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Gravity Study over Jos – Bukuru Younger Granite Complex, North Central Nigeria

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ABSTRACT

Horizontal gradient filtering on the Bouguer anomaly data indicates contour values between -1.5 and 1.3. Zero contour zones are interpreted as faults and other abrupt geologic edges. Bouguer anomaly field is characterized by negative values between -90 and -10 mGal. Values of – 90 mGals are centred on the Jos - Bukuru Younger Granite complex. Lower values at the eastern side are separated from higher ones at the western side by a NW – SE diagonal line. The anomaly contour closures trend in the E – W, NE – SW, N – S and NNW – SSE directions. Third order polynomial trend surface fitting shows the contour levels of the regional anomaly field in a NNE – SSW direction, consisting of increasing N – S values. Map of the residual anomaly is characterized by both negative and positive values between -25 to +20 mGals. The negative values are probably located on the intrusive younger granite rocks while the positive values may explain areas underlain by volcanic rocks. The contour closures of the residual anomaly map are oriented along the same directions as the Bouguer anomaly map but without any line separating higher values from lower ones. Two and one half models of the residual anomaly along profiles indicate depths up to 18.75 km for the plutonic rocks and 13.96 km for the volcanic rocks. These large depths are attributed to the presence of a large-scale fault associated with the Romanche fracture zone in the basement around the Jos - Bukuru Younger Granite complex.

Key words: Positive, Negative, Anomaly, Residual and Gravity modeling.

INTRODUCTION

The topography of Nigeria is influenced by planar and linear structures resulting from ductile and brittle deformational events (19). The structures generally have N – S, NE – SW, NW – SE and sometimes E – W trends (17, 18, 29, and 31). Regional strikes of foliations in basement rocks, lithologic boundaries, fold axes and axial planes maintain the N – S Pan-African imprint. Numerous fractures and faults formed river valleys all over the country.

Local lineaments discernable are mostly fracture lines defined by joints that formed as a result of tensional stresses. These form a network cross cutting each other, which generally decrease in width and size with increase in depth, as they are commonly sealed up at depth by the lithostatic pressure and/or siliceous materials. Because geologic features are often large, structural analyses are conducted on regional scales, to provide a comprehensive look at the extent of faults, lineaments and other structural features. Thus the applications therefore require small-scale imagery to cover the extent of the element of interest. This study is intended to delineate new structures and extend known ones. Accordingly it will help in gaining better understanding of the structural set-up of the area of interest.

The study area constituting the Jos - Bukuru Younger Granite complex of North Central Nigeria is shown in Fig. 1. It is bounded by latitudes 9^{o}35' N and 10^{o}05' N and longitudes 8^{o}46' E and 9^{o}10' E., and forms part of Naraguta Southeast sheet 189 of Federal Survey of Nigeria. It has an estimated area of 2536.08 km^2

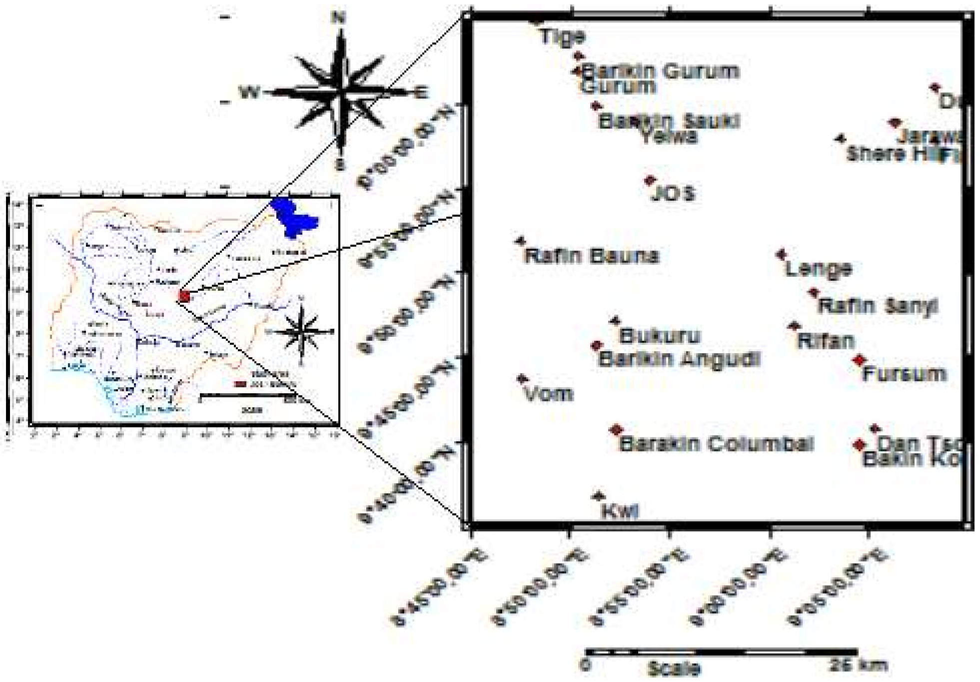


Fig. 1: Location map of the study area

Literature Review

The Younger Granite Province comprises of Precambrian to Lower Paleozoic Basement rocks into which the Younger Granites suites are emplaced (15). The basement rocks cover about three quarters of the province and consist of ancient sediments (15, 22).

Electrical resistivity and magnetic methods were first used in the study area along buried channels that contained cassiterite, columbite and other accessory resistant minerals (24). Magnetic, seismic, resistivity and gravity methods were used in the search for basalt covered alluvial cassiterite (16). Gravity surveys across the Younger Granite province show negative Bouguer anomalies ranging from –94 to –25 mGals (1, 2 and 3).

Seismic, gravity and magnetic data have shown four major offshore fractured zones cutting the Atlantic sea floor of West Africa coast. These oceanic fracture zones cut to the northeast on approaching coast of Guinea at the north and terminated at a relatively short distance inland

(6,10,14). Fracture zones tend to develop near pre-existing zones of weakness inherited from major orogenic activities in the continents (27). Aeromagnetic anomalies and tectonic trends in and around the Benue Trough of Nigeria show that the Nigerian continental landmass contains lineaments with definite magnetic signatures (4), enhanced by the presence of anorogenic ring complexes. The lineaments possibly reflect major fracture zones on the Atlantic sea floor off the west coast of Africa (25). The works of Ajala (5) near Kaltungo and Ekanem (9) around the Kerri-Kerri Formation offered evidences on extrapolation of fracture zones into the continental landmass of Nigeria.

General Geology of the Younger Granites

In Nigeria about fifty separate Younger Granites complexes are recognized with a total area of 7511 km^2. The individual massifs range in size from 1036 km^2 to smaller stocks of less than 2.59 km^2 with circular or elliptical outlines. Several cycles of intrusion occur within one complex and the sizes of many of the structures are due to overlapping and superposition of separate intrusive cycles.

The Younger Granites are discordant, high-level intrusions, which transgressed all units of the basement complex. They have been preceded by extensive acid volcanism and emplaced by ring faulting and block subsidence. Granites and rhyolites underlay more than 90 percent of the total area of the province. Intermediate and basic rocks occur in Emplacement of the Younger Granites is associated with epeirogenic uplift (28). Their age is Jurassic. The Older Granites and accompanying metamorphism of the basement represent the Pan African orogeny in Nigeria (13, 30). A great variety and number of Younger Granite complexes in Nigeria exhibit different degrees of erosion. The large complexes of the Jos Plateau (Jos - Bukuru and Sha - Kaleri), involved much greater volumes of magma.

In most of the complexes, the volcanic rocks have either been obliterated by later granite intrusions or eroded to an extent that their original pattern of distribution is conjectural. Where the lavas are preserved they are invariably confined within the major peripheral ring faults. The early groups are products of vent intrusion from group of vents aligned along ring-fractures. The fractures extended to the surface and provided zones of weakness that facilitated the upward passage of the magma. These same ring-fractures frequently served as the loci of intrusion of the large ring-dykes. Pyroclastic rocks are abundant and there are thick interactions of tuffs and coarse agglomerates within the lava succession. The later group of rhyolite includes both intrusive and extrusive rocks that either extruded on the surface or emplaced at shallow depth.

The emplacement of ring-dykes within circular and polygonal features initiated many of the intrusive cycles. The emplacement of the ring-dykes has directly succeeded the volcanic cycle and many of the initial ring-fractures, which control the distribution of the volcanic eruptions, have also served as the loci of the ring-dykes. The ring dykes are both smoothly acute and polygonal. The ring dykes are generally steep structures and contact dipping outwards at angles less than 80^o are rare. Some of the ring dykes are as much as 2 km in widths. In the Younger Granite province there is a practically continuous sequence of intrusive forms from the narrow ring dykes to large irregular granite plutons. Many of the smaller granite intrusions represent the upper, flat-lying roof sections of the ring intrusions and, some of these are remarkably shallow in comparison with their lateral dimensions. Others are stock and bosses with steeply dipping contacts, which probably continued to a considerable depth.

The granite pluton of the Jos Plateau exemplifies extreme mode of operation of large-scale underground cauldron subsidence. Their emplacement resulted from segmentation and foundering of large adjacent blocks of the basement and accompanying rise of magma. The process continued intermittently, allowing individual phases to consolidate before the next stage of intrusion. Cauldron structures were superimposed on earlier ones in the cycle and piecemeal stopping operated to blur the outlines of the original tectonic pattern. The Jos- Bukuru-Jarawa group of granite intrusions is the best example of large-scale subsidence and superimposition of structure.

MATERIALS AND METHODS

Methodology

The data sets for this study consist of a topography map of the Jos - Bukuru Younger Granite complex and its environment on sheet 168 Naraguta Southeast, a LaCoste and Romberg gravimeter, a Nissan station wagon, global positioning system (GPS), computer hard and software etc. Gravity field data were acquired with a LaCoste and Romberg gravimeter using vehicle to establish spacing between gravity stations and acquiring data. The GPS was used to determine the geographical position of the gravity stations as well as their heights.

The main software used in the analyses of the gravity data are Integrated Land and Watershed Information System3.3 (2005) (ILWIS 3.3)), Surfer8 (2003), Grapher5 (2004) and OriginLab7 (2002). ILWIS was applied in digitizing, extracting and proper positioning of prominent features using the Universal Transverse Mercator (UTM) system. Third order regional polynomial trend surface was fitted to the Bouguer anomaly field in the same environment to obtain a general surface view of the residual anomaly. Also third order polynomial fitting along profiles was used to remove the regional anomaly field from the Bouguer anomaly field in an OriginLab7 environment in order to obtain the residual anomaly field used for the models. Surfer8 and Grapher 5 were used basically to compose the maps and to plot some terrain models. The gravity software used for quantitative determination of the various bodies along the profiles is Cooper (2003) Grav2dc for windows.

Distance measurements on this study used the central meridian scale factor of 0.9996. Clarke 1880 ellipsoid is applied since the study area is located south of 5° N latitude and south of the equator. The coordinate system projection parameter is presented in Table 1.

Table 1: Coordinate System projection parameters for the study

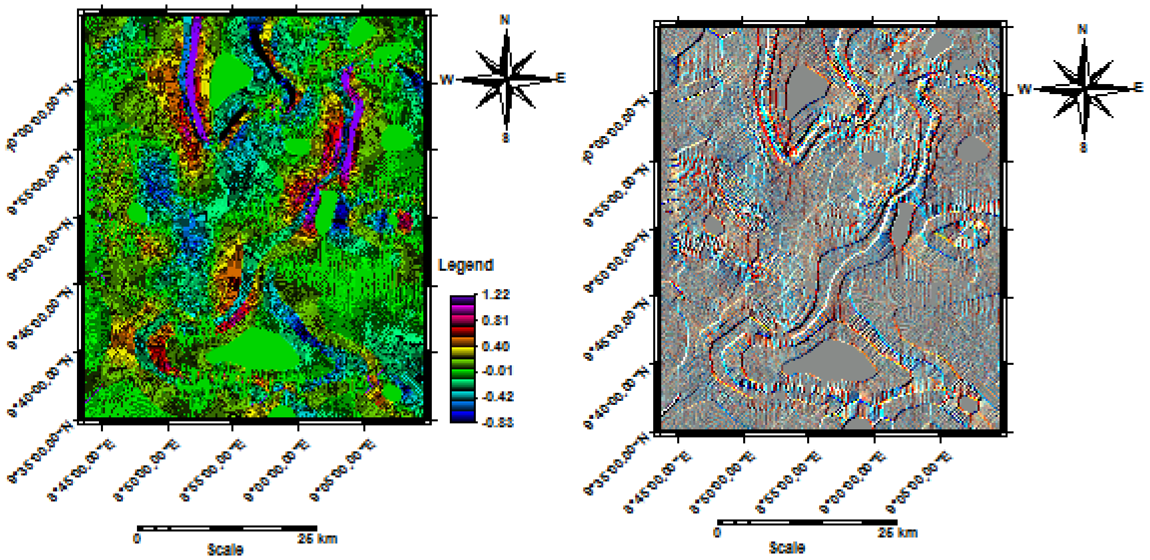
Projection	Datum Area	Datum	Ellipsoid Parameters		Ellipsoid	Hemisphere	Zone
UTM	Nigeria	Minna	A	6378249	Clarke, 1880	Northern	32
			1/f	293.465			

Corrections to Gravity Measurements

In order to arrive at meaningful Bouguer anomaly values, drift, tidal, latitude, free air and Bouguer corrections were applied to the raw observations of differences between gravity measured at a station and a base station.

Filtering

The horizontal gradient technique was used to filter the data. The magnitude of the gradient values range between -1.5 to 1.3. Zero gradient values are interpreted as discontinuities such as faults and other abrupt geologic discontinuities. The filtered map is shown on Fig. 2



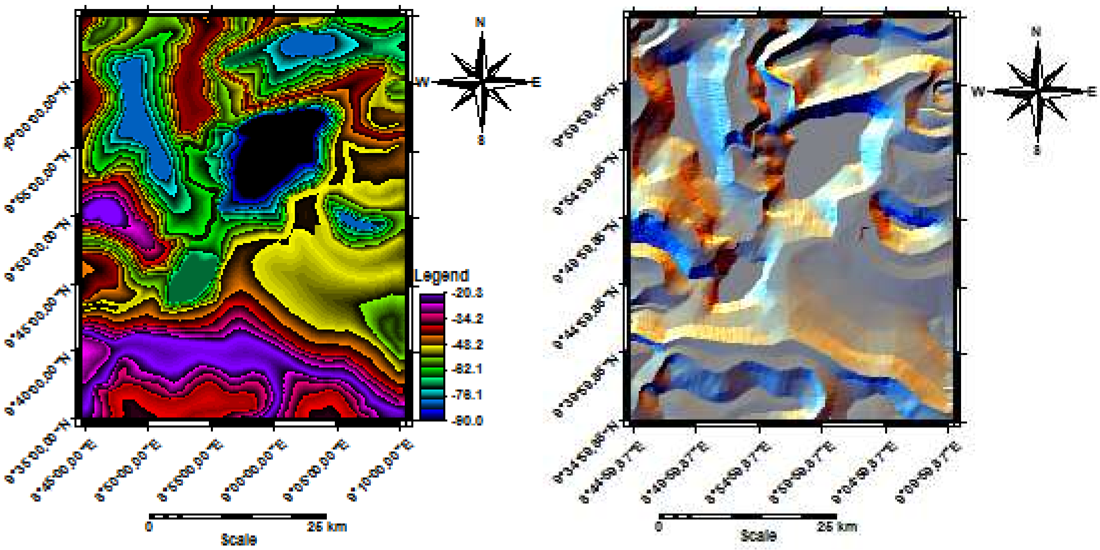
(a) Raster map (b) Digital elevation map

Fig. 2: Horizontal gradient of the Bouguer anomaly field

Qualitative Interpretation of the anomaly fields

Bouguer Anomaly Field

The Bouguer anomaly field is characterized by negative values between -90 and -10 mGal (Fig. 3). The lowest values of – 90 mGals are centred on the Jos - Bukuru Younger Granite complex. Lower Bouguer anomaly values at the eastern side are separated from higher ones at the western side by a NW – SE diagonal line. The Bouguer anomaly contour closures trend in the E – W, NE – SW, N – S and NNW – SSE directions.



(a) Raster map (b) Digital elevation map

Fig. 3: Bouguer anomaly field

Regional – residual separation

The mapped potential field data are the sum of the effect of all sources causing a gravity anomaly. An important technique is residual mapping, that is, to eliminate or reduce to minima the effects of deep-seated, non-commercial sources with as little distortion of the resultant anomaly as possible.

Analytical methods are applied by using special filtering techniques. One of the simplest methods is to subtract the result of a smoothing filter or low pass filter from the original image. The noise present in the original data is often revealed when subtracting. Third order polynomial trend surface fitting was used in an ILWIS environment to define the regional field of the gravity map shown in Figs. 4. Trend surface calculates pixel values by fitting one surface through all point values in the map (12). Surface fitting is performed by least squares fit.

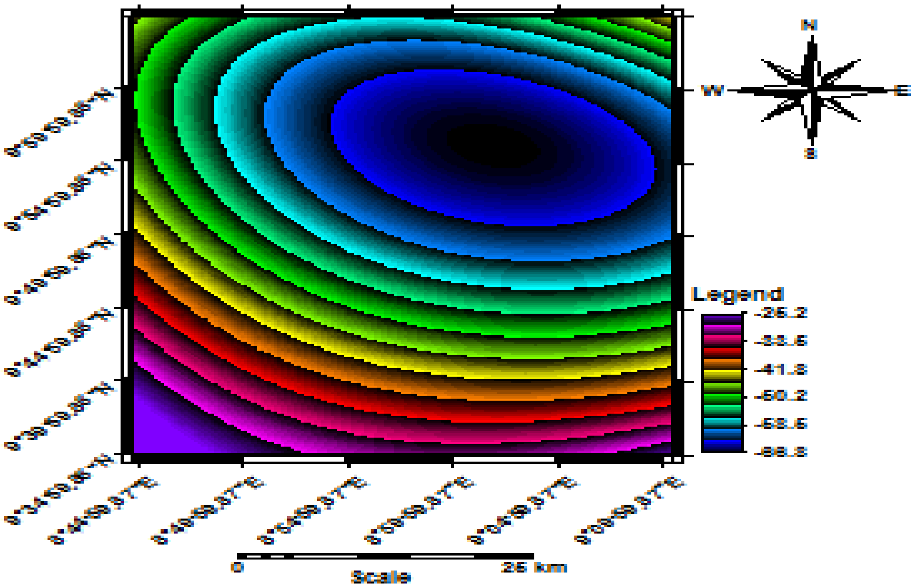
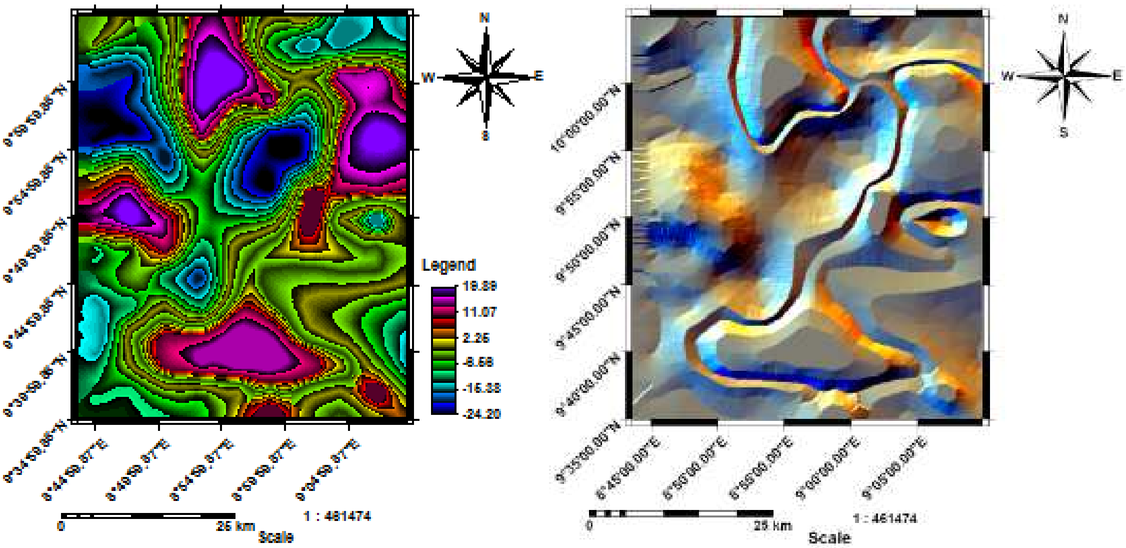


Fig. 4: Regional anomaly field

The contour levels of the trend surface regional field indicate a general NNE – SSW trend consisting of increasing N – S values, which depicts the thickening of the crust towards the north.

The Residual Anomalies

Fig. 5 shows the map of the Bouguer residual anomaly in raster and digital elevation visualization after subtracting the regional anomaly field from the Bouguer anomaly field. The field is characterized by positive and negative values between -25 to +20 mGals. The negative values probably correspond to the intrusive younger granite rocks while the positive values may explain areas underlain by volcanic rocks. Like the Bouguer anomaly map, the residual anomaly map also has its closures mainly oriented along the E – W, NE – SW, N – S and NNW – SSE directions, but without any specific dividing line separating the higher from the lower values towards a particular direction.



(a) Raster format (b) Digital elevation model

Fig. 5: Residual anomaly field

Quantitative interpretation of the residual anomaly

The mathematical problem of gravity interpretation consists of finding the mass distribution whose gravitational fields are given on plane surfaces. In this case, we are confronted with determining the source from its potential which, unfortunately, does not have a unique solution. This is because of the insufficient information available to determine the size and shape of the source completely and unambiguously from its potential field. The difficulty arises in trying to separate the physical size from the density of the gravitating mass.

The essence of quantitative interpretation is to obtain information about the depth to the gravity body, its shape and size, and detail about its density in two possible ways. One is direct, where the field data are interpreted to yield a physical model. The other is the inverse method, where models are generated from which synthetic gravity anomalies are generated and fitted statistically against the observed data. The degree of detail is limited by the quality and amount of available data and by the sophistication of the computer software.

Table 3 shows the latitudes of the four gravimetric sections (from top to bottom) used in the models and Fig. 6 is the superimposed profile sections (in the same order) on the Bouguer anomaly map. The profiles were chosen so as to cut across major anomalies.

Table 3 Reference Latitudes of the profile sections

Profile Name	Reference Latitude
GH1	10^{0}03'50.37''
GH2	9^{0}55'38.15''
GH3	9^{0}45'08.72''
GH4	9^{0}38'56.17''

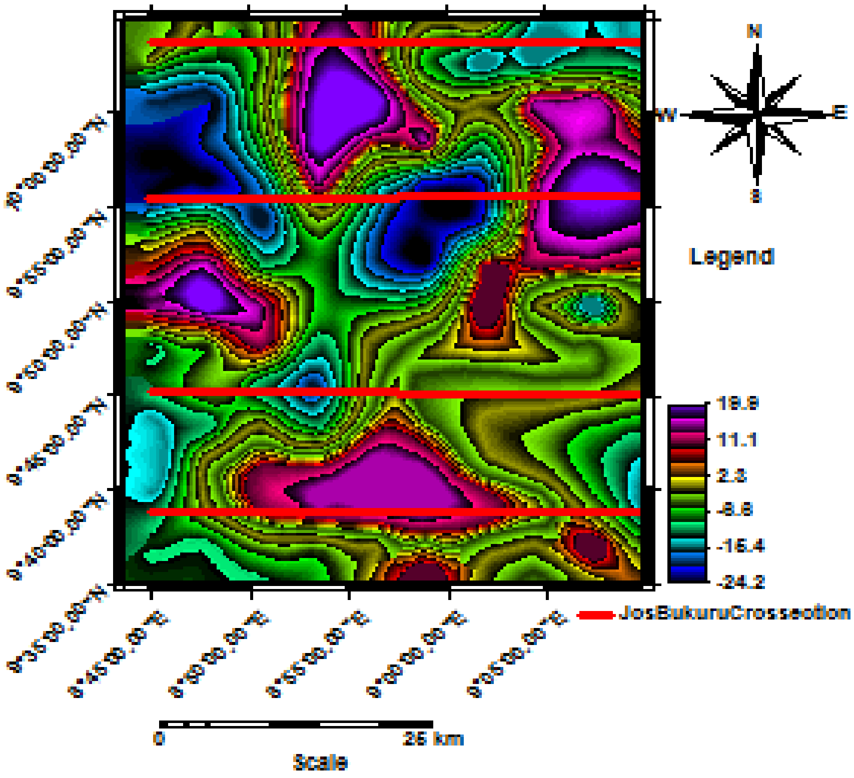
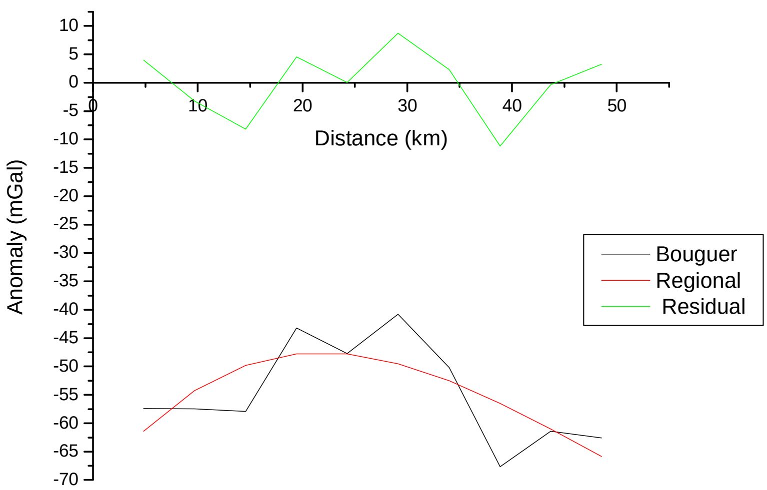
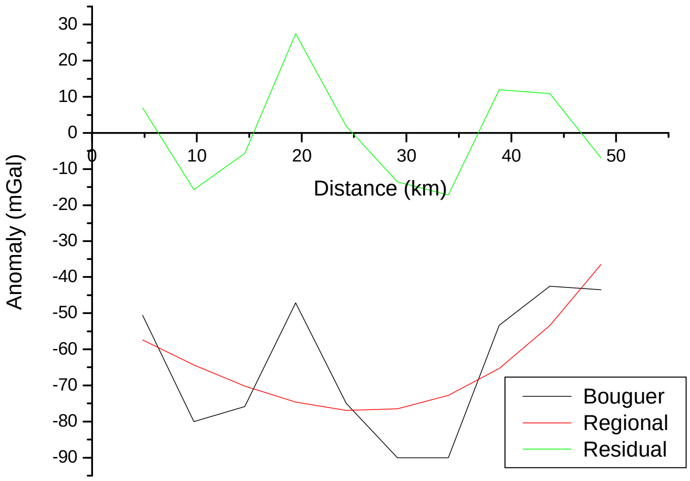


Fig. 6 Cross sections superimposed on Bouguer raster map

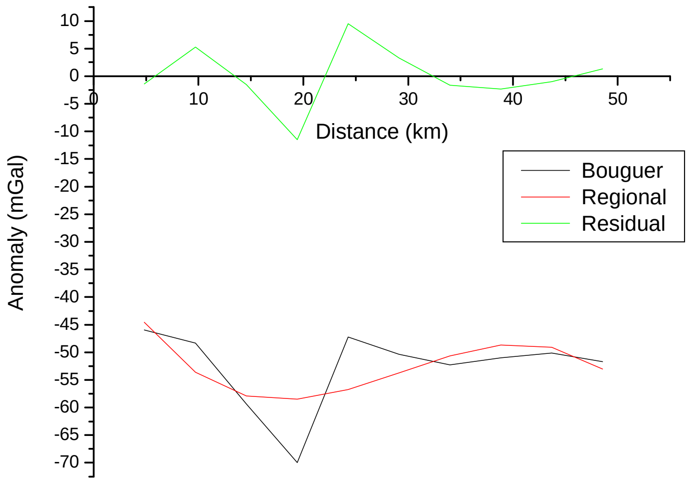
To minimize errors in interpreting the gravimetric data, third order polynomial regional curves were fitted on the Bouguer anomaly fields using Origin7 (2002) software. The residual anomaly results shown in Fig. 7 along with the Bouguer and regional anomaly field curves were obtained by subtracting these regional backgrounds from the Bouguer anomaly fields.



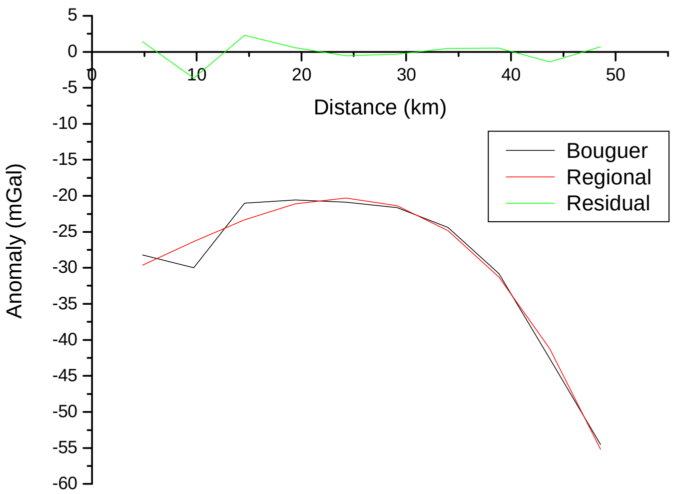
(a) Profile section GH1



(b) Profile section GH2



(c) Profile section GH3



(d) Profile section GH4

Fig. 7: Bouguer, Regional and Residual anomalies along profiles

Gravity Modeling

To account for the residual anomalies, a Grav2dc algorithm for gravity modeling was used. Grav2dc is two and one half dimensional computer software developed by Cooper (2003). The models were fitted using polygonal approximation method of determining gravity attraction of polygonal cross section. Two and one half dimensional modeling is an extension of two dimensional modeling, but allows for end effects to be considered (7, 23).

The interpreted results are given in Table 4, and the corresponding models shown in Fig. 9. The depths to the different rock bodies along the profiles were controlled using depth estimation by (4) in the area. The density values for the different rock units were taken from available literature and typical values for basement rock units. The upper parts of the figures show observed and calculated gravity data (profiles). The lower parts of the modeled in the figures show the rock units after the adjustment of their depths.

Table 4 Interpreted results of the residual anomalies along profile sections

(a) Profile section GH1

Body No.	Density Contrast (x 10^3 kgm^{-3})	Width (km)	Thickness (km)	Rock Type
1	0.100000	1.695	7.783	Volcanic
2	-0.17765	1.369	8.654	Plutonic
3	0.136125	1.108	10.096	Volcanic
4	0.190505	2.079	12.305	Volcanic
5	-0.264337	1.238	9.632	Plutonic
6	0.050000	0.978	10.928	Volcanic
7	-0.078300	1.108	10.593	Plutonic
8	-0.078488	1.853	9.615	Plutonic

(b) Profile section GH2

Body No.	Density Contrast (x 10^3 kgm^{-3})	Width (km)	Thickness (km)	Rock Type
1	-0.159133	4.747	12.500	Plutonic
2	0.499973	1.680	13.462	Volcanic
3	-0.147424	5.745	18.750	Plutonic
4	0.289085	1.906	11.075	Volcanic
5	0.232000	0.932	10.096	Volcanic
6	0.262500	1.108	13/962	Volcanic

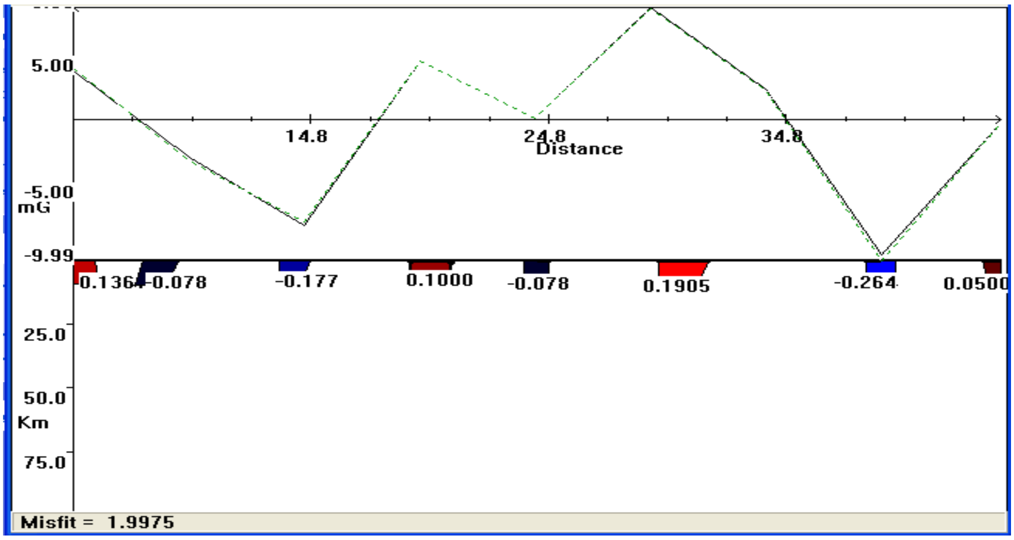
(c) Profile section GH3

Body No.	Density Contrast (x 10^3 kgm^{-3})	Width (km)	Thickness (km)	Rock Type
1	-0.093500	0.587	11.058	Plutonic
2	0.173971	0.996	12.500	Volcanic
3	-0.264000	1.872	12.981	Plutonic
4	0.302841	1.760	11.538	Volcanic
5	-0.090250	1.619	12.825	Plutonic
6	-0.012000	0.782	9.690	Plutonic
7	-0.030360	1.094	11.058	Plutonic

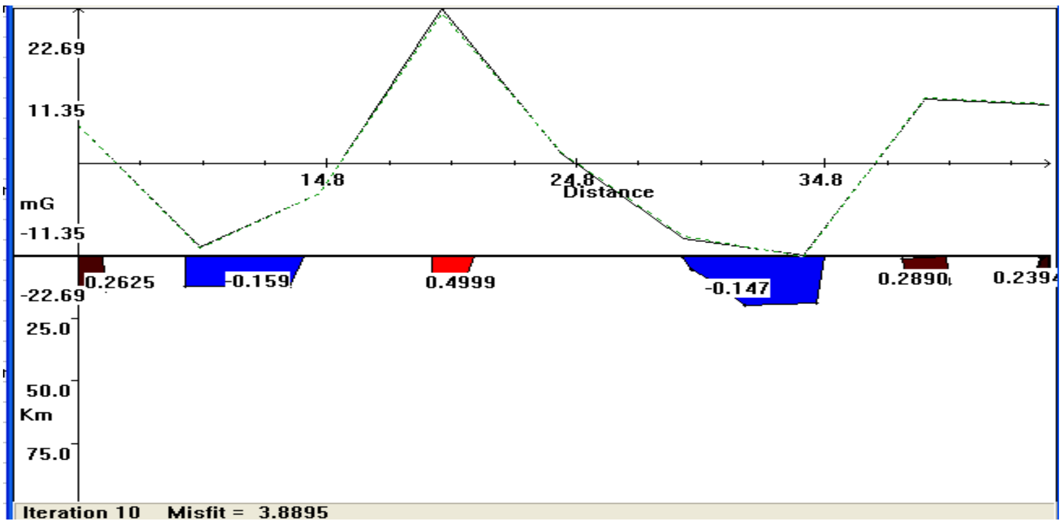
(d) Profile section GH4

Body No.	Density Contrast (x 10^3 kgm^{-3})	Width (km)	Thickness (km)	Rock Type
1	0.055000	0.782	12.019	Volcanic
2	-0.09000	1.043	12.500	Plutonic
3	-0.04400	0.717	13.462	Plutonic
4	-0.02070	1.434	13.463	Plutonic
5	0.006864	1.499	12.981	Volcanic
6	0.032917	1.857	12.019	Volcanic
7	0.078179	1.083	13.130	Volcanic

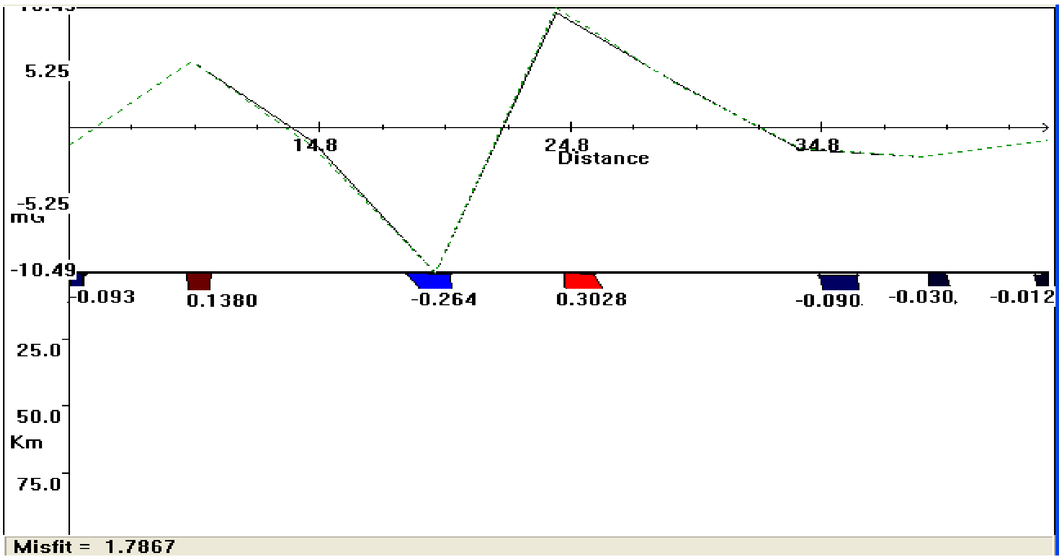
The simplest interpretation technique is to identify zones with different gravity characteristics. Segments of the profile with little variations are considered gravity 'quiet' and are associated with rocks with low density (23). Segments showing considerable variation are 'noisy' and indicate gravity sources in the subsurface.



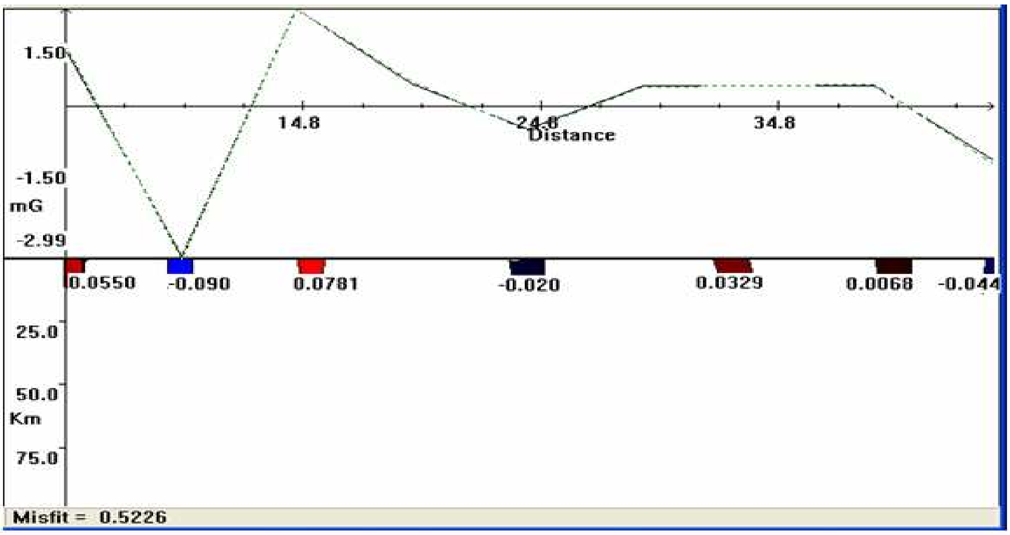
(a):GH1



(b):GH2



(c):GH3



(d) : H4

Fig. 8: Interpreted models along the profiles

RESULTS AND DISCUSSION

GH1 has eight bodies (Table 4a and Fig. 8a). Four of such bodies are suspected to be plutonic rocks whose density contrast range between - 0.050 and – 0.264 kgm^{-3}. The range of width and depths of these plutons are calculated at 1.108 and 1.853 km, and between 8.654 and 10.593 km respectively. The remaining four bodies along the same profile section have density contrast in the range of 0.050 and 0.191 kgm^{-3}, width between 0.978 and 2.079 km; and depth of 8.654 to 12.305 km.

Six individual bodies were interpreted along profile section GH2 of which two are plutonics and four are volcanics (Table 4b and Fig. 8b). The range of the density contrasts for the plutonic rocks varies between – 0.159 and – 0.147 kgm^{-3}, The calculated widths ranges between 0.932 and 4.747 km, while the depth range varies from 12.50 to 18.75 km. The four volcanic rock units along the section have density contrast range of 0.232 to 0.055 kgm^{-3}. Their respective widths and depths ranges are from 0.932 km to 1.906 km, and from 10.096 to 13.962 km.

Profile section GH3 model considers both the intrusive and the volcanic rock units along the traverse outcropping on the surface. The residual anomaly curve obtained with the third degree polynomial fitting indicates five intrusive bodies and two extrusive ones (Table 4c and Fig. 8c). Density contrasts for the intrusive models vary between – 0.264 and – 0.012 kgm^{-3}. The width varies between 0.587 and 1.619 km. The depth estimated for the intrusive range between 9.690 and 12.981 km. The volcanic rocks occur in isolation with density contrast ranging between 0.174 and 0.303 kgm^{-3} and between 0.996 to 1.700 km wide. The calculated depth ranges from 11.538 to 12.500 km.

GH4 has seven gravity anomaly bodies along its profile section (Table 4d and Fig. 8d). Three of such bodies are of plutonic origin while four originated by volcanic activity. Like other profile sections different density contrasts were used in the various models and different widths and depths were also revealed. The plutonic rocks density contrast is between -0.090 and -0.021 kgm^{-3}. Their widths range from 0.717 and 1.434 km and depths range is between 12.500 and 13.463 km. With a density contrast between 0.007 and 0.782 kgm^{-3} for the volcanic rocks, the widths calculated vary between 0.782 and 1.857 km. The range of depths attained is between 12.019 and 13.130 km.

CONCLUSION

The conclusions from this study are:
(i) The Jos - Bukuru Younger Granite Complex is characterized by negative Bouguer anomalies ranging from -90 to – 10 mGals. The different Bouguer values conform to the regional.
(ii) The contour levels of the residual anomaly values fall between -25 to +20 mGals. Also the E – W, NE – SW, N – S and NNW – SSE closure patterns are the main structural features of the gravity residual anomalies in the area, which also proved the isolated nature of the intrusions.
(iii) Two and a half dimensional gravity models of the subsurface structures identified prominent deep seated faults along the profile sections in the area. The faults as revealed by the gravity models attained maximum depth of 18.75 km. The steepness of the gravity contours supports possible relative displacement of the bocks of the intrusive bodies of that magnitude.
(iv) The faults correlate with Romanche fracture zone which, if extrapolated into the Nigerian landmass will cut across the Jos – Bukuru complex.

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