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Basement Depths from Aeromagnetic Data in Southern Niger Delta Basin of Nigeria Using Euler-3D Method

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Abstract— Residual aeromagnetic data over parts of the Niger delta basin of Nigeria has been interpreted for source positions and depth to basement using Euler-3D deconvolution method. Using structural index values of 1, 2, and 3, the Euler solutions were windowed to accept depth tolerance level of between ±10% and ±20%. The results show sedimentary thickness of between 1,000 m to 10,100 m for structural index value of one, 200 m to 10,600 m for structural index value of two and; 800 m to 9,200 m for structural index value of three. These results show that the maximum depth to basement in this region lie between 9,600 m to 10, 600 m with the shallow magnetic layers lying between 200 m to 1, 000 m.

Index Terms— Aeromagnetic data, Basement, Niger delta, Euler deconvolution, Structural index, Residual anomaly, Magnetic susceptibility.

1 INTRODUCTION

THE Niger delta is considered the most prolific sedimentary basin in Nigeria because it is the twelfth richest in petroleum resources in the world, with about 2.2% of the world's discovered oil, and 1.4% discovered gas [1]. The occurrence of solid minerals is also reported in some parts of the region [2]. However, the exploration of minerals is focused more on petroleum by using the seismic and borehole methods with little input from others like the gravity and magnetic methods. The large volume of sediments in most parts of the region and their heights of accumulation has made it more challenging for boreholes to drill to the bottom of the basement rocks. Similarly, the loss of energy by seismic signal due to attenuation at greater depths and its low resolution has made it difficult in providing information on basement depths in this region. The gravity and magnetic methods can provide information on Earth properties at greater depths and inaccessible areas especially if the survey is airborne [3]. The acquisition and release of high resolution airborne data of the Niger delta by the Nigerian Geological Survey Agency in 2010 has made it possible for more input on the evaluation of the structural geology of the area in recent time [4], [5], [6] and [7]. To further improve on existing knowledge of the basement information of the region, aeromagnetic data from six sheets (319, 320, 321, 327, 328 and 329) was interpreted using Euler3D deconvolution method to obtain the depths to basement.

Depth to basement is important in exploration particularly for the determination of areas where there may be mature hydrocarbon. Reeves [8] explain that magnetic susceptibility is the fundamental parameter in magnetic prospecting with sedimentary rocks having the lowest average susceptibility values because they are non-magnetic. This is the basis for many applications of aeromagnetic surveying since the magnetic sources lie below the base of the sedimentary sequence and allows for rapid identification and mapping of hidden sedimentary basins and the magnetic basement [8].

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2 LOCATION OF STUDY AREA

The study area (Fig. 1) lies within longitudes 6°00′ to 7° 30′ E and latitudes 4°30′ to 5°30′ N south of the Niger delta with an area of about 19, 000 km². According to Reijers [9] the Niger delta originated from the breakup of the South American and African plates in the late Jurassic era that 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 according to Doust and Omatsola [10] and over the years has prograded a distance of more than 250 km from the Benin and Calabar flanks to the present delta front, controlled by synsedimentary faults, folding and subsidence with sediment supply mainly from the Niger, Benue and Cross Rivers accumulating up to 12, 000 m thickness in some regions [11] and [12].

The stratigraphy of the Tertiary Niger delta as documented by Reijers [9], Evamy et al. [12] and Tuttle et al. [13] is divided into three formations (Table 1) representing prograding depositional facies that are distinguished mostly on the basis of sand-shale ratios. 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 silts formed within the periods of the Paleocene 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 paralic siliciclastics over 3700 m thick. The Benin Formation is a continental latest Eocene

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to Recent deposit of alluvial and upper coastal plain sandstones (30% - 70%) that are up to 2000 m thick.

Fig.1The Niger delta showing the study area modified from Google maps 2011[14].

Table 1 – Stratigraphic setting of Niger delta, Southern Nigeria, modified from Reijers [9] and Tuttle [13].

Age	Formation	Thickness (m)	Lithology
Quaternary	Benin	~ 2, 100	Sandstones
Pliocene			
Miocene			
• Late			
• Middle	Agbada	>3, 000	Sands, silts and Shales (paralic siliciclastics)
• Early			
Oligocene			
• Late			
• Middle			
• Early	Akata	600-6,000	
Palaeocene			Shales, turbidite sands, clay, silts

3 MATERIALS AND METHODS

The aeromagnetic data used for this study was collected by Fugro Airborne Survey Limited between 2003 and 2010 for Nigerian Geological Survey Agency (NGSA) Abuja as part of a nationwide high resolution airborne geophysical survey aimed at assisting and promoting mineral exploration in Nigeria. Data was collected at 1km line spacing in a flight direction of NW-SE and 2km tie-line direction of NE-SW with terrain clearance of 80 m. The geomagnetic gradient was removed from the data using the International Geomagnetic Reference Field (IGRF) and the data presented in a digitized format. The study area lies between longitudes 6°.00′ and 7°.30′ E and latitudes 4°.30′ and 5.30′ N and comprises of six digitized data sheets: 319, 320, 321, 327, 328 and 329.

The Euler deconvolution method can be applied to potential data to determine the depth to basement [15]. Several authors have used this method in the determination of sedimentary thickness in various basins of the world [16] and [17]. The method is based on Euler's homogeneity equation that relates the potential field and its gradient components to the location of the source with the rate of change with distance of the field. Reid et al. [15] shows that the Euler's equation satisfies the following

$$(x-x_o)\frac{\partial T}{\partial x}+(y-y_o)\frac{\partial T}{\partial y}+(z-z_o)\frac{\partial T}{\partial z}=\eta(T-B) \qquad (1)$$

where (x_o, y_o, z_o) is the position of the magnetic source with total field T measured at the point (x, y, z). B is the regional total field detected at any point and η is the structural index (SI) defined as the degree of homogeneity of the source body and interpreted physically as the attenuation rate with distance. The residual field can be solved as a matrix [18] which is insensitive to magnetic inclination, declination and remanence and hence does not require reduction to pole operation. Similarly no particular geologic model is assumed or required to appraise the geological and structural interpretations [15].

To obtain the residual field, a second order polynomial approximation method [19] was used in which the regional field was represented by the equation of the form

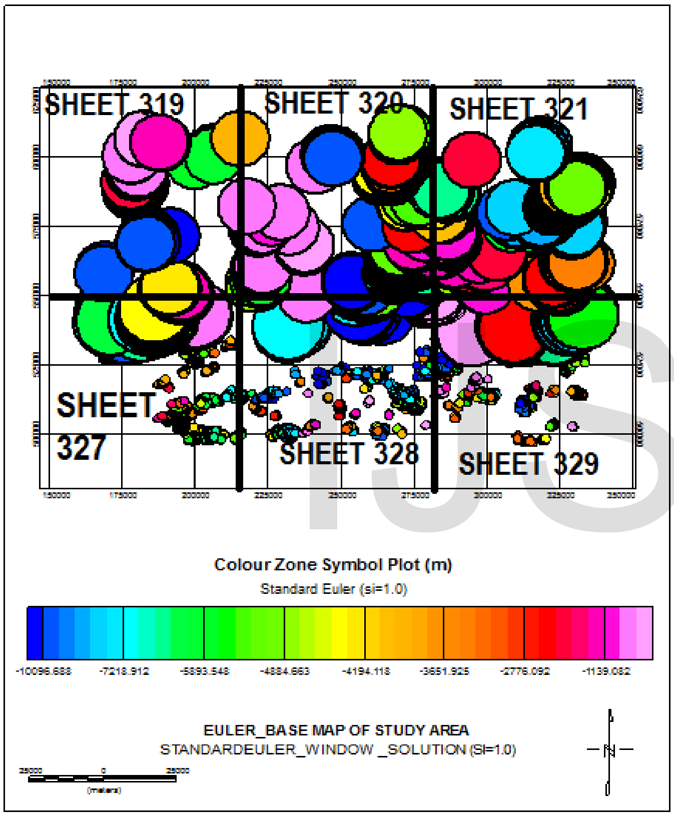
$$g_r = a_o + a_1 x + a_2 x^2 \qquad (2)$$

The resultant residual data was enhanced by applying a high pass filter and then downward continued to a distance of 200 m. All operations were achieved using Oasis Montaj software. Euler Deconvolution algorithm of the Oasis Montaj™ software was then applied to locate and estimate the depths of anomalous sources and depth to basement using structural index values of 1, 2 and 3 that are suitable for analyzing structures modeled as dykes, spheres and cylinders by adopting the steps outlined by Reid et al. [15]. The Euler Deconvolution solutions obtained were windowed to reduce uncertainty to the minimum by constraining results to accept depth (dz) tolerance of 10% and horizontal (dy) tolerance of 20%. Thereafter the solutions were gridded to estimate the depths as shown on the colour legend bars of the solutions.

4 RESULTS

The Euler deconvolution maps indicates the derived source positions represented as circles at the located depths with colors indicating the depth ranges. The diameter of the circles indicates areal extent of located depths, while the clustering gives an indication of correct index. Figures 2, 3 and 4 show the color symbol and color legend bar base maps for structural indices of 1, 2 and 3 respectively for the residual field of the study area, while Table 2 shows a summary of the results.

Fig.2 Euler 3D Deconvolution color symbol solution for



SI=1. [19]

With structural index value of one, which models a dyke-like structure, the sedimentary thickness of the region ranges between 1, 000 m to 10, 000 m (Fig. 2). For structural index of two used for spherical models of anticline and syncline structures, the sedimentary thickness is between 200 m to 10, 600 m (Fig.3). Figure 4 shows the sedimentary thickness of 800 m to 9, 200 m for structural index of three that can model structures represented by a cylinder.

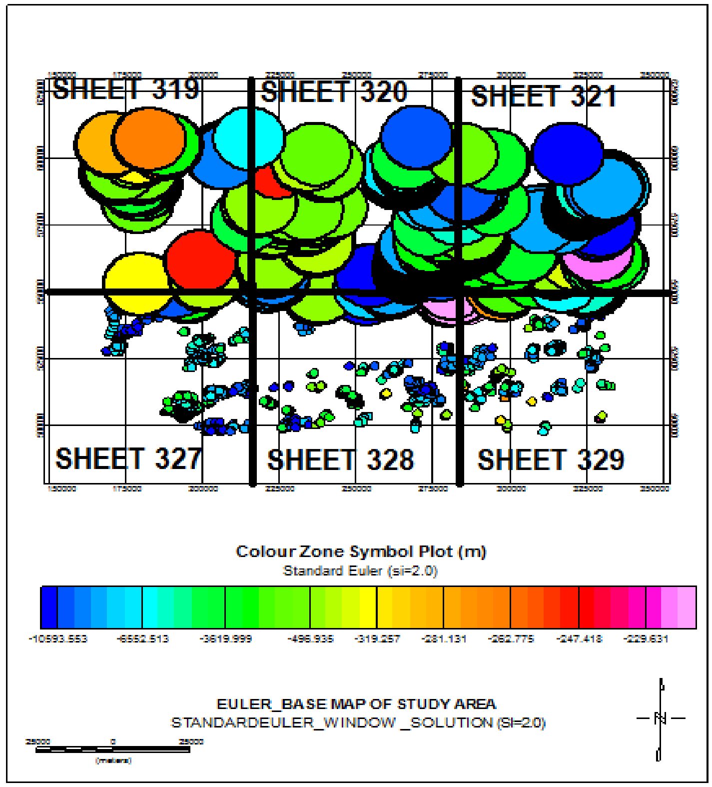
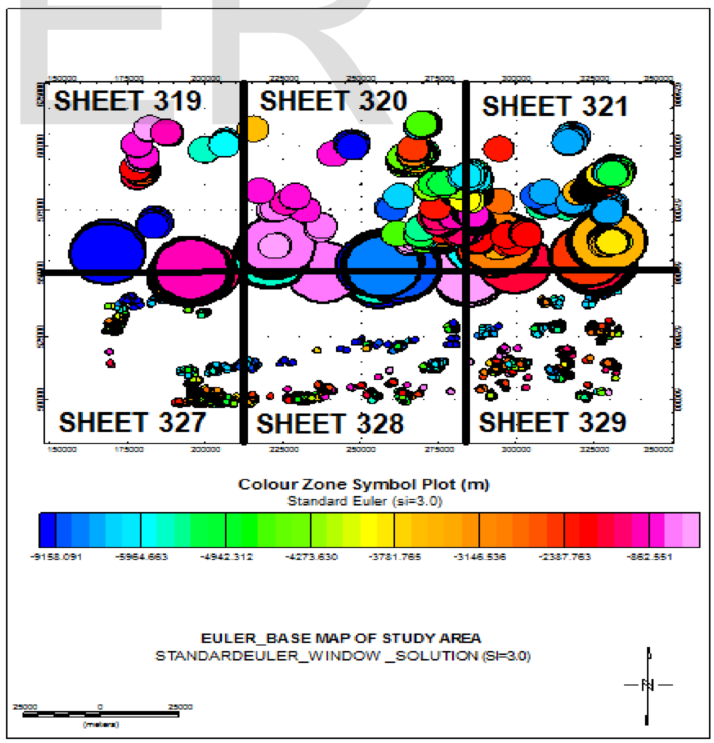


Fig 3. Euler 3Ddeconvolution color symbol solution for SI= 2 [19].

Fig.4. Euler 3D deconvolution color symbol solution for SI = 3 [19].



Detailed analysis of the various sheets show that in the northern part of sheet 319, the sedimentary thickness ranges from 200 m to 4,000 m while in the southern part it ranges

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from 3,000 m to 10,000 m. For sheet 320 the sedimentary thickness ranges from 800 m to 5,000 m in the south-west, while in the north-east and southern part of the area, it ranges from 5,000 m to 10,600 m. The south-east and south-west regions of sheet 321 revealed sedimentary depths of 1,000 m to 3,000 m while in the north-east region it is between 5,000 m to 10,600 m. Sheet 327 indicates sedimentary thickness ranging from 3,000 to 10,600 m while sheet 328 reveal depths of between 2,000 m and 10,600 m. In sheet 329 sedimentary thickness of between 2,000 m to 5,000 m can be found in the northern part of the region while at the central part the thickness ranges from 2,000 m to 10,600 m.

Table 2. Results of depth ranges from Euler deconvolution solutions

Structural Index	Approximate Depth Ranges/m
1	1, 000 – 10, 100
2	200 – 10, 600
3	800 – 9, 200

5 DISCUSSIONS

Evidence from literature on the geology of the Niger delta shows that the region is underlain by syncline and anticline structures identified as roll over structures, faults, diapers etc [11] and [12]. These structures can be modeled as spheres, dykes or cylinders. Since no particular geological model is required to appraise the geological and structural interpretations by use of Euler deconvolution method [15] then any of these models can be used to obtain basement information of the area. The results from this work show that the maximum depth to basement in the study area from a spherical model is 10, 600 m, while for a dyke like model it is 10,100 m, and for a cylindrical model it is 9,600 m. Thus, we can conclude that the maximum depth to the basement in this region is between 9, 600 m to 10, 600 m with shallow magnetic layers of 200 m to 1, 000 m thickness. The depths of the other sediments indicate that the region also has sediment layers that hold promise for petroleum accumulation and entrapment. These values are in agreement with the works of Okiwelu and Ude [4] Oladele and Ojo [6] and Evamy et al [12].

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