

GRAVITY SURVEY OF THE OLDER
GRANTS PLUTONS IN ZARIA AREA
OF KADUNA STATE NIGERIA

BY

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requirements for the degree of Master of Science in
(Applied Geophysics).

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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 acknowledged by means of references.


.....
O. O. ADENIYI

CERTIFICATION

This thesis entitled "Gravity Survey of the Older Granite plutons in Zaria area of Kaduna State, Nigeria" by Omolayo Olusegun Adeniyi 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 my
children

Adepeju O. Adeniyi

and

Imoleayo T. Adeniyi

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A B S T R A C T

A gravity survey over the Precambrian "Older Granite" intrusives in Zaria area of northern Nigeria was carried out. The survey was aimed at investigating the structure, depth and extent, and the mode of occurrence of the Older Granites.

A LaCoste - Romberg gravimeter (model G468) was used in collecting gravity data while station elevation determinations were accomplished using 2 altimeters. In all, 279 stations were established at intervals of 1 to 2 km. Laboratory density determination was carried out on 118 rock samples collected from the area.

Interpretation of the gravity anomaly shows that the area is characterised by prominent residual gravity lows of -12. mGal to -8 mGal relative to a N-S trending regional anomaly of gradient 0.07 mGal/km. Three - dimensional modelling of the residual gravity shows that there are 3 batholiths in the area, with floors which are located at depths 2,3 and 1.7 km respectively, and the walls of the batholiths are, in general, inward dipping. Five prominent plugs in the survey area extended to depths of between 2 and 8 Km locally.

The general configuration of the modelled bodies and pattern of the gravity anomalies suggest that the area is characterised by a multiple batholith which were magmatically emplaced with the 5 plugs acting as conduits for the ascent of the magma.

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CHAPTER 1

INTRODUCTION

1.1 General

The area covered by this study lies between latitudes $10^{\circ}45'N$ and $11^{\circ}20'N$, and longitudes $7^{\circ}30'E$ and $8^{\circ}00'E$ within the northern Nigerian Precambrian belt. It is located partly within topographic map sheet 102 (Zaria) and partly within sheet 124 (Igabi). The survey area is approximately 2,800 sq. km. This area, referred to as Zaria area throughout this report, is shown on figure 1.1 and 1.2.

The road network in the area can be classified into two broad groups. The tarred roads which include those linking Zaria to Kaduna, Jos, Malumfashi, Kano, Birni-Gwari and Funtua. These roads are very well developed. The other types are those which could be referred to as tracks. They are numerous and only motorable during the dry season.

The plains on which Zaria area is situated are part of the vast, gentle undulating plain scenery which extends almost unbroken from Sokoto to Lake Chad and beyond, and from south of Kaduna to the Tiqueddi scarp near Agades (Thorp, 1970). Within a radius of about 80 km from Zaria, elevations vary from 550 m to 715 m with local relief varying from 30 m to 45 m and a regional slope to the south. Slope angles although generally

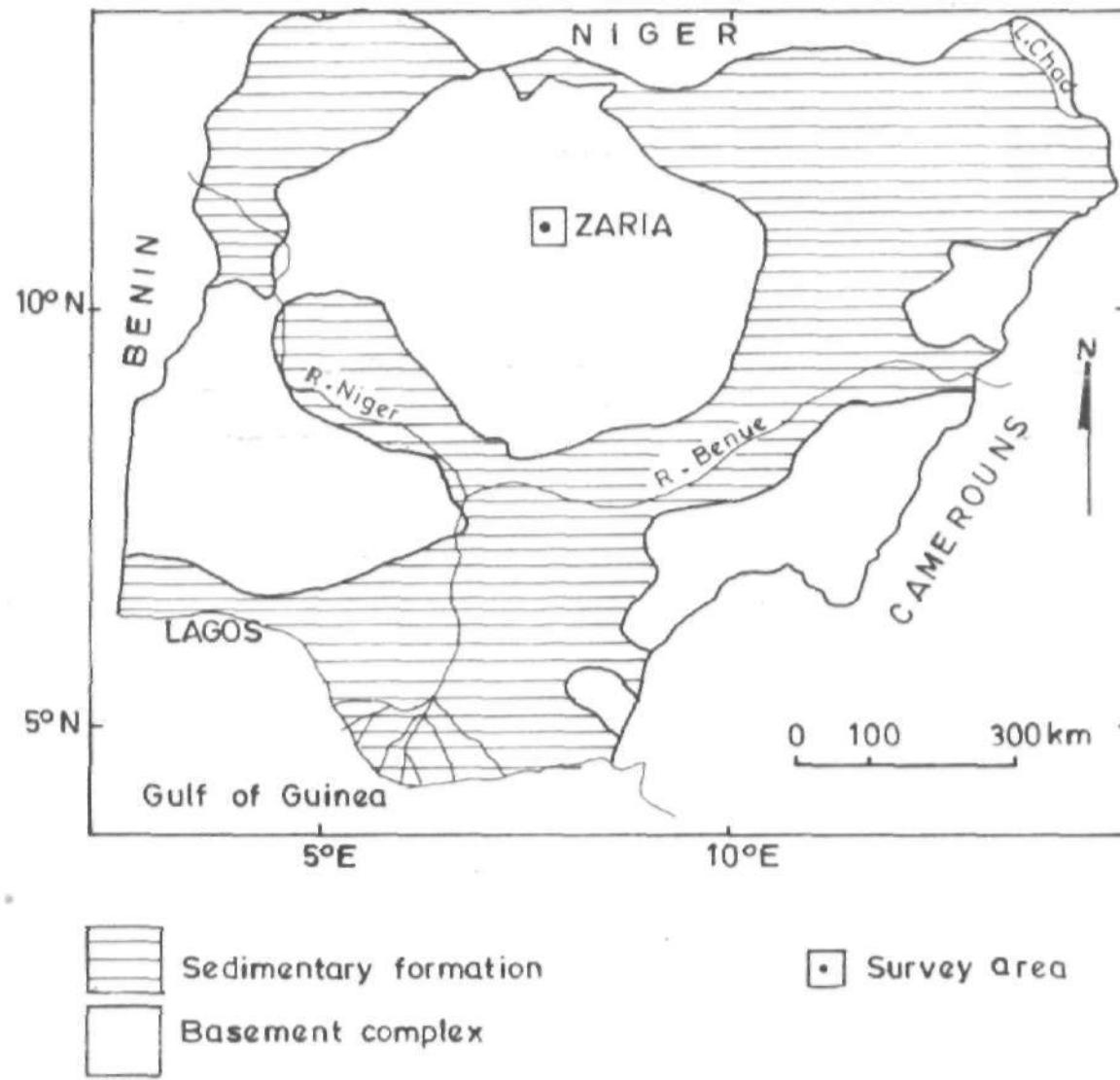


Fig.1-1. Location map of the survey area .

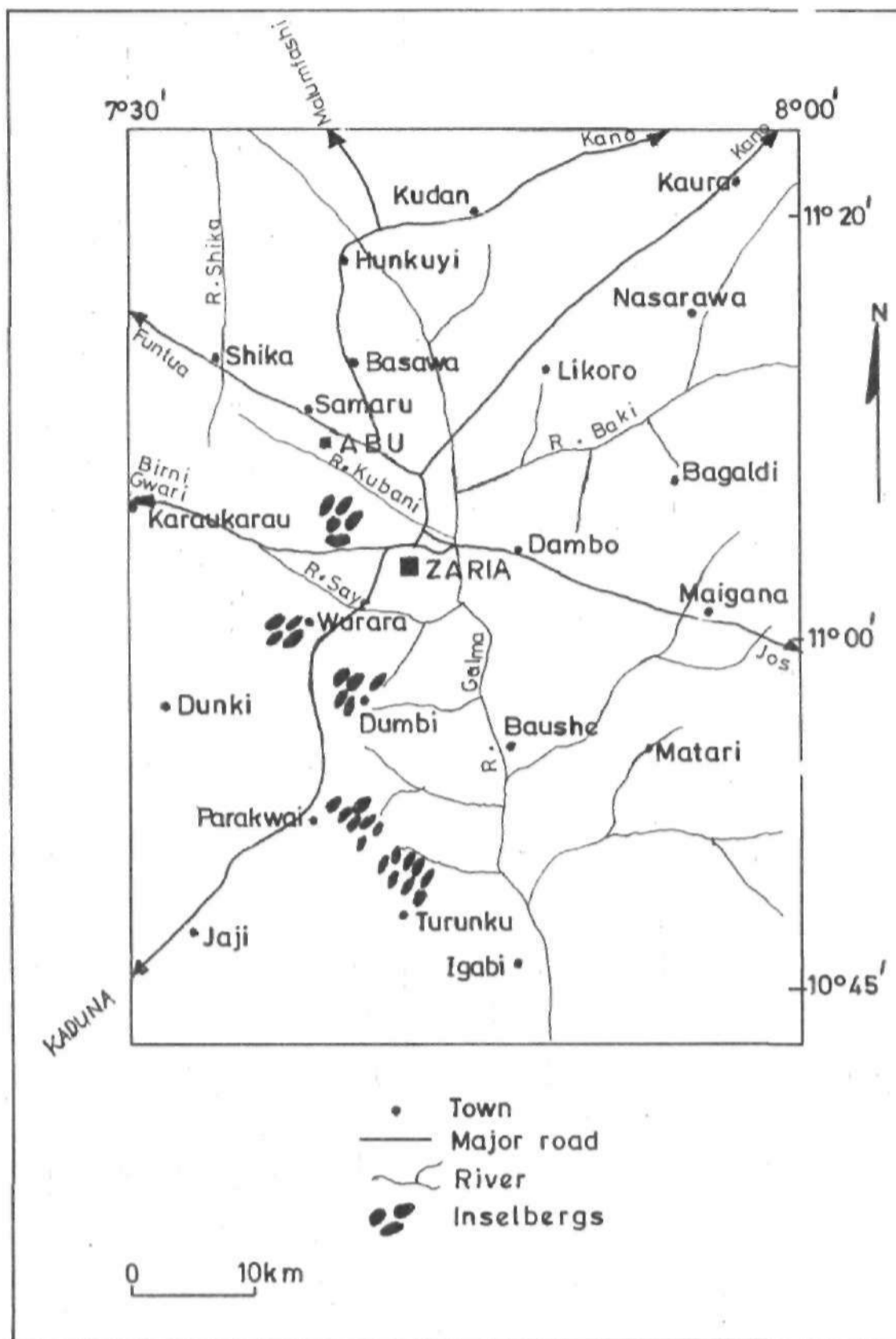


Fig.1.2. A sketch map of the survey area.

low, between $\frac{1}{2}^{\circ}$ and 4° , attain comparatively steep values over restricted areas. The plains are surmounted by hill features of two kinds: rock inselbergs and iron-stone-capped mesas (Thorp, 1970).

The drainage system of Zaria area focuses on the River Galma, a major tributary to River Kaduna. Supplied with run-off and seepage from a drainage basin of about 6,900 sq. km., the Galma carries water throughout the year unlike many of its tributaries which dry up during January to June (Thorp, 1970).

The area is located on a plateau at a height of about 670m above sea-level in the centre of northern Nigeria (figure 1.1) and it possesses a tropical continental climate. The area is invaded by two distinct air masses, one from the north-dry and continental in origin and the other from over the Atlantic in the south-moist, cool and equatorial maritime in nature.

1.2 Previous Work in the Area

Related previous work in the area could be classified into two broad groups: viz geophysical and geological.

The only remarkable geophysical work in the area was the aeromagnetic mapping of the area among those of northern Nigeria. This was part of the aero-survey project carried out throughout the country

by the Geological Survey of Nigeria. Aeromagnetic maps produced from such mapping had since gone into use.

Earlier geologic work in the area has largely been restricted to water supply investigations and gives little information about the basement geology (McCurry, 1970). However, Olowu (1967), in a report on groundwater conditions in the area, produced a small-scale map which incorporated most of the main geologic units.

McCurry (1970) reported the mapping of an area approximately 12,000 sq. km. in the Zaria-Funtua-Malumfashi region at a reconnaissance level and mapped in detail an area approximately 15 sq. km. to the west of Zaria. Geologic information from such mapping was presented on map sheets 78 (Funtua), 79 (Malumfashi), 101 (Maska) and 102 (Zaria). The same area was also remapped by the Geological Survey of Nigeria.

Later geologic work in the area was reported by Webb (1972). However this reported work was limited to areas between Zaria and Kaduna. Findings from this work led to a revision of parts of map sheets 101 and 102 previously mapped by McCurry (1970). From the mapping, Webb (1972) regarded the granite plutons in Zaria area, mapped by McCurry (1970), as part of a single batholith.

1.3 Objective and Scope

The main theme of this study was born out of the geologic mapping of degree sheet 21 (Zaria) by McCurry (1970). Result of the mapping showed the emplacement of two separate Older Granite plutons within the Zaria area basement.

This work, which entails a gravity survey of these Older Granite plutons, has the following objectives:

- i) To investigate the extent of the Older Granite suite within the Zaria basement and determine the shape of the plutons.
- ii) To investigate the deep structure of the Older Granite suite and how this can be related to its origin and mode of emplacement.

It is also hoped that the work would throw more light on the structural relationship between the Older Granites and the surrounding metasediments and gneisses.

As gravity survey involves measuring minute variations in the pull of gravity from rocks within the first few kilometers of the earth, and as different types of rocks have different densities, the scope of work include:

- i) Obtaining gravimeter and altimeter data over the area.

- ii) Collection of unweathered rock samples over the survey area for density determination.
- iii) Reduction of field data to Bouguer anomalies.
- iv) Interpretation of Bouguer anomalies.

The interpretative work however include quantitative modelling of the residual gravity field.

CHAPTER 2

GEOLOGICAL REVIEW2.1 Geology of Zaria Area

Based on the work of McCurry (1970), the principal rock units in the area are:

- i) Metasediments, which was laid down, and then metamorphosed during the Pan-African orogeny between 850 and 650 m.y. ago, and which occupy linear north-south trending isoclinal belt to the west of the survey area.
- ii) A crystalline complex composed of gneisses, considered to have been metamorphosed more than 2,000 m.y. ago.
- iii) Older Granites, which intruded the gneissic crystalline complex from 647 to 618 m.y. ago.

Figure 2.1 shows the locations of the various rock units as mapped by McCurry (1970) and presented on geologic maps sheets 102 (Zaria) and 124 (Igabi). However, Webb (1972) mapped in detail part of sheet 124 and re-examined part of sheet 102 among others. Results of the mapping had led to a revision of parts of sheet 102 earlier mapped by McCurry (1970), and a summary of the revision are stated below.

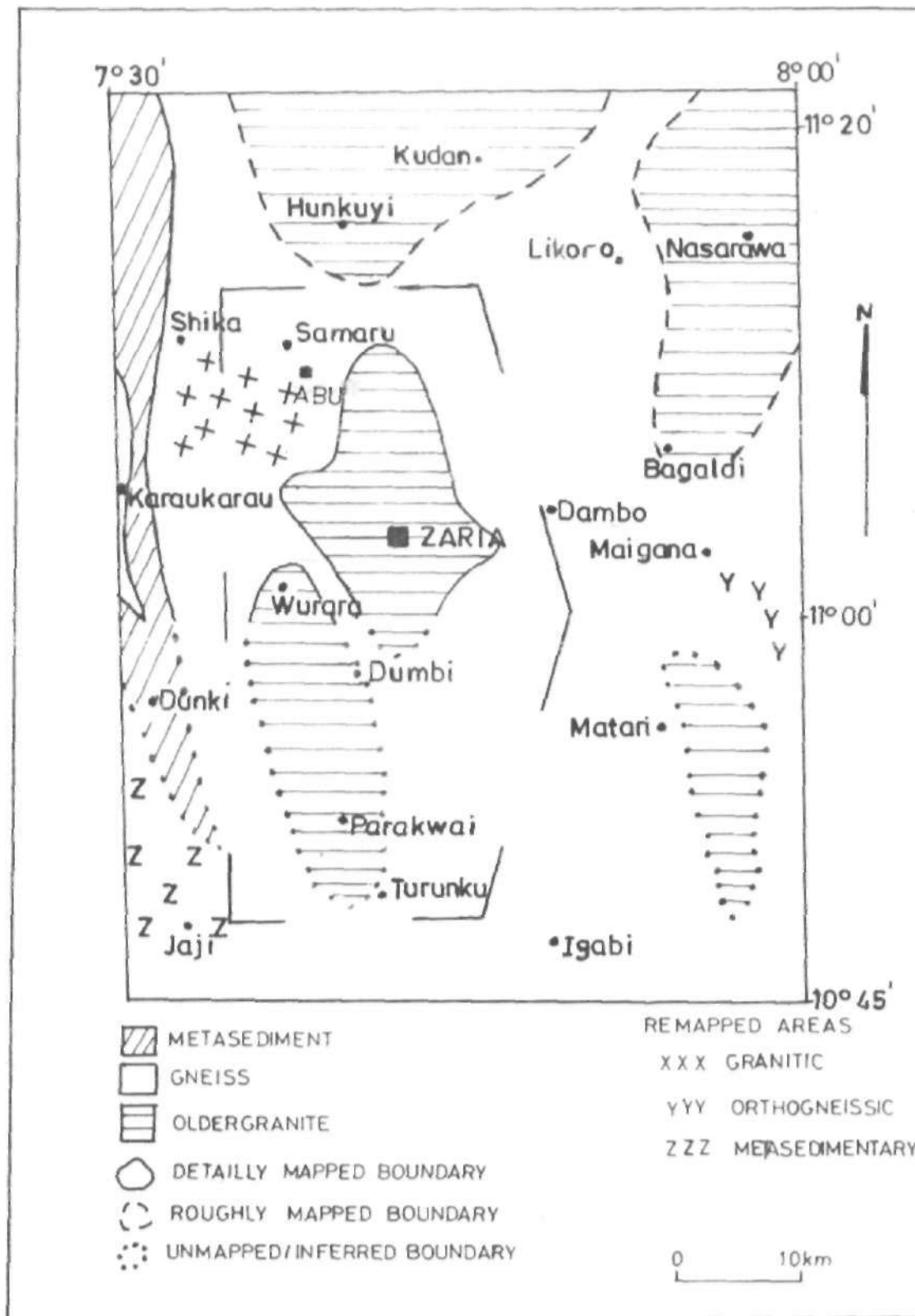


Fig. 2-1. Geologic map of Zaria area.

According to Webb (1972), McCurry (1970) mapped the extent of the granite plutons and metasediments (Fig. 2.1) to coincide more or less with the extent of granite inselbergs and quartzite ridges respectively, both of which are prominent on aerial photographs. She considered the more or less featureless ground around Samaru and Shika (Fig. 2.1) to coincide with the extent of the gneisses. Webb (1972) mapped such ground in detail, and found much of it to be underlain by weathered granites and schists. Also, orthogneisses outcropped around Maigana (Fig. 2.1). These are considered to be granites intrusive into the gneiss unit, but older than the Older Granites (Webb, 1972). Furthermore, the metasedimentary belt is wider than formerly shown, and extends into and beyond Jaji (Fig. 2.1) (Webb, 1972).

However, the various principal rock units in the area have variable petrographic compositions, the detail of which are given by McCurry (1970) and also summarized in McCurry (1971, 1973, 1976). The petrology of the metasediments, crystalline gneissic complex and the Older Granites are here summarized below.

2.1.1 Metasediments

Metasediments occur in a north-south synclinal belt to the west of the survey area. Regional metamorphism has produced these metasediments which range from low-grade phyllites to

relatively high-grade schists and gneisses. They have apparently conformable relationship with the crystalline host rocks (McCurry, 1970).

Prominent ridges in the belt consist of massive to granular quartzites, while predominantly fissile muscovitic varieties tend to form lower ridge features. Massive quartzites contain relatively few impurities and are usually grey-white in colour. The fissile varieties vary from yellow to brown depending on the relative amount of muscovite and oxide present (McCurry, 1970).

Schists occupy the greater part of the metasedimentary belt, varying in colour, texture and outcrop. They are soft, friable and deeply weathered. Gradational boundaries within the schists are ubiquitous, and the schists also grade into adjacent crystalline gneisses. Varieties of schists encountered are muscovite - quartz - schists, biotite - muscovite - schists, talc - schists and feldspathic - schists (McCurry, 1970).

Crystalline basement gneisses occur in the metasediments as anticlinal fold cores. They are concordant, generally rather schistose gneisses which are believed to be due to higher grades of metamorphism within the metasedimentary sequence. The more resistant facies of the gneissic complex however form low ridges or whalebacks in the metasediments (McCurry, 1970).

2.1.2 Gneissic crystalline complex

Gneisses comprise the ancient crystalline basement which underlies the whole area and accommodates the belt of metasediments described above. There is evidence that the gneisses are sedimentary in origin (McCurry, 1970). Some of the gneisses assume a more granitic appearance. They are very variable both in composition and texture, and major varieties in the area are biotite-gneisses, granite-gneisses and augen-gneisses.

2.1.3 Older granite suite

According to McCurry (1970), a suite of granites intruded the crystalline complex in the area. These granite bodies are sub-elliptical and are discordant with rather diffuse contacts. The rocks are compositionally similar in that they contain quartz, microcline, plagioclase and biotite as essential minerals with accessory apatite and zircon. Porphyroblastic biotite-granite is the commonest and the most distinctive. It is richly potassic with large microcline megacrysts. The rocks have a pink-grey colour due to large rectangular carlsbad twinned microcline megacrysts, set in a granitic groundmass of quartz, microcline, plagioclase and biotite.

Discordant contacts show that most of the granites are intrusive, while flow xenoliths, boudinage aplite veins and mafic pods are suggestive of movement in a semi-plastic condition.

McCurry and Wright (1971), concluding on the age and origin of the granites, mentioned that during the Pan-African orogeny in Nigeria, an ancient basement was remobilised to develop a crystalline complex of gneisses and migmatites and was intruded by a suite of variably microcline-megacrystic granitic rocks, the so called Older Granites.

2.2 General Characteristics of Batholiths

Batholiths are gigantic masses of essentially igneous rocks, generally composed of granite or granodiorite, with highly irregular dome-like roof, and walls that dip outwards so that the intrusions enlarge with depth and appear to be without visible foundations. Smaller intrusions of similar type, but less elongated and with areal dimension of only a few square kilometer, are called "stocks".

On batholith's origin and mode of emplacement, while some researchers (e.g. Russ (1957) and Rahman (1976)) believe the origin to be granitic magma intruding into the earth crust, other (e.g. Grant (1978)) favour the explanation according to which batholiths were formed by the transformation of sedimentary rocks into granite.

Structurally however, batholiths are of two types: concordant and discordant. Batholiths that intruded during crustal deformation tend to have concordant contacts. The discordant types, which cut across trends of fold and other structures of their surrounding walls, were emplaced at the end of a period of intense deformation. Granites are surrounded by a zone of re-crystallized rocks consisting of intimately penetrating masses of some batholiths, the invaded rocks show a gradation from typical sedimentary and metamorphic characters to various mixed types and finally to granite (Emmons et. al., 1960). Batholiths are typically distinguished by cross-contact with the enclosing rocks, homogeneous composition, and the fact that they are confined to the central part of folded zones. Often, they are many times as long as they are wide (Yakushova, 1967).

CHAPTER 3

FIELD-WORK AND DATA REDUCTION3.1 Planning and General Preparations

Planning for the field-work include:

- i) Collecting all relevant topographic maps of the area (scales 1:100,000 and 1:50,000) and outlining the boundaries of all formations in the area on the 1:100,000 scale maps,
- ii) Choosing survey routes,
- iii) Positioning field stations along survey routes and
- iv) Writing out tentative field occupational sequences.

However, preparations for the field-work entailed principally the checking of all required instruments.

3.1.1 Planning

The details of the planning processes itemised above is summarized as follows: Boundaries of all geologic formations in the area were traced on the topographic map of the area. Survey routes were subsequently chosen. The choice of routes were dictated by available road network and also influenced by the desired even spatial coverage over the area to be surveyed. The extent of survey was determined by

the geologic information and the necessity to establish adequate regional gravity field. Field stations were positioned along routes at 1 km intervals in areas underlain by the Older Granites and 2 km elsewhere. Tentative field sequences were prepared using the single loop method (Osazuwa, 1985) with the main-base at the Nigeria College of Aviation Technology, Zaria. Four other sub-base stations were also established (Fig. 3.3.).

3.1.2 Preparations and instrumentations

The checking of all the required instruments was aimed at detecting any malfunctioning of the instruments as well as to establish their drift characteristics. It was also aimed at the calibration constant of the instruments to see if re-calibration of the instruments was required. The instruments tested were a LaCoste-Romberg gravimeter (model G468) and two Wallace and Tiernan altimeters (model FA181). They were observed for 3 days prior to the field-work and also during and after the field-work. The details of these observations are summarized below:

LaCoste-Romberg Gravimeter

The gravimeter, model G468, was connected to its charger and left to stabilize at its operating temperature (49.5°C). Gravity measurements were

observed between 6.00 a.m and 11.00 p.m on hourly basis. The instrument readings, converted to mGal values, are shown in Figure 3.1. The figure indicates two forms of drift. The tidal effect superposed over the instrumental drift. From the figure, the tidal variation was noted to be periodic. Thus, with frequent re-occupation of between 2-2½ hours at a base, it was planned to incorporate the correction for tidal drift into that for the instrumental drift (Dobrin, 1976). Further investigation of the instrumental drift characteristics was not attempted as the separation of the total drift into its components (instrumental and tidal) cannot be made because of non-availability of the tidal correction table for the current year, but Osazuwa (1978), after removing the tidal drift effect, showed the instrumental drift characteristics to be linear.

The period of the drift wave is accompanied by a mean gravity amplitude of 0.22 mGal, giving a maximum gross drift rate of 0.02 mGal/hr. However, during the survey, repeated visits to a base station revealed a drift rate as large as 0.05 mGal/hr. A probable cause of the increase in drift in the field could be due to vibration arising from the means of transportation as one goes from one station to another.

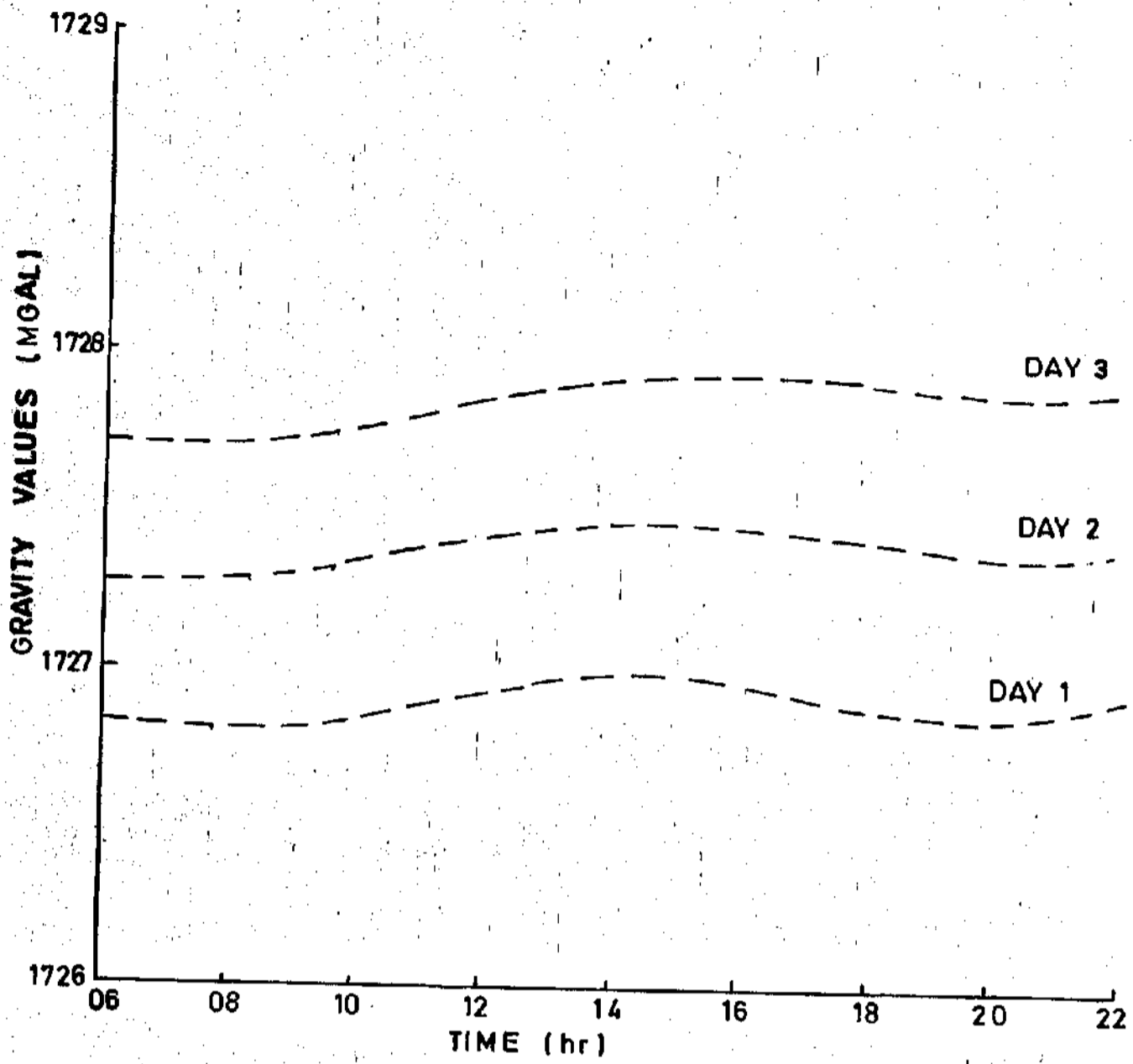


Fig.3.1. Lacoste - Romberg gravimeter drift curves.

According to Osazuwa (1985), the calibration constant of this instrument does not change perceptibly with time and for the accuracy required for a survey of this type, re-calibration of the instrument was not considered necessary. However, during the field-work, differences in repeated gravity measurements between the main-base and sub-base stations remained constant within the period of the survey.

Wallace and Tiernan Altimeter

Two altimeters, model FA181, were also tested and the observed measurements at the same location for different times are plotted as shown in Figure 3.2. In the figure, 3 segments of near linear drift are identified and consequently, field measurements with the altimeters were planned such that any complete altimeter loop sequence was contained within any of the 3 linear drift segments.

3.2 Field-work

The field-work was carried out in January and February, 1987. In all, three weeks were used. During the field-work, the instruments were transported in a Peugeot 504 station-wagon and 1:50,000 scale topographic maps were used to locate field stations. Although the odometer of the vehicle was used to locate station positions, other features like road junctions,

rivers, and rail crossing were also used to affirm station positions and establish new ones. Figure 3.3 shows the location and the general distribution of field stations over the survey area.

Data collected during the field-work were gravimeter data, altimeter data as well as dry and wet temperatures. For the gravimetry and altimetry work, the main base was the Reference National Gravity Station (GMSC4) at the Nigerian College of Aviation Technology, Zaria. This base has an absolute gravity value of 978031.225 mGal (Osazuwa, 1985) and at elevation 662.62 m (Osazuwa, personal communication). Four other sub-base stations were also selected to establish loop sequences at places which are far from the main base. For such far places, the main base was always visited at the beginning and at the end of each day's work in order to have additional control of the instrument drift.

For both the gravimetry and altimetry work, re-occupation at bases was limited to between 2 and 2½ hours. This was aimed at reducing errors due to tidal effect which would then be incorporated into the instrumental drift. In addition, this also allowed for a combined observation of the gravimeter and the altimeters.

While handling the gravimeter, notable precautionary steps taken include:

- i) keeping the observation points away as much as possible from activities of cities, near highways and under trees so that the instrument was not disturbed due to surface oscillations,
- ii) not exposing the gravimeter to direct heat of the sun as Osazuwa and Ajakaiye (1982), in their investigation, found that when the gravimeter is exposed to the hot tropical sun, it suffers thermal shock,
- iii) minimize jerks or mechanical disturbances on the instrument so that the instrument do not suffer drift due to undetectable creep (Hamilton and Brule, 1967).

In all, 279 field stations were established and all were tied to the main base. The number of stations that could be occupied in one day varied from 12 to 37, depending on quality of the road, accessibility and weather.

Rock samples were collected in order to estimate the densities of the main geologic formations in the area. Fresh rock samples were collected from outcrops within the surveyed area. A total of 118 rock samples were collected and labelled for identification purpose.

3.3 Data Reduction

3.3.1 Field Data

According to Bhimasankarah (1977), the observed gravity values are used directly only in geodetic studies and are to be transformed into what are called Bouguer anomalies to make them represent the variation in the sub-surface mass distribution which is of geological interest. This process of transformation implies bringing the observed gravity value at a particular latitude, longitude and surface elevation to a reference datum (usually mean sea-level) at which the theoretical gravity obtained from the Gravity Reference System of 1967 (GRS'67) is available for comparison.

For the interpretation of the gravity data, the GRS'67 given in Osazuwa (1985) as

$$G_T = 978031.846 (1 + 0.005278895 \sin^2 \phi + 0.000023462 \sin^4 \phi) \dots (3.1)$$

was used. This expression gives the variation with latitude of normal gravity G_T , in mGals, on the reference ellipsoid. The Bouguer anomaly (BA) is given by

$$BA = G_S - G_T + FAC - BC - BUF \dots (3.2)$$

where G_S = observed gravity; G_T = the theoretical value of gravity on the ellipsoid at the latitude of the station; FAC = the free-air correction; BC = Bouguer correction and BUF = Bullard term correction. The free-air correction, which is given by $0.3086h$ accounts for the differences in station's elevation (h)

above the datum plane. The Bouguer correction ($2\pi G\rho h$) is the attraction exerted on a unit mass by a slab of rock material of density ρ between a station and the reference datum ($G = 6.67 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$). The Bullard term correction accounts for the curvature of the earth, though this correction is insignificant, being less than 0.05 mGal.

The complete reduction of the raw data entailed several stages of computation. The initial stages which comprise the altimeter data reduction was computed manually and the reduction of the gravimeter data was accomplished with the aid of the computer.

The absolute elevations measured by the altimeters are grossly in error when compared with elevation range for Zaria area. In view of this systematic shift in datum, the altimeters were used as relative instruments for better resolution. Elevations of stations were obtained by interpolation between stations of known absolute height. The altimeter data were first corrected for humidity effect using the dry and wet temperatures and the psychrometric chart prepared by the manufacturer, and then corrected for drift. The height difference between each station and the main base was calculated, and the absolute elevation for each station was also

computed using the absolute elevation value of the main base. The mean of the 2 values from each of the altimeters was taken as the correct absolute elevation for respective stations. These values however agree with the height values on the topographic map of the area.

The gravimeter data reduction was carried out using a computer program originally written by Osazuwa (personal communication) in FORTRAN 77 and adapted to FORTRAN IV to suit the Computer system at Ahmadu Bello University Zaria. The program which uses the GRS'67 for the computation of the theoretical value of gravity on the reference ellipsoid assumes a density of $2.67 \times 10^3 \text{kgm}^{-3}$ for the surface rocks. This value was so chosen to make the results comparable with similar survey elsewhere. Gravity data reduction stages are:

- i) conversion of the gravimeter to corresponding mGal value,
- ii) tidal correction,
- iii) drift correction, and
- iv) free-air, Bouguer and Bullard term corrections.

3.3.2 Rock Densities

To aid in the interpretation of the gravity anomalies, density measurements were made on rock

specimens from the surveyed area. The rock comprise mainly of granites, followed by gneisses, quartzites and mafic xenoliths.

Parasnis (1952) emphasised that the "field" density of a rock must be between the dry and saturated density. Laboratory density measurement were made using the formula

$$\rho = W_1 / (W_1 - W_2) \quad \dots\dots\dots(3.3)$$

where ρ is the density, W_1 is the weight of the sample in air, W_2 is the weight of the sample in water.

Saturated density measurements were made after soaking the samples in water for 48 hours. The weighings were made with the mettler balance model P515. The balance has an accuracy of 0.001 kg and the measured density values are correct to 0.4 kgm^{-3} . Though the calculated mean density values may be subject to a sampling error, a comparison between the density of dry and saturated samples showed a maximum difference of only $0.04 \times 10^3 \text{ kgm}^{-3}$, showing that the porosity or permeability of metamorphic and igneous rocks in the area is very small, as is to be expected.

Figure 3.4 shows the densities of the various rock units in the surveyed area and Table 3.1 contains the results of the density measurements. The mean densities assigned to the main geologic units in the area are $2.60 \times 10^3 \text{ kgm}^{-3}$ (granites), $2.70 \times 10^3 \text{ kgm}^{-3}$ (gneisses), and $2.62 \times 10^3 \text{ kgm}^{-3}$ (quartzites).

TABLE 3.1 DENSITIES OF SURFACE SAMPLES IN ZARIA AREA BASED ON LABORATORY MEASUREMENTS.

Rock Type	Number of Samples	Range of densities $\times 10^3 \text{ kgm}^{-3}$	Mean dry density & s.d. $\times 10^3 \text{ kgm}^{-3}$	Mean wet density & s.d. $\times 10^3 \text{ kgm}^{-3}$	Average density & s.d. $\times 10^3 \text{ kgm}^{-3}$
Quartzite	20	2.59-2.64	2.62+0.03	2.61+0.03	2.62+0.03
Mafic Xenolith	12	2.79-2.86	2.82+0.04	2.82+0.04	2.82+0.03
Gneiss	18	2.66-2.73	2.69+0.02	2.70+0.02	2.70+0.02
Granite:					
Micro-grained	19	2.54-2.60	2.57+0.03	2.57+0.03	2.57+0.02
Medium-grained	28	2.56-2.65	2.60+0.04	2.61+0.04	2.60+0.04
Coarse-grained	21	2.54-2.69	2.62+0.06	2.63+0.06	2.63+0.06

The average density of the entire group of samples is $2.64 \times 10^3 \text{kgm}^{-3}$. This value is however, a non-weighted mean density with respect to the outcrop area of the lithologic units.

3.4 Errors in the Bouguer Anomalies

The anomalies obtained from procedures of reduction depend on several other factors in addition to the sub-surface geological causes that are of interest. These other factors give rise to errors in the anomalies. The various errors could be error from elevation determination (ϵ_h), error in assumed reduction density (ϵ_ρ), error in station location (ϵ_ϕ), error in terrain effect (ϵ_t) and error in base value (ϵ_b). Other errors are those due to mode of observation, non-linear drift of instrument and calibration factor (ϵ_o). Murty (1977) gave the total error (ϵ_T) as

$$\epsilon_T = (\epsilon_h^2 + \epsilon_\rho^2 + \epsilon_\phi^2 + \epsilon_t^2 + \epsilon_b^2 + \epsilon_o^2)^{1/2} \quad \dots\dots (3.4)$$

When altimeters are used, elevation could be in error by as much as 3 m (Verheijen and Ajakaiye, 1980) and this could cause an error in the Bouguer anomaly values of 0.98 mGal.

The average density of the entire samples in the area was found to be $2.64 \times 10^3 \text{kgm}^{-3}$, but as this density may not be truly representative of the density

of the crust, the average crustal density of $2.67 \times 10^3 \text{ kgm}^{-3}$ was used for the data reduction. This would result in a density uncertainty of $0.03 \times 10^3 \text{ kgm}^{-3}$ causing error of 0.098 mGal over the height range of 78 m observed during the survey.

All the maps used to obtain the latitudes of stations were on a scale of 1:50,000 and latitude of stations were determined to the nearest second. An estimated maximum location error of 10 seconds of latitude would introduce an error of 0.1 mGal in the latitude range covered by this survey.

Terrain correction was computed for a few stations around wurara and Turunku where the highest mountain range abound, the maximum terrain correction is less than 0.01 mGal for close stations and this is considered insignificant. Terrain correction was therefore not considered necessary and hence not applied. For error due to base value, Osazuwa (1985) put it at 0.012 mGal. The error due to tidal effect was computed for latitude range of the surveyed area using tidal correction tables for some past years as that for 1987 was not available when this project was being carried out. However, it was supposed that the mean tidal effect from these years would satisfactorily approximate the estimated error from tidal drift. Moreover, this maximum error (0.31 mGal) has been significantly reduced by the field sequence designed for re-occupation at base

within 2½ hours. Mode of observation error arises from precision and clamping of instrument.

According to Bréin et. al. (1977), the effect of all these gives a maximum error of 0.01 mGal.

From the foregoing, the total error (ϵ_T) at each station would be 1.0 mGal.

CHAPTER 4

INTERPRETATIONS

4.1 Description of Bouguer and Free-Air Anomalies

The Bouguer anomaly map of the area is shown in Figure 4.1. The area is characterised by negative Bouguer anomalies ranging from - 52 to - 68 mGal with a mean value for all the stations of -63.4 mGal. The maximum value of -52 mGal occurs near Karaukarau and west of Jaji. Of the two minimum closures of -68 mGal, the more prominent one occur a few kilometer west of Samaru while the other occurs around Basawa. Although the pattern of the Bouguer field is rather complex, the dominant trend is N-S. From figure 4.2 which contains the geologic map of the area superposed over the Bouguer anomaly map, there is a very good correlation of this Bouguer anomaly field trend (i.e N-S) to the regional geological feature of the area.

Gradients of the Bouguer fields are generally less than 2 mGal/km. In areas of the gneisses, gradients are further low, being less than 1 mGal/km. A much prominent steeper gradient of more than 4 mGal/km occur east of Karaukarau. This high gradient could be related to a steep, sharp contact between the intrusive granite and the gneissic complex (Fig 4.2).

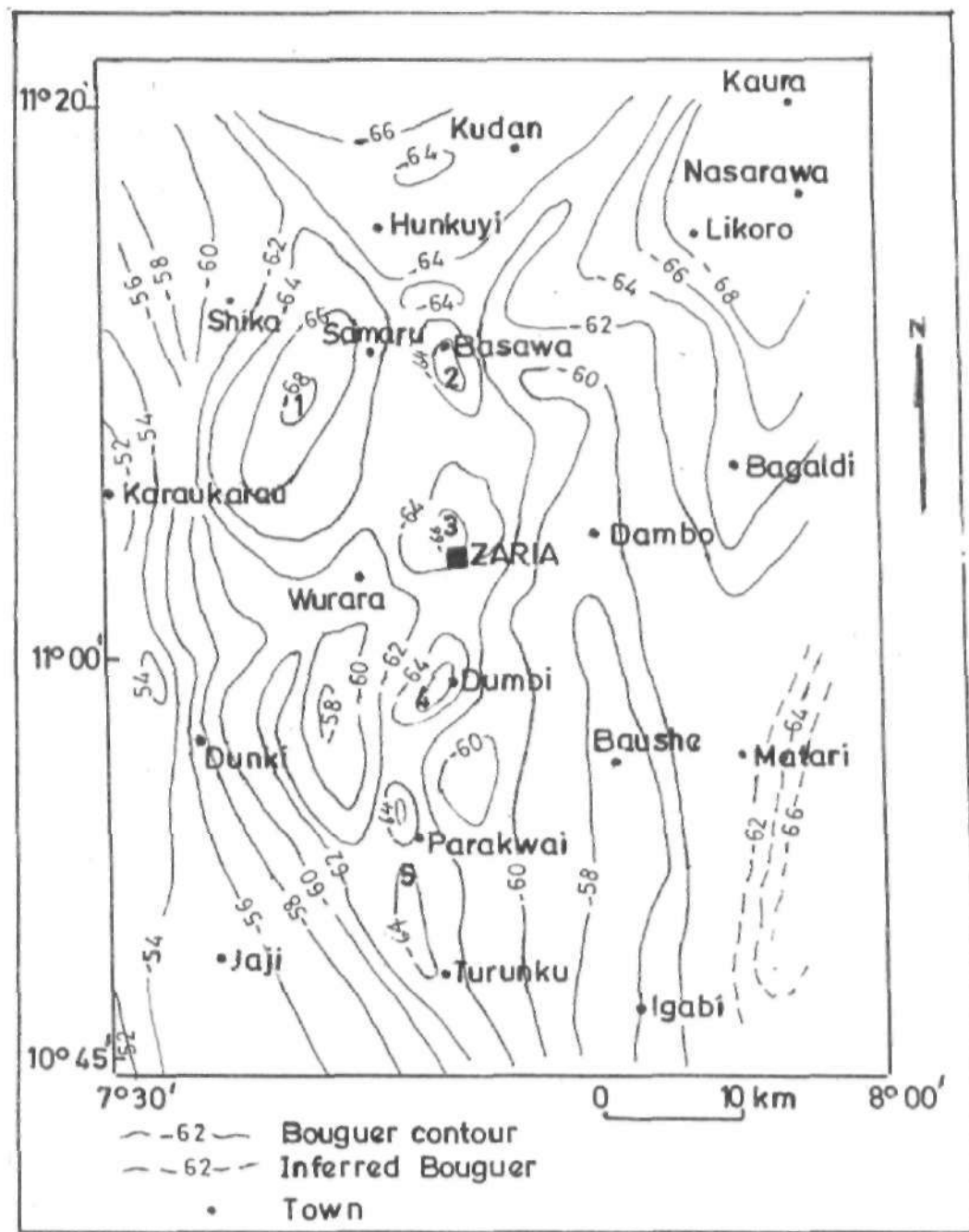


Fig.4.1. Bouguer anomaly map of Zaria area.
Contour at 2mGal interval

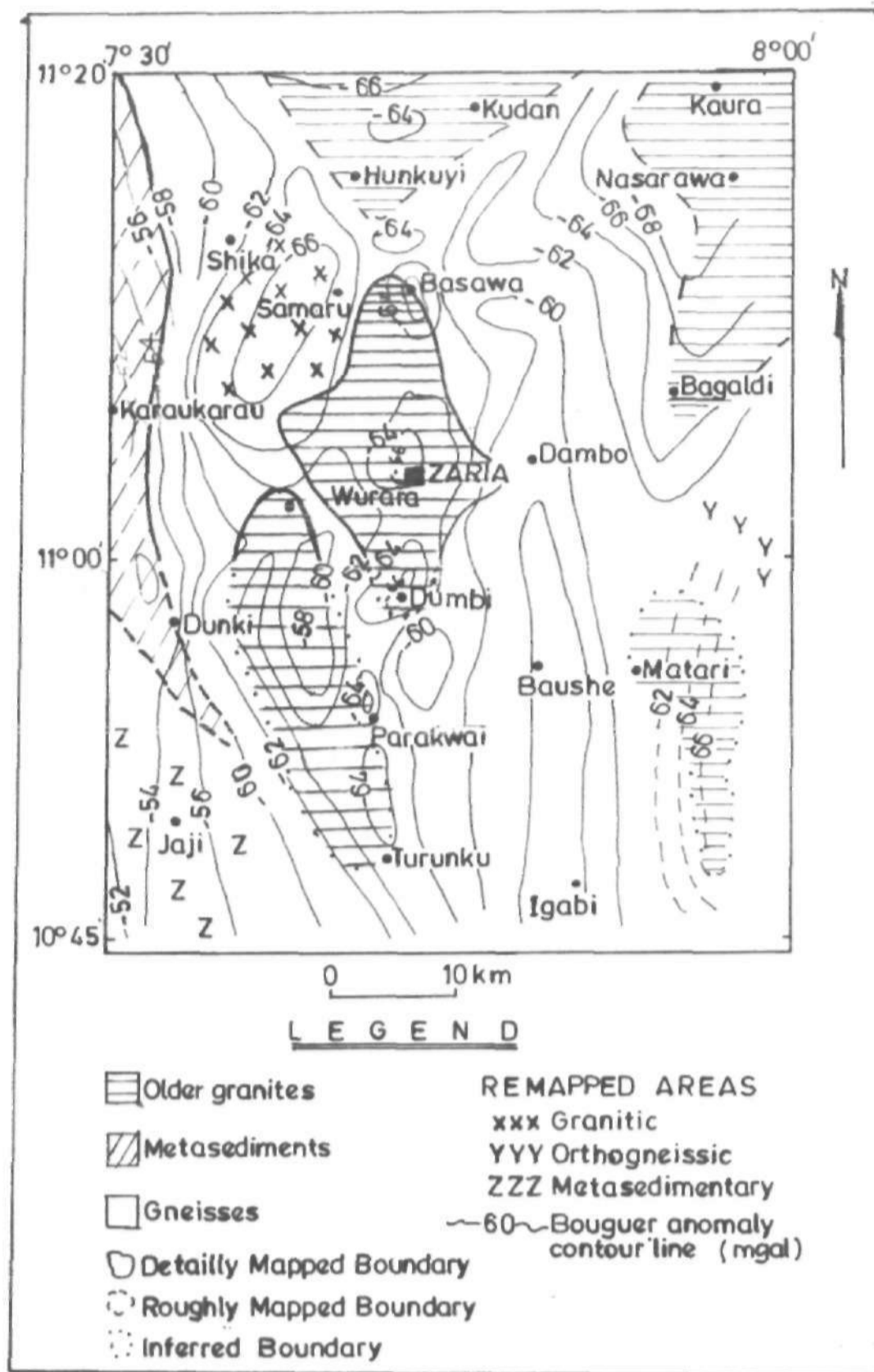


Fig.4.2. Bouguer anomaly map of Zaria area superposed over the geologic map

The free-air anomaly map is shown in Figure 4.3. It is characterised by positive anomaly ranging from a maximum of 24 mGal to a minimum of 4 mGal. The trend of the field could be roughly described as N-S, being much distorted in the central part of the surveyed area. However, it is observed that closures on the free-air anomaly fields occur in areas of both granitic intrusives as well as the basement gneissic complex.

As the mass between the observation height and the sea-level is not considered in the computation of the free-air anomaly, the anomaly mainly represents the influences of the topographic features superposed over the effect of the sub-surface. This anomaly is used for studies on geoidal height determination (Osazuwa, personal communication). It is also used to determine crustal thickness variation and to understand more general problems like isostasy (Murty, 1977). However, as the Bouguer anomaly is free from the effect of material lying between the observation point and the datum, it is the one necessarily to be analysed in geological problems and exploration (Murty, 1977).

4.2 Regional and Residual Anomalies

The critical phase in the interpretation of gravity anomalies which is also one of the most

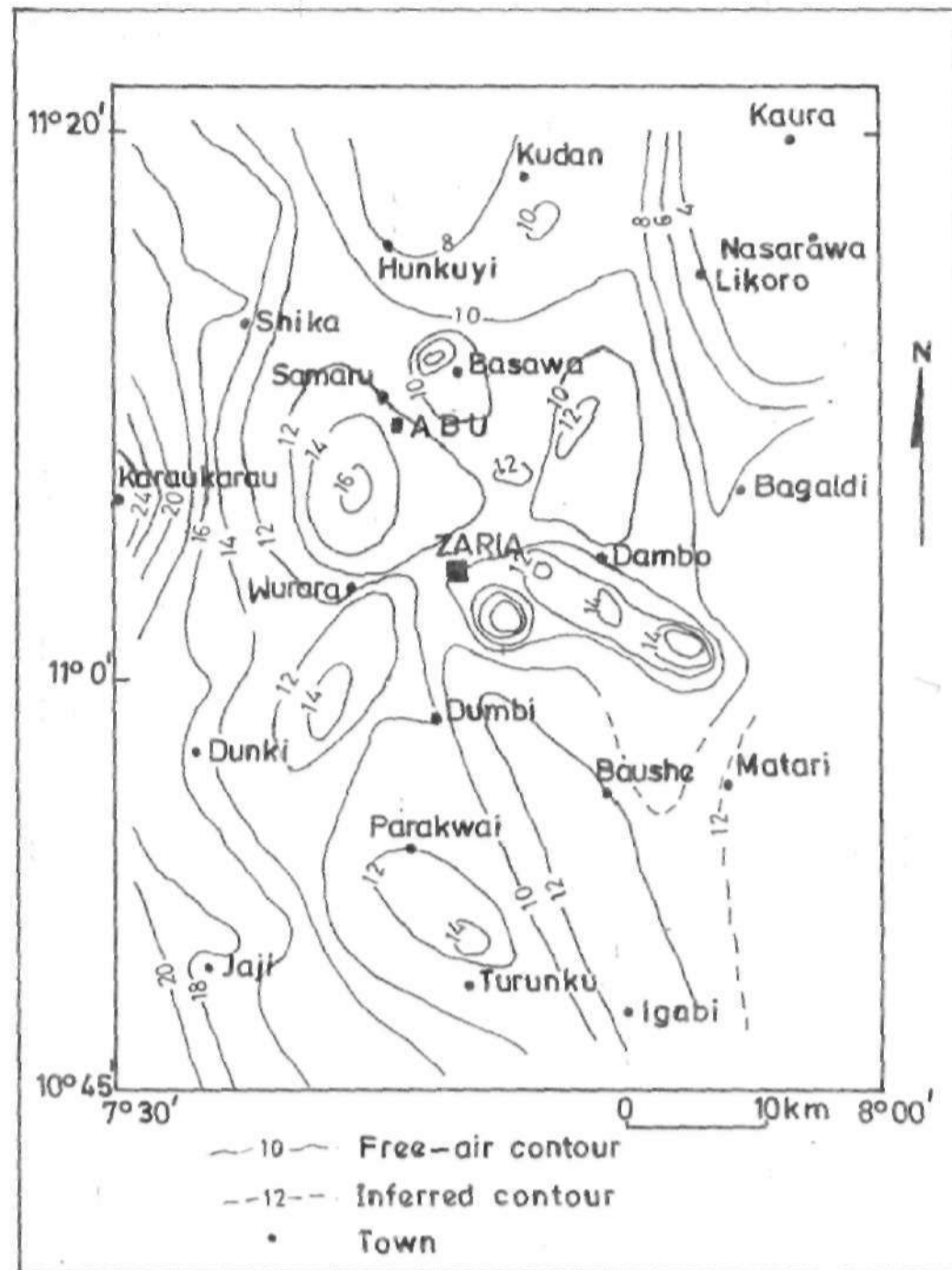


Fig.4.3. Free-air anomaly map of Zaria area.
 Contour at 0.5 mGal interval

sensitive sources of error in the final interpretation is the separation of regional anomalies from the Bouguer anomalies to obtain the residual anomalies. The regional anomalies are usually of long wavelength, and show a gradual change in value, while the residual anomalies, which are due to local effects may show large variations.

No unique determination of the regional effect is possible and several graphical and mathematical methods have been developed for the regional-residual separation. Each method has its own advantages and disadvantages. While the graphical methods depends on the judgement of the operator, the mathematical system depend on assumptions or empirical steps in the mathematical derivation of the numerical factors or coefficients used in the calculations. Once the mathematical equations are set up, the removal becomes automatically determined.

Four analytical approaches are in common use for direct calculation of residuals. These are the direct calculation of residuals by techniques such as the centre-point-and-ring method, the determination of second derivatives, polynomial fitting and downward continuation. In this study the first order polynomial fitting method was used in removing the regional effect from the

Bouguer anomalies as the trend of the regional field was not clearly obvious due to effects from other adjoining geologic bodies and because of the small extent of areal coverage of the survey. The regional map thus obtained is shown in Figure 4.4. The map shows a N-S regional trend and has a uniform E-W gradient of 0.07 mGal/km dipping to the east.

4.3 Correlation of the Residual Anomalies with the Surface Geology

The residual Bouguer anomaly is shown in Figure 4.5. The map shows 5 negative gravity closures and shows the same general N-S trend as the regional field. In order to ascertain the correlation between the residual anomaly and the geology of the area, the residual anomaly map was superposed over the geologic map (Fig. 2.1) and is shown in Figure 4.6. The combined map confirms that the whole area was intruded by granites as most of the local gravity relief is related to the surface geology.

From the residual gravity map (Fig. 4.6), it is obvious that the areas around Shika and Samaru; Basawa, Zaria, Dumbi, Parakwai and Turunku were characterised by acidic intrusions. To the west of Samaru, the negative residual (No. 1) of -12 mGal occur over an area mapped as gneissic by McCurry

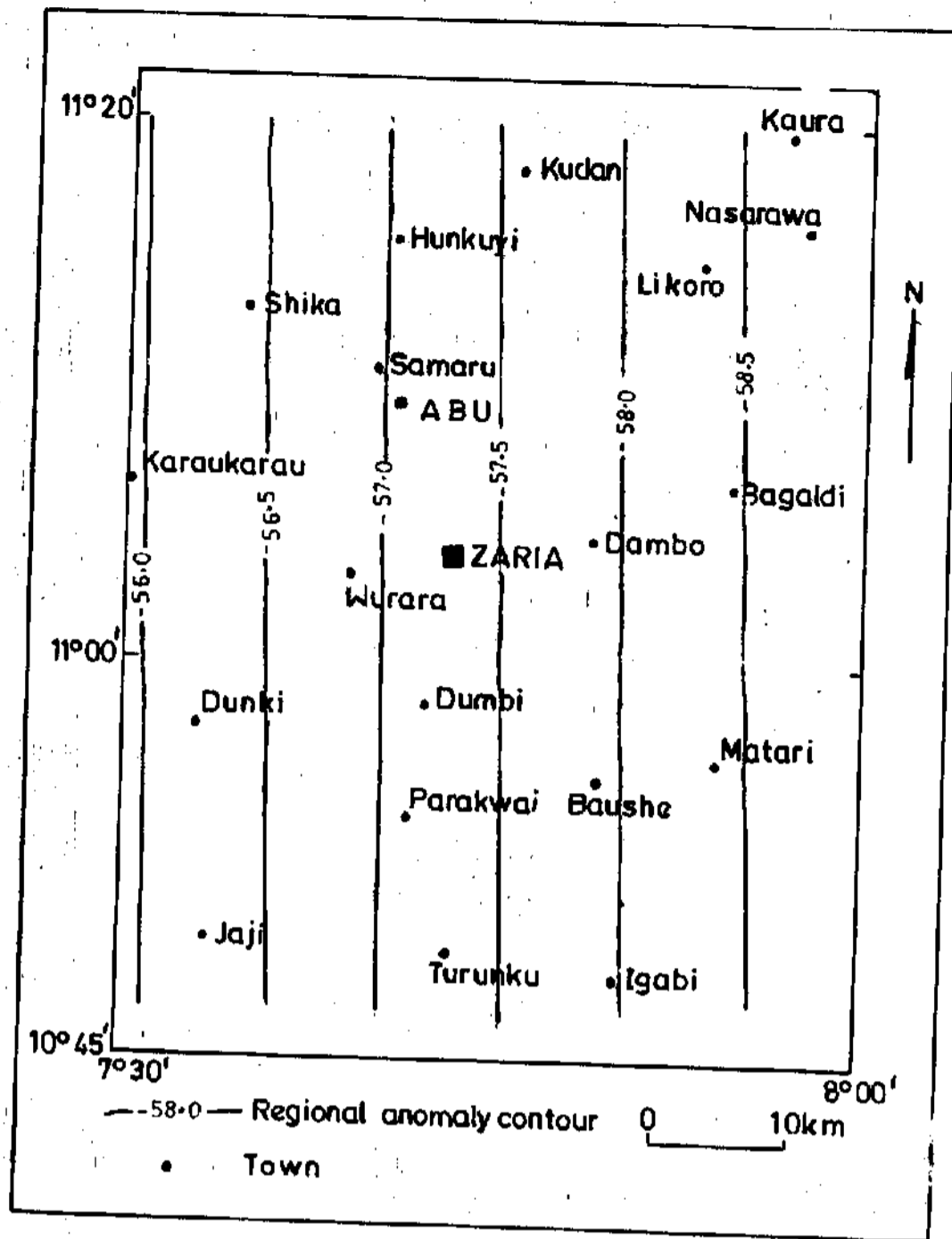


Fig.4-4. Regional anomaly map of Zaria area.
Contour at 0.5mGal interval

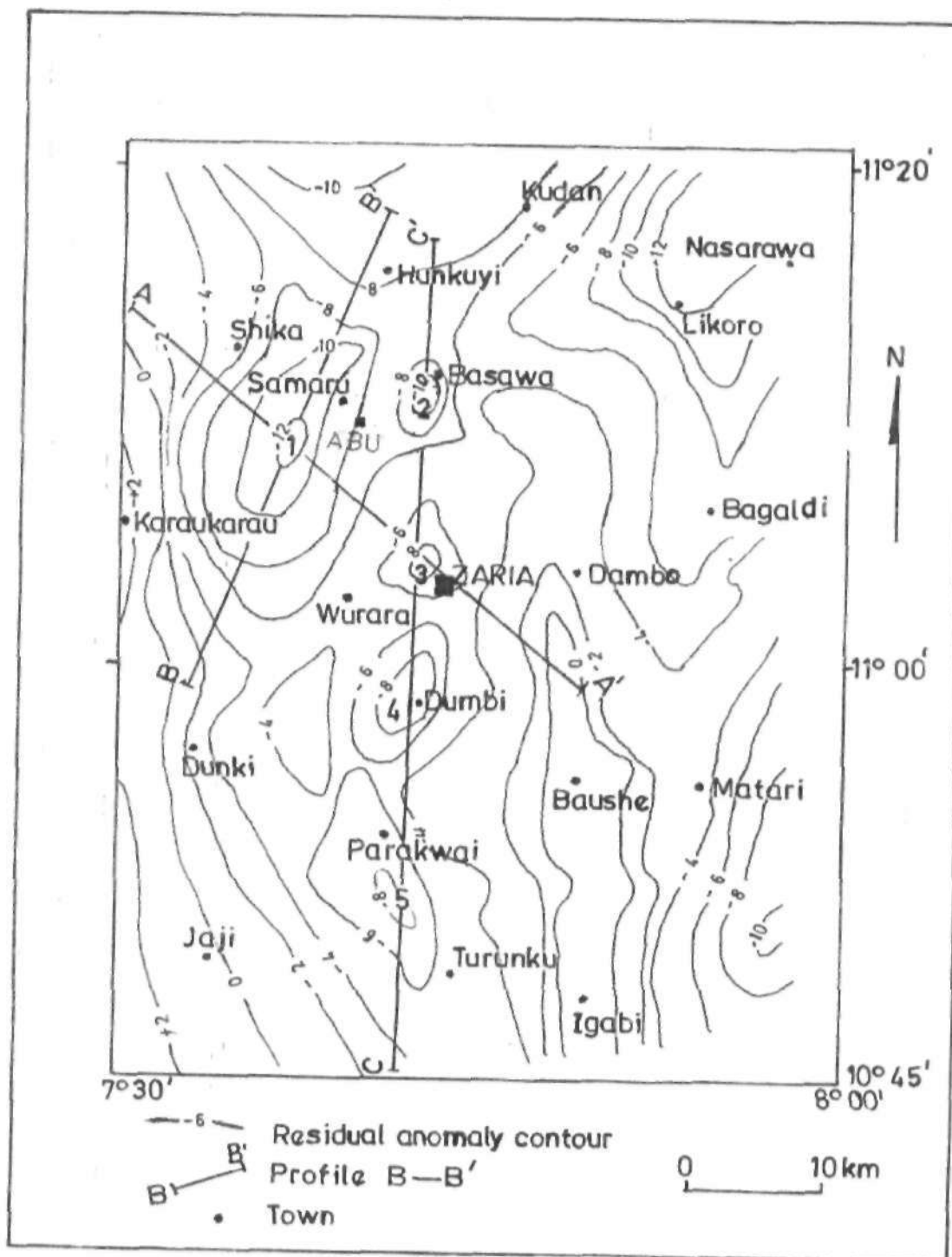


Fig. 4.5. Residual anomaly map of Zaria area.
Contour at 2mGal interval

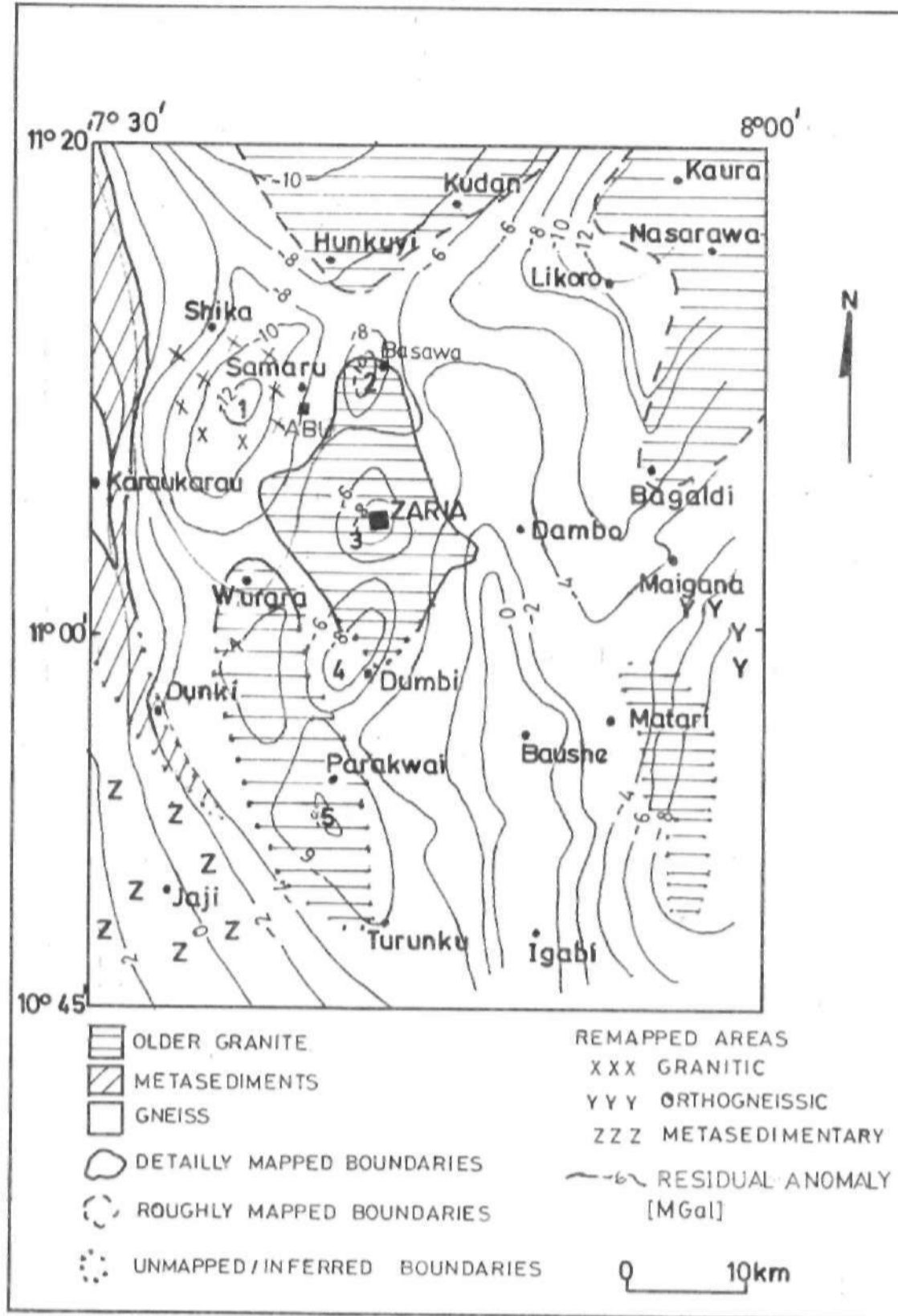


Fig.4.6. Residual anomaly map of Zaria area superposed over the geologic map.

(1970), but Webb (1972) remapped same area as being underlain by granites and schists. However, this study suggest that the area is underlain by acidic intrusives. Also, the Zaria batholith, mapped from around Basawa down to the south of Zaria by McCurry (1970) shows good correlation with residual closures Nos. 2,3 and 4 and residuals in these areas have values as low as -10 mGal. Furthermore, the batholith inferred southward to the Zaria batholith by McCurry (1970) correlate with residual closure No. 5 with gravity as low as -8 mGal around Parakwai and Turunku.

There also exist good correlations in other parts of the surveyed area. Around Hunkuyi, Kudan, Kaura, Nasarawa, Bagaldi and Matari, residual gravity as low as -10 mGal and the surface geology confirms granitic intrusives in these areas. Also, the metasediments around Karaukarau, Dunki down to Jaji show a relatively high residual anomaly of up to $+2$ mGal. Lastly, the gneissic complex areas around Likoro, Dambo, Baushe and Igabi correlate with the approximately N-S residual field in those areas.

4.4 Quantitative Interpretation of Residual Anomalies

4.4.1 Modelling Technique

The problem of gravity interpretation consist of finding the sub-surface mass distribution whose

gravitational effect is observed at the surface. This is an inverse problem of potential theory which involves determining the source from its potential field. The modelling technique that is usually adopted is to compare the gravity effect from a hypothetical set of bodies intruding into the sub-surface, with density contrast to the host rock, with the obtained residual field. When the differences between the observed and computed gravity values are sufficiently small, the modelled configuration constitute a possible representation of mass distribution which exist in that region. Theoretically, an infinite number of models can be generated to fit the observed gravity field, but restrictions imposed by surface lithological distributions and structures usually eliminate most of the models.

The computer program used for modelling, due to Talwani and Ewing (1960), calculates the gravity field due to an arbitrarily shaped three-dimensional body using polygonal shaped laminae as the basic modelling blocks. The outline of the body is defined by horizontal polygonal shaped depth contours. In the calculation, these contours are replaced effectively by horizontal polygonal laminae and numerical integration, with respect to depth, yields the gravity anomaly of the entire body. The

theory is based on the expression.

$$\Delta g = \rho dz$$

where Δg = the gravity anomaly caused by a laminae of infinitesimal thickness dz . V , the laminae anomaly, is expressed by a surface integral given by

$$V = G\rho \left[\int d\psi - \int \frac{z}{(r^2 + z^2)^{3/2}} d\psi \right] \dots (4.1)$$

where G is the universal constant of gravitation, ρ is the volume density of the laminae and z, ψ and r are the cylindrical coordinates used to define the boundary of the laminae (see Talwani and Swing, 1960). The total anomaly, Δg_{total} , caused by the entire body is evaluated by integrating between z_{top} and z_{bottom} , the vertical limits of the massive body i.e.

$$\Delta g_{\text{total}} = \int_{z_{\text{bottom}}}^{z_{\text{top}}} V dz \dots (4.2)$$

4.4.2 Three-dimensional Interpretation of the Residual Anomalies

On the residual Bouguer anomaly map (Fig 4.5), three profiles were chosen for quantitative interpretation of the anomaly. Figures 4.7, 4.8 and 4.9 show the amplitude of the Bouguer, regional and residual fields across the profiles A-A', B-B' and C-C' respectively. The major considerations in

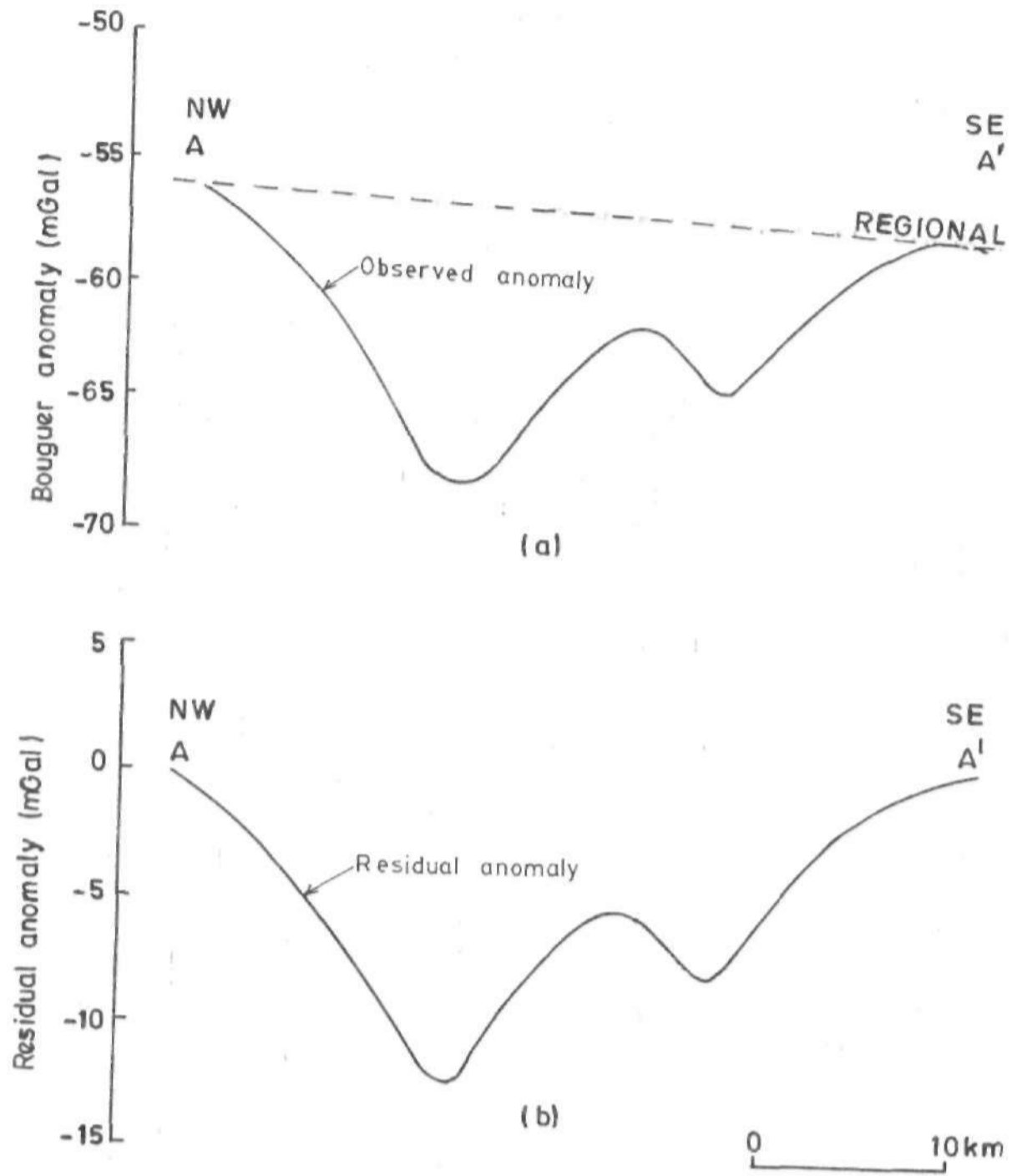


Fig.4.7. Bouguer anomaly, assumed regional and residual along profile A - A'.

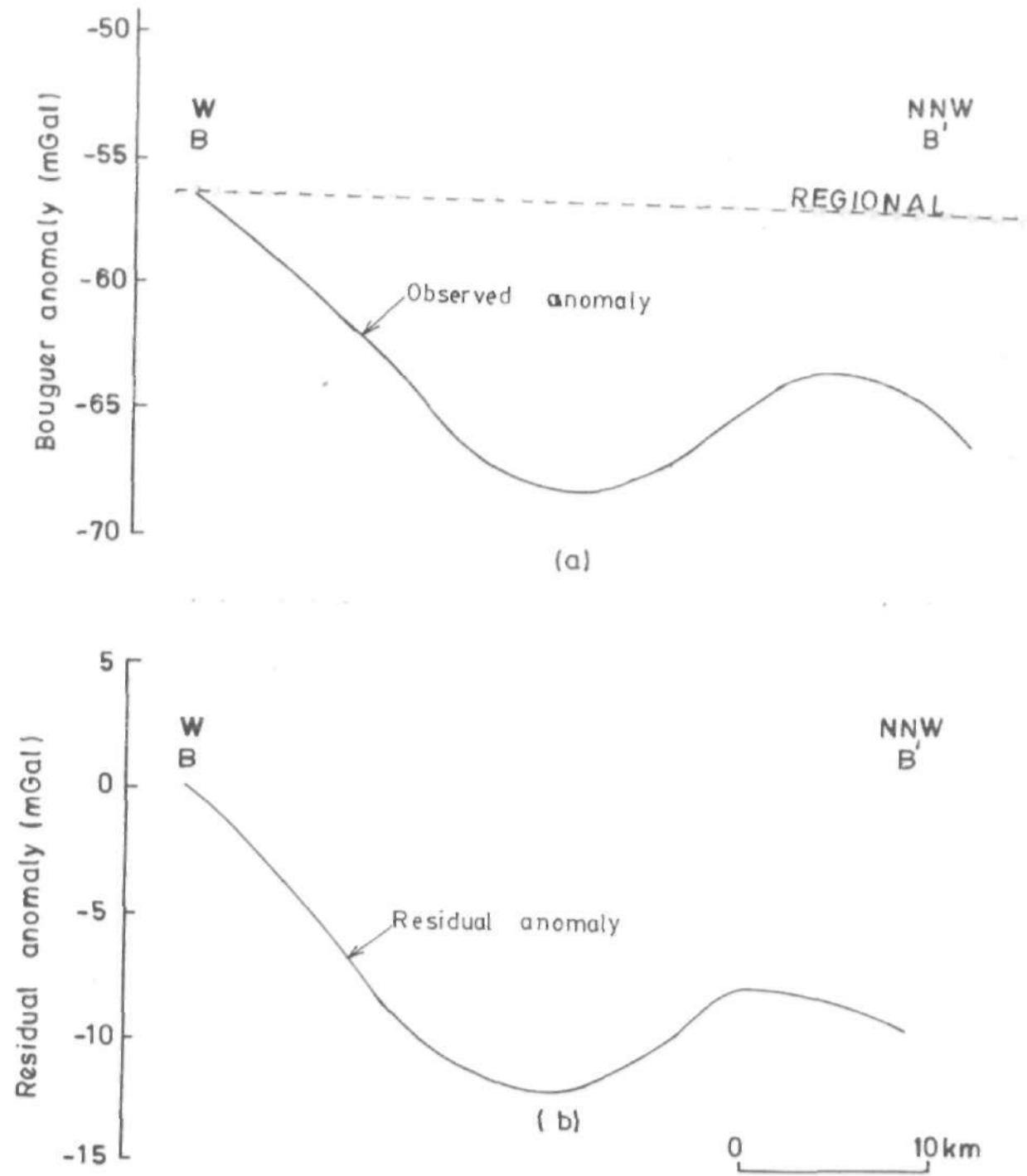


Fig.4.8. Bouguer anomaly, assumed regional and residual along profile B - B'.

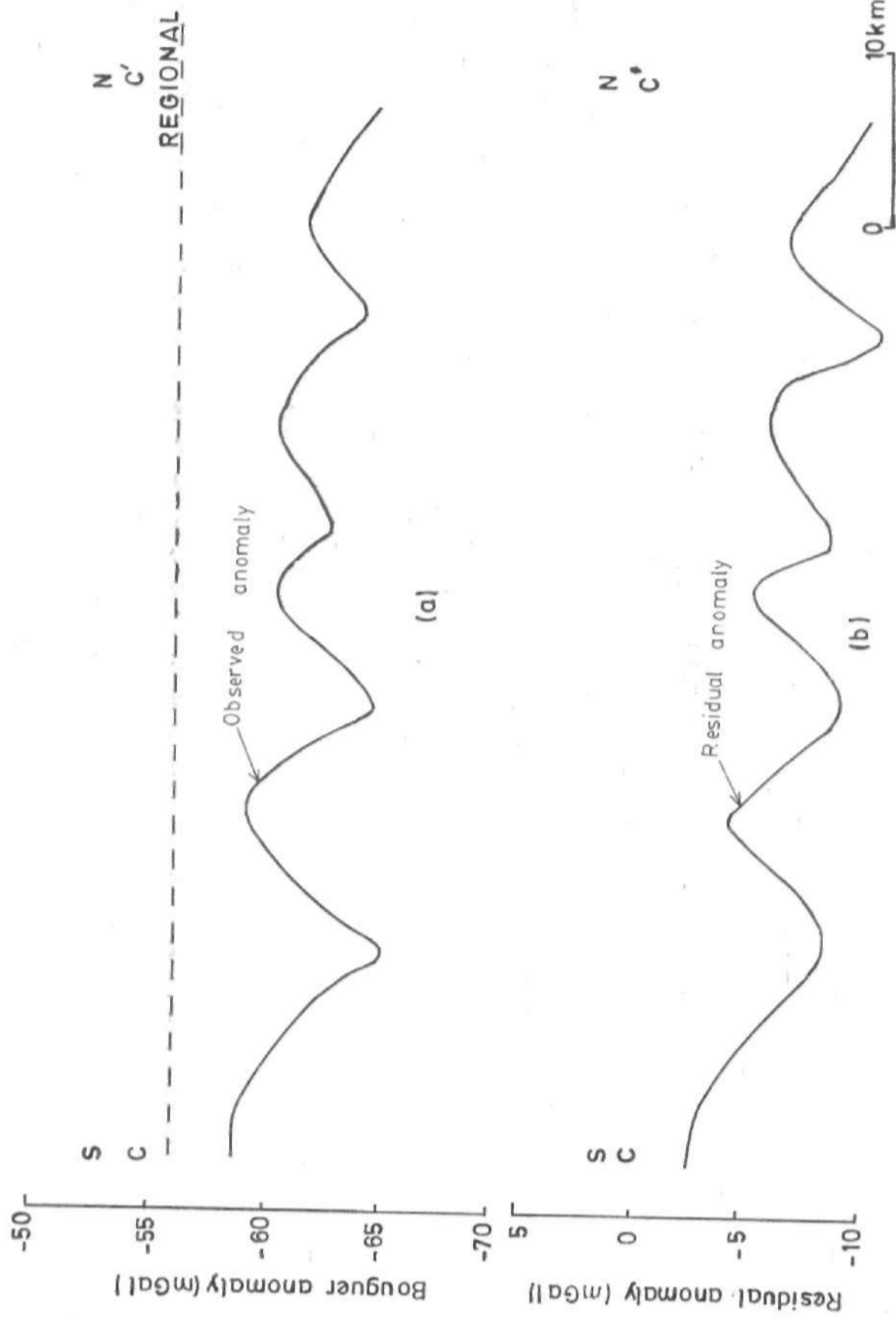


Fig.4-9. Bouguer anomaly, assumed regional and residual along profile C — C'.

choosing these profiles is that they cross the major anomalies in the area as well as many contour closures.

Prior to the modelling along the profiles, the program was tested with a hypothetical cylindrical body of depth 10km and diameter 10km with a density of $-0.1 \times 10^3 \text{kgm}^{-3}$. A comparison of the gravitation effect of this body along a profile which crosses the top of the body diametrically using the computer program and standard theoretical expression for vertical cylinder gave values of -15.97 mGal and -16.00 mGal respectively at the centre top of the body. At a distance of 10km away from the edge of the body, the gravitational effect had fallen to -0.6 mGal. Since this is less than the assumed error of about 1 mGal in the Bouguer anomaly, it was decided that the effect of any adjoining formation which is away by more than 10km from the edges of the modelled intrusives would not be considered in the modelling.

Also, in modelling along profile A-A¹, no consideration was given to effect from the metasedimentary belt which it crossed. From geological evidences, the metasediments in the area is composed of quartzites, schists and gneisses with the gneisses outcropping as anticlinal fold cores within the metasediment. As the gravity measurement could not

resolve the presence of the metasediment in this area, it was assumed that the metasediments in the area are not deep-rooted as is to be expected since they were originally deposited.

To model, an initial configuration of the structure of the intrusives was assumed. Through systematic trials and adjustments, fits were obtained between the observed and computed gravity fields along each of the three profiles. However, the depth contours of the model accepted to be realistic based on the known geology of the area is shown in Figure 4.10. The cross-section of the model along profiles A-A', B-B' and C-C' are shown in Figures 4.11, 4.12 and 4.13 respectively.

4.4.3 The Granite models

Figure 4.10 shows that the surveyed area is characterised by granitic intrusives (numbered 1, 2, 3 and 4). The intrusive No. 4 extends further north than shown in this model. It is part of the so-called Hunkuyi granite (McCurry, 1970). However, effects from these extensions are not expected to have significant effect on the computed anomalies of profiles A-A', B-B' and C-C'. The other 3 intrusives (numbered 1, 2 and 3 on Fig. 4.10) are separate batholiths, each lying wholly within the surveyed area. They could be collectively referred to as multiple batholith (Woakes, pers. comm.).

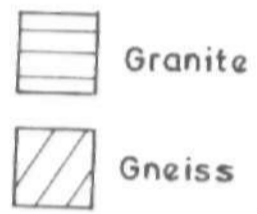
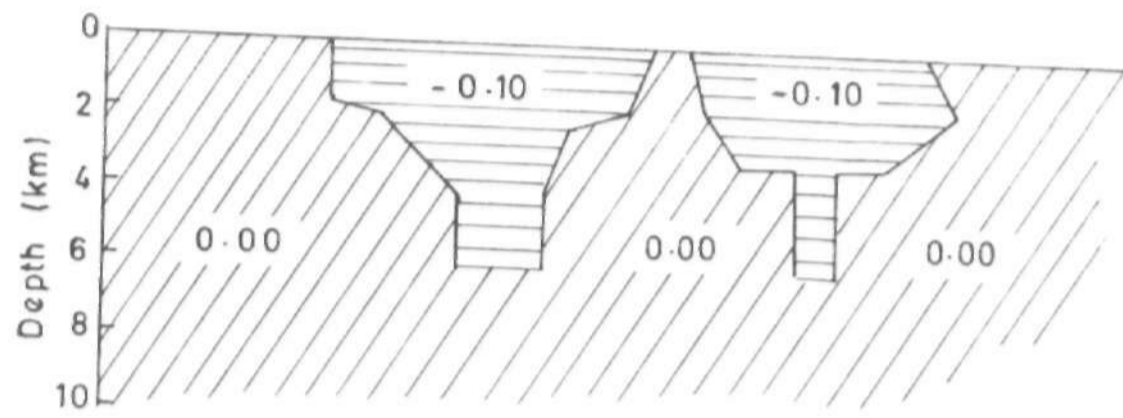
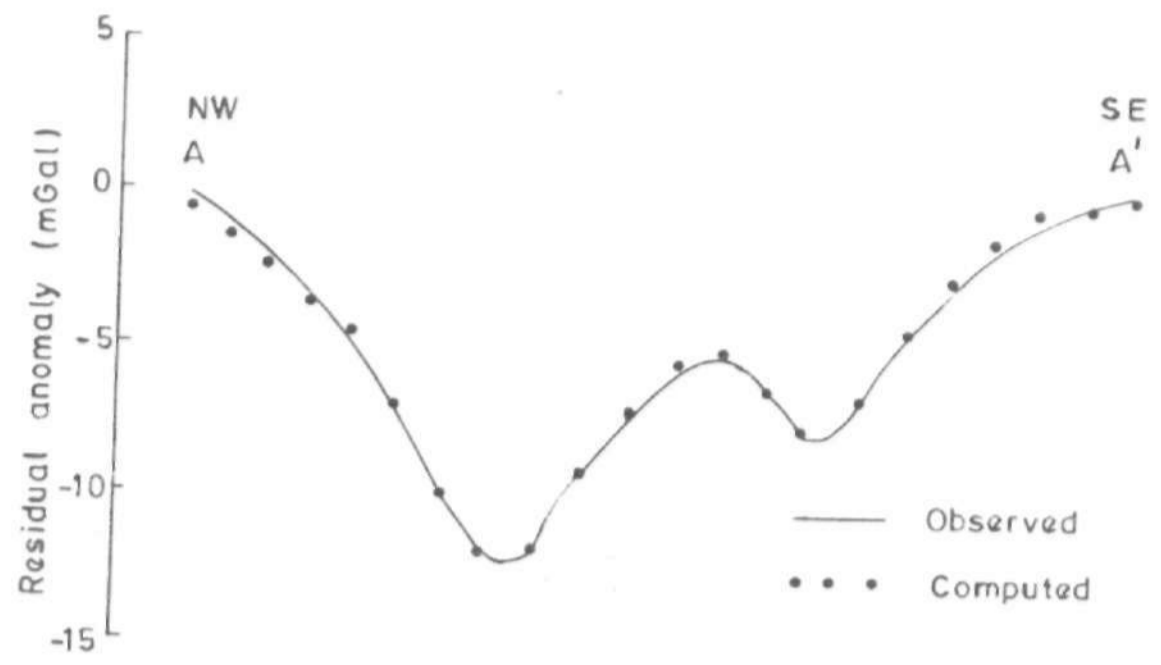


Fig.4.11. Three — dimensional model of residual profile A — A'.

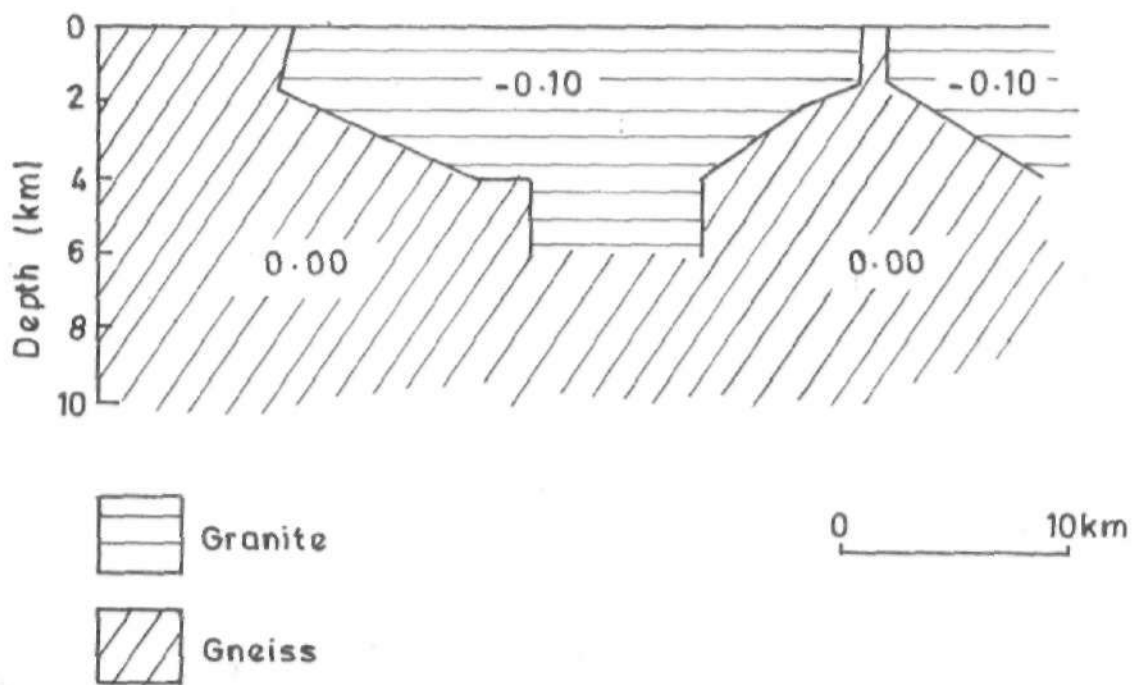
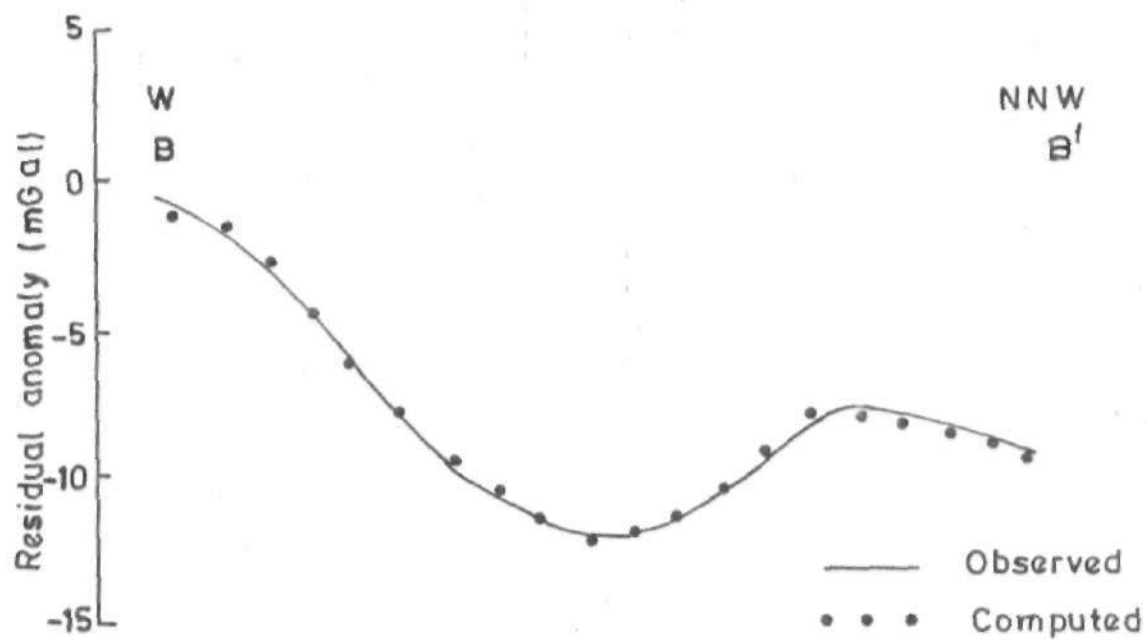


Fig. 4.12. Three — dimensional model of residual profile B-B'.

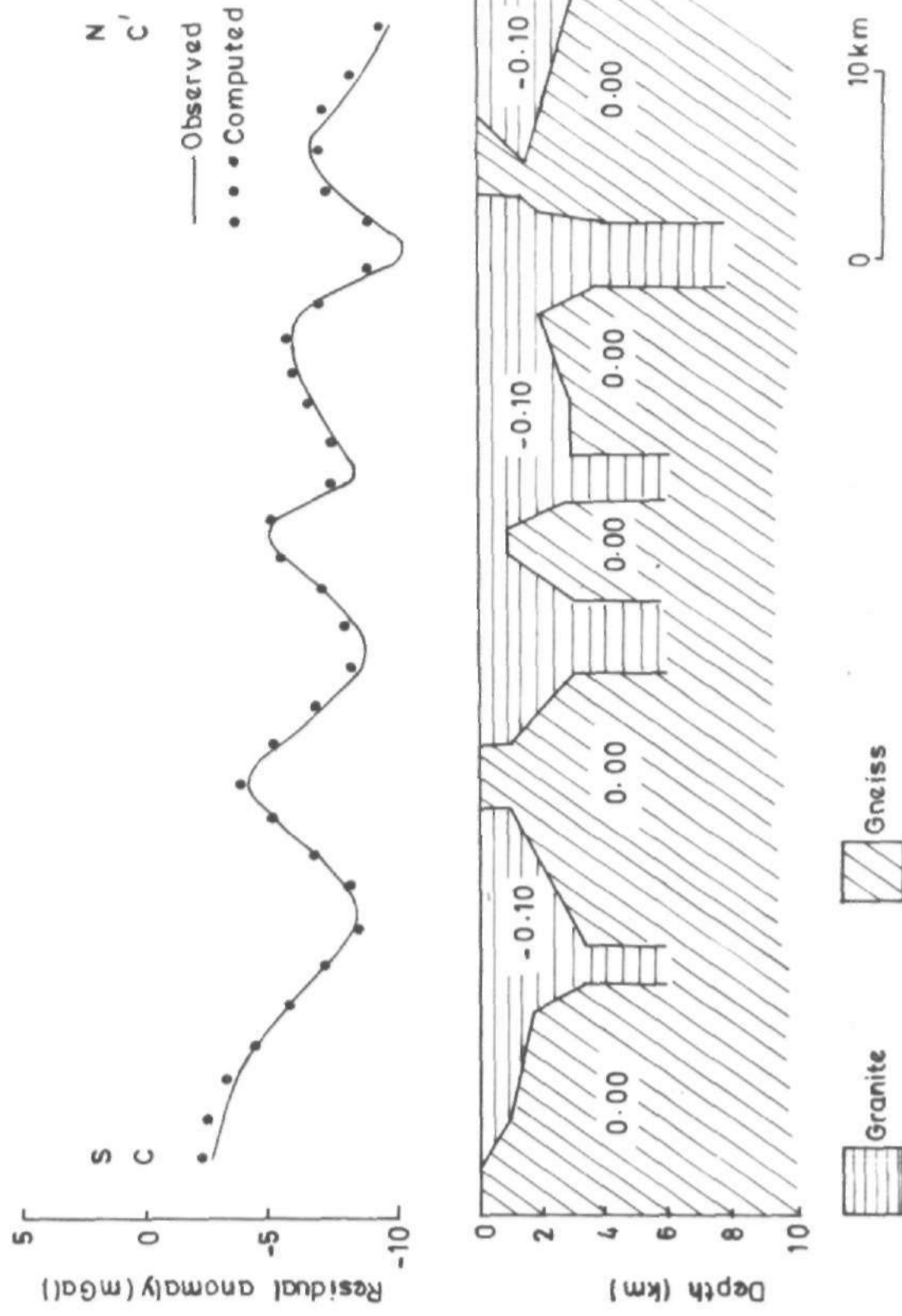


Fig. 4.13, Three-dimensional model of residual profile C - C'.

However, for further description of these intrusives, intrusive No. 1 would be referred to as BIYE BATHOLITH, intrusive No. 2 has been referred to as ZARIA BATHOLITH by McCurry (1970) and intrusive No. 3 as PARAKWAI BATHOLITH.

BIYE BATHOLITH:

Figure 4.10 shows that the strike length of the Biye batholith is approximately 28 km and its shortest and longest surface widths are 2.5 km and 13 km respectively. The general thickness of the batholith over a large area is 2 km. It has a single plug which dips gently from the general depth of 2 km to a depth of 4 km and then dip sharply to a depth of 6 km. The model suggests that the granite body dips inwards at angle of 38° on the eastern side; has a vertical contact on the northern and western sides; and has an outward dip of 25° in the south. The general configuration of the batholith is elliptical and it is aligned N-S.

ZARIA BATHOLITH:

Figure 4.10 shows the Zaria batholith lying east of the Biye batholith. It is sub-elliptical and aligned N-S. The strike length of the batholith is approximately 32 km and its shortest and longest surface widths are 3.5 km and 15 km respectively.

The general thickness of the batholith over a large area is 3 km, however, three separate plugs identified by the letters a, b and c (Fig. 4.10) were required to explain the corresponding negative anomalies in Figure 4.6. These plugs dip sharply from the general depth of 3 km to depth of 8 km for 'a' and 6 km for 'b' and 'c'. The model also suggests that the batholith dips inwards at angles of 68° , 26° and 30° in the north, east and west respectively; and has an outward dip of 45° in the south.

PARAKWAI BATHOLITH:

Figure 4.10 however shows the Parakwai batholith lying southward of the Zaria batholith. It is elliptical and also aligned N-S. The strike length of the batholith is approximately 23 km. Its average surface width is 8 km. The general thickness of the batholith is 1.7 km. It has only one plug. The model suggests that the granite body dips inward at angles at 23° and 12° in the north and south respectively; and has vertical contact with the host rock on the western and eastern sides.

DISCUSSIONS:

In a similar three-dimensional interpretation of the Bouguer anomalies over the Minna batholith, in Central Nigeria, Udensi et al. (1986) showed that the

granite body has an average thickness of 5 km with three plugs whose depths vary from 8 to 14 km. The Minna batholith also show inward dip. Also, Gandu (1984) showed that the Older Granite in the Malumfashi area of northern Nigeria has a depth of 4 km. Similarly, a gravity study of the Bodin Moor granite, southwest England by Bott (1961) revealed that the granite has a maximum thickness of 12 km. Brisbin and Green (1986) also showed that the Aulneau batholith, Canada, has a depth of 5 km with two plugs extending to between 7 and 12 km depth. Therefore, comparing these results with that obtained from this study showed that the results agree with similar ones.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS5.1 General Discussions

There are two main hypothesis with regards to the origin of granite masses. These are the hypothesis of essentially magmatic origin and the hypothesis of essentially metasomatic origin whereby sedimentary and metamorphic rocks are converted to granites by metasomatic migration of materials.

From chemical analysis and examination of petrological features, Russ (1957) proposed a single magmatic epoch for the Older Granites. So also did Rahaman (1976), on account of the mode of occurrence of charnockites in Ibadan area, and Ajibade (1980), on the basis of field relations in the Zungeru region. However, Oyawoye (1964) suggested potash metasomatism as the origin. Grant (1978) also believes that the Older Granites originated through a metasomatic process on the basis of geochronological evidence.

However, little deductions can be made from this study which may have consequence on the origin of the Zaria multiple batholith and the Nigeria Older Granites in general. The presence of several gravity lows of high amplitudes in the Bouguer and residual anomaly maps of the area strongly rules

out metasomatism as a possible origin. This had also been stated by Ajakaiye (1976). High gravity gradient (over 4 mGal/km) was found in one location. This indicates sharp contact with the surrounding rocks. This sharp contact indicates that magmatic stopping is the most likely mode of emplacement. The geological evidence in support of this view is the presence of contact metamorphism of the country rock and the presence of rotated xenoliths in the granites. These were observed on collected rock samples.

Further on the possible origin of the Zaria multiple batholith, McCurry (1970) reported that discordant contacts show that most of the granites are intrusive, while flow features such as swirling foliation, rotated xenoliths, and boudinage aplite veins and mafic pods, are suggestive of movement in a semi-plastic condition. Static granitisation has nowhere been identified (McCurry, 1970). She further states that it is believed that mobility of the basement caused less dense granitic facies to move from lower to higher crustal levels.

In his own report, Webb (1972) states that the evidence of sharp contacts of the multiple batholith and the presence of numerous xenoliths of gneiss in the granite south of the A.B.U. campus,

suggests that the granite was intruded in a liquid condition, and did not originate in-situ by the regional granitization of gneiss. On the mineral composition of granites in Zaria area, Webb (1972) stated that at least 4 types of granites occur in the area. Woakes (pers. comm.) further confirm the variable composition of the granites in the area. The explanation that could be given was that the multiple batholith might have been emplaced through different magnetic episodes (Woakes, pers. comm.).

However, from the results of this study, the three batholiths did not have contact with each other. This fact is supported by the work of McCurry (1970). Though, she mapped two separate batholiths (Fig. 2.1) to exist within the surveyed area, the two intrusives were clearly shown not to have any contact. Secondly, the fact that the A.B.U. area was mapped as gneissic also confirmed by this study, is an evidence that the Biye batholith and the Zaria batholith have no contact. Further to this, and according to Webb (1972), 2 km north-east of A.B.U., a sharp contact between the Zaria batholith and the gneiss was seen. Also, around and up to 2 km west of A.B.U., the gneisses are intruded by a complex of granite sheets and the margin of the batholith

appears to be marked by repeated injections of granite.

Hence, relating the results of geologic work to the findings of this survey reveals that the Biye batholith was not discovered by McCurry (1970). This may be due to the fact that her work was based mainly on photogeological interpretation supported by selected ground traverses. She rightly mapped the location of the Zaria batholith from evidences of surface geology. The location of the granitic intrusive southward of the Zaria batholith however tallies with the location of its main root as determined from the present study.

5.2 Summary of Results and Conclusions

The Zaria area is characterised by negative Bouguer anomaly ranging from -52 mGal to -68 mGal with an average of -63.4 mGal. The minimum value of -68 mGal occur a few kilometers west of Samaru and around Basawa.

The regional - residual anomalies were separated using the first order polynomial fitting. The regional contours trend N-S with a gradient of 0.07 mGal/km to the west. On the residual map are 5 negative gravity closures with gravity values ranging from -12 mGal to -8 mGal. The residual map

correlate well with the surface geology.

Three-dimensional modelling of the structures in the area show that three batholiths exist and extend to depths between 6km and 8km. The batholiths in the area generally show inward dip. They are rather elliptical in shape and all aligned N-S. The strike length of the Biye, Zaria and Parakwai batholiths are 28 km, 32 km and 20 km respectively.

From this study, it would appear that the three granite bodies in the area do not have a common source. The Biye batholith has only one feeder plug, the Parakwai batholith also has only one while the Zaria batholith has three feeder plugs.

5.3 Recommendations

As the determination of the deep-seated structural relationship of the multiple batholith and the surrounding gneisses would remain unconvincing unless similar geophysical work is carried out using other methods apart from gravity, the recommendation is that work on other geophysical method be carried out in the area.

The refraction seismic and magnetic methods would throw more light on the structural relationship between the intrusives and the host gneisses. Since the gravity method does not map

the thickness of the regolith, magnetic survey along with resistivity survey applied on strategic profiles all over the area, would throw more light on this and any crack zones and fault lines in the sub-surface. The determination of the thickness of the regolith would enhance the agricultural potential of the area and also delineate constructional materials borrow pit sites which would in many ways boost the construction industry in the area. The determination of crack zones and fault lines would be of much use in the water supply sector and all these brought together, would enhance the geological knowledge of the area. These recommendations will stimulate an integrated study that will require inputs from geophysics, geology, civil engineering and agriculture.

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