Isolation of Residuals Determined from Polynomial Fitting to Gravity Data of Calabar Flank, Southeastern Nigeria.

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ABSTRACT

The first degree polynomial order is fitted to the Bouguer gravity anomaly data to produce the first residual gravity anomaly map of Calabar Flank. The residual gravity data was computed by subtracting the regional trend from the Bouguer gravity field. The regional trend in the flank is the first degree surface fit and represents anomaly of long wavelength while the residual component have their origin from short wavelength sources (shallow sources). This quantitative approach is advantageous over the wavelength filtering methods. The result of this low order fitting shows that the residual gravity field is characterized by positive and negative gravity anomalies. This is consistent with the geologic setting and tectonics of the Calabar Flank.

(Keywords: Bouguer gravity anomaly data, Calabar Flank, gravity field)

INTRODUCTION

Gravity and magnetic fields data are composed of anomalies of different sizes from various depths. In order to model the anomalies of interest (geological sources), it is desirable to separate anomalies caused by deeper features from those caused by shallow sources. Anomalies with long wavelength (large width) are generated by deeper sources while short wavelength anomalies are from shallow sources.

However, long wavelength signals can have shallow source depths. In this case, the large shallow masses need to be supported by the strength of the lithosphere.

Various processing techniques are used to isolate the residual field, which is generated by geological sources of interest from the regional trend (long wavelength component) in potential field data. The various techniques include: the derivative methods, which sharpen up anomalies over bodies and tend to reduce anomaly complexity and also designed to look at fault and contact features. The second vertical derivative serves specifically to emphasize the expression of local features and removes the effects of large anomalies (regional influences); the matched residual filter technique (Urquhart, 2008) removes the long wavelength component from potential field data and thus the shallow sources are better resolved.

The matched residual technique involves the computation and examination of the shape of the spectrum of deeper and shallow bodies. Upward continuation suppresses signals from short wavelength sources at shallow depth and reveals the signals from long wavelength sources while downward continuation enhances the response of the sources at depth by magnifying the short wavelength relative to the long wavelength, thus bringing the shallow sources more in focus.

The graphical method is also employed in which case the regional background is estimated by visual inspection. In band-pass filtering, if large or deeper sources are of interest, all anomalies that have wavelength smaller than a certain value are removed. However, long wavelength which represents the most regional trend may also be cut out to analyze the remaining anomalies. That is, all frequencies between certain values are passed while others are eliminated. It is also possible to isolate certain anomalies with respect to orientation (Fogarty 1985). In this case, a look is taken at features that have trends between certain orientations (strike-pass filtering). Beltrao (1991) proposed a regional-residual separation method based on polynomial fitting in which the coefficients are determined by a robust procedure consisting of iteratively re-weighted least squares solutions. By successively assigning small weights to large residuals, their influence in the fitted regional is minimized regardless of the 'true' residual anomalies signs. The term 'robust' as applied to a statistical estimator, means insensitive to small departure from the idealized assumptions for which the estimator is optimized (Press et al., 1992).

Abdelrahman et al. (2003) presented a procedure to select the optimum polynomial order, based on the correlation between residuals of successive orders. Abdelrahman et al. (1985) showed that the least-squares derivatives method which involves the determination of amplitude coefficients related to the density contrast can be used to compute the thickness of buried faulted slab from numerical derivative anomalies. They concluded that the success of this method depends on the accuracy with which the residual anomaly is separated from the observed gravity anomaly.

Even though some of the above techniques have been applied successfully, they still have some setbacks. Band-pass filtering requires assuming the cut-off wavelength and can smear the separation due to non-vertical filter roll-off. The graphical method, although simple, is very subjective due to the fact that the estimation of the regional trend relies on the judgment of the operator. In downward continuation, if the plane of calculation is below the top of the causative body , high–frequency ringing is produced by the calculation and minor noise present in the original observed gravity field is amplified in the downward continued field and may mask or partially obscure signals of interest (Hearst and Morris, 1994). In upward continuation method when there is overlap between numbers of closely spaced high- frequency anomalies, upward continuation may result in the merger of the individual features to form a single apparent broad feature.

Roach et al. (1993) assessed the possible methods for separation of regional and residual gravity data of Tasmanian gravity field. He noted that polynomial fitting (trend surface analysis) provided the best numerical approach. Therefore it is more appropriate to compute from a gridded data, the best fit smooth surface using the least-squares polynomial fitting order and then remove the regional background. This quantitative approach is superior to the gravity anomaly wavelength filtering. If one knows the specific regional trends, major geological feature of interest can be adequately modeled.

The Bouguer gravity anomaly is frequently used in geophysics to infer geological information from observed gravity (Keller et al., 1985). A regional-anomaly component of Bouguer gravity field distorts and sometimes masks the relationship that exists between the shapes of the anomalies and the near surface geology (Gupta and Grant, 1985). Therefore, in this paper, it became imperative to prepare and compile the first residual gravity anomaly map of the Calabar Flank. The residual gravity map is important from the stand point of defining geological structures and boundaries which are targets of geophysical exploration. The residual gravity map will be useful for the determination of the thickness of the basin and the study of the underlying basement. It will also be handy for tectonic studies, anomaly transformation and mineral exploration in the flank.

THEORY AND METHODOLOGY

Concept of Linear Least Square Polynomial Fitting

Kangkolo (1995) and Press et al (1992) showed that it is possible to fit N data points,

$$(T_i, x_{i,} y_i); i = 1,...N$$

to a model which has m adjustable parameters

$$c_j, j = 1,...m$$

The model predicts a functional relationship between the measured independent and dependent variables:

$$T(x, y) = T(x, y, c_1.....c_m) \qquad \textbf{(1)}$$

The general form of this kind of model is

$$T(x, y) = \sum_{j=1}^{m} c_j p_j(x, y) \qquad \textbf{(2)}$$

where $p_1(x, y).....p_m(x, y)$ are arbitrary functions of x and y called the basis functions.

In the general least squares technique, to obtain the fitted values for the c_j, s, we minimize over $c_1 \ldots\ldots c_m$ the merit function,

$$X^2=\sum_{i=1}^{N}\left[T_i-T(x_i,y_i,c_1\ldots\ldots c_m)\right]^2 \qquad \textbf{(3)}$$

The minimum value occurs where the derivative of x^2 with respect to all m parameters, c_j vanishes. This condition yields the m equation:

$$0=\sum_{i=1}^{N}[T_i-\sum_{J=1}^{N}c_{j,}p_j(x_{i,}y_i)]p_k(x_iy_i) \qquad \textbf{(4)}$$
$$k=1\ldots\ldots\ldots\ldots\ldots m$$

Interchanging the order of summations, we can write (4) as the matrix equation:

$$\sum_{j=i}^{N} a_{kj}c_j = b_k \qquad \textbf{(5)}$$

where,

$$a_{kj}=\sum_{j=1}^{N} p_j(x_i,y_i)p_k(x_i,y_i) \qquad \textbf{(6)}$$

is an mxm matrix and

$$b_k=\sum_{i=1}^{N} T_iP_k(x_j,y_j) \qquad \textbf{(7)}$$

is a column vector of length, m.

Equations (5) or (6) are called normal equations of the least squares problem. The solution of this system of equation yield's the unknown coefficients, c_j of the model. The model representing the first degree surface is a two dimensional first order polynomial of the form:

$$T(x,y)=c_1+c_2x+c_3y \qquad \textbf{(8)}$$

This is the special case of Equation (3) for which:

$$m=1;\ p_1(x,y)=1;\ p_2(x,y)=x;\ p_3(x,y)=y$$

Substituting these into the general form of the normal Equations (5), (6), and (7), we obtain the following system of equations given the observed value T_i at N data points (x_iy_i):

$$c_1\sum_{i=1}^{N}1+c_2\sum_{i=1}^{N}x_i+c_3\sum_{i=1}^{N}y_i=\sum_{i=1}^{N}T_i \qquad \textbf{(9)}$$

$$c_1\sum_{i=1}^{N}x_i+c_2\sum_{i=1}^{N}x_i^2+c_3\sum_{i=1}^{N}x_iy_i=\sum_{i=1}^{N}x_iT_i \qquad \textbf{(10)}$$

$$c_1\sum_{i=1}^{N}y_i+c_2\sum_{i=1}^{N}x_iy_i+c_3\sum_{i=1}^{N}y_i^2=\sum_{i=1}^{N}y_iT_i \qquad \textbf{(11)}$$

Theses equations can be written in matrix form as:

$$\left|\begin{matrix}\sum 1 & \sum x_i & \sum y_i\\ \sum x_i & \sum x_i^2 & \sum x_iy_i\\ \sum y_i & \sum x_iy_i & \sum y_i^2\end{matrix}\right|\left|\begin{matrix}c_1\\ c_2\\ c_3\end{matrix}\right|=\left|\begin{matrix}\sum z_i\\ \sum x_iz_i\\ \sum y_iz_i\end{matrix}\right| \qquad \textbf{(12)}$$

This is in the form of $A.C.=B$

The elements of the matrices A and B are known. Since this is a low order system of equations the elements of the matrix of unknowns C can easily be evaluated from Cramer's formula. Therefore, the following determinants can be evaluated:

D_0............. Determinants of the matrix A.

D_1............................. Determinants of the matrix A with elements of the first column replaced by the elements of B.

D_2............................ Determinant of the matrix A with elements of the second column replaced by the elements of B.

D_3.............................. Determinant of the matrix A with the elements of the third column replaced by the elements of B.

The elements, c_j of the matrix of unknowns c are then given by:

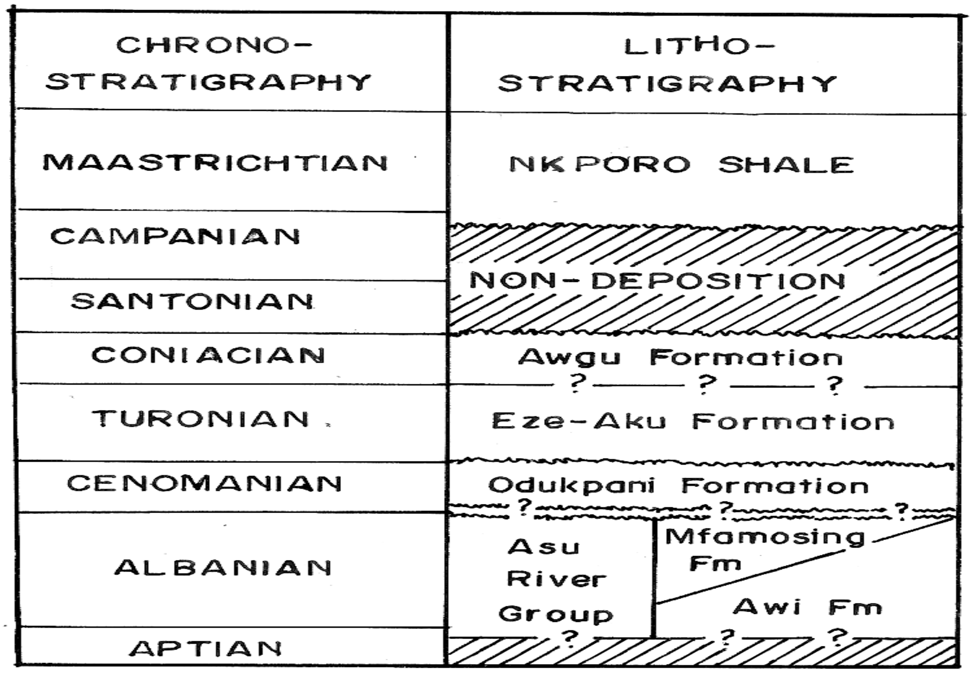
$$c_1 = \frac{D_1}{D_0};\ c_2 = \frac{D_2}{D_0};\ c_3 = \frac{D_3}{D_0}$$ (Kangkolo, 1995).

These values define the form of the first degree surface fit (Equation 8).

Geology of the Flank

Detailed geological and stratigraphic sequence (Figure 1) compiled by Edet and Nyong (1993) from Adeleye and Fayose (1978) and Peters (1982) shows that Calabar Flank consists of basal Fluvio-deltaic grits and sandstones of the Awi Formation (Aptian-Albian); Limestone and Calcareous sandstones of the Mfamosing Formation (Mid-late Albian); alternating limestones and shales of the Odukpani Formation (Cenomanian); shales and marls of the Eze-Aku Formation Turonian); marls of the Awgu Formation (Coniacian) and Carbonaceous shales of the Nkporo shales (Campanian–Maastrichtian).

Nyong (1995) stated that after the initial rifting episode in Calabar Flank, the area underwent a different tectonic and stratigrapic development compared to the adjacent Anambra and southern Benue Trough sedimentary basins of Nigeria. The initial rifting of the southern Nigerian margin produced two principal sets of faults; a NE-SW and NW-SE system. 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 (Figure 2).



CHRONO-STRATIGRAPHY	LITHO-STRATIGRAPHY	
MAASTRICHTIAN	NKPORO SHALE	
CAMPANIAN	NON-DEPOSITION	
SANTONIAN		
CONIACIAN	Awgu Formation	
TURONIAN	Eze-Aku Formation	
CENOMANIAN	Odukpani Formation	
ALBANIAN	Asu River Group	Mfamosing Fm Awi Fm
APTIAN		

Figure 1: Lithostratigraphic and Chronostratigraphic Succession in the Calabar Flank.

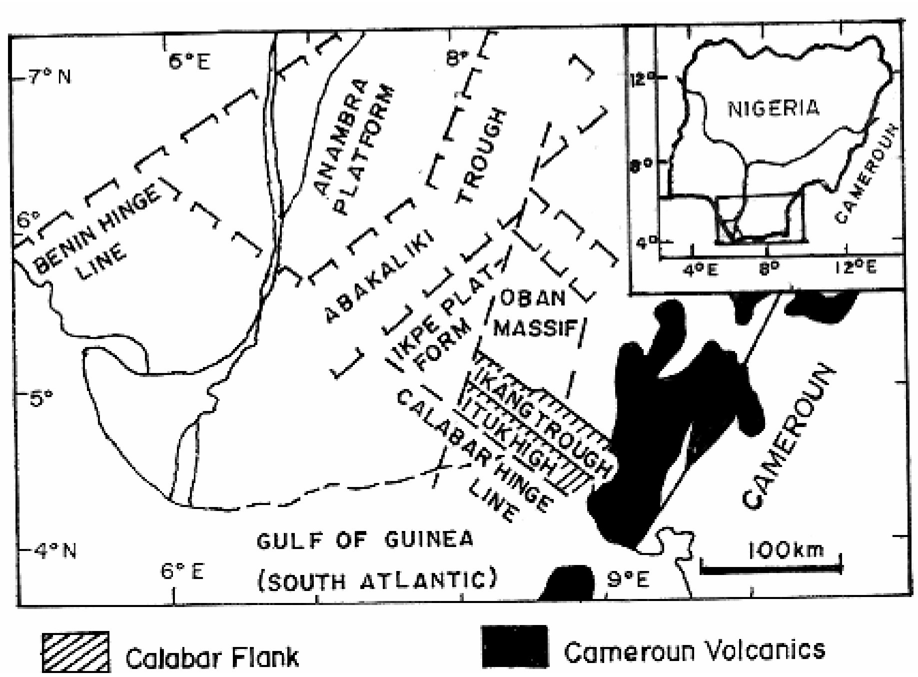


Figure 2: Location Map and Structural Elements of the Calabar Flank and Adjacent Areas (After Nyong and Ramanathan, 1995).

The Bouguer Gravity Field of the Calabar Flank

The gravity data was obtained from the gravity survey conducted in the Flank in 2005 using the Lacoste and Romberg Gravimeter (model G446). The data were referenced to the International Gravity Standardization Net 1971(ISGN71). THE Bouguer gravity field was computed using the average crustal density ($2.67\,{}^{g}\!/_{cm^3}$).

Prominent features which are similar to the tectonic and geological setting can be identified in the Bouguer anomaly map (Figure 3). They include: the Okurikang gradient in north-western sector of the Flank (lat.5.15^{o}-5.35^{o}N, long.8.05^{o}-8.20^{o}N).

This gradient is a manifestation of block faulting where the Calabar hinge line delineates from the adjacent Niger Delta basin; the positive Bouguer gravity anomaly (12-60mGal) which is compatible with mid-continent values and the broadening of the contours at the middle to eastern edge of the Flank. This broadening of the contours is indicative of sediment filled Ikang trough. The feature of the Bouguer anomalies is also characterized by the relatively low gravity anomaly in the south-eastern sector of the Flank.

The first order polynomial fitting based on the least square was adopted in separating the regional and residual fields in the Bouguer gravity anomaly map of the study area. The procedure of polynomial fitting by least- squares technique to obtain the regional field data is commonly used in processing geophysical data.

The degree of polynomial usually increases with increase in the size of survey area. Thus, the first degree polynomial technique was more amenable to this study because the area of study is relatively small (50km^2). Considering the problem arising due to the effect of observation distribution and the resulting complexity of the calculated surface, the Bouguer anomaly data was gridded using a program based on minimum-curvature method (Briggs, 1974) at approximately 1km interval at a scale of 0.01^0.The gridded data now has a uniform distribution of observation points on which the polynomial fitting technique was applied. The regional being fitted to the data is a two-dimensional first degree polynomial surface of the form given in Equation (8).

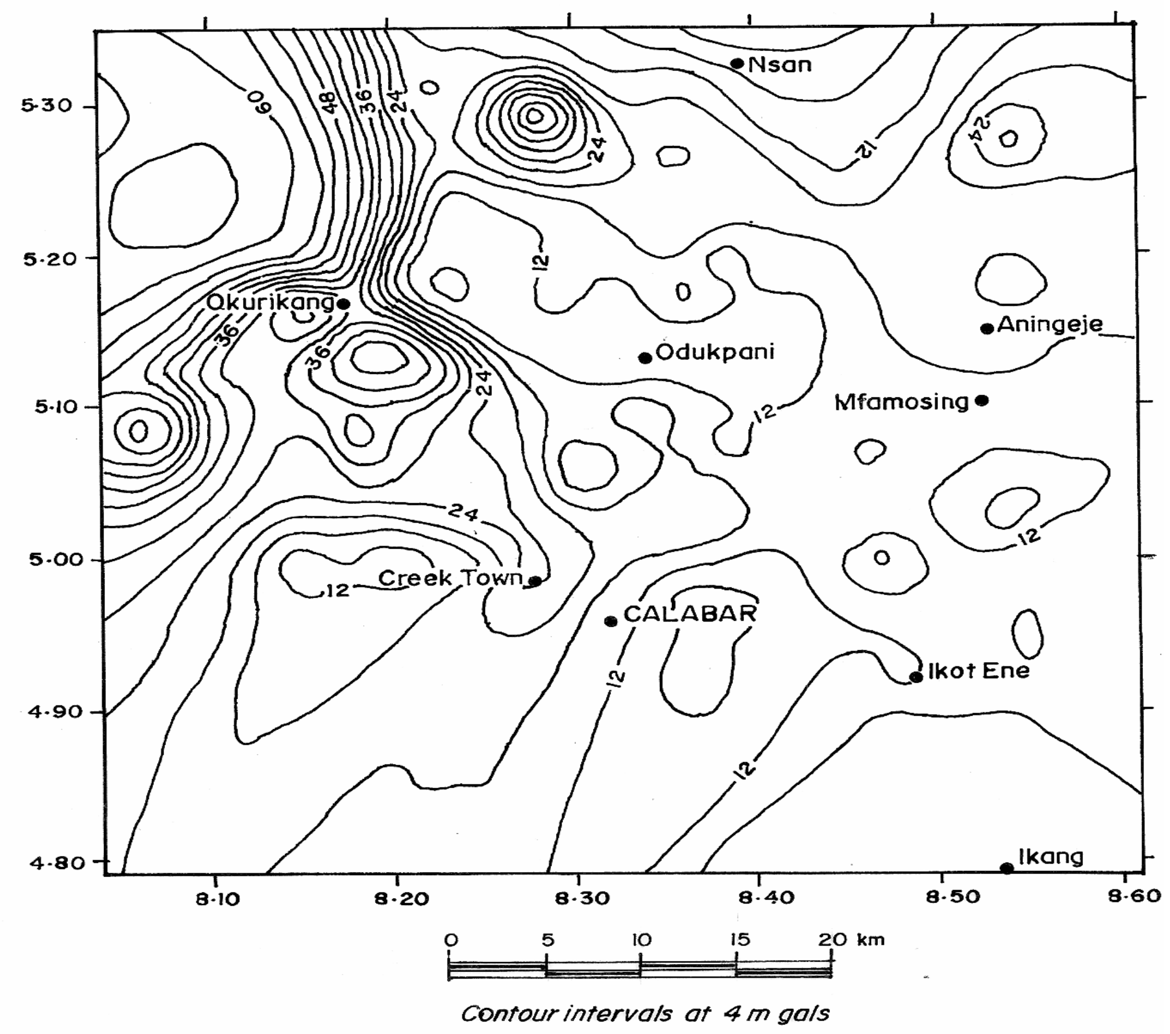


Figure 3: Bouguer Gravity Anomaly Map Characterized by Positive Gravity Values.

RESULTS AND DISCUSSION

The result of the polynomial fitting is presented in the form of regional gravity field (Figure 4) and the residual gravity field (Figure 5).The coefficients obtained from the analyses of the Bouguer gravity field are C_1 = 26.64513, C_2 = -46.68486, and C_3 = 27.69958. Therefore, the regional gravity field over the flank is given by:

$T(x, y) = 26.64513 – 46.68486x + 27.69958y$.

The procedure of polynomial fitting by least squares technique to obtain the regional field data is commonly used in processing geophysical data. However, Ojo, and Kangkolo (1997) pointed out that the unguarded use of this procedure with measured field data may lead to erroneous regional fields. This is due to the fact that the least-squares technique pre-supposes a random variation of the residual. The degree of polynomial increases with increase in the size of survey area. Selection of too high an order polynomial might result in the introduction of inappropriate signal.

The residual Bouguer gravity map is more closely related to the geology than the Bouguer gravity anomaly map. The residual gravity data are not at variance with the proposed grabben and horst structure model of the Calabar Flank. The grabben structure (Ikang trough) is represented by gravity lows South-East of Calabar Flank and gravity modeling Okiwelu (2007) constrained by

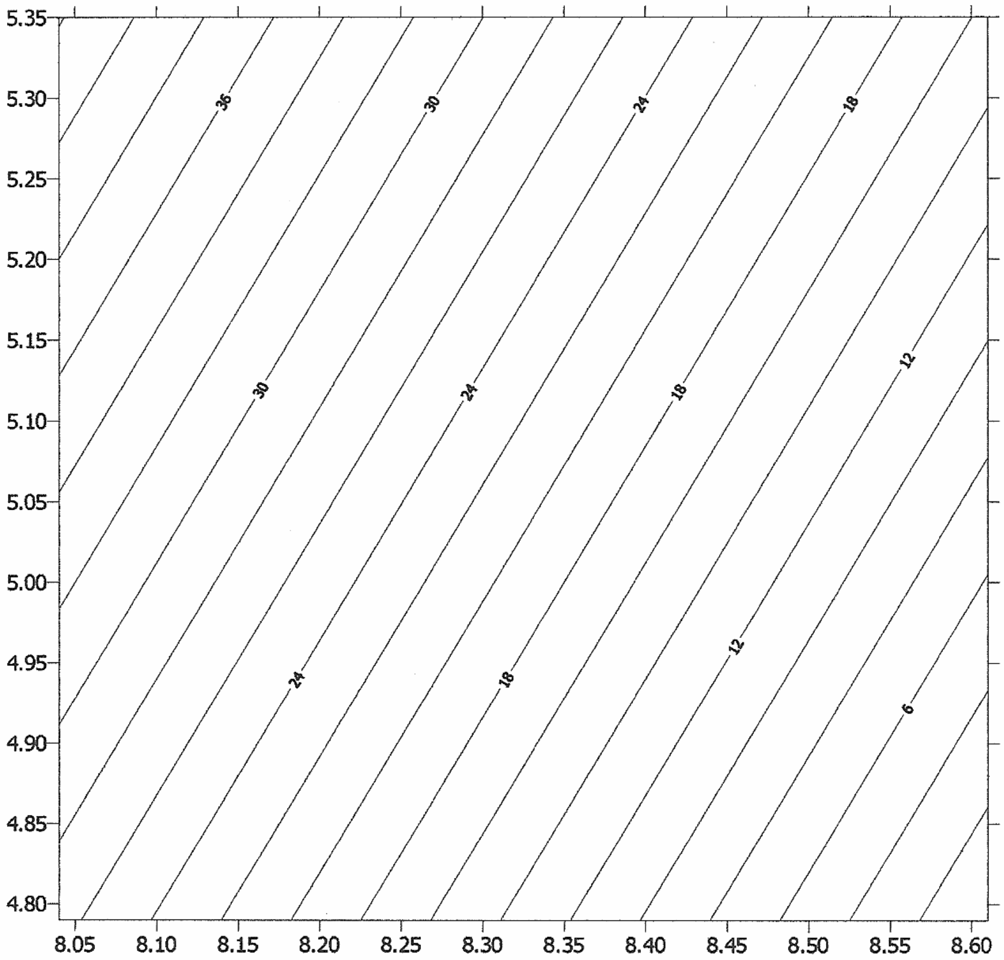


Figure 4: Regional Gravity Field Exhibiting NE-SW Trends. Contour interval is 2mGals.

geological model indicates that this feature is associated with thick section of Cretaceous sediment. The density contrast of -0.02g/cm^3 gave rise to the gravity low which is relatively smooth and uncomplicated because of the thick sedimentary cover [3,000m]. North of the grabben structure is a horst [Ituk high].

The horst is represented by a gravity high trending E-W [5.15^{0}N, 8.52^{0}E].Gravity modeling shows that the positive density contrast (0.05g/cm^3) gave rise to the gravity high and the causative body is attributed to an intra-basement mass (intrusive) of density 2.7g/cm^3. This intrusive is likely to be granodiorite which has been reported by Ekwueme (2003) in the North-Eastern part of the study area. The broadening of the contour around Odukpani, Aningeje and Mfamosing are indicative of down thrown side of the fault in the area of study. These characteristics exhibited by the gravity contours are evidence of block faulting and dyke intrusion occurring probably during the initial stage of rifting in the Flank. The above evidences apparently suggest that rifting in the Flank did not progress beyond the stage of block faulting and dike intrusion.

The associated intrusive is probably an intermediate basic rock (diorite) with a density of 2.87g/cm^3. This intrusive body is well documented in geological report from the adjacent Oban Massif. The intrusive is defined by circular contour in the geophysical map. Adjacent to this intrusive body towards the middle of the coastal basin is a circular gravity low [5.05^{0}N, 8.30^{0}E]

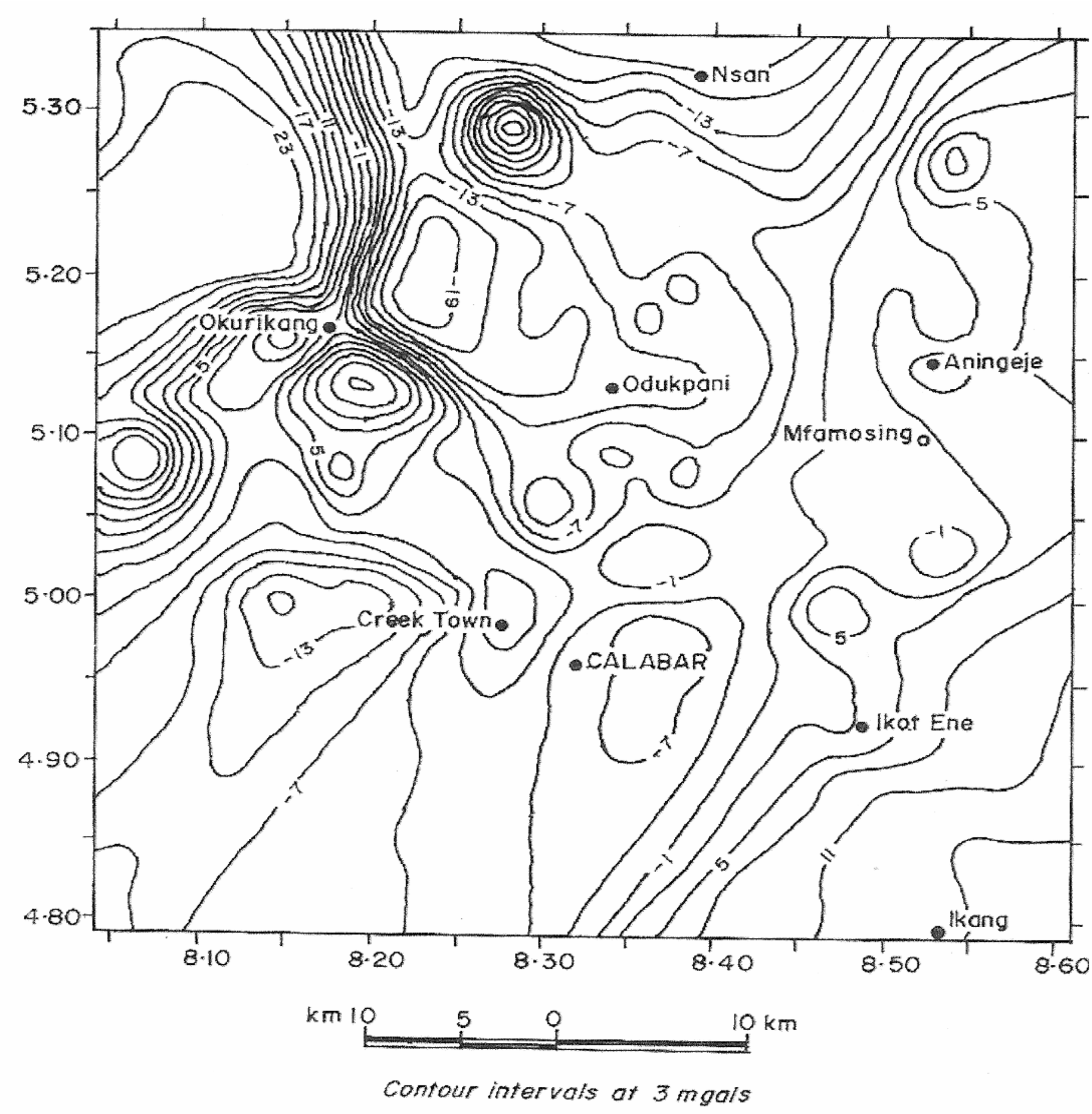


Figure 5: Residual Gravity Field Characterized by Negative and Positive Gravity Values. The Features in the Residual Field are Consistent with Tectonics and Geologic Setting of the Flank.

suggesting a source of low magnetic susceptibility. Jachens and Griscom (1985) are of the opinion that most gravity lows lie over low-density plutons or over structural depressions filled with low density sediments or volcanic rocks. Keller et al. (1985) opined that circular gravity low is associated with granitic batholiths that have negative density contrast. Modeling shows that the source of the negative gravity anomaly has a negative density contrast (-0.05g/cm) and therefore a density of 2.62g/cm. It intruded into the sedimentary sequence to a depth of 1,000m from the surface. Therefore, the residual gravity low is attributed to granitic intrusion.

Adjacent to this large elliptical source is a positive anomaly with positive density contrast

(0.12g/cm^3) [density = 2.89g/cm^3]. The high density body is of course an intrusive of basic composition. Geological evidence supported by measured density values Ugbaja (2007) points to a source of gabbroic composition. Model calculation indicates that the source intruded 4,000m of sedimentary sequence. This source has a tabular disposition (sill-like structure) and is interpreted as an indication of more mafic material in the subsurface. The residual gravity data also revealed a narrow trough in the northeastern edge of the study area. The trough is marked by change in gravity gradient which probably delineates an area of thick sedimentary sequence. The large variation in amplitude and steep gradient are compatible with structures formed by extensional tectonism in the Flank.

CONCLUSION

The first order degree polynomial fit to the Bouguer gravity field is more amenable in this study because it represents the surface that best describes the regional gravity background of the Calabar Flank. The area of study is relatively small and therefore the low order polynomial is more appropriate to this study. This approach is more quantitative than the wavelength filtering methods because if one knows the specific regional trends, major geological features of interest can be adequately modeled. The application of the low order polynomial shows that the Flank is characterized by positive and negative residual gravity fields. This is compatible with the tectonics and geological setting of the Calabar Flank.

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