AJGR
AFRICAN JOURNAL OF GEO- SCIENCES RESEARCH
African Journal of Geo-Science Research, 2013, 1(3):24-31
ISSN: 2307-6992
Available Online: http://ajgr.rstpublishers.com/

USE OF GGM DERIVED GRAVITY ANORMALY (EGM2008) FOR REGIONAL RECONNAISSANCE EXPLORATION.

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Abstract
Considering the rigors of terrain based gravity observation and subsequent reductions, EGM 2008 derived gravity anomaly is herein suggested as an alternative measure in reconnaissance exploration. Aerial gravity anomaly maps of Niger State (north-central Nigeria) have been used to make inference(s) on the geologic information and the nature of crust. Attempt was made to interpret the Bouguer map based on distribution, nature, and characteristics of anomalies and integrate the data with known geologic and tectonic features. The Bouguer anomaly map was superimposed on geographical map of Niger State to determine the geographical locations with gravity/lows and highs and corresponding closures. It reveals that the gravity anomaly map helps delineate major tectonic boundaries and infer the structural trends of the area. It is observed that the gravity high zones are associated with geologic structure-like lineaments in their proximity.

Key words: GGM, *Gravity Anormaly, Reconnaissance Exploration and* Niger State.

INTRODUCTION

Mineral exploration in countries which are blessed with such resources seems to be a major source of income and high pricing activity. Sequel to this, several methods exists for discovering and exploring these scarcely existent resources from within the sub-surface.

Geophysical exploration is a reliable technique for detecting underground mineral resources, it is a branch of geophysics that is concerned with investigations of the interior earth which involves taking measurements that are influenced by the distribution of earth's underground masses (Idowu, 2011). One major role it plays is the provision of information in the location of subsurface mineral deposits before drilling takes place (Idowu 2011). Divided into natural and artificial techniques, the natural –source methods were observed to provide information on sub-surface body to a significantly greater depth and logistically simpler to carry out than the artificial source methods (Kearey and Brooks, 1988, Senti, 1988, Robin, 1995).

Gravity methods are employed in the analysis of geologic structures and evolution of the earth's crust. Though detailed surveys are always expedient, in order to establish the basic scientific framework it is required that preliminary investigation be done by employing a broad and regional approach to achieve most of the objectives. Regional gravity anomaly maps are particularly useful for mapping geographic distribution and configuration of the basement rocks, structural and lithologic provinces, zones of crustal weakness, mass imbalances within the lithosphere, geometrical configuration of sedimentary basins, and the distribution of extrusive and plutonic rocks.
Be that as it may, the process of gravity observation and the requirement for precise value of orthometric height at each gravity measurement location, makes the techniques quite cumbersome and seemingly unrealistic. Recent developments in satellite and physical geodesy however provide some near-measure alternatives which could be used as a first approximation for reconnaissance at regional levels for mineral exploration.

STUDY AREA

Niger State located in the North Western part of Nigeria is the largest state in the country bounded by coordinates 7º 13.2'E, 8º 6.6'N on the SE; 3º 33.42'E, 8º 5.16'N on the SW; 3º 31.86'E, 11º 27.666'N on the NW and 7º 16.926'E, 11º 27.666'N on the NE. With its highly irregular undulation of high lands interlocked amid lowland field-based surveys and geophysical observations across the state becomes a very herculean and rigorous task.

Fig. 1: Administrative Map of Niger State.

Fundamental Concept of Gravitation

Isaac Newton observed that: The force between two attracting bodies is proportional to the individual masses and is inversely proportional to the square of their distance apart mathematically:

$$F \propto \frac{M1M2}{r^2} \quad (1)$$

$$F = G\frac{M1M2}{l^2} \quad (2)$$

According to Groten (2004) the current best value of G is:

$$G = 66.7x10 - 9\ cm^3/g/Sec^2$$

A modern view of gravitation already adorpted by Gauss (1777 – 1855) and Green (1793 – 1841) holds that it is a field having a gravitational potential V, which is mathematically illustrated by Jekili, 2007 as:

$$\nabla V = \mathbf{g}$$

$$\mathbf{V} = \frac{Gm}{l} \quad \mathbf{(3)}$$

For discreet points: $V_p = \boldsymbol{G} \sum_i \frac{m_i}{l_i}$ **(4)**

While for infinitely many points in a closed bounded region with infinitesimally small masses:

$$V_p = \boldsymbol{G} \int_{mass} \frac{dm}{l} \quad \mathbf{(5)}$$

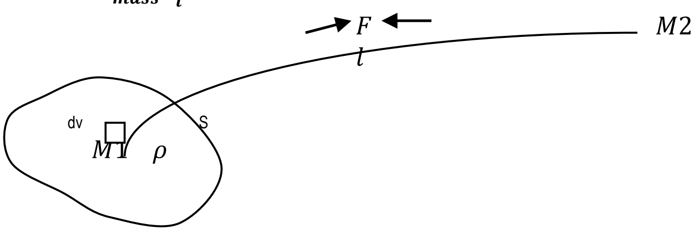

Figure 2: Continuous density distribution

Consider the model shown below as given by Heskanem and Moritz (1990), shows that Gravitational potential is composed of 3-dimensional components.

Where l = the distance between evaluation point with mass M_1 and integration point.

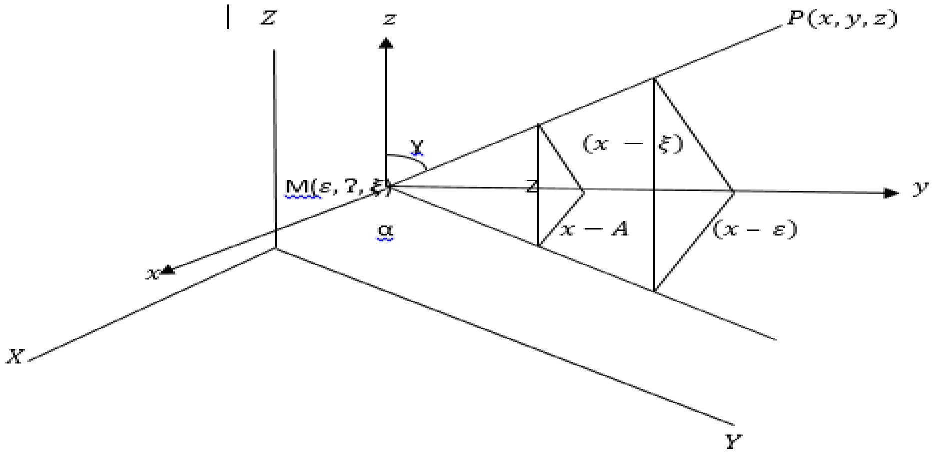

Figure3: Components of Gravitational Force (Heiskanem and Moritz, 1990)

$$X = -G\cos\propto = -\frac{km}{l\hat{}2}.\frac{x-\varepsilon}{l}$$

$$Y = -G\cos\beta = -\frac{km}{l^2}.\frac{y-\eta}{l}$$

$$Z = -G\cos\gamma = -\frac{km}{l^2}.\frac{z-\xi}{l}$$

Where: $l = \sqrt{(x-\varepsilon)^2} + (y-?)^2 + (y-\xi)^2$

The gravitational potential is a harmonic function outside the attracting body, because it involves the reciprocal distance which is a harmonic function between two points M (ε, η, ξ) and P(x;y;z). This means that outside the attracting body, the laplacian operator acting on the potential becomes:

$V_p = \boldsymbol{G} \iiint_{\boldsymbol{Volume}} \frac{\boldsymbol{\rho}}{\boldsymbol{l}}\, \boldsymbol{dv}$ **(6)**

Equation (6) is then further expanded and expressed in spherical harmonics (as we shall see in further sections) to derive further formulations which are utilised in satellite geodesy for determination of geoidal undulation, gravity anormaly and other related parameters.

Basically, the principle behind determination of anomalous densities (masses) within the earth's sub-surface can be mathematically represented as shown below:

Again $F = G\frac{m1m2}{(R)^2}$ -- (1)

$Where\ R = distance\ to\ earth\ centre$

$M1 = mass\ of\ the\ earth$

$M2 = earth\ surface\ body$

$F = mg$ -- (7)

$G\frac{m1m2}{(R)^2} = mg$ --- (8)

$Gm_1m_2 = mgR^2$ --- (9)

$g = \frac{GM1}{R^2} = \frac{GM}{R^2}$ --- (10)

This provides the value of g (gravity) for all points in the earth surface. The relationship between the gravity and the earth's average density (ρ) is given by:

$\rho = mass/volume \quad = \quad \frac{M}{4\pi\frac{R^3}{3}} = \frac{3M}{4\pi R^3}$

From equation (10)

$M = \frac{gR^2}{G}$

$\rho = 3\frac{gR^2}{4\pi R^{3G}}$

$\rho = \frac{3g}{4\pi RG}$ -- (11)

Mathematical approximations reveal the average value of $g = 9.8\, m/s$. This value is not same for all earth surface points. Hence, there are points with excess or deficit mass/density due to inhomogeneity of the earth's density. Gravimetric survey for geophysical applications thus is interested in measuring and interpreting variations in g (as shown by equation 11) in terms of the Earth's subsurface structure thus detecting areas with anomalous gravity distribution.

Gravity Anomalies

Gravity observation measured on the earth surface are not useful in geophysical exploration until they have been reduced to the geoid. The geoid is an equipotential surface of the earth gravity field which best fits in a least square sense, the mean level (Deakin, 1996).

The various corrections applied in the reduction process are given by (Torge, 1980, Telford et al, 1990 and Regnolds, 1998):

1. Instrumental Draft Correction (dgD)
2. Earth tide correction ($dgET$)
3. Eotrors correction (when taken on a moving platform)
4. Free Air correction: 0.3086h meters (dgf)
5. Bouguer correction: 0.1119h meters (dgB)
6. Terrain correction: ($dgTc$)
7. Local latitude correction: 8.108 sin 2θ. (dgL)
8. Isostatic correction (dgl)

Where g_r = corrected gravity

g_{obs} = observed gravity

$g_r = g_{obs} - dg_D \pm dg_{ET} \pm dg_{EC} + dg_F - dg_B + dg_L \pm dgl$ -- (12)

Details of equation 12 above given in (Idowu, 2011).

Thereafter, normal gravity value is computed using (Telford et al, 1990).

$Y = ge\frac{1 + k\sin^2\theta}{\sqrt{1 - e^2\sin^2\theta}}$ −(13a)

Chebychev's approximation of 13a yields

$Y = ge\,(1 + a_2\sin^2\theta + a_4\sin^4\theta + a_6\sin^6\theta + \ldots\ldots)$ -- (13b)

Using Geodetic Reference System (GRS 80) equation 13a and 13b becomes

$Y = g_e(1 + 0.0052790414\,\sin^2\theta + 0.0000232718\,\sin^4\theta)$ ------------------------------------ (13c)

Pitfalls of Terrain –Obtained Gravity Measurements

Apart from the large amount of time required to conduct observations, the difficulty of obtaining orthometric heights for all gravity stations especially in land lock states or countries with non-unified height datum system like Nigeria makes gravity survey near-unrealistic. This stems from the fact that an accurate value of orthometric height (H) for each gravity station is required in computing the Free-air and Bouguer corrections respectively.

The Global Geopotential Models

Accurate knowledge of the gravitational potential of the Earth on a global scale and at a very high resolution is a fundamental prerequisite for various geodetic, geophysics and oceanographic investigations and applications. (Pavlis et al, 2011)With the launch of three dedicated gravity mapping missions: CHAMP (Reigber et al, 1996) launched in July 2000, GRACE (GRACE, 1998) launched in March 2002 and GOCE (ESA, 1999) launched in March 2009 there presently is availability of accurate long wavelength gravitational models.

These advances have brought the – state – of – the – art from the early spherical harmonic model of degree 8 (Zhongolovich, 1952) to the present solution that extends to degree 2190. (EGM 2008 notes).

Therefore combining the GRACE-derived satellite only model (long-wavelength path) with terrain obtained 5 –arc minute equiangular grid of area-mean free air gravity anormalies resulted in the development of a global geopotential model (EGM 2008) which was set at ±15cm global root mean square (RMS) global undulation commission error.
In other words, the EGM 2008 model is an integration of satellite derived gravity data, terrestrial observed with high and ultrahigh resolution models with spherical harmonics representation.

Model derivation for determination of gravity anormaly from satellite
The global model are derived by expansion of the earth external gravitational potential Equ (6)

$$V(r, \theta, \lambda) = \frac{GM1}{r^2}\sum_{n=2}^{m}\left(\frac{a}{r}\right)^n \sum_{m=0}^{n}(Cnm\ Cos\ (m\lambda) + Snm \sin(m\lambda))Pnm\ Cos(\theta) \text{------ (14)}$$

Where v^1 = Gravitational Potential to degree N from geopotential model (EGM 2008)
$a1 = r$
r, θ, λ = geocentric radius, spherical co-latitudes and longitude of the computational point respectively
a_1 = Equatorial scale factor of the geopotential model
Pnm= Fully normalized Legendre function.
Cnm, Snm = Fully normalized Legendre coefficient of geopotential model
Where according to Heiskanem and Moritz (1990).

$$Pnm\ (t) = 2^{-n}\ (1-t^2)^{m/2}\sum_{k=0}^{r}(-1)^k\frac{(2n-2k)!}{k!(n-k)!(n-m-2k)!}t^{n-m-2k} \text{ ------------------- (15)}$$

$$(t^2-1)^n = \sum_{k=0}^{m}(-1)^k\binom{n}{k}t^{2n-2k} = \sum_{k=0}^{n}(-1)^k\ \frac{n!}{k!(n-k)!}\ t^{2n-2k} \text{ -------------------- (16)}$$

$$Pnm = \frac{1}{2^n}\ (1-t^2)^{\frac{m}{2}}\ \sum_{k=0}^{n}(-1)^k\ \frac{1}{k!(n-k)!}\ \frac{d^{n+m}}{dt^{n+m}}(t^{2n-2k}) \text{ -------------------- (17)}$$

Gravity anomaly is computed by similar expansions using the formulation below given by Amos et al, 2003:

$$\Delta g_{ggm} = \frac{GM1}{R^2}\sum_{n=2}^{m}\left(\left(\frac{a}{r}\right)^n(n-1)\right)\ \sum_{m=0}^{n}(Cnm\ Cos\ (m\lambda) + Snm\sin(m\lambda))Pnm\ (Cos\theta) \text{ (18)}$$

MATERIALS AND METHODS

A total of 6901 points at 2.5' X 2.5' grids of the earth's free air and bouguer anormaly from EGM2008 were downloaded from the EGM 2008 website Gravity anormaly file. These values were downloaded alongside their locations and used in analyzing the geologic structure of Niger state as a reconnaissance to determine possible existence of mineral resources within the study area.The linear equivalent of the grid spacing is 9.2km by 9.2km which is still a fairly reasonable estimate for state wide reconnaissance exploration. The data was downloaded from EGM 2008 website (section for gravity anomaly).

ANALYSIS AND DISCUSSION OF RESULTS

The result of this gravity investigation is presented in the three forms; the Bouguer anomaly map, the free air anomaly map and the three dimensional model of the Bouguer anomaly. Contour interval is 5 mGal.

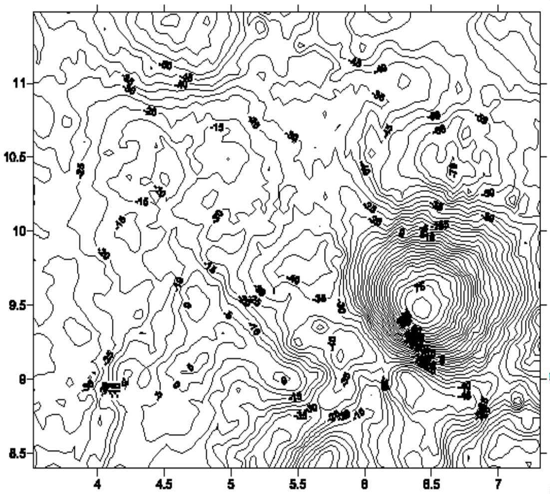

Fig. 4a: Regional Bouguer anomaly map of Niger State.

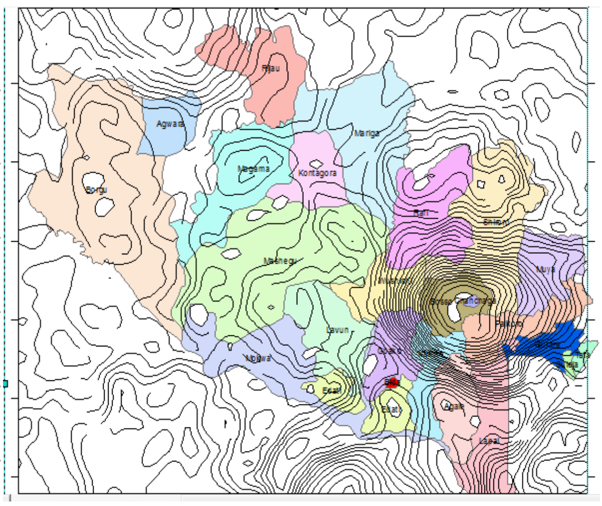

Fig. 4b: Regional Bouguer anomaly map of Niger State superimposed on the Niger State map to enhance ease of spatial interpretation.

This map presents many closures around gravity 'highs' and 'lows'. The iso-anomaly lines follow a NE-SW trend and are in accordance with the general geologic Nigeria.

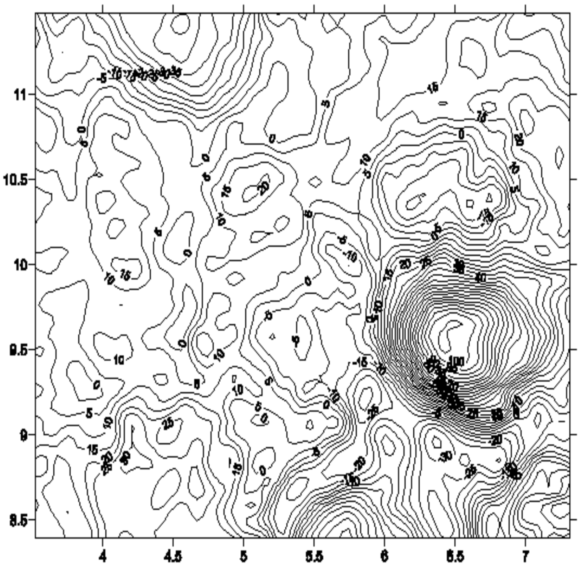

Fig 5a: Free air anomaly map of Niger State,

(North-Central Nigeria associated with many closures around gravity 'highs' and 'lows')

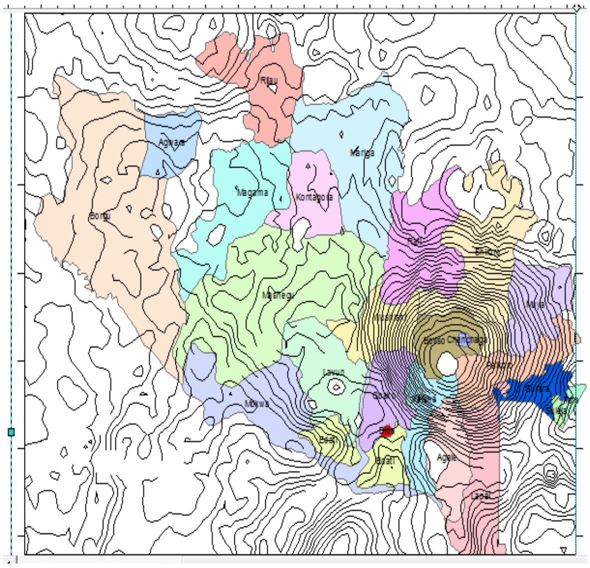

Fig 5b: Free air anomaly map of Niger State superimposed on Niger State map for ease of spatial interpretation.

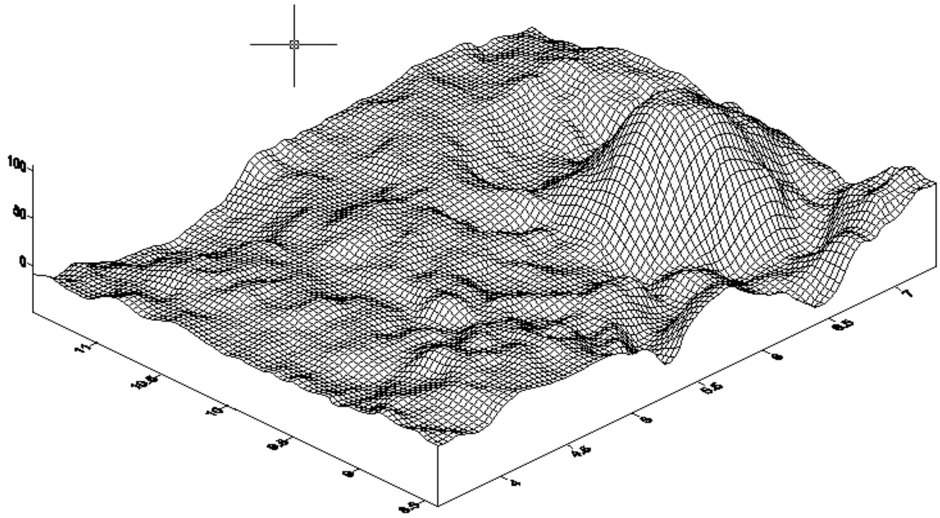

Fig 6: A three dimensional model of Bouguer anomaly map of Niger State, North-Central Nigeria.

The interpretation of the gravity data from an aerial gravity survey over the Precambrian 'Older Granite intrusion of Niger State region (part of North-central Nigeria) revealed an eye-catching residual gravity as low as -60mGal around Rafi and tend to 0mGal around Shiroro. The isoanomaly map in the map generally correspond to a NE-SW trending regional anomaly of the area. The Bouguer anomaly contour also shows an enclosure with a relatively gravity high (as high as 60 to 75 mgal around Bosso and Chanchaga). It is reasonably inferred from a view of 3-Dimensional model of the residual gravity (Fig 5) that the granite is slightly dipping and that the base of the granite suite is, in general, placed at a great depth. The general structural arrangement of the modelled bodies and pattern of the gravity anomalies suggest that the granitic suite is a batholithic body formed by Precambrian magmatic emplacement having few plugs as conduits for the upward migration of magma due to buoyancy.

From the model it can also be inferred that there is a sharp contact between the granite suite and the adjoining Kushaka and Birnin Gwari Formations, and that the maximum thickness of these formations ranges from 10.5 and 5 km respectively. The close affiliation of the schist formations with the batholith, and the inferred sharp contact between them, is a possible indication that the palaeo-geologic margins of the schist formations probably were zones of weakness through which the magma migrated. From the Bouguer anomaly contour it can be inferred that the older granites suites has wide compositional variation which is apparently reflected by gravity lows and highs within the rock mass. This is confirmed by their proven alternating light and dark color.

The result of the analysis is authenticated by the present on-going minning activities taking place along the Minna – Bida Road. Therefore, based on this research, it provides a pointer to the Niger State government that there is a possibility of minerals within Gurara, Suleja, Lapai, Edati, Gbako, Agaie, Bosso, Chanchaga and Paikoro Local Government areas.

CONCLUSION

Global Geo-potential Models have proven to be a useful tool for reconnaissance exploration in large scale area coverage. As the geopotential solutions continues to get refined over the years in terms of data availability (Satellite derived for the long wavelength path and terrain observed for the short and intermediate wavelength path) as well as degree and order of solution of the associated fully normalized Legendre polynomials, much more refined results would be expected in the near future.

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