A DETAILED GRAVITY INVESTIGATION IN THE MALUMFASHI AREA OF KADUNA STATE, NIGERIA.

BY

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D E C L A R A T I O N

I hereby declare that, this thesis is an original work carried out by the author under the supervision of Dr. S.B. Ojo and Professor D. E. Ajakaiye, Head of Department of Physics.

To the best of my knowledge no part thereof has been submitted elsewhere for the award of a degree or diploma. The work of others is duly acknowledged and referenced.

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October, 1984

DEDICATION

This work is dedicated to my father, Mallam Musa Haruna, and my mother, Malama Jessie Kande Haruna, and all the other members of Haruna family.

ACKNOWLEDGEMENTS

I am deeply indepted to Professor D. E. Ajakaiye, the Head of Physics Department who gave me the initial encouragement to take up the challenge of Applied Geophysics. I also wish to thank her for suggesting the project and graciously availing me of the preliminary data which was used as the basis for this survey. Her keen interest in the work and supervision are highly appreciated.

Sincere thanks are also due to my supervisor Dr. S. B. Ojo, without those patient guidance, useful suggestions and assistance, the completion of this work would not have been possible.

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I share the joy of the completion of this work with my husband Mr. D.A. Gandu who along with his nephew Dan'Azumi Gandu helped during the field work. His constant moral encouragement throughout the duration of the project is highly appreciated. At this point I wish to express my sincere thanks to my daughter Victoria, who patiently

bore my absence during the field work.

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ABSTRACT

Gravity measurements in the Malumfashi Area show that the area is characterized by large negative Bouguer anomalies ranging in values from -33 mGal to -65 mGal. Free-air anomalies are distributed about a mean of +15 mGal and projected sea level gravity value in the area is -41 mGal. A regional anomaly ranging in value from about -56 mGal in the south western part to about -44 mGal in the north eastern part of the area is correlated to a gradual thinning of the crust from southwest to northeast. Negative residual anomalies in the area correlate well with granite bodies thus confirming the acidic (low density) nature of the older granites. Positive residual anomalies of values up to about 12 mGal are correlated to the schist bodies in the area.

From two dimensional modelling, it is estimated that the schists in the area vary in depth from 3 km to 5 km and the granite bodies have thicknesses of the order of 4 km.

High gravity gradients of up to 6 mGal/km at some contact areas are attributed to sharp contacts and magmatic stoping is thought to be the most likely mode of emplce-ment of the granites. The sharp contacts also indicate that the contacts are possibly faulted.

The positive Bouguer anomalies over the schists in the area have a maximum amplitude of only -34 mGal. These values are thought to be too low to indicate the existence

of more mafic rocks at depth. The schists in the Malumfashi Area are therefore thought to have evolved in an ensialic environment,

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ABBREVIATIONS

m	.....	meter
km	.....	kilometer
N	.....	North
S	.....	South
NE	.....	northeast
NW	.....	northwest
SE	.....	southeast
SW	.....	southwest
kg	.....	kilogram
GSN	.....	Geological Survey of Nigeria
m.y.	.....	million years

CHAPTER I

INTRODUCTION

1.1 Scope of the Survey

The area covered by this survey lies between latitudes 11°30' N and 12°15' N and longitudes 7°30' E and 8°15' E and covers an area of about 6500 km² (Fig. 1.1). On a scale of 1:100,000, it is represented by sheet 79, (Malumfashi) and parts of sheet 80 (Kabo), 56 (Musawa) and 57 (Bichi). The climate of the area is that of a strongly contrasting seasons of aridic savanna belt of Northern Nigeria where the rainfall is between the months of April and September with a mean annual rainfall of about 1000-1250 mm. The mean annual temperature is about 27°C but during the harmattan period of November to January, temperatures could fall as low as 13°C. The months of February to April are usually very hot. Weathering processes throughout the year are very intense and the soils generally sandy. The drainage pattern is dendritic while height range is 480 - 660 m above sea level.

The area became of interest when it was observed that the schist belts of northwestern Nigeria actually extended beyond longitude 7°30' E, farther east than was previously reported by Russ (1957). This survey is of some significance since virtually no detail geophysical work has been done on the schist belts of Nigeria despite the fact that they are possible areas of mineralization, especially

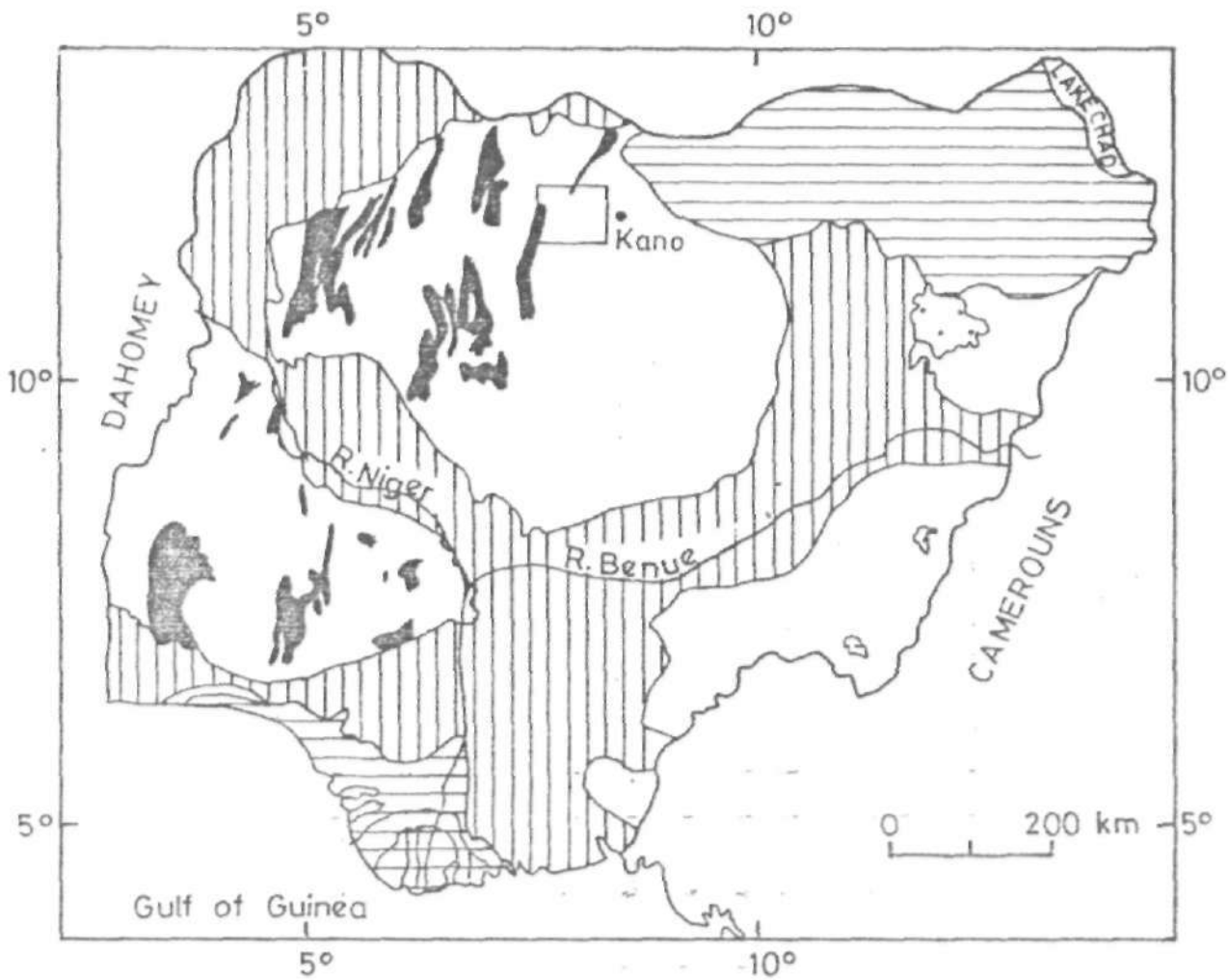
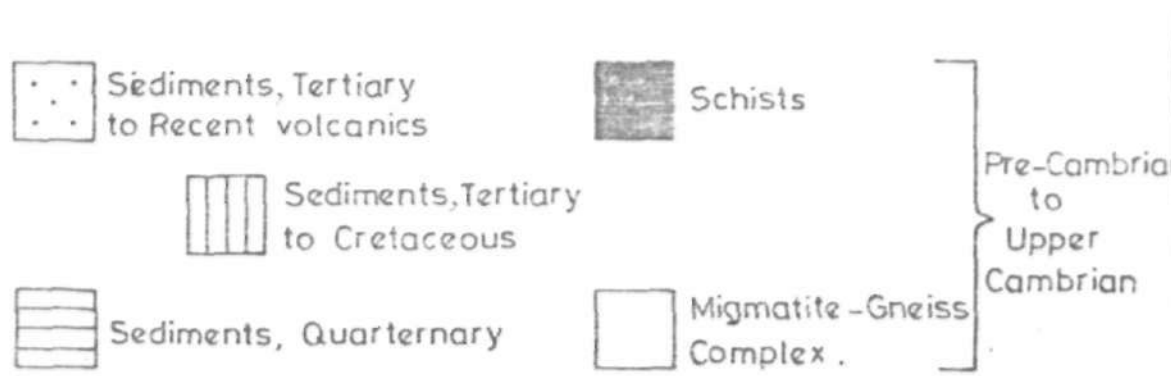


Fig. 1.1 Simplified geological map of Nigeria showing the gravity survey area in box



of gold. The main objectives of this survey are:

(i) to obtain information on the structures of the schist belts and their structural relationship at depth with the granitic intrusions,

(ii) to throw more light on the geologic history of the area on the basis of results obtained.

The field work was carried out in January 1984 with an additional two-day period in April 1984 devoted mainly to the collection of additional rock samples. 232 gravity stations at 2-3 and occassionally 4 km intervals were established on available motorable roads and tracks in the area. The base stations and base station values used were those which had been established in the regional gravity survey of Kano State and parts of Kaduna State (Ajakaiye and Verheijen, 1977). 26 detail station Bouguer anomaly and Free-air anomaly values from the Kano State gravity survey were incorporated in the analysis of data of this survey.

1.2 Previous Work in the Area

Geophysically, the most important previous work in the area as it affects the present work, was the Kano State regional gravity survey carried out in 1973 and 1974 where the results showed two adjacent and enlongated negative and positive anomalies in the present survey area (Ajakaiye and Verheijen, 1977).

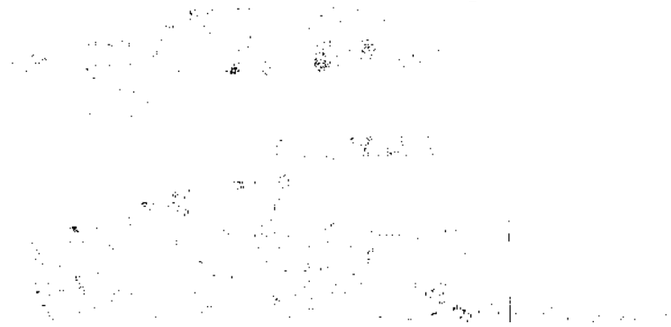
Following the location of a structure suspected to be a kimberlite pipe 1 km south of latitude 11°39' N

and longitude 7°41' E by the Diamond Corporation of Sierra Leone between 1961 and 1965, Verheijen and Ajakaiye (1979) carried out a gravity survey over the area of the pipe. Results of their survey showed a gravity low consistent with the gravity characteristics of kimberlite pipes. The nature, extent and other physical properties of the pipe were investigated in 1979 using the resistivity and seismic methods of investigation. Results showed that the pipe is between 560 - 660 m in length, striking in direction east of northeast with a maximum width of 140 m (Onugba, 1979).

Geologically, detail information is available only for Malumfashi Sheet 79, scale 1:100,000 mapped by McCurry (1970). Her map indicates the presence of a schist belt and some granitic bodies as well as a major transcurrent fault. The sheet was also recently remapped by the Geological Survey of Nigeria (GSN). The new map (GSN, in preparation) include several details which appear to have been omitted in the map of McCurry (1970). These differences are discussed in this thesis in the light of the gravity observations.

The gravity method of investigation was chosen for this survey because the subsurface shape of structures can be readily determined from the gravity anomalies they produce if the density contrast between the structures and their host rocks is known. The survey area is fairly large (about 6500 km^2) and

the gravity method lends itself as one of the cheap methods for covering large areas. The third reason for chosing the gravity method for this survey is that it was hoped that the survey would serve as a follow up study giving additonal gravity information to the regional gravity survey of Kano State with particular reference to the area of study.



CHAPTER II

GEOLOGY OF THE AREA OF STUDY

2.1 General Geology

The survey area (Fig. 2.1) is underlain by rocks of the Nigerian Basement Complex first described by Falconer (1911). Different parts of the complex have since been studied by various authors (King and De Swardt, 1949; Russ, 1957; Truswell and Cope, 1963; Oyawoye, 1972; McCurry, 1970; Ajibade, 1980). The rocks of the Nigerian basement complex are grouped into three lithological units (Oyawoye, 1972; Ajibade, 1980; and others) and these are:

(i) a crystalline complex of migmatites and gneisses which are the dominant rock types

(ii) the metasediments and metavolcanics which form northsouth trending schist belts and

(iii) the Older Granite series which intrude both the migmatite gneiss complex and the schist belts.

The rocks are the result of at least two major orogenic cycles (Wright and McCurry, 1971). These orogenic cycles correspond to the Birrimian (2,500 m.y) and the Pan-African (600 ± 5 m.y.) (Grant et al., 1969). Intense deformation and isoclinal folding was accompanied by regional metamorphism, which was further followed by extensive migmatization. The second deformation (Pan-African) was accompanied by a regional metamorphism, migmatization and extensive granitization and

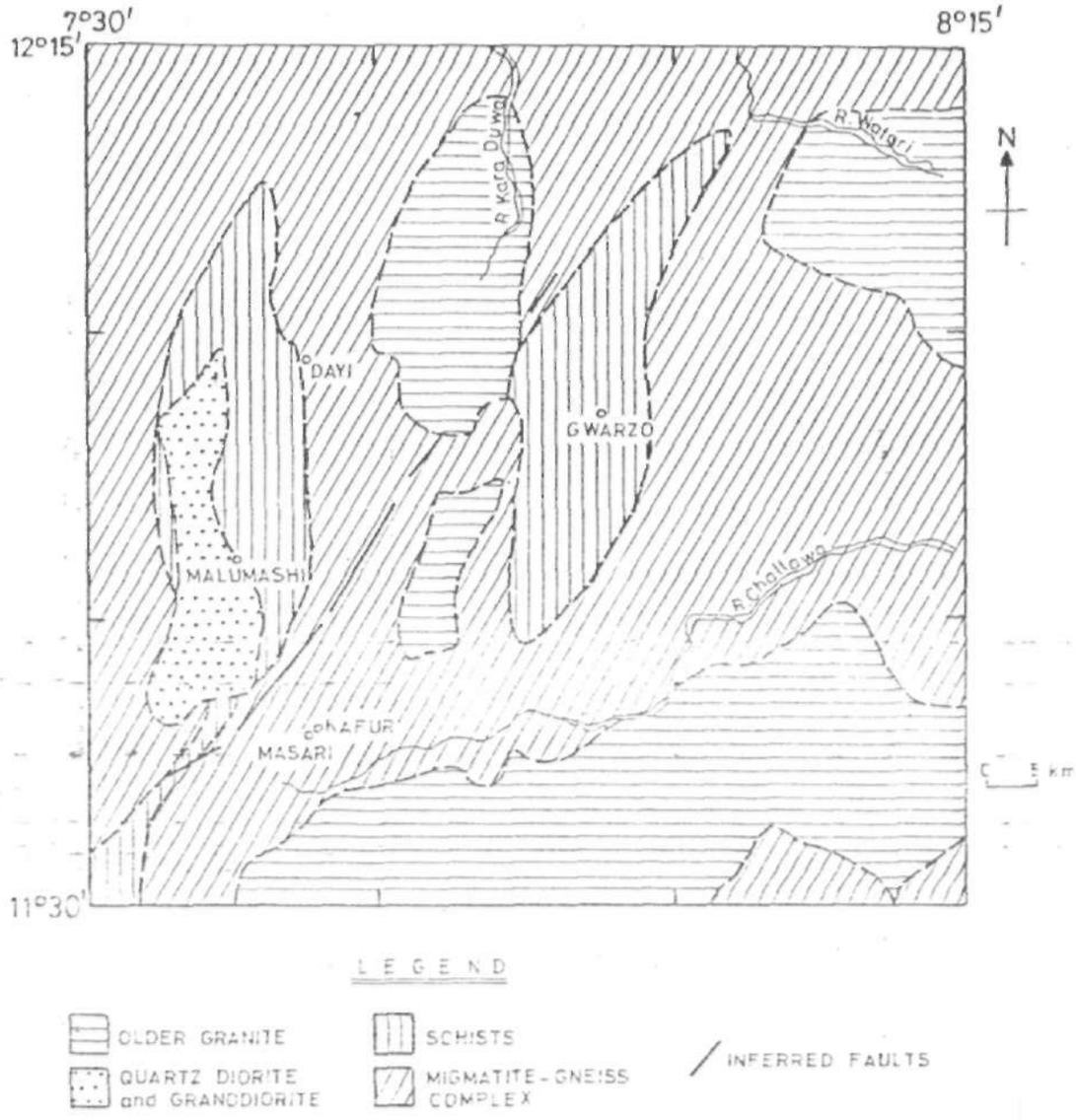


Fig. 2.1 Geological Sketch map of Malumfashi Area.
(Sketch based on McCurry (1970) together with additional information from the Geological Surveys of Nigeria, Kaduna).

gneissification which produced potassic syntectonic granites and homogeneous gneissis (Abaa, 1983). Late tectonic emplacement of granites and granodiorites and associated contact metamorphism accompanied the end stages of this last deformation. The end of the orogeny was marked by cooling, faulting and fracturing (Jacobson et al, 1963). Other rock types are mainly metasediments comprising feldspathic quartzites, schists, basic and calcerous rocks (Abaa, 1983). The generalized chronological sequence of the various rock types found in the Nigerian Basement Complex is shown in Table 1.

2.2. Rock Types in the Study Area

The different rock types found in the study area are as follows:

Granites and Granodiorites

The granites and granodiorites occur in the form of elliptical plutons, inselbergs and whalebacks. The granite types based on texture are coarse porphyritic granites, medium-coarse grained granites and equiangular fine-medium grained granites. The granodiorites are generally medium to coarse grained with a gneissose texture. Some of the granites exhibit some flow structures and contain rotated xenoliths indicating some movement of the granitic material (Webb, 1972). The main minerals of the granites are quartz, orthoclase, perthites, some sodic

Table 1

GENERALIZED CHRONOLOGICAL SEQUENCE OF THE VARIOUS ROCK TYPES

PERIOD	ROCK UNIT	ROCK TYPE
467-618 m.y. Late Pre-cambrian -Lower Paleozoic	Older Granites	pegmatites granodiorites granites
about 650-850 m.y. -Pan-African	Metasedi-ments	schists, gneisses quartzites, mylonites crusshed breccia diorites
about 2,000 m.y. -Birrimian	Metasedi-ments	felspathic quartzites sillimanite gneiss basic and calcarous rocks
>2,000 m.y. -Dahomeyan	Crystalline Complex	gneisses migmatites

(after Grant et al, 1969)

plagioclase while the main mafic minerals are biotite and hornblende. The granodiorites have similar mineral contents except that the feldspars are predominantly plagioclase instead of alkali feldspars and the amount of mafic minerals is greater in the granodiorites than in the granites (Abaa, pers. comm.).

Migmatites

These form subdued relief and are usually grey with bands of white and dark materials (McCurry, 1970). In some localities the dark bands prevail over the light bands while in other areas, the reverse is the case. The light bands are generally medium grained containing microcline, plagioclase and quartz in nearly equal amounts. In the dark bands the main feldspars appear to be plagioclase while biotite and hornblende are in greater quantity than the felsic minerals (McCurry, 1970).

Gneisses

The gneisses cover about 60-70% of the area (fig. 2.1) and are the most abundant rock type found in the area. They vary from equigranular to porphyroblastic in texture and are generally light to dark coloured. The major minerals in the gneisses are perthitic feldspars, quartz and some plagioclase. Biotite and hornblende are the abundant mafic minerals (McCurry, 1970).

Schists

Schists constitute a fairly large part of the area and form northsouth trending zones. They constitute mica schists which are transitional into biotite gneisses. Pegmatites and quartzites form large veins in the schists. The main minerals of the schists are muscovite, quartz, chlorite, garnet and tourmaline. The schists are usually only exposed in river valleys (McCurry, 1970).

Quartzites

These occur as elongated bodies and may sometime be several kilometers long before appearing to wedge out or disappear under superficial cover (McCurry, 1970). As they are more resistant to weathering they form well marked ridges in morphology and they usually trend northsouth or northeast-southwest. The rocks are whitish or brownish but in some places fragments of darker material are present. The minerals present are muscovite, iron oxide and tourmaline (McCurry, 1970).

Superficial deposits

The superficial deposits are alluvial deposits and laterites. The laterites are grouped into older and younger laterites (Wright and McCurry, 1970), the former occuring as prominent mesas usually along small water sheds and containing quartz veins and pegmatites, while the latter occurs along edges of present river valleys and pediment slopes and are usually

derived by erosion of older laterites. The younger laterites are partly formed in situ from weathered basement rocks and have had negligible surface movement (McCurry, 1970).

2.3 Structural Aspects

The main structures of the area are described below:

Foliation

Parallel orientation of muscovite and chlorite in schists are common giving the rocks a predominant schistosity. Foliation in the granite and granodiorites is well defined by the sub-parallel alignment of feldspar crystals (McCurry, 1970). In some granites xenoliths of dioritic rocks are also aligned in the direction of feldspar phenocrysts.

Faults

McCurry (1970) has observed numerous faults in this area several of which are large with displacements of several meters. She also inferred a major transcurrent fault in the NE-SW direction. The faults which occur in all rock types in the area can be grouped into two sets, trending NW-SE and NE-SW.

Joint/Fractures

Joints are well developed but in the granites they are small, hardly exceeding 5 m in length. The joints must be several generations since they cross cut each other with small displacement in some localities (Wright & McCurry, 1971). Some of the

joints have been filled with quartz and small amounts of biotite. Some of the rocks have weathered into small slabs due to numerous closely spaced horizontal joints. The main type of fractures are shear and tensional fractures which are distinguishable from the joints by slickensides developed along the shear planes.

Microgranite dykes

These vary in size, are usually reddish brown in colour and they differ in texture from the host granites and granodiorites. They are usually fine grained and contain mainly feldspars, quartz and biotite. The dykes have similar strike direction with the joints and fractures. In places where they are narrow (less than 2 m wide) they are considered to be aplites (Abaa, pers. comm.).

Pegmatites

The pegmatite veins are weathered. Some of the veins are sheared or folded and also show smaller branches and cross cut each other in some localities indicating that there are several generations of the pegmatites (Abaa, 1983). Chilled margins between the pegmatites and their host rocks are very faint. The older generations of pegmatites are more coarse grained than the younger ones that cross cut them. The main minerals of the pegmatites are quartz, feldspars, biotite and muscovite, while tourmaline is present in some localities.

Quartz Veins

These are the most abundant and widespread minor geological formations in the area (McCurry, 1970). They occur as thin veins which may be straight or winding. They are found cutting the microgranite dykes and pegmatites indicating that they may be the last geological event in the area. The veins have sharp contacts with the host rocks and their mineralogy is simple. Besides quartz in the veins, tourmaline may be present (McCurry, 1970) and, rarely, a few flakes of biotite.

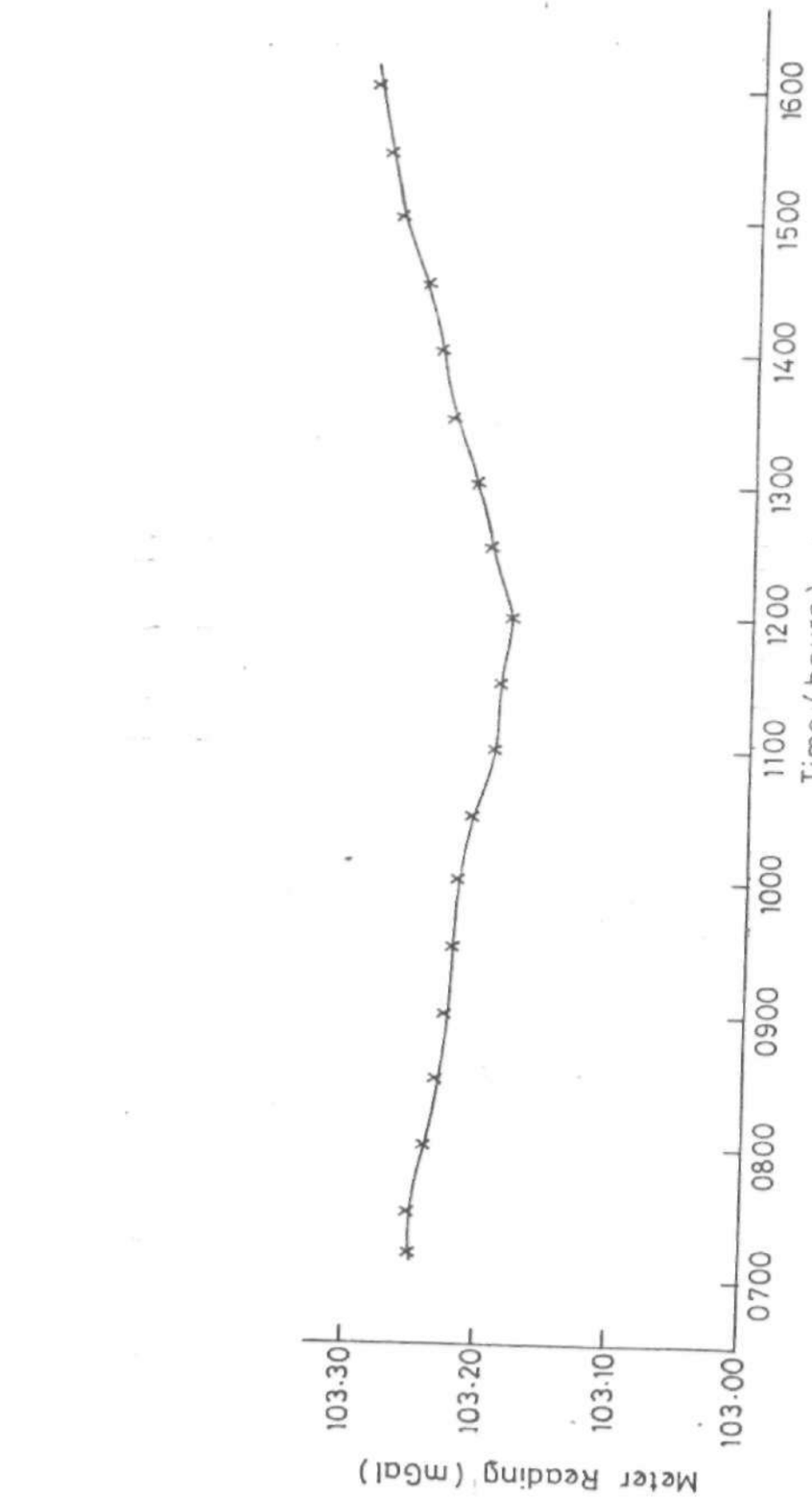


Fig. 3.1 Gravimeter Drift Curve

(e.g. between 1130 - 1230 hrs) gravimeter readings were not taken on the field since the drift rate during this time is not unidirectional.

3.2 Base Network and Data Reduction

The survey was carried out using an existing gravity network of base stations (Fig. 3.2) where all gravity values are relative to the value of 978120.773 mGal at a standard benchmark at Kano airport (Verheijen and Ajakaiye, 1978).

The gravity data collected was reduced to Free-air and Bouguer anomaly values by use of a computer program executed by a CDC CYBER 72 Computer at the Ahmadu Bello University. The standard reduction procedures and basic equations used to obtain the anomalies are as follows:

a) Drift rate

A linear relationship of drift with time was assumed and the drift rate σ is given by:

$$\sigma = \frac{(R_1 - R_2) - \frac{(g_1 - g_2)}{k}}{t_1 - t_2}$$

where R_1 and R_2, g_1 and g_2 and t_1 and t_2 are the readings, gravity values, and times of readings at the first and second base stations respectively. k is the gravimeter constant.

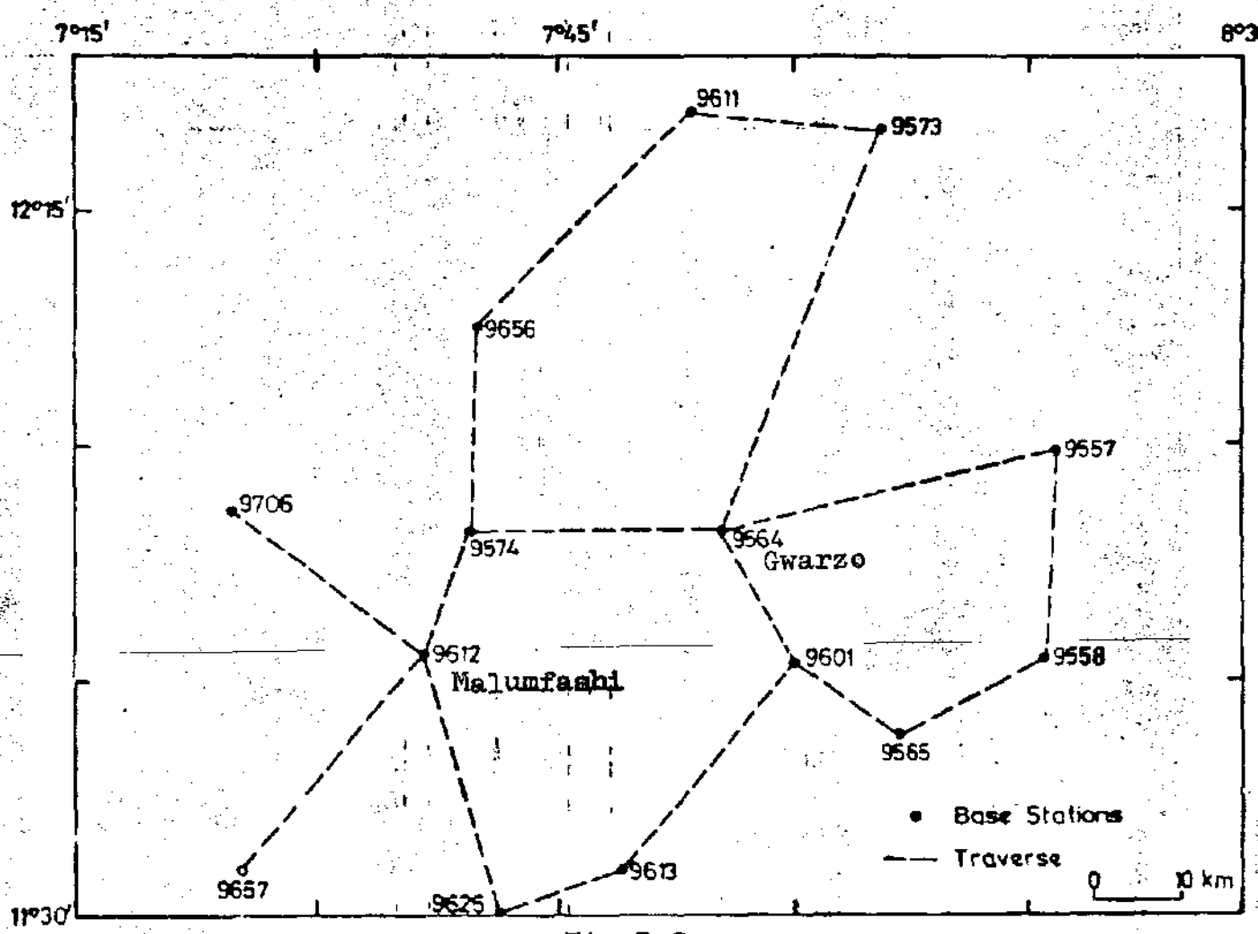


Fig.3.2

Gravity Base Network.

(After Ajakaiye and Verheijen, 1977)

b) Observed gravity at a detail station

The observed gravity value g_s at a detail station is then given by:

$$g_s = g_1 + k((R_1 \quad R_s) - \sigma\ (t_s - t_1))\ \text{mGal}$$

where g_1 is the gravity value at the first base station, k is the meter constant, R_1 and R_s, t_1 and t_s are the readings and times at the first base station and detail station respectively.

c) Theoretical gravity or latitude effect

The theoretical gravity at a station is given by the 1967 Geodetic Reference System (GRS 67) Formula which is

$$\gamma_t = 978031.85\ (1+0.0052788\ \sin^2\phi + 0.00002346\ \sin^4\phi)\ \text{mGal}.$$

where ϕ is the latitude of the station.

d) Free-air anomaly.

Correcting the difference between g_s and γ_t for the vertical decrease of gravity with increase in elevation, gives the free-air anomaly $\Delta g_{F.A}$ and it is computed from the expression:

$$\Delta g_{F.A} = g_s - (\gamma_t - \frac{dg}{dz} h)$$

where $\frac{dg}{dz}$ is the vertical gradient of gravity and its value is 0.3086 mGal/meter (Parasnis, 1962) and h is the station elevation above sea level.

e) Bouguer Anomaly

This is determined using the expression:

$$\Delta g_{B.A.} = g_s - \gamma_t + \frac{dg}{dz} h - 2\pi G\rho_c h$$

where $\Delta g_{B.A}$ is the Bouguer anomaly, ρ_c is the assumed crustal density of value 2.67×10^3 kg.m^{-3} and G is the universal constant of gravitation. The term $2\pi G\rho_c h$ is the additional attraction exerted on a unit mass by a slab of rock material of density ρ_c between a station and the reference datum (usually the sea level) and it is called the Bouguer correction. Its value works out to be $0.04191\rho_c$ mGal per meter of elevation. If ρ is assumed equal to the crustal density, ρ_c, the value becomes $0.04191\rho_c$ mGal per meter.

3.3 Sources of Error in the Bouguer anomalies

The computed Bouguer anomaly at each station is usually subject to errors from several sources, the most significant of which is inaccurate station elevation. Where stations are on Federal Survey Bench Marks, the height values usually have errors less than 0.03 m and the error in the Bouguer anomaly due to inaccurate elevation determination would be less than 0.006 mGal which is insignificant. However, when altimeters are used, elevation determination could be in error by as much as 5 meters (Verheijen and Ajakaiye, 1980) and this would cause an error in the Bouguer anomaly values of 0.98 mGal.

Other sources of error are those due to non-linear drift of the instrument, instrument and operator precision, the calibration factor of the instrument, incorrect latitude determination, the terrain effect and those due to the use of inaccurate density in the Bouguer correction.

The average density of the most abundant rock types in the area (migmatite - gneiss complex) was found to be 2.70×10^3 kg.m^{-3} but as this density may not be truly representative of the density of the crust the average crustal density of 2.67×10^3 kg.m^{-3} was used for the data reduction. This would result in a density uncertainty of 0.03×10^3 kg.m^{-3} causing a maximum error of 0.24 mGal over the height range of 190 meters observed during the survey.

Most of the maps used to obtain the latitudes of stations were on a scale of 1:50,000 and latitudes of stations were determined to the nearest 0.01 seconds. Errors due to inaccurate latitude determination would therefore be about 0.02 mGal.

The maximum elevation difference in the area was found to be 190 m in a distance of 75 km and using a density of 2.67×10^3 kg.m^{-3}, the maximum terrain correction is less than 0.0002 mGal which is considered insignificant. Terrain correction was therefore not considered necessary, hence not applied.

From the foregoing, if the maximum error computed for each of the above sources is assumed, the total

cumulative error at each station would be 1.24 mGal. For most stations however, the actual errors would be less than this value especially for stations located at bench marks.

CHAPTER IV

DENSITY MEASUREMENTS

4.1 Introduction

Variations in the earth's gravity field result from special characteristics of the earth's shape and its near surface density distribution (Grant & West, 1965). Gravity anomalies are therefore caused by the lateral heterogeneity of upper crustal density, and a knowledge of the densities of rock formations in a survey area is therefore necessary in the interpretation of such anomalies.

In order to ease the difficulties encountered in situations where rock densities must be assumed, tables of rock densities from different parts of the world have been published by various authors (Dobrin, 1960; Ajakaiye, 1976; Telford et al, 1976 etc.). However, the published values may only give a general overview of rock densities and the density contrasts required for interpretation in a particular area may be so small that actual measurements of the rock densities in that area must be made. To obtain reliable density values, for an area, careful measurements of the densities of fresh and unweathered rock samples from the area must be made.

4.2 Sampling Procedure and Measurements

A total of 143 fresh rock samples were collected from rock outcrops along all the traverses during the

field work. The fresh samples were either broken (using a hammer) from outcrops or collected from active quarries.

The true densities of the rocks were found by computing the mean of the dry and saturated densities. Using the universally accepted Archemedes Principle, the dry and saturated densities were computed from the expressions:

$$\text{dry density} = \frac{\text{dry weight}}{\text{dry weight} - \text{weight in water}}$$

$$\text{saturated density} = \frac{\text{wet weight}}{\text{wet weight} - \text{saturated weight}}$$

Measurements needed for the computations of the saturated densities were done after the samples were submerged in water for at least 48 hours. The wet weight is the weight of the saturated sample in air while the saturated weight is the weight of the saturated sample in water. Due care was taken to wipe off any excess water on the saturated samples before making the wet weight measurements.

4.3 Results

The summary of results of the density determinations are shown in Table 2. Errors in the density measurements are shown as standard deviations. The true densities for reach rock type were divided into class interval of 0.03 units and histograms (Fig. 4.1) were plotted to enable a study of the density distribution. Where the rock samples of a given type were very few, however, a histogram was not plotted. The mean densities for

Table 2

SUMMARY OF ROCK DENSITIES

Rock Type	No. of Samples	Range of Densities in 10^3 kg.m^{-3}	Average Densities in 10^3kg.m^{-3}	Standard Deviation in 10^3kg.m^{-3}
Gneisses	83	2.53 - 2.79	2.70	0.05
Migmatites	16	2.62 - 2.76	2.69	0.04
Granites	17	2.51 - 2.71	2.63	0.01
Quartzites	10	2.60 - 2.77	2.66	0.04
Schists	6	2.77 - 2.80	2.78	0.01
Quartz diorite	2	2.78 - 2.79	2.79	-
Diorites	6	2.81 - 3.11	2.99	0.10
Crushed Breccia	3	2.56 - 2.60	2.58	-

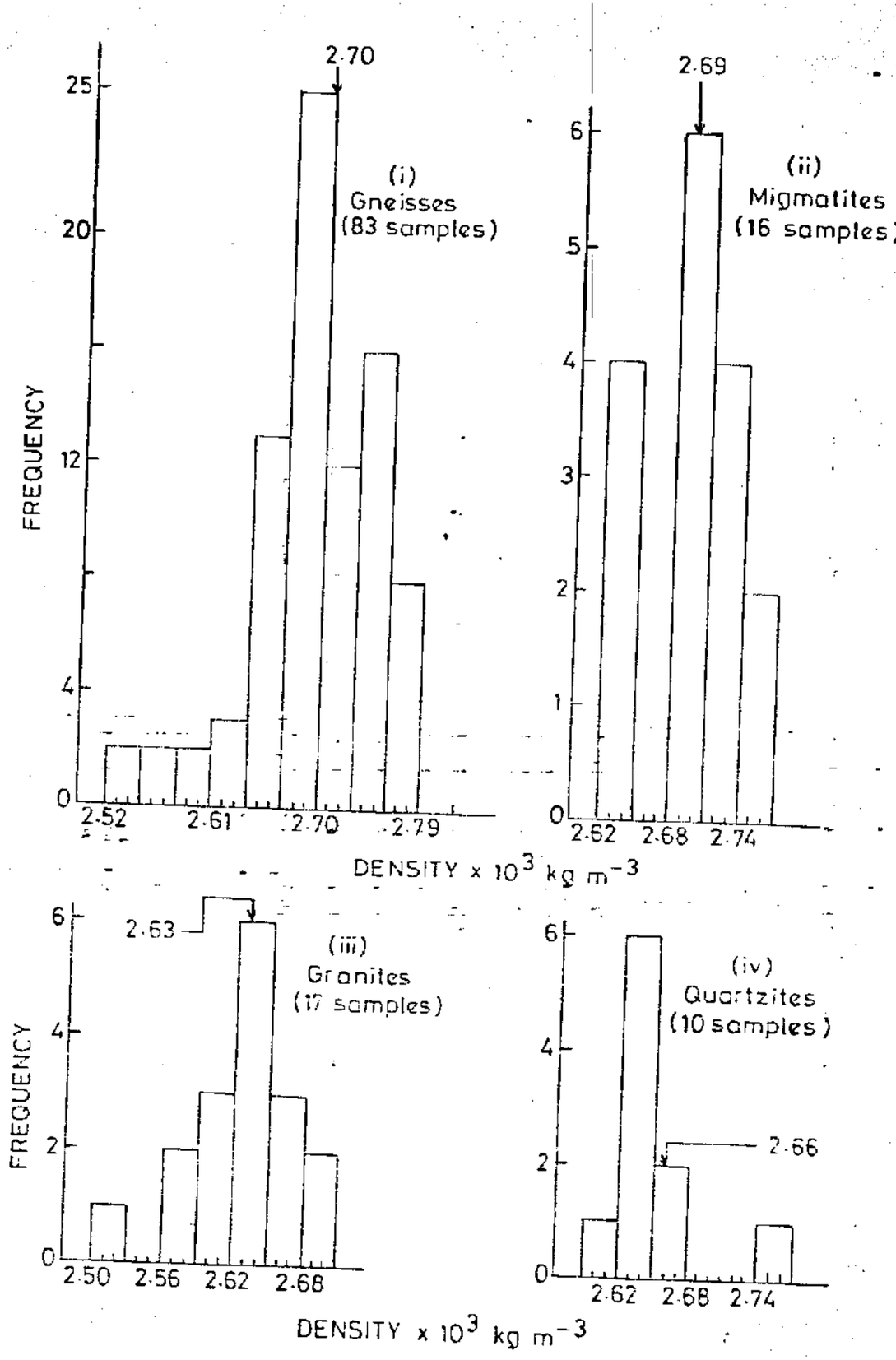


FIG. 4.1 DENSITY HISTOGRAMS

the different rock types ranged from 2.99 x 10^3 kg.m^{-3} for diorites to 2.58 x 10^3 kg m^{-3} for crushed breccia. A brief description of the various histograms is given below:

83 samples of gneisses were obtained and their density distribution is shown in Figure 4.1(i). The calculated mean density for the group is 2.70 x 10^3 kg.m^{-3} with a standard deviation of ± 0.05 x 10^3 kg.m^{-3}. The histogram is bimodal and negatively skewed. The two modes could be depicting two main types of mineralogical content of the gneisses which are quartz and biotite. From the 16 samples of migmatites, a mean density of 2.69 x 10^3 kg.m^{-3} was obtained with a standard deviation of 0.04 x 10^3 kg.m^{-3}. The mean density falls within the modal group (Fig.5.1.(ii)).

Only the histogram for the granites (Fig. 4.1(iii)) shows a near normal density distribution with a mean density of 2.63 x 10^3 kg.m^{-3} which falls within the modal group. The normal density distribution indicates that the granites have similar mineralogical content. The standard deviation of the mean is 0.01 x 10^3 kg.m^{-3}.

The density histogram for the quartzites (Fig. 4.1(iv)) shows a positive skew with a computed mean density of 2.66 x 10^3 kg.m^{-3} and a standard deviation of 0.04 x 10^2 kg.m^{-3}. Other rock samples collected but considered too few for a density histogram to be plotted were schists, diorites, quartz

diorites and crushed breccia which had mean densities of 2.78 x 10^3 kg.m^{-3}, 2.99 x 10^3 kg.m^{-3} 2.79 x 10^3 kg.m^{-3} and 2.58 x 10^3 kg.m^{-3} respectively.

It is pertinent to state here that very few samples of schists (6) were obtained even though the geological map (Fig. 2.1) indicates that they cover a fairly large area. This is because the exposure of the schists is very poor especially along the traverses.

4.4 Densities accepted for Models

Generally, the skewness of the density histograms for the metamorphic rocks (e.g. quartzites, schists) could be due to the different degrees of metamorphism which gives a general characteristic irregularity in the density behaviour of metamorphic rocks. It has been shown (Grant & West, 1965) that distinct zoning and chemical differentiation causing irregular density behaviour, could be found in a single rock formation.

The skewness of the density histogram of the non-metamorphic rocks could be due to differences in their mineralogies.

The mean density of 2.70 x 10^3 kg.m^{-3} for the gneisses and 2.69 x 10^3 kg.m^{-3} for the migmatites agree with other published figures of 2.70 x 10^3 kg.m^{-3} and 2.69 x 10^3 kg.m^{-3} respectively. (Ajakaiye, 1976; Telford et al, 1976).

Since the gneisses have been found to pre-dominate over the migmatities and occupy about 60-70% of

the area, the value of 2.70 x 10^3 kg.m-^{3} for the basement complex was used in the interpretation. The mean densities of 2.63 x 10^3 kg.m^{-3} for granites, 2.78 x 10^3 kg.m^{-3} for schists and 2.99 x 10^3 kg.m^{-3} for diorites, 2.79 x 10^3 kg.m^{-3} for quartz diorites were accepted for interpretation. These values were found to be in agreement with other published figures of 2.63 x 10^3 kg.m^{-3} for granites, (Ajakaiye, 1976), 2.99 x 10^3 kg.m^{-3} for diorites and 2.79 x 10^3 kg.m^{-3} for quartz diorite (Telford et al, 1976). The value of 2.78 x 10^3 kg.m^{-3} for schists falls within the acceptable range of 2.39 - 2.90 x 10^3 kg.m^{-3} (Telford et al, 1976).

CHAPTER V

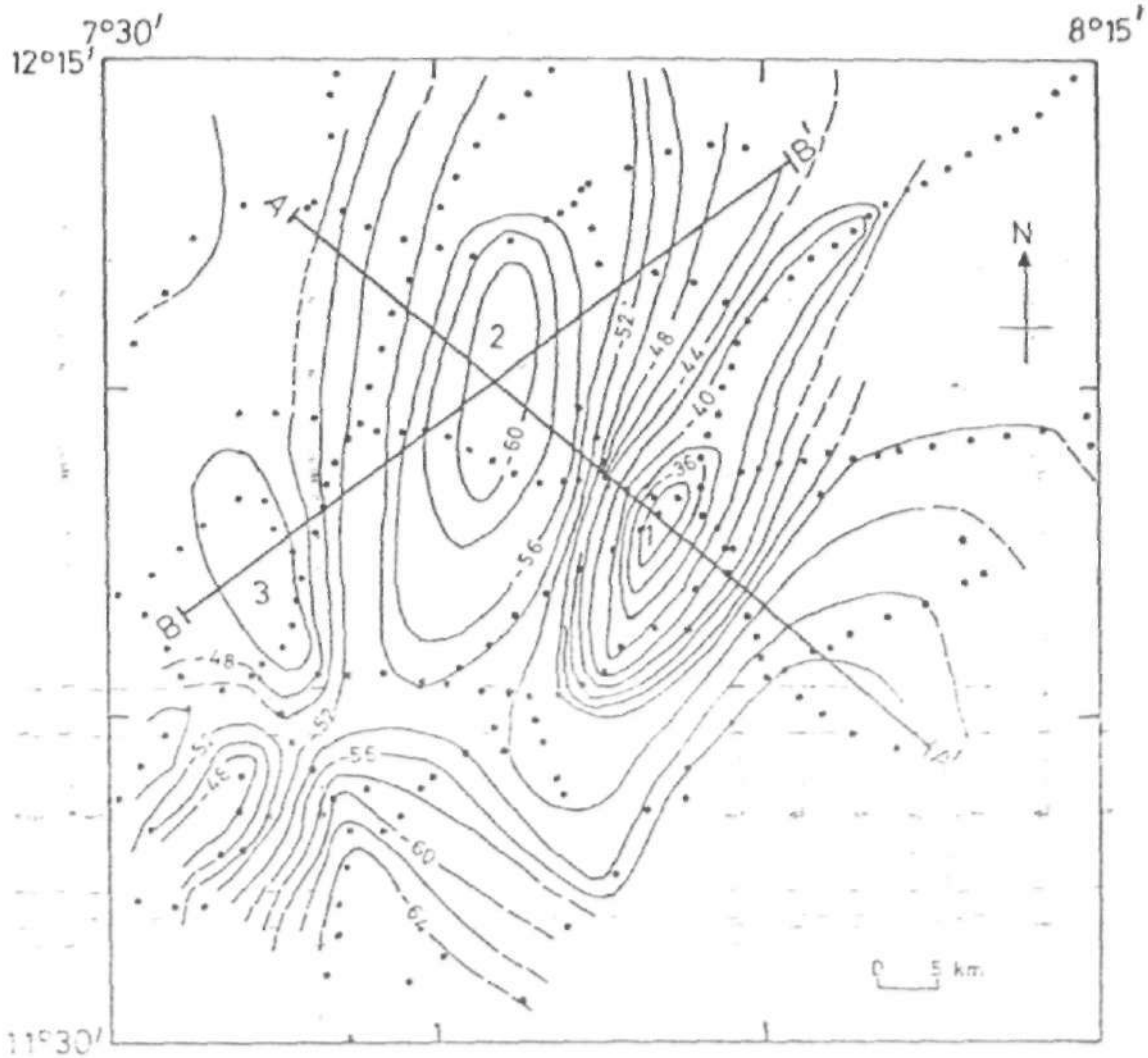
DESCRIPTION AND INTERPRETATION OF THE BOUGUER AND RESIDUAL ANOMALIES

5.1 The Gravity Field

The Bouguer gravity field is shown in Figure 5.1. It is characterized by negative Bouguer contoured values ranging from -34 mGal in the eastern part of the area to -64 mGal in the southern part. Individual station values of the Bouguer anomalies ranged from -33 mGal centred in the eastern part to -65 mGal centred in the southern part, and the average value for all the stations is -51 mGal.

The major gravity high of -34 mGal identified as "1" on Figure 5.1 is centred on a schist body while the gravity low of -60 mGal identified as "2" (Fig. 5.1) is centred on a stock of granites. A steep gradient of 6 mGal per kilometer is indicated between these two anomalies. The steepness suggests a sharp geologic contact or possibly, faulting.

In the western part of the area, the Bouguer anomaly values become more positive ranging from -58 mGal to -46 mGal after a general westward plunge of up to -60 mGal. The Bouguer anomaly values (maximum -46 mGal) in the western part are not as positive as those in the eastern part (maximum -33 mGal) and this might be a reflection of the varying thicknesses of the schists in the two areas. It could



• GRAVITY STATIONS

CONTOUR INTERVAL : 2 mGal

Fig. 5.1 Bouguer anomaly map of the Malumfashi Area.

also suggest that the schists in the west are more intruded by granites than those in the east.

The Bouguer anomaly values also show a general plunge to the south where a granitic body is mapped. The contour pattern in the south indicates that the centre of this granitic body is beyong the limits of the survey area to the south.

The contour pattern of the Bouguer anomaly map in general shows that the area is characterized by three distinct Bouguer anomaly trends, NE-SW trend in the eastern part, a general N-S trend in the middle and western part and a general northwesterly trend in the southern part. The different trends, together with available geological information suggest that they are heavily influenced by the local geology of the area.

5.2 The Regional Anomaly Field

The critical phase in the interpretation of gravity anomalies which is also one of the most sensitive sources of error in the final interpretation, is the separation of regional anomalies from the residual anomalies. The regional anomalies are usually of long wavelength, sometimes in the order of 100 km (see for example Ajakaiye, 1976) 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 although several graphical and mathematical methods

have been developed by various authors for the regional-residual separation (Elkins, 1951; Krumbein, 1950; Grant, 1953; Nettleton, 1954; Gupta and Ramani, 1980; etc.). Each method has its advantages and disadvantages. While the graphical methods depend on the judgement of the operator, the mathematical systems depend on assumptions or empirical steps in the mathematical derivation of the numerical factors or coefficients used in the calculations. Once the mathematical coefficients are set up, the whole exercise becomes automatic and this automation is both an advantage and a disadvantage. It is an advantage because it rules out the judgement of the operator and a disadvantage because it lacks flexibility and cannot be adapted to changing situations.

In the graphical method, the choice of regional is very largely empirical. In simple situations such as a rather uniform gradient over a large area, the selection of a regional is not difficult and different operators will make about the same choice. As the regional background becomes complicated, or the difference in magnitude of the regional and residual effects becomes less, the choice become difficult and arbitrary so that different people may arrive at different solutions. An essential aspect for the successful use of the graphical method is therefore a good geological background knowledge although it is what Vajk (1954) terms the "personal factor".

Because the station distribution in this survey was not on a regular grid and also because the lack of accessible roads in some areas resulted in gaps in the data, the traditional graphical method of regional-residual separation has been used. As already indicated earlier, the area is characterized by three distinct trends which are heavily influenced by the local geology and this made the regional determination difficult. It was therefore necessary to use additional information for areas beyond the survey area. In this regard, the Bouguer gravity map of Kano State (Ajakaiye and Verheijen, 1977) which covered the area of the present survey and a much larger area as far east as the Quarternary Sediments of the Chad Basin was very useful. Fig. 5.2 shows the resulting trend with a northwesternly strike which is consistent with trends found in other parts of Nigeria adjacent to or near the present survey area (Ajakaiye, 1976, Cratchley and Jones, 1965; Ajakaiye and Burke, 1973). The average gradient of the trend is + 0.15 mGal/km in the NE direction. This low value suggests that the causative body is of deep origin, possibly an indication of the behaviour of the Moho surface. On this assumption, the increase of the regional anomaly in the NE direction therefore suggests that the crust is thinning in that direction. The regional anomaly showed a total change of 12 mGal in a distance of 80 km. Assuming a density contrast

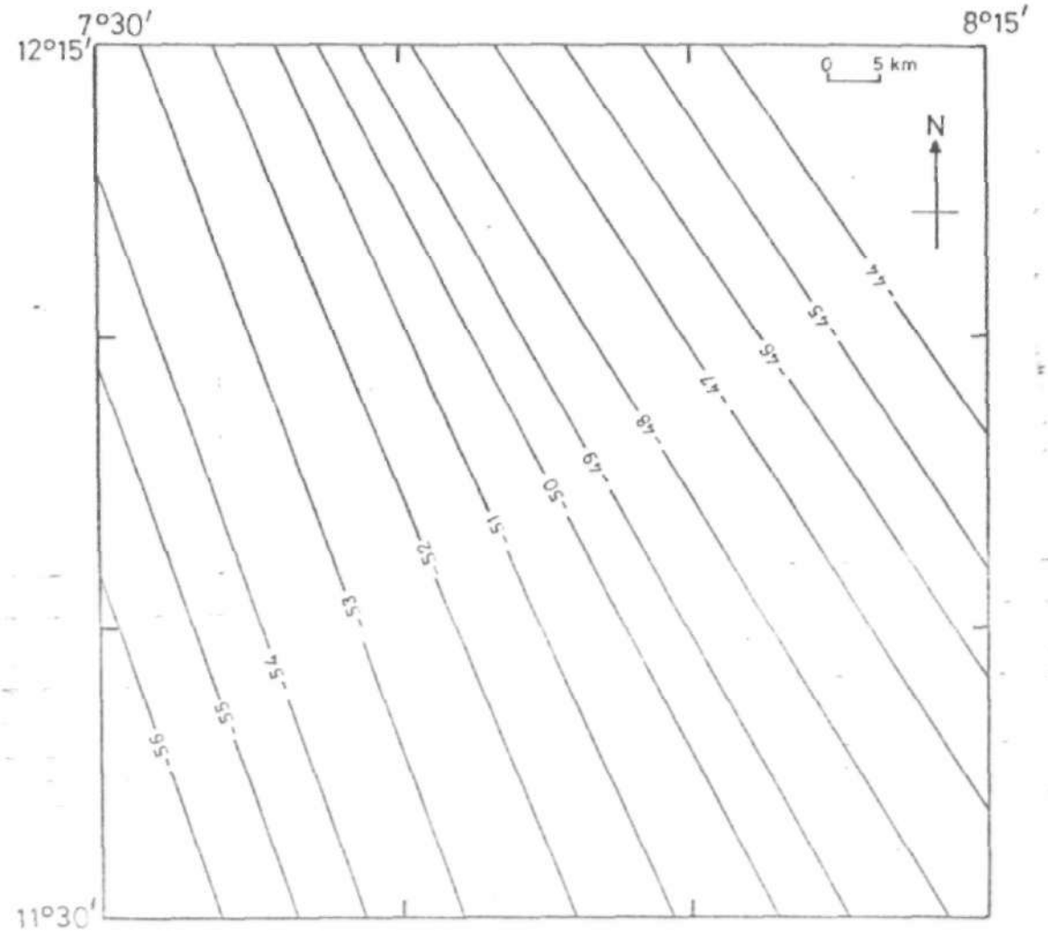


Fig. 5.2 Regional anomaly map of the Malumfashi Area.

of 0.4×10^3 kg.m^{-3} at the crust/mantle boundary and using a two dimensional modelling method, (Nagy, 1964) the maximum estimated thinning is 1.4 km.

5.3 The Free-Air anomalies

The free-air anomalies (Fig. 5.3) are strongly positive and they range from -2 mGal to +26 mGal. The pattern of the contours suggests that the presence of schists in the area may have influenced the free-air anomalies such that high free-air anomalies are found where the Bouguer anomalies are more positive. Studies in Ghana, (Hastings, 1975) where it was shown that there is a substantial increase in the free-air anomalies around the gold-manganese province where the Bouguer anomalies are highly positive, tend to confirm this.

To investigate the relationship between the free-air anomalies and height, a plot of the computed mean free-air anomalies against mean elevation for stations grouped according to their elevation in 10 m interval was made (Fig. 5.4). The relation obtained from the plot gives the free-air anomaly in terms of height H in meters as:

$$\text{Free-air anomaly} = -41 \text{ mGal} + 0.09857 \text{ H}.$$

To obtain the relation between the height H in meters and Bouguer anomalies, a similar plot for the Bouguer anomaly was made (Fig. 5.4). The relation obtained is:

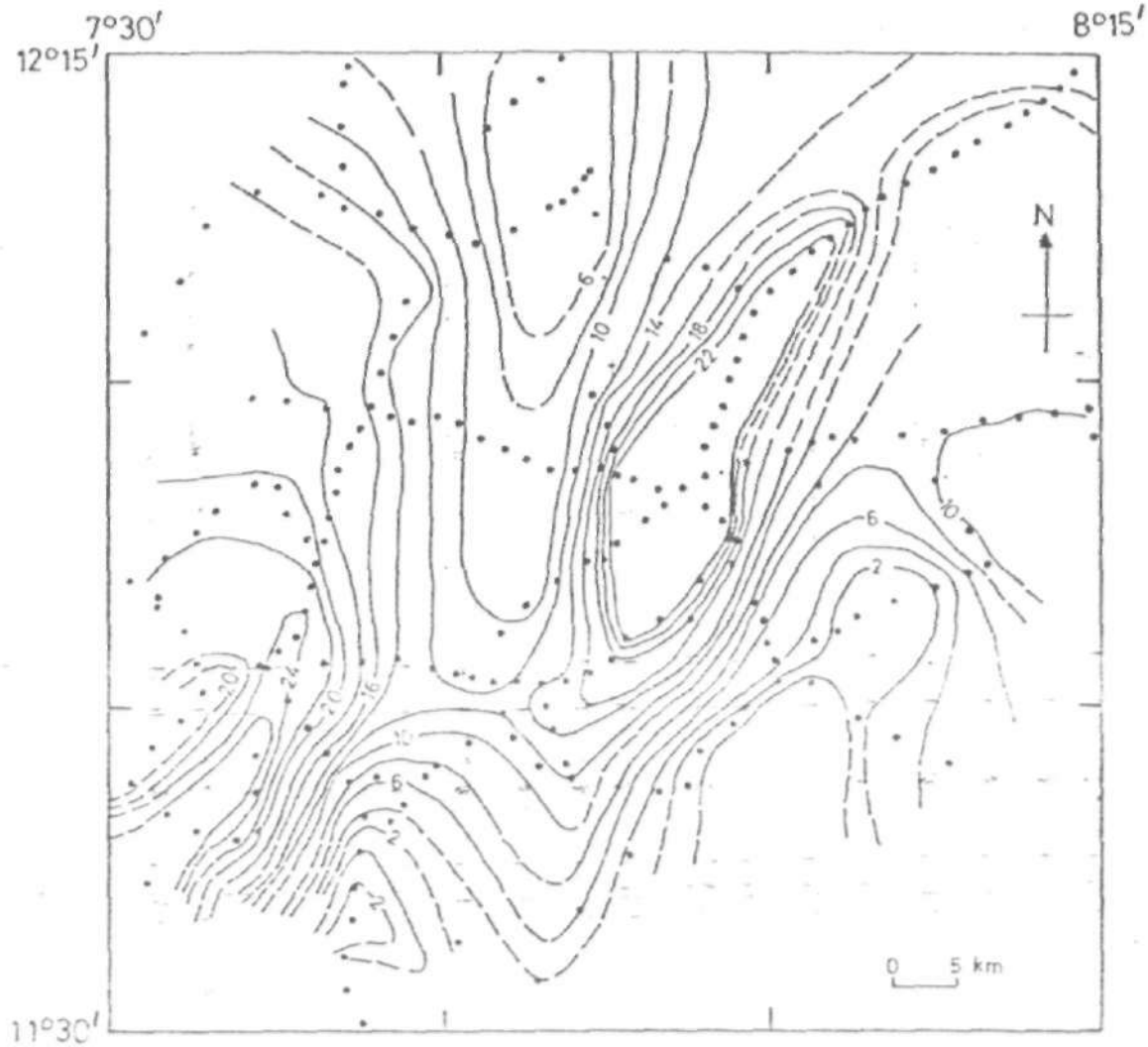


Fig. 5.3 Free-air anomaly map of the Malumfashi Area.

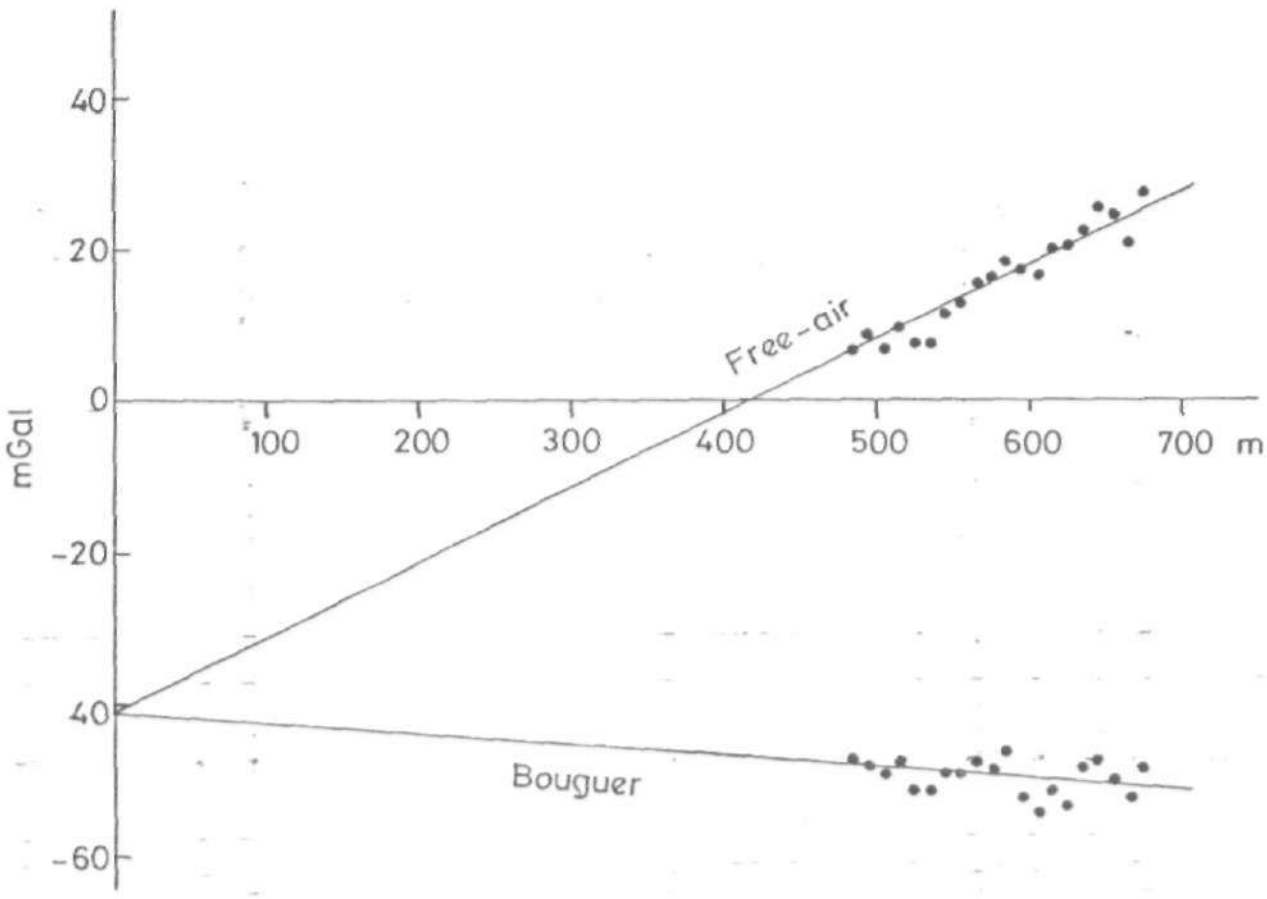


Fig. 5.4 The relation between Bouguer anomaly, Free-air anomaly and Elevation.

Bouguer anomaly = -41 mGal - 0.01429 H.

The relation between Free-air anomaly and height, Bouguer anomaly and height, suggests that the gravity anomaly at sea level (zero height) is -41 mGal. This value compares favourably with the value of -45 mGal obtained by Ajakaiye (1976) after comparing sattelite data (Lundsquist 1967) with her data in the Nigerian Younger Granite Province.

5.4 The Residual Anomalies

The residual anomaly map obtained by the graphical method is shown in Figure 5.5. In order to ascertain the correlation between the residual anomalies and the geology of the area, the residual anomaly map was superimposed on the geological map (Fig. 2.1) and the result is shown in Figure 5.6. As discussed earlier, the geological information of the area is still very sketchy and therefore the correlation shown in Figure 5.6 is only tentative. However, the most prominent features of the residual anomalies appear to correlate fairly well with the known geology of the area. These are the anomalies identified as 1, 2, and 3 in Figure 5.5 and 5.6. Anomaly 1 is positive with maximum amplitude of 12 mGal and is directly located over a mapped body of schist. This body of schist which was not shown in the map of McCurry (1970) was indicated during a remapping exercise by the Geological Survey of Nigeria (GSN) and it is wider in its southern end

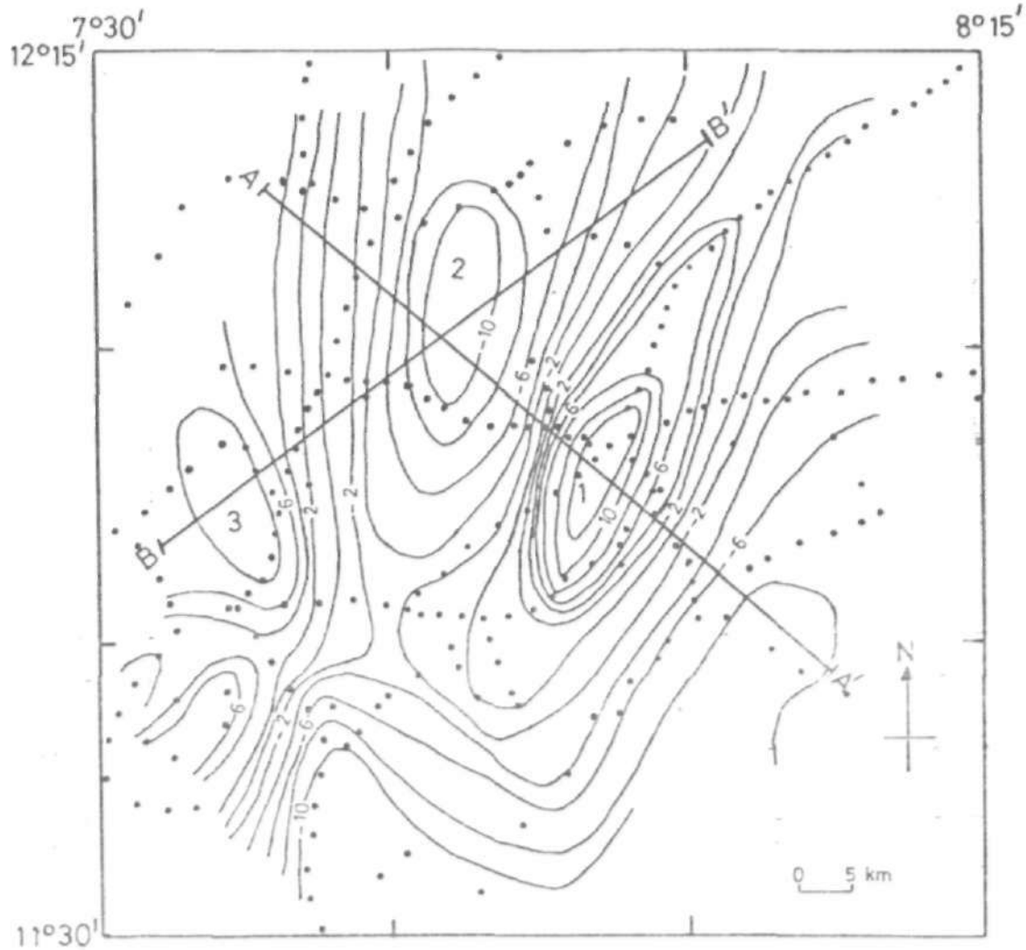


Fig. 5.5 Residual Anomaly Map of the Malumfashi Area

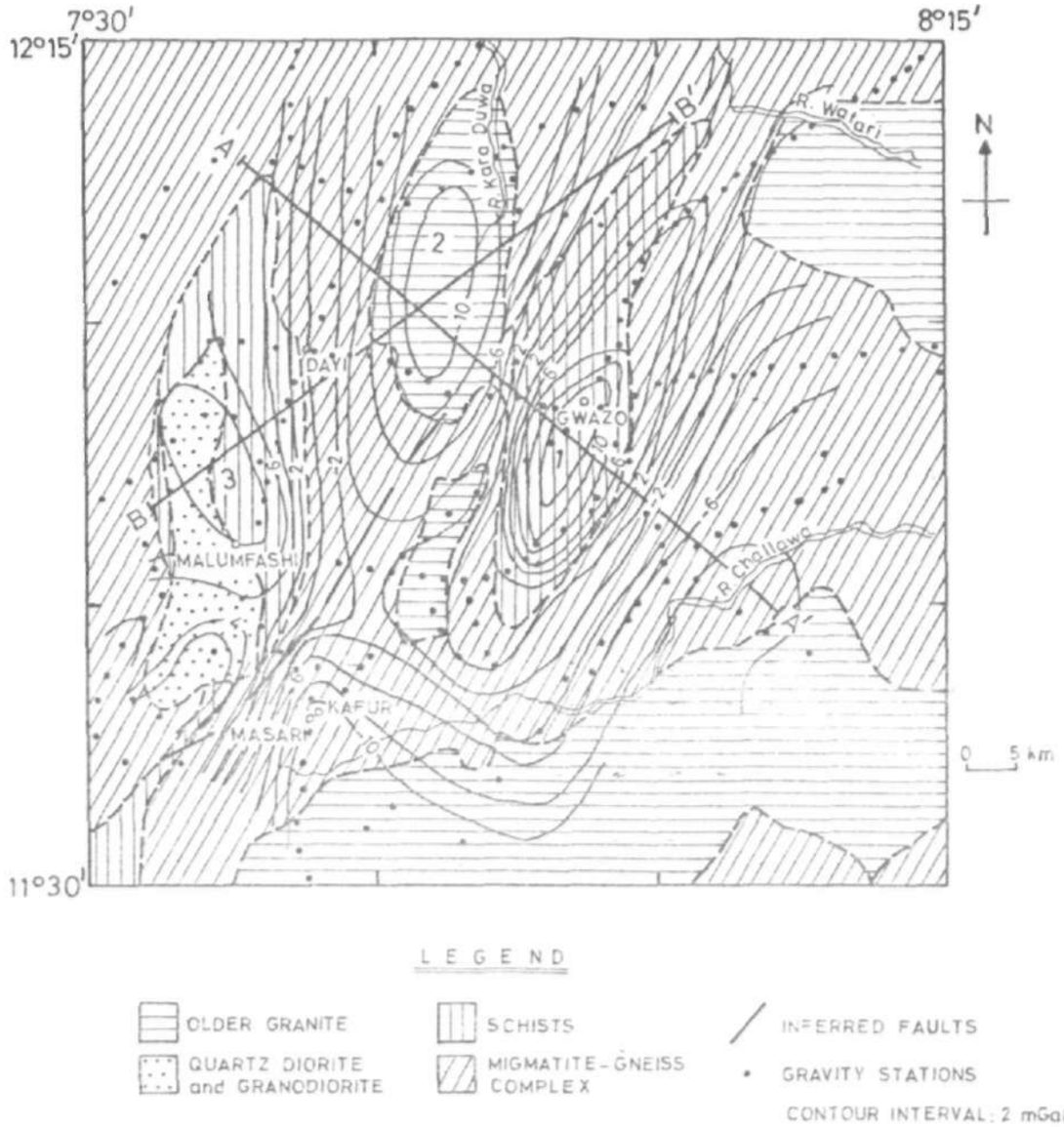


Fig. 5.6 Geological and Residual Anomaly Map of the Malumfashi Area

than in the northern end. Its general strike in the NE-SW direction is parallel to the major transcurrent fault suggested by McCurry (1970).

Another prominent feature of the residual anomaly is the negative anomaly identified as anomaly 2 (Fig. 5.6) which corresponds to the mapped granite body. The shape of the contours for this anomaly suggests that the granite body shown about 5 km south of it may be connected at depth to the mapped granite body indicated as anomaly 2.

The positive anomaly 3 (Fig. 5.6) located in the western section of the area also occurs over a mapped body of schist although the contours indicate that the extent of the body to the west is more than is indicated on the geological map.

5.5 Quantitative Interpretation of the Residual Anomalies

As the available geological information show that the bodies in the area are elongated with a width to length ratio of about 1:5 (Fig. 2.1), and the principal anomalies on the residual map are distinctly elongated, it was felt that a 2-D interpretation would be adequate in fitting models that would account for the residual anomalies. The method used was that described by Nagy (1964) using the polygon approximation method of determining the gravitational attraction over a cross section of a polygonal body which extends infinitely in a direction perpendicular to the cross section.

To minimise errors in the residual anomaly values to be used in the interpretation, the residuals for the interpretation were obtained by taking profiles from the Bouguer anomaly map (Fig. 5.1), fitting regional curves graphically and substracting the regionals from the observed Bouguer anomaly values along the profiles. Profile A-A' (Fig. 5.1) was chosen so as to pass through the centres of the anomalies identified as 1 and 2. Apparently, the positive anomaly (1) along this profile appears to be flanked by another negative anomaly in the southeast direction. This negative anomaly is assumed to be due to a granite body at depth and is most likely a continuation (due to lateral spreading) of the large granite body which is indicated south of the area (Fig. 2.1).

Several models using various widths and depth estimates of the granitic bodies and the schist bodies were considered. Comparing the computed anomalies with the observed, figures 5.7a and b show two possible models which could account for the residual anomalies along the profile. A brief discussion of the models is given below:

McCurry (1970) suggested that the granite bodies in the area may be divided into two groups according to their contact relationship with the surrounding rocks. The first of these groups are the more nearly concordant batholithic sheets in the southeastern part of the area which are exposed nearer their root zones.

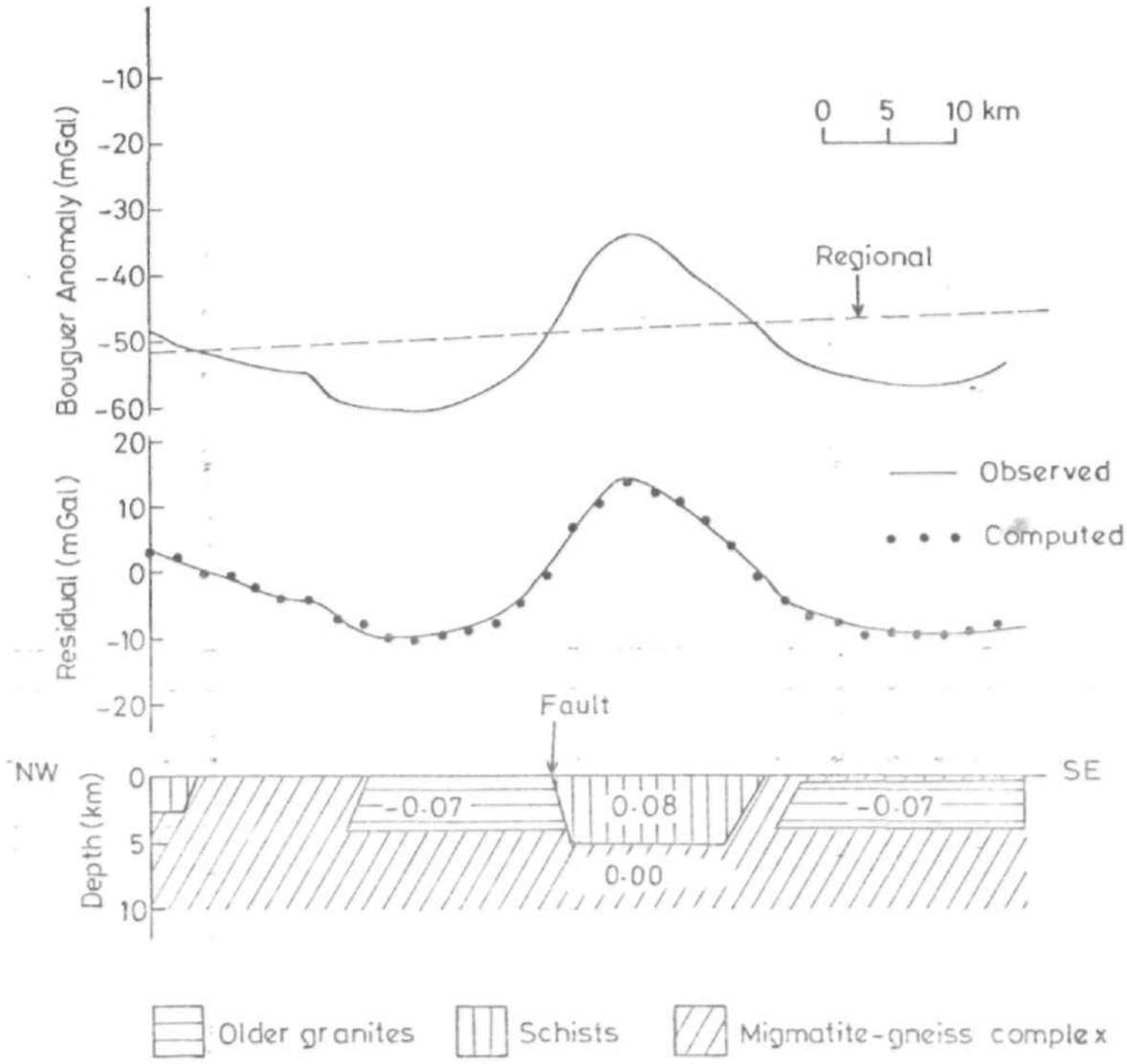


Fig. 5·7a 2-D Model of Profile A-A'

Model II

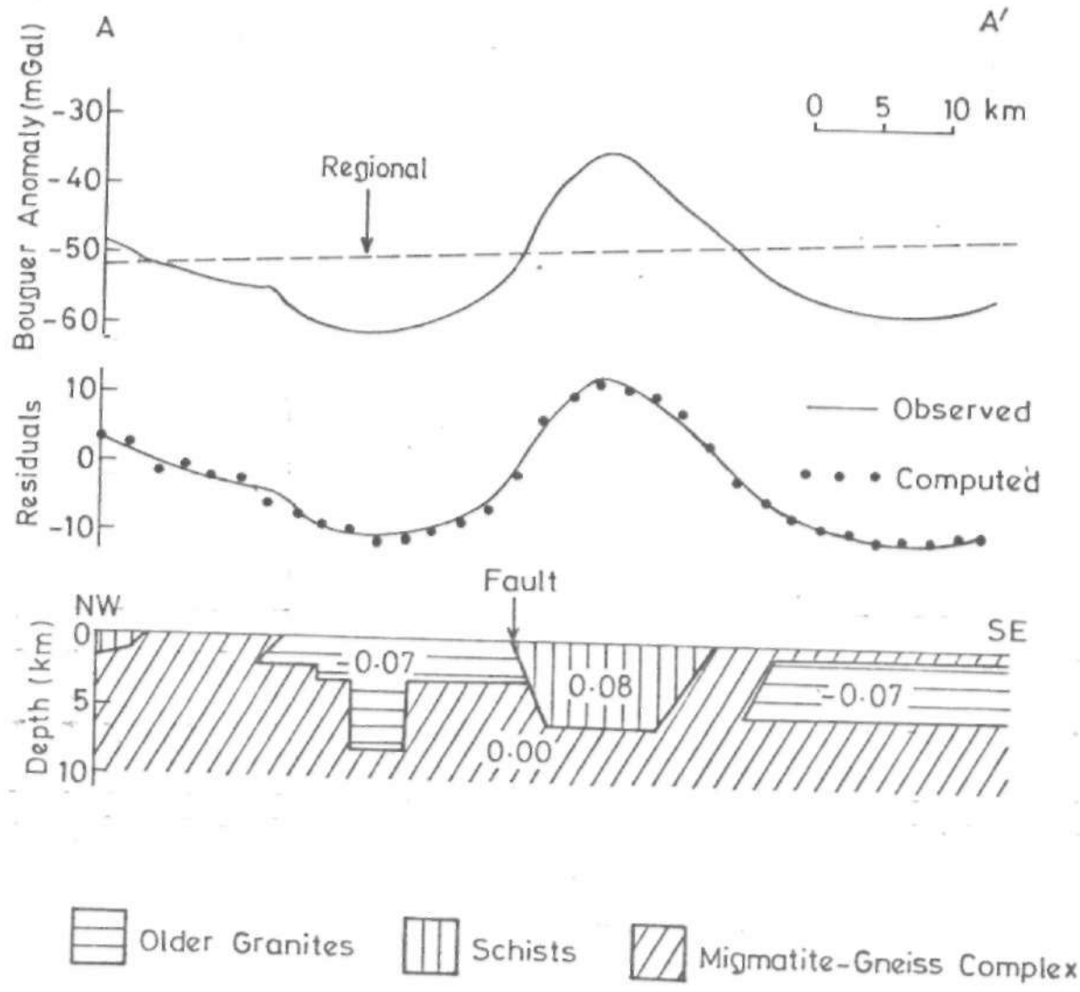


Fig. 5.7b 2-D Model of Profile A-A'

The granites in this group are also believed to be syn-tectonic (McCurry, 1970).

The second group she suggested are the discordant granites in the northern part which are often associated with contact metamorphism and are believed to have a late-tectonic origin. The granites in this group are today exposed at their roof zones (McCurry, 1970). On the basis of these groupings, the possible models are shown in Figure 5.7 a (Model I) for the first group and a model for the second group is shown in Figure 5.6 b(Model II). It is to be noted, however, that only the granite body indicated as anomaly 2 (Fig. 5.1) is affected by these possible groupings since the geological map (Fig. 2.1) indicates that it is an isolated body. The presence of the granite body in the southeast of this profile is, as earlier suggested, believed to be due to the lateral spreading of the granitic material of the large granite body in the south of the area.

Model I

This model (Fig. 5.7 a) assumes outcropping of the granite (anomaly 2, Fig. 5.1) at its root zones, the roof zones having been removed through the process of erosion. The depth extent of the granites in this model is 4 km while the depth extent of the schist reaches a maximum of 5 km.

Model II

This model (Fig. 5.7b) assumes outcropping of the granite body (anomaly 2, Fig. 5.1) at its roof zone hence the assumed presence of a plug in the modelled granite body. The model suggests that the granitic material may have risen through weak zones of the country rock for about 5-6 km before spreading to its present width possibly due to changes in the temperature and pressure conditions near the surface. The maximum depth extent of the granites and schists in the area are 8 km and 6 km respectively. However, an assumption of uniform density contrast with depth has been made in fitting the models and it is unlikely that up to a depth of 8 km this assumption is still valid. This model, (Model II) is therefore considered unlikely. Model I is therefore thought to be the more likely model.

In this model (Fig. 5.7a) the schist body (anomaly 1 Fig. 5.1) extends to a depth of 5 km and dips 83° and 60° on its NW and SE flanks respectively. The granite body (anomaly 2, Fig. 5.1) in contact with the schist body has an almost vertical contact (also dips 83°) while its dip on its other flank is 70°.

It should be noted that while profile A-A' is approximately perpendicular to the strike of anomaly 1, it is less so for the second anomaly (2). The width of anomaly 2 should therefore be adjusted by a factor equal to the cosine of the angle between the profile and the direction which would have been the direction perpendicular to its strike. This angle is about 40°

meaning that probable cross sectional width of the body can be obtained by multiplying the width shown in Figure 5.7a by 0.77.

To get a better picture of the relationship between the structures in the area, another profile (B - B', Fig. 5.1) was chosen. This profile passes through the centres of anomalies 2 and 3, and the two possible models are shown in Figures 5.8a (Model III) and Figure 5.8b(Model IV). Since profile A-A'and B-B' have anomaly 2 as a common body, models III and IV correspond to models I and II respectively. Here again model IV is thought to be an unlikely model along profile B-B'for the same reasons given for rejecting model II along profile A-A'. Model III is therefore accepted for the purpose of subsequent discussion.

In this model (Fig. 5.8a) the schist body in the western part of the area (anomaly 3) has a maximum depth of 3 km. The model again shows the granite body (anomaly 2) extending to a depth of 4 km. The direction of the profile is at an angle of about 38° to the dominant strike of these anomalies. Probable cross sectional widths may therefore be obtained by multiplying widths in Figure 5.8a by 0.79.

The gradients of the Bouguer and residual anomalies of up to 6 mGal/km at the boundary between anomalies 1 and 2 (Fig. 5.1 and 5.6) as well as dips of 83° of the schist and the granite body at the contact areas all point to the possibility of faulting in this region.. The sharp contacts of the granites with

MODEL III

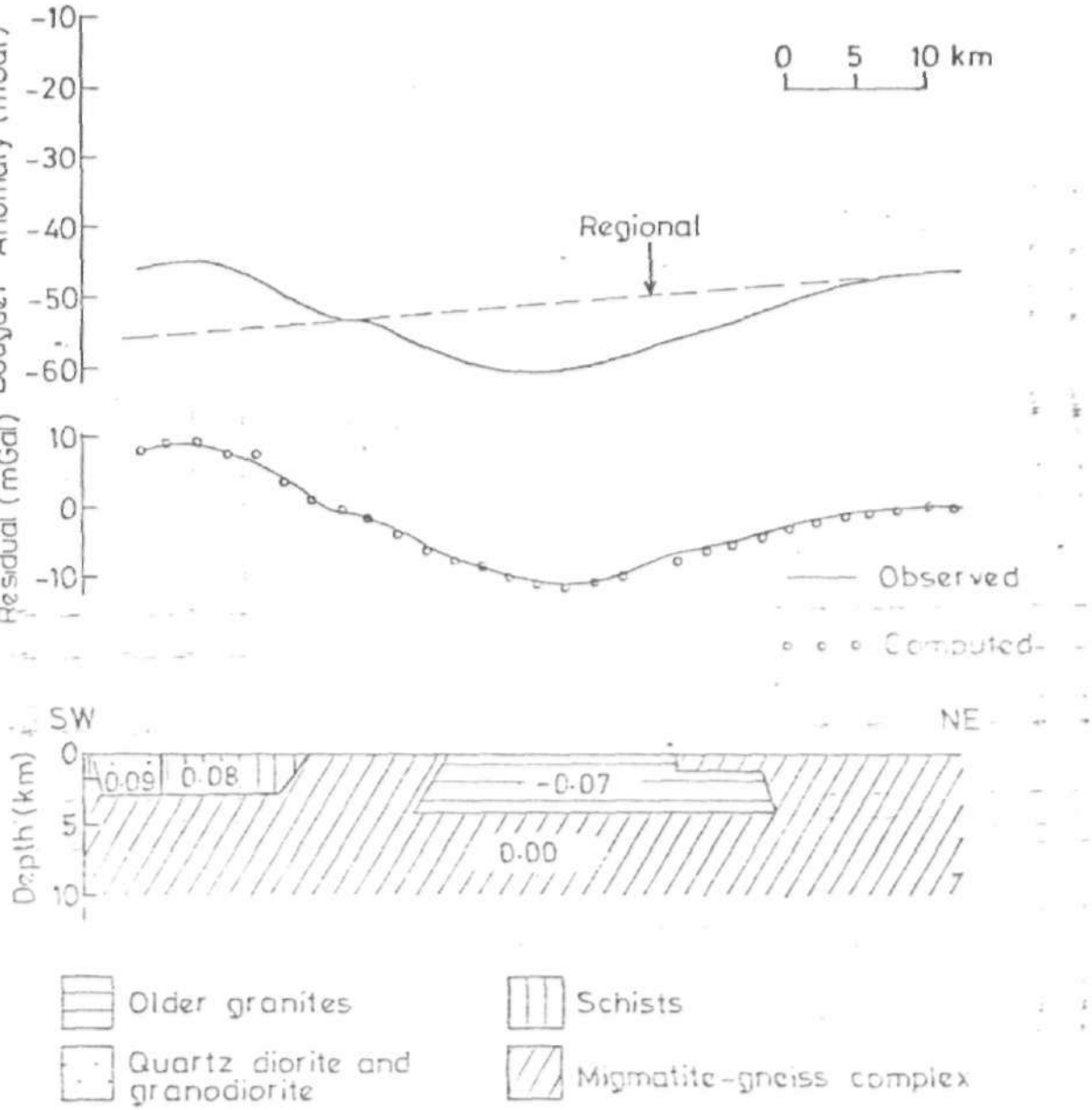


Fig. 5·8a 2-D Model of Profile B-B'

Model IV

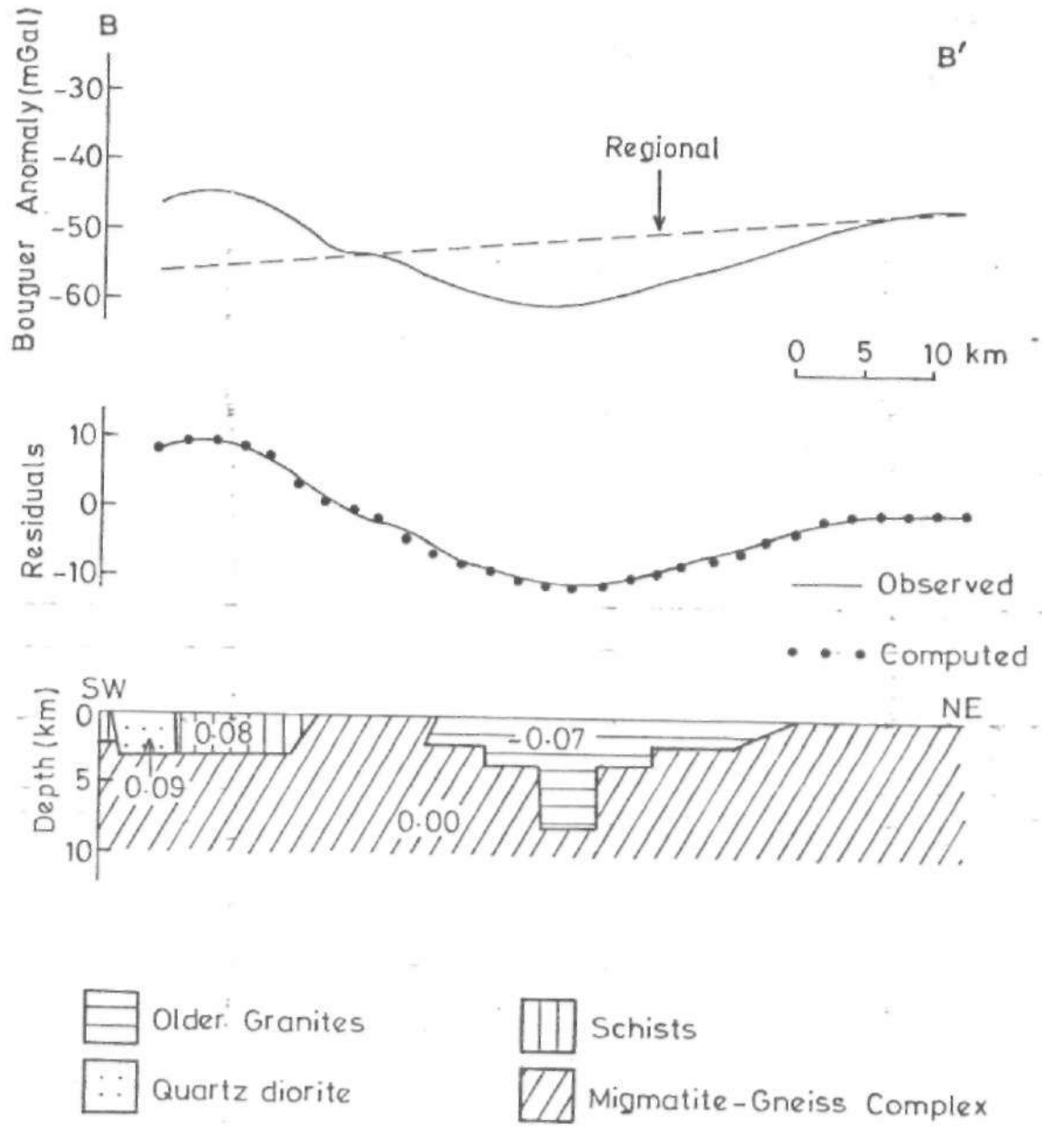
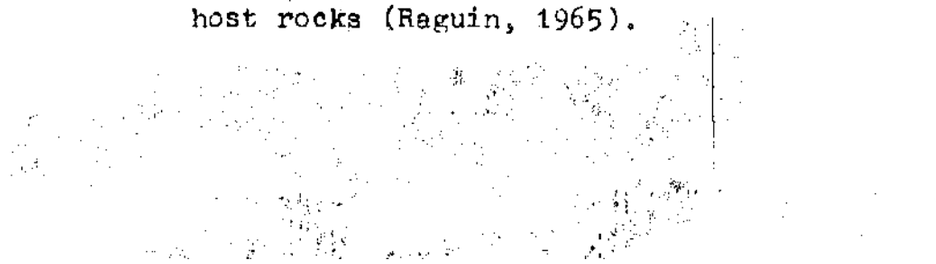


Fig. 5.8b 2-D Model of Profile B-B'

other surrounding rocks also suggest that magmatic stopping is the most likely mode of emplacement of the granites. The granitic material must then have been drawn out and localized through weak zones of the host rocks (Raguin, 1965).



CHAPTER VI

CONCLUSION

6.1 General Discussions

6.1.1 The Schists

The schist belts of northwestern Nigeria are considered to be a once continuous sedimentary cover on the migmatite gneiss complex (Russ, 1957; McCurry, 1976). However, Grant, (1978), Holt et al (1978); Ajibade, (1980) have described different belts which have contrasted lithology and concluded that the belts were probably not deposited in the same basin. Grant (1978) also suggested that the belts might be of two different ages, Kibaran (1100 m.y.) and Pan African (600 m.y.).

The schist belts were believed to be restricted to the western part of the country, west of longitude 7°30' E (Russ 1957; Oyawoye, 1972). However, recent work (Turner, 1983; Geological Survey of Nigeria, work in progress) have reported the occurence of schists east of this longitude. The present gravity survey confirms the occurence of schists in the Gwarzo area (Fig. 2.1) although the rock is poorly exposed.

Since the evolution of the idea of plate tectonics, geologists in Nigeria have interpreted the schist belts as either ensialic, which involves deposition on continental crust (Ajibade, 1980; Turner 1983) or ensimatic which involves deposition on oceanic crust

(McCurry, 1976). McCurry, (1976) considers that the schist belts were formed as a result of the opening and closing of an ocean comparable to the Red Sea. Other geologists however, (e.g. Wright, 1979 and unpublished data) propose a compromise between an entirely ensialic and an entirely ensimatic processes for the schists. He considers that the zone in the Anka belt where serpentinite bodies and calc-alkaline volcanics occur could be taken to be evidence for an ancient subduction zone, but considers the other Nigerian schist belts to represent former ensialic basins.

The occurences of ophiolites, calc-alkaline volcanics, high pressure metamorphism and island arcs, is the geological evidence for ensimatic processes (Ajibade, 1980). As these rock types are absent in the Malumfashi Area, the geological evidence thus suggests that the schists in the area were formed through ensialic processes.

The present gravity survey does not show the existence of deep seated mafic material or any anomalous gravity highs that are usually associated with plate boundaries. It is pertinent to state here that the Pan African belt east of the West African Craton is now considered to have evolved by ensimatic processes (Burke and Dewey, 1972). Gravity survey across the eastern margin of the craton have shown the existence of a string of positive gravity anomalies with amplitudes over 30 mGal, locally reaching 80 mGal for over 2000 km.

(Caby et al, 1981). Since such high positive anomalies were not observed in this survey, it is concluded that the gravity evidence confirms that the schist belts in the Malumfashi Area evolved in an ensialic environment.

6.1.2 The Older Granites

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

Through chemical analysis and examinaton of petrological features, Russ (1957) considers the Older Granites of the Nigerian Basement Complex to belong to a single magmatic epoch. Rahaman, (1976) on account of the mode of occurence of charnockites in the Ibadan area, and Ajibade (1980) on the basis of field relations in the Zungeru Region, suggested a magmatic origin for the Older Granites. However, Oyawoye (1964) suggested that most of the large masses of granites and quartz monzonite in the complex originated through potash metasomatism. Grant (1978) also believes that the Older Granites originated through a metasomatic process on the basis of geochronological evidence.

Typical gravity gradients across granites of supposedly magmatic origin in other parts of the world have been found to be in the order of 1.9 mGal/km (Bott, 1953). Gravity gradients across the granite bodies in this survey were found to vary from about 1.2 mGal/km to about 6 mGal/km indicating that contacts with the surrounding rocks are sharp. These sharp contacts indicate that magmatic stopping is the most likely mode of emplacement. The geological evidence in support of this view include the presence of contact metamorphism of the country rock (Russ, 1957; Ajibade, 1980), the presence of rotated xenoliths in the granites which suggests movement of the granitic material (Webb, 1972).

6.2 Summary of Results and Conclusions

(i) The Malumfashi Area is characterized by large negative Bouguer anomalies ranging from -33 mGal to -65 mGal. It is also characterized by three distinct N-S, NE-SW, and NW-SE trends which appear to correlate with those of the major structures in the area. A regional gradient of 0.15 mGal/km in the NE direction is interpreted as being due to a thinning of the crust in that direction. The maximum thinning in a distance of 80 km was estimated at 1.4 km.

(ii) The mean Free-air and mean Bouguer anomalies are +15 mGal and -51 mGal respectively and extrapolated

sea level gravity value in the area is about -41 mGal. For a complete isostatic compensation of an area, the mean sea level value should approximate to zero. A value of -41 mGal therefore either shows that the area is not isostatically compensated or that the data is not large enough for a valid conclusion to be reached in this regards.

(iii) The results of the density determination of the major rock groups in the area show that the host rocks (migmatites and gneisses) have an average density of 2.70×10^3 kg.m^{-3}, the schists have and average density of 2.78×10^3 kg.m^{-3} while the Older Granites have a relatively low density of 2.63×10^3 kg.m^{-3}. These results thus confirm the acidic nature (low density) of the older Granites in the Malumfashi Area.

(iv) The area is also characterized by a negative residual anomaly in the centre, flanked by two positive residual anomalies to the west and east. The central negative residual anomaly is caused by a mapped granitic body while the positive residual anomalies are caused by outcropping bodies of schists. Depth estimates obtained from a two-dimensional modelling was 4 km for the granites while for the schists in the West and East sections of the area, the depths were 3 and 5 km respectively.

(v) A steep Bouguer anomaly gradient in some contact areas between the central negative anomaly and the eastern positive anomaly indicates sharp contact which may be faulted. Dips obtained at the contact area from two-dimensional modelling are an outward dip of 83° for the granite and inward dip of 83° for the schist body. Bouguer anomaly pattern over the whole area however, does not show that such faulting, if present, is as extensive over the area as indicated by McCurry (1970).

(vi) A magmatic origin for the granites is suggested on the basis of the gravity gradients across the granite bodies. The gravity data also suggests that the schists in the area evolved in an ensialic environment.

6.3 Recommendations

Due to the limited nature of this survey, the problem of evolution of the Nigerian Schist Belts and the origin of the Older Granites of the basement complex, cannot be finally resolved now. It is therefore recommended that more geophysical work needs to be done not only in the Malumfashi Area but in the Nigerian Basement complex in general. This is needed so as to obtain more information which would throw more light to the origin and mode of emplacement of the Older Granites and the processes of evolution of the schist belts.

Detailed density information is an essential aspect of the interpretation of gravity data, it is therefore recommended that more density data be collected both in the area and the basement complex in general.

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