A GRAVITY INVESTIGATION OF THE YOUNGER GRANITES IN LERE/SAMINAKA AREA, KADUNA STATE, NIGERIA

By

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DEDICATION

This thesis is dedicated to my parents; Madam Eunice N. Ekwue and Late Mr. Clifford G. Ekwue who sacrificed a lot for my education; to my wife Mrs Uche C. Ekwue and my children - Newman, Chimdinma and Onyenmeri.

DECLARATION

This is an original work carried out by the author under the supervision of Dr. I. B. Osazuwa and Prof. S. B. Ojo. The thesis has not been submitted in whatever form to any institution, organization or body for the award of any degree. The works of others are duely acknowledged and referenced.

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E. U. Ekwue

CERTIFICATION

This thesis entitled "A Gravity Investigation of the Younger Granites in Lere/Saminaka Area, Kaduna State, Nigeria" by E. U. Ekwue, meets the regulation governing the award of thee degree of Master of Science (Applied Geophysics) of Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

A gravity survey of the Younger Grinite suites around Lere-Saminaka was carried out to obtain more subsurface information on the Geology of the area following a general study earlier carried out on the Younger Granite series of Nigeria in the early seventies. A number of gravity and height measurements were carried out on 190 field stations in Saminaka area. Also, a total of 154 fresh rock samples were collected from the field to aid interpretation of the field results. The result showed that the area is characterised by negative Bouguer Anomaly ranging from -26 mgal in the northeast part, to -80 mgal in the centre of the southern portion of the surveyed area. The mean value for all the stations is -55 mgal.

A two dimensional interpretation of the residuals carried out along three different profiles indicate that the Younger Granite suites in the area extend to depths of 7.5 to 11.5 km with a density of 2.62 $kg \cdot m^{-3}$ in contrast to an average density of 2.65 $kg\text{-}m^{-3}$ for the basement complex which they intrude. Structurally, the contacts between the Younger Granites and the basement complex is vertical in some places and inclined in some other, with outward dips and spread laterally at depth beyond the exposed contact.

The models also suggest the existence of some unexposed intrusions in the area. These intrusions are suspected to be basalt in Jangre area and in Mariri areas respectively; dolerite towards the east of Saminaka and the granite around Saminaka.

The large negative Bouguer anomalies and the relatively low density values of the granites as compared to those of the surrounding host rocks strongly indicate the acidic nature of the Younger Granite, and hence the possibility of a parent magma as the source.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

1.1 LOCATION AND EXTENT OF SURVEY AREA

In this project, a geophysical investigation of Lere/Saminaka area in Kaduna state of Nigeria was carried out.

Saminaka is the headquarters of Saminaka Local Government Area of Kaduna State in northern Nigeria. Along the road, Saminaka is about 70 km from Jos and 180 km from Kaduna.

The extent of the area surveyed in this project is located between latitude 10°00' and 10°30' North and between longitude 8°30' and 9°00' East. It occupies an area of about 3,025 km^2 sandwiched among Kaduna, Plateau and Bauchi States. Geologically, the survey area lies within the Younger Granite Province of Nigeria. Figure 1.1 shows the location of the survey area within the geological sketch map of Nigeria.

1.2 GEOGRAPHICAL DESCRIPTION OF THE PROJECT AREA

The land area around Saminaka is generally flat and dotted here and there with some granite hills and ridges. The average elevation of Saminaka is about 750

m above sea level. By virtue of its proximity to Jos, the climatic condition of Saminaka is comparable to that of the Jos Plateau in Central Nigeria. The climatic condition is normal with a mean annual temperature which oscillates between 25°C and 27°C. There are two main seasons consisting of a long dry season from October to April and a wet season from the remaining five months. The dry season is usually characterised by a general lack of rainfall and the dry atmosphere develops cracks on clay soil. The nights are usually cold while the dusty afternoon haze helps to minimise the heat of the sun. During the wet season however, the heavy rainfall, frequently accompanied
by storms, causes gullies on laterite-surface roads. This is also the planting season in Saminaka.

The total annual rainfall is between 100 cm and 150 cm and the relative humidity is constantly below 40% except in the few wet months when it sometimes goes up to an average of 60%. The vegetation is typical of the Guinea/Sudan Savanna. It consists of short to tall grasses 1.5 - 2 m high and some stunted trees which grows in clusters and generally not more than 6 m high.

Saminaka is covered mainly with laterite soil. The amount of precipitation is too low to encourage

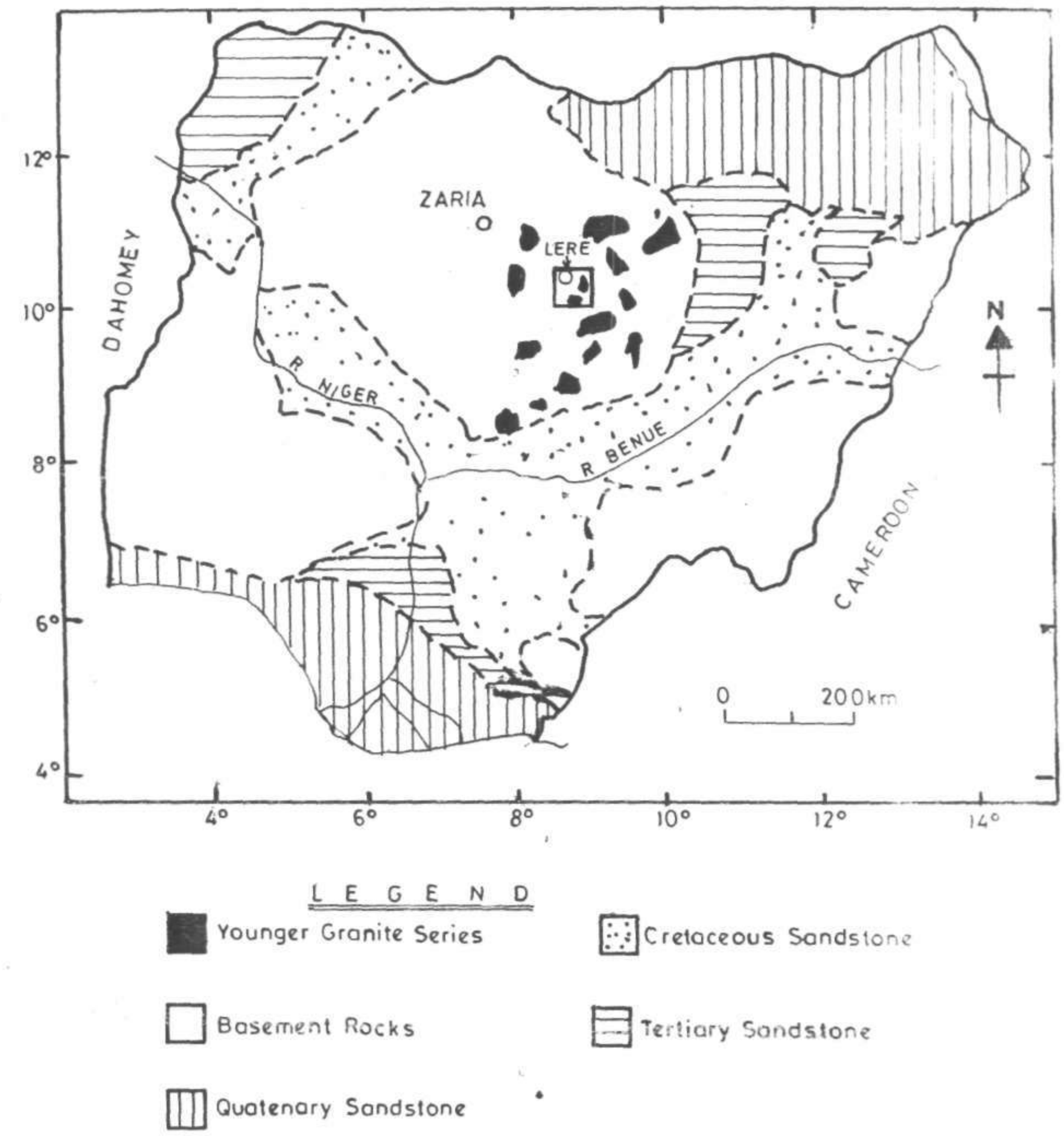


FIG-1·1: GENERALISED GEOLOGICAL SKETCH MAP OF NIGERIA SHOWING THE SURVEY AREA IN BOX leaching. The soil is deeply corroded, grey or reddish in colour, generally sticky, impervious to water and of mediocre fertility (Iloeje, 1979). Hence the soils are of little use for agriculture unless artificial fertilizer is used. When exposed to the surface, the soil becomes as hard as brick and is therefore more useful in road paving and wall construction than for farming. However, areas where soils disintegrated from local granite and volcanic lava, they are productive and useful for cotton production.

The inhabitants of Saminaka were mainly the Kuramas, Surubus, Gures and the Jeres. Hausa is the general language spoken in the area although each tribe has its own local language. The inhabitants and their main food/cash crops include maize, guinea corn, yam and locust bean.

Saminaka, along with Jos Plateau, being an isolated upland massif, has naturally developed a radial pattern of drainage which flows into four major river systems mainly: Chad (Largely Delimi River), Gongola, Benue and Kaduna. The Benue tributaries are cutting back most actively and are at present truncating the headwaters of the Kaduna and Gongola systems.

1.3 PREVIOUS WORK DONE IN THE PROJECT AREA.

1.3.1 Mineral Exploration

Prior to 1965, geophysical activities carried out in the Nigerian Younger Granite series were only for exploration purposes. Tin, columbite and some minerals were mined using electrical resistivity methods and magnetic methods (Shaw and Cole, 1961). Following the publication of an aero-magnetic map (Sheet 168 Naraguta S.E.) by the Canadian Aeroservice Limited under a Canadian Technical Assistance Programme in Nigeria, a comprehensive geophysical study of the area was carried out in 1964 and 1965 under the auspices of a United Nations Mineral Project and the British Overseas Geological Surveys. Several geophysical methods were used in the search for basalt covered alluvial cassiterite (Masson-Smith, 1965 and Ikpokonte, *et al.*, 1992).

1.3.2 Gravity Investigation

The first major regional geophysical study carried out in the Younger Granite Province was in 1967 and 1968 (Ajakaiye, 1974) when several gravity stations were established at 3 to 6 km intervals on all accessible roads in the area. In 1969 and 1970 additional gravity observations were made. The result of the survey indicates a granitic parent magma for the suite due to the predominantly negative Bouguer anomalies over the area.

1.4 AIMS AND SCOPE OF THE SURVEY

This project is aimed at providing a more detailed follow up survey to the general study carried out between 1967 to 1970 by Ajakaiye on the Younger Granite series of Nigeria (Ajakaiye, 1974). That study suggested a large negative Bouguer anomaly over the area.

This work is also a continuation of a series of gravity studies on the granites of northern Nigeria which was started in 1983 by some geophysics students of A.B.U. Zaria.(see Gandu, *et al.*, 1986; Udensi, *et al*, 1986; Adeniyi, 1987, Oladosu, 1987 and Ojo *et al.*, 1992). In addition, it is also intended that this survey would provide more sub-surface information on the geology of the area.

In order to achieve these objectives, a detailed gravity survey of the area was carried out.

CHAPTER TWO

GEOLOGY OF THE STUDY AREA

2.1 INTRODUCTION

The Lere-Saminaka area belongs to the Basement Complex of Nigeria which covers about half the area of Nigeria and at least two-third of the area surveyed in this project (Fig. 2.1). The rocks of the Nigerian Basement Complex can be grouped into three lithological units (Oyawoye, 1972, Ajibade, 1980).

i) the Migmatite-gneiss complex, which covers about 70% of the basement.
ii) The metasediments and metavolcanics which form the schist Belt, and
iii) The older granite which intruded both the migmatite-gneiss complex and the schist belt.

A group of rocks known as the Younger Granites, which dominated the survey area, is the body of interest in this survey. They are known to be a series of discordant, high level intrusions which transgress all units of the basement complex (Turner and Macleod, 1971). They are believed to be of Jurassic age. Generally they are grouped in the north-central part of Nigeria extending from the Benue valley to Southern Kano area - a distance of about 322 km along the meridian. The Jos Plateau forms the focal area of the Younger Granite suite and has been the principal centre of the associated tin and columbite mineralisation.

Altogether, about 50 Younger Granite ring complexes, about 150 - 180 m.y. old have been recognised in Nigeria (Jacobson *et al*, 1958; Darnley, 1962; Breeman and Bowden, 1973). They occupy a total area of 7510 km^2 and vary in size from 1.5 to 160 km with a circular or elliptical outline. The large size of many of the structures is due to the overlapping and superposition of separate intrusive cycles; smaller complexes form isolated structures. In general, they have a clear topographical definition and there is usually a close coincidence between the geological and topographical boundaries at the margins of the granites.

The rock types consist mainly of rhyolites, biotite-granites, riebeckite-granites, hornblende-granites, fayalite-granites, syenites and their corresponding porphyries (Macleod, 1971).

2.2 MAJOR ROCK TYPES

2.2.1 Rhyolites

The rhyolites can be sub-divided into two types namely: the early rhyolite and the later cauldron rhyolite. Although commonly found in association, they can usually be distinguished in the field on the basis of texture and mode of occurrence. In the hand specimen, they display a great

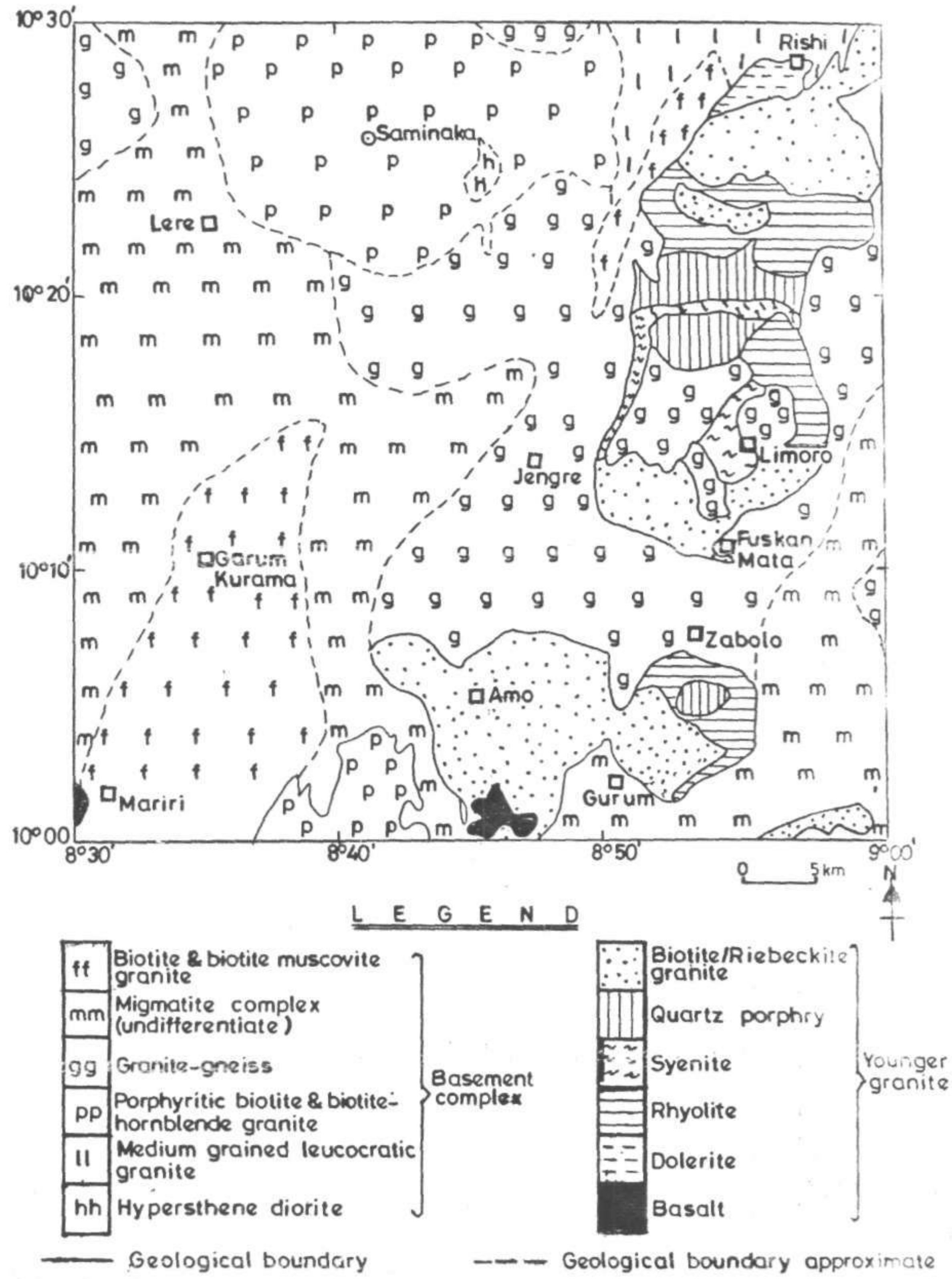


FIG-2-1: SIMPLIFIED GEOLOGICAL MAP OF THE SURVEYED AREA diversity of textures and of colours which range from grey and brown to bluish grey and green in the alkaline facies. The early rhyolites display more varieties.

The later cauldron rhyolites are remarkably uniform in texture, and are almost invariably porphyritic, with the proportion of phenocrysts being equal or greater than half the volume of the rock. When intruded into vent agglomerates or communited zones in the earlier groups, they form spectacular intrusion brecias. In the Buji complex, there are fine examples of vent agglomerates closely net-viewed by the intrusive rhyolite.

2.2.2 Hornblende-Granites and Porphyries

The hornblende-granite and porphyries is an important group which frequently forms the conspicuous ring dykes found in the area. On the basis of both texture and mineralogy the group can be divided into two types namely (i) the hunblende-granite with a truly granitic texture and which sometimes appear as large plutons, and (ii) the granite-porphry which commonly assumed a porphyritic texture in the ring dykes.

However, a more distinctive sub-division consists of the quartz-fayalite-porphyries which form the great ring-dyke at Kudaru and small plugs cutting rhyolites at Buji, Jere-Sanga and Liruei. These rocks according to Turner and Macleod (1971), occur as the last stage in the volcanic phase of activity and are transitional between the micro-crystalline cauldron rhyolites and the granite-porphyries, both texturally in time and mode of occurrence. Secondly we have the hornblende-biotite-granites a group of coarse-grained granites occurring as massive ring-dykes or plutons in the area.

2.3.3 Biotite-Granites

This is the most abundant and widespread rock-type in the Younger Granite area of Lere-Saminaka environment. Some of the largest individual intrusions is formed by this rock-type. Occasionally, the rock occurs as ring-dykes but is more commonly found in the form of large circular and crescentic pluton and as small stocks. It is common to observe a general consistency in texture and mineral composition over the greater part of its extent in any single intrusive phase of biotite granite.

Based on texture and colour, the Biotite Granite are divided into three groups (Turner and Macleod, 1971). Group I are the coarse grained biotie-granites, generally pink in colour and with very widely spaced joints so that they weather to extensive slabs and extremely large boulders. Group II are the medium-grained granites, pinkish in colour and grading into white, even texture, medium grained granites of Group III. (Jacobson *et al*, 1958).

The nature of contacts between biotite-granites and other rocks in the area varies considerably. Often, the granite shows a progressive decrease in grain size towards its outer contact, and porphyritic microgranite zones appear sometimes as gradations from the main body and again as separate minor irregular intrusions. In many cases, the actual contact zone is so confused by minor intrusions that no reliable estimation of the attitude of the contact can be made even in well exposed ground. Some contacts have been noted to have knife-edge sharpness and the normal texture of both granites can be observed in a single hand specimen.

2.2.4 Riebeckite-Granites

This rock type is most abundant in the eastern part of the survey area where we have the Choko riebeckite-granite, Dutsen-Jere riebeckite granite, and Fuskan-mata riebeckite biotite-granite. The riebeckite granites occasionally appear as ring-dykes but are commonly found as elliptical plutons. Small sheet-like intrusive granites containing both riebeckite and biotite are fairly common and form a well characterised group of intrusions. They may show fairly regular variations in the proportion of riebeckite to biotite as at Amo. The common occurrence riebeckite-biotite-granite as at Shere in Jos Plateau, has led to the suggestion that they may be the product of some form of hybridization or of metasomatism between riebeckite-granite and the more alluminious members of the Younger Granites (Tuner and Macleod, 1971).

2.2.5 Syenites

The most extensive occurrence of syenite in the survey area is the Limoro and Rishi complexes in the eastern part of the region. The syenites have a close affinity to the hornblend-fayalite-granites. Many of them carry fayalite and the same soda-hornblendes as occur in the granites and there is usually some free quarts which may range as high as 10%. Their transitional relationship to the hornblende-fayalite-granites indicates that the intermediate rocks appear early in the intrusive cycles but more often appear as stocks than as ring-dykes.

2.3 MINERALISATION

The mineral content of each rock type is shown in Table 2.1. Quartz and feldspar are the most common mineral in the area as they occur in most rock type. The mineral content and their properties distinguish each rock from the other. Such properties include the colour, form and lustre which may vary from one rock formation to another.

2.4 GEOLOGICAL STRUCTURES

2.4.1 Ring Fractures

Ring faulting and cauldron subsidence are the major tectonic controls governing the emplacement of the Younger Granites. Some of the finest examples of multiple ring

Table 2.1: Mineralization

Rock Type	Major Mineral Content
Rhyolite	Quartz, feldspar, plagioclase
Hornblende-Granite and Porphyries	Fayalite, pyroxene, hornblende arfvedsonite, biotite
Biotite-Granite	Quartz, feldspar, plagioclase, biotite
Riebeckite-Granite	Quartz, feldspar, pyroxeene, biotite
Syenite	Fayalite, quartz, hornblende, ferroaugite, feldspar

intrusions in the world is therefore located in this region. Usually ring fractures occur either as ring guides or as cone sheets. Ring dykes are intrusive masses filling curved fractures, sometimes appearing as a complete cycle or loop in plan, while cone sheets are fractures which are shaped like the surface of a cone with its apex downwards and are filled with igneous materials.

A continuous sequence can often be demonstrated between volcanic and plutonic igneous activities and the mechanism of ring subsidence has continued to operate at all stages of the cycles. The pattern for the initial volcanism has been determined largely by ring-fractures which have extended to the surface. These fractures have controlled the alignment and distribution of the vents and the major surface cauldrons. Continuation of the same mechanism at greater depth beneath the lava accumulation has localised the peripheral ring-dykes and the granite plutons. Hence, a great variety and number of Younger Granite complexes exist in Nigeria, and different degrees of erosion have resulted in the entire range of igneous structural patterns being clearly exhibited.

2.2.4 Volcanic Structures

The early volcanic structures are demonstrated in complexes such as Buji and Saiye-Shokobo. The degree of preservation of the initial volcanic structures varies considerably in different complexes. In some areas, volcanic rocks are better preserved and the underlying granites are exposed only in more deeply eroded zones. Saiye-Shokobo is an example of this group. In other complexes, the volcanic rocks have been eroded to such an extent that their original pattern of distribution is conjectural. Some of the large complexes of Jos Plateau form examples of this group.

Intrusive acid lava at shallow depth result to the formation of hypabyssal ring-intrusions, plugs, dykes, irregular sheets and diatremes cutting the early volcanic materials and the adjacent basement rocks.

2.4.3 Cone-sheets

Cone-sheets have been recognised in several of the complexes and are best developed at Amo and Buji. As is common with all Nigerian cone-sheets, they are highly acid rocks and show much greater deviations from the ideal patterns of dip and distribution. At Amo, the cone-sheets attain a thickness of nearly 60 m and all gradations are found to be narrow veins a few centimeters in thickness. Many of the granites are associated with extensive and irregular swarms of felsite and quartz-porphyry dykes and it seems likely that many of these are genetically related to the felsitic cone-sheets (Turner and Macleod, 1971).

2.4.4 Ring-Dykes

Ring-dykes constitute one of the most important structural features due to its abundance in the Younger Granite especially within the southern part of the survey area.

The ring-dykes are both smoothly accurate and polygonal. The narrower dykes take polygonal form cutting the migmatites and metasediments of the basement complex. Here, the strong structural patterns have exerted a measure of control on the fracture directions. Smooth accurate ring-dykes are usually found within the Younger Granites themselves and in some of the older granites, where the host rocks have less pronounced structural trends, such as the ring-dyke of Amo in the survey area.

The ring-dykes are generally steep structures and contacts dipping outwards at angles less than 80° are rare. Some of the ring-dykes are as much as 1.6 km in width, and few if any can be simple permissive intrusions following block subsidence between outward-dipping fractures (Turner and Macleod, 1971).

2.4.5 Granite Plutons

There is practically, a continuous sequence of intrusive forms in the Younger Granite ranging from the narrow ring-dykes to large irregular granite plutons. Some of them exceed

260 km^2 in area. Many of the smaller granite intrusions clearly represent the upper, flat-lying roof sections of the ring intrusions. Some of these are remarkably shallow in comparison with their lateral dimensions. Others are stocks and bases with steeply dipping contacts which probably continue to a considerable depth. In some of the smaller granitic complexes such as Amo, a close approach is seen to the ideal pattern of concentric, steeply dipping ring-intrusions emplaced by repeated cauldron subsidence.

2.5 SOURCE OF YOUNGER GRANITE MAGMATISM

A lot of propositions have been put forward by many geologist to account for the origin of the Younger Granite magma. Two of the most recent theories are summaries here. The first, suggests that peralkaline silicic magma generated within the lower crust on the upper mantle, are contaminated while ascending into the upper crust to yield non-peralkaline magma (Bailey and Schairer, 1966). The other theory, states that the peralkaline magma was generated in the upper crust from some basement rocks and that on further progressive melting and cooling, yields the non-peralkaline magma of metahuminous and peraluminous trends (Oyewoye, 1968; Bowden, 1970).

While both theories agree on peralkaline liquid as the source liquid, the point of disagreement lies on the source region for the generation of the peralkaline magma and how the associated non-peralkaline granite was derived. Evidence from the gravity survey carried out in the Younger Granite suite of Nigeria by Ajakaiye (1974) indicates a granitic parent magma for the suite due to the predominantly acidic low density rocks and large negative Bouguer anomalies over the area. This result agrees with Bott (1953) who has earlier pointed out that large negative Bouguer anomalies over granites would suggest a magmatic origin either by direct intrusion from the 'granitic layer' or possibly by melting, differentiations and intrusion of the "metamorphic layer"

In fact, a magmatic origin has since been proposed for the Younger Granite suite (Falconer *et al.*, 1926; Jacobson *et al.*, 1958; Turner, 1963) and was re-emphasied later by Bowden (1970) who suggested that the absence of contact metamorphism around the Younger Granite ring complexes indicated that granitic magma was intruded into preheated rocks.

Another issue, concerning the emplacement of the Younger Granite has also remained an unresolved problem. However, concerning the general sequence in the emplacement of the Younger Granite, it is believed that, there was usually a volcanic phase during which volumes of rhyolite were extruded from ring fractures, followed by the emplacement of a peripheral ring dyke, then series of granite and synites by cauldron or block subsidences (Jacobson *et al.*, 1958; Turner, 1963, 1969; Jacobson, and Macleod, 1972).

2.6 ECONOMIC GEOLOGY OF THE AREA

A good number of the rock types in the area surveyed is of great economic importance. Tin mineralisation in this area is almost entirely confined to the biotite-granite suite especially in Liruei, Tongolo and Rishi. Columbite, Monazite, theorite and xenotite are some accessory minerals of Biotite-Granite some of which have been extracted as economic-product of the tin mining.

The riebeckite granites are quarried for road construction and residential buildings. The rhyolites, weathered into kaoline are very useful for pottery work. Those which weather into alkaline elements enrich the soil for farming.

CHAPTER THREE

INSTRUMENTATION, FIELD WORK AND DATA REDUCTION

3.1 CHOICE OF SURVEY METHOD

Apparently, many geophysical techniques, can be applied in prospecting Younger Granite regions depending on the purpose of the survey. Masson-Smith (1965) used magnetic, seismic, resistivity and gravity techniques in the search for basalt-covered alluvial cassiterite in the Younger Granite suite of Nigeria. Since such minerals occur in buried river channels, he used the electrical resistivity method and magnetic method to locate these buried channels thus enabling a reduction in the amount of exploratory drilling in the search for the cassiterite. The seismic method enabled the determination of the structures associated with the mineral, such as faults, while gravity techniques was used as a secondary detailed method for confirmation and further analysis of the anomalies already outlined by magnetic and electrical methods. The physical justification for using each method will be explained later. Employing these methods, Masson-Smith (1965) was able to locate and fully delineate the extent of the cassiterite mineral in order to enhance its exploratory drilling.

Ajakaiye (1974) used gravity method to obtain information on the form, shape and origin of the Younger Granite ring-complexes and to discover any unexposed ring complexes in the area. According to Hall and Hajnal (1969) and Green *et al.* (1978) the seismic refraction and reflection methods can be used to map the structure of the suite because of the low seismic velocity usually associated with granite rocks.

Seismic method involves an artificial source unlike some other methods which make use of natural potential fields. In seismic method, elastic wave energy is introduced in the earth and the elastic property of the rocks are measured. In the case of electrical technique, measurements are made on the variation in the electrical properties of rocks such as the potential, conductivity and resistivity. The parameters used in gravity and magnetic methods respectively are the variations in the earth's gravitational attraction due to lateral changes in rock densities and the magnetic properties of rocks due to variation in susceptibility.

Although seismic method has an advantage of ensuring high accuracy, high resolution and great penetration (Telford *et al.*, 1976), the cost involved as well as the unavailability of the necessary seismic equipments discouraged its use in this survey.

Electrical method has much greater variety of measurable parameters (e.g. resistivities, potentials and currents) unlike in the other prospecting methods where only one anomalous property can be measured. However, most electrical methods prove effective only for shallow prospecting and hardly provides information on subsurface features deeper than about 300 m or 500 m (Dobrin 1976) which is far too small compared with the expected depth of investigation in this survey. Even the magnetotelluric methods, which give greater depth penetration if low frequencies are selected, can be limited by non-uniformity of the subsurface and by the fact that the signal is rarely sinusoidal.

Magnetic and gravity methods have much in common and also employ similar interpretation technique. However, the magnetic map is generally more complex and the variations in field more erratic and localised than the gravity map. This is because, dipole magnetic fields have magnitude and variable direction and the force is both attractive and repulsive. On the other hand, although gravitational field has both magnitude and direction, however only the component along the vertical direction is of interest in gravitational prospecting. By vertical direction here, we mean the line which is parallel or coincidental to the radial line from the centre of the earth to the gravity station on the earth's surface. Its force is also attractive but not repulsive. Apart from these, small traces of certain minerals may greatly influence magnetic effects on rocks, while gravitational effects originate mainly from the rocks' primary constituents.

Nevertheless, previous work carried out on granitic rocks in the past in different parts of the world has consistently upheld the general view that gravity method has been successfully applied in mapping out granitic intrusions all over the world (Bott, 1953, 1955; Bott and Smithson 1967; Ajakaiye, 1976; Brisbin and Green 1980). The results indicate that granitic rocks show negative Bouguer anomalies because of the negative density contrast. With these preliminary results, the gravity method was chosen for this survey in preference to the other methods.

3.2 CHOICE OF OBSERVATION TECHNIQUE

Generally, controlled observational techniques are employed in gravimetric studies in order to control the drift of the instrument on one hand and the tidal variation on the other hand (Osazuwa, personal communication). In carrying out this gravity survey, the "Ladder sequence" was employed. As the name suggests, the sequence in comparable to a systematic movement as in ascending and descending a ladder. Thus, if A, B, C, D are base stations and s_1, s_2, ... are the intermediate stations, then the sequence can be represented thus:

A, s_1, s_2, B, s_3, s_4, C, s_5, s_6, D, s_7, D, s_6, s_5, C, s_4, s_3, B, s_2, s_1, A.

The reason for the choice of this sequence is the fact that it saves both time and transportation costs

(Osazuwa, 1985). The sequence requires that the time between the first measurement on a particular base station and the return measurement, should not exceed 2 hours if both altimeter and gravimeters are used simultaneously. When gravimeter is used alone, a maximum of up to 3 hours is tolerated since this is the period when the instrument's observational windows are linear, that is when its drift characteristics are almost linear. The duration depends on the maximum drift time involved in the use of the instruments concerned. Hence the number of the intermediate stations (in between the base stations) depends on the duration of readings at each station as well as on the length of time window for the linear portion of the characteristic drift curve (Osazuwa, 1992).

During the survey, gravity and height differences were measured at intervals of 2 km along all the motorable accessible network of roads and tracks within the region. Several fresh rock samples were also collected during the field survey for density determination. Apart from the elevations of the stations which were determined manually, all the gravity corrections as well as the data reduction were carried out using a comprehensive computer programme for processing gravity data written by Osazuwa (1986).

3.3 FIELD PROBLEMS

A number of problems were encountered during the field operations. One of these is the inconsistency of the road map used with the actual road situations. In few cases, the road networks as shown in the map have been altered in the field or even non-existence either due to general road re-construction or due to migration of villagers to new settlements. In such cases, some map features which are still in existence were used to establish the actual bearing and direction of the present road system.

Along some of the roads or paths, there were either incomplete or absence of kilometre posts for the location of field stations. In this case, the odometer in the vehicle is used for the placement of stations along the roads.

There were cases where roads were suddenly truncated by rivers/stream without bridges. Such problem was surmounted by circumventing the river, if possible, to continue the measurement on the other side of the river.

Other problems include frequent breakdown of the vehicle used for field transportation, as well as roughness of roads and traffic congestions along major roads. These problems tend to slow down the rate of data collection arbitrary.

3.4 DATA COLLECTION AND INSTRUMENTATION

The three field crew and all the instruments used for the survey were transported along the stations with a 404 pick-up van. The following measurements were taken at 190 field stations spaced at 2 km intervals along all the motorable roads and tracks that could possibly be used within the region.

3.4.1 Gravity measurement

Gravity measurements were made within three weeks in March, 1988. The La Coste and Romberg Gravity meter model G.446 belonging to the Physics Department of A.B.U., Zaria was used for this purpose. The gravity meter has a nominal precision of 0.01 mgal and a drift rate of less than 1 mgal per month.

Prior to the field work, the reading of two gravity meters - G.468 and G.446 were observed simultaneously on the same spot in the laboratory on hourly interval from 0700 hours to 1800 hours local time. This corresponds to the period during which the instruments would be used in the field. The purpose of this exercise is to monitor the reliability of the gravity meters and their drift characteristic. The drift curve for each meter was therefore plotted as shown in Fig. 3.1(a) and (b). From the drift curves, there is no significant difference between the characteristics of the two gravimeters. However, the gravimeter G.446 was chosen for the survey because it is older and it is more likely to drift less than G.468.

In the field, measurements were taken with the instrument between 0600 hours - 1100 hours local time, and between 1600 hours - 1800 hours during which the drift characteristic was linear.

All the gravity measurements were tied to the primary gravity network for Nigeria (Osazuwa, 1985) via a base station located at Saminaka Police Station with Absolute Gravity value, 977984.609 ± 0.012 mgal.

The relative height differences were measured at every station where the gravity measurements were taken.

3.4.2 The Altimeter

Two Wallace and Tiernan Surveying Altimeter were used for the height measurements. Four of the models namely MM19111, NN13561, NN13560 and NN12511 were initially observed simultaneously in the laboratory at the same sport from 0700 hours to 1800 hours local time before the field work. Apart from the altimeter NN13561 whose drift curve was not consistent with the others, the drift curves for the rest (Shown in Figure 3.2) indicate that near-linear drift rate occurs between 0700 hours - 0900 hours and between 1200 hours and 1500 hours local time. The average value of the drift rate were 0.30 m/hr and 0.23 m/hr respectively for the

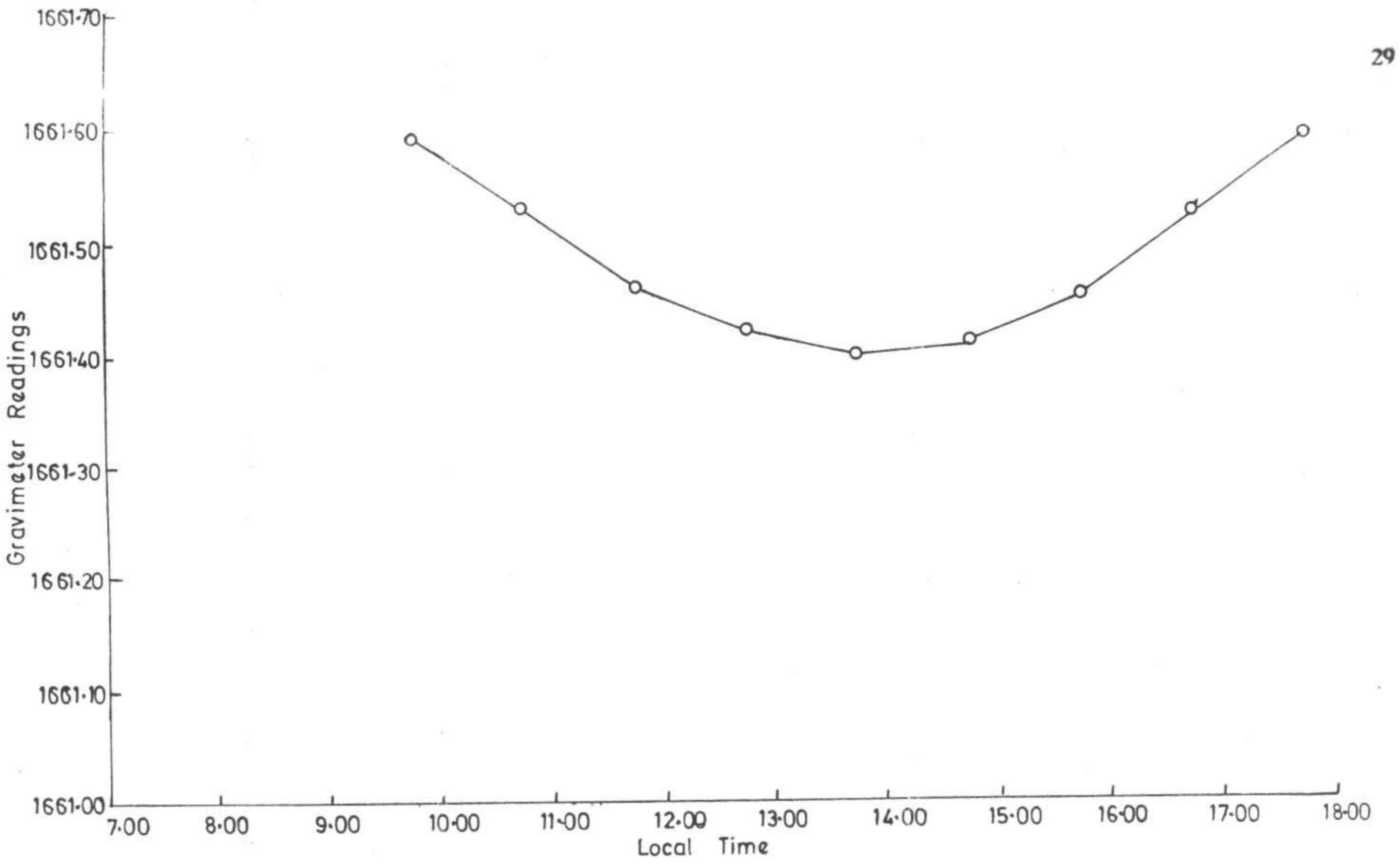


FIG.3·1(a) :DRIFT CURVE FOR GRAVIMETER G, 468

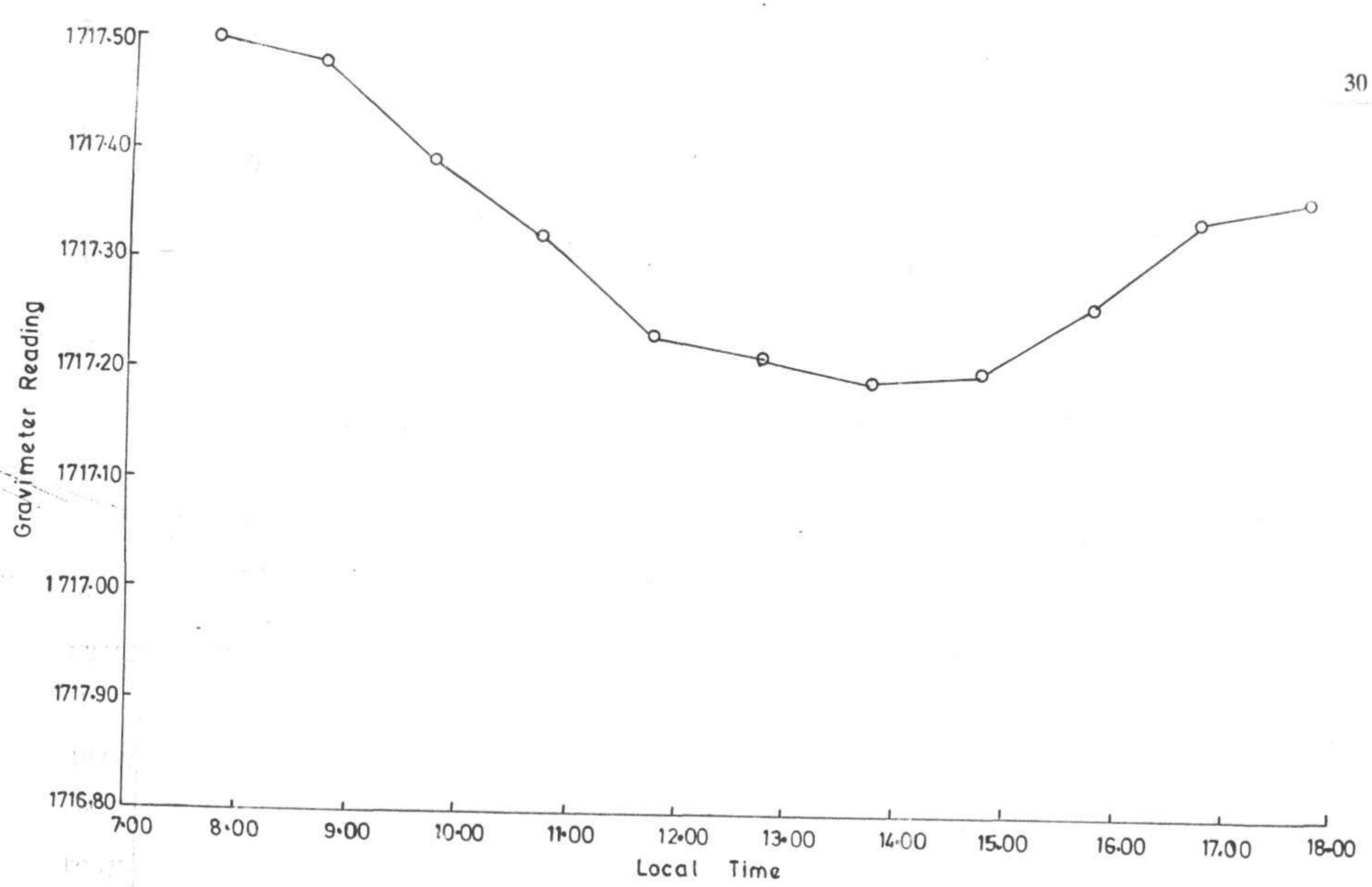


FIG-3.1(b): DRIFT CURVE FOR GRAIMETER G-446

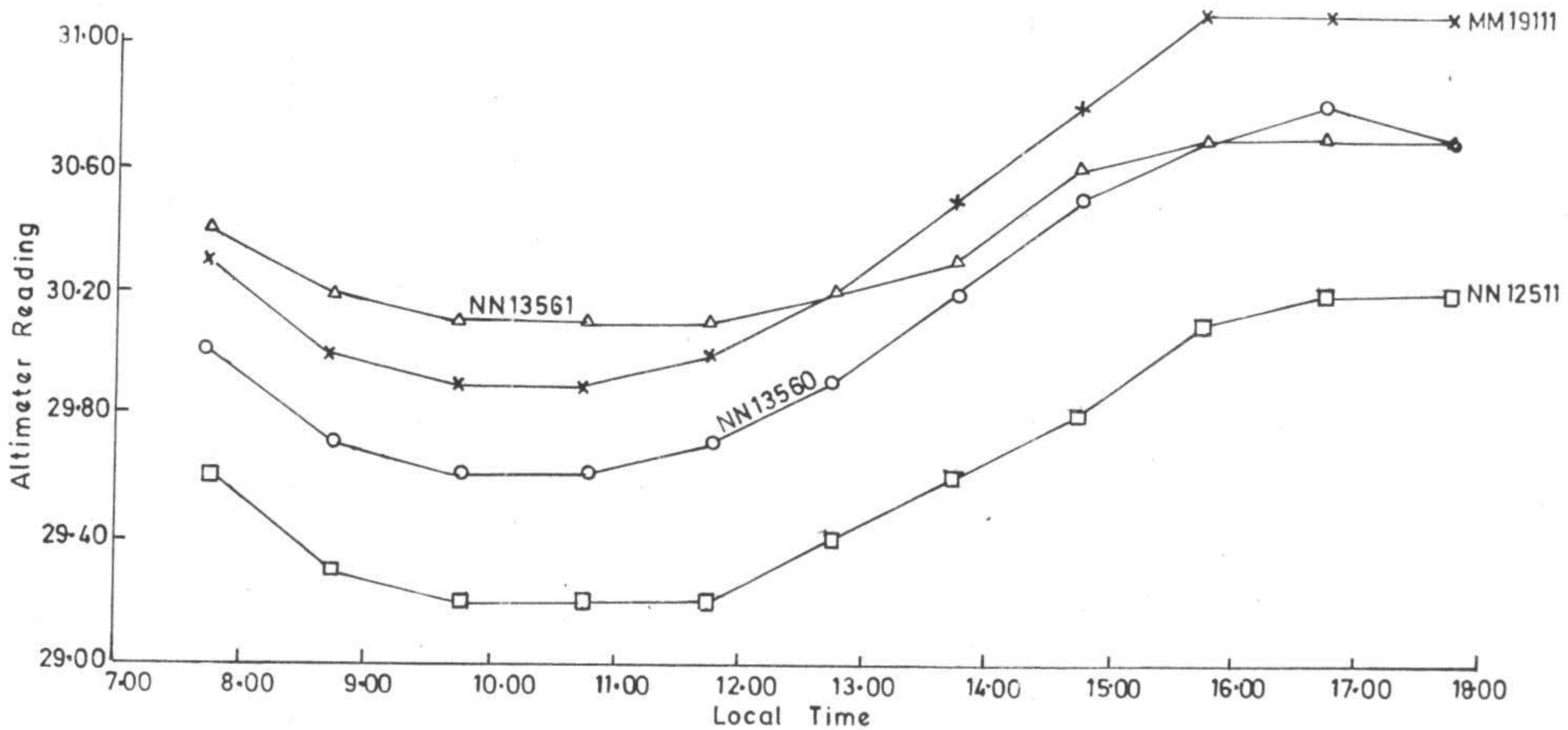


FIG-3·2:ALTIMETER DRIFT CURVES (19/2/88) two periods. Therefore, relative heights measurements in the field were done within these periods when the drift characteristic is linear in order to be able to apply the cascade drift correction model effectively.

Along with the altimeter observations, the readings of a sling psychrometer (wet and dry bulb thermometers) were obtained for each station, in order to determine the percentage relative humidity required for the stations. A psychrometric chart was used to obtain the altitude correction factor applicable for each station.

3.4.3 Determination of Absolute Height Base Station

Since none of the field station has a known height above the sea level, the absolute height for the main base station at Saminaka Police station was determined using a reference absolute height of 617.48532 m (Osazuwa, personal communication) at Kafin Maiyaki primary school - a town along Zaria-Kano road. In order to calibrate the altimeters and also determine absolute height at the stations, the altimeters were observed at three gravity base station located at school of Aviation Zaria (station no. GMSC 4), Saminaka Police Station (Station no. 105601) and Kafin Maiyaki Primary School (Station No. GMSD 5). Four Wallace and Tiernan surveying Altimeters models NN13560, MM19111, NN13561 and NN12511 were used during this height determination applying the ladder sequence. The result gave a value of 778.2452227 m for the absolute height of the main base station at Saminaka Police Station. All the elevation values of other stations were therefore tied to this main base station value.

3.5 DATA REDUCTION

The date and the exact time at which observations were made at each station were recorded during the field work. The date is required for tidal correction, the time of observation is necessary for drift and tidal corrections of the instrument readings.

The positions of all the field stations were carefully located on a road map, scale 1:100,000. The latitude and longitude of each station were determined from the map. The determination of the elevations of all the stations was done manually. The rest of the reduction of the field data up to the determination of the Bouguer anomaly gravity values were carried out with the comprehensive FORTRAN 77 computer program designed by Osazuwa (1986) for the reduction of gravity data.

The gravity data obtained in the field is generally influenced by a number of factors ranging from the instrument behaviour to the field factors. Hence for the reduction of the data, a number of corrections were applied after converting to milligal values. The corrections and methods affecting them can be found in the literature (Osazuwa, 1985 and Telford *et al.*, 1980).

For reduction to the reference ellipsoid, the gravity reference system of 1967 (GRS 67) was used. This is given by:

$$g_{\phi} = 978.031846\ (1 + 0.005278895\ \sin^2\phi + 0.000023462\ \sin^4\phi)\ \text{Gal}$$

where g_{ϕ} is the absolute gravity value at a station on latitude ϕ projected to the ellipsoidal plane.

3.6 SOURCES OF ERROR IN BOUGUER ANOMALY

The purpose of all the corrections carried out before obtaining Bouguer anomaly, is to establish a variation in the earth's gravitational field which will depend only on the lateral variation of the densities of subsurface rocks below the sea level.

The major sources of errors in the Bouguer anomalies include (i) inaccurately assumed crustal density (ii) elevation inaccuracies (iii) inaccurate determination of the station coordinates and (iv) errors due to instrument drift.

A value of 2.67 $kg{\cdot}m^{-3}$ was used as the mean crustal density for the Bouguer anomaly reduction, as this is the generally accepted density value for Bouguer correction. This value is slightly above 2.62 $kg{\cdot}m^{-3}$ determined for the Younger Granite rocks in this survey. An error of ±0.05 obtained in the determination of the density could introduce an error of about ±0.86 in Bouguer anomaly values over the elevation range encountered in this area. Elevation errors in the range 1.5 to 10 m cause errors in anomaly of 0.3 to 2.0 mgal. Hence an estimated maximum elevation error of up to 5 m in this survey will contribute an error of about 1 mgal in the Bouguer anomaly.

Errors due to inaccurate station coordinates, instrument drift and latitude correction are all small (about 0.3 mgal) compared with the main sources of errors. Hence by estimation, the maximum probably error in Bouguer anomaly at any given station is less than 2 mgal for most of the stations.

CHAPTER FOUR

DENSITY DETERMINATION AND ANALYSIS

4.1 INTRODUCTION

A knowledge of the near surface densities of rocks is essential in gravity survey for the reasons stated below:

i) In gravity exploration, the anomaly sources have densities which are appreciably different from those of surrounding formations.

ii) The terrain and Bouguer corrections require a knowledge of the density distribution of rocks above the mean sea level.

iii) A successful quantitative interpretation of gravity data requires the use of the right density contrast(s) for the modelling of the body responsible for the anomaly.

Hence, part of the field survey activities included the collection of several rock samples whose densities were later determined in the laboratory for use in the interpretation of the gravity anomalies.

4.2 COLLECTION OF ROCK SAMPLES

A total of 154 fresh rock samples were collected between March 1988 and February, 1989 from outcrops which are sufficiently close to the field stations. Fresh rock samples are preferable because weathered rock samples will not provide true value of the rock densities since weathering involves a change in both physical and chemical properties of the rock.

The rock samples collected were properly classified and identified.

4.3 DENSITY MEASUREMENTS

An electronic digital Mettler balance model P1515, belonging to the Physics Department, was used to determine the individual rock densities in the laboratory. This was done by employing Archemedes principle to determine both the dry and saturated densities of the samples. The bulk density of each sample was obtained by finding the average of the dry and saturated densities.

4.4. DENSITY ANALYSIS

The result of the density determination of the various rock types is summarised in Table 4.1. The error in density measurement are shown as standard deviation.

The mean dry densities of the Nigerian Younger Granite series as published by Ajakaiye (1974) are shown in Table 4.2 for purpose of comparison with the mean dry density values in Table 4.1. Corresponding values of bulk densities for Table 4.2 were not determined during the survey. For further analysis, density histograms are plotted for the rock samples collected during the survey. These are shown in Figures 4.1 and 4.2.

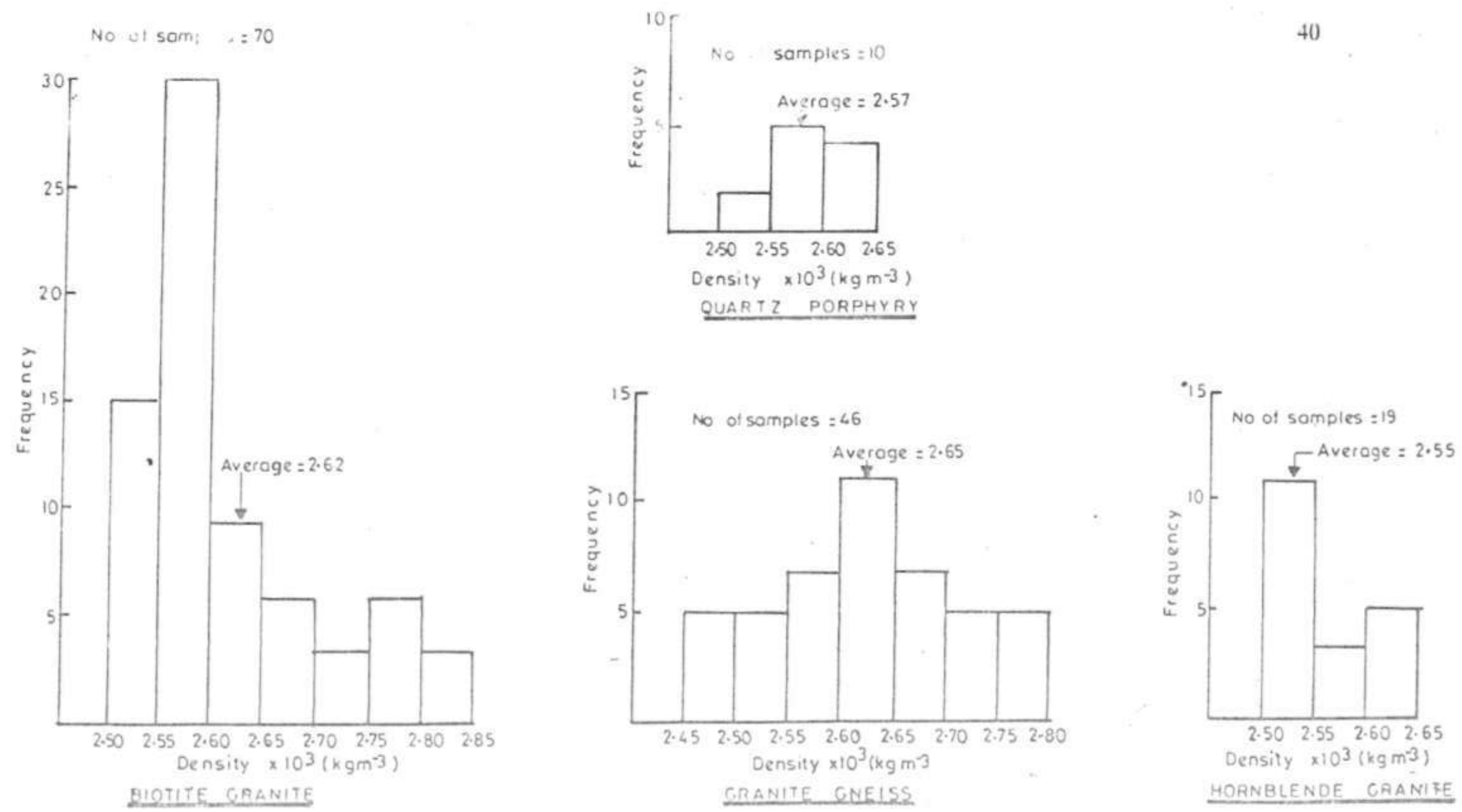
Table 4.1: Densities of Various Rock Types

ROCK TYPE	Number of Samples	Range of Densities ($x10^3$ kgm^{-3})	Mean Dry Density ($x10^3$ kgm^{-3})	Mean Saturated Density ($x10^3$ kgm^{-3})	Average Bulk Density ($x10^3$ kgm^{-3})	Standard Deviation
RHYOLITE	3	2.50-2.72	2.59	2.62	2.61	0.09
HORNBLENDE-GRANITE	19	2.51-2.62	2.54	2.55	2.55	0.05
BIOTITE-GRANITE	70	2.53-2.93	2.61	2.62	2.62	0.11
RIEBECKITE-GRANITE	3	2.54-2.71	2.61	2.62	2.62	0.07
SYENITE	3	2.60-2.86	2.73	2.73	2.74	0.11
GRANITE GNEISS	46	2.46-2.96	2.65	2.65	2.65	0.11
QUARTZ PORPHYRY	10	2.55-2.62	2.57	2.57	2.57	0.04

GRAND AVERAGE DENSITY = 2.62 ± 0.05 $x10^3$ kgm^{-3}

Table 4.2: Densities of the Younger Granite Series (After Ajakaiye, 1974)

Rock Type	Number of samples	Range (gcm^{-3})	Mean Dry Density and SD (gcm^{-3})
Gabbro	22	2.65 - 2.99	2.85 ± 0.05
Dolerite	22	2.88 - 3.04	2.97 ± 0.05
Basalt	40	2.59 - 3.02	2.85 ± 0.10
Syenite	29	2.65 - 2.87	2.70 ± 0.05
Rhyolite	133	2.47 - 2.77	2.62 ± 0.03
Biotite-Granite	236	2.49 - 2.76	2.60 ± 0.03
Riebeckiite-Granite	154	2.50 - 2.70	2.61 ± 0.04
Granite Porphyry	71	2.53 - 2.70	2.61 ± 0.04
Amphibole-Granite	24	2.59 - 2.68	2.63 ± 0.02
Quartz Pyrozene Fayalite Porphyry	22	2.58 - 2.68	2.64 ± 0.03
Comendite	6	2.62 - 2.67	2.66 ± 0.02
Tuff	39	2.50 - 3.20	2.68 ± 0.15
Greisen	10	2.60 - 3.08	2.84 ± 0.17
Breccia	7	2.56 - 2.77	2.63 ± 0.06
Aegirine-Arfvedsonite Porphryry	3	2.60 - 2.61	2.61 ± 0.01



FIG·4·1: DENSITY HISTOGRAM OF VARIOUS ROCK SAMPLES

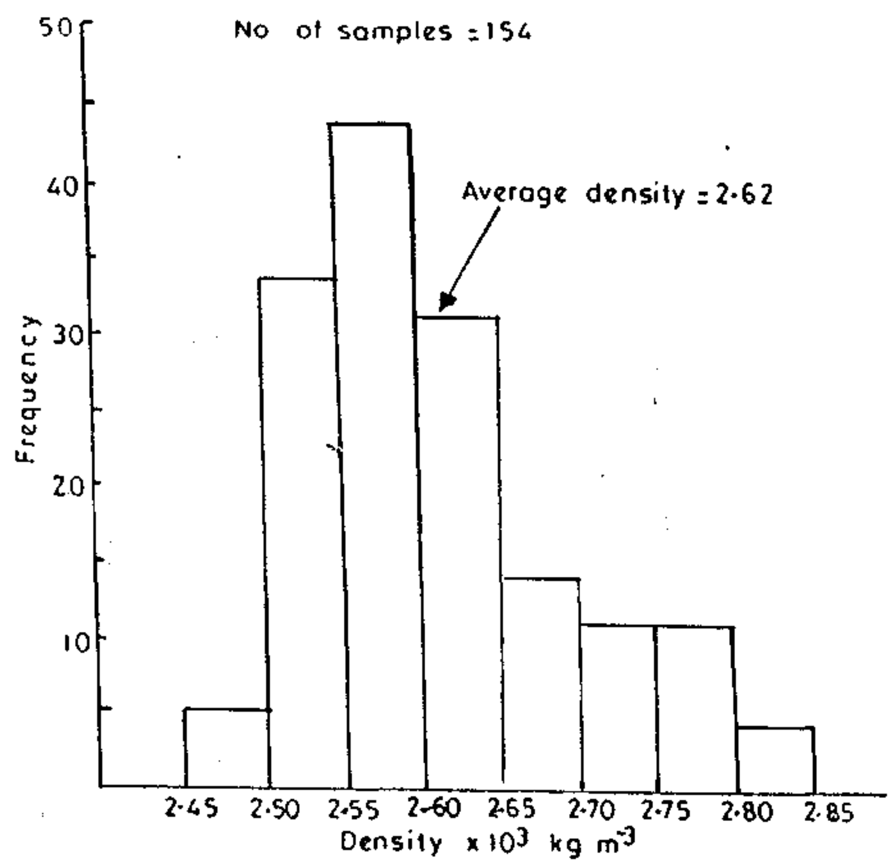


FIG.4.2: COMBINED DENSITY HISTOGRAM OF ALL ROCK SAMPLES

4.5 INTERPRETATION OF DENSITY RESULTS

From Table 4.1 and the various histograms drawn, the following facts could be deduced.

(i) There is no significant difference between the dry and wet densities in the rock samples. Therefore, the sample densities will simply be referred to as "density".

(ii) The average density of all the rock samples collected during the survey is $2.62 \pm 0.05 \times 10^3$ kg·m^{-3}

(iii) The density values of all the samples ranges from 2.45 to 2.85×10^3 kg·m^{-3}, however, syenite has the highest mean value of 2.73×10^3 kg·m^{-3} while hornblende granite has the lowest value of 2.55×10^3 kg·m^{-3}.

(iv) Samples of the same rock type collected from different localities have density values which are slightly different from one another (Table 4.1). This may be due to differences in mineralogy, chemistry, rate of metamorphism and extent of tectonic activities prevalent in the area (Telford *et al*, 1980).

(v) The mean dry density values of the various rock types (Table 4.1) compare favourably with the corresponding values shown in Table 4.2 (after Ajakaiye, 1974). However, the wider range of values in Table 4.2 might be as a result of the regional nature of the survey as well as the greater number of samples considered.

4.5.1 Difference Between Dry and Wet Densities

As already mentioned in section 4.5 (i) there is no significant difference between the combined mean saturated density (2.62×10^3 kg·m^{-3}) and the combined mean dry density (2.61×10^3 kg·m^{-3}) obtained during the survey. The reasons could be due to the compact nature of the rock grains and the matrix having extremely narrow pore, little or no cracks and fractures.

4.5.2 The Bulk Density

The combined mean bulk density of the sampled rock-types in the survey area is $2.62 \pm 0.05 \times 10^3$ kg·m^{-3}. The value compares very favourably with the general result obtained on the Nigerian Younger Granite series by Ajakaiye (1974), who showed that the density values of the Nigerian Younger Granite fall in the range 2.61 to 2.63×10^3 kg·m^{-3}, while those of the predominant basement rocks are 2.66 to 2.70 10^3 kg·m^{-3}. Also the above values of basement rock densities agree fairly well with the density values obtained in this survey for the basement rock - Granite Gneiss and Quartz porphyry - (Table 4.1) which gives a range of 2. 65 - 2.73×10^3 kg·m^{-3}.

The mean bulk density also falls within the general average density range of 2.52 - 2.81 and 2.50 - 2.81 for granites as published by Dobrin (1976) and Telford *et al* (1980) respectively.

The value of 2.62 x 103 kgm^{-3} obtained from this survey, may not be the actual representative of the true *in-situ* values. The reason may be attributed to the fact that under laboratory conditions, the natural conditions of samples cannot be preserved, especially its moisture content and mineralisation of the pore water. Based on this reason, Mares *et al.* (1984) concluded that the density of rocks determined on samples under laboratory conditions is usually lower than the *in-situ* value.

4.5.3 Mean Densities of Different Rock Types

The mean densities of the different rock types varies from 2.45 - 2.85 x 10^3 $kg{\cdot}m^{-3}$. This variation is due to a number of factors notably, differences in rock types, the composition and texture of the rocks, porosity, mineralisation, extent of weathering, fracture, as well as the degree of metamorphism. The process of metamorphism tends to fill the pore spaces and re-crystallise the rock in a denser form. Hence the average density of the Younger Granite rocks (2.62 x 10^3 $kg{\cdot}m^{-3}$) is found to be lower than the average density 2.65 x 10^3 $kg{\cdot}m^{-3}$ obtained for the basement rocks (Granite Gneiss) mainly on the basis of metamorphism and mineral composition. Syenite with density value of 2.73 x 10^3 $kg{\cdot}m^{-3}$, possess the highest value as compared to other rock types in the area due to its less acidic content (Turner and Macleod, 1971). According to Telford, *et al.* (1980), the density of igneous and metamorphic rocks usually increases as the acidity decreases.

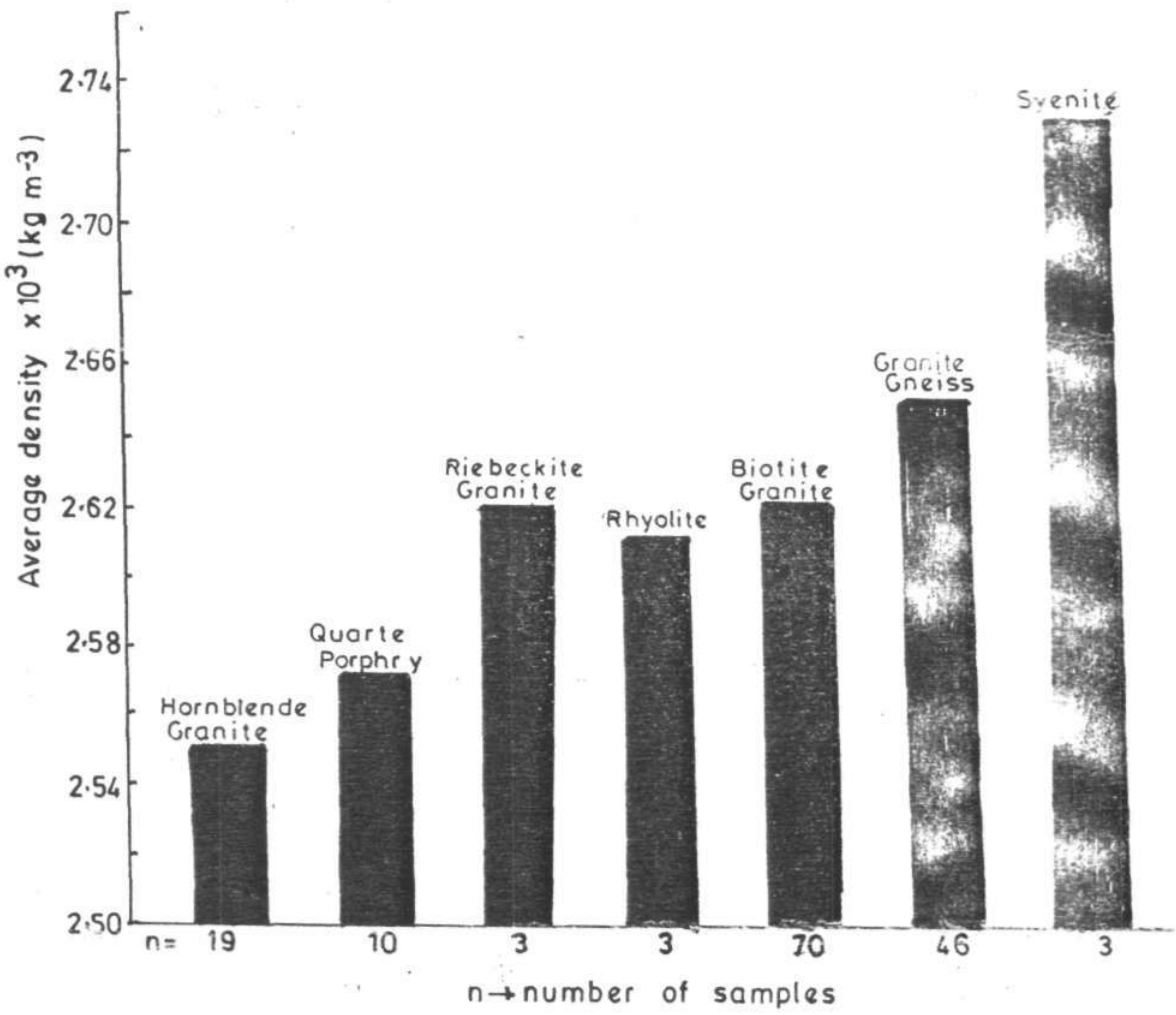
The different rock types within the family of the Younger Granite differ mainly in mineral composition and texture. These differences in turn, brought about the slight variation in densities. Thus the low density value (2.55×10^3 $kg \cdot m^{-3}$) of hornblende granite (Figure 4.3) may be attributed to its coarse-grained texture.

4.5.4 Densities of Individual Rock Types

The reason for the appreciable variations in the range of density (Table 4.1) of samples of the same rock type collected from different localities may be due to differences in mineralogy, chemistry, rate of metamorphism and extent of tectonic activities prevalent in the area (Telford *et al.*, 1980). It therefore follows that the greater the area covered by the survey, the wider the range in density values to be expected.

(i) Biotite Granite

This is by far, the most predominant rock type in the area, hence the number of samples gathered. The densities of the 70 samples collected ranges from 2.53 to 2.93×10^3 $kg \cdot m^{-3}$, with an average value of $2.62 \pm 0.11 \times 10^3$ $kg \cdot m^{-3}$.



FIG·4·3 :AVERAGE DENSITY HISTOGRM OF VARIOUS ROCK TYPES IN THE AREA

The near normal distribution of density values in Fig. 4.1 shows that the sampling is uniform and that the density values are independent of locality.

When compared with the values available from similar surveys and at other places, it is found that the mean density obtained for biotite granite falls within the ranges. Ajakaiye (1974) found a range of values 2.49 - 2.76 $x10^3 kgm^{-3}$, while Dobrin (1976) and Telford *et al.* (1980) published values of 2.516 - 2.809 $x10^3$ $kg \cdot m^{-3}$ and 2.50 - 2.81 $x10^3$ kgm^{-3} respectively for granites generally.

(ii) Hornblende Granite

An average value of $2.55 \pm 0.05 \times 10^3$ $kg \cdot m^{-3}$ was found for the hornblende granites for the 19 samples considered. The individual densities range f rom 2.51 to 2.62 x 10^3 $kg \cdot m^{-3}$. The density histogram for this rock type (Fig. 4.1) shows that its mean density lies on the modal class of range 2.50 - 2.55 x 10^3 $kg \cdot m^{-3}$. The positive skew of the histogram implies that the density distribution is not symmetrical. There are more rock samples with densities less than the mean value.

(iii) Quartz Porphyry

A total of 10 samples of quartz porphyry were used for density sampling. The average value of $2.57 \pm 0.04 \times 10^3$ $kg \cdot m^{-3}$ lies on the modal class as shown in Fig. 4.1 for density values ranging from 2.55 to 2.62 x 10^3 kgm^{-3}.

Previous work done on the Nigerian Younger Granite by Ajakaiye (1974) found a mean density range 2.58 - 2.68 ± 0.03 x 10^3 kg·m^{-3} for this rock type. Hence the average value obtained in this survey also lies within this range.

iv) Granite Gneiss

The density histogram shows a normal density distribution for the 46 samples with a mean value of 2.65 ± 0.11 x 10^3 kg·m^{-3} located on the modal range which is centrally situated.

This basement rock complex has the widest density range of 2.46 - 2.96 x 10^3 kg·m^{-3}. The wide range may be explained on the basis of wide range in mineralisation of the various samples.

The density result obtained for the gneiss in this survey is generally higher than the density values recorded for other rock types in the area. The main reason for this is that granite gneiss is a metamorphic rock, which must have undergone a high degree of compaction than the non-metamorphic rocks.

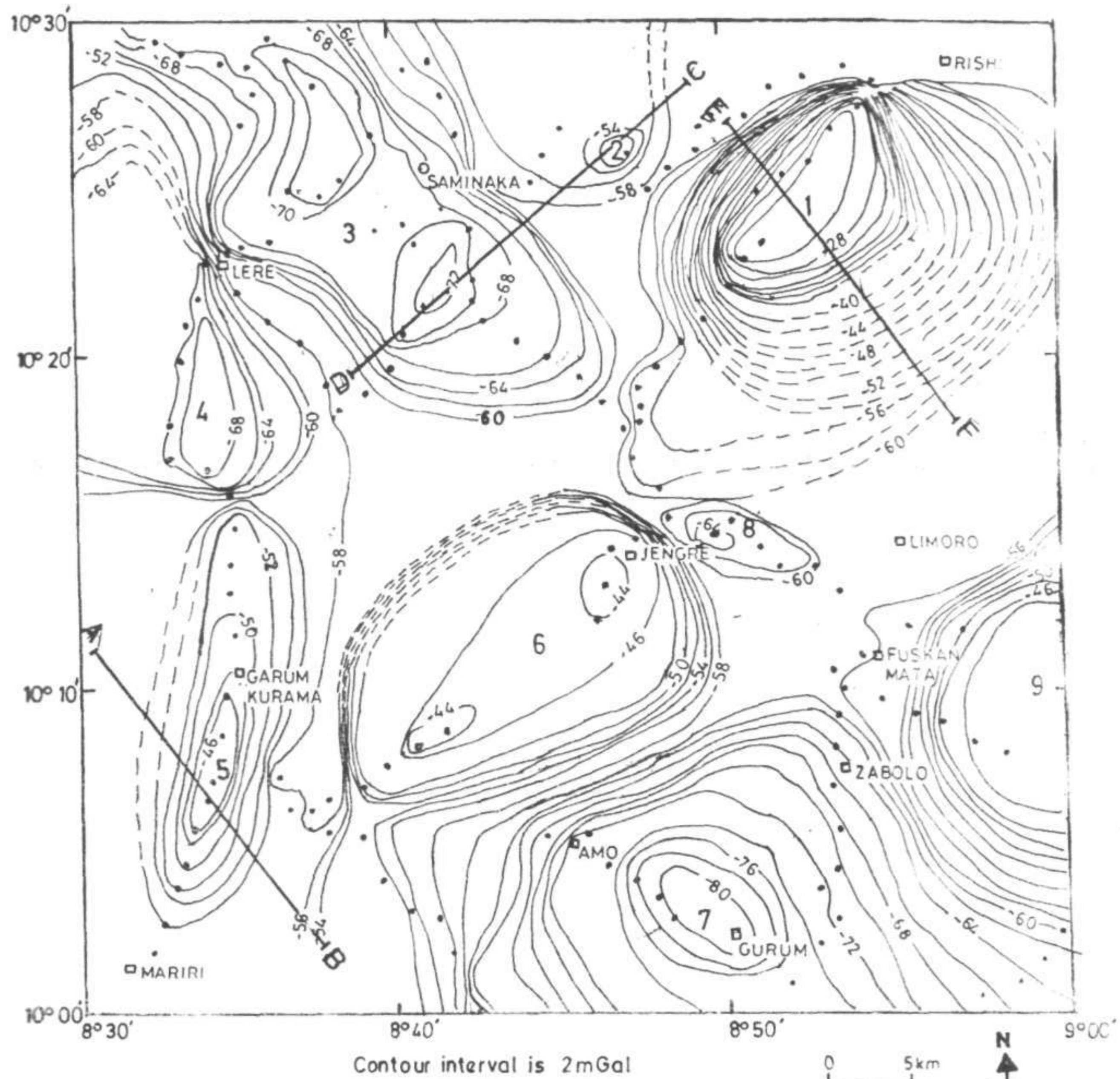
CHAPTER FIVE

THE BOUGUER AND RESIDUAL ANOMALIES

5.1 THE BOUGUER ANOMALY FIELD

The Bouguer anomaly map of the area is shown in Figure 5.1. It is characterised by negative Bouguer anomaly ranging from -26 to -80 mgal. The negative values of Bouguer anomaly obtained from this survey agree with the result of the regional survey carried out in the area in 1970 (Ajakaiye, 1974) in which negative values ranging from -33 mgal to about -65 mgal were obtained. The result is also consistent with the general fact that gravity survey over granite rocks show negative Bouguer anomalies.

The mean value of the Bouguer anomalies for all the stations is -55 mgal. The minimum values occurs in Gurum, a mining camp S.E. of the survey area, while the maximum value is located in the NE part of the map - a few kilometres SW of Rishi. The most pronounced overall trend of the anomaly field is NE-SW. Generally, the Bouguer anomaly map consists of simple pattern of the contours with large anomalous closures in the area. Some of the contours were inferred in area with inadequate data coverage. Most of the closures have gravity high except at Saminaka and Gurum areas which indicate gravity lows. The gradient of the gravity field is as steep as about 8.5 $mgal \cdot km^{-1}$ observed few kilometres SW of Rishi.



LEGEND
• Gravity station
□ Major town
Gravity contours
Inferred Gravity contours

FIG.5-1: BOUGUER ANOMALY MAP OF LERE / SAMINAKA AREA

On the whole, nine gravity closures can be distinguished, four of them (labelled 3, 4, 7 and 8 for easier identification) have a moderate gravity amplitude while the rest have high gravity amplitude ranging from -56 mgal in the north central part of the map to -26 mgal south of Rishi. Contour closure 9 extends beyond the limit of the survey area. The gravity lows on the map may be associated with the different episodes of igneous activities that led to the emplacement of the granite bodies. On the other hand, the gravity highs could be attributed to the presence of high density subsurface structures at depth.

5.2 THE REGIONAL GRAVITY

Usually, the local anomalies which are important in delineating structures on the gravity map are frequently masked or covered by some regional anomalies caused by deep-seated structures. The separation of the effects of these unwanted regional anomalies from the anomalies of interest must be carried out before any meaningful interpretation can be done. The resultant anomalies after the separation is referred to as the residual anomaly. It can be determined by using any of the following methods which are briefly described below:

(i) Visual Smoothing

This is a method in which the regional background is removed by usually smoothing the Bouguer gravity data. The residual is thus obtained by subtracting the regional from the Bouguer map either graphically or numerically. The method is subjective, in that it requires the ability of the interpreter to make use of geological information as well as his personal bias and experience. The result is most reliable if the general trend of the residual is clearly different from that of the regional, otherwise the smoothing process becomes ineffective.

(ii) Empirical Gridding

Here, the regional gravity is assumed to be the average value of the gravity in the neighbourhood of the station. Such values are calculated by finding the mean observed values on the circumference of a circle centred at each station. Hence the distracting effect can be filtered out. The method lacks a good theoretical background and is often mechanical in practice.

iii) Polynomial surface fitting

This is purely an analytical method involving the fitting of a mathematical surface to the gravity data by the process of least squares. The matching of the regional by a polynomial surface of low order usually exposes the residual features as random errors whose sum is zero. Thus the residual is composed of both positive and negative parts. The advantages of this method are that it is easily adapted to computer use and that the methods of statistical analysis are available since the treatment is based on statistical theory.

Most importantly, this method is unbiased which is why polynomial surface fitting was used in this work. Other mathematical methods have been developed by various authors for the regional residual separation (Elkins, 1951; Krubein, 1950; Grant, 1953; Gupta and Ramani, 1980).

5.3 THE REGIONAL ANOMALY

For reasons already highlighted above, the method of polynomial surface fitting is applied in this project for the removal of the regional gravity. The computed regional anomalies were manually contoured to give the regional anomaly map shown in Figure 5.2.

Usually, in polynomial fitting one aims at obtaining the mathematical surface which gives the closest fit to the gravity field within a specified degree depending on the complexity of the regional geology. Since the regional field is a simple plane as in Figure 5.2, a first degree surface would be sufficient. The region surveyed in this project is relatively small in size. It also consists of geological structures (Fig. 2.1) whose densities are almost similar implying that their density contrast with the basement structure is very small.

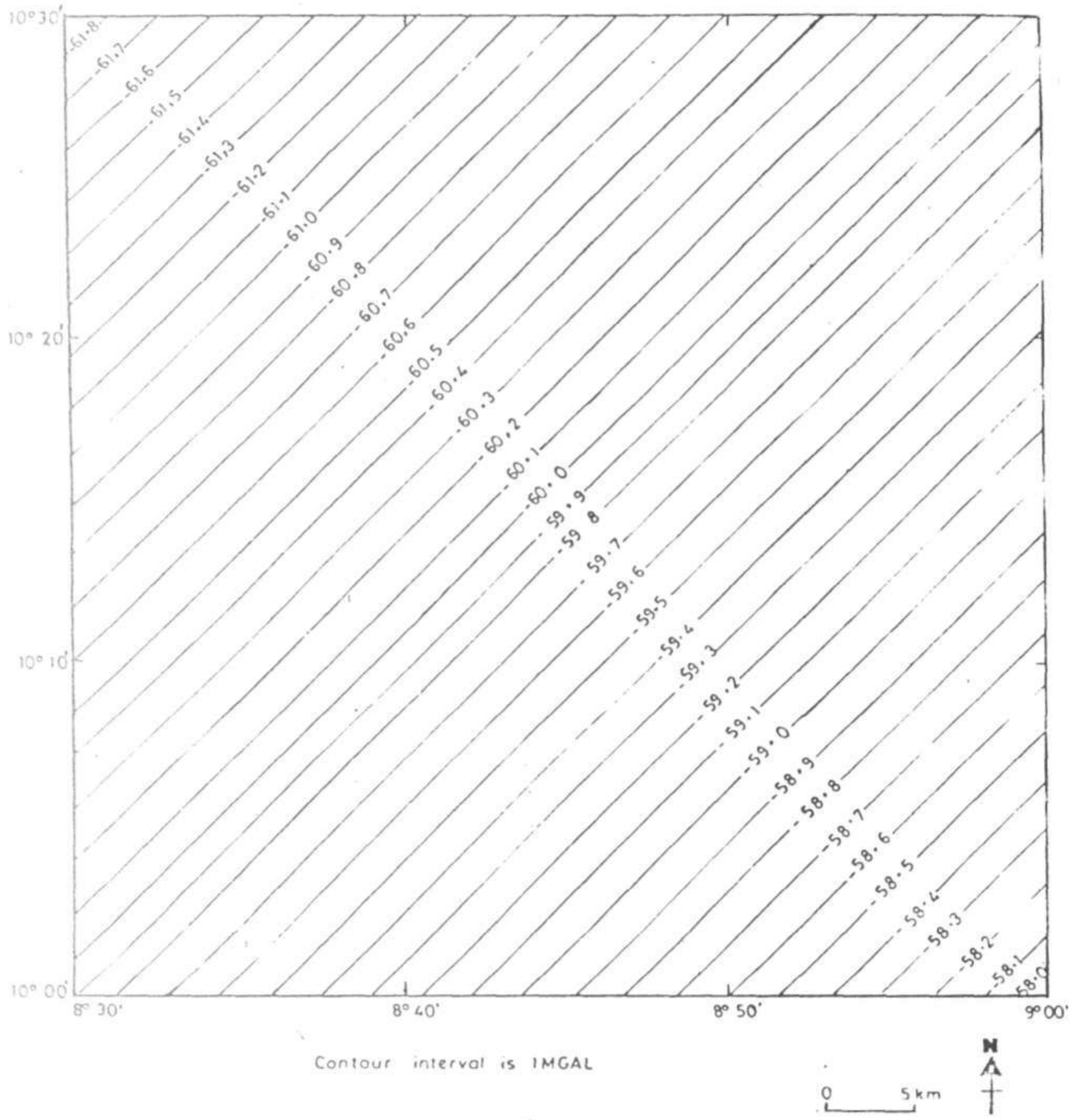


FIG.5.2: REGIONAL FIELD MAP OF LERE AREA

Consequently, the first degree surface fitting is used in this survey.

The map (Figure. 5.2) shows that the regional field in this area tends Northeast to Southwest (NE-SW) with gradual increase towards the Southeast and an average gradient of about 0.05 mgal/km. The low gradient suggests that the causative body is of very deep origin

5.4 THE RESIDUAL ANOMALIES

Figure 5.3 shows the residual anomaly map which is obtained after subtracting the regional field from the observed Bouguer anomaly field. The maximum residual gravity value of +30 mgal occurs approximately 10 km southwest of Rishi while the minimum of -20 mgal is located at the southern part of the map around Gurum.

The resultant map obtained from superimposing the residual anomaly map on the simplified geological map of Figure 2.1 is shown in Figure 5.4 the superposition of the two maps is necessary for the purpose of easy correlation between the residual anomalies and the geology of the area. The correlation shows that there is a close match between the various anomalies and the surface geology of the area. Anomaly No. 1 might be as a result of the series of outcrops NE of the map. The rock units include the Biotite/Ryebeckite Granites, the Ryolite, quartz porphry, dolerites, syenites as well as some basement complex formations such as the Biotite

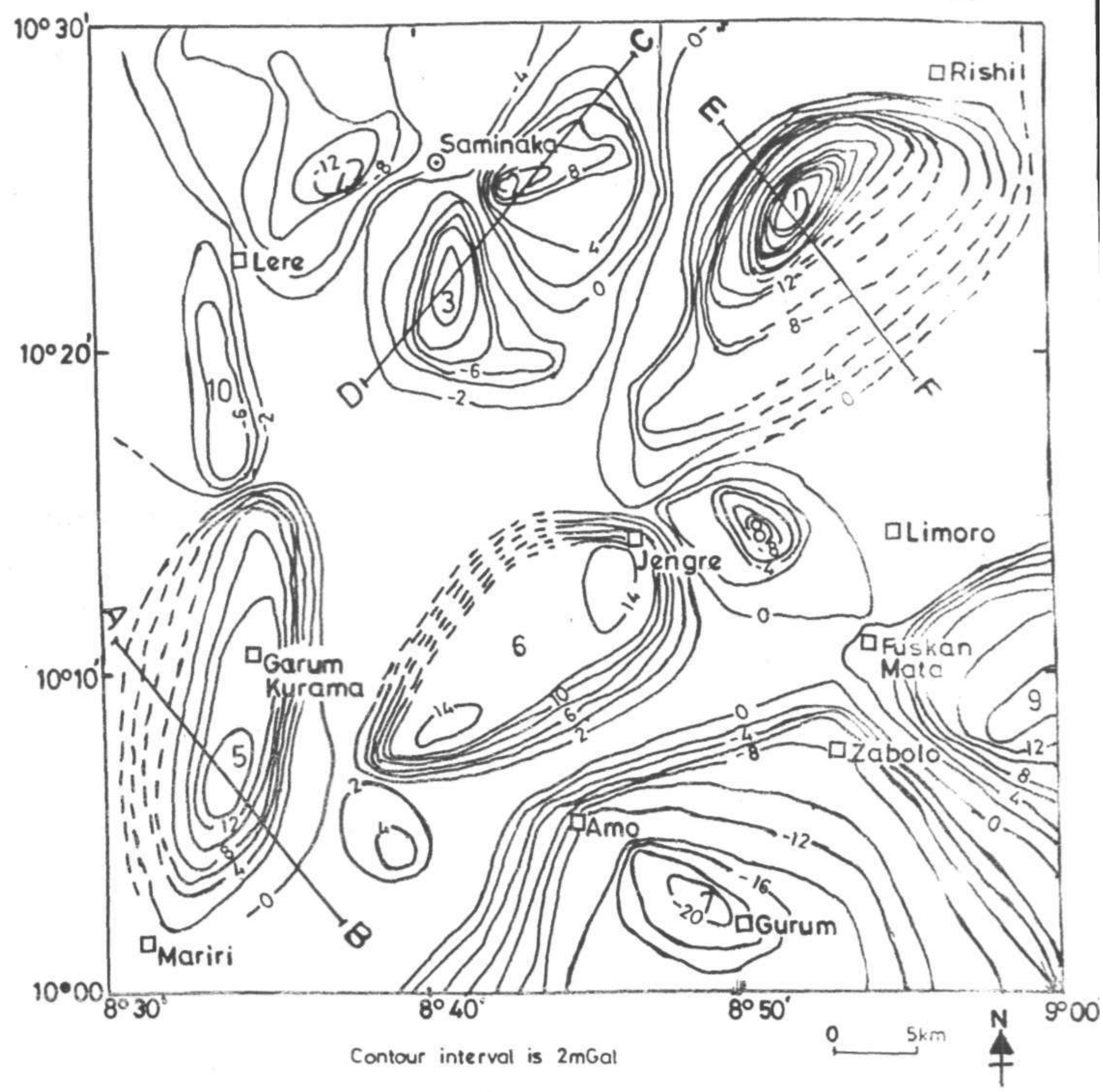


FIG. 5.3: RESIDUAL ANOMALY MAP OF LERE / SAMINAKA AREA

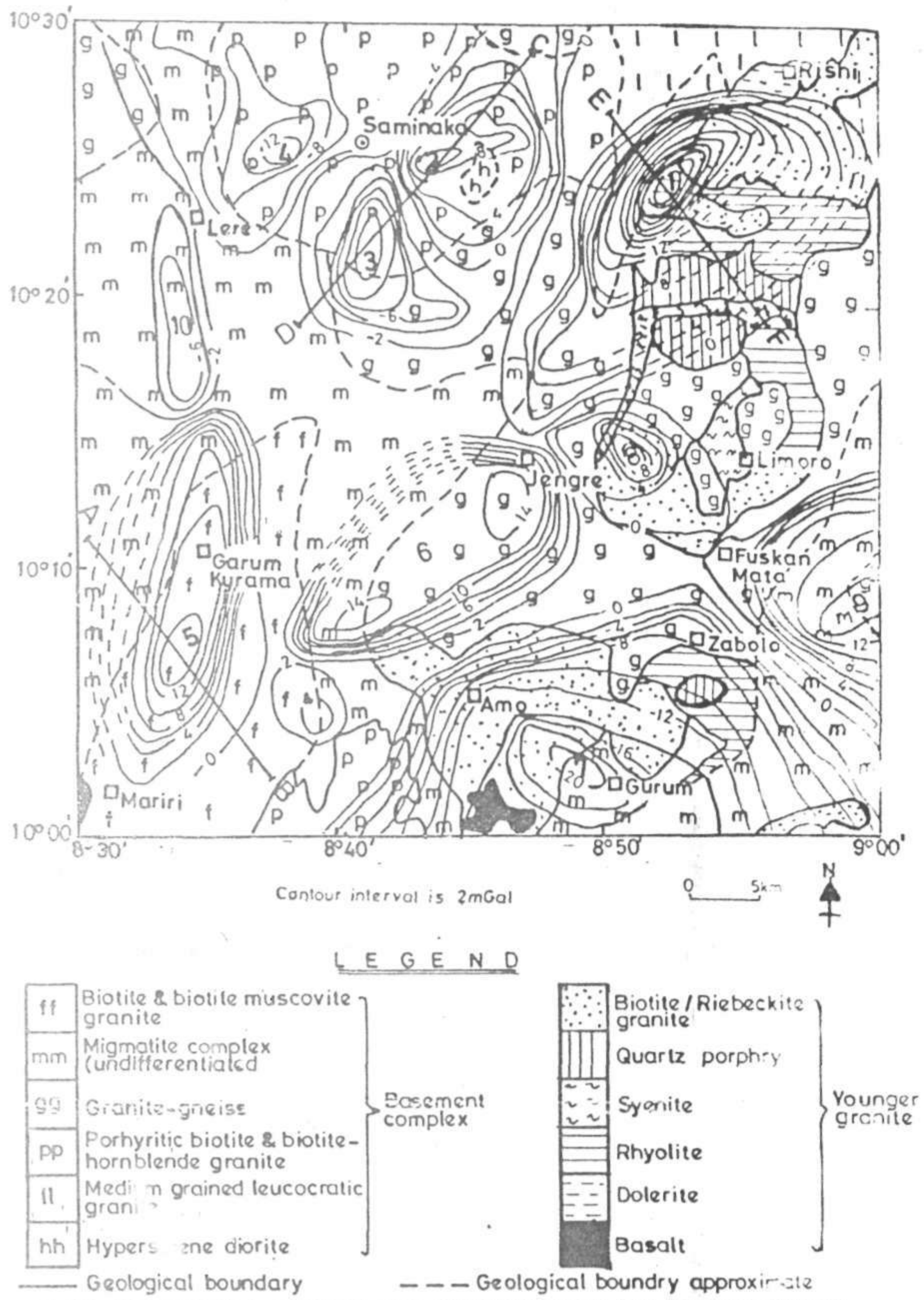


FIG.5.4: THE RESIDUAL GRAVITY MAP SUPERIMPOSED ON THE SIMPLIFIED GEOLOGICAL MAP OF THE AREA

muscovites, leucoratic granites, and the granit gneiss. The gravity high in this anomaly may be attributed partly to the relatively high density rock formations of the basement complex and partly to the presence of syenite and dolerite which are also high density rocks.

The series of anomalies numbered 2, 3 and 4 correspond to the porphyritic biotite and biotite-hornblende granite formation around Saminaka. The variation of the anomalies is most likely due to possible existence of different rock bodies of different densities in the subsurface. Specifically, the occurence of hypersthene diorite about 8 km east of Saminaka must have contributed to the gravity high of anomaly No. 2 as compared to anomalies No. 3 and 4.

The anomaly labelled 5 does not correlate perfectly with surface geology around Garum Kurama. It is therefore likely that the surface extent of the rock formation (fine-medium grained biotite and biotite muscovite granite) which is approximate, does not coincide with the subsurface extent as shown by the anomaly. The presence of basalt close to Mariri is the most likely reason for the gravity high of this anomaly. Other anomalies such as No. 7 and 9 are located at the biotite/riebeckite granites and the granite-gneiss formations respectively.

5.5 QUANTITATIVE INTERPRETATION OF THE ANOMALY MAPS

Usually, two basic approaches should be adopted for gravity interpretation. A direct inversion approach involves determining a plausible mass distribution directly from the gravity data. The other approach is a foward modelling technique in which the observed residual gravity values are computed for various models assumed for the buried source. Hence, in this approach a hypothetical model is first assumed and its gravity effect at the surface is calculated These calculated values are then compared with the observed values. The model is modified and the process repeated until one obtains a model that gives the best fit and would represent the subsurface picture. Usually, the choice of possible models should be guided by a good knowledge of the surface geology of the area such as the distribution of the rock units and the structures. For most interpretation problems, this technique is used due to the limitations of the use of direct method except for special cases (Dobrin, 1976)

5.5.1 Interpretation of the Major Residuals

A computer programme was used for the quantitative interpretation of the residual anomalies. The programme computes the gravity attraction of an arbitrarily shaped two dimensional body of polygonal cross section which extends to infinity in the direction of the strike (Nagy, 1964). The approximation of the source body to two dimensional structure is informed by the shape and trend of the residual Bouguer gravity anomaly (Figure 5.3). According to Telford *et* *al.* (1980), generally a body is considered two-dimensional when its cross-section is small compared to the strike length and is the same at all points along the strike.

In order to interpret the residual anomalies quantitatively, three profiles AB, CD, and EF were chosen along the general strike of the contour trends (Fig. 5.3). The choice of the profiles was based on the reliability of each anomaly with regards to the availability of the control points for the contour lines. A two dimensional interpretation of the residuals was carried out along the profiles. The computations were done at Bauchi using the VAX/VMS version V4.5 belonging to the Abubakar Tafawa Balewa University, Bauchi, due to the breakdown of the computer earlier used for the data reduction in A.B.U., Zaria.

Gravity values for a given model were computed at 2 km intervals along each of the profiles and a number of trials and adjustments were made to obtain the models described below. The rather large discrepancy between the calculated and the observed results at the two ends of most of the profiles could be attributed mainly to edge effects and to insufficient data along the profiles.

(i) Profile A-B

At the southwest part of the residual anomaly map is profile *A-B* which is inclined to the strike of the gravity anomaly No. 5 traversing Mariri and Garum Kurama villages. Although the practice is to choose a profile perpendicular to the strike of the anomalous body, but in this case, a profile perpendicular to the stike would be too short for a realistic interpretation considering the fact that the contours at the

Western flank of the anomaly is greatly inferred. Therefore, the profile A-B is inclined so as to include a greater part of the anomalous body. However, the section of the profile that traverses the anomaly in this case, does not represent the actual width of the anomaly.

The amplitude of the anomaly is +14 mgal, and the length of the profile is 20.13 km. The profile lies in the basement complex along part of the fine-medium grained biotite and biotite muscovite granite and part of the migmatite complex. The model assumed is shown in Figure 5.5. The anomaly source is suspected to be basalt in view of a nearby basalt exposure just 1.83 km west of Mariri (10°02' N, 8°30'E). The model therefore suggests the presence of a basalt body of density 2.85 $\times10^{3}$ $kg{\cdot}m^{-3}$ buried at a depth of about 1.25 km below the surface but which outcrops just few kilometres to the west. The density contrast used for the model is 0.18 $\times10^{3}$ $kg{\cdot}m^{-3}$. The cross-section of the model is conical in shape. The section of the anomaly traversed by the profile is 4.9 km long. Therefore the effective width of the anomaly is about 3.46 km given the fact that the angle made by the profile with the horizontal is about 45°. Finally, the apex of the cone-like body is seen to extend downwards to a depth of about 10 km below the surface.

(ii) Profile C - D

Figure 5.6 describes the cross-section of the model assumed for profile C - D drawn across two anomalies No. 2

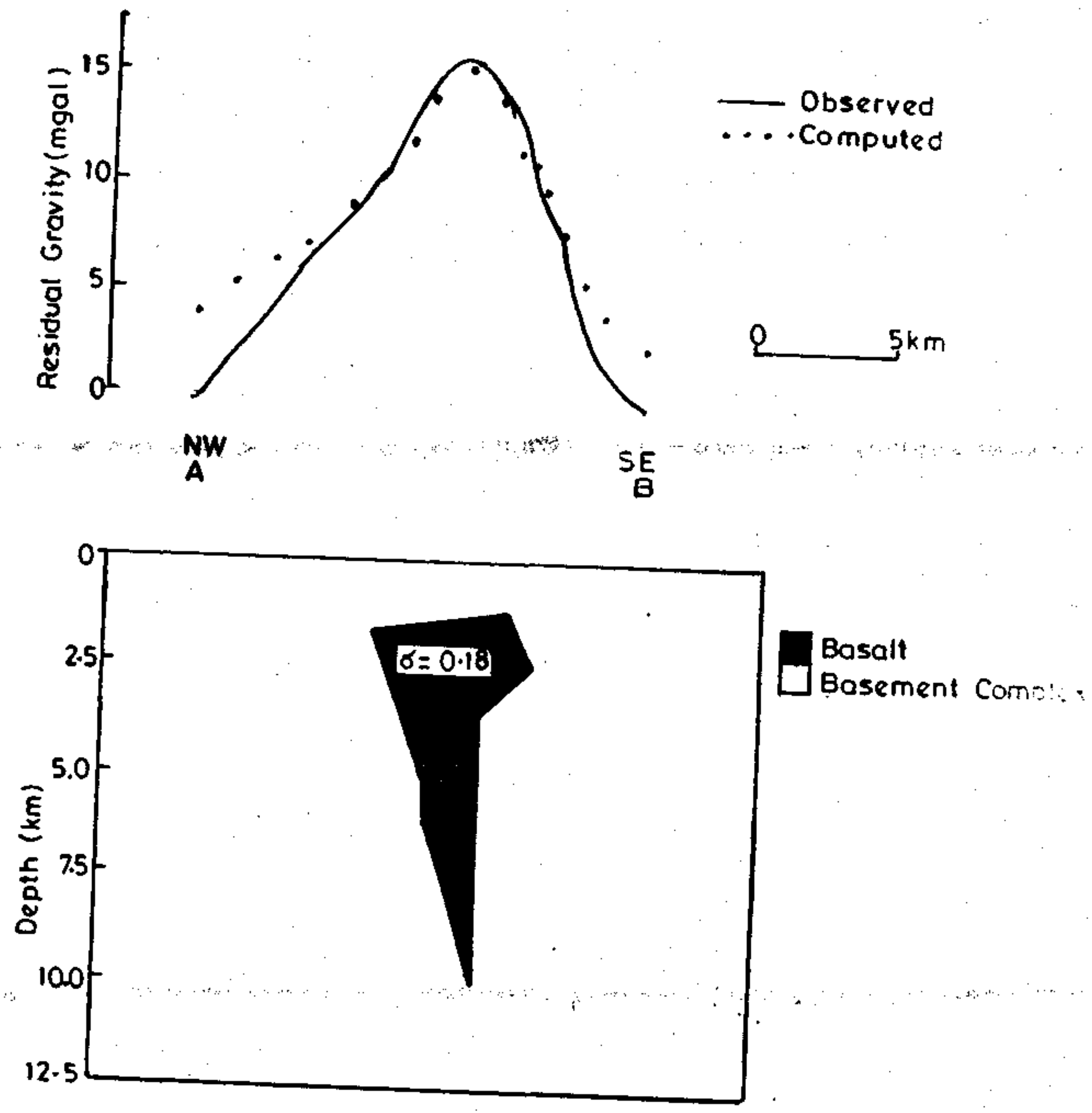


FIG.5.5: MODEL OF THE RESIDUAL ANOMALY ALONG PROFILE A – B

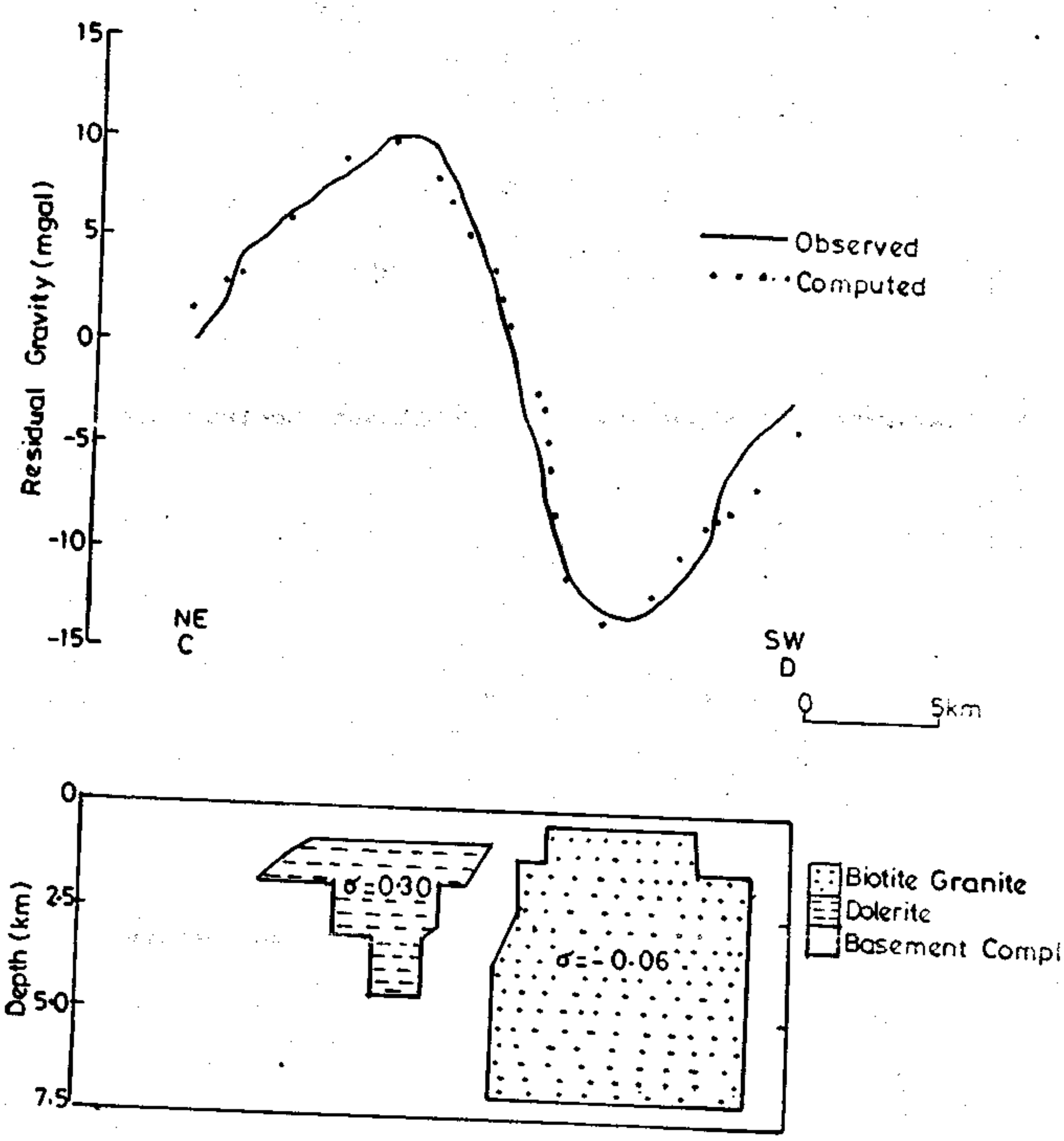


FIG.5.6 : MODEL OF THE RESIDUAL ANOMALY ALONG PROFILE C – D

and 3 respectively which are located in the north-central part of the survey area around Saminaka. Anomaly No. 2 which is a gravity high lies mainly on the fine to medium grained biotite and biotite muscovite granite formation as well as on the hyperstene diorite formation. The profile is 5.6 km long while the amplitudes of the anomalies are +10 mgal and -12 mgal respectively. On the other hand, the gravity low anomaly No. 3 lies across the fine-medium grained biotite and biotite muscovite granite formation and granite gneiss body. The gravity high is suspected to be due to dolerite of density 2.97 $\times 10^3$ $kg{\cdot}m^{-3}$ while the gravity low could be attributed to the Younger Granite intrusion which outcrops at the NE part of the map and whose density is 2.61 $\times 10^3$ $kg{\cdot}m^{-3}$. The choice of dolerite model is due to the proximity of large dolerite outcrop extending SW from Rishi and making contact with the biotite riebeckite granite.

The Figure indicates that the dolerite model is about 1 km beneath the surface from where it dips gently to the south-west for a vertical distance of 1 km before it narrows down to a maximum depth of about 4.5 km below the surface. The surface width of the model is 6.4 km, while at the bottom it is only 1.83 km long. A density contrast of 0.30 $\times 10^3$ $kg{\cdot}m^{-3}$ is used for the model study.

The granite model at the other hand, lies beside the dolerite formation but at a comparatively shallower depth. Using a density contrast of -0.06×10^3 $kg{\cdot}m^{-3}$, the depth to the top of the body is only 0.38 km. The model with a thickness of 5.5 km at the top broadened to a thickness of 9.2 km at the maximum depth of 7 km below the surface. The Figure also suggests that the two models assumed for these anomalies are separated by the basement complex at a maximum distance of 1.2 km apart.

(iii) Profile E - F

Located close to Rishi at the North-East of the residual anomaly map is profile E - F which is drawn across the positive anomaly No. 1. Although this anomaly lacks adequate control points an interpretation along this profile will lend a clue to understanding the nature of the Younger Granite in the area. Its length is 17.75 km. Figure 5.7 indicates that this profile has a steep gradient thus indicating the gravitating source to be at shallow level.

The best model obtained for this profile is shown in Figure 5.7. The area is dominated by Younger Granite which outcrops on the central region of the anomalous areas. Due to the high positive amplitude of 30 mgal for this anomaly, it is suspected that high density rock, most probably dolerite lies right beneath these granite complexes.

A density contrast of -0.08×10^3 $kg \cdot m^{-3}$ was used for the Younger Granite complexes in the area. The granite formation is shown with a minimum surface width of about 20 km From the surface, the body extended downwards to a depth of 8 km

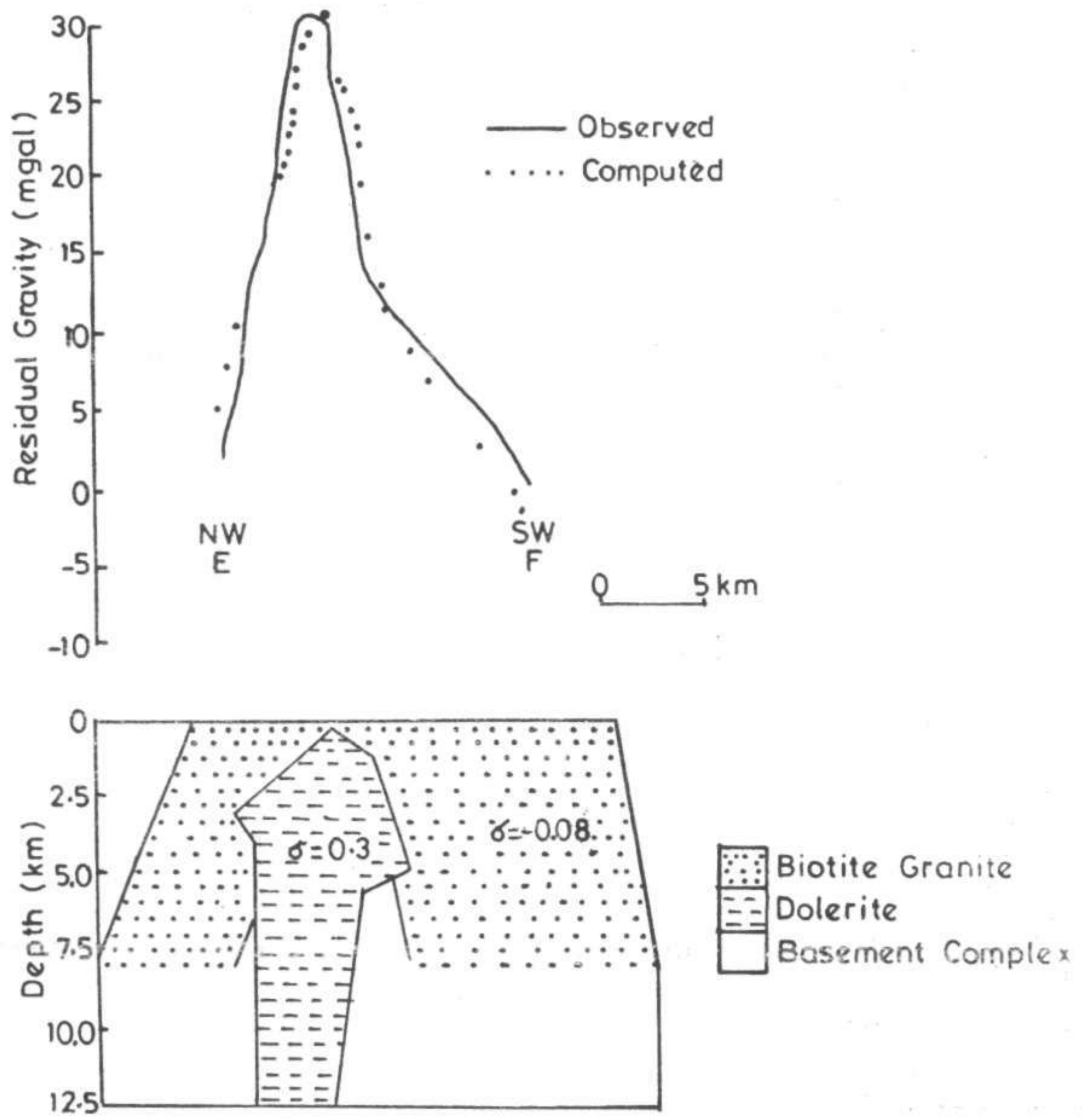


FIG.5.7: MODEL OF THE RESIDUAL ANOMALY ALONG PROFILE E – F

with a depth width of approximately 26.5 km. The Figure shows that the Dolerite body lies just 0.25 km below the surface where it intruded the granite complexes thereby contributing to the large gravity high in the area. The upper portion is surrounded completely by the granite body, while the lower part extends downwards into the basement complex up to approximately 12.5 km below the surface. The width at this depth is 3.7 km and the size of the body increases upwards, dipping gently to the right up to a maximum thickness of about 7.3 km

5.5.2 Discussion of the models and Deductions

The model studies indicate that biotite granite is the main rock unit of the Younger Granite series of the Saminaka/Lere region. Most of the exposed formations consist of biotite granite (Figure 5.7) and even some of the basement complex areas consist of biotite granite formations buried at depth, some of them as shallow as 37.5 m beneath the surface (Figure 5.6). In most of these granite outcrops, the lateral extent at depth far exceeds that which the surface exposure suggests (Figure 5.7). The overwhelming abundance of biotite granite in this area is confirmed by the observation made by Ajakaiye (1974). Some of the granite intrusions extend to depths of about 7 km below the surface (Fig. 5.6) thus agreeing with the results obtained from Younger Granites studies in other areas (Ajakaiye, 1970; 1976).

The basalt intrusion around Gurum and Mariri areas (Figure 5.5) suggests that some part of basement complex are underlain by basalt rocks at depth of about 1.25 km. This is to be expected because the presence of basalt outcrop 2 km west of Mariri and 5.9 km south of Amo is an indication that both of them may have extended to the anomalous region at depth. The contacts made by the basalt with the basement complex is sharp and steep (Figures 5.5); dipping generally inwards and terminating with a narrower base than at the top.

Dolerite is another rock formation which occurs either at close range or in contact with the granites (Figures 5.6 and 5.7). Close to Saminaka, the dolerite, about 1 km below the surface appears to have spread itself out like mushroom at the upper level where it has contact with basement rocks. Elsewhere, around Rishi, Dolerite formation appear to lie directly beneath the exposed granite complexes at a shallow depth of only 0.25 km making sharp contact with them (Fig. 5.7). It can be inferred therefore that the Younger Granite complexes in the area are underlain by the high density dolerite which outcrops at Rishi as seen in the geological map (Fig. 2.1). It is the influence of this high density rock at depth that gave rise to the large positive anomaly characterising an otherwise low density Younger Granite dominated area.

The structural relationship between the different bodies as inferred from the models shows that in general, the contact between the Younger Granites and the basement complex is vertical or highly inclined with outward dips (Figures 5.6 and 5.7). This mode of contact conforms with the geological information of the area (Macleod, 1971). This implies that the exposed Younger Granite in areas such as Rishi, Fuskan Mata and Amo complexes, must have spread extensively beneath the basement complexes.

On the question of the origin of the Younger Granites in Nigeria, Falconer *et al.*, (1926), Jacobson *et al.*, (1958) and Turner (1963) have all since proposed a magmatic origin which was later re-emphasized by Bowden (1970). They all agreed that there was an evolution of granitic magma which began with the development of a peralkaline liquid. However, the source regions for the generation of the peralkaline magma is still one of the areas of controversy.

In the present survey over the Younger Granite in Kere-Saminaka area, large negative Bouguer anomalies (up to −80 mgal) characterise the area. The negative gravity anomalies usually associated with granites are caused by the relatively low densities of the granites compared to the densities of the surrounding host rocks. Hence the large negative Bouguer anomalies over the area, undoubtedly indicate that granitic materials of a lesser density than that of the crystalline basement rocks underly a greater part of the granite formation to a depth of the order of 5 km. Bott (1953) pointed out that large negative Bouguer anomalies over granites would suggest a magmatic origin either by direct intrusion from the granitic layer or possibly by melting, differentiation and intrusion of the 'metamorphic' layer. Hence both gravity and density results in this survey have strongly confirmed the acidic nature of the Younger Granite suite in this area and thus indicating a granitic parent magma for the suite.

In addition, the pattern of the contours consisting of several negative closures in the Bouguer and residual anomaly maps (Fig. 5.1 and 5.3) strongly suggest a magmatic origin. The resultant abrupt changes in the gradient of the gravity field over the granite suite rules out the possibility of a metasomatic origin.

The view is strongly held that the Younger Granite suite originated from magma which initially squeezed their way laterally on the basement complex after passing through zones of weakness at higher levels.

5.6 CONCLUSIONS AND RECOMMENDATIONS

From the on-going study, the following conclusions and recommendations can be made:

i) The area under study is characterised by negative Bouguer anomalies ranging from −26 mgal in the northeast portion of the surveyed area to −80 mgal in the centre of the southern portion of the area.

ii) The Younger Granite suites in the area extend to depths of 7.5 to 11.5 km and have a density of 2.62 $\times10^{3}$ $kg{\cdot}m^{-3}$ in contrast to an average density of 2.65 $\times10^{3}$ $kg{\cdot}m^{-3}$ for the basement complex they intrude. They have steep outward dipping contacts and spread laterally at depth beyond the exposed extent.

iii) The negative closure pattern of the residual anomalies in the area coupled with sharp gradients confirm the magmatic origin of the Younger Granite.

iv) A number of unexposed intrusions have been shown to exist as seen in the models. These include basalt intrusions located around Garum Kurama and Mariri, the dolerite intrusions east of Saminaka as well as the granite intrusion around Saminaka. These are reflected as positive residual anomalies as shown in the models (Fig. 5.5 and 5.6).

v) The central and part of the northeast regions of the surveyed area were inaccessible for data collection. Further gravity investigation is necessary as road network improves in these regions so as to verify the assumed anomalies deduced from the inferred gravity contours.

vi) More evidences in favour of the magmatic origin of the Younger Granite suite can be obtained by the use of some other geophysical methods. Hence, a further investigation of the Younger Granites in this area employing another technique other than gravity method is therefore necessary.

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