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Interpretation Of Gravity Data Over Parts Of Akwa-Ibom And Cross-River States For Hydrocarbon Potentials

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***Abstract:** Gravity anomaly over parts of Cross-river and Akwa-Ibom states has been interpreted qualitatively and quantitatively. The residual anomaly was obtained from the retrieved field data through a second order polynomial fitting and the high pass filtering technique at a wavelength cut-off of zero, which is the best fit for the data, the resultant grid was generated. The qualitative interpretation of the gridded data reveals EW-NS trending subsurface structures that consists majorly of faulted anticlines. The inverse and forward modeling results show spherical and dyke-like anomaly structures at depths between 2,000 m to 5,427m, while the density contrast of formations identifies areas of possible hydrocarbon deposits. The Euler deconvolution windowed solutions' reveals depth to anomalous sources of between 31m to 6,385 m using a structural index of zero. The work reveals that the prevalent faulting system in the survey area is the strike-slip faults and gives the range of the hydrocarbon window in the study area as 2,000m-5,427m*

***Keywords:** gravity data, Anomalous bodies, forward and inverse modeling, cross-river, Akwa-Ibom, Niger delta, hydrocarbon windows, faults*

I. INTRODUCTION

The seismic and borehole methods have been use widely and majorly for interpretation of the stratigraphic, petroleum and structural geology of the Niger Delta region. They are preferred for their ability to produce a detailed picture with very clear resolution of the subsurface structures, yet they have limitations in terms of depth of penetration, cost of survey and overall area coverage. Although, most people think of magnetic and gravity methods as tools to only map structures, yet gravity data can be analyzed to provide insights to other elements of petroleum exploration and production, and it equally has the advantage of providing information on earth properties at greater depths with simple logistics and coverage of inaccessible areas (Hinze, 1990; Johnson, 1998).

The operative physical property for the Gravity method is the density of the medium, which has found wide application in regional geological studies, mineral exploration and other subsurface investigations. Thus for a homogeneous medium, the reaction product will be the same value each distance on the medium until a medium of different density contrast is reached giving rise to a change in density. (Telford et al, 1990; Reynolds, 1997).

The Bouguer gravity anomaly can be analyzed and interpreted to get useful information such as defining the size and extent of ore bodies, estimating the depth to basement, delineating intrusive bodies, estimation of hydrocarbon windows, defining buried river channels, demarcating faults and noting the prevalent faulting system (change of anomaly shape), and the detection of salt dome and salt deposits and reefs (negative anomalies), in a region.

In a bid to interpreting the gravity data over Akwa-Ibom and Cross-river states, the Forward and Inverse modeling, and Euler Deconvolution methods were employed in this work to evaluate the prevalent faulting system, determine the depth to anomalous gravity sources and hence estimate the hydrocarbon window range in the study area.

II. LOCATION AND GEOLOGY OF THE STUDY AREA

The study area (Fig.1 and Fig.2), which lies within latitude 4.32-5.33^{0}N, longitude 7.25-8.25^{0}E (Akwa-Ibom), and latitude 4.27-7.00^{0}N, longitude 7.50-9.28^{0}E (Cross-River state), falls within the Niger delta region which extends from about latitudes 4^0 to 7^{0}N and longitudes 3^0 to 10^{0}E. The Niger delta is situated at the intersection of the Benue trough and the South Atlantic ocean where a triple junction developed during the separation of the continents of South America and Africa in the late Jurassic (Whiteman, 1982). The Niger delta started to evolve in early tertiary times when clastic river input increased (Doust and Omatsola, 1989). The delta prograded over the subsiding continental-oceanic lithospheric transition zone, and during the Oligocene spread onto oceanic crust of the gulf of Guinea (Adesida et al. 1997). The region is situated in the southern part of Nigeria and bordered to the south by the Atlantic ocean and to the east by Cameroon. It occupies a surface area of about 112,110 square kilometers and represents about 12% of Nigeria's total surface area. While the Niger delta is mainly associated with oil and gas production, the region is also endowed with several solid minerals. The stratigraphic sequence of the Niger delta (Fig.3) comprises three broad litho-stratigraphic units which are the continental shallow massive sand sequence – the Benin formation, a coastal marine sequence of alternating sands and shales – the Agbada formation and a basal marine shale unit- the Akata formation. The Akata formation consists of clays and shales with minor sand intercalations of less than 30% and its sediments were deposited in pro-delta environments. The Agbada formation consists of alternating sand and shales representing sediments of the transitional environment comprising the lower delta plain (mangrove swamps, floodplain, and marsh) and the coastal barrier and fluviomarine realms. The sand percentage within the Agbada formation varies from 30 to 70% (Weber, 1971; Ejedawe, 1979). The Benin formation is characterized by high sand percentage (70–100%) and forms the top layer of the Niger delta depositional sequence. The massive sands were deposited in continental environment comprising the fluvial realms (braided and meandering systems) of the upper delta plain. The Niger delta time-stratigraphy is based on biochronological interpretations of fossil spores, foraminifera and calcareous no-noplankton.

The deposition of the three formations and the progradation of the Niger delta has been dependent on the interaction between rates of subsidence and sediment supply, and modified by faulting. Several growth-fault-bounded sedimentary units (depobelts) are present. (Stacher, 1995; Tuttle et al, 1999).

There are eleven (11) proven sequences in the Niger delta Basin, the Agbada group sequence being the main contributors of reserves. Agbada stratigraphic structural sequence accounts for 58% of the basin recoverable oil reserves (34,603 MMb) and 55% of the basin recoverable gas reserves (114,925 Bcf) while the Agbada structural sequence accounts for another 40% of hydrocarbon reserves (Tuttle et al, 1999). Among the structural features are anticlinal traps (folds and diapirs); roll-over anticlines; and faults (growth faults) (Evamy et al, 1978; Doust and Omatsola, 1990; Stacher, 1995; Etu-Efeotor, 1997; Tuttle et al, 1999). The maximum thickness for the subsurface Niger delta is 12km (Merki, 1971).

Figure 1: Akwa-Ibom state (www.naiscon.net)

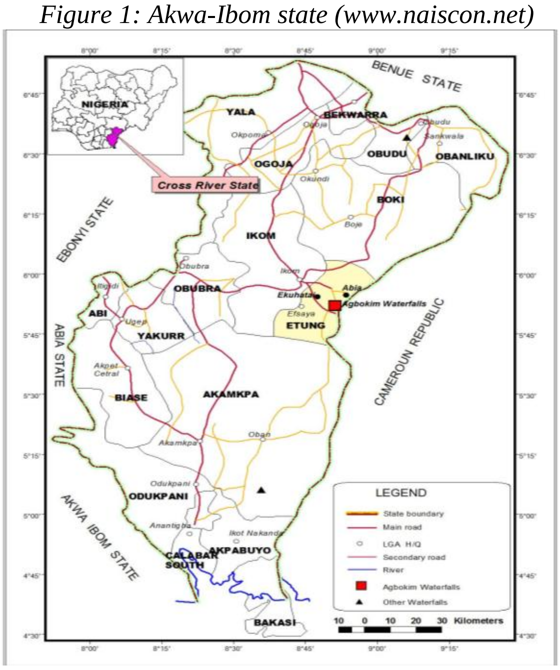


Figure 2: Cross-River state (www.naiscon.net)

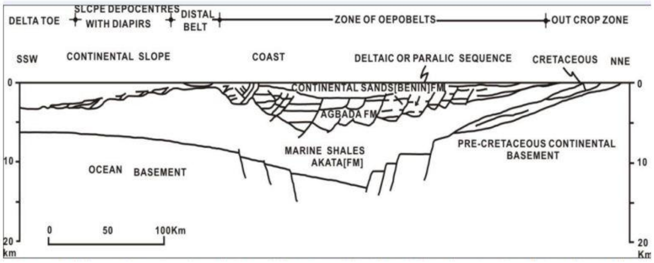


Figure 3: The Niger delta showing the relationships of the tripartite division of the tertiary sequence to basement. (Modified from Doust and Omatsola (1990))

III. MATERIALS AND METHODS

The data used in this research work was gotten courtesy of Bureau Gravimetry International (BGI). BGI, created in 1951 by the International association of geodesy (IAG), is saddled with the task of collecting, on a world-wide basis, all gravity measurements to generate a global digital database of gravity data for any public or private user. The BGI database, which uses a flat file data model contains over 12 million of observations compiled and computerized from land, marine and airborne gravity measurements, and has been extensively used for the definition of earth gravity field models and for many applications in geodesy, satellite orbit computation, oceanography, and geophysics. The gravity data in the database with respect to the survey area was retrieved with permission, extracted based on the longitude and latitude of the two states (Akwa-Ibom: latitude 4.32-5.33N and longitude 7.25-8.25 and Cross-River: latitude 4.27-7.00N and longitude 7.50-9.28E) and further translated from degrees unit to meters using a scale factor of 1^0 =111,111m. This was done using the Oasis Montaj Software.

To achieve the purpose of this study aimed at interpreting the gravity anomaly, determination of the prevalent fault system, and to identify the subsurface structures in the study area, the following approach was adopted guided by the geology of the area. Firstly, the residual anomaly was obtained from the retrieved field data through a second order polynomial fitting and the high pass filtering at a cut wavelength of zero. The polynomial is fitted by the method of least squares to the observed gravity profile. This gives optimum values for the coefficients. The higher the order of the polynomial, the better it fits the observations, more so, to express changes in the gradient of gravity, a higher-order polynomial is needed (Hinze, 1990).

Since, in sedimentary basins, short- or intermediate-wavelength anomalies may arise from structures related to reservoirs for petroleum or natural gas, High pass filters which are effective for removing long wavelengths anomalies representing regional trends from observed gravity thus enhances (short or intermediate wavelengths) local anomalies (Telford et al, 1990)

The residual anomaly was obtained for Cross-Rivers by applying only the second order polynomial fit to the original data to get the residual anomaly while the high pass filter was used at a wavelength cut-off of zero for Akwa-Ibom. The statistical package for social sciences (SPSS) software was used to plot a line graph to see the various fits before an acceptable fit was chosen.

The residual anomalies were then gridded through the minimum curvature method which fits a minimum curvature surface to the data points using a method similar to that described by Briggs (1974) and the residual Bouguer base maps were also made. This was done through the Oasis Montaj software in the X and Y direction, using the grid cell size of 400.

Depth to the source of anomaly was obtained using the forward and inverse modeling (Saltus and Blackely, 1983) and the Euler depth estimation methods (Thompson, 1982; Reid et al., 1990). Selected portions (Fig.3b) of the residual Bouguer base maps were chosen for modeling. The areas were modeled using the PotentQ-3D modeling software which is an extension in the Oasis MontajTM software. Furthermore, the Euler Deconvolution was applied to estimate the depths to the anomalous bodies using the 3D Euler menu of the Oasis Montaj software. The 3D Euler menu of the Oasis Montaj software uses an integration of both the analytic signals and the first and second order derivatives to give a reliable depth estimate. This was achieved using structural index values of 0 which is an expression of the degree of homogeneity. A window size of 20 and a grid cell size of 400 were also used. Thereafter the solutions were gridded to estimate the depths.

IV. RESULTS

Figures 3(a,b,c,d) shows the contoured map and residual Bouguer gravity base map respectively. The points M (1,2,3,4), and C(1,2,3,4) were the points modeled with two results each as shown Figures 4(a), (b), (c) and (d).

Figures 4(a), (b), (c) and (d) shows the profile model results obtained for points M1, M2, M3, M4, and C1,C2,C3,C4.

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

The windowed Euler 3D Euler Depth solution estimates are shown respectively in figures 5(a) and (b), while Table 2 shows the summary of the depth results.

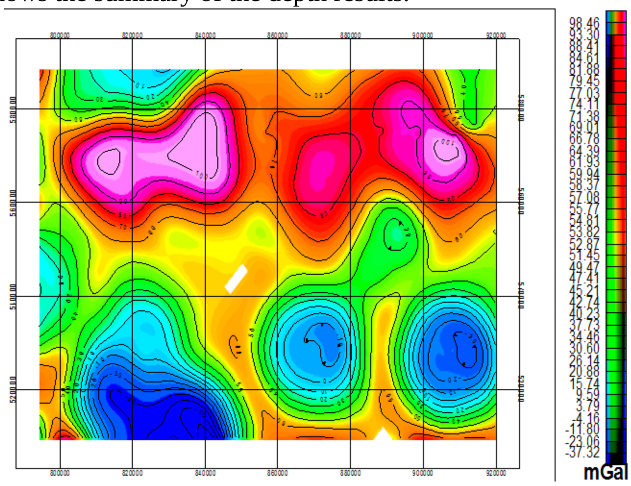


Figure 3 (a): Contour Map of Akwa-Ibom Using A Contour Interval Of 10mGals (Babalola,2015)

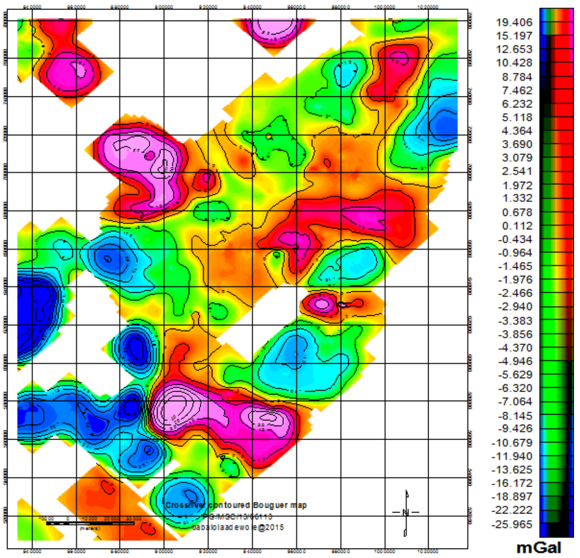


Figure 3 (b): Contour Map of Cross-River Using A Contour Interval Of 5mGals (Babalola, 2015)

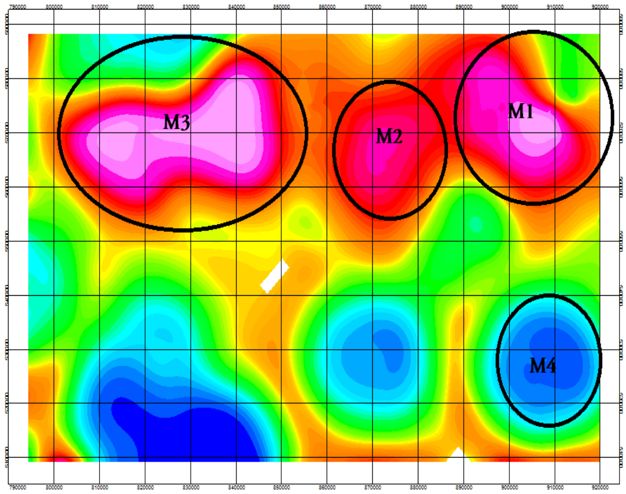


Figure 3 (c): Bouguer base Map Of Akwa-Ibom (Babalola, 2015)

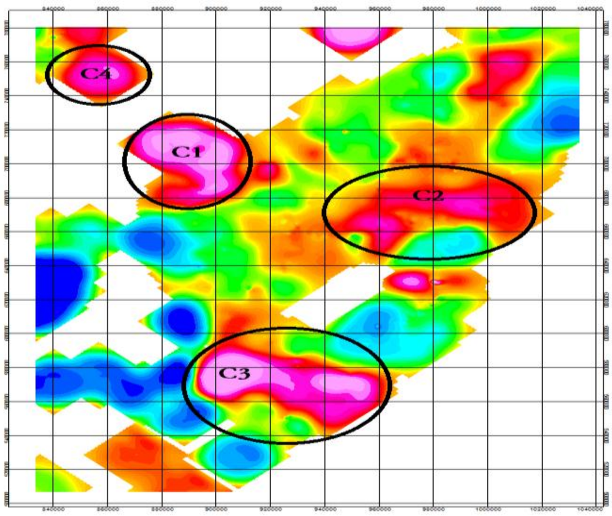


Figure 3 (d): Bouguer Base map of Cross-River (Babalola, 2015)

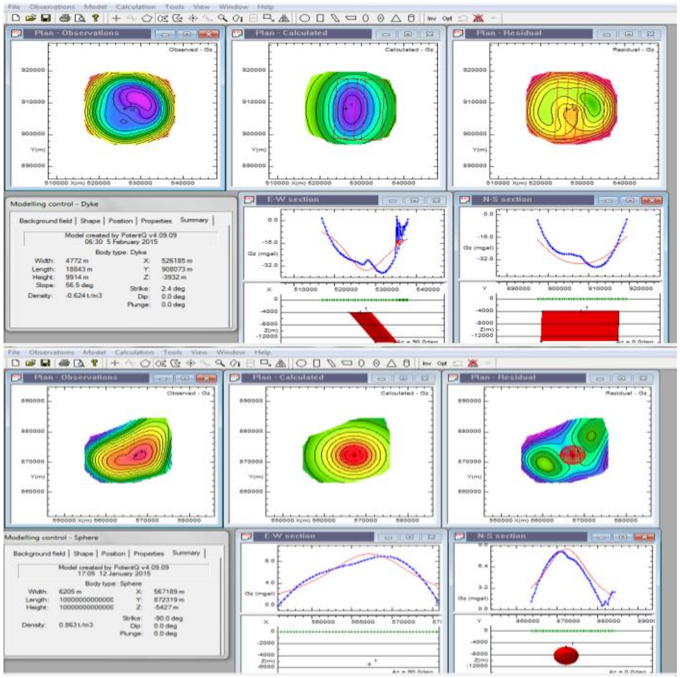


Figure 4 (a): Model for profile points, M4 and M3 (Babalola, 2015)

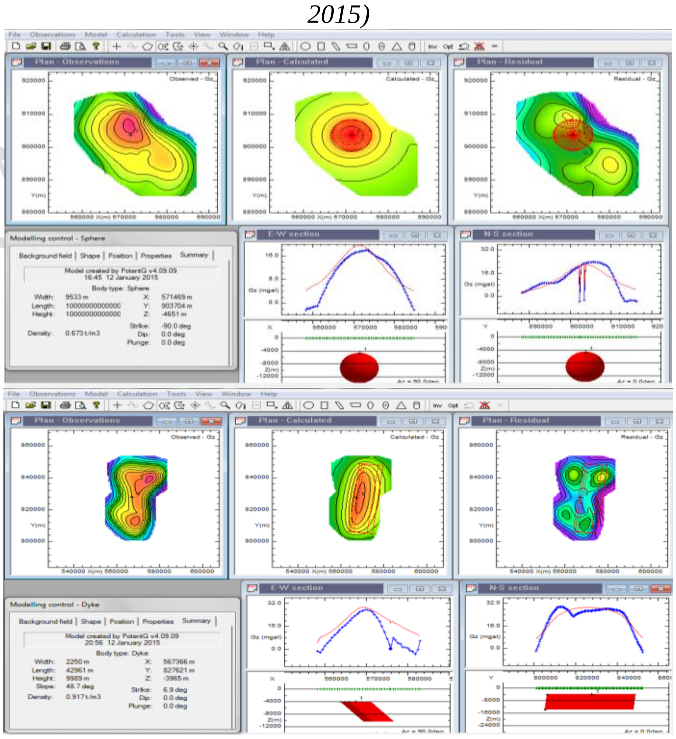
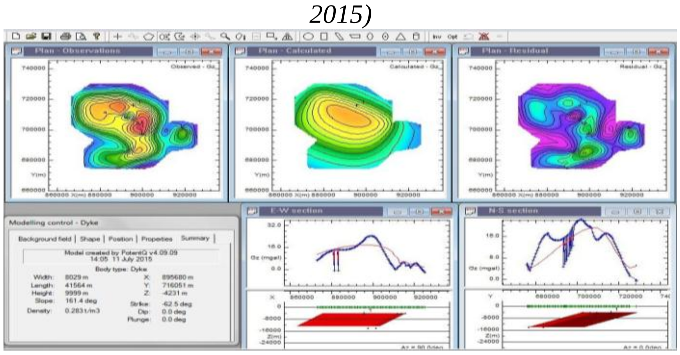


Figure 4 (b): Model for profile points, M2 and M1 (Babalola, 2015)



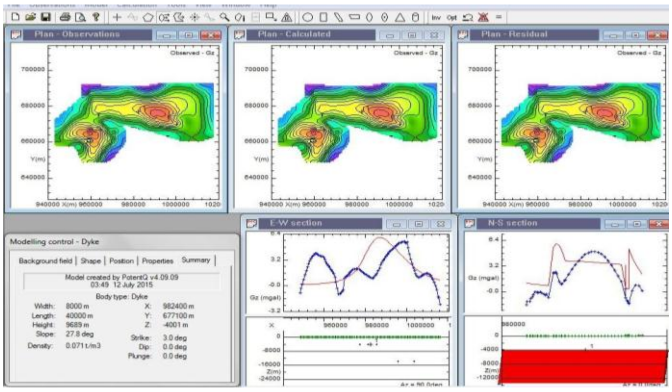


Figure 4 (c): Model for profile points, C4 and C3 (Babalola, 2015)

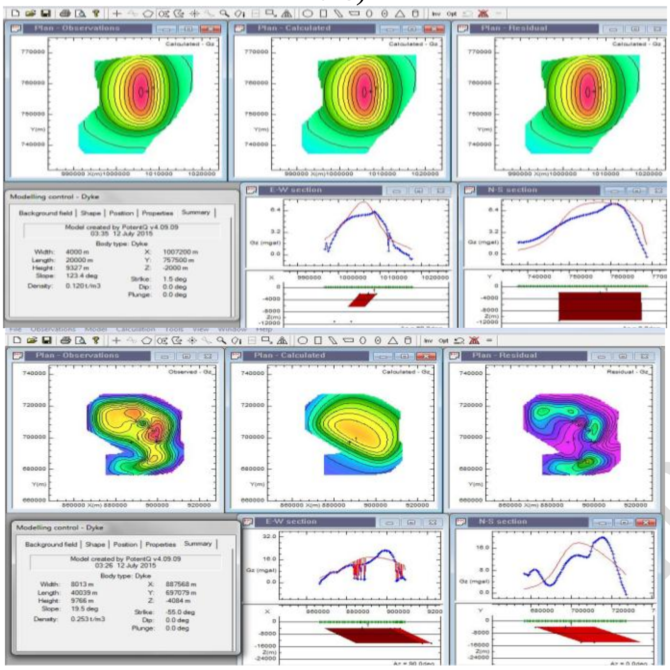


Figure 4 (d): Model for profile points, C2 and C1 (Babalola, 2015)

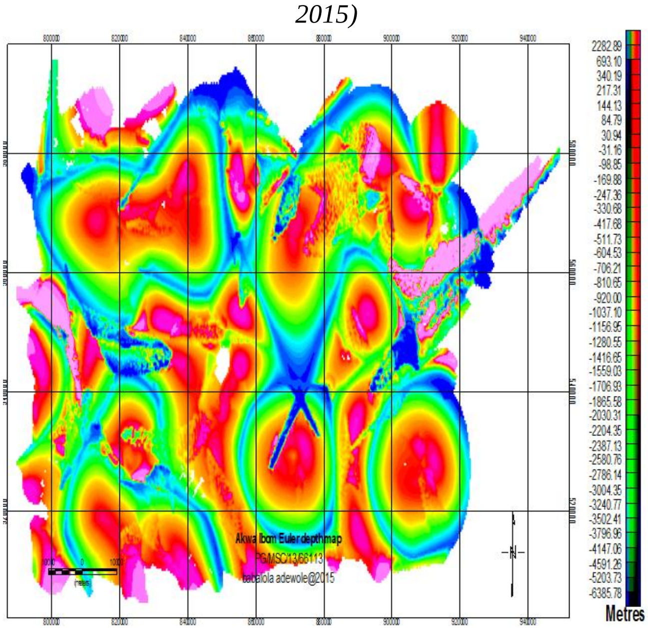


Figure 5(a): Akwa-Ibom state Euler depth solution estimate. (Babalola, 2015)

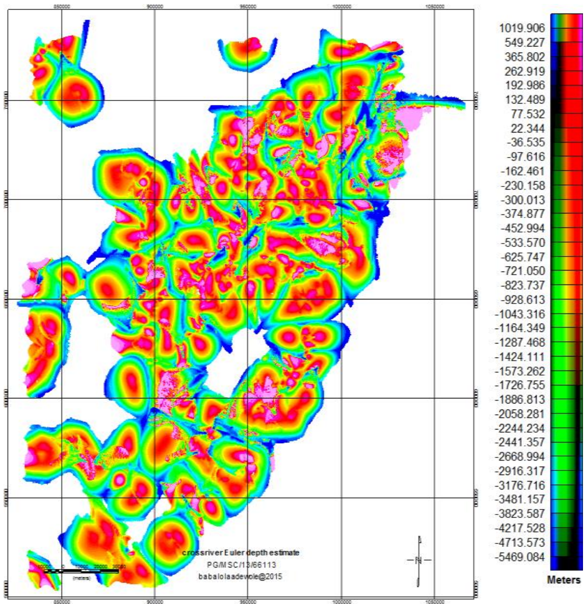


Figure 5(b): Cross-River state Euler depth solution estimate. (Babalola, 2015)

V. DISCUSSIONS

The residual Bouguer gravity has values ranging from -37.32 to 98.46mGals for Akwa-Ibom state. We observed more of strongly positive values and very low negative values. The positive values are indications of oceanic regions while the low negative values implies shallow continental, thin crustal region. We have a gravity minimum as low as -37.32mGal which is in agreement with Hospers (1965). For, Cross-River, it ranges from -25.965 to 19.406mGals, this is strongly indicative of a coastal-oceanic region, where the crust has a thickness range of 5km-10km and as we move close to the coast, the Bouguer values goes close to zero (Robinson and Coruh, 1988). The color legend bar has three distinct colors. The red color indicates area with gravity highs, the green color, areas with intermediate gravity values while the blue colors shows areas with gravity lows. Figures 3(a&b) is the contoured Bouguer gravity anomaly maps drawn at intervals of 10mGals and 5mGal. 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. Circular contours are best modeled as spheres while diapiric contours are best modeled as dykes. Both are directly related to petroleum reservoirs, basins and gas structures. 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). From the models, we have two curves that appear to superpose on each other. The red curve is the theoretical curve while the blue curve stands for our field curve. Their fitness is measured by their visible super imposition on each other. The sub profiles in each model shows a variation or iteration of our Bouguer values with distances at the area we modeled. Where, x. y, and z are dimensions, we are more interested in 'z' that is indicative of our depth to anomalous sources. The negative sign attached to the 'z' indicates a downward progression and not elevation.

The dip is the slope of a geological surface and beddings. A dip angle of 90 implies that the plane is vertical while an angle of 0 implies that we are dealing with horizontal layers, beddings or planes (Richard, 1988). Strike lines are non-plunging or horizontal line within a dipping plane. Our models shows strike angles of varying degrees, showing us that the prevalent faulting system in the survey area is the strike-slip. Strike-slip faults are also known as a wrench, tear or trans-current faults. The standard recognized fault signature is a steep gradient. In the gravity case the gradient deepens as the faults becomes shallower. A syncline can often be masked on the seismic sections by diffractions or velocity problems but it is rare that gravity data cannot verify a synclinal structure (Corine, 1996).

A positive density indicates that the anomalous body has a higher density than the host rock or surrounding layer while a negative density indicates that the anomalous body has a lower density than the surrounding host rock or layer. Simple folded symmetrical anticline produces a symmetrical positive gravity anomaly. While normal faulted anticline consists of a sedimentary sequence of density values that increase with depth and a faulted basement uplift. This structure produces a broad maximum gravity anomaly indicating the area extent of the entire uplifted section. A faulted syncline was observed on profile M4, while faulted anticlines were seen on profile M2, M1, C3, C1, and C2. From the models, it was deduced that the faults trends evenly E-W and N-S, this agrees with the work of Ajibola (2004). Also from the results of the forward and inverse modeling, we also infer from the densities (0.071-0.917g/cm^3) of the anomalous bodies, the possible causative bodies for the anomalies as hydrocarbons (petroleum and gas). Comparing the Forward and Inverse modeling depth estimates (Table 1) where our depth ranges from 2km-5.4km and the Euler 3D depth estimates (Table 2) where the depth ranges from 31m-6.4km, we can safely infer a concord of the two depth estimation techniques used in this work. The depth range obtained in this work is from 2km-5.5km which is in agreement with the depth range for hydrocarbon maturation and generation. It also agrees with works carried out by other researchers and also consistent with the depth to basement of the survey area. The depth ranges agrees with the works of Enikanselu and Adeboye (2009), Akponunu et al (2012), Chiadikobi et al (2012), Emujakporue and Ekine (2014) and Adedapo et al (2014). From this we can also infer that the oil and gas windows in the survey area lies within the depth range of 2km-5.5km which agrees with recent works of Adedapo et al. (2014) and Emujakporue and Ekine (2014). Most of the depths to anomalous sources fall within the Agbada formation that has a maximum thickness of about 13,000 feet (3.9km), while the rest are within the lower Benin formation, from which we opined that the source rock for the survey area lies within the Agbada formation.

States	Profile	Depth to anomalous bodies (m)	Density of the body (g/cm^3)	Model Shape
Akwa-Ibom	M4	3932	0.624	Dyke
	M3	5427	0.863	Sphere
	M2	4651	0.673	Sphere
	M1	3965	0.917	Dyke
Cross-River	C4	4231	0.283	Dyke
	C3	4001	0.071	Dyke
	C2	2000	0.120	Dyke
	C1	4084	0.253	Dyke

Table 1: Summary of inverse and forward modeling results for Bouguer gravity profile points (Babalola, 2015)

Akwa-Ibom state	
Parameters	Depth Range (m) 31-6385
	S.I = 0, W.S = 20, G.C.S = 400
Cross river state	
Parameters	Depth Range (m) 36-5469
	S.I = 0, W.S = 20, G.C.S = 400

Table 2: Summary of Euler depth solution estimates. (Babalola, 2015)

VI. CONCLUSION

From the result of the quantitative interpretations, we have been able to interpret the gravity anomalies in the study area. We have identified the type of intrusive in the area and the possible causative bodies responsible for the anomalies. We have been able to establish that the study area has huge hydrocarbon potentials with the hydrocarbon windows lying within depths of 2km-5.5km. We also have been able to determine the depth to anomalous bodies in the area, delineated the structural trap predominant in the study area, and characterized the prevalent faulting system in the survey area as the strike-slip faults.

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