MEASUREMENTS OF VERTICAL GRADIENT OF GRAVITY IN ZARIA AREA OF KADUNA STATE, NIGERIA

BY

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DECLARATION

I hereby declare that this thesis has been prepared by me and that it is a record of my review of some literature and my own research work. It has not been presented in any previous application for a higher degree.

All quotations are indicated and the sources of information are specifically acknowleged by means of references.

A. D. OKONTA

CERTIFICATION

This thesis entitled "Measurements of Vertical Gradient of Gravity in Zaria area of Kaduna State, Nigeria" by Anthony Dumebi Okonta meets the regulation governing the award of the degree of Master of Science in Applied Geophysics of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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Dedicated

to

All the suffering souls of humanity.

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ABSTRACT

In this survey, the possibilty of using local materials in the fabrication of a stool that could be used in taking graviraeter readings at two vertically separated platforms was investigated. It was also aimed at using the stool in obtaining data to be used for the production of a vertical gradient of gravity map for Zaria area of Kaduna State, Nigeria.

A LaCoste - Romberg Gravimeter (model G512) was used to obtain data for a total of 121 stations in the survey area. The results of the measurements showed that the vertical gradient of gravity in Zaria varies from 2700 to 3800E yielding a range of 1100E. *A* vertical gradient of gravity contour map was then produced and correlated with the existing geologic and gravity residual anomaly maps for the same area.

An analysis of the correlation showed that the low closures of the vertical gradient of gravity map corresponds to the low closures of the residual anomaly map. Since these low residual closures correspond to important geologic features, then the low vertical gradient of gravity closures bear a strong relationship with the geology of the area. The correlation also showed that a few oi the residual anomaly closures were relatively displaced to the East when compared to the corresponding low vertical gradient of gravity closures.

TABLE OF CONTENTS

LIST OF FIGURES

Figures Pages

LIST OF PLATES

LIST OF APPENDICES

ABBREVIATIONS AND SYMBOLS

VGG - Vertical Gradient of Gravity

ρ - Density

m - Mass

% - Percentage

g - Gravity or Acceleration due to Gravity

E - Eotvos Unit ($1E = 10^{-4}$ mgal m^{-1})

CHAPTER ONE

INTRODUCTION

1.1 The Survey Area

This geophysical survey has covered a land area of approximately 3,400 sq. km and is located in Northern Nigeria within latitudes 10° 45'N and 11° 22' N and between longitudes 7° 30' E and 8°00'E (fig. 1.1).
This area is referred to in this work as Zaria area and is enclosed partly within the 1:100,000 scale topographic map sheet 102 (Zaria) and partly by the 1:100,000 scale topographic map sheet 124 (Igabi). Accessibility within the survey area has been made possible by;

(i) the network of Nigerian railway entering the area from the South-west, branching off at Zaria to Kano in the North-east and to Gusau in the North-west of Zaria.

(ii) a number of major all season roads. Zaria town is centrally placed and well connected with good all-season roads linking it in all directions such as the Zaria-Kaduna to the South-west, the Zaria-Jos road to the South-east, the Zaria-Kano to the North-east, the Zaria-Funtua road to the North-west, Zaria-Birnin Gwari road to the West(Fig. 1.1).

(iii) A number of untarred roads which are motorable only during the dry season, from November to May, and very many tracks that can only be used by cycles or foot.

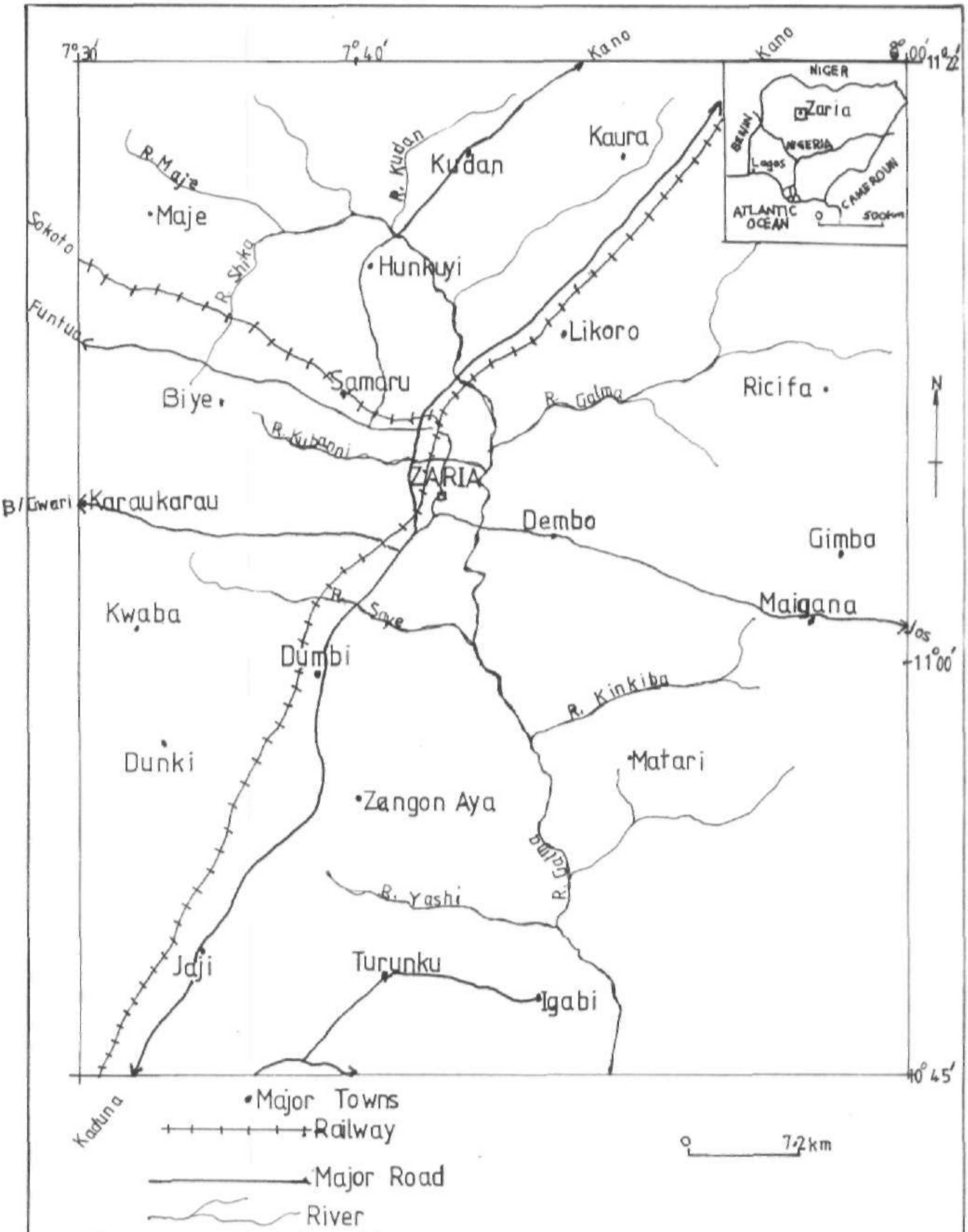

Fig 1.1 Location Map of Zaria Area. Inset, Nigeria.

1.1.1 Relief

Zaria area lies in the ancient peneplain which forms part of the Zaria-Kano plains that has been dissected by river erosion. Its average height in the southern half is about 650m above mean sea level. It rises gently towards the central part and North-east to a height of about 700m while to the North-west, it rises up to between 700m and 750m above mean sea level,(McCurry, 1970). The monotonous relief of the thickly alluviated plains in the South of the area is broken only by occasional granite inselbergs, whale-backs and low quartzite ridges which rise to between 30-45m above the present land surface in the surrounding, while in the West, North-west and North, the topography becomes rugged, characterized by migmatite and quartzite ridges and well exposed elliptical granite bodies(McCurry, 1970).

1.1.2 Drainage

The area lies in the Northern Guinea Savanna belt with a tropical bushland vegetation. The annual rainfall of the area, with a precipitation of approximately 100cm, is almost wholly confined to the period from April to September (McCurry, 1970).

In the South-West, rivers Yashi, Kubanni and Shika flow out through the Biye-Karaukarau escarpments. Rivers Maje and Kudan have their headwaters from the Northern Zarewa-Dabai escarpments and rivers Kinkiba and other tributaries of river Galma have their headwaters from the Eastern

Ricifa-Gimba Divide (McCurry,1970). All these rivers empty their waters into the main river Galma which drains the entire Zaria area southwards into river Kaduna. River Galma and a few other rivers e.g Shika, contain water through out the year while many like rivers Kubanni, Saye etc. flow only during the short rainy season.

1.2 Geology of the Area

Zaria area forms part of the Northern Nigerian basement complex and apart from an extensive superficial cover, the rocks in this area can be divided according to McCurry (1970, 1973) into:

(i) a crystalline complex of migmatites and gneisses probably of Dahomeyan age, including relicts of an ancient (Birrimian) metasedimantary sequence,

(ii) a Younger metasedimentary series of Katangan age occupying North-South trending synclinal belts in the crystalline complex and

(iii) a suite of intrusive syntectonic to late-tectonic granites and granodiorites of late Precambrian to Lower Paleozoic age associated with extensive aplite and pegmatite development.

These rocks have been variably metamorphosed and granitized through at least two tectono-metamorphic cycles and folded during the Pan African orogeny resulting in tight isoclinal folding about an East-West and North-South axes and the altering and deformation of rocks from low grade phyllites to high grade gneisses (McCurry 1970).

The major rock types as given by McCurry (1970, 1973) are shown in fig 1.2.

1.2.1 The Crystalline Complex

Gneisses and migmatites comprise the ancient crystalline basement which underlies the whole of Zaria area and accomodates the belts of Younger metasediments as well as remnants of an Older metasedimentary group preserved mainly as feldspathic quartzites, amphibolite and calcareous rocks (McCurry 1970). The gneissis are very variable in composition including the biotite gneisses, the hornblende gneisses, banded gneisses, granite gneisses, sheared gneisses, augen gneisses and cataclastic gneisses (McCurry, 1970). There is evidence that some of the gneisses are sedimentary in origin.

The migmatite complex occupies the North-West part of the survey area where they have graded into one another with the gneisses. Granitic and granodioritic facies occur within the migmatitie complex. Generally well exposed in low, bouldery, joint-controlled ridges, the migmatite terrain displays isoclinal, non-cylindrical major folds on aerial photographs.

1.2.2 The Metasediments

These occur in North-South trending synclinal belts as lenses which apparently have conformable relation-ships with the crystalline host-rock, (McCurry, 1970). One such belt passes through the western part of the survey area

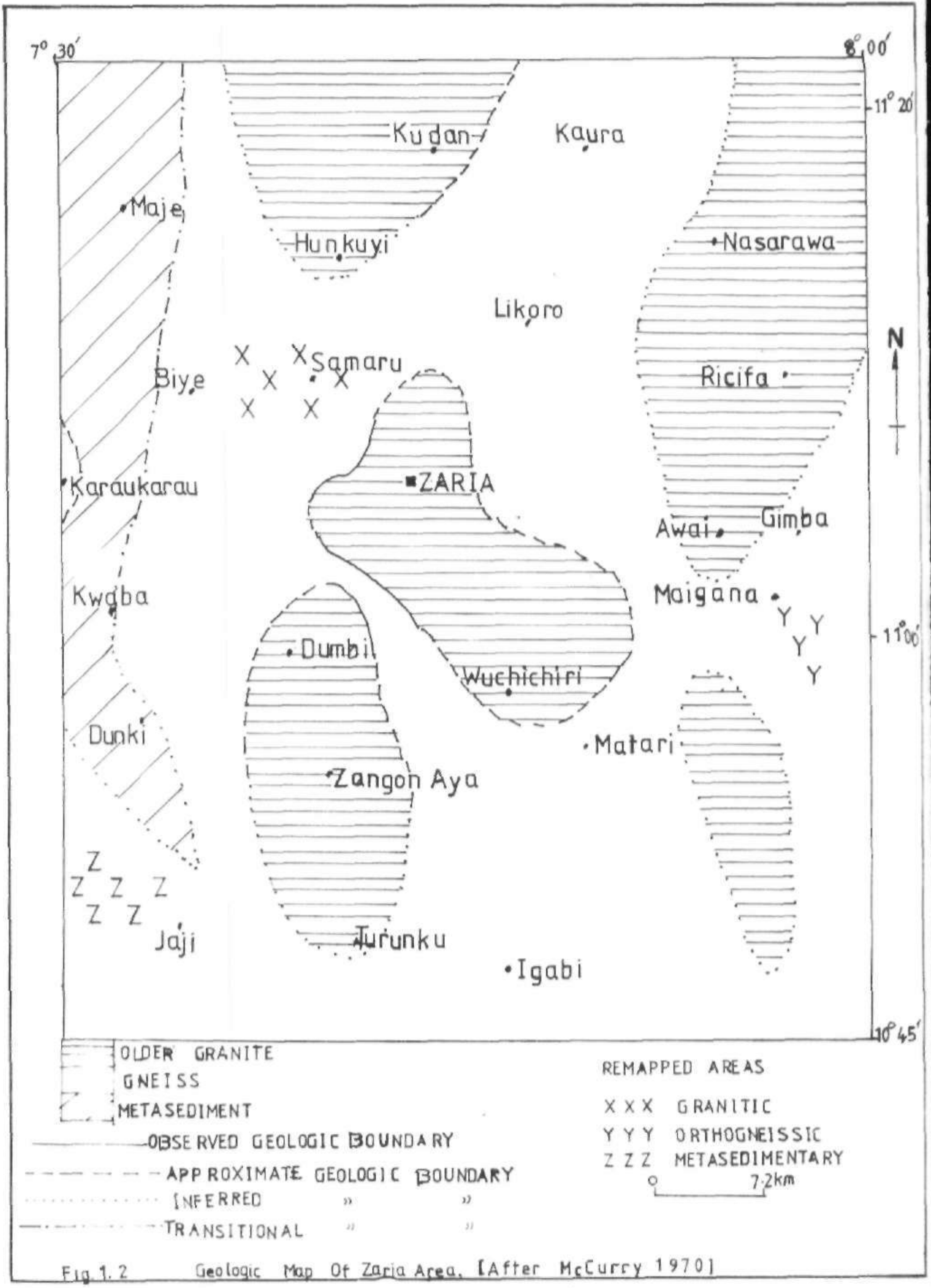

Fig. 1.2 Geologic Map Of Zaria Area. [After McCurry 1970]

extending North-South from an area North of Maje to South of Dunki(fig. 1.2). The main subdivisions are the quartzites and schists.

Quartzites

Quartzite ridges are well exposed in the Karaukarau area and prominent ridges consist of massive to granular quartzites while predominantly fissile muscovite varieties tend to form lower ridge features. With increasing muscovite the quartzites grade into muscovite-quartz schists (McCurry, 1970). The quartzites are well foliated especially more fissile varieties. Massive quartzites contain relatively few impurities and are usually grey-white in colour, while fissile varieties vary from yellow to brown depending on relative amount of muscovite and oxide present.

Schists

These occupy the greater part of the metasedimentary belts and vary in colour, texture and outcrop. Due to their soft and friable nature, they are usually only exposed in river valleys and excarvations where they are deeply weathered. Schists grade into quartzites within the metasedimentary belt, and into adjacent crystalline gneisses. The various schists are muscovite-quartz schists, biotite-muscovite schists, feldspathic schists and carbonaceous schists.

1.2.3 Granitic Rocks

These are well exposed especially in the North- West area where extensive outcrops occur. Elsewhere, the granites are buried beneath a thick superficial cover, and only outcrop in isolated hills or groups of inselbergs, low whalebacks and granite pavements. Ihe granite bodies range in size from sub-elliptical plutons not more than about 125 sq. km. in area up to masses of batholithic dimensions and fall into two groups (McCurry, 1970):

(i) elongate batholiths, discordant in part but mainly concordant, with rather diffuse contacts.

(ii) discordant, very fractured bodies introducing crystalline rocks and metasediments with cross-cutting contacts.

The rocks are all compositionally similar in that they contain quartz, microline, plagioclase and biotite as essential minerals, with accessory apatite and zircon. The different types of granitic rocks are porphyroblastic biotite granite, fine to medium-grained biotite granites, pophyroblastic hornblende granite and granodiorites (McCurry, 1970).

Fine-grained granites, aplites and pegmatites occur as irregular facies in the main granite bodies and in some of the surrounding gneisses. Also, these form concordant or discordant veins, lenses, pods and sheets and are particularly concentrated in the more richly pophyroblastic granites in the South-Eastern part of the area.

1.2.4 Others

The other rock types found scattered in the area include;

(i) Phyllites

Asociated with the Carbonaceous schists and also occur in a faulted sliver in gneisses North of Zaria.

(ii) Vein rocks

Though pegmatites are more common in the crystalline rocks , quartz-veins and schorl rocks are widespread throughout the area. However, schorl rocks show a preference for the sedimentary belts.

(iii) Tourmaline

This is mostly concentrated in or marginal to the metasedimentary belts in pegmatites, quartz-veins and schorl rocks, or impregnating the country rocks.

1.3 Background Theory

Gravity survey techniques are based upon the principles which states that when the centres of two objects of masses m_1 and m_2 are separated by a distance r, they experience an attracttive force, F, whose magnitude is given by Newton's inverse square law of gravitation as

$$F = G\, m_1\, m_2/r^2 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad 1.0$$

where G is the Universal gravitational constant having a value approximately 6.67×10^{-11} Nm^2 kg^{-2}. If one of the objects is the earth of mass M and the other is a unit mass placed on the surface of the earth of radius R, assumed spherical, the force of attraction per unit mass acting on the object is

$$F/m = GM/R^2 \quad \ldots\ldots\ldots\ldots \quad 1.1$$

where M, the mass of the earth, is assumed to be concentrated at its centre. Equation 1.1 holds only for a model of the earth that is assumed spherical, non-rotating and of homogeneous mass distribution and this force per unit mass g' together with the centrifugal force per unit mass on the body gives g which is called gravity. In this case the variation of the gravity g with distance r fron the centre of the earth based on equation 1.1 is shown in fig. 1.3

Experiments have however shown the earth to be rotating, non-spherical and of heterogeneous mass distribution. The value of g therefore, got at any point on the earth's surface is affected by the factors listed above and more.

Consider a body of unit mass situated at a point p(x,y,z), distance r from the centre of the earth, the potential due to the element of the earth of mass δm and dimensions δx, δy and δz is given as

$$\delta U = G\,\delta m/r = G\,\rho\,\delta x\,\delta y\,\delta z/r \quad \ldots\ldots\ldots\ldots \quad 1.2$$

where ρ is the density of the material assumed constant within the element and $r = (x^2+y^2+z^2)^{1/2}$ in 3-D cartesian coordinates (fig. 1.4).

The potential, U, due to the total mass M would be

$$U = \iiint G\,\rho\,1/r\;dx\,dy\,dz \quad \ldots\ldots\ldots\ldots \quad 1.3$$

assuming W is the potential of gravity then

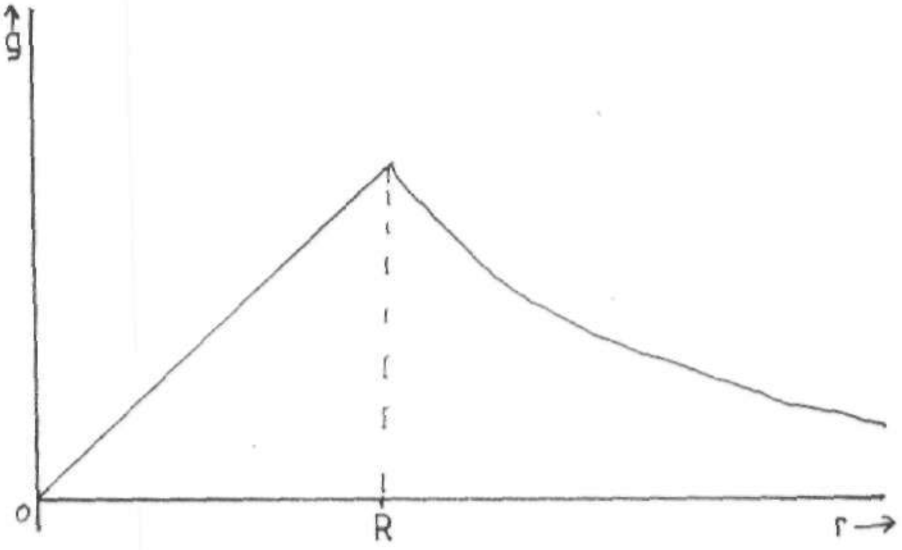

Fig 1.3. Variation of g with distance r from the centre of the Earth of radius R. [After Nelkon & Parker, 1984]

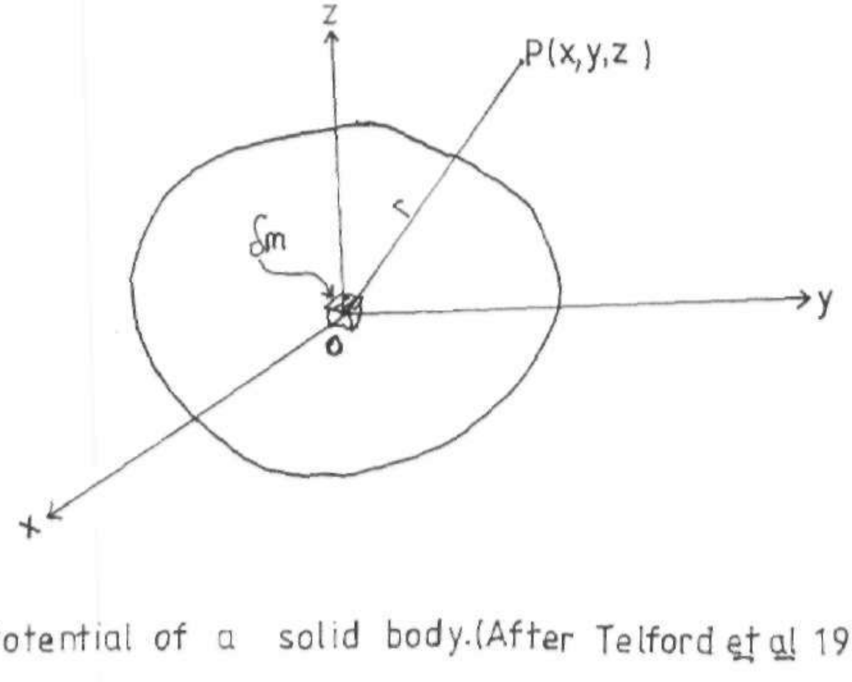

Fig 1·4. Potential of a solid body. (After Telford et al 1976).

$$W = U + \phi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 1.4$$

where ϕ is the potential due to the centrifugal force per unit mass on the surface of the earth.

The component of the force of attraction in the vertical z direction is given as

$$g_z = \partial W / \partial z = - G \rho \iiint z/r^3 \, dx \, dy \, dz \ \ldots . \ 1.4$$

The variation of gravity g_z with respect to elevation from the centre of the earth in the vertical direction, i.e the vertical gradient of gravity, is given as

$$\frac{\partial g_z}{\partial z} = \partial^2 u / \partial z^2$$

$$= - G \rho \iiint (1/r^3 - 2z^2/r^5) \, dx \, dy \, dz \ldots\ldots \ 1.5$$

and for a 2-D body becomes

$$\partial g_z / \partial z = 2G \rho \iint 1/r^4 (2z^2 - r^2) \, dx \, dz \ \ldots\ldots . 1.6$$

From equations 1.5 and 1.6, it is clear that taking the derivatives of equation 1.4 tends to magnify near-surface features and discriminates between them by increasing the power of the linear dimensions in the denominator. For a 3-D body therefore, since the gravity effect varies inversely as the square of the distance, the first derivative varies as the inverse cube (Telford *et al.*, 1976).

The variation in g due to distance from the earth's centre as obtained by considering the potential theory and known data for the earth gives the formula for the normal "free air" gravity gradient as

$$\partial g/\partial h = 0.30855 + 0.000227\cos 2\phi - 0.145\times 10^{-6}h \ldots \quad 1.7$$

in mgals/metre, where ϕ is the geocentric latitude and h is the elevation in metres above mean sea level of the point of observation.

Two methods exist today of obtaining vertical gradient of gravity ($\partial g/\partial h$) values. First, from conventional gravity surveys, gradient values can be computed as shown by Evjen (1936), and others. However, such computed values always give rise to fictitious anomalies (Fajklewicz, 1965). The other method involves the measurement of gravity values at two points, one vertically placed above the other at a known distance, and calculating the vertical gradient of gravity values from such measured gravity values. The setback is the erratic behaviour caused by strong and short-wavelength surface density variations.

1.4 Review of Previous Related Work in the Area .

Most of the earlier surveys in this area had been partly geological and partly geophysical and are summarised below.

There was an initial water supply investigation as reported by McCurry (1970) which gave little geological information about the basement complex. This was followed by the first documented geophysical survey which was part of the nation-wide aeromagnetic survey project carried out by the Geological Survey of Nigeria between 1966 and 1969. Aeromagnetic maps were prepared although there had not been a comprehensive interpretation of the maps produced.

Olowu (1967), working on groundwater conditions in Zaria area, produced a small scale geological sketch map showing the major rock types and a description of Zaria area.

McCurry (1970) carried out the mapping, on a reconnaissance level, of an area of approximately 12,000 sq.km. in the Zaria-Funtua-Malumfashi region of Northern Nigeria. A geologic map was produced which incorporated Olowu's work.

McCurry (1973) also did an extensive mapping of an area approximately 15 sq. km. to the West of Zaria and this led to the updating of the then existing geology of degree sheet 21, Zaria.

Webb (1972) carried out a mapping of areas between Zaria and Kaduna and in the report regarded the granite plutons in Zaria area mapped by McCurry (1970) as part of a single batholith. Some of the gelogic information in McCurry's work were modified due to the remapping of Webb.

Later, a gravity survey over the Precambrian Older granite intrusives in Zaria area of Northern Nigeria was carried out by Adeniyi (1987) which led to the production of a gravity anomaly map of Zaria area. Subsequent interpretation of the gravity anomalies by Adeniyi (1987) suggests the existence of three Batholiths with five 'plugs' acting as conduits for the ascent of magma.

1.5 Objectives of the Present Survey

Vertical gradient of gravity survey involves the measurement of gravity at two points at a location, one vertically placed above the other and separated by a distance from it. Previous surveys by Hammer (1938), Thyseen-Bornemisza and Stackler (1956), Thyseen-Bornemisza and Jacoby (1971), Janle et. al. (1971), Thyseen-Bornemisza et. al. (1972), Fajklewicz (1976), Ager and Liard (1982), and Butler (1984), had reported measurable successes while using specially designed metal (mostly aluminium) towers in taking vertical gradient of gravity measurements. Their towers were of different heights (0.25m - 4.00m) and they also reported different measurement accuracies (10E - 50E) in their results.

It was the intent of this survey to investigate the possibility or otherwise of using wood for the design and construction of a stool that could be used in place of a metal tower. It was also, intended to find out the optimum height of the wooden stool that guarrantees a successful practical survey with acceptable measurement accuracy while still taking into account the problems associated with earlier reported surveys. Such problems are the vibrations induced in the stands and gravimeters due to wind gusts, vibrations due to the movement of the gravimeter up and down the high stands, vibrations induced in the gravimeter due to transportation from one station to another etc.

From theoretical considerations, the global value of the vertical gradient of gravity from the geographic equator to latitude 45° North and South of the equator is between 3083 - 3086E. There are, however, reported cases of gradient values within this region ranging from 3128E (Hammer, 1938) to between 2600 - 2800E (Ager *et al.*, 1982). It was then decided in this survey to show how the various vertical gradient values determined for each station in Zaria varies from this global value. In summary, therefore, the objectives of the survey is to determine the variation of the vertical gradient of gravity and hence produce a vertical gradient of gravity map for Zaria area. In achieving this aim;

(i) a vertical gradient of gravity measuring stool (or tower) was designed

(ii) vertical gradient of gravity measurements were carried out at locations within the area

(iii) vertical gradient of gravity map of Zaria was produced.

In addition possible application of vertical gradient of gravity as a tool for geophysical exploration was explored by correlating the VGG map with the geophysical and the residual anomaly map of Zaria area.

CHAPTER TWO

INSTRUMENTATION

2.1 General

The advantages of vertical gradient of gravity determinations as reported by Thyseen-Bornemisza and Stackler (1956), Kuo et. al. (1969), Thyseen-Bornemisza and Jacoby (1970), Thyseen Bornemisza et. al. (1972), Fajklewicz (1976), Ager and Liard (1982), and Butler (1984) include addition of information:

(i) to our fundamental understanding of the earth's gravity field

(ii) to assess the shape of the earth and

(iii) to assess the shape and nature of subsurface structure within the earth.

How far these and other lofty ideals of the advantages of vertical gradient of gravity surveys are realised depend on the accuracy with which the gradient data are obtained. The data collecting process involves the interplay of the three major factors or variables listed below:

(a) the observer of the instrument

(b) the performance of the gravimeter used and

(c) the design of the stool or tower which provides the platforms used for the observation of the gravimeter.

2.2 The Observer of the Instrument

It had been observed by Fajklewicz (1976) that not every observer, however experienced, can make vertical gradient of gravity measurements. When processing the results of a series of measurements made by many observers, he observed that a certain heterogeneity may manifest itself. For this survey only one observer took the gravimeter readings to reduce the above stated problem.

2.3 The Performance of the Gravimeter

It was also reported by Faklewicz (1976) that not every given type of gravimeter can be used for gradient measurements. There are also bound to be a certain heterogeneity when readings taken with various gravimeters are analysed. The gravimeter must be sensitive enough to be able to detect vertical gradient of gravity anomalies between 1 to 3 microgals (Thyseen-Bornemisza, (1972), if it is to be useful for vertical gradient of gravity surveys. For a gravimeter of precision ±0.01 mgals, this would require a vertical distance between the platforms of approximately 3 or more metres. To overcome this problem, a Lacoste - Romberg, Model G512, geodetic gravity meter with its accessories was used for the survey. Model G gravity meters have a range of over 7000 mgals and a reading accaracy of 0.01 mgal. The gravimeter was carefully calibrated prior to this survey to yield a precision of ±0.002 mgals with a measurement accuracy of 20E when a vertical separation of 1.0m was used between the lower and upper reading platforms.

The instrument has a drift rate of less than 1 mgal per month as supplied by the manufacturers and confirmed by Kuo *et al.* (1969). It is also sealed to eliminate any effect from changes in the atmospheric pressure. The sensor is completely demagnetized and then enclosed within a magnetic shield which makes the instrument virtually free from magnetic effects. This was also confirmed by Kuo *et al.* (1969). It's operating temperature was maintained at the stipulated 52.5°C and the gel battery was always put back to recharge after each day's survey. This was to enable the battery to be fully recharged and thus to be able to supply energy to the thermostatically controlled instrument during the subsequent field outings.

2.4 Measuring Towers / Tripods

Even with the most modern and sophisticated gravity meters capable of reading accuracies of the order of microgals, the measurement accuracy of any vertical gradient of gravity survey values depend on the vertical distance separating the lower and upper platforms on which the meters are read. For a gravimeter of fixed reading accuracy, the measurement acuracy improves with increase in the vertical separation of the platforms. Conversely, as the meter precision improves, the vertical separation of platforms that give the same measurment accuracy reduces. Since the measuring towers/tripods provide the platform on which gravity meters are read, the history of the development or improvement of accuracies of gravity meters has a direct bearing on the history of the development of design and construction of towers/tripods. Initially, the early gravity meters did not have sufficient accuracy and to produce vertical gradient of gravity values of satisfactory measurement accuracy, large vertical distances as were found in tall buildings and mine shafts were used.

With improvement in design and increased accuracy of gravimeters, various devices were designed to substitute the more difficult readings in tall buildings and mine shafts. Moreover, if vertical gradient of gravity surveys were to attain the status of a prospsecting techniqne, it had to be tested and used in the fields and forest and not limited to towers and cities. Such extended applications had necessitated the various designs and use of measuring towers/tripods by Thyseen-Bornemisza and Stackler (1956), Thyseen-Bornemisza and Jacoby (1970), Fajklewicz (1976), and Ager *et al.* (1982). These devices were designed with the aim of enhancing the potential of vertical gradient of gravity as a geophysical prospecting tool against the background of numerous problems associated with the technique, some of which are discussed below.

2.4.1 Height of Tower / Tripod

It had been mentioned earlier on that the vertical distance of separation between the lower and upper platforms affect the measurement accuracy. It was also reported by Hammer (1938), Kuo *et al.* (1969), Thyseen-Bornemiza *et al.* (1956), and Fajklewicz (1976) that unfavourable atmospheric conditions, movement of gravimeter up and down etc. have a direct influence on the measurement error. Not only does an increase in the height of the measuring tower cause difficulties in maintaining its stability, it also prolongs the reading time of an observation and that of making a series of measurement (Fajklewicz, 1976). The height of the tower/ tripod thus plays a significant role in vertical gradient of gravity surveys.

2.4.2 Vibration:

The causes of vibration of both tower and gravimeter are transportation to and from the survey area, movement of gravimeter up and down the tower, wind gusts, touching the tower while reading the gravimeter at the upper platform, ground movement around the tower etc. (Thyseen-Bornemisza and Stackler, 1956, Fajklewicz, 1976, Ager and Liard, 1982). The effect of vibration increases with the height of the tripod/tower. A tower of small height is more resistant to vibrations than that of appreciable height but small height makes the calculation of the value of vertical gradient of gravity dependent on the gravimeter reading error (Fajklewicz, 1976). The ultimate, therefore, in tower design is for an optimum height which accommodates all the factors above and still secures a permissible measurement accuracy.

2.5 The Wooden Stool

The wooden stool is the name given, in this report to the device which provided the two platforms on which the gravimeter was placed during measurments at a location. Three major factors contributed to the use of wood as a material for the stool and its design.

First of all, compared to either aluminium or steel of same dimensions, wood is cheaper in this area.

Secondly, the design of the stool was such that only minor adjustments and preparations need to be made in the field before reading the gravimeter at the different heights. This resulted in reduction of surveying time.

Thirdly, owing to the height of the stool, which was fixed at about 1.20m, a small supporting bench about 0.40m high was needed when readings at the upper platform were being taken. This reduced height thus helped in saving surveying time also as vibrations were reduced appreciably as discussed in section 2.4.2. The wooden stool is shown in Plate I.

2.5.1 Design of the Wooden Stool

The wooden stool and its dimensions are shown in fig 2.1. It has an upper reading platform, T, of surface dimensions 0.400m x 0.400m, thickness 0.019m and made of plywood. The shape, size and thickness of the platform was to make it able to accommodate the base reading plate

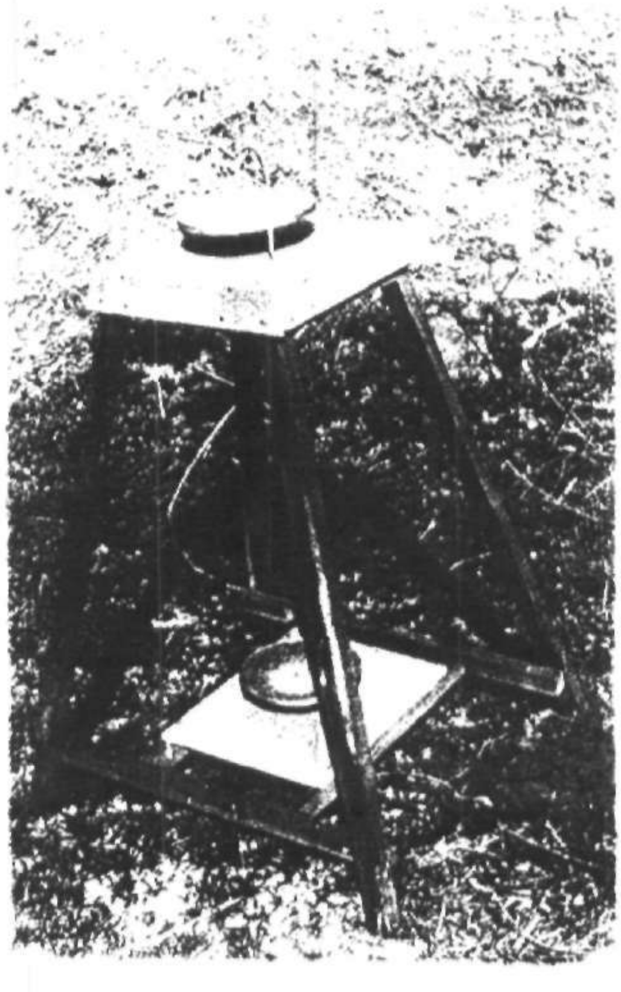

Plate I. The wooden stool.

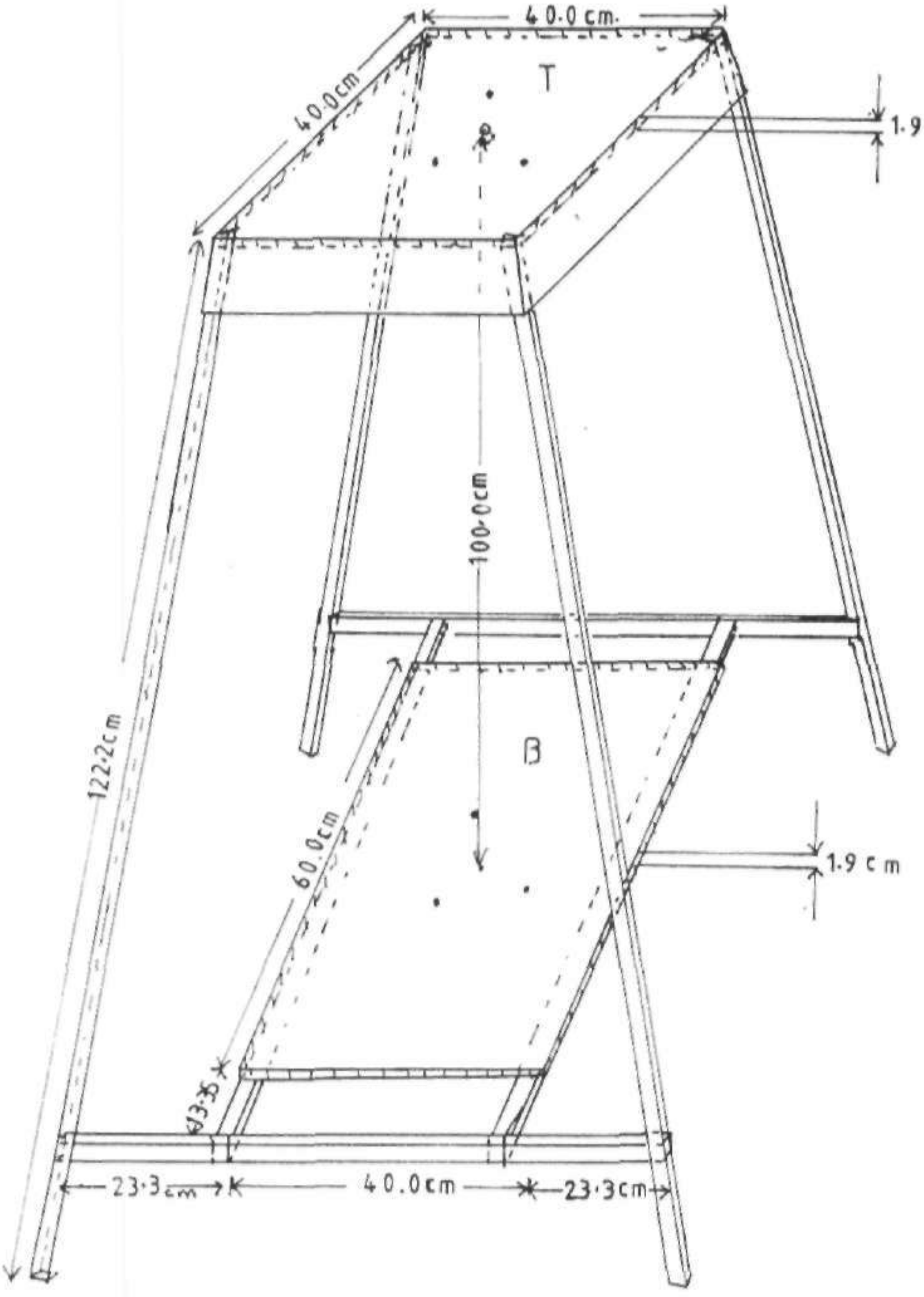

Fig 2.1 Dimensions of the wooden stool.

of the gravimeter, the gel battery, and to prevent sagging under the weights of these items. The upper platform is supported by four wooden legs of uniform cross-section area of dimensions 0.038m x 0.038m and of length 1.220m, all spreading out at an angle of 11° to provide an extended square base of 0.867m x 0.867m. The increase in its base area compared with the area of the upper platform was intended to increase the stability of the stool and its content by lowering the centre of gravity of the system. The increased stability was to ensure that the system was more resistant to vibrations.

The lower measuring platform, B, was fixed at exactly 1.00m below the upper platform T, and had dimensions 0.600m x 0.400m with a thickness of 0.019m. The lower platform was larger and hence heavier than the top platform , to ensure that the bulk of the weight of the system (stool and its content) was concentrated near the ground surface and this made the system to become more stable.

It had been reported by Fajklewicz (1976) that when the lower platform of the measuring tower is situated on the ground surface, the gravitational effect of the near-surface heterogeneity of the density distribution e.g difference in the kinds of soil, those between hardened zones and arable land, erosive subsoil surface etc. would dominate in the distribution of the vertical gradient values. Thus by moving the lower measuring platform with respect to the ground surface, frequency selection of the measured fields may be acheived from the point of view of the source- depth (Fajklewicz, (1976). Due to this consideration, the heavier lower platform was fixed at about 0.200m from the ground surface.

An error would be introduced into the vertical gradient of gravity value if the axes of the gravimeter on both platforms are not vertically aligned (fig 2.2) on both platforms.

If g_z is the vertical component of gravity at point O, then error is introduced by placing the gravimeter at B instead of O. The value of g_z read at B would be g_z Sec θ To avoid this error, a small diameter hole was drilled through the upper platform where the centre of the base plate would be located. A mark of this point was made on the lower platform.

Even when the vertical axis has been fixed and established between the two platforms, a considerable amount of time could still be wasted in making sure that the centres of the base plates were perfectly aligned at each station. To reduce the time spent on such positioning process, the positions of the three 'legs' of the base plates were marked on both platforms while the plumbline was still in place so that at any station the 'legs' of the base plates would simply be positioned on these already marked spots on the platforms. A speedy positioning of the gravimeter was thus achieved because of these repro-duceable marked positions.

The axis of the gravimeter on both platforms cannot be

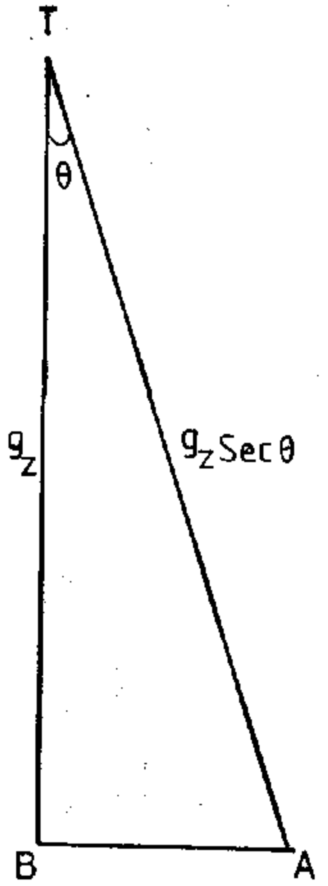

Fig 2·2 Error is introduced if Gravimeter is read at A instead of B due to non-vertical alignment said to be perfectly colinear if the platforms themselves are not levelled horzontally or horizontally parallel to one another. This was accomplished in the workshop during construction by placing a spirit-level on top of the platforms while fixing them permanently in their positions with nails.

With this constructional arrangement, all that was done at any station was to place a base plate, that has a spirit-level fitted to its centre, on the lower platform. If this platform is not horizontally level, one or more pieces of small wooden wedges would be used to raise the leg(s) of the stool in contact with the ground where the imbalance is detected. Once the lower platform was horizontal, the upper platform would automatically be horizontal and the vertical distance separating them would be exactly 1.00m, the axis of the gravimeter on both platforms would be automatically vertically aligned.

Test Trial of the Initial Design

The initially designed separation between the platforms was 1.50m and it was possible to null the gravimeter inside the carpenter's workshop probably because the arrangement was shielded from atmospheric effects. However, on the first day in the field at Zabin Zaria Station (VGG002ZA), all attempts to null the gravimeter at the upper platform was futile due to vibrations. This failure led to the re-design of the wooden stool and to the reduction of the vertical separation to 1.00m.

CHAPTER 3

FIELD PROCEDURE

3.1 Preliminary Preparations

The choice of the survey area had to satisfy certain conditions, principally due to the setback arising from the limited literature on the vertical gradient of gravity interpretation. Fortunately, the geology of the survey area had been fairly well establised and even a gravity survey of the area had been carried out. The contributions of these two previous surveys to the correlation with the vertical gradient of gravity cannot therefore be overemphasized.

Zaria area has the advantage of being situated on a peneplain which is located in the sahel region of sparse vegetal cover. It also has a long dry season (November to May) during which period any geophysical survey of this nature can be carried out. During the rainy season, most of the access roads would have become unusable because of mud cover, highly eroded sections etc. The time of survey was then tentatively fixed between January and May 1990 after the consideration of the above factors.

When the final decision on the survey area and survey time had been taken, the design and construction of the wooden stool followed. On completion, a test reading of the gravimeter was successfully carried out at the platforms that were initially separated by a vertical distance of 1.50m.

The confidence acquired from the succssful design, construction and testing of the wooden stool resulted in the actual preparation for the field work. The following topographic maps of the survey area were collected:

1:50,000 Zaria Sheet 102 (NE, NW, SW, SE - 4 sheets)
1:100,000 Zaria Sheet 102 (single sheet) and
1:50,000 Igabi Sheet 124 (NW and NE - 2heets).

From these maps, locations of features such as all-seasonal roads, minor seasonal roads, tracks and foot-paths, oil pipeline, railway tracks, streams, hills, wooded forest areas, farmlands, valleys, swamps, settlements etc. were noted and their positions were used as guides in the planning of distribution of stations to ensure a uniform spread. These also helped in deciding on the choice of survey routes within the area.

3.2 Observation of the Gravimeter

For any vertical gravity gradient survey, the most important instrument is the gravimeter. It's functioning or malfunctioning will determine the possibility or otherwise of conducting the survey. The proper functioning would enable the determination of its true drift charcteristics and the tidal gravity effect. It would also enable the sensitivity of the instrument to be monitored. To determine all these, the gravimeter model G512 was observed for three days inside the Geophysics Laboratory prior to the field work. It also became necessary to check the calibration constant of the instrument to see if re-calibration was required. To avoid errors due to instrument performance the above routine observation was repeated after the field survey. The two drifts were still evident but occured at higher instrument readings.

3.3 Field Procedure

When the collection of the field equipment was completed, a field party was constituted and made up of the author, a driver, and a field assistant. With the improved design of the stool, careful gravity measurements were made at 121 stations fairly evenly distributed throughout the survey area and mostly in towns, cities, structures of fairly permanent natures like road junctions, river and road junctions, rail-crossings etc. in the month of May 1990.

The daily survey was always started from Physics Department, Ahmadu Bello University, Zaria in Samaru area; the choice of which direction to follow was random such that in any two consecutive days, direction of routes could be North-west of Zaria on one day and Eastwards the next day.

At any station, a relatively horizontally level ground surface would be located, at least about 10.00m radius from valleys, hills, large buildings etc. to reduce the effect due to terrain irregularities. The point would also be at least 20.00m from roads to reduce the effect of ground vibration. The stool would be hand-carried gently from the van and placed on its legs. The base plates would be placed on the previously marked positions on the platform with the base plate on the lower platform containing a spirit-level with which the horizontality of the platforms was ensured using the small wooden wedges to support the leg(s) of the wooden stool. At times, it was necessary to remove a small layer of sand or mud from the position of one of the legs of the wooden stool, a process the termed "preliminary site preparation" and which took a maximum of two minutes to accomplish. Once the lower platform was fixed on a horizontal level, the vertical separation between the tops of the base plates was automatically set at 1.00m and vertically aligned. The gravimeter would then be read at the lower platform B (for bottom) and then at the upper platform called T (for top). The process would then be repeated to get two additional readings; one for the lower platform and the other for the upper platform. Most of the readings at B and T were repeated and the averages taken. Whenever it was observed that the gravimeter readings were erratic, all the readings at that station were repeated several times until reasonable and steady values were obtained.

3.4 Preliminary Site Preparation

Vertical gradient of gravity is terrain sensitive and to avoid this problem requires that the station surrounding should be flat. This is not always the case in the field and a preliminary site preparation is necessary to achieve this objective. This is accomplished by choosing a relatively flat site to stand the stool vertically. If the spirit level placed on the lower platform shows tilting to any side, the leg of the stool on that side is raised with the aid of small wooden wedges. This process does not result in any appreciable loss of time since it normally takes a few minutes to achieve. It may atimes be necessary, especially in sandy or muddy sites to use a hoe or cutlass to remove some soil materials before this horizontal levelling is achieved.

3.5 Data Collection

The data normally collected at each station included:

(i) the date of survey
(ii) the station name and identification number
(iii) four average gravimeter readings, two at B and two at T
(iv) height of the gravimeter above the edge of the base plates
(v) local time taken for each reading of the gravimeter including intervals between readings.

Sample data recordings are given in appendix A. To ensure consistent results, some of the precautionary steps taken were against:

(a) Wind Gusts

The wooden stool was always mounted in a location shielded as much as possible from direct wind and atmospheric effects. Such readings were thus taken around school buildings, health clinic verandahs, use of sides of the van as wind shields, etc. As much as possible readings were taken during short intervals between spells of wind.

(b) Thermal Shocks

It was reported by Osazuwa and Ajakaiye (1982), that exposing the gravimeter to direct sunlight and heat leads to thermal shock of the gravimeter. A large, fixed umbrella was used to protect the gravimeter from direct heat and sunlight when it was read in the open field.

(c) Vibrations

The carrying of the gravimeter to and from the upper platform was always done with great care, caution and gently to reduce the vibration of both gravimeter and stool. The gravimeter was never touched when reading on the upper platform. Readings were taken far from roads to reduce effect due to ground movements(traffic). Also a few minutes was normally allowed after arranging the gravimeter and stool before readings were taken at the platforms to reduce the effect of vibration due to handling and transportation.

CHAPTER 4

DATA PROCESSING AND ANALYSIS OF RESULTS

4.1 Corrections to Vertical Gradient of Gravity data.

The vertical gradient of gravity values determined at a point depends on, among other factors; the density distribution of masses in near-surface rocks, the height of the point above mean sea level, the behaviour of the instrument used, the gravitational effect of the tide. It is intended in this survey to show the special relationships between the vertical gradient of gravity and the above mentioned factors.

4.1.1 Drift Correction

The drift curves of fig. 4.1 are made up of both instrumental and tidal drifts. Taking a maximum drift rate of 0.00139 mgals, (obtained from the steepest part of the drift curves), for each vertical gradient of gravity (VGG) value obtained on the average of four minutes gives a vertical gradient of gravity rate of 14E. The minimum value of VGG for Zaria area is 2682E and a drift rate of 14E gives 0.52% of this minimum value. For the maximum value 3842E obtained for the area, the drift is 0.36%.

4.1.2 Terrain Correction

It had been reported that vertical gradient of gravity

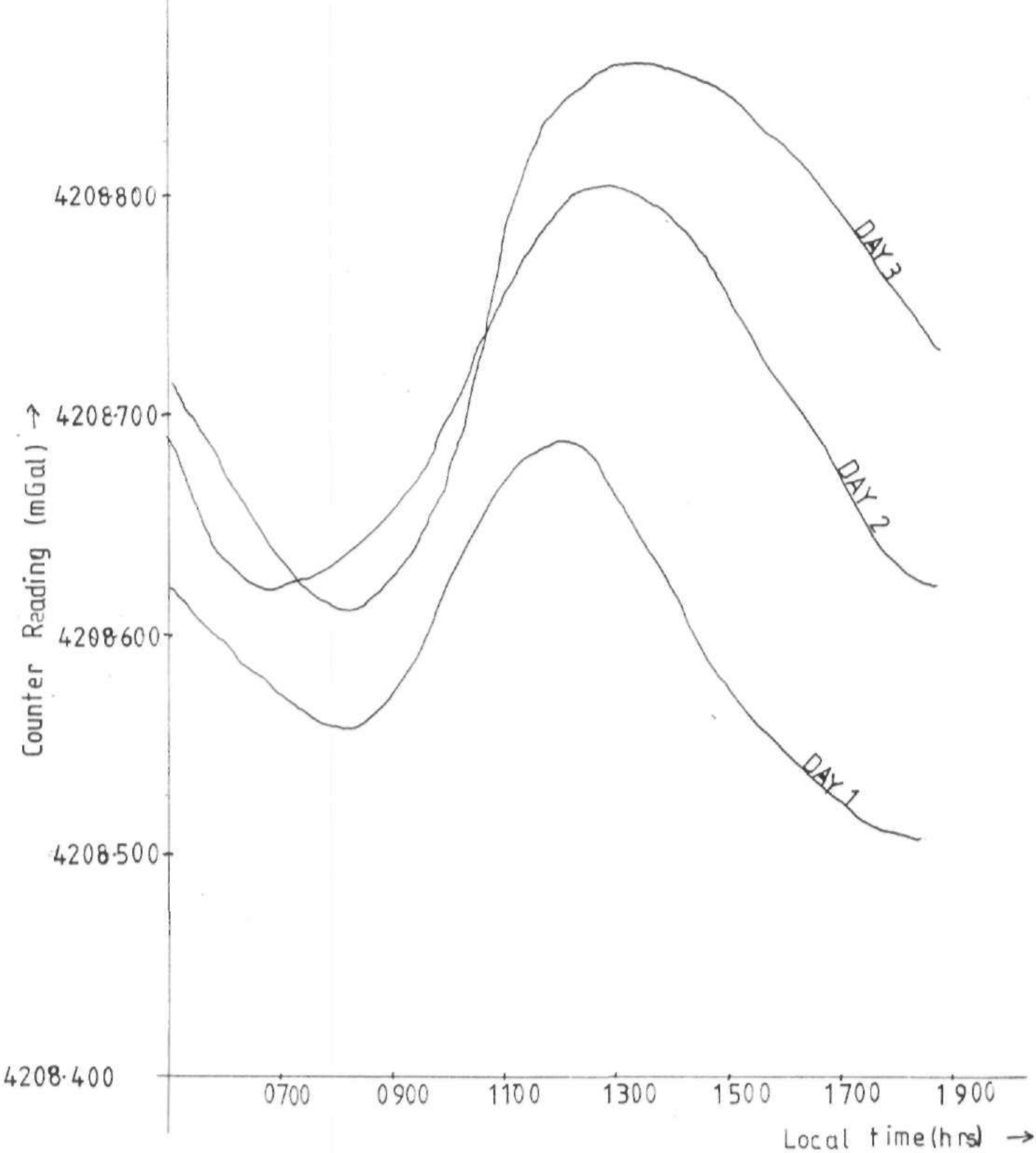

Fig. 4.1 Drift Curves for G512. LaCoste - Romberg.

value obtained for a point is terrain sensitive (Thyseen-Bornemisza *et al.* 1956; Kuo *et al.*, 1969; Fajklewicz, 1976 and Ager *et al.*, 1982). However, it was proposed by Thyseen-Bornemisza (1972) that if accurate gravity measurments are taken over a relatively flat area, the strong and unpredictable anomalous vertical gradients should deserve special attention. Zaria lies in the Northen peneplain and thus variations in gradient values should be more related to other factors than topopraphy or terrain. Height determinations above mean sea level in the area varied from a minimum of 622.27m (VGG002ZA) Zabin Zaria to a maximum of 696.69m (VGG077ZA)Ungwan Tsauni, as shown in Appendix B. The maximum height gives a maximum topographic correction of 0.022 mgals. This value reduces as the height of station above mean sea level reduces.

4.2 Calculation of VGG Values from Data

From the four average gravity measurements made, two at the bottom and two at the upper platforms, three vertical gradient of gravity values were calculated on the average time interval of four minutes. The gravimeter readings were first converted to mgal values and the differences calculated since the vertical distance between the platforms was 1.00m. A fourth value was calculated to check the effect of drift and its value was got from the difference between the first bottom platform reading and the last top platform reading, sometimes within the average time interval of 15 minutes. Errors introduced by these fourth values varied on the average from ±0.1% to ±1.0%, still confirming that consideration of drift correction within the interval was unnecessary. From the four values of the vertical gradient of gravity thus calculated, an average value for the station was calculated. These average values were used for the production of the vertical gradient of gravity map of the area.

4.2.1 Discussion of Errors

Some of the factors that affect the vertical gradient of gravity values determined for a point had been discussed and their contirbutions assessed. It had also been mentioned earlier that errors in VGG surveys arise because of the observer, the instrument performance and the measurement process itself or a combination of these and other factors. Some of the errors associated with the measurement process are given below:

(i) Non-Alignment of Vertical Axis of Gravimeter on Both Platforms

There is always a possibility that the axis of the gravimeter at the two platforms may not exactly be vertically aligned due to the levelling process. This would introduce an error depending on the degree of deflection as shown in fig 4.2. with the diameter of the base plate (levelling disc) of 26.50cm and the gravimeter dimensions of 17.00 x 19.00cm, the maximum possible deflection from the vertical axis would be 5.0cm. For a vertical distance of 100.0 cm corresponding to a global value of the VGG around

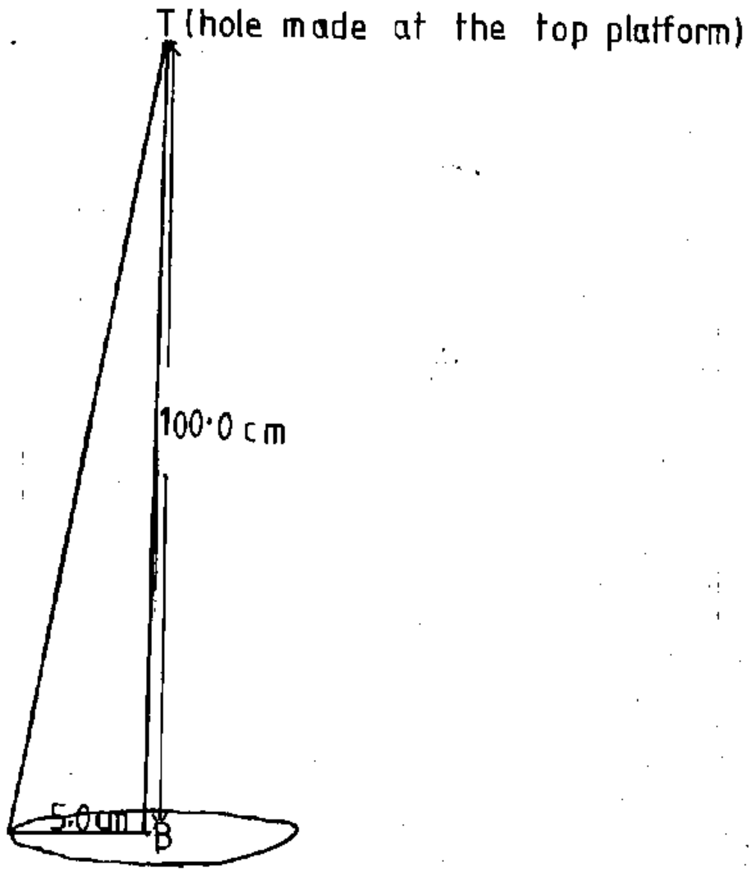

Fig 4.2 Maximum possible shift from the vertical alignment.

the geographic equator as 3088E, this deflection amounts to a height difference of ±0.1249 cm and gives an error of 3.856E.

(ii) Location of Stations on the VGG Map from the Topographic Maps

The process of locating stations on the VGG map from the topographic map would introduce an error resulting in a shift of stations in the vertical gradient of gravity map with respect to the longitude and latitude positions on the topographic map. As much as ±1' can be introduced in these positions taking a topography map of accuracy ±1'. The global change in VGG value from the geographic equator, 0°, to latitude 45°N of the equator is 2E i.e from 3088E to 3086E. This gives on the average a value of $\pm 7.4 \times 10^{-4}$E.

The total error due to the measuring process is thus ±4.06E.

4.3 The Vertical Gradient of Gravity Map Production.

A scale of 1:360,000 was chosen on a 1.0cm x 1.0cm graph paper and the values of longitudes and latitudes on the topography map were used to locate stations on the graph sheet. The vertical gradient of gravity values calculated from data were written on these locations and the VGG contour map was produced with a contour interval of 200E. Fig 4.3 shows both the VGG values and the contour map. The trend of the vertical gradient of gravity values was carefully observed before drawing the contours.

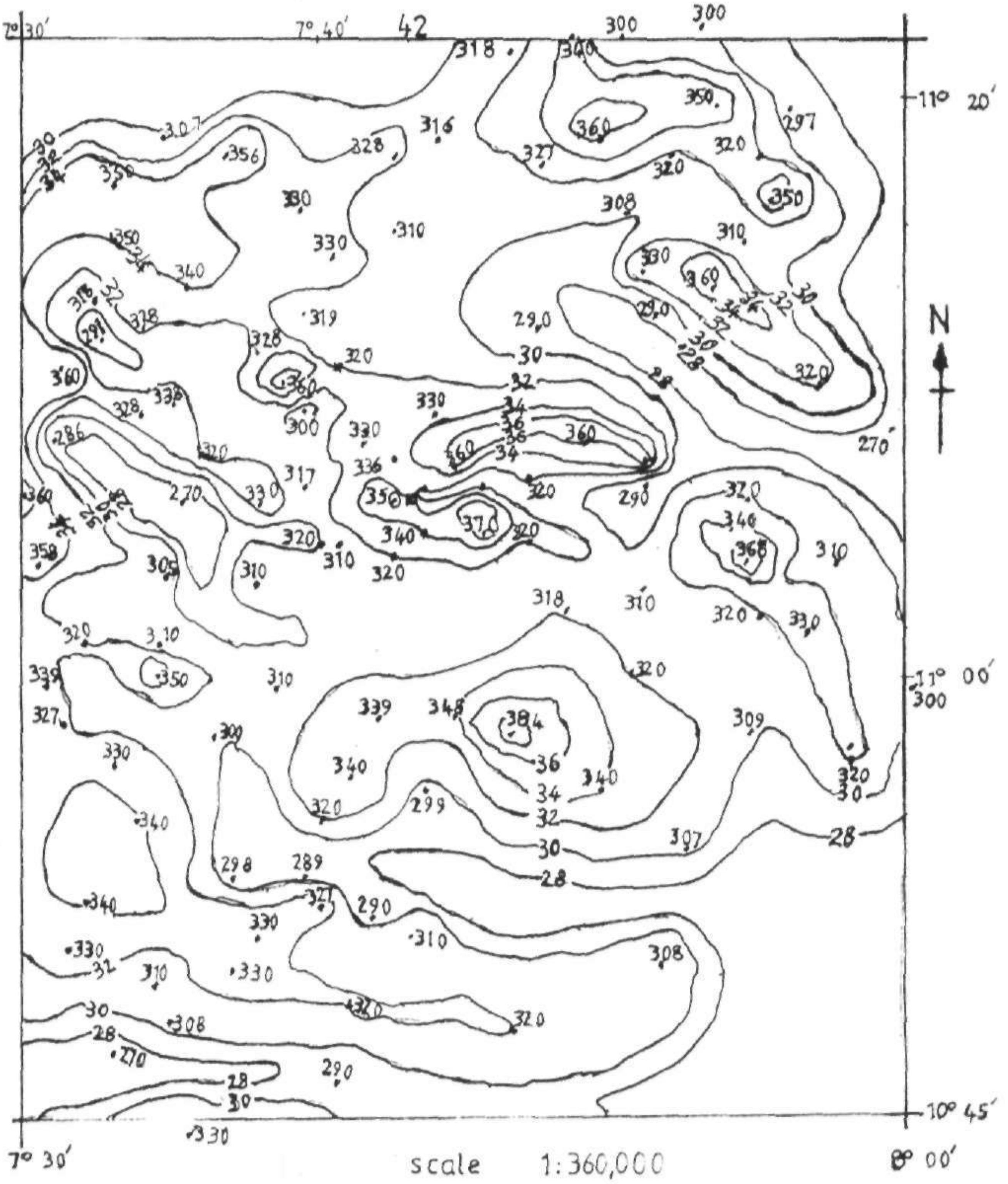

Fig. 4.3. Vertical Gradient Of Gravity map of Zaria area superposed on station values (x-10E). Contour values (x-100E). Contour Interval is 200E. 0 7.2 km

•Station (Data point)

4.4 Correlation with Previous Related Surveys

A look at the produced vertical gradient of gravity map shows some striking similarities between the map and the geologic, free-air and residual anomaly maps produced for this area by previous workers (McCurry, 1970 and Adeniyi, 1987). It was then decided that a qualitative interpretation of the VGG map with these other maps be done. Vertical gradient of gravity surveys can be used to:

(i) determine the density of subsurface and surface rocks in mineral exploration,

(ii) correct gravity surveys,

(iii) determine the earth's curvature parameters in geodesy,

(iv) detect faults and faulted zones.

Correlation here seeks to achieve one or more of these uses from the present survey.

4.4.1 Correlation with the Geology of the Area

The geologic map (fig. 1.2) was superposed on the vertical gradient of gravity map (fig. 4.4) to correlate them effectivelly and the resultan map is shown on fig.4.5. It had been suggested by Thyseen-Bornemisza (1972) that in a relatively flat terrain, fluctuations of the vertical gradient of gravity are caused by surface density contrasts originating from usual lithological features. It had also been reported by Evjen (1938) that the vertical gradient of gravity map gives a sharper picture and defines better the edge of a structure.

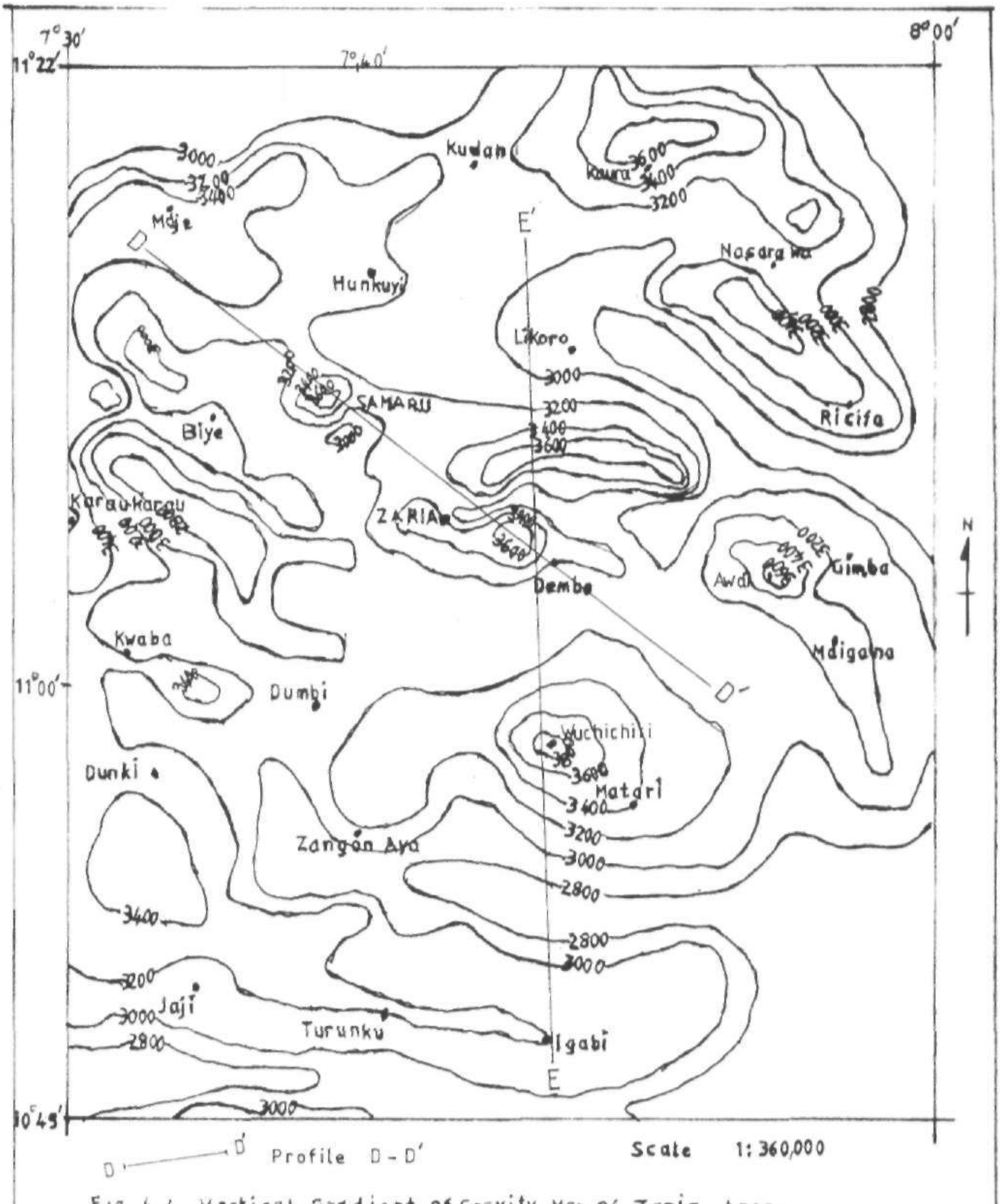

Fig. 4.4 Vertical Gradient Of Gravity Map Of Zaria Area.

Contour interval is 200E. Contour value is x−1E.

0 7.2 km

• Town (Data point).

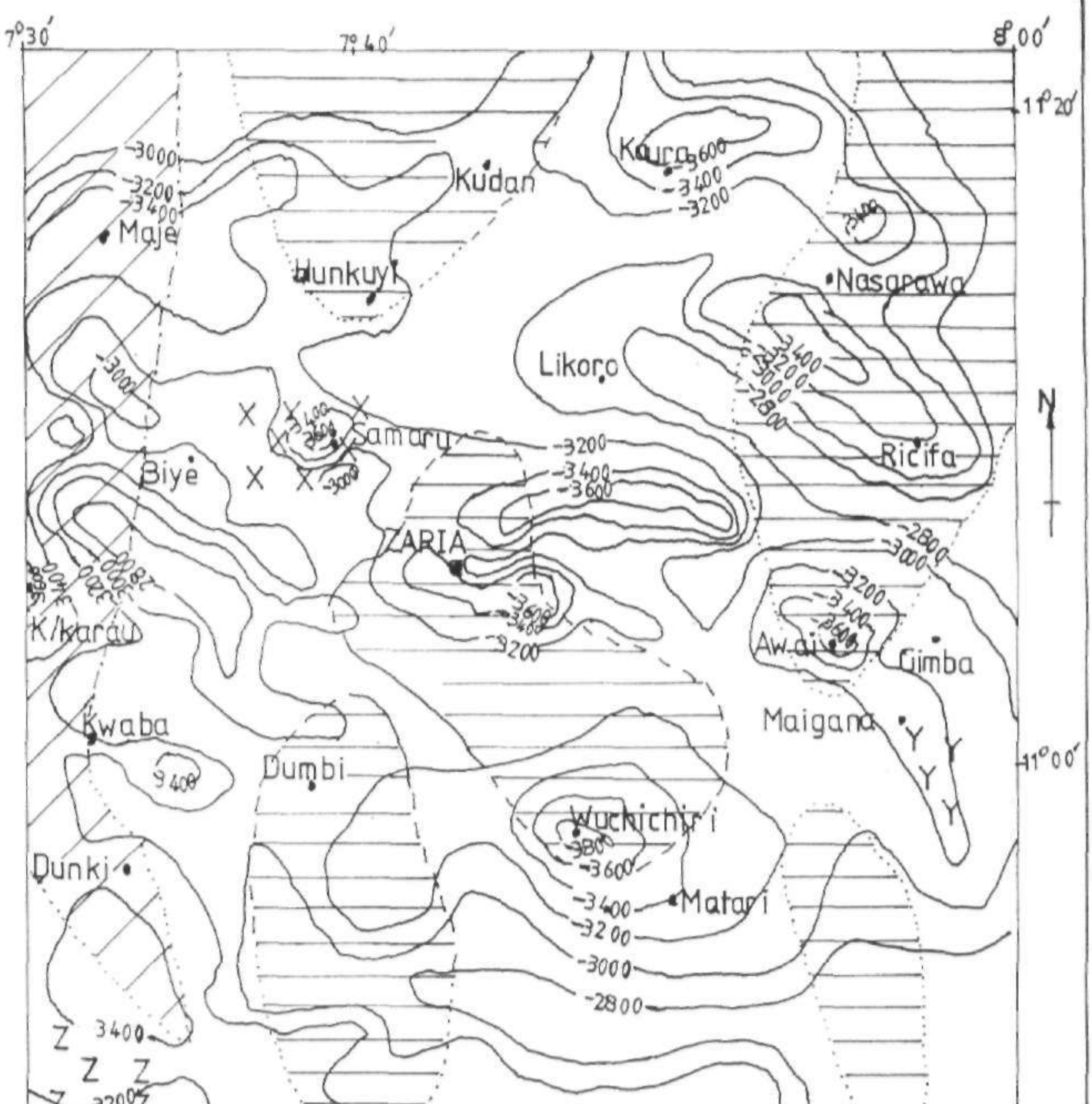

Fig 4. 5 Zaria area Geologic map superposed on the Vertical Gradient of Gravity map of the area. Contour interval, 200E. Geologic information as in Fig 1.2

▤, X X X Older Granite

☐, Y Y Y Gneiss, Orthogneissic

▨, Z Z Z Metasediment

0 ——— 7·2km

———, — — — —, ... OBSERVED, APPROXIMATE & INFERRED GEOL. BOUNDARIES RESPECTIVELY

According to the density values determined by Adeniyi (1987) for the rocks in the survey area, the average density of granite is 2.60 x 10^3kg/m^3, while that of gneiss is 2.7 x 10^3kg/m^3 and mafic xenoliths have a mean density of 2.82 x 10^3kg/m^3. Also from the geologic map of the area produced by McCurry (1970), it can be observed that the whole area was generally intruded by the older granites except the southeast part. The older granite intrusions clearly correspond to lowest VGG values of between -3400 to -3800E and are pronounced in areas around Samaru, Zaria, Wuchichiri, Awai and below Nasarawa. Areas of low VGG values (between -3200 to -3400E) correspond to the metasediments found on the western part of the survey area trending North-South from Maje down to below Dunki. The areas of high VGG values (between -2600 to -3000E correspond to the gneisses mostly and other higher density rocks.

It should be borne in mind that the geologic boundaries were mostly inferred and that the VGG map gives a better definition of the edges of a structure. However, the older granite intrusions around Hunkuyi, Kudan, Dumbi, Zango Aya did not show up on the VGG map. Instead, they have appeared as low VGG value areas. Other factors , aside density, may account for this disparity.

It should also be noted that the VGG map indicates the extent of mass alteration and this may explain some of the disparities observed.

From these considerations, therefore, there seems to exist a direct relationship between the VGG values and the corresponding rock densities, the denser the rock, the higher its VGG value.

4.4.2 Correlation with Free-Air Anomaly Map

Vertical gradient of gravity is essentially a free-air effect especially in a region where the geology is homogenous and can be got from conventional surface gravity surveys. However, it should be remembered that a constant global value 3086E had been used in obtaining the free-air anomaly map while the vertical gradient of gravity is actually a variation of this parameter. The free-air anomaly map of the area (Adeniyi, 1987) is shown in fig 4.6. Comparison of the figure with fig 4.4 shows some similarities in terms of high closures around Zaria, Samaru, Karaukarau and Awai. It also shows identical contour lines on the western side of the area from around Maje down a N-S trend to below Dunki. The general trend in fig. 4.6 of increasing contour values from the Northeastern part of the area to the Southwestern part is not so obvious in fig. 4.4. This is due probably to the fact that in free-air effect, the effect of the masses that form the topography have not been taken into account. Thus differences are bound to appear between these two maps - because assuming a constant value for free air effect makes it a regional effect while the variable VGG values used in this survey are sensitive to local gravitational effects. This emphasizes the importance of using the local VGG values for stations when local gravity survey is to be carried out.

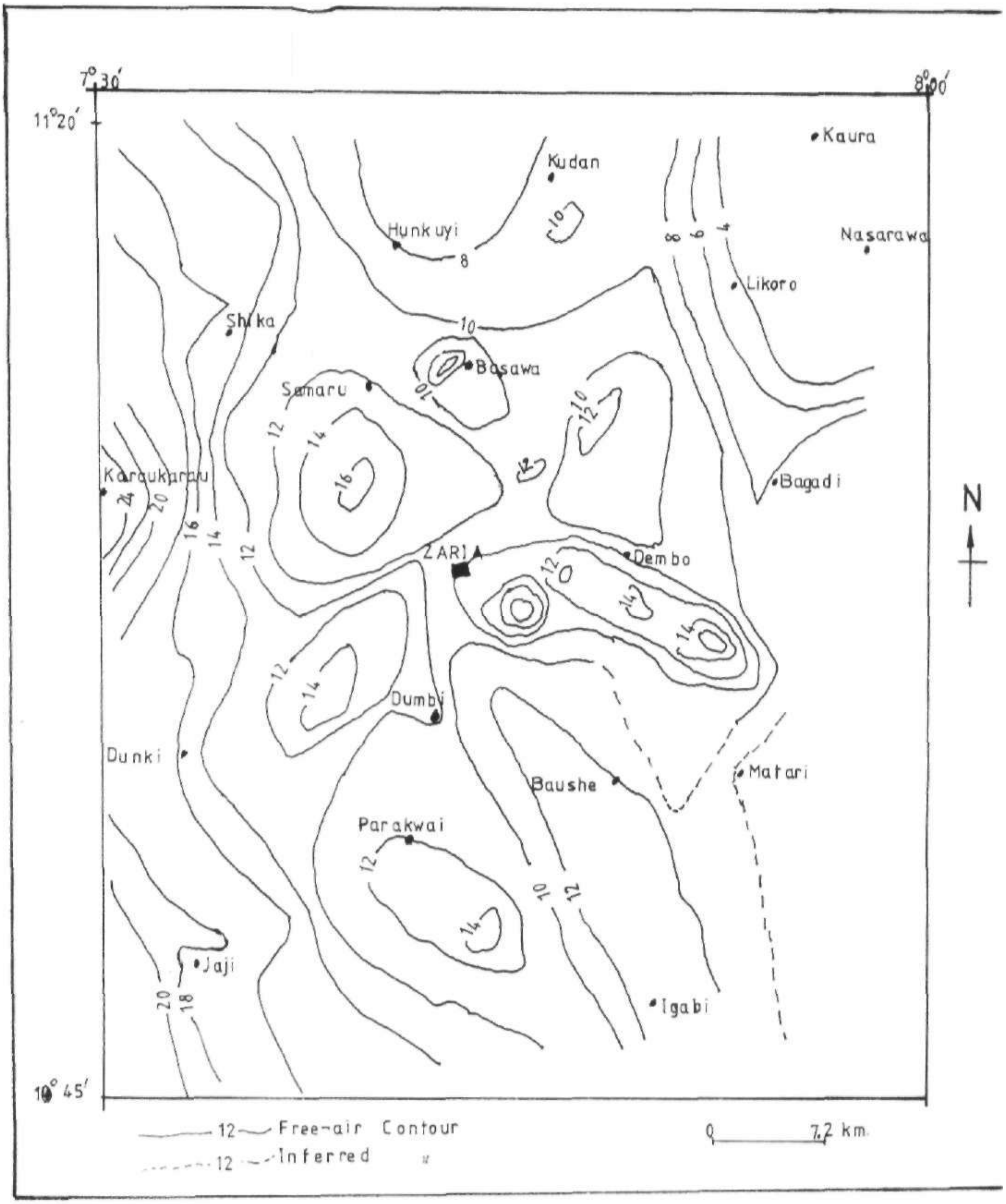

Fig. 4.6 Free-air anomaly map of Zaria area. Contour interval at 2 mGal. [After Adeniyi 1987].

4.4.3 Correlation with the Residual Anomaly Map.

The residual anomaly is got by removing the regional trend from the Bouguer anomaly. The regional trend originates from the gradual variation in the density of deep seated earth material and is normally considered to be of long wavelength and shows a gradual variation in gravity values. TheBouguer corrections for this flat lying area should have approximately constant values, thus the residual anomaly and the free-air anomaly will present more or less the same picture. However, the residual anomaly varied a little from the free-air anomaly of the area due to the influence of the regional trend on the Bouguer anomaly. Comparing the VGG map of fig. 4.4. with the residual anomaly map of the area (Adeniyi, 1987) shown in fig 4.7 shows that the low closures of the residual anomaly map correspond with the low closures of the VGG map in areas around Samaru and Zaria. The low closure at Dumbi in fig. 4.7 have been displaced relatively to the east in fig. 4.4 of low closure (-3800E). The low VGG values around Kaura and Nasarawa (-3400 to -3600E) now coincide with the lowest residual anomaly value in the whole area of -12mgals. Thus the direct relationship between the VGG values and the density of the rocks is reproduced here with the residual anomaly values.

However, there is an interesting case in Karaukarau area. While the VGG has low values trending N-S, the residual anomaly value is now the highest (+2mgals)- again trending N-S. The direct relationship between VGG and residual

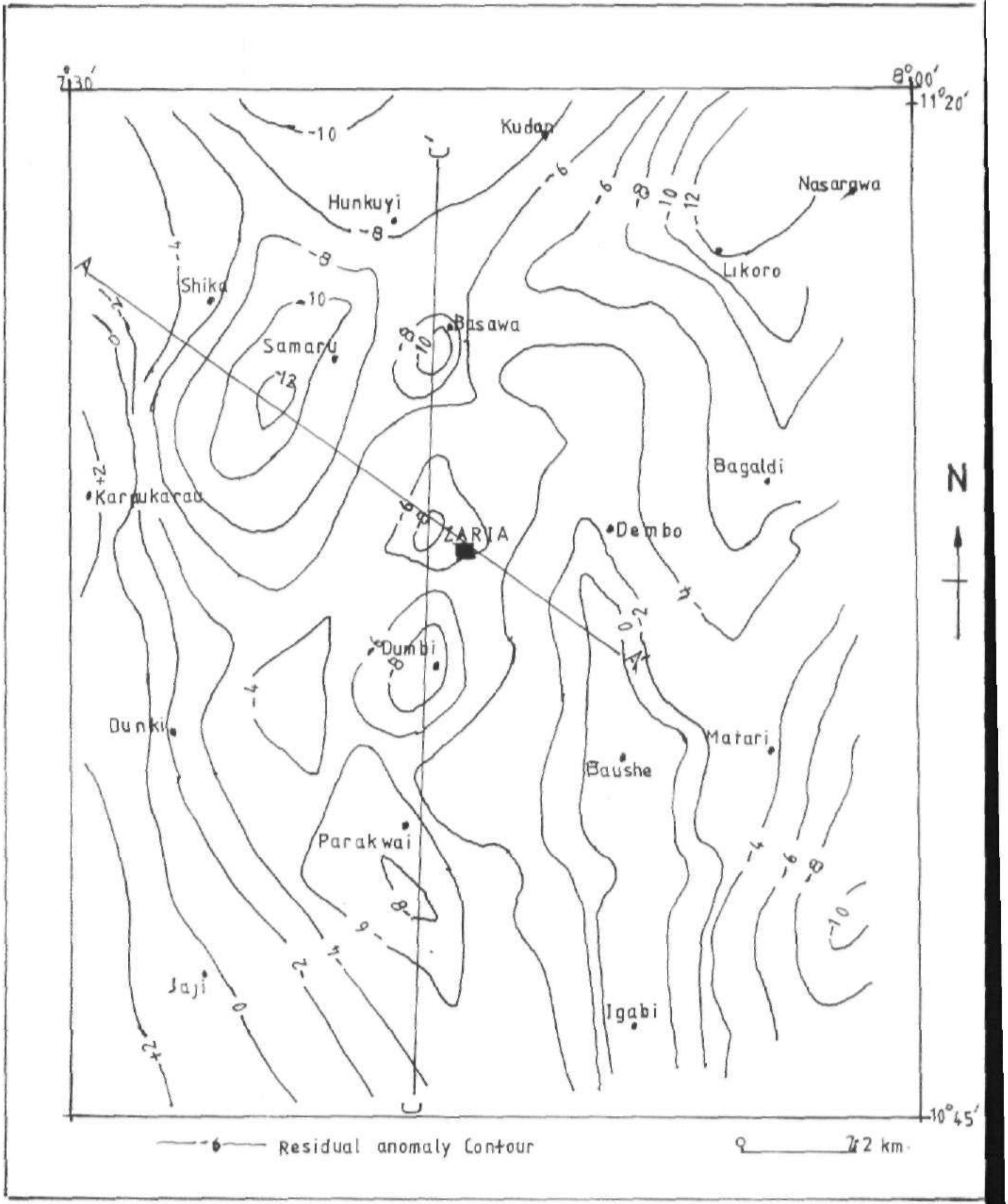

Fig 4.7 Residual anomaly map of Zaria area. Contour interval at 2 mGal with profiles A – A′ and C – C′. [After Adeniyi 1987]

anomaly is not obeyed here. Other factors e.g a N-S trending fault or fold or ridge that has been dissected by river erosion may account for this observation.

To further correlate the two maps, profiles DD' and EE' of fig. 4.4 are plotted in figs. 4.9 and 4.11 respectively and then compared with profiles AA' and CC' respectively of fig. 4.7. The corresponding plots along the profiles are shown in figs. 4.8 and 4.10. It had been reported by Evjen (1938) that the VGG is apt to behave erratically due to shallow irregularities. However, closures in a VGG map drawn over a relatively flat area would not be interpreted as erratic, moreso when the closures bear a direct relationship with the geology and the residual anomaly map of the area and also since the VGG map did not not show any bearing with the topography. As was stated earlier that the vertical gradient of gravity gives a sharper picture, a better structural resolution and defines better the edge of a structure, the agreement between the residual anomaly profiles and that of the VGG profiles confirms the presence of anomalous structures (batholiths and conduits) in Samaru and Zaria as reported by Adeniyi (1987).

In fig. 4.4., the profile EE' was relatively shifted to the east when compared with profile CC' of fig 4.7 to enable the closures on both maps be correlated.

There are three promiment closures around Wuchichiri, Zaria and Farin Kasa on profile EE' of fig. 4.11 as compared to four closures along profile CC' of fig. 4.7 around Zaria, Bassawa, Dumbi and Parakwai. The Dumbi-Parakwai closures of

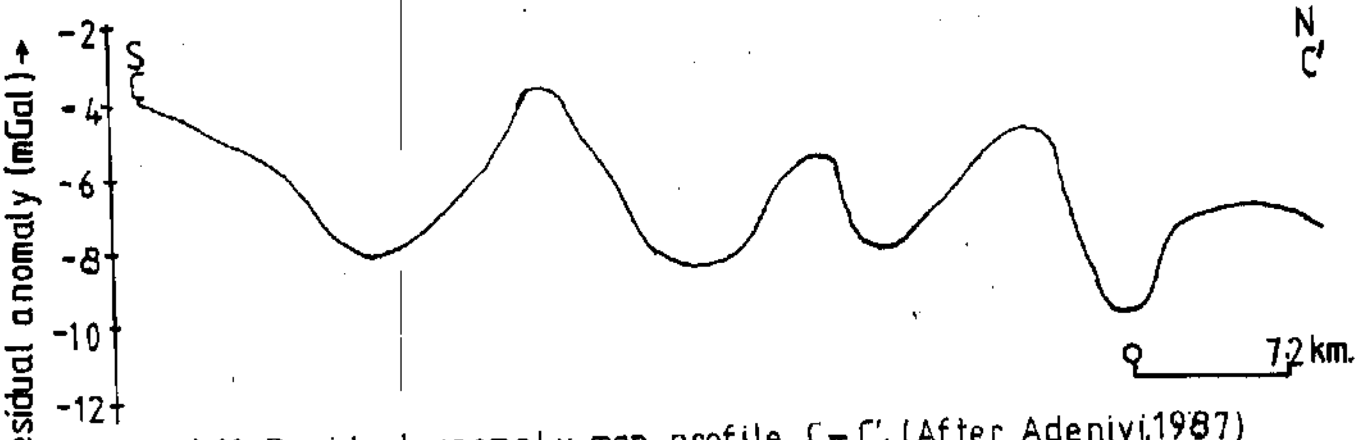

Fig 4.10 Residual anomaly map profile C – C′. (After Adeniyi,1987)

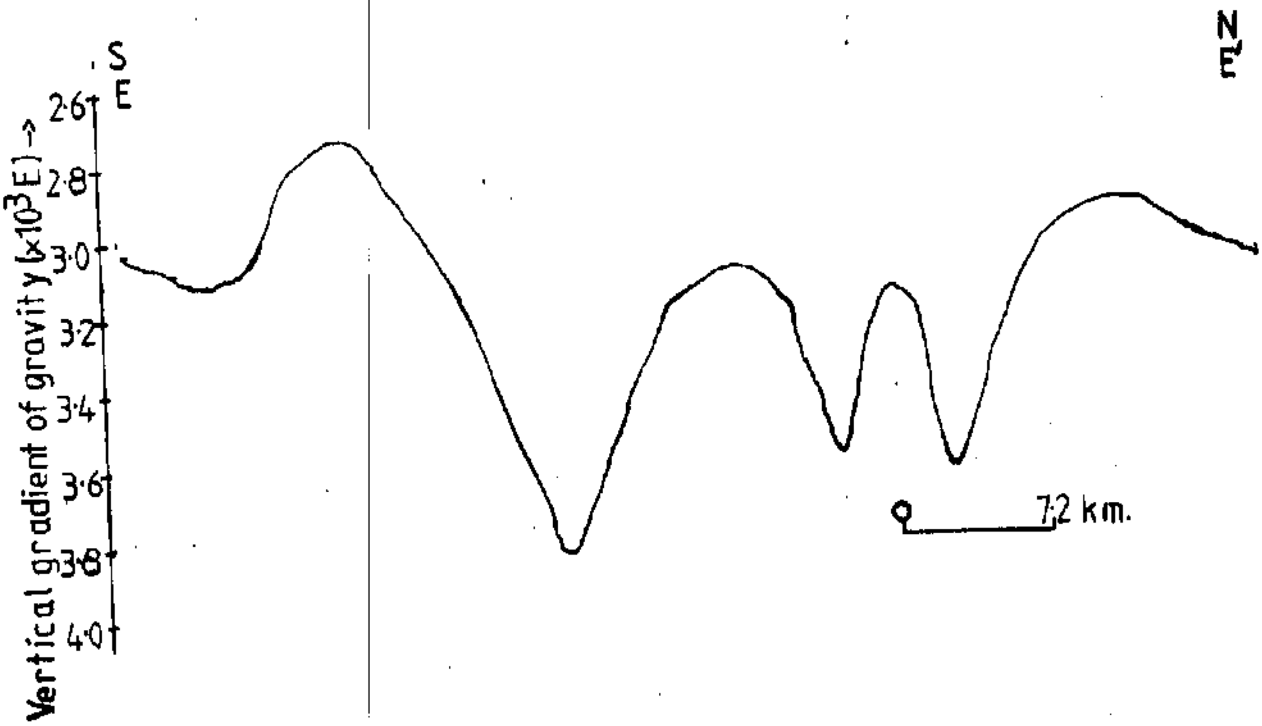

Fig 4.11 Vertical gradient of gravity profile E – E′

fig. 4.7 appear to have been displaced eastwards in fig. 4.4 to form the Wuchichiri closures. These relative shifts of the closures can be accounted for by one or a combination of the factors listed below:

(i) poor geographical location of the stations while producing the maps

(ii) poor boundary or edge of structure determinations of the residual anomaly map and

(iii) poor separation of regional background from the Bouguer anomaly in the process of producing the residual anomaly map.

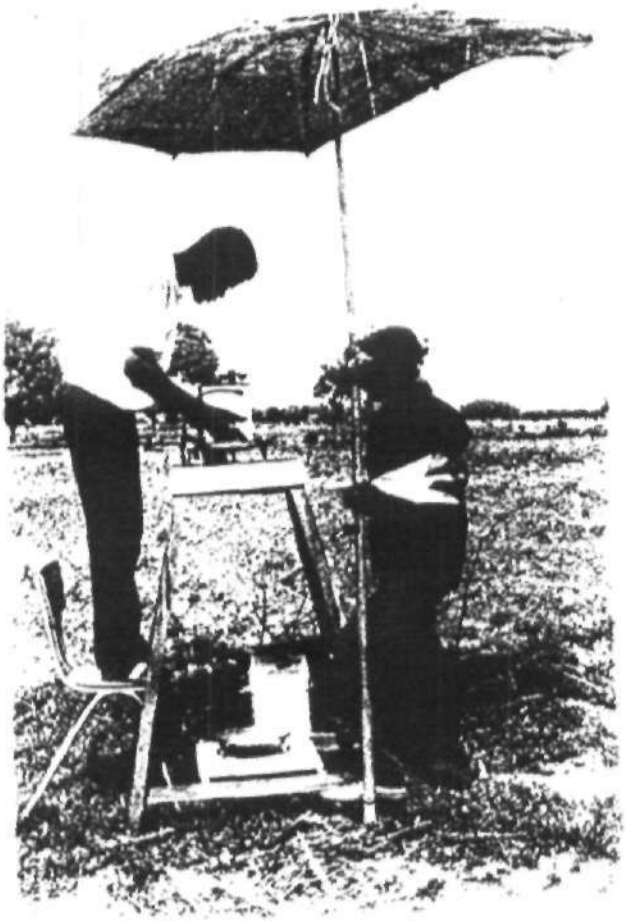

Plate II. Prospecting with a two-man crew.

saving time since it was not necessary everytime to check on the vertical alignment once the 'legs' of the base plates were in their marked/fixed positions on the platforms and once the lower platform was horizontally levelled.

5.2 Limitations of the Wooden Stool

Inspite of the advantages and the design facilities provided which were discussed in the previous section, there are some inherent operational precautions that must be taken in using the stool. These are discussed below.

5.2.1 Fragility

By its nature, wood is more fragile than an equal dimension of metal. This fragile quality was further weakened by the type of joining used for the construction of the ends of the stool. Thus, if a survey area is undulating and traversed by bumpy access roads, vibrations are set up in the various parts of the stool during transportation. This can affect the vertical and horizontal alignments of the platforms. To prevent this, it is adviceable to always lay the stool on a foam mattress at the back of the truck. It should also be carried down care-fully at every station, preferably by two persons. It is necessary to recheck on the alignments occasionally after the day's field work. This should not constitute a major problem for any survey once an extra care is taken in the form of the above precautions.

5.3 Discussion of Result

It had been reported by Fajklewicz (1976) that the measured distribution of the gravity vertical gradient should not be determined from the differences in gravity between two points positioned in the vertical when one of the points is situated on the ground surface. In such a case the gravitational effect of the near-surface heterogeneity of the density distribution would dominate in the distribution of the gravity vertical gradient. By moving the lower measuring plate with respect to the ground surface, frequency selection of the measured fields may also be made from the point of view of the source depth. The results of earlier surveys by Thyseen-Bornemisza et al. (1956) etc. reflected the gravitational effect of the heterogenous mass ditribution in near-surface rocks rather than the structure itself. However, by raising the lower measuring plate, 10.0cm from the ground surface Fajklewicz (1976) was able so detect some small geologic and anthropogenic forms. Also, Ager and Liard (1982) working in British Columbia, raised the lower measuring plate by 15.0cm from the ground surface and his result showed that about 15% of the VGG variations were contributed by the geoloogic structure itself.

In this survey, the lower measuring plate was raised about 20.0cm from the ground surface and the agreement of the results obtained with the geology and residual anomaly maps of the area shows that structures of geologic importance can be detected with the VGG technique without elaborate topographic corrections especially in a relatively flat area.

5.4 Conclusion

From this survey, it is now obvious that there is no justification whatsoever not to prospect with the vertical gradient of gravity method on the excuse of non-availability of light metal material in a country like Nigeria where hardwood is in abundant supply and relatively cheaper than aluminium and iron.

For conventional gravity surveys, the free-air effect had always been given a global constant value of 3086E. This value has now been shown to be regional (Torge,1989) and only realised at not less than 40.0m above the terrain level. The regional effect cannot be utilised in prospecting near the earth's surface. Thus for any local gravity prospecting to be meaningful, the local value of the free-air gravity i.e the vertical gradient of gravity values must be used for the free-air corrections. This survey, with it's high variability in the value of the vertical gradient of gravity in Zaria area has underscored this point. The agreements of the results of this VGG survey with the geology of the area and the residual anomaly map confirms the potential of prospecting with the vertical gradient of gravity method using a wooden stool.

5.5 Suggestions for Further Work

This experimental survey involved the design, construction and use of a wooden stool in obtaining gravity data for the determination of the vertical gradient of gravity map of Zaria area. Some precautionary steps to be taken in connection with the use of this stool had also been discussed in earlier sections. To further enhance the quality and confidence of results to be obtained while using the VGG technique, the following suggestions are made.

5.5.1 Wooden Stool Modifications

The following modifications are suggested in connection with the design, construction and use of the wooden stool.

It is necessary to increase the vertical distance between the lower and upper platforms if measurement accuracies of the order of 20E are required for a gravimeter of reading accuracy 0.01 mgals. All the problems enumerated in connection with increased height must be solved, the most serious being the vibrations set up in the system. One method is to increase the weight of the stool at its base so that it becomes more stable. This can be achieved by using a lower platform of increased weight. The other method may be the rounding up of the legs of the stool so that the wind speed at which turbulence sets in is increased i.e making it more streamlined. Widening of the base would also result in a more stable system if it will not make it become too bulky.

As a prospecting device, the stool must be rugged if it is to withstand any prolonged field use. The vibrations due to the moving truck, the sudden jerks on the application of vehicle brakes etc. should not have effect on the alignment of the vertical and horizontal axes of the stool. It is being suggested that the type of joining, the type of glue used for the joints, nails and other materials used in holding the different parts of the stool together should result in a more rugged stool.

5.5.2 The Vertical Gradient of Gravity Map

The closures of the vertical gradient map were obtained by observing trends in the distibution of the VGG data. The agreement of these closures with the geology of the area and those of the gravity residual anomaly map suggest that the VGG anomalies have some physical significance. The fact that the VGG anomalies correlate fairly well with the free-air anomaly and in particular the geology of the area implies that a constant value of 3086E often assigned to it during gravity data processing may be misleading. The variations in the VGG values in this survey are so prominent that it has become necessary to use the local values in getting the free-air anomaly map in local surveys. The values of the VGG obtained in this survey should be used to correct the free-air values of the previous gravity work done in this area. The resultant residual anomaly map would then be correlated with the VGG map produced in this work. The outcome may explain the shift or displacement of the closures discussed earlier.

It is also suggested that a quantitative correlation be done so that the relationship between the lowest VGG values and the location of the Older granite intrusions and between high VGG values and high density metamophic rocks be determined. The information so obtained may help in updating the present knowledge of the geology of the area.

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APPENDICES

APPENDIX A

Sample Data for G512

S/No	Date	Station	Mode	Local Time (hrs)	Instrument Reading
25	5-5-90	Giwa	B	1257	3974.161
		VGG025ZA	T	1303	3973.879
			B	1309	3974.165
			T	1313	3973.878
26	5-5-90	Marke	B	1512	3954.460
		VGG026ZA	T	1514	3954.169
			B	1520	3954.457
			T	1525	3954.168
27	6-5-90	AD4	B	0621	3953.565
		VGG027ZA	T	0626	3953.286
		(Village	B		
		between			
		U.P.E and		0630	3953.568
		Dumbi)	T	0634	3953.281

Appendix A continued

28	6-5-90	Dumbi Stn	B	0701	3948.352
		VGG028ZA	T	0705	3948.061
			B	0709	3948.356
			T	0712	3948.061
29	6-5-90	Zango Aya	B	0736	3945.833
		VGG029ZA	T	0741	3945.530
			B	0745	3945.835
			T	0801	3945.528
30	6-5-90	Parakwai	B	0826	3944.218
		VGG030ZA	T	0831	3943.948
			B	0839	3944.220
			T	0843	3943 946

Appendix A continued

S/No.	Converted Values (mgals)	Gradient Values (mgals/m)	Average Gradient Values (mgals/m)
25	4227.735509	0.300232	0.3028
	4227.435277	0.304490	
	4227.739767	0.305554	
	4227.434213	0.301296	
26	4206.760839	0.309813	0.3087
	4206.451026	0.306619	
	4206.757645	0.307684	
	4206.449961	0.310878	
27	4205.807977	0.287037	0.3012
	4205.510940	0.300231	
	4205.811171	0.305554	
	4205.505617	0.302360	
28	4200.257957	0.309813	0.3119
	4199.948144	0.314071	
	4200.262215	0.314071	
	4199.948144	0.309813	
29	4197.576104	0.322589	0.3247
	4197.253515	0.324918	
	4197.578233	0.326848	
	4197.251385	0.324719	
30	4195.856694	0.287356	0.2895
	4195.569238	0.289585	
	4195.858823	0.291714	
	4195.567109	0.289585	

APPENDIX B

Height of Selected Stations
(After Joda, 1990)

S/No	Name of Station	Identification Number	Height(m) above Mean Sea Level
1.	Bassawa	VGG 008 ZA	665.25
2.	Biye	VGG 020 ZA	687.48
3.	Bomo	VGG 019 ZA	685.77
4.	Dambo	VGG 039 ZA	631.80
5.	Hanwa	VGG 094 ZA	666.07
6.	Sabon Gari Zaria	VGG 097 ZA	633.93
7.	Karaukarau	VGG 056 ZA	679.33
8.	Kufena	VGG 050 ZA	687.49
9	Samaru	VGG 018 ZA	670.77
10	Shika	VGG 021 ZA	668.73
11.	Tsibiri	VGG 022 ZA	666.70
12.	Ungwan Maguzawa	VGG 091 ZA	688.23
13.	Ungwan Sarkin kufena	VGG 051 ZA	666.63
14..	Ungwan Tsauni	VGG 053 ZA	696.69
15.	Wusasa	VGG 048 ZA	659.21
16.	Zaria City	VGG 098 ZA	661.79
17.	Zabin Zaria	VGG 002 ZA	622.27