The Bouguer Gravity Anomaly Map of the Calabar Flank, Southeastern, Nigeria.

A.A. Okiwelu, Ph.D.[1*], E.E. Okwueze, Ph.D.[1], and I.O. Akpabio, Ph.D.[2]

[1]Geophysics Unit, Department of Physics, University of Calabar, Nigeria.
[2]Department of Physics, University of Uyo, Nigeria.

[*]E-mail: Okiwelu2000@yahoo.com

ABSTRACT

Raw gravity data acquired using a Lacoste and Romberg (model G446) gravimeter and its accessories have been converted to a digital data set and were contoured to produce the first Bouguer gravity anomaly map of Calabar Flank. The data were corrected for drift and elevation (Bouguer and free air). The average crustal density of $2.67 g/cm^3$ was used to compute the Bouguer correction. The effect of the curvature of the earth was taken into consideration. To account for tidal effect, an observational time window for forty-eight hours was determined prior to the actual field survey. Humidity/temperature correction was made to remove effects caused by humidity/temperature variations on raw data. The data was latitude-corrected based on the 1967 Geodetic Reference System (GRS67). This invariably gave the theoretical gravity. A comprehensive computer program for processing raw gravity data was used to compute the Bouguer and free air anomalies and were converted from their geodetic coordinates to x-y coordinates. The data were then transformed to an equally spaced grid (1km). The Bouguer and free air anomaly maps were produced from this grid using a Surfer Plot program. The results from these analyses showed a close relationship between the Bouguer and free air anomaly data; which is compatible with mid-continental results. Calabar Flank is largely not in isostatic equilibrium judging from the dominance of short-wavelength free-air anomaly patterns. The circular, elliptical contours in the Bouguer and free air anomaly maps are lineaments with distinctive trends. These trends indicate structural features that pre-date exposed geology and that have probably controlled the tectonic expressions of the geological province.

(Keywords: gravity, anomaly, Bouguer, free-air, drift, geology, Calabar Flank)

INTRODUCTION

The Calabar Flank is a sedimentary basin extending from the southern margins of the igneous Oban Massif to the hinge line of the Niger Delta (Figure 1a) [Reijers and Petters, 1997]. The Flank extends to the Cameroun volcanic ridge in the east.

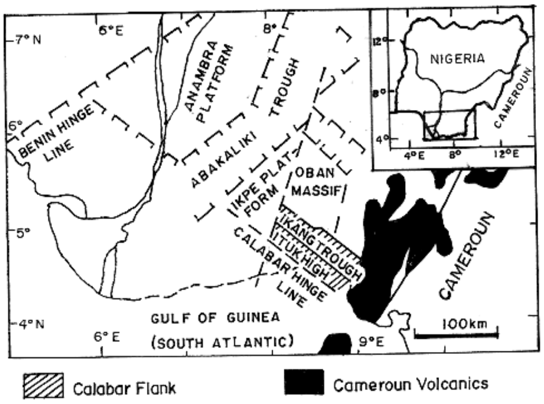

Figure 1a: Location Map of the Calabar Flank (Nyong and Ramanathan, 1985).

Petters (1980), opined that the Calabar Flank is southeast extension of the Benue aulacogen. Northwest–southeast trending basement structures underlie the Flank and define the Ituk high and the Ikang trough; thus relating the Calabar Flank to the south Atlantic Cretaceous marginal basins with similar horst and graben structures.

The stratigraphic succession compiled by Petters (1982) shows that the Flank is mostly of Cretaceous age, comprising a basal Neocomiam-Aptian syn-rift fluvial sandstone, the Awi Formation and the marine post – rift Odukpani Group. The Odukpani Group consists of the middle Albian Mfamosing limestone, the Late Albian Ekenkpon shale and the Coniacian New

Netim marl. It is unconformably covered by the Nkporo shale. Tertiary marine shale and regressive sandstone overlie the Cretaceous succession. Reijers and Petters (1997) document that the total sediment thickness is over 3500m. After the initial rifting episode in Calabar Flank, the area underwent a different tectonic and stratigraphic development compared to the adjacent Anambra and Southern Benue Trough sedimentary basins (Nyong 1995). The initial rifting of the southern Nigerian margin produced two principal sets of faults, a NE-SW and NW-SE system. The former set of faults bound the Benue depression while the later sets were more prominent and active in Calabar Flank.

Two major tectonic elements in the Calabar Flank include the Ikang Trough, which for most depositional history was a mobile depression, and the Ituk high, that was a stable to somewhat mobile submarine ridge. These structural styles (Figure 1b) are reflected in the sedimentation facies distribution in the area (Peters, 1982). The structural alignment of the Calabar Flank is in NW-SE direction.

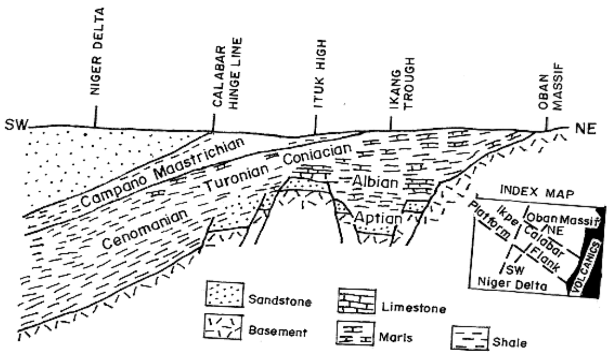

Figure 1b: Structural Elements and Conceptual Subsurface Distribution of Cretaceous Sediments in the Calabar Flank (Nyong, 1995).

Prior to this study, comprehensive gravity data were not available in the Flank. Realizing the potential use of regional gravity data, the objective of this study has therefore been to compile the first gravity anomaly map of Calabar Flank. The regional Bouguer gravity anomaly map will be useful in mapping geographic distribution and configuration of the underlying basement crystalline rocks, structural and lithologic provinces, zones of crustal weakness, mass imbalances within the lithosphere, and geometry of the sedimentary basin (O'Hara and Lyons, 1985); bearing also in mind that digital data set in grid format are more suitable for contouring and analytical transformation.

MATERIALS AND METHODS

Field Survey

The gravity survey took a total of sixteen days and commenced by monitoring the tide for forty-eight hours. This involved obtaining gravity readings with the Lacoste and Romberg gravimeter (G446 model) at one hour intervals within the area of study. A plot of gravity values against time (Figures 2a and 2b) showed that the tidal effect is strong at the hours corresponding to maxima and minima. This technique of monitoring the tide is called "observational time window". Therefore measurements were avoided during these hours. This technique is thus, advantageous because tidal correction will not be required.

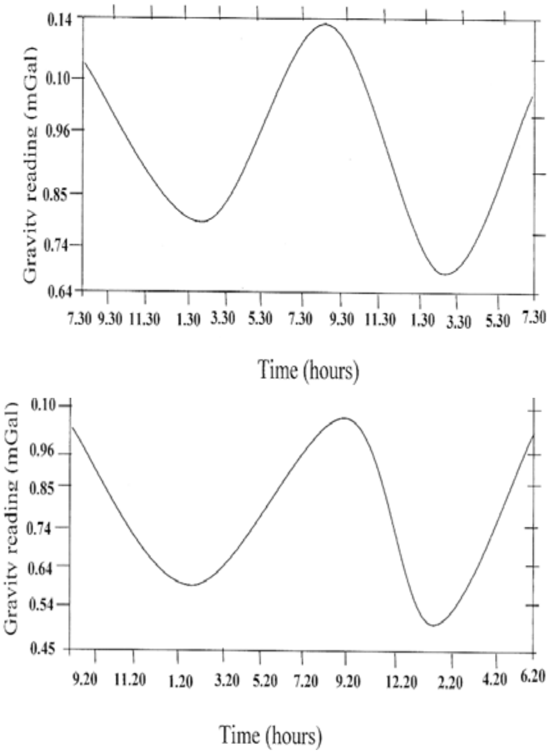

Figure 2a: Observational Time Window for Day 1 Eliminated the Tidal Effect for Day 1.

2b: Observational Time Window for Day 2 Eliminated the Tidal Effect for Day 2.

All the gravity readings obtained from the study area were tied to the absolute gravity base station. For the purpose of proximity, another base station (Figure 3) was established.

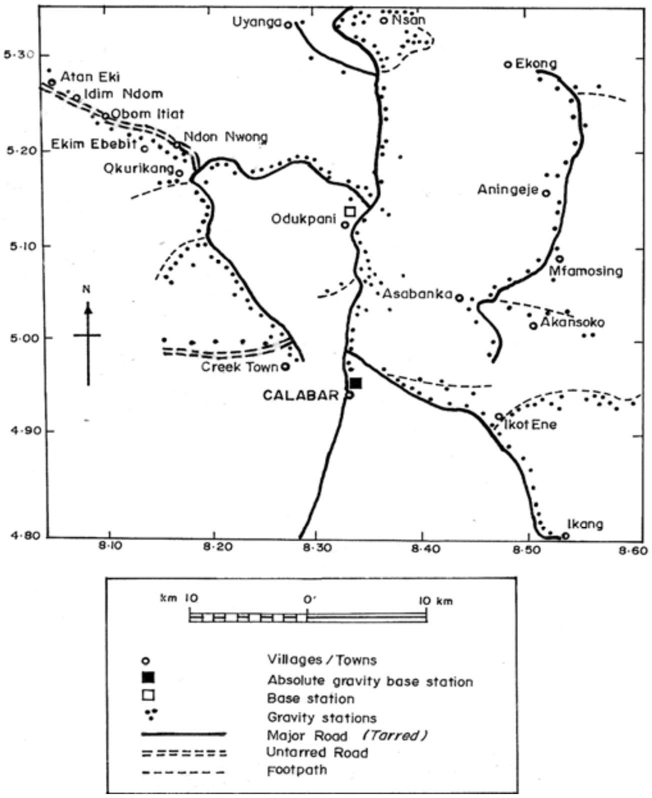

Figure 3: Gravity Station Location Map Showing Gravity Stations.

The establishment of this base station was accomplished by repeated readings (looping) between the absolute gravity base station and the base station. This base station served as a station for the commencement of the gravity survey each day and was re-occupied at the end of each day (closing).

The profiling method of survey was adopted and readings were taken at intervals of 1-3km, which is consistent with regional gravity survey. Since the gravimeter (Lacoste and Romberg) does not drift appreciably, the closed loop observational sequence was adopted. To prevent the gravimeter from thermal shock, it was shielded with a large umbrella throughout the field survey. A first-order leveling technique with the assistance of the Federal Survey of Nigeria was used to determine the absolute height (elevation) above sea level at the absolute gravity base station. This made it possible to compute absolute height above sea level in other stations.

Gravity Data Reduction

All measured gravity data were referred to the International Gravity Standardization Net 1971 (IGSN71). To correct for variation in gravitational acceleration that is not from a geologic signal, two categories of data corrections were considered. These were; temporal variations and spatial variations. Temporal-based variations are changes in observed acceleration that are time dependent (e.g. instrumental drift). The result of the drift portion of a gravity observation is that repeated observations at one location yields different values for the gravitational acceleration. It is assumed that the drift component of the gravity field varies linearly between subsequent base station reoccupation. Using linear interpolation between base station reoccupation, this temporal variation in the gravity field is estimated. Since the observer has no direct control on the trends that the drift can follow, an observational technique can be adopted in order to determine the amount of drift involved (Osazuwa, 2007). At the base station, the observed and interpolated readings are identical.

Spatial based variations are changes in observed acceleration that are space dependent but not related to geology. These include, elevation correction (Free air and Bouguer), latitude and humidity / temperature corrections. To compute the Bouguer correction, the average crustal density of 2.67g/cm^3 was considered. It has been a common practice in the process of calculating Bouguer gravity anomaly to use an average crustal density of 2.67g/cm^3 (Lawal and Akaolisa, 2006). One of the most widely recorgnized parameters in solid earth geophysics is the assumed density of the surface rocks of the continental crust, 2.67g/cm^3 (Hinze, 2003).

A comprehensive computer program for processing raw gravity data by Osazuwa (1988) was used to compute the drift, theoretical gravity based on the 1967 geodetic Reference System (GRS67), the Bullard term, and free air correction. Terrain correction was not required since the surveyed area has a low relief (12-124m) above sea level. Air temperature/humidity charts were used for temperature/humidity correction. This correction is necessary because the pressure caused by the column of air above the observer decreases as the observer rises in altitude. Since air is compressible, the relationship between pressure and altitude is not constant. Changes in air density caused by variation in temperature, relative humidity, and gravity will change the pressure versus altitude ratio. Temperature has the greatest effect on the density of the air and is therefore the most significant.

Computation of Gravity Anomalies and Map Compilation

A comprehensive computer program by Osazuwa (1988) was used to compute the Bouguer anomalies. To grid the Bouguer anomaly data, their geodetic coordinates were converted to x-y coordinates. The data were then transformed to an equally spaced grid using a program based on minimum-curvature method (Briggs, 1974). This approach is more amenable to the girding of data because individual random values were not discarded and smooth surfaces were generated. A grid interval of 1km was selected, an empirical value based on the objective of this study. This gridding translates to a scale of 0.01^0 = 1km. The Bouguer anomaly map was contoured from the grided data using a surfer plot program and compilation scale of 1cm = 4km and contour intervals of 4mGal.

RESULTS AND DISCUSSION

The results of the gravity data analyses are presented in the form of Bouguer and free air anomaly maps (Figures 4 and 5). In the north-western sector of the Calabar Flank, the Bouguer gravity field is dominated by distinctive gradient, here called 'Okurikang gradient'. This Bouguer anomaly increased in value from 24mgal to 60mgal and extends over a distance of about 15.7km to the NNW direction. These are lineations.

These linearments which bifurcate at Okurikang as shown on geophysical maps, indicate a structural alignment due to the tectonically active area. Okiwelu et al (2002), using aeromagnetic data showed that there is a relationship between these lineaments and the tectonic trend in the Flank.

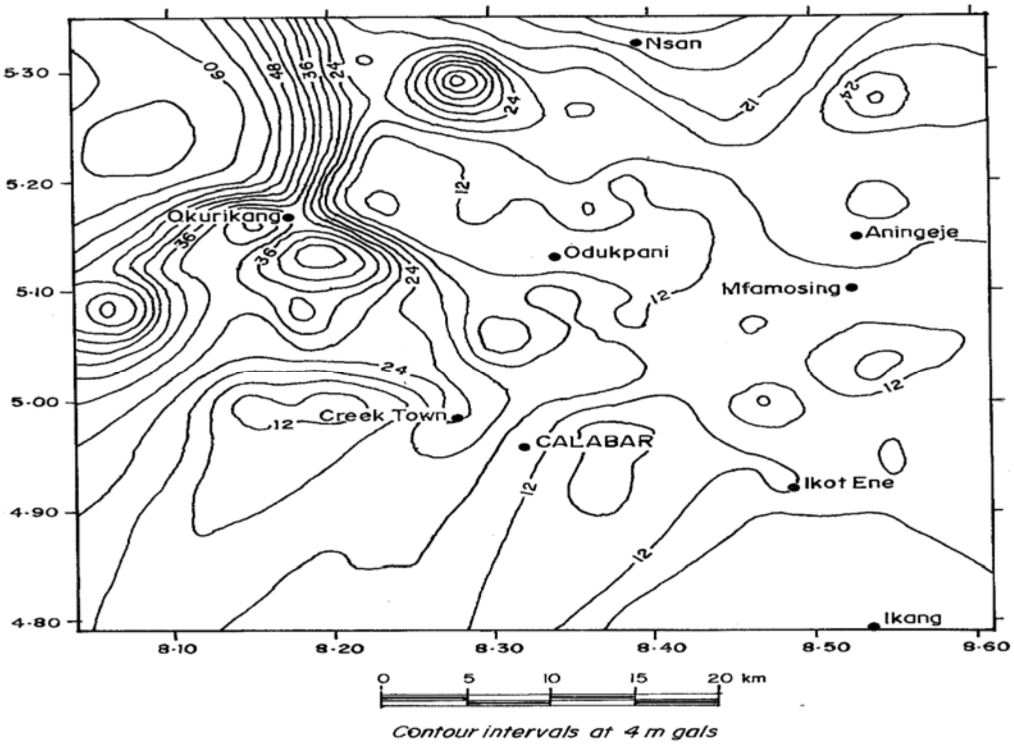

Figure 4: Bouguer Anomaly Map of the Calabar Flank Characterized by Mid-Continent Values (12-60mGals).

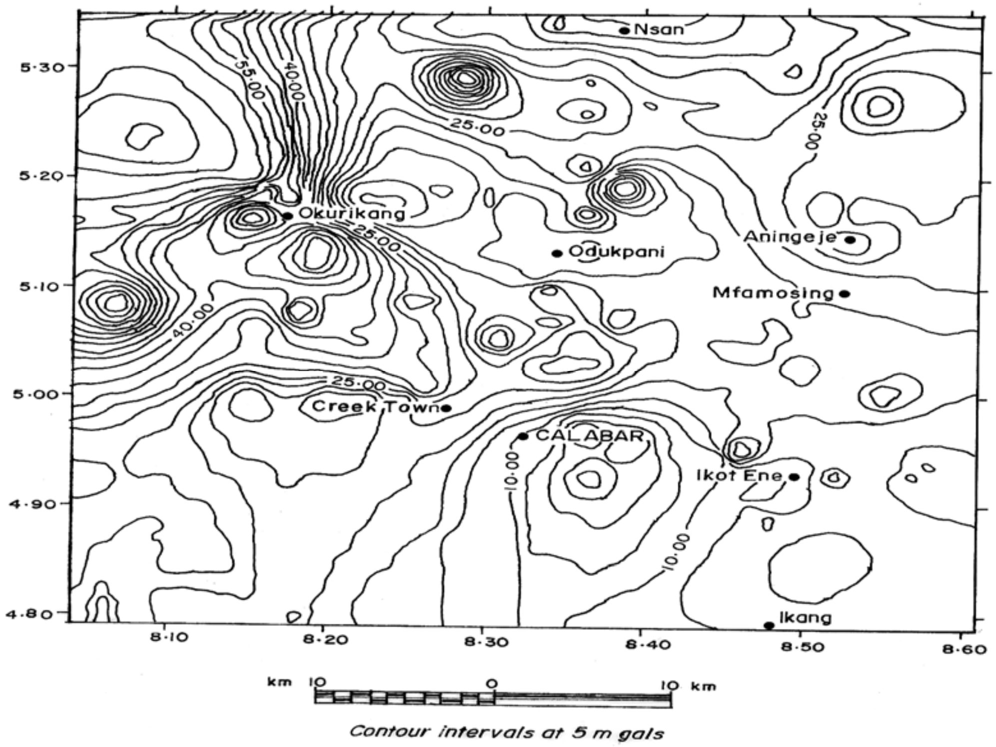

Figure 5: Free Air Anomaly Map Characterized by Short Wavelength Anomalies.

One interpretation of this distinctive gradient is that it marks the Calabar hinge line where there is block faulting. This is consistent with the geology of the area (Nyong, 1995), where the Calabar Flank is delineated from the adjacent Niger delta basin to the south. The block faulting appears to be due to local isostatic adjustment related to deep basement structure.

There is a close correlation between the free-air and Bouguer anomaly maps. This is compatible with what is obtained in the mid-continent (coastal region). Lowrie (1997) showed that in the continent proper, Bouguer gravity anomaly lies between zero and -200mGal. In the mid-continent, it is between 0 and 100mGal, and in the oceanic area it attains a maximum of 300mGal. This implies that Bouguer anomaly is a function of crustal thickness and topographic elevation. The Calabar Flank is a mid-continent region characterized by Bouguer anomaly values between 12-60mGal (Figure 4). This is an expected result.

The surface plot shown in Fig.6 is dominated with intrusive bodies. Residual gravity modeling (Okiwelu, 2007) shows that the intrusives are either basic or granitic.

The gravity anomaly maps are characterized by circular, elliptical contours with well defined trends and have tectonic implications. The short wavelength free air anomaly pattern is an indication that the Flank is not in isostatic equilibrium. The block faulting interpreted from the gravity data is consistent with the tectonics and geology of the Flank.

CONCLUSION

The compiled Bouguer anomaly map will not only serve as a useful regional framework for interpretation of gravity anomalies in Calabar Flank but as a data bank that will be significant for anomaly transformation. It will also be useful for selecting areas of more detailed gravity investigations in the Flank and in analyzing the distribution and pattern of regional geophysical and geological features.

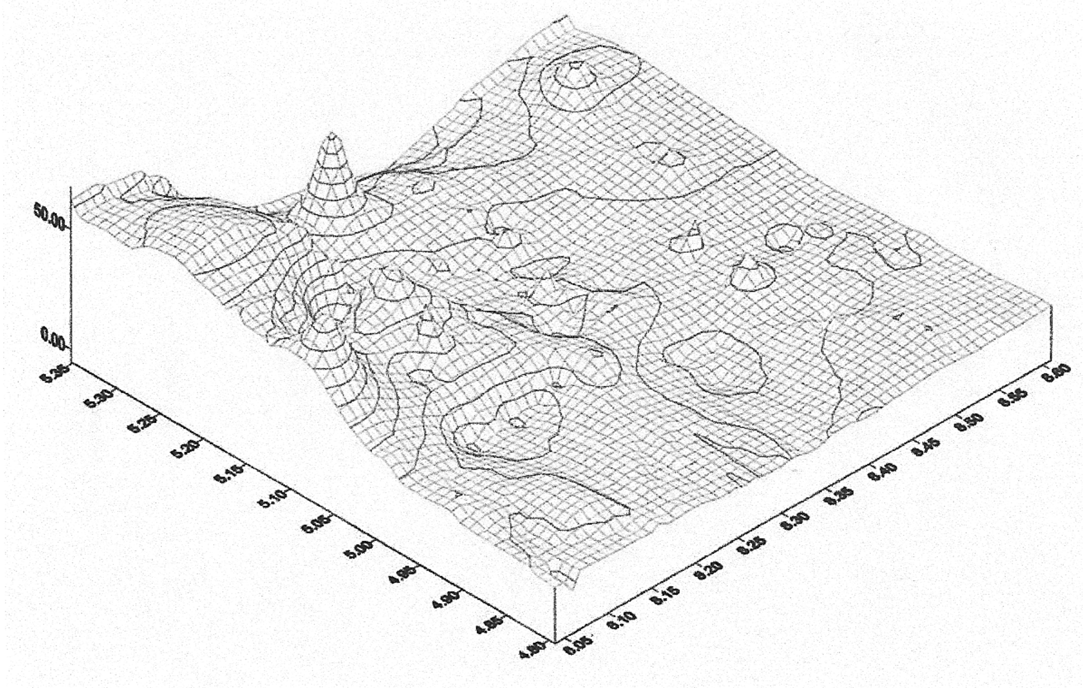

Figure 6: Surface Plot of Bouguer Anomaly Dominated by Intrusives.

The close relationship regarding the gravity anomaly patterns in both the Bouguer and free air anomaly maps is anticipated because of the mid-continent type terriane. The lineaments (circular and elliptical contours) in the gravity anomaly maps are structural features that have trends. These structural Trends and numerous intrusives are consistent with the tectonics and deeper geology of the Flank.

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ABOUT THE AUTHORS

Dr. Anthony A. Okiwelu, holds a Ph.D. degree in geophysics and he is at present a Lecturer I in the Geophysics Unit in the Department of Physics, University of Calabar, Nigeria. His research interest is in the area of application of gravimetry and geomagnetism to crustal studies, tectonics, and mineral exploration. He is a member of Nigerian Institute of Physics (NIP).

Prof. Emeka E. Okwuese, obtained a Ph.D. in Geophysics from the University of Wisconsin, Madison-USA in 1983. He is presently a Professor and Head of the Geophysics Unit in the Department of Physics, University of Calabar, Nigeria. He has published over thirty journal articles and four books and he is also the National President and fellow of the Nigeria Institute of Physics and Active member of the Society of Exploration Geophysicists (SEG).

Dr. Idara O. Akpabio, holds a Ph.D. in Geophysics and he is at present a Senior Lecturer in the Department of Physics, University of Uyo, Nigeria. He is a member of Nigerian Institute of Physics (NIP) and his research interest is in the area of bore-hole geophysics and seismology.

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