INTERPRETATION OF GRAVITY ANOMALIES DUE TO SIMPLE GEOMETRICAL SHAPES USING MASTER CURVES

BY

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CERTIFICATION

This thesis has been read and approved as meeting the requirements of the Physics Program ATBU, Bauchi.

By

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Supervisor

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Program Coordinator

3. ______________________________ Date ________

Dean, School of Science and Science Education

ACKNOWLEDGEMENT

When I started this study, I had one wish - to use data of a gravity survey conducted in this country. The University library had none. Visits to the exploration unit of NNPC, Maiduguri and the Geological Surveys of Nigeria, Kaduna did not yield good result. In Maiduguri, only data on seismic and magnetic prospecting were available. While in Kaduna, data available on gravity prospecting have not been published and so could not be released to me. I therefore started the study without the desired data.

I must acknowledge with thanks the contribution of Dr. E.F.C. Dike of the Geology Program ATBU. His contribution in the form of discussion and source materials enabled me to make an inroad into the study. I found his book on Applied Geophysics for Engineers and Geologists (by C.H. Griffiths & R.F. King) quite useful. My acknowledgement is also due to two fellow students Mr. Timothy Tunde of the Maths Program and Mr. Samuel Ben Mbang of the Physics Program who helped out in the computer centre during the formulation of the computer program to plot the curves.

I wish to thank Mr. Sani Ali who proposed the topic and patiently supervised this study. My sincere appreciation go to the Program Coordinator, Professor E.D. Mshelia who suggested I work on this topic.

DEDICATION

This thesis is dedicated to my wife, MRS. GRACE DYAJI and our first and newly born baby, Master DONALD WYUK DYAJI, who was delivered to us on 23rd July, 1991 (the eve of my final examination in this University) at the PACOA Hospital and Maternity, Jos.

ABSTRACT

The project sets out to explore the possibility of interpreting gravity anomalies, especially those due to simple geometrical shapes using Master Curves Matching.

The choice of parameters such as density contrast intervals, depth of burial intervals, anomalous body size intervals and lateral extent of observation intervals that are to be used in plotting the Master Curves are discussed. Also discussed are the scales of plotting the Master Curves as this has to be the same with that of the field data.

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CHAPTER ONE

INTRODUCTION

1.1 GENERAL

Before discussing the subject of curve matching, it is pertinent to define the terms that relate to it. The first of these terms is GRAVITY. Gravity is defined by the Concise Science Dictionary as the phenomenon associated with gravitational force acting on any object that has mass and is situated within the earth's gravitational field. Within this gravitational field, the object will experience a force of attraction towards the centre of the earth. Gravity becomes less with increasing distance from the centre of the earth. It also varies according to the mass of the rocks below the surface. One peculiar aspect of gravity is that it is part of the framework in which our lives are set. Yet, we have a poor understanding of it. It is part of the framework of our lives because it is the force of attraction of gravity that keeps the earth in its course around the sun. The force is therefore experienced by all of us throughout our existence on earth. We have a poor understanding of it partly because it is a rather mysterious and exceedingly weak force; especially when compared with other forms of forces - electrical, magnetic, etc - which are more striking.

In gravity survey, what is of interest is the variations in gravity produced by the subsurface structure and not the absolute value of gravity. These variations are known as ANOMALIES and are measured by gravity meters which respond to them. Gravity meters are extremely sensitive instruments with some having a sensitivity of about 0.01 mgal (Grant & West, 1965). Variation in gravity due to geological causes fall well within their range of detectability. During gravity survey, values of these small variations recorded over the survey area are known as GRAVITY DATA. These data contain several effects that are unrelated to geology and therefore irrelevant to geological interpretation. They would therefore have to be removed before geo-physical interpretation can be seriously attempted. The process of removing these irrelevant effects is known as DATA REDUCTION. Most of the formulae for interpreting gravity shapes are difficult to apply because they contain many unknowns. It is always a tedious task to plot theoretical profiles from expressions with many unknowns. Therefore, MASTER CURVES which are a collection of characteristic curves are employed to interprete the anomalies. The interpretation of gravity anomalies by means of master curves is the area in which this thesis seeks to address.

The units employed for measuring gravitational fieldstrength is the 'gal', a contraction of Galileo.

Dimensionally, the gal is equivalent to 1 cm s^{-2}. The gravitational field strength of the earth has a universal average value of about 980 gals and the total range of variation of gravity from the equator to the poles is about 5 gals or ± 0.5 % of gravity (Grant & West, 1965).

1.2 REVIEW OF LITERATURE

Correct interpretation of gravity anomaly is obtained through proper acquisition, reduction, and mapping of gravity data. This is achieved by precise instrumentation, skillful planning and execution of the field measurements and expertise in the correction of data obtained in the field. Gravity maps have ressemblance to structural maps therefore, they should not be identified as being indicative of structure. It should be noted that the contours depict a potential field and not a subsurface structure. Also, the interpretation is not a clear cut process. It requires a great deal of intuition both physical and geological. To achieve the desired result, detailed data analysis must be done.

A significant parameter in gravity exploration is the local variation in density. The terrain and Bouguer corrections made in the reduction of gravity data require a knowledge of the densities of rocks near the surface. Since it is not possible to measure density in situ, sufficient knowledge of geology is required if the gravity survey is to be properly conducted. Several procedures have been employed for estimating density for gravity measurements. Some of these procedures are direct while others are indirect.

The direct procedure determines the density directly. It involves collecting a representative samples of rocks from surface outcrops, mines, or well cores and cuttings. These samples are then measured in the laboratory using a Pyknometer, or a Schwarz or Jolly balance. The indirect procedure involves the use of density logger, borehole gravimeters, the Parasin's method and the Nettleton's method. Nettleton's method is a reasonably satisfactory estimate of the near surface density. It is obtained from representative gravity profile over the survey area. The field readings are reduced to produce Bouguer gravity profile assuming several values of density for the Bouguer and terrain correction. The smoothest of these profiles - the one that least reflects the topography - is assumed to have the correct density. This method is more satisfactory for density determination than the direct method. This is because it has the advantage of averaging the effect of density variations more accurately than can be done from surface samples. Even so, it gives information on density only when the near surface lithology is homogeneous.

In most geological environments, densities of 1.98 - 2.30 g cm^{-3} have been recorded for sedimentary rocks, 2.24 - 3.16 g cm^{-3} for igneous rocks, 3.6 - 3.37 g cm^{-3} for metamorphic rocks and 0.125 - 4.57 g cm^{-3} for non-metallic minerals and other miscellaneous materials. In this study, the discussion have been restricted to basement areas where spherical and cylinderical anomalies do occur.

There are two basic approaches to gravity interpretation. One is to determine a plausible mass distribution directly from gravity data. This approach looks difficult to achieve. This is because it is impossible to derive a valid subsurface picture from mass distribution especially if the source were 3-dimensional in form. The second approach is to assume various models conforming to all known constraints and to match gravity predicted for each model with the gravity field that has actually been observed. The model that gives the best fit is then considered to be the most probable one even though it cannot provide a definite subsurface picture. But different subsurface mass distributions can give identical gravity pictures on the surface. Therefore, this approach suffers from inherent potential ambiguities. The approach is seldom useful unless there is independent geological or geophysical information that will keep the ambiguity within manageable limits. This information can be obtained from preliminary survey of the lithology of the area, accurate estimation of the rock densities and a planned and well executed method of data acquisition and reduction.

1.3 AIM AND SCOPE

This thesis sets out to propose a method known as Master Curves matching for the interpretation of gravity anomalies especially those due to simple geometrical shapes. The theory of gravitational force and acceleration with regards to buried masses and that of the operation of gravimeters are discussed. Also discussed are data collection, processes in data reduction, separation of residual effects from the regional effects, the choice of parameters to be used in plotting the curves and the scales of plotting the curves as this has to be the same with that of the field data. Two geometrical shapes are chosen as case study. These are the sphere and the horizontal cylinder. Theoretical values were assumed for these shapes and their profiles known as master curves plotted by use of the computer. Principal profile of a field survey was then plotted and matched with the master curves. The result is discussed as the concluding part of the study.

CHAPTER TWO

PRINCIPLES, FIELD MEASUREMENTS AND REDUCTIONS

2.1 GENERAL

The quantity actually observed in gravity measurements is the variation of the gravitational attraction from one point to another, and field instruments are designed to measure these variations rather than the actual magnitude of gravity. The development of the instruments and techniques requires a combination of engineering skill and operational efficiency. The instruments are designed for ruggedness so that they can operate reliably under difficult field conditions. The procedure have been designed for maximizing the speed with which traverses can be covered.

The variations in measurements depend upon the lateral changes in the density of earth materials in the vicinity of the measuring point. Many types of rocks have characteristics ranges of density which may differ from those of other types that are laterally adjacent. Thus, anomaly is often related to a buried geological feature, like salt dome, intrusion, oil well which have limited horizontal extent.

The object of correction is to obtain a picture of the variations. The variations depend on lateral departures from constancy in the densities of the subsurface structures below the datum plane. The most likely source of error lies in the Bouguer and terrain corrections especially where the lithology of the nearsurface formation is not well known.

In this chapter, the principles behind gravity prospecting and operation of instruments are considered. A look is also taken at field measurements, the method of data reduction and the separation of Residual from Regional effects.

2.2 GRAVITATIONAL FORCE AND ACCELERATION

Gravity method involves measuring a field of force in the earth that is neither generated by the observer nor influenced by anything he does. The basis of this method is Newton's Law of gravitation. The law expresses the force of mutual attraction between two bodies in terms of their masses say m_1, m_2 and their separation (r). It states that every particle of matter exerts a force of attraction on every other particle and this force is proportional to the product of the masses (m_1, m_2) and inversely proportional to the square of their distance of separation (r). Mathematically, it is stated as:

$$F = \frac{G\, m_1\, m_2}{r^2} \quad \ldots. \quad 2.1$$

where, F = Force between the particles

r = their separation

G = Universal gravitational constant

$= 6.664 \times 10^{-11}\ Nm^2\ kg^{-2}$

Acceleration (a) is the force acting per unit mass and according to Newton's second law of motion:

$$F = ma \qquad \ldots\ldots \qquad 2.2$$

where F = force producing an acceleration on a body of mass (m)

Combining equations 2.1 and 2.2, we have:

$$\frac{G\, m_1\, m_2}{r^2} = ma \ , \ m = m_1$$

It follows that:

$$g = \frac{G\, m_2}{r^2} \qquad \ldots\ldots \qquad 2.3, \quad a = g$$

where g = gravitational acceleration.

The gravitational acceleration acts more or less normally to the surface of the earth. However, the attraction due to the buried mass act along a line joining the centre of the mass to the point of measurement as shown in figure 2.1.

Take the element dm of the buried mass.

It follows from equation 2.3 that

$$g = \frac{G\, dm}{r^2}$$

Since gravity meters measure only the vertical component (z) of acceleration, then at any point on the surface:

DETERMINING GRAVITATIONAL ACCELERATION OF IRREGULAR SHAPE.

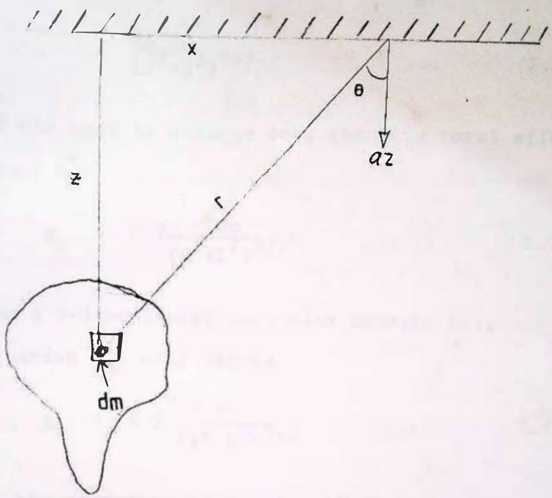

FIG. 2·1

$$\frac{z}{r} = \cos\theta$$

$$\Longrightarrow \frac{z}{r} dm = dm \cos\theta$$

$$r = (x^2 + z^2)^{\frac{1}{2}}$$

$$r^3 = (x^2 + z^2)^{\frac{3}{2}}$$

$$g_z = \frac{G\, dm \cos\theta}{r^2}$$

$$= \frac{Gz\, dm}{r^3}, \quad \cos\theta = \frac{z}{r}$$

$$= \frac{GZ\, dm}{(x^2+Z^2)^{3/2}} \quad \ldots. \quad 2.4$$

If the body is a large one, then its total effect would be:

$$g_z = G \int \frac{Zdm}{(x^2+Z^2)^{3/2}} \quad \ldots. \quad 2.5$$

For a 3-dimensional body with density (ρ), equation 2.5 will become.

$$g_z = G \int^{v} \frac{\rho Z\, dv}{(x^2+Z^2)^{3/2}} \quad \ldots. \quad 2.6$$

If the geometry and density of the body is known, its gravitational acceleration can be computed from equation 2.6. The Sphere and the horizontal cylinder are treated from equation 2.6 in the next chapter.

2.3 THEORY OF INSTRUMENTS

The theory behind the technique for making relative measurement of gravity is that of a beam carrying a mass at one end and pivoted at the other. It is maintained horizontally against the attraction of gravity by the tension of a spring as shown in figure 2.2. If gravity increases, the beam will deflect downwards until a new equilibrium position is reached. This will cause an increase in the spring length and hence of the restoring force.

In practice, rather than measure the actual deflection, some measurable force is employed to return the beam to its null position when deflected by a change in gravity. This is done by attaching the upper end of the main spring to a micrometer head. The displacement needed to restore the beam to its null position is measured in terms of the micrometer reading. An example of this type of arrangement is the Worden gravimeter, one of the most modern gravimeters in use today. In the Worden gravimeter, the main spring is coupled at its upper end to two subsidiary springs of different strength. Each is attached to a micrometer. One of the micrometers (the small dial) provides a scale which is often adjusted to be of the order of 100 mgal. in range and can be read to 0.01 mgal. The other micrometer has a range of several thousand mgals but can only be read with an accuracy of about 0.2 mgals. It is used for the measurement of large gravity differences and as a coarse adjustment to bring the small dial on scale when the gravimeter is moved to a different Latitude (Griffiths & King, 1965).

OPERATION OF GRAVIMETER

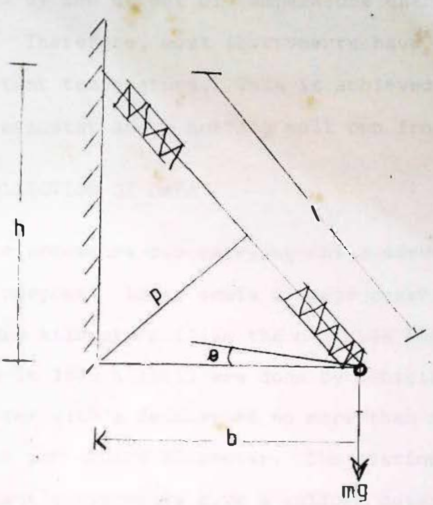

FIG. 2·2

b = length of beam

l = extended length of spring.

lo = length of spring when tension is zero.

h = height of the point of attachment of spring above pivot,

θ = angle the beam makes with the horizontal.

k = spring constant.

p = length of the perpendicular from the pivot to the spring.

T = tension in the spring.

Large deflections of the gravimeter would be produced by the effect of temperature change on the spring. Therefore, most instruments have to be kept at constant temperature. This is achieved by means of a thermostat and a heating coil run from a battery.

2.4 COLLECTION OF DATA

The procedure for carrying out a survey depends on its purpose. Large scale surveys covering hundreds of square kilometers (like the one over the Benue trough in 1960 & 1961) are done by vehicle or helicopter with a density of no more than a few stations per square kilometer. The stations are conveniently placed to give a uniform cover. Since station positions and heights have to be known accurately, a gravity survey requires some amount of preliminary survey. In settled areas, much of this would have been done already. In remote areas, the map has to be made before the survey can be conveniently carried out. Some geological recce and the collection of unweathered rock samples should be done so that data on rock density can be made available for the elevation and terrain correction.

In carrying out the survey, a reference point should first be established. After that, a number of widely separated base stations are then established. The base stations should be measured in a series of closed triangular or polygonal traverses each side of which should be measured at least twice. Secondary stations are then put in, starting and finishing a set (say 10 stations) at a previously measured base station so that a drift correction can be made. The data collected are then corrected for Bouguer anomaly. An isogal or contours map of the area is prepared, showing lines of equal Bouguer Anomaly. If data reduction have been performed correctly, the map should show only gravity changes due to subsurface geological structures. If the survey only covers a small area like it is being proposed in this thesis, it may not be necessary to measure base stations. An occasional return to one reference point to check for drift is all that is required.

2.5 DATA REDUCTION

Gravity data contain many effects that are unrelated to geology and therefore irrelevant to geological interpretation. The process of removing these irrelevant effects is known as Data Reduction. The magnitude of gravity on the earth's surface depends on the latitude, elevation, topography of the surrounding terrain, earth's tides and variations in density in the subsurface. Variation in the density of the subsurface is the only factor of significance in gravity exploration. Before any meaningful geophysical interpretation can be attempted, the effects of theother factors including drift in gravimeters will have to be removed. We shall therefore consider the processes involved in removing these effects.

2.6 DRIFT CORRECTION

The reading of a gravimeter at any point depends on where the scale is set and bears no relation to the absolute value of gravity at that point. If the gravimeter is carried round for a few hours, or even left on spot untouched and then read again at the same place, a change in reading will be noticed. This is mainly due to the very slow creep of the spring, temperature and pressure changes. This effect is known as DRIFT and has to be corrected for. The correction is often made by commencing and finishing a set of observations at the same point having noted the time at which all measurements were taken. The drift which is usually positive is the difference between the last and first observations. It is found to be proportional to time. That means, the amount of drift to be subtracted from the observations taken over the period would be known. The drift rate may vary a little from day to day and during the course of a single day which is why a return to base every few hours is necessary.

An example where drift correction has been done in Nigeria and published is during the survey of the Benue Trough. The survey was conducted in the periods June-July, 1960 and February-March 1961. The gravity meter used was the World-wide gravimeter No. 36 which was on loan from Overseas Geological Surveys. The instrument was carried by landrover over roads and tracks and stations were established at 5 kilometre intervals. Prior to the field work, the instrument drift was observed over a period of six days at the Geological Survey Headquarters in Kaduna. The mean drift rate was found to be +0.1 mgal in 6 hours (Cratchley & Jones, 1965).

2.7 LATITUDE CORRECTION

The formula adopted by the International Association of Geodesy in 1967, gives the value of gravity (g) at any point on the surface of the earth as:

$$g = g_o (1 + \alpha \sin^2 \phi + \beta \sin^2 2\phi)$$

where α = constant

= 0.005302

β = constant

= -0.0000058.

ϕ = Latitude

g_o = 978.031 gals.

= Equatorial gravity

This equation can be used for calculating the variation of gravity with latitude.

In prospecting, we are concerned only with gravity differences. The correction may be applied as a difference from an arbitrarily chosen base. As the rate of change of gravity with latitude is fairly constant over a small range (for limited survey), a constant factor can be used. In mid-latitudes, this works out to be about 1.0 mgal per kilometer (Griffith & King, 1965). If a higher accuracy of measurement is aimed at, then the relative station position must be known with a corresponding higher accuracy. Nigeria landmass covers approximately from latitude 4° in the south to 12° in thenorth. Calculating gravity for points along latitude 8° we have g = 978,13188 gals while for 12°, g = 978.25611 gals. Thus the gravity variation over Nigeria is approx 0.124 mgal. One would recall that gravity at the equator is 978.031 gals.

2.8 ELEVATION CORRECTION

Since the earth's mass is concentrated at its centre, the value of gravity at sea leavel assuming the earth to be a sphere is:

$$g_o = \frac{GM}{R^2}$$

where M = mass of earth.

R = Its radius.

The value of gravity at a height h above sea level is given by:

$$g = \frac{GM}{(R+h)^2}$$

$$= \frac{GM}{R^2}(1-\frac{2h}{R} + \ldots\ldots)$$

Using the 1st two terms of the binominal expansion we have:

$$g = g_o\left(1 - \frac{2h}{R}\right) = g_o - \frac{2g_o h}{R}$$

$$\text{or } g-g_o = -\frac{2g_o h}{R} \qquad \ldots\ldots \quad 2.12.$$

Equation 2.12 is independent of whether or not there is any rock material between the sea level datum and the station at elevation h. It is therefore referred to for this reason as the free-air effect. The portion of the elevation correction which compensates for it is referred to as the 'Free-air Correction'. If h is positive, that is the elevation is above sea level, the effect is to lower the earth's attraction. To compensate for this lowering, the free-air correction must be added. If the station is located on an extended horizontal surface having an elevation h above sea level, one must also correct for the attraction of the slab of material having a bottom surface at sea level and a top surface at the elevation of the station. If the material in this slab has a density (ρ), the attraction will be.

$$g_z = 2\Pi r\rho L \qquad .... 2.13.$$

Equation 2.13 is the equation for the gravitational attraction of a slab. If values of r, L and ρ are substituted in the equation, the result is known as the 'Bouguer Correction'. This correction is subtracted from the observed reading. It is dependent on the ρ assumed for that material in the slab between the observed station and the datum. The elevation correction therefore, is the sum of the Free-air and Bouguer corrections. For station above the datum plane, whether at sea level or at some elevation, the correction is added. For station below the datum plane, it is subtracted. It is usual to combine the Free-air and Bouguer corrections into a single elevation correction of the form:

$$g_o = g_h + (0.09406 - 0.01276\ \rho)h \text{ mgal.}$$

where g_o = gravity corrected to sea level.

g_h = observed gravity at height h.

A problem in making the Bouguer correction is to know what density to use. Therefore, for a survey of any size, a geological map is necessary.

2.9 TERRAIN CORRECTION

Terrain correction allows for surface irregularities in the vicinity of the station. That is hills rising above the gravity station and valleys below it. These topographic undulations affect gravity measurement in the same sense, reducing the readings because of upward attraction (hills) or lack of downward attraction (valleys). Hence, the terrain correction is always added to the station reading.

The terrain corrections cannot be made easily unless the topography is sufficiently regular that it can be approximated to a simple geometrical shape. For example, an infinitely long mountain range of triangular cross-section. In general, the correction is made by computing the attraction of a small raised area after making assumptions about its density and obtaining its volume and approximate centre of gravity from the measured height and base area obtained from maps. In principle, the terrain correction is easy to make but in practice, it can be quite laborious.

2.10 EARTH - TIDES CORRECTION

The normal value of gravity at any point will vary cyclically during the course of the day by as much as 0.3 mgal. This is because of the tidal attraction of the sun and the moon. In a high precision survey, this much variation might well be a significant source of error in the relative gravity between two points at which measurements are made at different times. To correct for tidal effect, constant daily charts of tidal variation in gravity with time from readings on a station instrument will have to be maintained and to correct all readings in the field by means of such charts. The other method is for the observer to return to the base station so often that earth-tide effect will be fully incorporated into the instrumental drift curve.

2.11 ISOSTATIC CORRECTION

This correction is of secondary importance in gravity prospecting and is rarely applied in exploration work. Suffice it to say however, that it is a large scale terrain correction. In elevated regions, the Bouguer anomaly is usually negative indicating a mass deficiency, while in depressed regions, it is normally positive indicating mass excess. These defects are due to density variations in the crust and indicate that the material beneath the oceans is more dense than normal, while in regions of elevated landmasses, it is less dense.

2.12 BOUGUER GRAVITY ANOMALY

When all of the preceding corrections have been applied to the observed values of gravity readings then, the theoretical gravity (g) is:

$$g_\theta = g_L + g_E + g_T \qquad .... \quad 2.14$$

where L, E, T stand for latitude, elevation and terrain respectively. In general, it is found that the two sides of equation 2.14 are not equal. Rewriting the equation, we have the Bouguer gravity anomaly (g_B) for the station as:

$$g_B = g_L + g_E + g_T - g_\theta$$

2.13 REGIONAL AND RESIDUAL SEPARATION

The separation of residual from regional effects is an important step in gravity interpretation. When the source with the larger dimensions is a regional geological structure like a basin or geosyncline and the one with smaller dimensions is a local feature such as an anticline or a salt dome, then the two anomalies must be separated from each other. Typical example is the Benue Trough which could represent a basin with large dimensions while somewhere in Lafia, there could be buried a salt dome with smaller dimensions. The large anomaly arising from the basin could be considered to have low spatial frequency or long wavelength while that from the salt dome a high spatial frequency or short wavelength. The component that has longer effective wavelength is known as REGIONAL while that with the shorter wavelength which is more localised is known as RESIDUAL.

The objective of separation is to isolate the two anomalies. Details of separation process will not be considered here. Suffice it to say however that the separation is done using graphical and computational methods. Under the computational method, four analytical approaches are in common use. These are the direct computations such as the centre-point and ring approach, the determination of the second derivatives for which several standard computational formulae are available, the polynomial fitting and the downward continuation.

CHAPTER THREE

PROPOSED METHOD, PLOTTING AND MATCHING OF MASTER CURVES

3.1 GENERAL

From the preceding chapters we saw that gravimeters measure variation of the attraction of gravity from one point to another. Also, data reduction and interpretation are not clear cut processes. They are processes that require a great deal of intuition both physical and geological. Furthermore, the method of data acquisition has been designed to maximise the speed with which traverses can be covered. To achieve the desired results in gravity survey, there is a need to correctly interprete data within the shortest possible time of their acquisition. In other words, a method whereby one would be able to look at the field data, effect corrections, expose the residual effects and then plot the profile while still in the field. It has to be a method which is not sophisticated, is less expensive, simple to execute and provides fast results. The method being proposed affords such advantages as long as the preliminaries before the field survey have been conducted properly.

The operating equation for this method is equation 2.6 which is again stated as:

$$g_z = G\int^{v} \rho z \cdot \frac{dv}{(z^2 + x^2)^{3/2}}$$

In the field, all parameters as stated in the equation would be known. The volume can be determined by integration.

Two geometrical shapes are used as case study. These are the sphere and the horizontal cylinder. Before the field survey, theoretical values of these shapes would have been computed and the profiles plotted. These profiles represent some definite shapes of buried structures. They are known as the Master Curves. Data obtained in the field are immediately reduced, regional-residually separated and a curve plotted. The curve is then matched with the master curves. Any curve from the master curves that gives the best fit to that of the field data is identified. If there is a need to modify the curve or repeat some field measurement, this can be effected immediately. When that has been done, inference can then be made on the nature of the subsurface structure that have generated the anomalies.

3.2 CASE 1. THE SPHERE

From potential theory, we know that the attraction at an external point of a homogeneous spherical shell or solid sphere in which the density depends only on the radius is the same as though the entire mass were

GRAVITY FIELD OVER A SPHERE

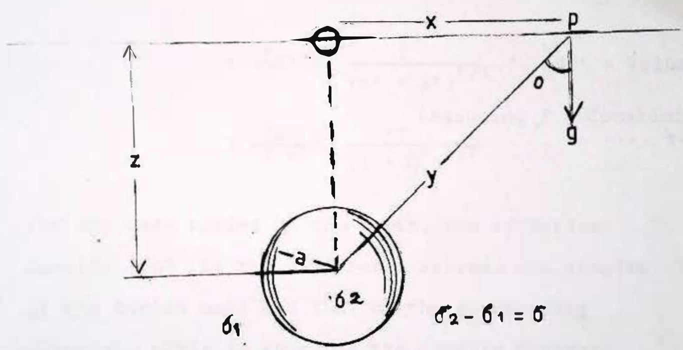

FIG. 3·1

concentrated at the centre of the sphere. The mass (m) of a sphere having a radius (R) and density (ρ) is:

$$M = 4/_3 \rho \Pi R^3$$

If the centre is at a depth z below the surface, then the total gravitational attraction, a horizontal distance X from the centre is:

$$g_z = G\int^v \rho z \cdot \frac{1 \quad dv}{(z^2 + x^2)^{3/2}}$$

$$= G\frac{4}{3}\Pi R^3 \rho z \frac{1}{(z^2 + x^2)^{3/2}}, \quad \frac{4}{3}\Pi R^3 = \text{Volume.}$$

(Assuming ρ = Constant)

$$= \frac{4\Pi G R^3 \rho}{3 \; z^2} \frac{1}{(1 + \frac{x^2}{z^2})^{3/2}} \quad \text{.... 4.1}$$

For any mass buried in the earth, the effective density (ρ) is the difference between the density of the buried mass and that of the surrounding material. This is known as the density contrast. See figure 3.1. If the contrast is negative, the corresponding gravity anomaly will also be negative.

3.3 CASE 2. THE HORIZONTAL CYLINDER

The analysis of the attraction of a Horizontal Cylinder at a point on the surface along a line perpendicular to its axis is considered from that of an infinitely long horizontal straight wire. See figure 3.2. Let the wire be at a depth z with linear density λ gcm^{-1}. Taking measurements along the x-axis perpendicular to the buried wire and the vertical component of attraction at P, we have:

$$dg_z = G \frac{dm}{r^2} \sin \frac{\phi R}{r}$$

$$= G \lambda \sin \phi R \frac{dl}{(R^2+L^2)^{3/2}}$$

All parameters are as defined in the diagram. The total vertical attraction is:

$$g_z = G \lambda \sin \phi R \int_{-\infty}^{\infty} \frac{dl}{(R^2+l^2)^{3/2}}$$

$$= G \lambda \sin \phi R \left[\frac{1}{R^2 \sqrt{R^2+l^2}} \right]_{-\infty}^{\infty}$$

$$= \frac{2 G \lambda \sin \phi}{R}$$

$$= \frac{2ZG \lambda}{R^2}, \quad \sin \phi = \frac{z}{R}$$

$$= 2 G \lambda . \frac{z}{x^2+z^2} \qquad \ldots . 4.2$$

If the wire is expanded into a cylinder of radius (R) and density (ρ), then the mass per unit length becomes:

$\pi A^2 \rho$.

where A = Area.

GRAVITY FIELD OVER A HORIZONTAL WIRE

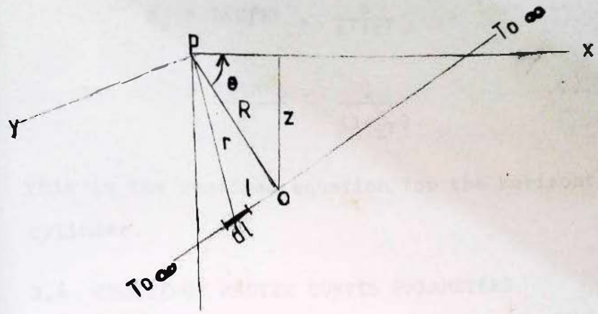

FIG. 3·2

R = perpendicular distance PO from measuring point P.

θ = angle between OP and the X - axis.

r = distance from P to an element of length dl.

l = distance from O to the element of mass

z = depth of burial

λ = linear density g/cm

Hence equation 4.2 becomes:

$$g_z = 2\pi G\rho R^2 \cdot \frac{z}{x^2+z^2}$$

$$= \frac{2\pi GR^2 \rho}{z} \cdot \frac{1}{(1+\frac{x^2}{z^2})} \quad \ldots\ 4.3$$

This is the required equation for the horizontal cylinder.

3.4 CHOICE OF MASTER CURVES PARAMETERS

3.4.1 Density Contrast (ρ). Because the method is being used to test for the sphere and the horizontal cylinder, it will find application in the mining industry where these shapes predominantly occur. Densities of basement rocks vary from 2000 kg m^{-3} for basic igneous rocks to 3180 kg m^{-3} for Hornblende-Gabbro. In this study density contrasts of 1000, 800, 500 and 200 kg m^{-3} are used. It is suggested however that in the field density contrasts intervals of 100 kg m^{-3} be adopted to plot the Master Curves. This implies that more curves would be generated in the field than have been done here.

3.4.2 Depth of Burial (z). The maximum depth of burial chosen for this study is 100 m. The least depth of 40 m was taken as an average for depth of anomalies occuring in basement areas even though smaller depths do occur. The choice of anomaly size also necessitated this because the structure should not appear to be exposed at the surface.

3.4.3 Anomaly Size(R). This refers to the radius of the anomalous body. The average range of anomalous sizes occuring in basement areas is employed for this method. This range is from 20 to 40 m at intervals of 5 m.

3.4.4 Lateral Extent(X). Due to limited extent of mining surveys, station spacings range from as small as 10 m or less to 200 m. A lateral extent interval of about 12 m for the scale was chosen in the plotting of the curves. The overall lateral extent was taken to be 100 m either side of the centre of the anomaly.

3.4.5 Choice of Plotting Scale. This is an important consideration in the application of Master Curves. The choice of plotting scale should be flexible and the scale a simple one. It should be a scale that is readily reproduceable in the field. Both the Master Curves and that obtained from field data should carry the same scale. For this study, the lateral scale was chosen to be 1 cm to about 24 m while the vertical scale was made 1 cm to 0.2 mgals.

at intervals of 0.1 mgal.

3.5 PLOTTING OF MASTER CURVES

The Master Curves were plotted with the aid of the computer. The use of the computer does not fully reflect the situation a surveyor will face in the field particularly in the developing countries where computers are not popular. However, in an organisation where such services exist, it is not only a very quick method but the surest way of dealing with very small gravity values. With the values discussed under choice of plotting parameters a computer program was formulated. The program to compute anomalies of a sphere is in Annexure 'A' and the curves that were generated are in Appendix A-1 to A-7. For the horizontal cylinder, the program is in Annexure 'B' and the curves are in Appendix B-1 to B-7. For every fixed parameters of S1 and z the anomalous size was varied from 20 to 40 m in step of 5 m. This gives a total of 5 curves per plot.

3.6 RESULTS

All together, a total of 70 curves were generated. These curves constitute what we call the Master Curves. Each of these curves represent a definite geometrical shape of a buried structure. The sphere and horizontal cylinder were chosen for the purpose of proposing this method of gravity interpretation. It is the duty of the surveyor based on his knowledge of the geology of the area of survey and having at the back of his mind the purpose of the survey to determine what geometrical shapes he should use and the anomalous size intervals. In gravity prospecting, apart from the sphere and the horizontal cylinder, other known shapes include the vertical cylinder, thin rod, thin dipping sheet, horizontal thin sheet, *faults* , thick prism, slab and dipping beds.

3.7 APPLICATION OF THE METHOD

Annexure (c) is the residual gravity contours of a field survey showing values of the anomalies. Appendix 'c-1' is the principal profile of the section AA' of the isogal map. This profile was used to match the Master Curves. All the 70 curves were matched but non of them fitted the configuration of the principal profile. The non-matching could be attributed to the difference in field data, scale, number of curves generated and the difference in profile.

The field data used to plot the principal profile are not the same with those chosen for the shapes under study. The data need not be the same. Also, the capacity of the computer that was used to plot the Master Curves is limited to only those data that were inputted. Higher values were tried on the same scale but they produced curves that could not be contained within the frame of the screen. The main computer frame (VAX) which could have been used broke down throughout the duration of this study. One possible reason for the non-matching could be the determination of the scale to plot. Because of the limitation of the computer, the scale used was the most convenient. Another possible reason could be the choice of size of anomaly interval. For a range of 20 to 40 m, only five curves were produced. Many more curves could have been produced within this range. Similarly, the density contrast intervals and the depth of burial intervals could have been given more values. Most importantly, a possible reason for non-matching could well be that the principal profile is that of a subsurface structure that is different from a sphere or cylinder.

3.8 ADVANTAGES OF THE METHOD

The method has the advantage of being simple since complicated instruments are not required. As long as the preliminary survey and correct density estimation has been done at the vicinity of the stations, it becomes a fast method of interpretation. It is a flexible method because plots can be done by hand and by use of computers and the scales are easily adopted. Success in the matching of curves instantly gives thedensity contrast, depth of burial, the anomalous size and the nature of the structure. It can be used to verify results of other methods of interpretation.

3.9 DISADVANTAGES OF THE METHOD

It is a tedious method which requires the services of experienced surveyors. A lot of preliminary work is required if the desired result is to be achieved. Knowledge of local geology particularly that of rock densities is needed for accurate results. Many processes are involved particularly in data reduction.

CHAPTER FOUR

CONCLUSIONS

4.1 The project sets out to explore the possibility of interpreting gravity anomalies especially those due to simple geometrical shapes by using Master Curves matching. Master curves are a collection of characteristic curves each depicting a definite geometrical shape. They are matched with principal profiles of field data to determine the nature of a subsurface structure. The basis of this method is Newton's law of gravitation which expresses the force of mutual attraction between two bodies in terms of their masses and distance of separation.

Gravity anomalies are variations in gravity produced by a subsurface structure. These variations are measured by gravity meters which respond to them. The variations contain many effects that are unrelated to geology and therefore irrelevant to geological interpretation. Before any serious geophysical interpretation is attempted, they must be removed. The corrections done on gravity data are those for drift, latitude, elevation, terrain, earth-tides and isostatic. When all the corrections have been performed, the Bouguer gravity anomaly is obtained. Residual effects are repeated from the regional effects before an isogal map is produced. This isogal map depicts a potential field and not a subsurface structure. It should therefore not be identified as being indicative of structure.

There are two basic approaches to gravity interpretation. One is to determine the mass distribution of the structure from the gravity data, the other is to assume various models conforming to known constraints and to match gravity predicted for each model with the gravity field that has actually been observed. The model that gives the best fit is considered to be the most probable representation of the structure.

The method being proposed in this study is that of interpretation using Master Curves. This method is executed by first determining a defining equation for the subsurface structure we want to find. In the equation, a number of parameters come into play. These are density contrasts, depth of burial, lateral extent, and the anomalous size. Some of the parameters are kept constant, while others are allowed to vary while data is being fed. The result is that a number of curves are generated. Data from field survey which are already in gravity units are plotted against the lateral extent to obtain a principal profile which is in turn matched with the master curves. Any of the curves from the set of master curves that gives the best fit to the principal profile is identified.

For this study, only two geometrical shapes were used. These are the Sphere and the horizontal cylinder. The defining equation to these shapes were formulated. Then, theoretical values were assumed and the computer was used to plot the Master Curves. A total of 70 curves were generated. In real situation, one could have a book full of curves which have been generated by assigning different values to the parameters in the defining equation. A principal profile of data from a field survey was plotted and matched with the master curves. Non of the curves fit the profile. A possible reason for this could be due to the difference between the field data and those that were assumed for the curves, limitation of scale, or the structure could well have a shape different from those of sphere and cylinder.

Though the anticipated result was not achieved, the method is workable. It has the advantage of being a simple method, itis fast and flexible in execution and readily reproduceable in the field. Where it works, the density, depth of burial, anomalous size and the nature of the structure can be instantly determined from the parameters assigned to the curve that gives the best fit. The method is however very tedious and requires adequate knowledge of the geology and density of the rock around the survey area for accurate interpretation to be obtained.

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PROGRAM TO COMPUTE GRAVITY ANOMALY OF A SPHERE

```
10 PLOTER IS 1
20 !PROGRAM TO COMPUTE GRAVITY ANOMALY OF A SPHERE
30 GCLEAR !
40 FRAME
50 DISP "INPUT X1,X2"
60 INPUT X1,X2
70 LOCATE 25,160,25,97
80 SCLAE -2.5,2.5,0,12
90 LAXES 1,1,0,0
100 READ S1,Z,R
110 DATA 1000, 80, 20, 1000, 80, 25, 1000, 80, 30, 1000, 80, 35, 1000, 80, 40, 0, 0, 0
120 IF S1=0 THEN 230
130 FOR X=X1 TO X2 STEP 12
140 Y= (1+X^2/Z^2)^-1.5
150 G=6.664E-11
160 P1=22/7
170 LET F=G*P1*4*R^3*S1/(3*Z^2)
180 g=F*Y*1000000
190 M=X/Z
200 PLOT M,g
210 NEXT X
220 GOTO 90
230 MOVE -2.5,2.1 @ LABEL "THE FORM OF GRAVITY ANOMALY OF A CYLINDER"
240 MOVE -2.5,-3.5 @ LABEL "FOR S1=1000,Z=80,R=20 TO STEP 5"
250 END
```

PROGRAM TO COMPUTE GRAVITY ANOMALY OF A HORIZONTAL CYLINDER

```
10 PLOTER IS 1
20 !PROGRAM TO COMPUTE GRAVITY ANOMALY OF A HORIZONTAL CYLINDER
30 GCLEAR !
40 FRAME
50 DISP "INPUT X1,X2"
60 INPUT X1,X2
70 LOCATE 25,160,25,97
80 SCLAE -2.5,2.5,0,12
90 LAXES 1,1,0,0
100 READ S1,Z,R
110 DATA 1000, 80, 20, 1000, 80, 25, 1000, 80, 30, 1000, 80, 35, 1000, 80, 40, 0, 0, 0
120 IF S1=0 THEN 230
130 FOR X=X1 TO X2 STEP 12
140 Y=Z* (1+X^2/Z^2)
150 G=6.664E-11
160 P1=22/7
170 LET F=G*P1*2R^S1
180 g=F/Y*1000000
190 M=X/Z
200 PLOT M,g
210 NEXT X
220 GOTO 90
230 MOVE -2.5,2.1 @ LABEL "THE FORM OF GRAVITY ANOMALY OF A CYLINDER"
240 MOVE -2.5,-3.5 @ LABEL "FOR S1=1000,Z=80,R=20 TO STEP 5"
250 END
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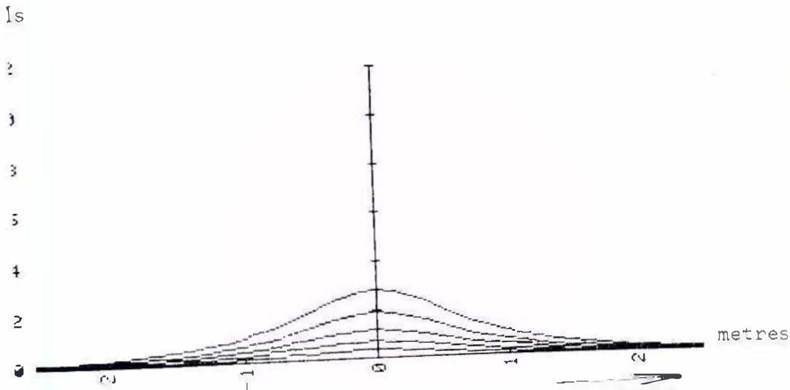
RESIDUAL GRAVITY CONTOURS

APPENDIX 'A-1' TO

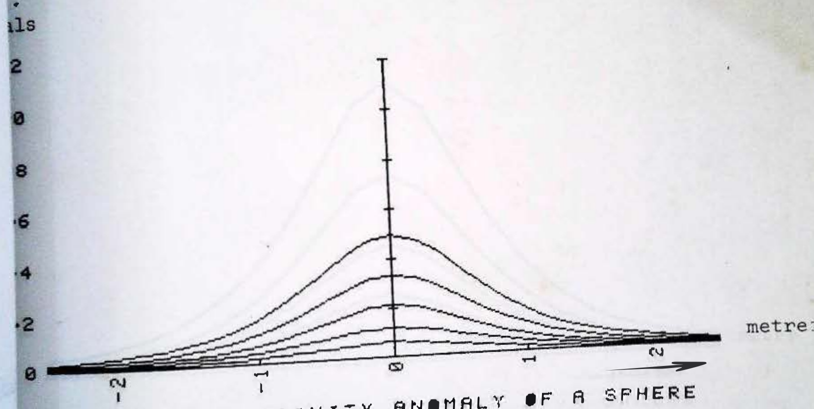
ANNEX 'C'



THE FORM OF GRAVITY ANOMALY OF A SPHERE
FOR S1=1000, Z=80, R=20 TO 40 STEP 5

APPENDIX 'A-2' TO

ANNEX 'C'



THE FORM OF GRAVITY ANOMALY OF A SPHERE
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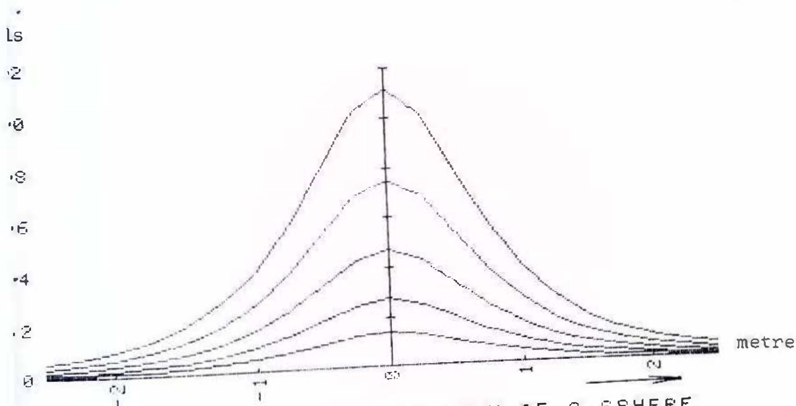
APPENDIX 'A-3' TO

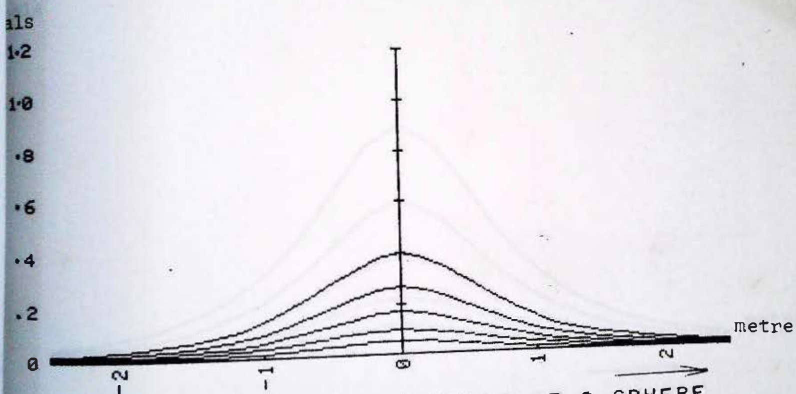
ANNEX 'C'



THE FORM OF GRAVITY ANOMALY OF A SPHERE
FOR S1=1000, Z=40, R=20 TO 40 STEP 5

APPENDIX 'A-4' TO

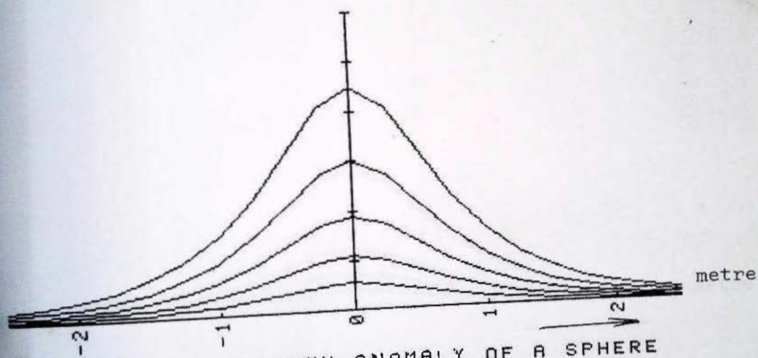
ANNEX 'C'



THE FORM OF GRAVITY ANOMALY OF A SPHERE
FOR S1=800, Z=60, R=20 TO 40 STEP 5

APPENDIX 'A-5' TO

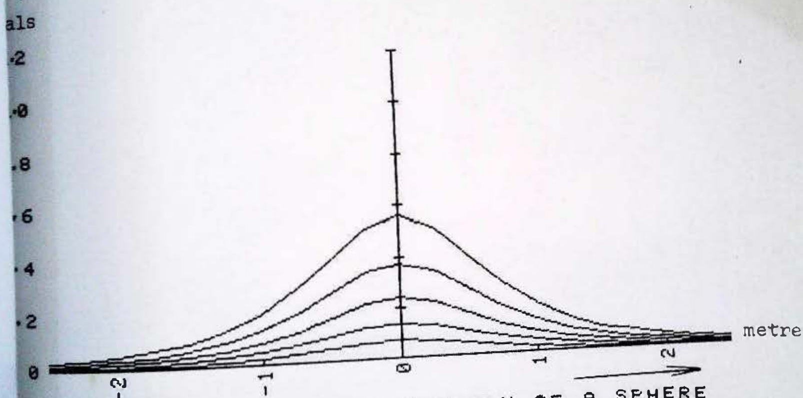
ANNEX 'C'



THE FORM OF GRAVITY ANOMALY OF A SPHERE
FOR S1=800,Z=40,R=20 TO 40 STEP 5

APPENDIX 'A-6' TO

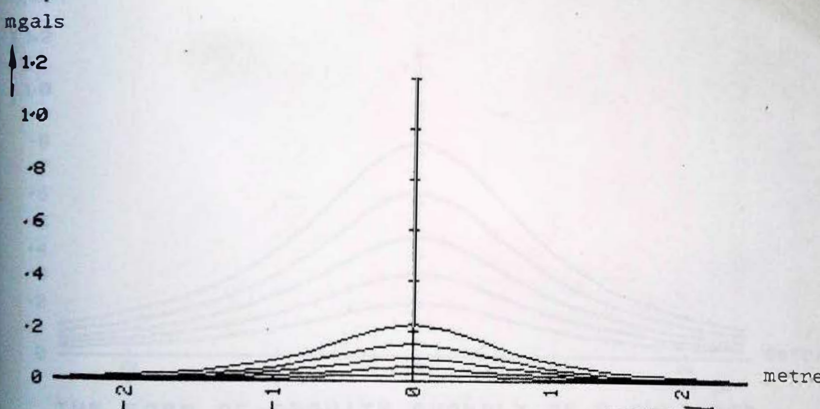
ANNEX 'C'



THE FORM OF GRAVITY ANOMALY OF A SPHERE
FOR S1=500, Z=40, R=20 TO 40 STEP 5

APPENDIX 'A-7' TO

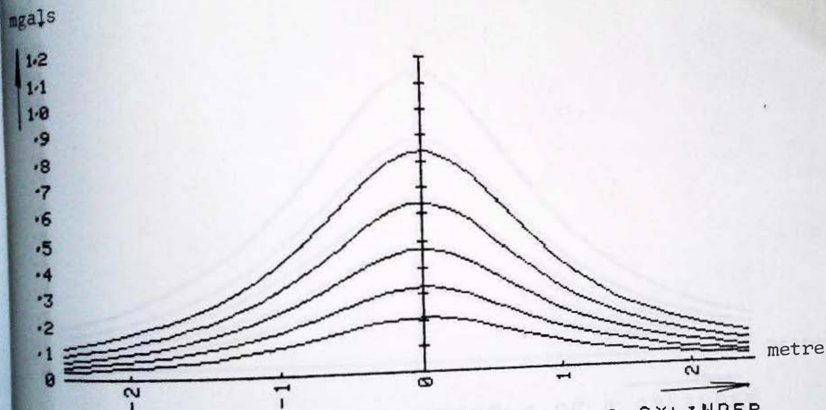
ANNEX 'C'



THE FORM OF GRAVITY ANOMALY OF A SPHERE
FOR S1=200, Z=40, R=20 TO 40 STEP 5

APPENDIX 'B-1' TO

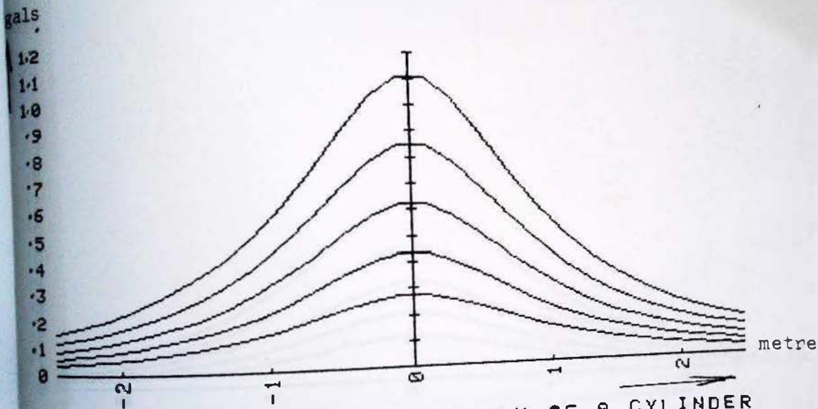
ANNEX 'B'



THE FORM OF GRAVITY ANOMALY OF A CYLINDER
FOR S1=1000,Z=80,R=20 TO 40 STEP 5

APPENDIX 'B-2' TO

ANNEX 'B'



THE FORM OF GRAVITY ANOMALY OF A CYLINDER
FOR S1=1000, Z=60, R=20 TO 40 STEP 5

APPENDIX 'B-3' TO

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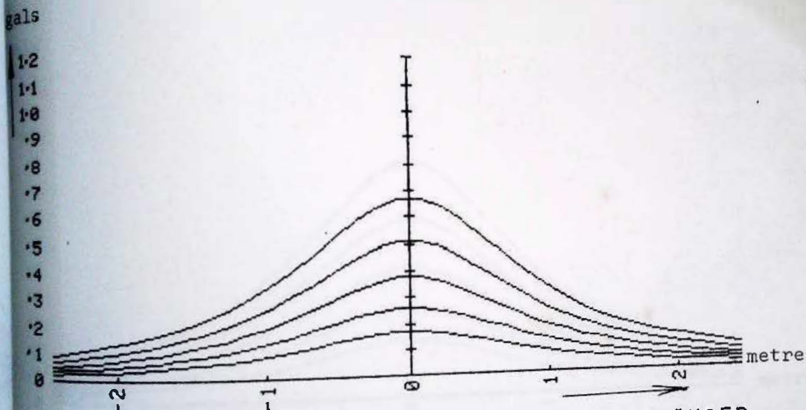
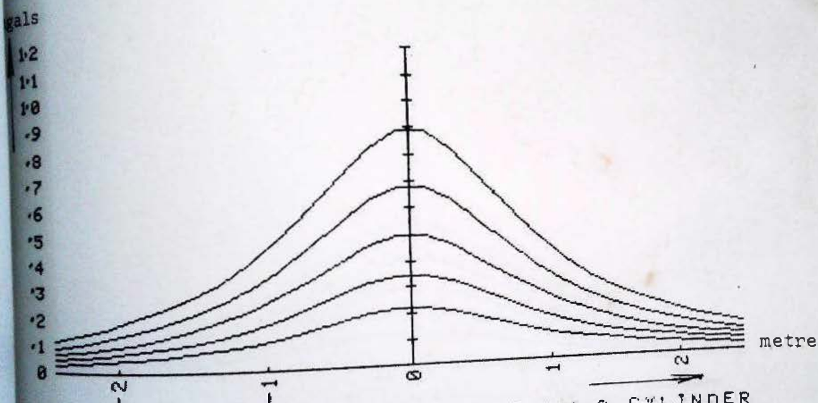


THE FORM OF GRAVITY ANOMALY OF A CYLINDER

FOR S1=800, Z=80, R=20 TO 40 STEP 5

APPENDIX 'B-4' TO

ANNEX 'B'



THE FORM OF GRAVITY ANOMALY OF A CYLINDER
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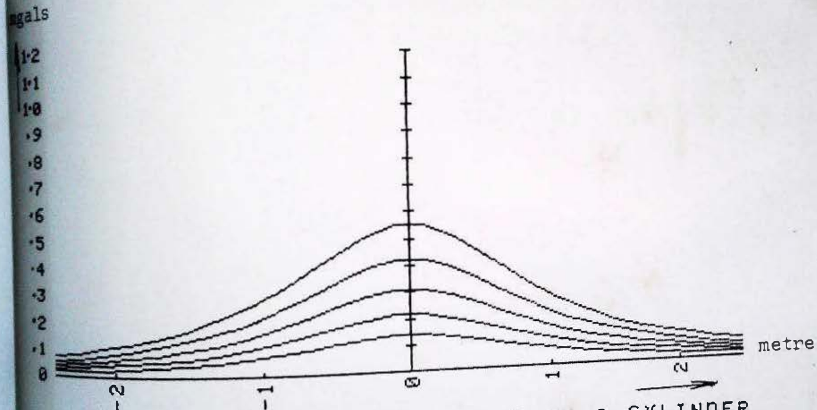
APPENDIX 'B-5' TO

ANNEX 'B'

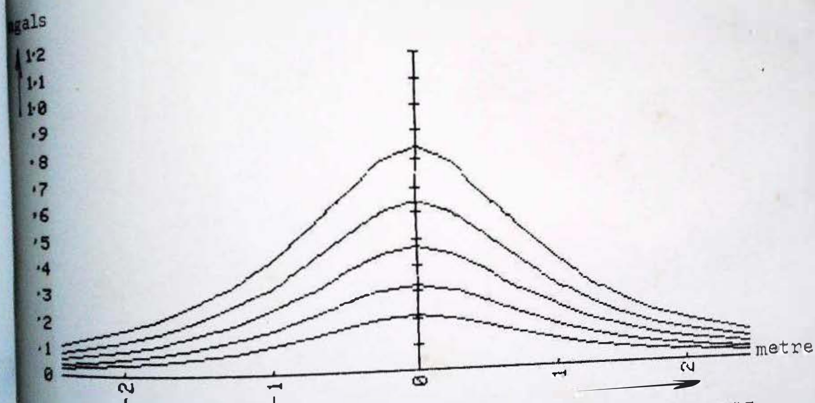


THE FORM OF GRAVITY ANOMALY OF A CYLINDER

FOR S1=500, Z=60, R=20 TO 40 STEP 5

APPENDIX'B-6' TO

ANNEX 'B'



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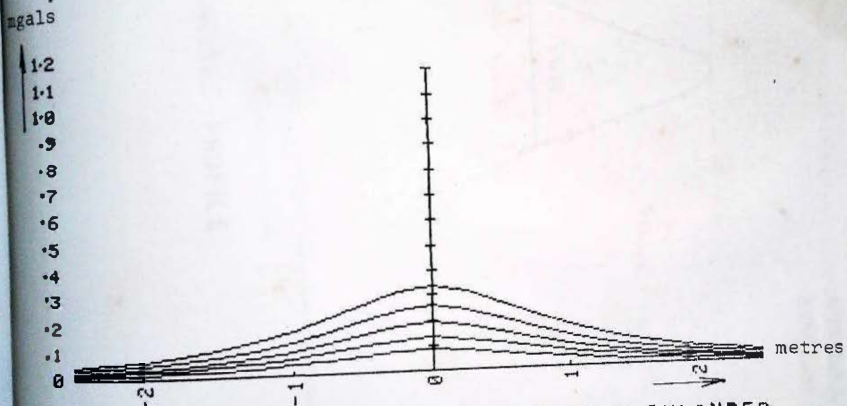
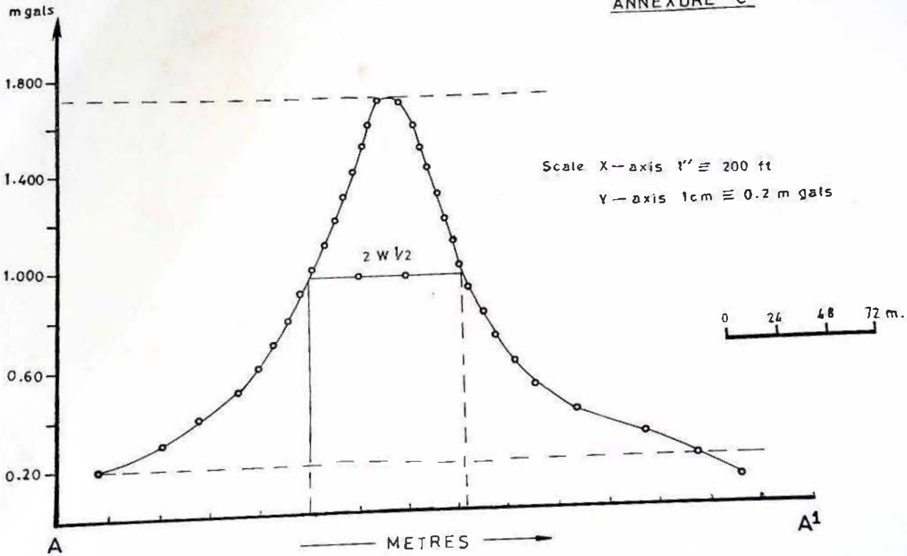
FOR S1=500, Z=40, R=20 TO 40 STEP 5



THE FORM OF GRAVITY ANOMALY OF A CYLINDER
FOR S1=200, Z=40, R=20 TO 40 STEP 5

APPENDIX 'C-1' TO
ANNEXURE 'C'



PRINCIPAL PROFILE