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Models for Gravity Data Interpretation

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Abstract Gravity anomaly across geological structures (faults, ore-bodies, and syncline and anticline structures) represented as models of spheres and cylinders have been analysed to obtain geometric information about them. The sphere model which has an anomaly peak at the centre of the structure gives an anomalous mass and depth-to-centre of anomaly relationship of; Δm equal to $\Delta g_{max}z^2/G$ and z equal to 1.305 of half the anomalous width. Similarly for the cylindrical model, the gravity anomaly peaks at the center of the model such that the anomalous mass, Δm, is equal to $\Delta g_{max}z/G$ and the depth-to-center of anomaly, z, equal half the anomaly width. The application of these models on airborne gravity data over parts of Niger delta using Oasis Montag software has been demonstrated with results within the model theory.

Keywords Gravity Anomaly, Models, Sphere, Cylinder, Depth to Centre of Anomaly, anomalous Mass, Niger Delta

Introduction

Scientific models are generated physical and conceptual/mathematical representation of real phenomena that is difficult to observe directly [1]. It is used to explain or predict the behaviour of real objects and is used in variety of discipline including exploratory geophysics that aims at obtaining subsurface information from the crustal earth.

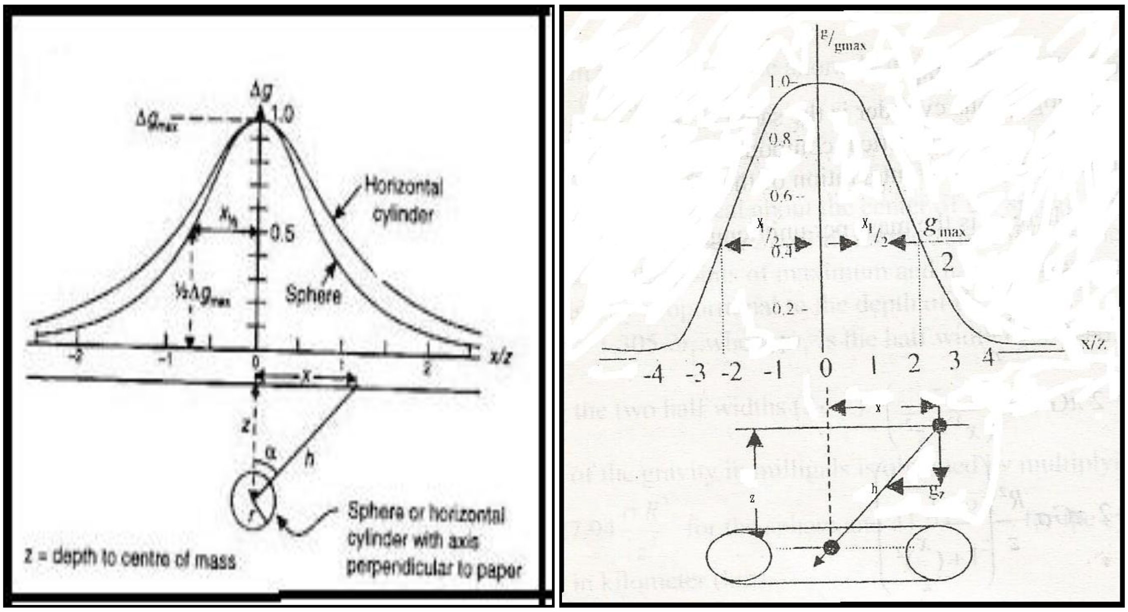
Geophysical exploration targets include; location of structures favourable for mineral entrapment, location of archaeological artefacts and ordinances, engineering site investigation; determination of depths of Formations, determination of nature and size of causative anomalies and more [2-3]. The gravity method can be applied to achieve all these. It is a non-destructive remote sensing method that measures the minute variations of the earth's natural gravitational field across a profile, based on the differences in density of the underlying subsurface rocks. Several authors have used this method for different interpretations. Examples; determination of soil layer thickness and depth to basement rocks [4-5]; engineering and environmental studies [6]; determination of changing water table levels [7-8] and location of unexploded ordinances and archaeogeophysics [9].

The method has good depth penetration when compared to some of the other methods. In addition, lateral boundaries of subsurface features can easily be obtained especially through the measurement of the derivatives of the gravitational field [10]. The major problem is the ambiguity in the interpretation of anomalies [10]. A given gravity anomaly can be caused by numerous source bodies. To obtain reliable results geological information of the area is required in addition to use of appropriate models to depict the observed structures. These combinations give better and plausible information of the subsurface structures [11].

The purpose of this paper therefore is to review the theoretical bases of the sphere and cylinder models and also apply them on aero gravity data from parts southern Niger delta of Nigeria to obtain depth and size information.

Theoretical Model

Practically the anomalous Bouguer gravity across most structures like ore-body, a thin sheet-like structure or a fault appears as a sphere or a cylinder as shown in Fig.1 (a) and (b).



(a) (b)

Figure 1: Gravity Anomaly over (a) A Spherical Mass and a Horizontal Cylindrical Subsurface Mass with Axis Perpendicular to the Paper; (b) A Horizontal Cylinder with Axis in Parallel to Paper [12].

The problem is to obtain geometric information about the structures from the observed gravity value over them. We adopt the following nomenclature for the various parameters:

Δg_s = Bouguer gravity anomaly due to the sphere (mgals)

Δg_c = Bouguer gravity anomaly due to the cylinder (mgals)

Δg_{max} = maximum Bouguer gravity anomaly over the sphere or cylinder (mgals)

$_{1/2}\Delta g_{max}$ = half the maximum Bouguer gravity anomaly across the sphere or cylinder (mgals)

x = profile distance (km)

z = depth to centre of the anomalous mass (km)

h = distance from centre of the anomaly to any point on the profile x (km)

r = radius of the anomaly (km)

$x_{½}$ = half width of the anomaly (km)

Δm = mass of the anomaly (kg)

Δρ = density contrast (kg/m^3)

α = angle in degrees

a = depth from surface to the top of the anomaly for the sphere (km)

Gravity acts downwards and therefore for the sphere model has a value of

$$\Delta g_s = \frac{G\Delta m}{h^2}\cos\alpha. \quad (1)$$

Using mass of a sphere and substituting $k = \frac{4}{3}\pi G$

$$\Delta g_s = k\Delta\rho r^3 \frac{z}{(x^2+z^2)^{3/2}} \quad . \quad (2)$$

And $$\Delta g_{max} = \frac{k\Delta\rho r^3}{z^2} \quad (3)$$

At any other point

$$\Delta g_s = \Delta g_{max} \frac{z^3}{(x^2+z^2)^{3/2}} = \frac{\Delta g_{max}}{\{(\frac{x}{z})^2+1\}^{3/2}} \quad (4)$$

As in [10]

$$_{1/2}\Delta g_{max} = \frac{\Delta g_{max}}{\{(\frac{x_{1/2}}{z})^2+1^2\}^{3/2}} \quad (5)$$

And

$$z = \frac{x_{1/2}}{\sqrt{2^{2/3}-1}} = 1.305 x_{1/2} \quad (6)$$

Hence the mass of the spherical structure, Δm, and depth from surface to the top of the anomaly, a, are deduced from;

$$\Delta m = \frac{\Delta g_{max} z^2}{G} \quad \text{and } a = z - r. \quad (7)$$

For the homogeneous horizontal cylinder (in Figure 2) approximated as a horizontal line element of infinite length [9] the vertical gravity anomaly along the profile is

$$\Delta g_c = 2G\Delta mz/h^2. \quad (8)$$

Using the mass of a cylinder

$$\Delta g_c = 2\pi G\Delta\rho \frac{r^2}{z}[\frac{1}{1+x^2/z^2}] \quad (9)$$

The maximum gravity anomaly is

$$\Delta g_{cmax} = 2\pi G\Delta\rho \frac{r^2}{z} \quad (10)$$

and

$$\Delta g_c = \Delta g_{cmax} \frac{1}{1+x^2/z^2} \quad (11)$$

By [10]

$$_{1/2}\Delta g_{cmax} = \frac{\Delta g_{c\,max}}{1+x_{1/2}^2/z^2} \quad (12)$$

and

$$z = x_{1/2}. \quad (13)$$

The depth of the structure from the surface is

$$x_{1/2} - r \quad (14)$$

and the anomalous mass,

$$\Delta m = \frac{\Delta g_{c\,max}}{2G} z \quad (15)$$

Application and Results

Equations 6, 7, 13, 14 and 15 are the basis of interpretation of gravity data using control models of spheres and cylinders. For best results considering the enormous field data involved the modelling are carried out by computer programs that generate hypothetic gravity anomalies and their properties that are compared with the observed residual gravity anomaly to obtain a best fit [13-14]. The model properties producing the best fit between the synthetic and observed anomaly is taken. The comparison can be by either forward or inverse modelling [13]. Both apply the principles of least square methods hence the decision on how to adjust the model is iterative. Various algorithms have been written to perform these iteration processes [15-18]. The processes involve calculation of density distribution given the geometry of the source, calculation of source geometry given the distribution of density or calculation of depth to source or depth to bottom of source [13].

Figures 2 and 3 show results from control models of a sphere and a cylinder used to obtain depth to source of observed anomalous structures from airborne gravity data over parts of Niger delta using Oasis Montaj^{TM} software. Having identified the region(s) of interest based on the contour base map signature and trend, a control model of sphere and cylinder was applied to them. By repeated adjustment of the modelling parameters a best fit was obtained for the theoretical and field data curves (red and blue line respectively).

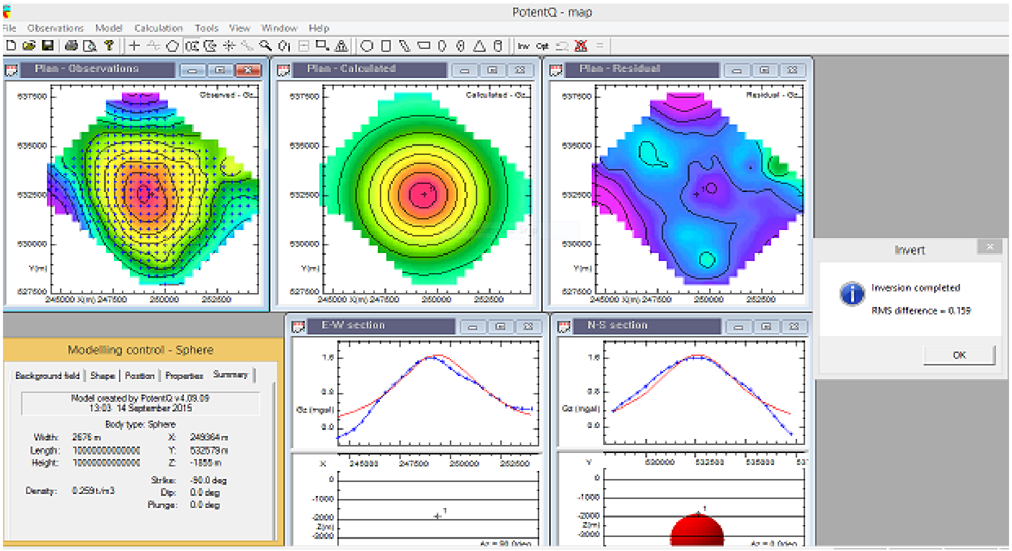


Figure 2: Computer Modelling Results from Potent-3D Modelling Software Using Control of a Sphere Model [4].

The modelling results reveal an anomalous mass of half width 1,400 m, corresponding to a depth of 1,855m for the spherical controlled model (Fig.2) while in Fig. 3 a basement structure at a depth of 11,218m was obtained for a cylinder controlled model.

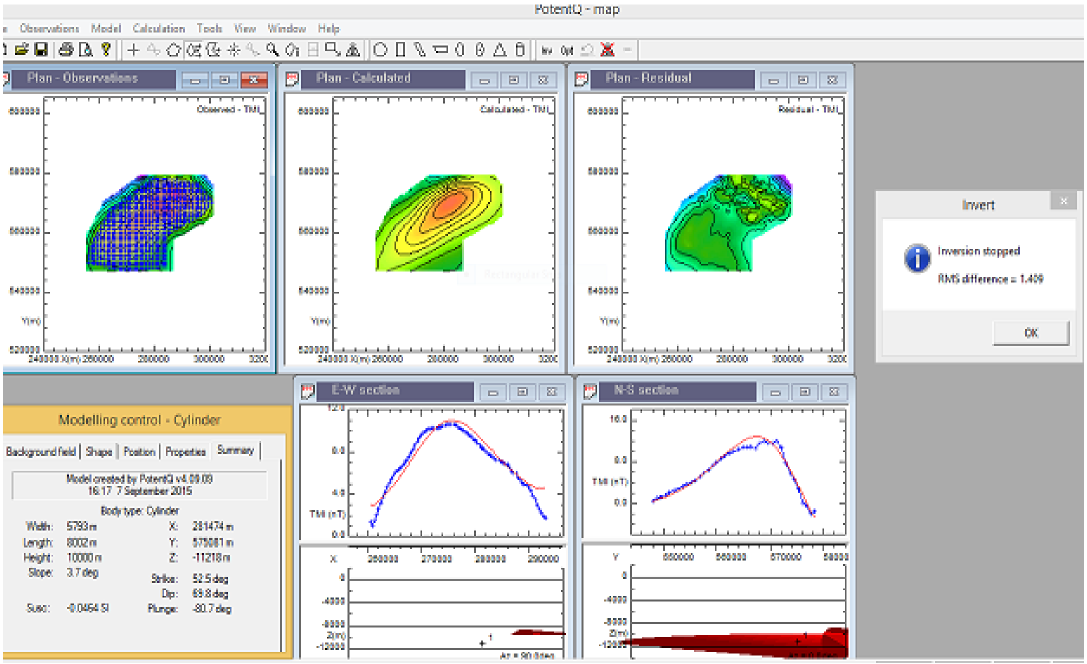


Figure 3: Computer Modelling Results from Potent-3D Modelling Software Using Control of a Cylinder Model [4].

Discussions

The model results from field data reveal sediments at depths of 1,855 m. This by theory corresponds to 1.305 of half the anomaly width for the spherical model. Figure 3 reveals a basement depth of 11,218 m. This also corresponds to half the anomaly width for the cylindrical model. In addition to this depth information, other geometric information that include the dip, strike, slope and plunge of the formations are also derived from the modelling. The depth results obtained are in agreement with results obtained in these parts of the Niger Delta from the previous works of [19-20].

Conclusion

As shown in this paper, a spherical and cylindrical model can be used to obtain depth and size information about structures from the Bouguer gravity data profile over them. This gravity profile over such structures peaks at their center and is related to the depth of occurrence and the width of the structures. These relations can be used to estimate the depth and size of such structures either manually or by use of computer aided forward and inverse modelling. These models provide a basis for geological interpretation of subsurface structures.

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