere model

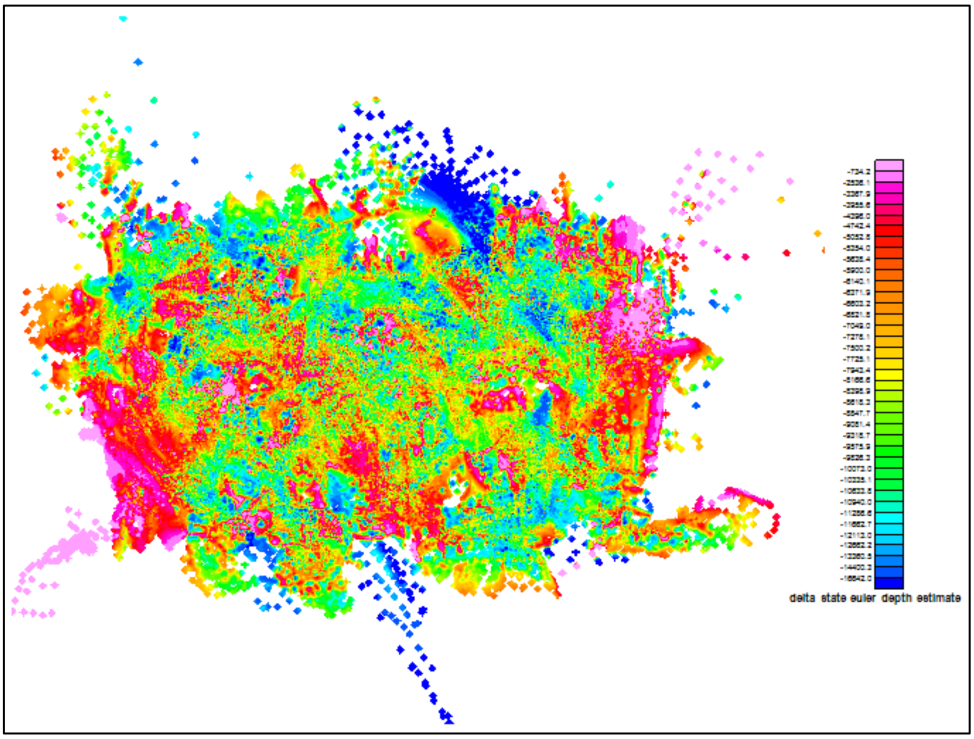

Fig. 8: Euler depth result of study area

Table1: Structural types and depths of occurrence from inverse and forward modelling

Point	Model Type	Structure	Depth (m)	Density (gcm^{-3})	Slope (deg.)	Strike (deg.)
A	Sphere	syncline	7372	1.13	112	17.4
B	Dyke	syncline	2005	2.21	71	-
C	Dyke	anticline	3543	1.12	212	48
D	Dyke	anticline	7246	2.70	38.8	13.5

The Bouguer gravity anomaly contour map of the study area (Fig2.) gives a good impression of the subsurface density of the structures in the region and their trending. This was obtained from a contour plotting interval of 10 mGals on the gridded residual anomaly. The anomalies range from -16.2 mGals for sediments in the SW and NE of the state to sediments with 22.5 mGals in the central part of the state. This shows that sediments in the central part of the state are composed of more dense materials than those in SW and NE.

Based on the available geophysical and geological information on the region [11], the model types of dyke and sphere were used to infer the structural types in the area as summarized in Table 1 and this show that the regions of low gravity values correspond to anticline structures, while those with high gravity values correspond to syncline structures. The results show that these structures occur at depths of 2005 m t0 7372 m with density contrast of 1.13 gcm^{-3} to 2.70 gcm^{-3}. The Euler deconvolution operation using structural index of one revel that the sediment depths to basement in the state range from 124.2 to 16,000 m, with the maximum depth occurring mostly in the north central part of the state.

5. CONCLUSION

Airborne gravity data has been interpreted qualitatively and quantitatively to obtain the structural types/trends and depth to basement in Delta State of Nigeria. From the result the syncline and anticline structures trend in SW and NE directions at depths of 2005 m to 7372 m with maximum depth to basement occurring in the north central part at a depth of 16,000 m.

ACKNOWLEDGEMENT

The authors wish to thank and acknowledge Bureau Gravimetrique International (BGI) for the data used in this study.

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