

A GRAVITY SURVEY OF THE IGNEOUS INTRUSIONS
IN THE RANO AREA OF KANO STATE, NIGERIA

BY

OLADOSU, Michael Olanrewaju B.Sc.(Hons) UNILAG

Thesis submitted to the Postgraduate School,
Ahmadu Bello University, in partial fulfillment
of the requirements for the award of the degree
of MASTER OF SCIENCE IN APPLIED GEOPHYSICS

Department of Physics
Faculty of Science
Ahmadu Bello University
Zaria, Nigeria.

October, 1987

DEDICATION

To the memory of my late father, Mr. M.F. Oladosu, my mother, Mrs. A.F. Oladosu, and to all those who despite the vicissitudes of life still remain steadfast in their abiding faith in the Lord.

DECLARATION

This is an original work carried out by the author under the supervisions of Dr. S.B. Ojo and Dr. I.B. Osazuwa. To the best of my knowledge, no part thereof has been submitted elsewhere for the award of a degree or diploma, and the work of others is acknowledged and referenced.

M. O. OLADOSU
Author
A.B.U., Zaria
October, 1987

CERTIFICATION

This thesis entitled "A Gravity Survey of the Igneous Intrusions in the Rano Area of Kano State, Nigeria" by M.O. Oladosu meets the regulation governing the award of the degree of M.Sc. Applied Geophysics of Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.



Name and Signature
Dr. S.B. Ojo
Chairman, Supervisory Committee

Date: 2/12/87



Name and Signature
Dr. I.B. Osazuwa
Member, Supervisory Committee

Date: 7/12/87



Name and Signature
Dr. J. Adetunji
Head of Department

Date: 16-12-87

Name and Signature
Prof. D.I. Saror
Dean, Postgraduate School

Date:

ACKNOWLEDGEMENT

Not by might nor by power but by my spirit says the Lord. Therefore, I am grateful to the Almighty God for helping me thus far during my two years stay in Ahmadu Bello University, Zaria.

I am greatly indebted to my supervisor, Dr. S.B. Ojo and Dr. I.B. Osazuwa who co-supervised this work. They did not only supervise this work to its logical conclusion, but were also concerned about my welfare as well. Their encouragements in the course of this work are all highly appreciated.

The author sincerely expresses his gratitude to Dr. J. Adetunji, Head, Department of Physics for his assistance particularly in my appointment as a part-time demonstrator in the department. Many thanks are also due to all academic and non academic members of staff in the department, particularly Mr. M.N. Umego, Dr. C.O. Ajayi and Mrs. A.I. Ojo for their encouragements. I must say a very big thank you to Messrs Jubril and Lawal for their cooperation and their tremendous assistance in spite of the Harmattan and language barrier during the field trip. I sincerely appreciate the encouragement of Rev. (Dr.) J.A. Ilori, Head, Department of Christian Religious studies of this University.

May the blessing of the Lord feed the following friends and relations who came over to Macedonia to donate generously in time of need: Mrs. V. Ogunwumi, and Messrs E.O. Amosu, B.A. Ereola, S.O. Ajani, S.I. Adeosun, O. Ogunwumi,

and a host of others whose name the author cannot remember now. To all these people, I say a very big thank you and may the good Lord continue to keep watch over you. I am equally grateful to my brothers who deserve more gratitude than I can express here.

The author thanks Mr. P. Oluyide and Mr. O.M. Akinyosoye of the Geological Surveys of Nigeria, Kaduna, for access to the unpublished preliminary geological reports. In the same vein, I sincerely thank Mr. M. Woakes in the Geology Department of this University for the rock samples identification and for many discussions.

Finally, may the Father's boundless love and the Holy Spirit favour be with all those whom it has pleased the Lord to use for my assistance in anyway.

ABSTRACT

Gravity measurements carried out in the Rano area of Kano State show that the area is characterised by large negative Bouguer anomalies ranging from -38 mGal to -68 mGal. A regional anomaly ranging from about -60 mGal in the south-eastern part to about -48 mGal in the northwestern part of the area is tentatively correlated with gradual thinning of the crust from southeast to the northwest, away from the Jurassic Younger Granite Province and the Jos Plateau.

Negative residual anomalies in the area with amplitudes ranging from -4 mGal to -6 mGal correlate well with granite bodies thus confirming the acidic (low density) nature of the Older Granites. A prominent positive residual anomaly with an amplitude of about 20 mGal is correlated with a basic igneous intrusion in the eastern part of the area. The western half of the area also shows two positive residual anomalies uncorrelated with the surface geology, but also ascribed to sub-surface basic intrusions.

From three dimensional modelling using approximate density contrasts, it has been estimated that the granite bodies extend to depths ranging from about 3 km to 4 km, and that the basic igneous intrusions extend to depths in the range of 5 km and 6 km.

TABLE OF CONTENTS

	PAGE
DEDICATION	i
DECLARATION	ii
CERTIFICATION	iii
ACKNOWLEDGEMENT	iv
ABSTRACT	vi
TABLE OF CONTENTS	vii
LIST OF TABLES	x
LIST OF FIGURES	xi
ABBREVIATIONS	xii
CHAPTER 1 - INTRODUCTION	1
1.1 Aims and Scope of the Survey	1
1.2 Previous Work in the Project Area	2
1.3 General Description of the Project Area	2
1.3.1 Location of the Project Area	2
1.3.2 Geography and Geomorphology of the Project Area	2
CHAPTER 2 - GEOLOGY OF THE STUDY AREA	5
2.1 General Geology	5
2.2 The Geological Map of the Study Area	7
2.3 Rock Types in the Study Area	10
2.4 Structures in the Study Area	12
2.4.1 Major Structures	13
2.4.2 Minor Structures	14
2.5 The Economic Geology of the Study Area	15
CHAPTER 3 - THE GRAVITY SURVEY	17
3.1 Instrumentation	17

3.1.1	The Gravimeter	17
3.1.2	The Altimeter	19
3.2	The Fieldwork	19
3.2.1	The Gravity Stations	22
3.2.2	Transportation Method Used	22
3.2.3	Data Coverage	24
3.2.4	Height Measurements	24
3.2.5	Field Problems Encountered	25
CHAPTER 4 - DATA REDUCTION AND DENSITY DETERMINATION		27
4.1	Data Reduction	27
4.2	Sources of Errors in the Bouguer Anomalies	30
4.2.1	Random Errors	30
4.2.2	Systematic Errors	33
4.3	Density Determination and Analysis	34
4.3.1	Sampling Technique	35
4.3.2	Method of Density Determination	35
4.3.3	Density Analysis	36
4.3.4	Densities Accepted for Interpretation.	36
CHAPTER 5 - DESCRIPTION AND INTERPRETATION OF THE BOUGUER AND RESIDUAL ANOMALIES		40
5.1	The Bouguer Anomaly	40
5.2	The Regional Gravity	42
5.2.1	Method Used in Removing Regional Anomaly	42
5.2.2	Regional Removal in the Present Survey	44
5.3	The Residual Anomaly and its correlation with Surface Geology	45
5.4	Quantitative Interpretation of the Residual Anomaly	49
5.4.1	Three dimensional Interpretation of the Major Residuals	51

5.4.2	Summary of Models	62
CHAPTER 6 - CONCLUSION		65
6.1	Summary of Results and Discussion.....	65
6.2	Recommendations	68
REFERENCES		69

LIST OF TABLES

TABLE	PAGE
2.1 Generalized Chronological Sequence of the various rock types in the Nigerian Base- ment Complex	8
4.1 Densities of rock types	37

LIST OF FIGURES

Figure No	Title	Page
1.1	Simplified geological map of Nigeria showing the survey area in box	3
2.1	Preliminary geological map of the survey area	9
3.1	Gravimeter Drift Curve	18
3.2a&b	Altimeters Drift Curve	20
3.3	Gravity Base Station Network	23
4.1	Combined Density Histogram	38
5.1	Bouguer anomaly map of the Rano area	41
5.2	Regional anomaly map of the Rano area	46
5.3	Residual anomaly map of the Rano area	47
5.4	Geological and Residual anomaly map of the Rano area	48
5.5a	Body contours and depths along Profile A-A'	52
5.5b	Three dimensional Model of residual Profile A-A'	53
5.6a	Alternative body contours and depths along Profile A-A'	54
5.6b	Alternative three dimensional model of residual Profile A-A'	55
5.7a	Body contours and depths along Profile B-B'	58
5.7b	Three dimensional model of residual Profile B-B'	59
5.8a	Alternative body contours and depths along Profiles B-B' and C-C'.	60
5.8b	Alternative three dimensional model of residual Profile B-B'	61
5.8c	Three dimensional model of residual Profile C-C'.	63
5.9	Body depth contours of models superimposed on the simplified geological map.	64

ABBREVIATION

m.....	meter
km	kilometer
N	North
S	South
NE	northeast
NW	northwest
SE	southeast
SW	southwest
NS	northsouth
NNE	north-northeast
NNW	north-northwest
kg	kilogram
GSN	Geological Survey of Nigeria
m.y.	million years
LCR	LaCoste and Romberg
IGSN	International Gravity Station Network

CHAPTER 1

INTRODUCTION

1.1 Aims and Scope of the Survey

The aim of this work is to serve as a detailed follow up survey to the Kano State regional gravity survey carried out in 1973 and 1974 by Ajakaiye and Verheijen (1977). That survey had suggested the presence of a residual positive anomaly uncorrelated with the predominantly granitic terrain. This work is also a continuation of a series of gravity studies on the granites of northern Nigeria started in 1983 (see Gandu *et al*, 1986; Udensi *et al*, 1986; and Adeniyi, 1987).

The gravity method which involves the measurement of variations in the gravitational field of the earth has been chosen for this work because, as a natural source method, like the magnetic method, it is based on the principle that 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. Also, the gravity method lends itself as one of the cheapest methods for investigations of this nature.

Finally, it was hoped that, apart from serving as a follow up study, this survey would provide more sub-surface information on the geology of the area.

1.2 Previous Work in the Project Area

At the time of writing this thesis, there was no record of any published work in the area. However, as mentioned in section 1.1 above, the most important geophysical work in the area as it affects this work is the Kano State regional gravity survey. Also, no detail geological map of the area has been published at the time of this report as the geological mapping of the area was still in progress by the Geological Surveys of Nigeria (GSN), Kaduna.

1.3 General Description of the Project Area

1.3.1 Location of the Project Area

Rano is one of the Kano State Local Government Headquarters. As shown in Figure 1.1, it is one of the native towns in the Northern (Hausa) Highlands south of Kano. The project area is bounded between latitudes $11^{\circ}6'N$ and $11^{\circ}54'N$, and longitudes $8^{\circ}24'E$ and $8^{\circ}54'E$ covering an area of about 3,200 square kilometers (km^2).

1.3.2 Geography and Geomorphology of the Project Area

The project area is sparsely populated with concentration of people being found in major towns. The main occupation of the inhabitants is farming and cattle rearing. The former is mainly done by the Hausas who form the majority and the latter is dominantly carried out by the nomadic Fulanis. Apart from streams and river banks which

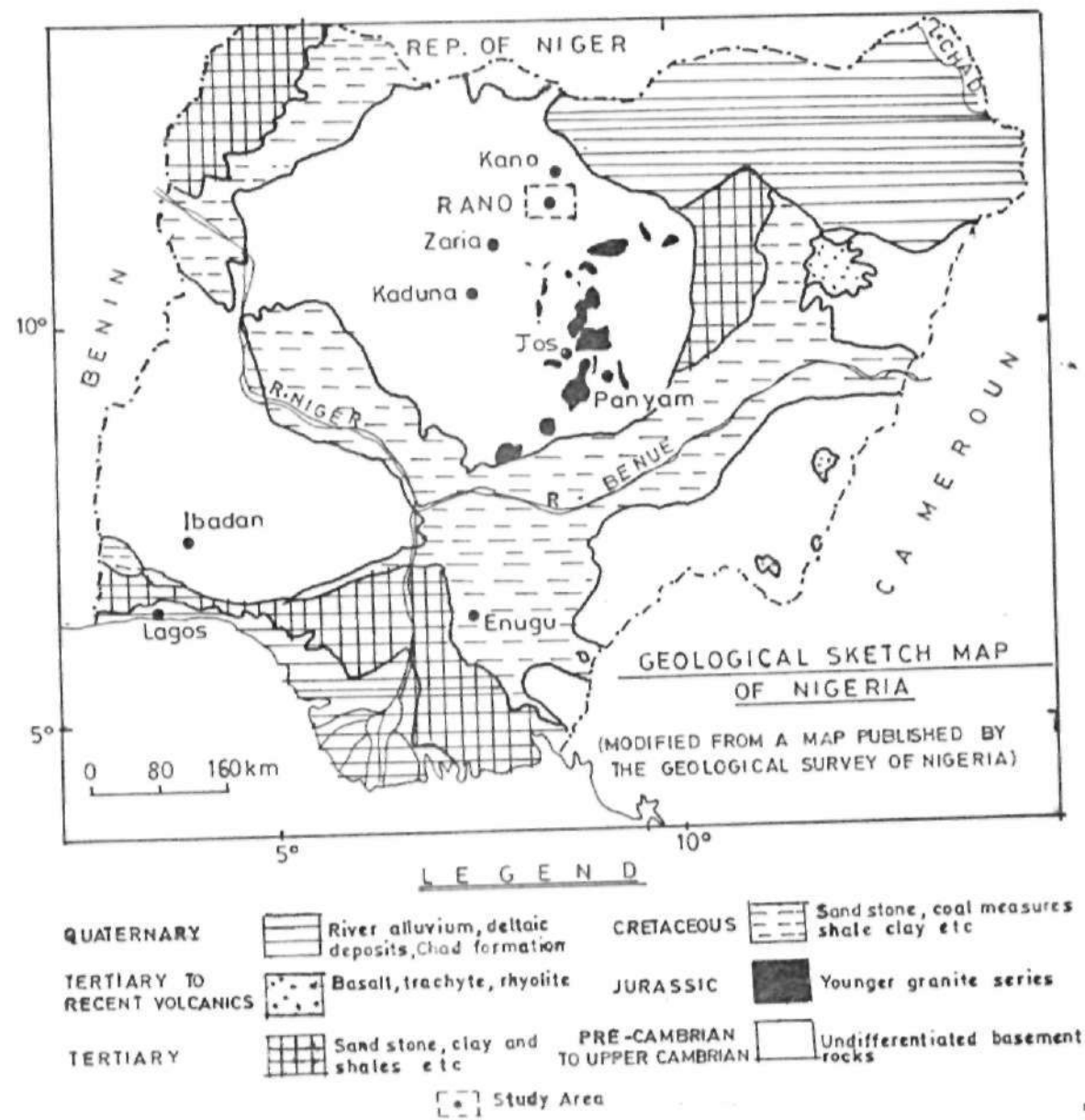


FIG.1.1 SIMPLIFIED GEOLOGICAL MAP OF NIGERIA SHOWING THE STUDY AREA

are fairly densely vegetated, the whole area is covered by savanah. The northwest quadrangle of the area is gradually becoming an agriculturally developed area as a result of the Chalawa and Tiga Dams project. This is evidenced by the large farming projects around the dams in the area such as the Kadawa irrigation scheme on the road to Kano.

The project area is drained mainly by rivers Kano and Chalawa with their surfaces along spurs of the uplands forming dendritic pattern with the main rivers. Most of the rivers are structurally controlled and forced to thus flow along the direction of strikes of fractures and joints.

The whole area is generally of low topography with few granite inselbergs. The climate is characterised by the dry and wet seasons. The dry season lasts for about 8 months and the wet season about 4 months; September - April and from May - August respectively. Annual rainfall is between 50 cm and 100 cm.

CHAPTER 2

GEOLOGY OF THE STUDY AREA

2.1 General Geology

The project area is part of the Nigerian Basement complex of Precambrian and early Paleozoic age. The superficial deposits overlying the basement complex are believed to be products of Pleistocene accumulation cycles (Wright and McCurry, 1970).

As shown in Fig. 1.1, the basement complex is exposed over nearly half of Nigeria. It also extends in the west into the Dahomeyan of Benin Republic and the east into the Cameroun. In the remaining half of the country, Cretaceous and younger sediments cover the basement complex. The earliest study of the complex was made by Falconer (1911) who recognised the age distinction between the Precambrian Older Granites and the Jurassic Younger Granites of the Jos Plateau. Though, the basement is believed to be mostly of Precambrian age, it probably contains a number of intrusions of Paleozoic age (Oyawoye, 1964). The present terrain represents former level at considerable depth in the earth which has now been exposed through erosion over several million years (m.y.). The rocks have been involved in multiple folding, fracturing and igneous activities.

The rocks of the Nigerian Basement complex can be grouped into three lithological units (Jones and Hockney, 1964; Oyawoye, 1964; Ajibade, 1980).

(i) The Migmatite-Gneiss complex which constitute about 70% of the whole basement complex and consists essentially of migmatites, quartzo-feldspathic-biotite-hornblende gneisses with relict metasedimentary rocks. It is considered to be the oldest unit in the complex and probably evolved by sedimentation followed by successive migmatisation, granitization and igneous intrusions (Russ, 1957).

(ii) The Younger Metasediments and Metavolcanics which form the Schist belts and are mainly in the western half of the country. They consist of low grade metamorphosed sedimentary rocks with associated rocks. All the metasediments have been isoclinally folded. Their age is believed to be between 1000 m.y. and 800 m.y. (McCurry, 1976). The metasediments are thought to have once covered the whole basement area and having been removed by subsequent erosion, remnants are now preserved in synclinal troughs (McCurry, 1976). They are deposited in a presumed geosynclinal basin. Russ (1957) suggested that the sediments were deposited in moderately deep water following the formation of the older gneisses.

(iii) The Older Granites are bodies of igneous rocks of various compositions, ranging from true granites to tonalites and charnockitic rocks which intrude the migmatite-gneiss complex and schist belts. They occur as elongated batholiths or small circular plutons. Age determinations of the Older Granites all over Nigeria have yielded Pan African ages (600 $\pm$ 100 m.y) (Van Breeman *et al*, 1977; Grant, 1978). The generalised chronological sequence of the various rock

types found in the Nigerian Basement complex is shown in Table 2.1.

2.2 The Geological Map of the Study Area

The preliminary geological report covers quarter degree sheets 80, 81, 103 and 104 which constitute the Rano degree sheet. It covers an area of about 9920 km² and is bounded by latitudes 11°N and 12°N, and longitudes 8°E and 9°E respectively. Figure 2.1 represents part of the preliminary geological map undertaken by the Geological Survey of Nigeria (GSN), Kaduna.

The migmatite-gneiss complex which includes the banded gneiss, migmatitic-granite-gneiss and porphyritic gneiss are found in the sheet area. Older Granites are made up of coarse porphyritic-biotite-granite, fine-medium grained biotite muscovite-granite, pegmatites and quartz veins (GSN, unpublished geological report). Tertiary to recent rocks are mainly laterites, sand and alluvial deposits along the river banks.

The granites are believed to be Paleozoic in age and to have been emplaced in the waning phase of the Pan African orogeny. Two groups based on Eskola's classification of 1932, were recognized by earlier workers in the basement (Russ, 1957; Truswell and Cope, 1963; Jones and Hockney, 1964) namely the syntectonic and late tectonic.

The syntectonic granites are concordant textured slightly foliated and have gradational contacts with the

Table 2.1: GENERALISED CHRONOLOGICAL SEQUENCE OF
VARIOUS ROCK TYPES IN THE NIGERIAN
BASEMENT COMPLEX

Period	Rock Unit	Rock type
467-618 m.y. Late PreCambrian- Lower Paleozoic.	Older Granites	Pegmatites, grano- diorites, granites.
About 650-850 m.y. Pan-African	Metasediments	Schists, gneisses, quartzites, mylonites, crushed breccia, diorites.
About 2000 m.y.- Birrimian	Metasediments	Feldspathic quartzites, sillimanite gneiss, basic and calcareous rocks.
>2000 m.y.- Dahomeyan	Crystalline Complex	Gneisses, Migmatites.

(After Grant et al., 1969)

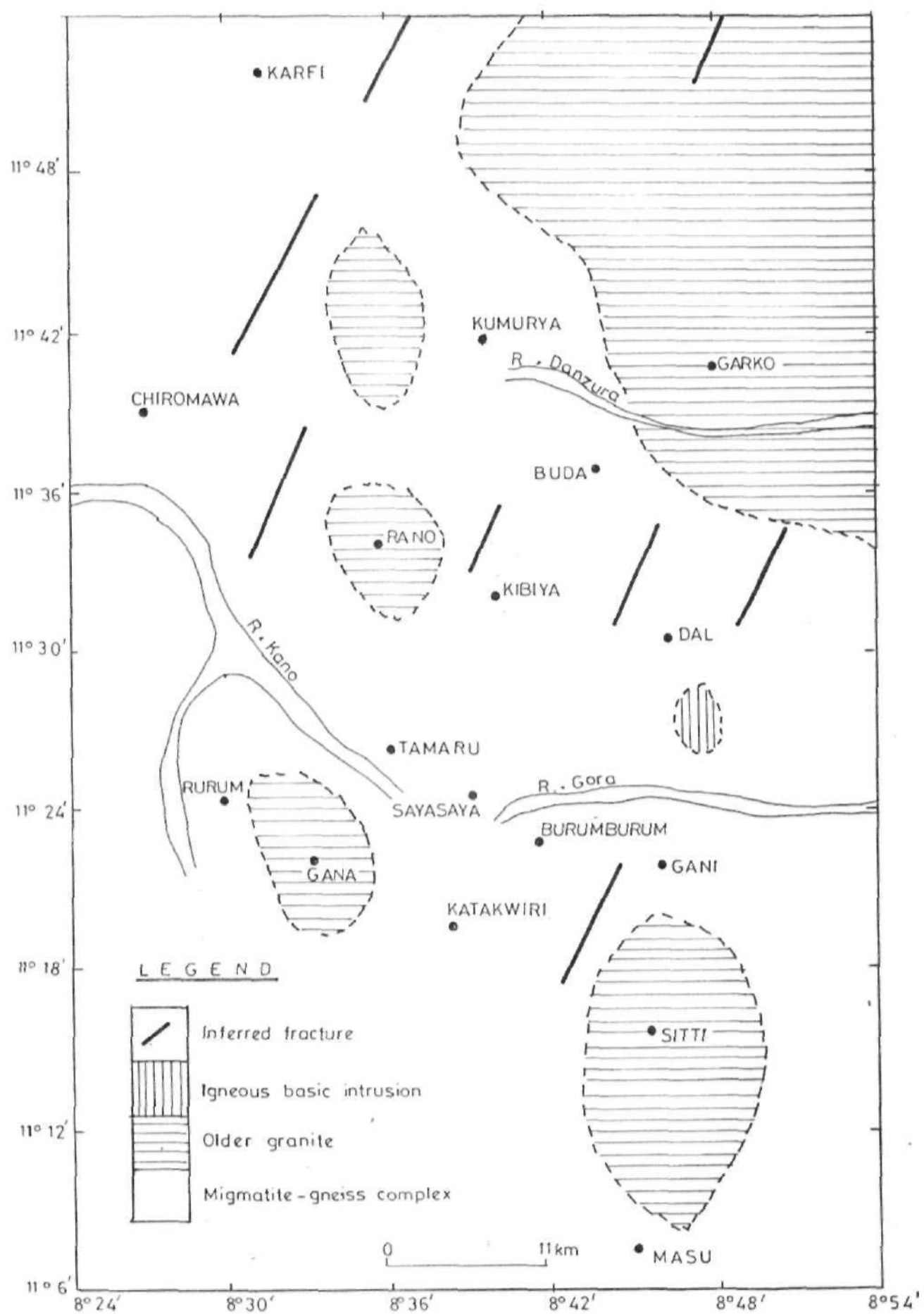


FIG. 2.1: SIMPLIFIED GEOLOGICAL MAP OF THE SURVEY AREA
(After GSN, Kaduna)

country rocks. These are believed to be metasomatic in origin having presumably been produced by selective granitisation of the pre-existing rocks probably gneisses and schists (McCurry, 1976).

Among field evidence that supports a metasomatic origin is the fact that the granites are very coarse grained and their contacts with migmatites are gradational where they occur together. The migmatites are often deeply weathered and are found associated with the porphyroblastic granites at Gani, Rano, Garko and Sitti (GSN, unpublished geological report).

The late tectonic granites are non-foliated and are usually fine to medium grained. These include the coarse porphyritic biotite and hornblende granites and the fine to medium grained biotite and muscovite granites.

2.3 Rock Types in the Study Area

Granites

The granites occur in 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. Some of the granites exhibit some flow structures and contain rotated xenoliths indicating some movement of granitic material (Webb, 1972). The main minerals of the granites are quartz, orthoclase, perthites, some sodic plagioclase while the mafic minerals are biotite and hornblende (M. Woakes, 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 dark bands, the main feldspars appear to be plagioclase while biotite and hornblende are in greater quantity than the felsic minerals (M. Woakes pers. comm.).

Gneisses

The gneisses vary from equiangular 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 (M. Woakes pers. comm.).

Basic Intrusives

These rock types are not very prominent as outcrops in the area probably because they are poorly exposed. One of the variety of this basic rock type-diorite is a granular rock characterised by plagioclase feldspar oligoclase composition but lacking quartz and K-feldspar in appreciable amount. Hornblende is the principal mafic mineral but biotite is usually present with magnetite, ilmenite and

apatite are common accessory minerals (GSN, unpublished geological report).

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 occurring as prominent 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 movement (GSN, unpublished geological report).

2.4 Structures in the Study Area

The general structural trend in the area is approximately northsouth. Within the granite, foliation and linear parallelism of elongated xenoliths or in some areas, oriented biotite flake trending along the length of the rock outcrop are common (GSN, unpublished geological report). The foliation is vertical or is always steep but does not alter its direction near the margin of the gneiss. Lineation in the gneisses involves a penetrative alignment of crystals of quartz and micaceous minerals (O.M. Akinyosoye, pers. comm.).

2.4.1 Major Structures

Joints

These are widespread in the granites. Three dominant directions could be observed and these are mainly vertical (O.M. Akinyosoye, pers. comm.). The major joints trend N-S and are parallel to the general foliation while others are approximately 120° and 045° . Random joints that could not be reconciled with any of the major sets also exist in the area (GSN, unpublished geological report). The numerous joints criss-cross in large outcrops breaking them up into boulders, some of which are columnar while others are delicately balanced on these pillars. Physical weathering of the porphyritic biotite granites typically result in horizontal structures and characteristic ex-foliations. The rocks are broken up into sheets which may be carried away from their places of origin by the force of gravity with water acting as lubricant between the sheets and the parent rock, thus leaving the outcrop smooth-topped (GSN, unpublished geological report).

Faults

No major faults in the area were observable but small faults occur extensively in the migmatites. They are commonly associated with minor folds and evidence of slight displacement of a few centimeters could be observed (O.M. Akinyosoye, pers. comm.). It is speculated that the sharp bends in the Chalawa river channel may have been fault controlled.

Fractures

The migmatites and Older Granites are highly fractured. The fractures are conspicuous in aerial photographs and trend in a NNE direction with the exception of a few running NNW (GSN, unpublished report). They tend to control the stream directions and are thus characterised by linear alluvial plains on the ground.

2.4.2 Minor Structures

Lineation

This is represented by a preferred orientation of feldspar porphyroblasts and elongated aggregates of biotite in some of the granites generally oriented in a N-S direction (O.M. Akinyosoye, pers. comm.)

Minor Folds

A lot of minor folds are observable in pegmatites which cut the porphyritic granites. These folds are usually tightly isoclinal with their axes generally parallel to the regional foliation. Some minor folds with plunges as low as 8° and fold axes running parallel to the regional strike could be observed (GSN, unpublished geological report).

Minor Faults

Small faults with few centimeters sinistral displacements could be observed in the area (O.M. Akinyosoye, pers. comm.).

2.5 The Economic Geology of the Study Area

The following represent the economic geology in the Rano area as reported by the GSN in an unpublished geological report.

Feldspar

Well-formed large pegmatite bodies are observable in the area. They show well developed crystals of feldspar and quartz that can be separated.

Quartz

Large outcrops of milky quartz could be found at different locations in the area. They occur as ridges of about 0.5 km to 1.5 km long and 0.1 km to 0.3 km wide.

Ceramic Materials

Clay is a major constituent of young alluvial material in the area but generally of poor quality as the percentage of impurities is too high to be of any economic use. Kaolinitic clay is available from deeply weathered granites and is being used by the local inhabitants for making pots.

Laterite and Building Materials

Laterite was originally being used as a source of iron ore. This practice has however been discontinued because the iron content in these laterites is too low for

industrial consideration. Laterites is now being used for road surfacing by the Rano Local Government Authority. Superficial deposits such as loam and weathered basement rocks have been dug and made into bricks for building. This explains the numerous pits occurring both within and outside most of the villages. Quarries found within the area are being modernised. The medium to fine grained granites are more useful for road construction than the porphyritic biotite variety. Quartz is also quarried wherever it occurs as a distinct body.

CHAPTER 3

THE GRAVITY SURVEY

3.1 Instrumentation

3.1.1 The Gravimeter

A LaCoste and Romberg (LCR) gravimeter model G468 belonging to the Federal Surveys of Nigeria was used for obtaining the gravity data. The gravimeter is a modified long period vertical seismograph originally designed by LaCoste in 1934 (Dobrin, 1976; Telford *et al*, 1976). The model which was used during the field work has a high reading precision of ± 0.01 mGal with a total range of over 7000 mGal which is far in excess of 376.716 mGal range so far found in Nigeria (Osazuwa, 1985, Osazuwa and Ajakaiye, 1986).

Since the reliability of the gravimeter can be measured by its drift characteristics, readings of the instrument were taken for two days in the laboratory at one hour intervals from 0600 hours to 1800 hours local time. The times of observation were chosen to be representative of those in which the actual fieldwork would be carried out. Figure 3.1 shows the diurnal base station drift curves of the gravimeter before and after the fieldwork. Tidal effect was not estimated for lack of tidal table at the time of compilation of this report, however, its amplitude which is usually not more than 0.3 mGal (Dobrin, 1976) can be almost completely corrected for by the field procedure used for the elimination of drift.

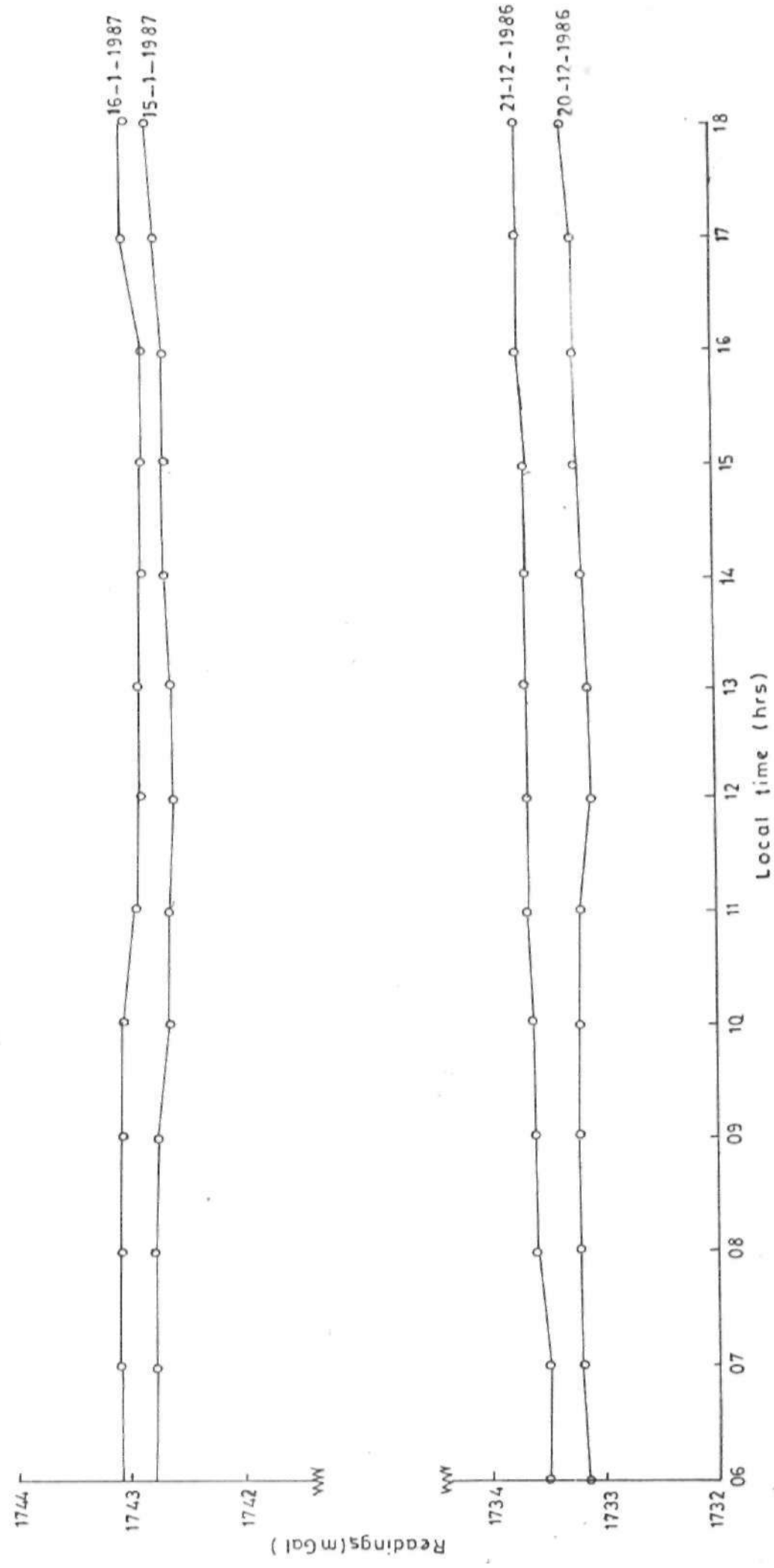


FIG. 3.1 GRAVIMETER DRIFT CURVE

3.1.2 The Altimeter

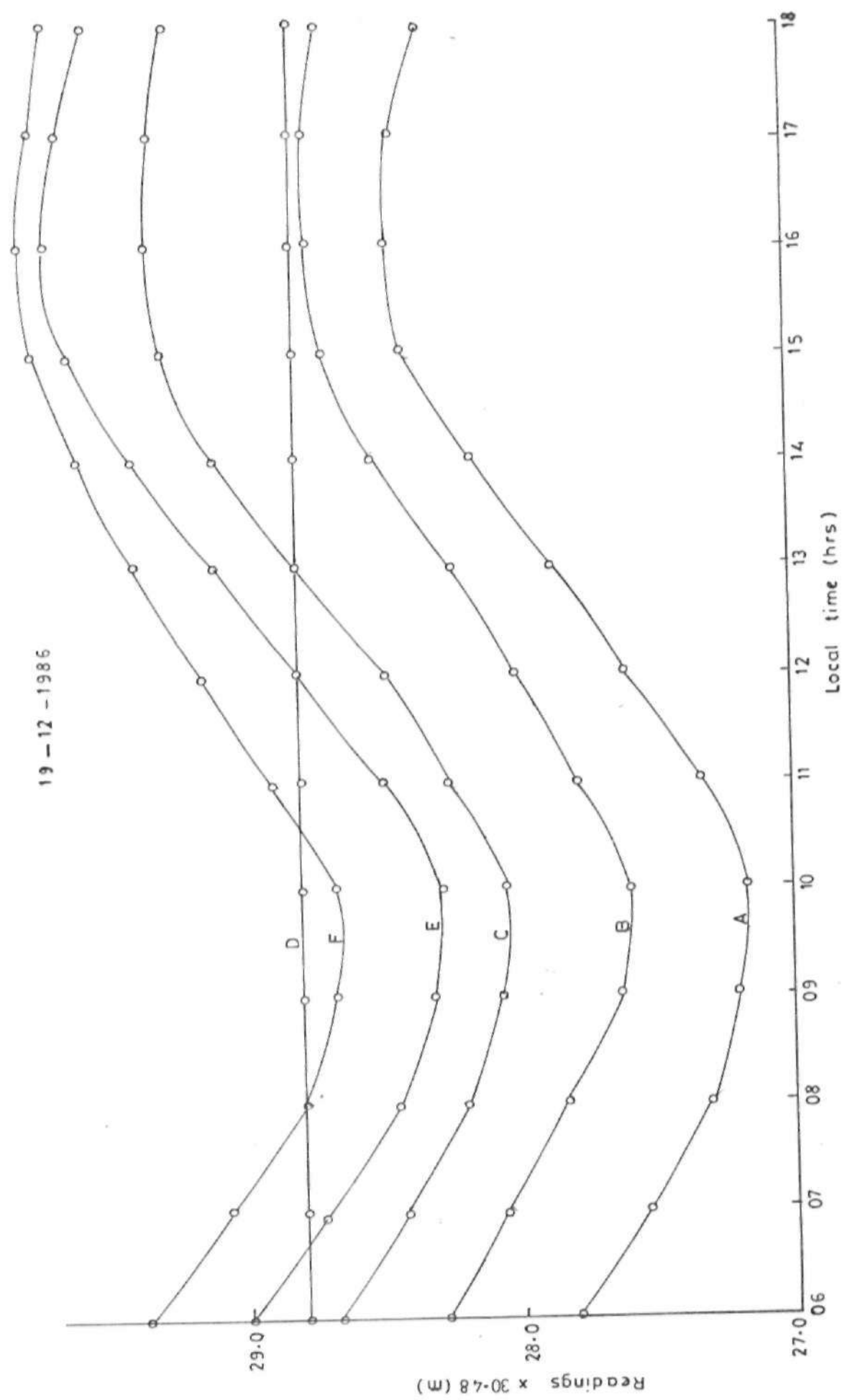
Six Wallace and Tiernan altimeters model FA181 were observed along with the gravimeter out of which two were used for height determination during the survey. The resulting typical drift curves for each altimeter for the two days of observations are shown in Figure 3.2 (a,b).

Apart from the altimeter labelled 'D' which was completely bad from its flat response, the apparent linear drift rate for each of the altimeters was found to occur between 0600 hours and 0900 hours. The values were -7.112 m/hr, -6.909 m/hr, -6.096 m/hr, -6.502 m/hr, and -6.096 m/hr for altimeters labelled 'A', 'B', 'C', 'E' and 'F' respectively. Between 1100 hours and 1500 hours, the altimeters also drifted "linearly" at the rate of 6.553 m/hr, 6.687 m/hr, 6.058 m/hr, 6.042 m/hr and 6.025 m/hr respectively. In the region between 1700 hours and beyond, no analysis was done because there are no sufficient data.

Based on the above analysis, height measurements were restricted to those regions where "linear" drift may be assumed to hold, that is from 0600-0900 hrs, 1100-1500 hours, and 1700-1800 hours respectively.

3.2 The Field Work

The fieldwork was carried out during the harmattan period of December and January. The raw data collection took almost three weeks and data were collected seven days a



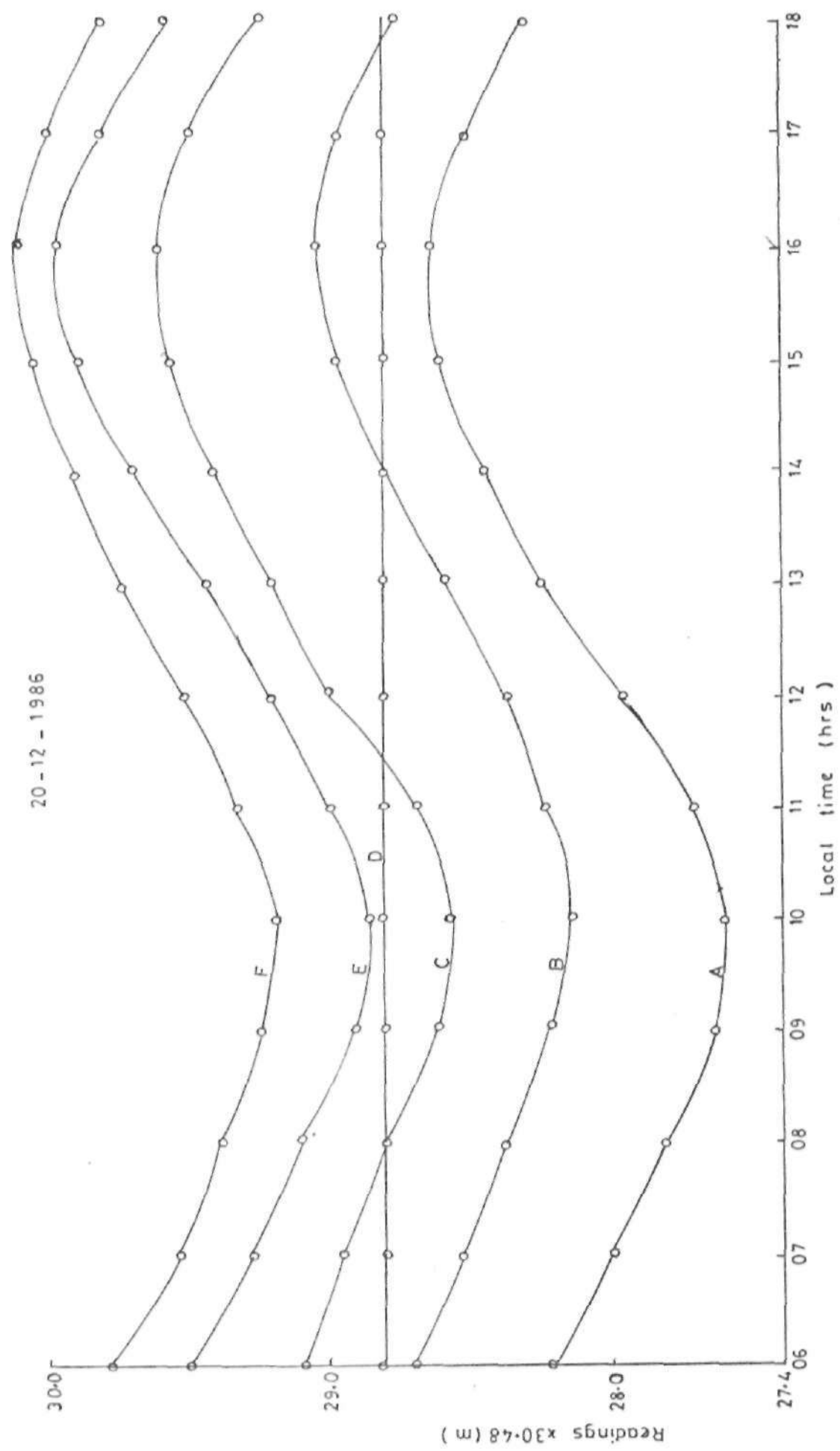


FIG. 3-2b, ALTIMETERS DRIFT CURVE

week for about ten to twelve hours a day. The instruments were always shielded from the direct sun rays by means of a large umbrella in order to protect them from direct sunlight.

3.2.1 The Gravity Stations

The leapfrog method of observation

(Nettleton, 1940) was adopted during the survey. During the survey, twenty-four base stations were established at approximately ten kilometers interval. Some base stations were established at easily locatable landmarks such as school compounds and village dispensaries. Figure 3.3 shows the resulting network made up of four closed loops. A total of two hundred and sixty-three detailed stations were occupied during the survey. Establishing the detailed stations involved collecting data at between one or two kilometers interval on motorable roads and tracks where possible in the area.

3.2.2 Transportation Method Used

The field crew, gravimeter and other instruments were transported by a motor vehicle. Because of the difficult terrain usually encountered on tertiary roads and tracks in the area, a requisite criterion of the motor vehicle was its good shock-absorber. Another criterion of the vehicle considered vital was its possessing a trip odometer in kilometers and tenths of a kilometer to ensure accurate spacings of the detail stations.

3.2.3 Data Coverage

Bearing in mind the aims of the survey, the survey was designed to cover the project area adequately in order to reveal both local and regional anomalies of interests. Ideally, such a survey should be on a regular (uniform) grid. This was however not possible because such an exercise would not only have been time consuming, the cost involved would also have been prohibitive. The latter factor would have been largely due to labour cost in cutting the traverses for the grids and levelling the grid points. Readings were therefore taken mainly at one kilometer interval along available roads in the area.

3.2.4 Height Measurements

Only one gravity base station was established on a benchmark. This was due to the extensive road reconstruction going on on most of the roads in the Rano area. Some roads were originally benchmarked but the benchmark had been removed by the road contractors. For example, by December 1986 to January 1987 when this work was done, the Karfi-Rano Road had no benchmarks. Also, Rano-Rurum-Tundun Wada road which was originally benchmarked had no benchmark because of road reconstruction.

For these reasons, the heights of the gravity stations were determined by means of Wallace and Tiernan altimeters referred to in section 3.1.2. The altimeters were treated exactly in the same way as the gravimeter. That is, the

altimeter readings were taken along with that of the gravimeter at both the base and detail stations. Whenever the readings of the altimeters were taken, the readings of a whirling wet and dry thermometer were also taken to determine the humidity correction factor for the altimeter readings.

3.2.5 Field Problems Encountered

During the course of the survey, some field problems were encountered. Some of these problems could be attributed to the fact that the base (topographic) maps were outdated. The maps were produced in 1960 and the aerial photographs used in their production were taken in 1950 (as indicated on the maps). As a result, roads indicated as being motorable on the maps were found not to be so during the survey. Also, on some newly constructed roads, the main problem encountered was that of locating on the maps the position of the gravity stations along the new extension or diversions made on the roads.

The mode of settlement of the inhabitants of the area also contributed to the problem discussed above. The inhabitants of the area are mainly farmers who settle, especially in the southern half of the project area, around their farms in families. However, as soon as the land around such a settlement became infertile, the family moved en-masse to another location. If some of them remained behind, the village assumed a new name. As a result, some

villages shown on the maps are either now non-existent or now bear new names.

Another problem encountered was that due to abrupt termination of some tracks by fairly big rivers over which there were no bridges. At some of these places, there were no settlements nearby and also no means of crossing the rivers. Such obstructions did not only slow down the rate of data collection, they also prevented uniform data coverage of the entire project area.

In some areas, mostly in the southern half of the project area, there were no roads. This also contributed to the unevenness of the data distribution (coverage) in the project area.

CHAPTER 4

DATA REDUCTION AND DENSITY DETERMINATION

4.1 Data Reduction

In reducing the data, the values determined at all the gravity stations were relative to 978120.773 mGal at a base station IGSN71-955173 in Kano (Verheijen and Ajakaiye, 1978). The height reduction was carried out manually and in calculating the Bouguer anomaly at each station, a simple programme using the University's CDC Cyber 72 computer was used.

The following formulae were used in the data reduction to Bouguer anomaly.

(a) Drift Rate - As earlier mentioned in section 3.1.1, the drift rate of the gravimeter or each altimeter was assumed linear for about three hour intervals. To determine the drift rate, d on a traverse in which A and B are base stations, the formular used was

$$d = \frac{\Delta R_{BA} - \Delta g_{BA}}{t_B - t_A} \quad (3-1)$$

where

ΔR_{BA} = the gravimeter (or altimeter) reading at B minus at A in gravity (or elevation) units.

Δg_{BA} = gravity (or height) difference between bases A and B in the instrument units.

t_B = observation time at base B

t_A = observation time at base A

(b) Observed Gravity- The equation used to determine the observed gravity value g_s , for any detail station s , on a profile AB above is given by

$$g_s = g_A + \Delta R_{AS} + d (t_s - t_A) \quad (3.2)$$

where

g_A = observed gravity value at base station A

ΔR_{AS} = gravimeter reading at s minus that at A

t_s = observation time at detail station.

d = the drift rate as in (3-1) above

(c) Theoretical Gravity - In calculating the theoretical gravity or the latitude effect at a station, the International Gravity Formula of 1967 was used. i.e.

$$g_t = 978031.85 (1 + 0.005278895 \sin^2 \phi + 0.000023462 \sin^4 \phi) \quad (3-3)$$

where

g_t = theoretical gravity value in mGal

ϕ = station latitude

(d) Elevation Correction - This correction is normally computed in two components - the Free-air and Bouguer corrections.

(i) The Free-air correction (FC) is due to the fact that the gravity field decreases with increase in elevation. It is given by

$$FC = (dg/dz) \cdot h \quad (3-4)$$

where

dg/dz = vertical gradient of gravity

$$= 0.3086 \text{ mGal/m}$$

h = station elevation (relative to sea level).

(ii) The Bouguer Correction(BC) - This is to correct for the attraction due to an infinite slab existing between the station and the sea level datum (i.e. for a slab of thickness h). For any station of elevation h , the Bouguer correction is given by

$$BC = 2\pi G \rho_m h \quad (3-5)$$

where

G = Universal Gravitational Constant

$$(6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2})$$

ρ_m = Mean crustal density above mean sea level

Usually the Bouguer correction is $0.04191\rho_m$ mGal/m.

(e) Free-Air Anomaly - At any station s , the Free-air anomaly (FA) is the difference between the observed gravity value (g_s) and the extrapolated theoretical gravity value (g_t) from the reference ellipsoid with the Free-air correction applied. The anomaly is given by

$$FA = g_s - (g_t - FC) \quad (3-6)$$

(f) Bouguer Anomaly - The Bouguer anomaly is the Free-air anomaly minus Bouguer correction given by

$$BA = FA - BC \quad (3-7)$$

substituting equations (3.4), (3.5) and (3.6) in (3.7), the Bouguer anomaly can also be represented by

$$BA = g_s - g_t + (dg/dz - 2\pi G\rho_m)h \quad (3-8)$$

4.2 Sources of Errors in the Bouguer Anomalies

The computed Bouguer anomaly at each station is usually subject to two major types of error - random and systematic errors.

4.2.1 Random Errors

The random errors could emanate from the following

- (i) the observed gravity, g_s
- (ii) the station height, h
- (iii) the station latitude, ϕ
- (iv) the terrain corrections

The error in obtaining g_s emanates from the reading error and the error originating from the gravimeter drift. In this work, the maximum error originating from reading the gravimeter could not be more than +0.01 mGal except where a reading mistake was made. The low value of the anticipated error was due to the high precision of the LCR gravimeter.

The error originating from the instrument drift originates from the linear drift assumptions between two adjacent base stations occupied within three hours. The error that could be introduced from the non-linearity of the

drift pattern cannot be more than 0.3 mGal and for effective drift control, time interval between closures was usually not more than three hours.

The major source of error in any gravity survey is the station elevation. This is due to the fact that both the Bouguer and Free-air corrections approximately add up to 0.2 mGal/m with an assumed crustal density of $2.67 \times 10^3 \text{ kg m}^{-3}$. As mentioned in section 3.2.4, most of the station elevations for this work was determined by means of two altimeters. The source of error in determining station elevation by means of altimeters as discussed by Verheijen and Ajakaiye (1980) are

- (i) calibration error
- (ii) error due to uncertainty in the removal of the drift
- (iii) error due to change in pressure
- (iv) reading error

These authors have shown that errors from sources (i), and (iv) amount to about 1.0 to 1.5 m. Errors due to (ii) and (iii) were found to be negligible for short periods of measurements when altimeter readings are taken in the dry season.

However, as discussed in section 3.2.5, lack of benchmarks would probably constitute a major source of height errors due to lack of adequate control. Nonetheless, the computed heights were compared with interpolated heights from the topographic (base) maps. In most of the stations, the two heights agreed to within 4.5 m. With a maximum error of 4.5 m in the value of the station elevations, the

corresponding error in the Bouguer anomalies would be about 0.9 mGal. It is however expected that the error would be much less in most of the stations.

The third component of the random errors is that due to wrong determinations of stations latitudes ϕ . Its value is $0.0081 \sin^2 \phi$ per metre north-south distance (Parasnis, 1973). The latitudes of the stations were determined by gridding each of the base maps using a transparent overlay. Because of the method used, the main source of this type of error would be from the relocation of stations on the maps due to factors discussed in section 3.2.5. On existing roads shown on the maps, the stations could be located exactly. For some roads which have changed course from those shown on the maps, the possibility existed that some stations on such roads or tracks might have been relocated to within ± 0.2 km in the north-south direction. Such a relocation would introduce an error of about 0.07 mGal if the relocation had occurred around the most northern latitude encountered (11.9°N).

The error introduced in the terrain, which is for the attraction due to the excess mass above or void below the level of gravity station, is determined by the accuracy of the mean height of each compartment and how far away from the stations concerned the compartments extend (Pick et al, 1973). No terrain correction was made for this work because the project area is fairly flat.

4.2.2 Systematic Errors

This type of error is not uniquely defined for a gravity anomaly because it depends on the aspect of the anomaly being investigated (Pick et al, 1973).

Irrespective of the aspect of the anomaly under investigation, the two main sources of error in this case are:

- (i) error in the calibration factor of the instrument used.
- (ii) error due to wrong mean crustal density in the Bouguer correction.

The gravity measurements were made by LCR model G468. It has been built with elaborate temperature regulating system and a mechanism for clamping the moving parts during transportation. This facility renders the instrument free from excessive drift which might arise from shock. The calibration factors of the instrument does not change perceptibly with time and so the need for frequent checks of calibration as is often done with the Worden is eliminated (Osazuwa, 1985).

The mean crustal density used in the Bouguer correction was $2.67 \times 10^3 \text{ kg m}^{-3}$. That determined from density analysis was $2.64 \times 10^3 \text{ kg m}^{-3}$ from the field samples collected. There is therefore a difference of about $0.03 \times 10^3 \text{ kg m}^{-3}$ between the assumed and the actual values. Therefore, the maximum error in the Bouguer correction would be about 0.24 mGal in the elevation range of about 190 m.

From the above analysis, the maximum error in the computed Bouguer anomaly at any station in this survey would be equal to 1.24 mGal and for most of the stations, the actual error in the Bouguer anomaly would be less than this.

4.3 Density Determination and Analysis

Variations in the earth's gravity field result from special characteristics of the earth's shape and its near surface density distribution (Grant and West, 1965). The gravity exploration primarily detects lateral variations in the densities of rocks under the ground surface. Therefore, for any meaningful interpretation of the gravity anomalies encountered in any survey, the best geologically permissible density contrasts must be used to model the body or bodies responsible for the anomalies. Although densities of the types of rocks found in the survey area have been published for other areas (Dobrin, 1976; Ajakaiye, 1974; Ojo, 1974; Telford *et al*, 1976), however, these published density contrasts required for interpretation in a particular area may be peculiar or small. In order to have a fair estimate

of this real density contrast, the densities of the rocks found in the survey area must be accurately determined.

4.3.1 Sampling Technique

For this survey, a total of 113 rock samples were collected during the fieldwork. The hand specimens were collected from outcrops along traverses and exposed rocks as a result of road construction work in the area. Each sample was labelled with the number of the station at which or in whose vicinity it was collected. Samples collected between two gravity stations were labelled with the numbers of the two stations.

4.3.2 Method of Density Determination

In order to determine the densities of the samples, each of the samples was initially weighed dry in air to obtain its dry weight before they were all soaked in water for about 48 hours until saturation.

Each rock was weighed uncovered in water to obtain its saturated weight in water and later weighed in air after wiping off the excess water on the samples to obtain its wet weight. The dry and wet densities for each rock were then calculated based on Archimedes Principle using the formulae

$$\rho_{\text{dry}} = \frac{\text{dry weight in air}}{\text{dry weight in air} - \text{weight in water}} \quad (4-1)$$

$$\rho_{\text{wet}} = \frac{\text{saturated weight in air}}{\text{sat. wt. in air} - \text{sat. weight in water}} \quad (4-2)$$

where

ρ_{dry} and ρ_{wet} are the dry and wet densities respectively.

Generally, differences obtained between the dry and wet densities were negligible. This negligible difference is to be expected for crystalline rocks which have less pore spaces compared with sedimentary rocks. The average of the dry and wet densities for each rock type was adopted as the density of the sample because it was considered a better approximation of the real density of the sample at depth. The results of the density determinations are shown in Table 4.1.

4.3.3 Density Analysis

The Mettler balance used for weighing the samples has a precision of 1.0×10^{-4} kg. The summary of results of the density determinations are shown in Table 4.1. Errors in each group of rock sample are also given as standard deviation.

After determining the average density for each rock type as discussed in section 4.3.2 above, a combined density histogram was then drawn as shown in Figure 4.1 for all the rock samples at interval of $0.04 \times 10^3 \text{ kg m}^{-3}$. The histogram showed a near normal distribution with a mean density of $2.64 \times 10^3 \text{ kg m}^{-3}$ and standard deviation of $\pm 0.08 \times 10^3 \text{ kg m}^{-3}$.

4.3.4 Densities Accepted for Interpretation

The mean densities of $2.63 \times 10^3 \text{ kg m}^{-3}$ and $2.70 \times 10^3 \text{ kg m}^{-3}$ for Granite and Migmatite respectively agree with other published figures (Ajakaiye, 1974; Ojo, 1974; Telford et al, 1976). The values were therefore accepted for

Table 4.1: DENSITIES OF ROCK TYPES

Rock Type	No of Samples	Density ($\times 10^3 \text{ kg m}^{-3}$)				Maximum Error
		Range	Dry	Wet	Mean	
Granite	75	2.51-2.66	2.61	2.65	2.63	± 0.02
Gneiss	8	2.58-2.73	2.68	2.70	2.69	± 0.03
Migmatite	30	2.64-2.78	2.69	2.71	2.70	± 0.04

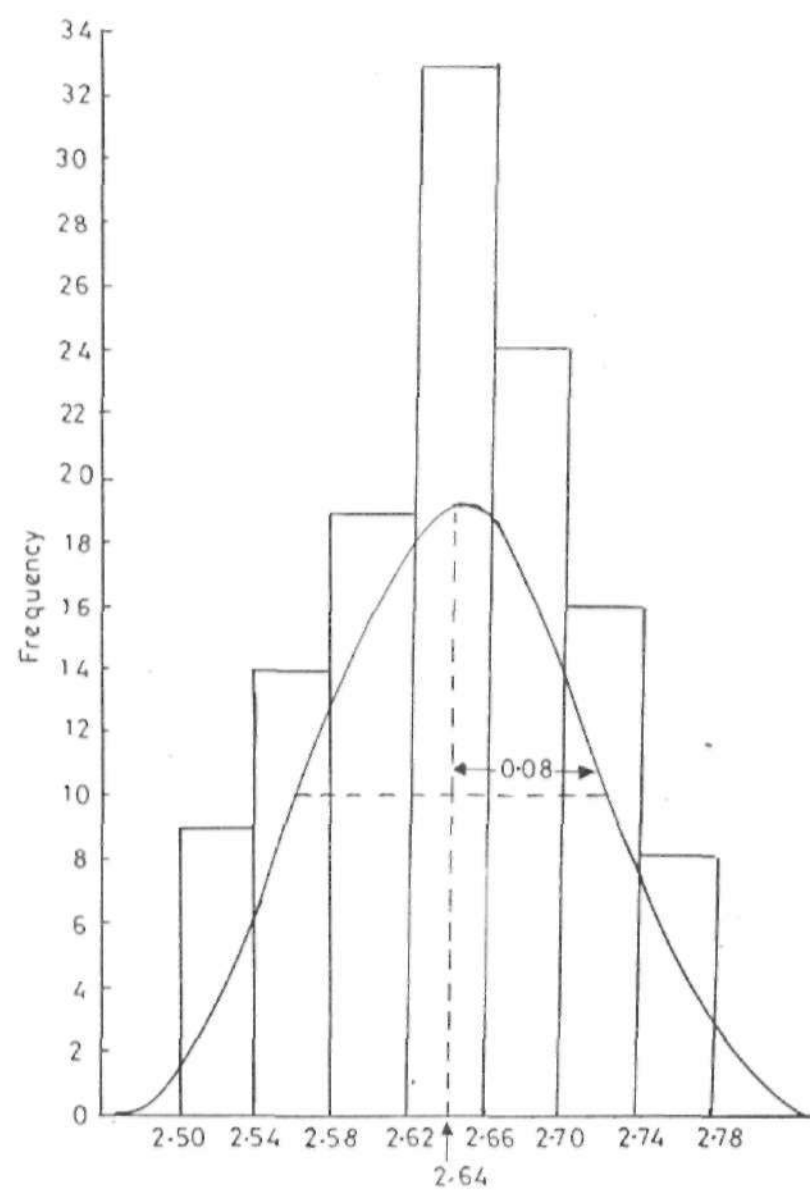


FIG.4.1 : COMBINED DENSITY HISTOGRAM

interpretation.

Also, a density of $2.976 \times 10^3 \text{kgm}^{-3}$ (Dobrin, 1976) was adopted for the interpretation of the positive anomaly found to correlate with area mapped as a basic igneous intrusion because samples of these rock types could not be obtained due to poor exposure along the traverse or poor accessibility.

CHAPTER 5

DESCRIPTION AND INTERPRETATION OF THE BOUGUER
AND RESIDUAL ANOMALIES

5.1 The Bouguer Anomaly

The Bouguer anomaly map which is presented in Figure 5.1 shows that the area is characterised by negative Bouguer anomalies ranging from -38 mGal to -68 mGal. This is consistent with negative Bouguer anomalies generally found over the continents. An individual station maximum value of -38 mGal occurs in the eastern half of the area while the minimum value of -68 mGal is located in the southeastern part of the area. The mean value for all the stations is about -56 mGal.

A relatively high gravity value of -38 mGal identified as 1 on the map is located about 8 km southeast of Dal. A gradient of about 5 mGal/km in this area may probably be indicative of contact between granite of low density and more mafic rocks of high density at depth.

A relatively low gravity identified as 2 with a value of -68 mGal is located between Sitti and Masu. Also, a gravity "low" identified as 3 with a value of -64 mGal is located at Gana. In the northwestern part of the area about 5 km southwest of Karfi, is located another body with a value of -40 mGal.

Other "low" gravity contour closures on the map may be

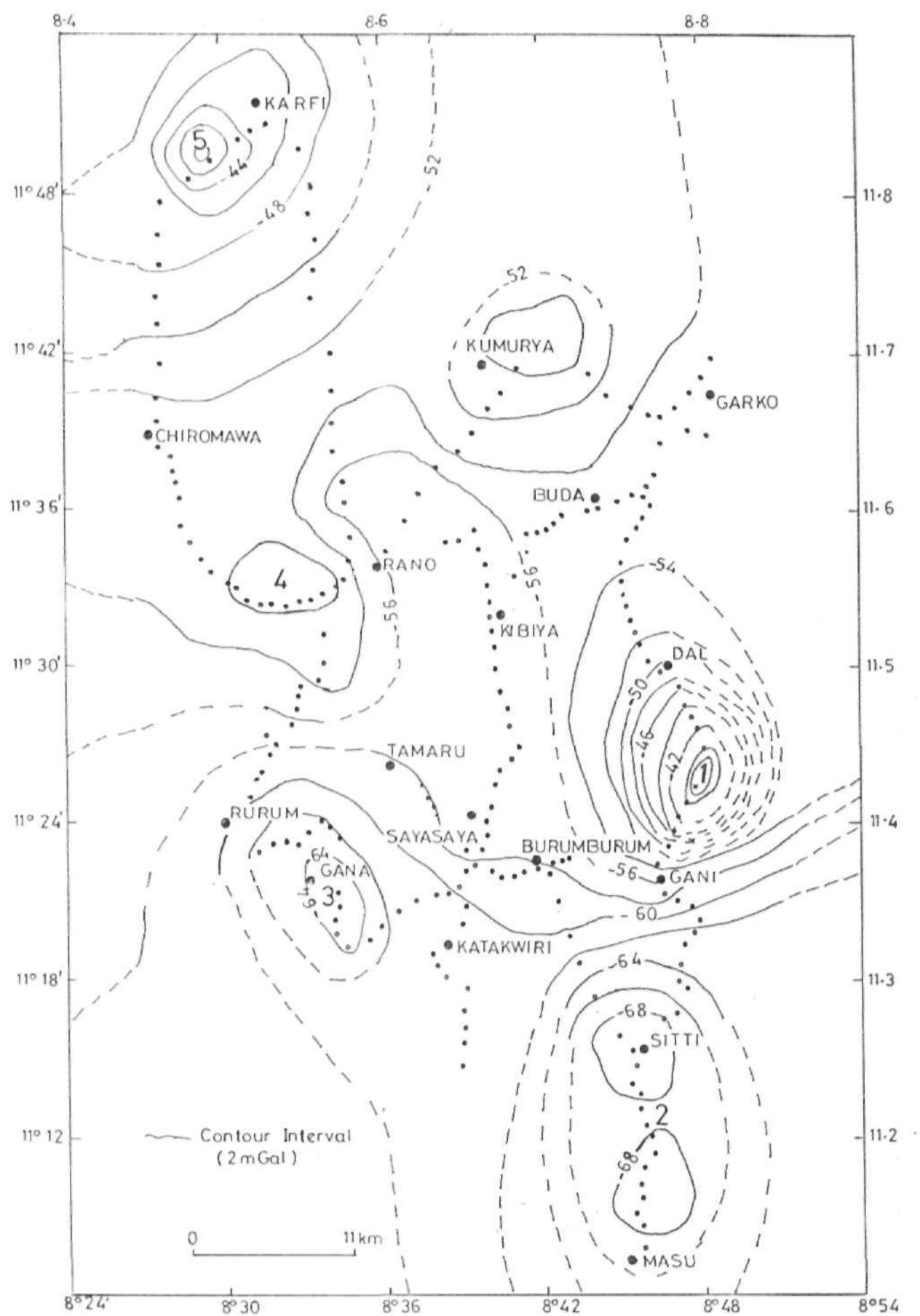


FIG. 5.1: BOUGUER ANOMALY MAP OF RANO AREA

associated with different episodes of igneous activity that led to the emplacement of the granite bodies, while other "high" contour closures could be due to high density subsurface structures at depth.

5.2 The Regional Gravity

5.2.1 Methods Used in Removing Regional Anomalies

Three main methods are used in removing the regional gravity from the reduced observed gravity data. These are:

- (i) smoothing (graphical) method
- (ii) gridding method
- (iii) polynomial surface fitting method.

Any one or the combination of the above methods can be used for a given survey depending on the complexity of the Bouguer anomaly map.

The first method entails visually examining the plotted Bouguer anomalies and drawing in a smooth curve or line as the regional gravity if a single profile is involved. If an entire map is involved, the process is carried out over selected longitudinal and traverse profiles using the common (crossing) points as control points. Then a regional map is subsequently deduced from the regional trends on the profiles. Whether the method is employed over a single profile or over a whole map, the method is subject to the personal prejudices of the interpreter (Paul, 1967; Skeels, 1967).

The gridding method which in essence involves two dimensional numerical filters is the most criticised in literature. The major criticism against the method is that, it does not possess any definite quantitative relationship with the anomalous mass (Skeels, 1967). Consequently, different results are obtained from different formulas and or grid spacings. According to Nettleton (1954) and Roy (1961), the only physical significance of the method is the proportionality that exists between the filters and second derivatives. The method is anomaly dependent (Vajk, 1951) but is useful in locating small anomalies and also for resolving overlapping ones (Skeel, 1967). However, the method also changes or distorts the shapes of anomalies (Appel, 1974). Another disadvantage of the method is that contouring errors are propagated to the derived residuals if the grid spacing is less than the data separation (Romberg, 1958). According to Lafehr (1965), in order to successfully remove the regional anomalies using this method, the grid spacing should depend on the size of the residuals to be resolved.

The Polynomial surface fitting method is based on fitting a low order polynomial surface, usually not more than second order polynomial, to the Bouguer anomaly map or over the entire area depending on the complexity of the Bouguer anomaly map. A modified version of the method was introduced by Paul (1967). In this method, the polynomial fitting is carried out in small areas around the data points. Either of the two methods just discussed has the

advantage of using data points in computing the regional. Hence the subsequent regionals are independent of contouring errors on the Bouguer anomaly maps (Appel, 1974). Therefore, a computer may have to be used in carrying out the fitting. This seems to be the major defect of the method.

Other mathematical methods have been developed by various authors for the regional-residual separation (Elkins, 1951; Krubein, 1950; Grant, 1953; Gupta and Ramani, 1980).

5.2.2 Regional Removal in the Present Survey

As discussed in section 5.2.1, the smoothing method can be used to derive the regional anomaly map from a Bouguer anomaly map. For example, Garland et al (1961) derived the regional gravity map for their survey in the Southern Rocky Mountain Trench, Canada by smoothing the longitudinal and traverse profiles of the Bouguer anomaly map. Also, Fairhead (1976) derived the regionals of his survey over the East African rift by assuming the continuity of the Bouguer anomaly trend over the basement across the rift. None of the two examples just given could be applied successfully in this survey because of the fact that the extent of the survey is small and might not be representative of the regional field on all the profiles. Consequently, the smoothing method was not used.

A cursory look at Figure 5.1 shows that the contours on the Bouguer anomaly map over some portions of the project area are inferred due to inadequate data in the appropriate

places necessitated by factors discussed in section 3.2.5. Therefore, using the gridding method would have introduced contouring errors carried over from the Bouguer anomaly map to the derived regional and residual anomaly maps as stated by Romberg (1958). Consequently, the method was considered not suitable for this work.

Because of the reasons discussed above, the polynomial surface fitting was used in deriving the regional and subsequently residual anomalies. The computed regional anomalies were manually contoured to give the regional anomaly map shown in Figure 5.2.

The regional increases gradually towards the northwest with northeast-southwest trend and an average gradient of about 0.16 mGal/km. This low value suggests that the causative body is of very deep origin.

5.3 The Residual Anomaly and its Correlation with Surface Geology

The residual anomaly map obtained by subtracting the regional obtained from polynomial fitting method from the Bouguer anomalies is shown in Figure 5.3. In order to ascertain the correlation between the residual anomaly and the geology of the area; the residual anomaly map was superimposed on the geological map of Figure 1.1 and the result is shown in Figure 5.4. As discussed in section 2.1, the geological detail of the area is still tentative.

However, the anomalies appear to correlate fairly well with the known geology of the area. For instance, the

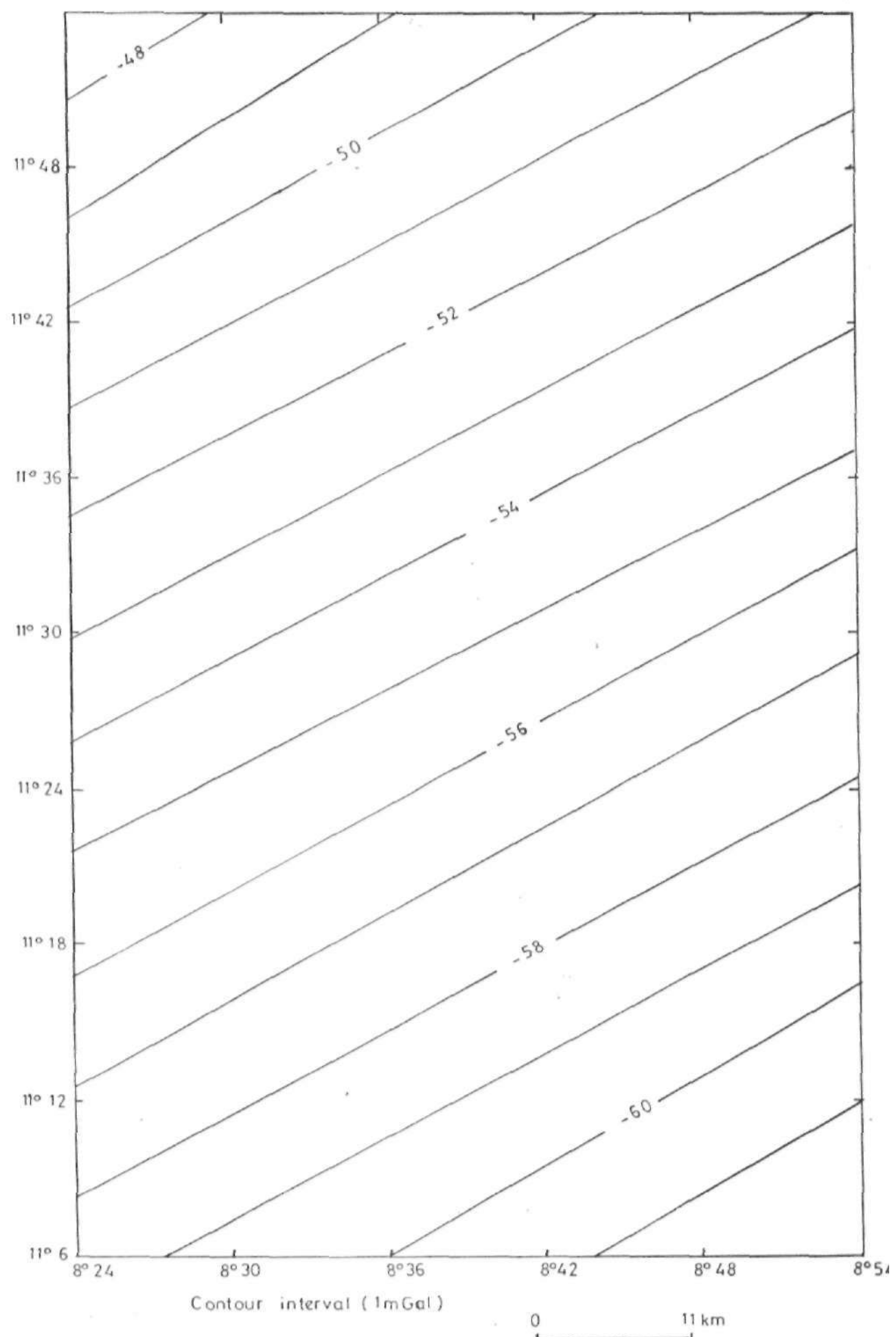


FIG. 5.2: RANO REGIONAL ANOMALY MAP OF RANO AREA

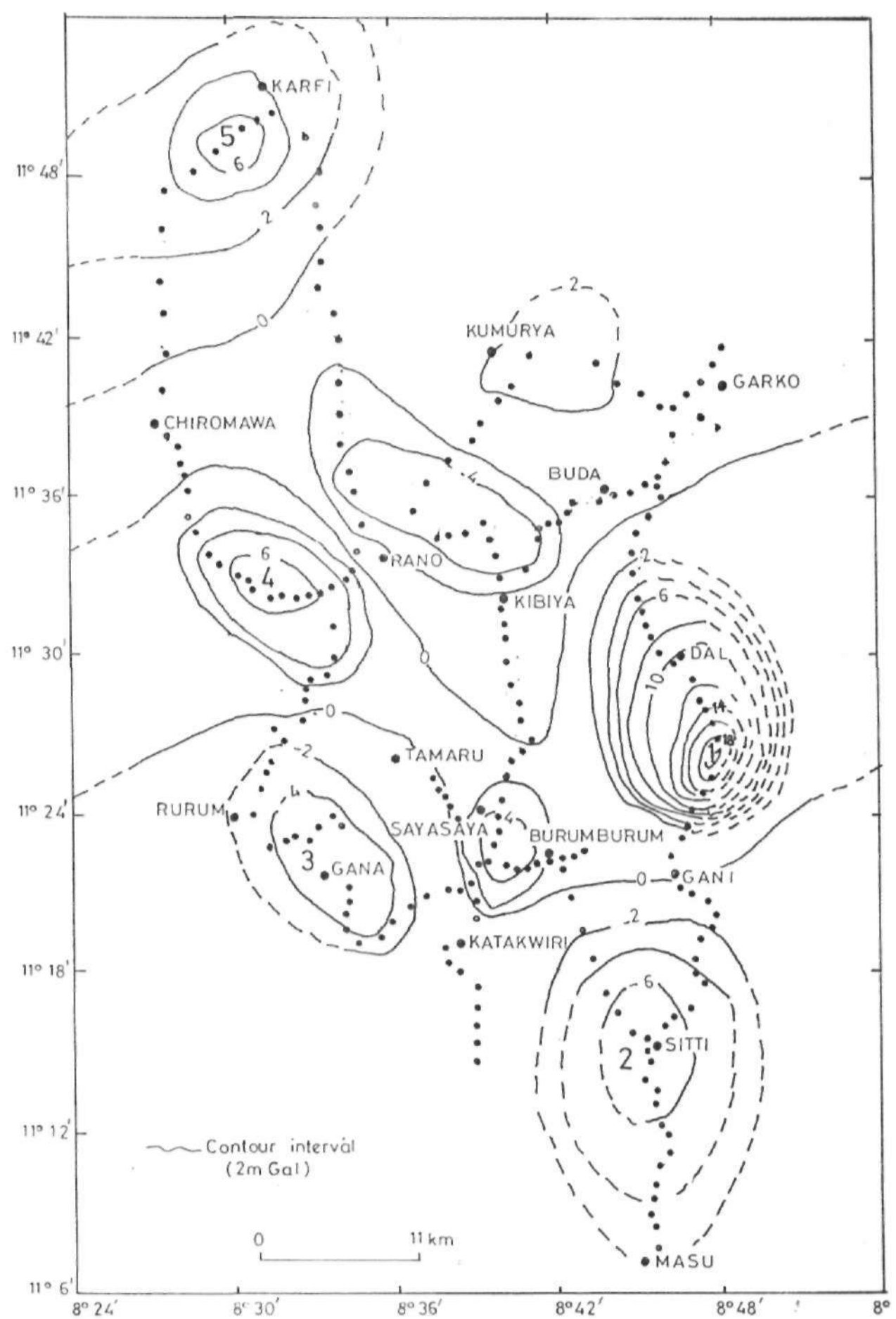


FIG-5.3: RESIDUAL ANOMALY MAP OF RANO AREA

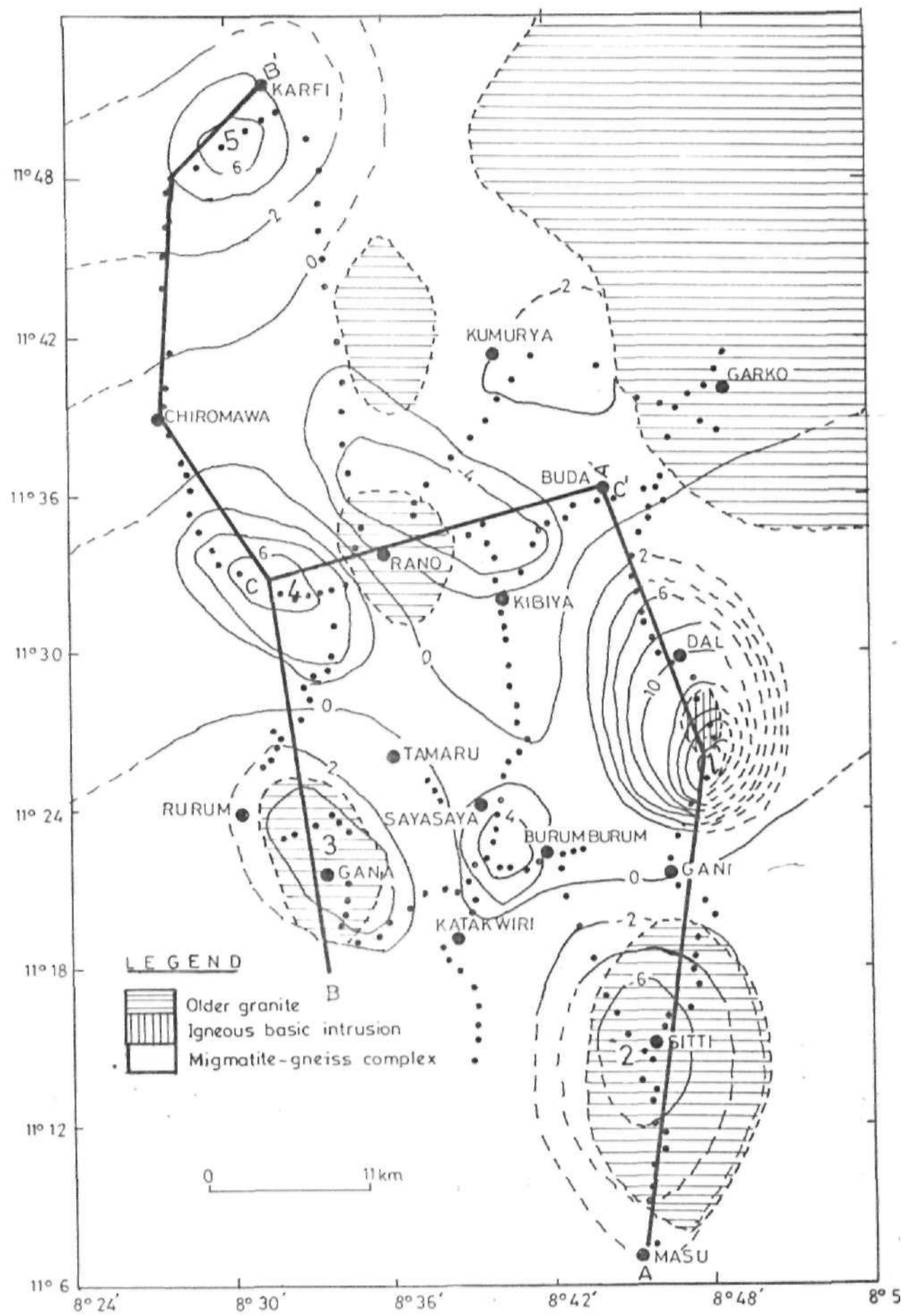


FIG. 5.4: RESIDUAL ANOMALY CONTOURS SUPERIMPOSED ON THE SIMPLIFIED GEOLOGICAL MAP

prominent positive residual anomaly identified as 1 on the map with a maximum amplitude of 20 mGal is fairly well correlated with a not so prominent outcrop of an igneous intrusive basic rock with general strike in the north-south direction.

Also negative residual anomalies identified as 2 and 3 respectively on the map are well correlated with the granite bodies in the area which occur as elliptically shaped bodies over the area.

However, the positive residual anomaly identified as 5 with amplitude of 6 mGal on the map is uncorrelated with the known surface geology of the area. Also, a positive residual anomaly of about 6 mGal about 10 km southeast of Chiromawa is uncorrelated with the surface geology. These two uncorrelated positive anomalies are however believed to be probably due to some intrusions of mantle material into the crust (M. Woakes, pers. comm.) or that volcanic materials may extend to the anomalous area at depths.

5.4 Quantitative Interpretation of the Residual Anomaly

The problem of gravity interpretation may be said to consist of finding the mass distribution whose gravitational effect is observed at the surface. This is an inverse problem of potential field theory which involves determining the source of its potential field, and does not have a unique solution. The modelling technique that is therefore usually employed in the quantitative interpretation of the residual anomalies is to compare the observed residual

gravity values with anomaly values computed for hypothetical set of bodies intruding into the subsurface with different shapes and density contrasts with the host rocks. When the difference between the observed and computed gravity values is small throughout the region of comparison, the model configuration constitute a possible model representation of mass distribution which exists in that region of the upper crust. Although an infinite number of models can be generated thereotically to fit the observed gravity pattern, restrictions imposed by surface geology, lithological distribution, and structures usually eliminate most of the models.

The computer programme used here for the quantitative interpretation calculates the gravitational effect of an arbitrary three dimensional body using polygonal laminae as the building blocks. The outline of the body is defined by horizontal polygonal shaped depth contours. Any complex structures or sloping boundaries can be accurately represented by a large number of sides on the polygons and a high density contours. These contours are effectively replaced by horizontal polygonal laminae and numerical integration with respect to depth yields the gravity anomaly of the entire body. Further theory on this can be found in Dobrin (1976) and Talwani and Ewing (1960).

5.4.1 Three-dimensional Interpretation of the Major Residuals

The criterion for selecting each profile interpreted on the residual map in Figure 5.3 was that it had data points throughout or almost throughout its entire length. Because the data points on any of the profiles do not lie on a single continuous straight line, the profiles have been approximated on the residual map by more than one segment. The data points were sampled on these profiles at 1 km interval, and in modelling the bodies, each body was assumed to be homogeneous and therefore assumed to have constant density. The three residual profiles A-A', B-B' and C-C' have been quantitatively interpreted using the modelling technique discussed in section 5.4.

Profile A-A'

This profile which runs along the eastern edge of the surveyed area begins in Masu and terminates at Buda. The profile which is shown in Figure 5.4 is about 55 km long. The residual gravity along the profile has a minimum with amplitude of -6 mGal in the southern part of the profile at Sitti and a maximum with amplitude of 20 mGal about 8 km southeast of Dal. Two possible models have been interpreted for this profile as shown in Figure 5.5a, b and Figure 5.6a, b respectively. The two models give an indication of the size and shape of the granite body at Sitti, and the not so prominent outcrop of a basic igneous intrusive north of the

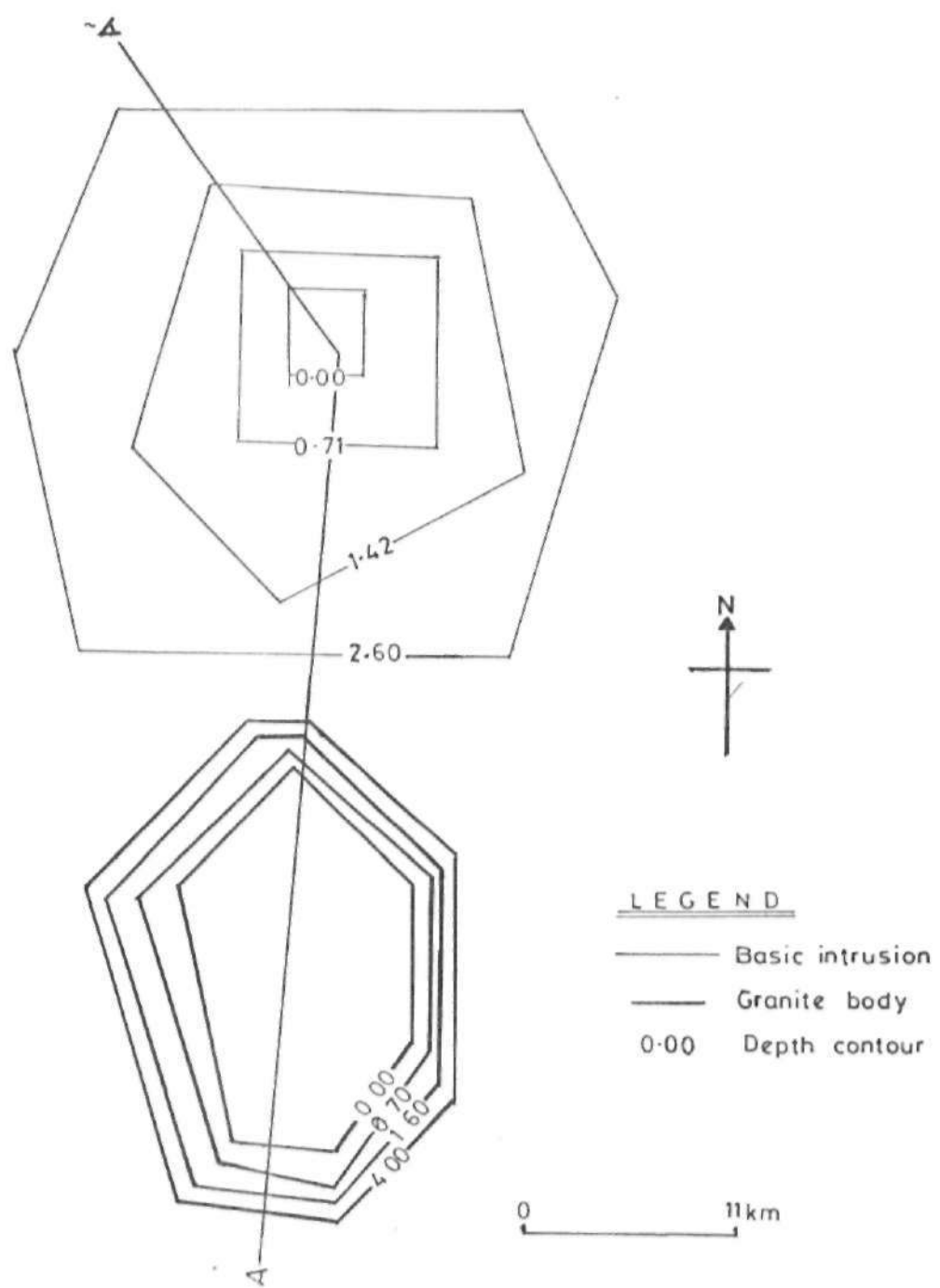


FIG. 5.5a : BODY CONTOURS AND DEPTH ALONG PROFILE A - A'

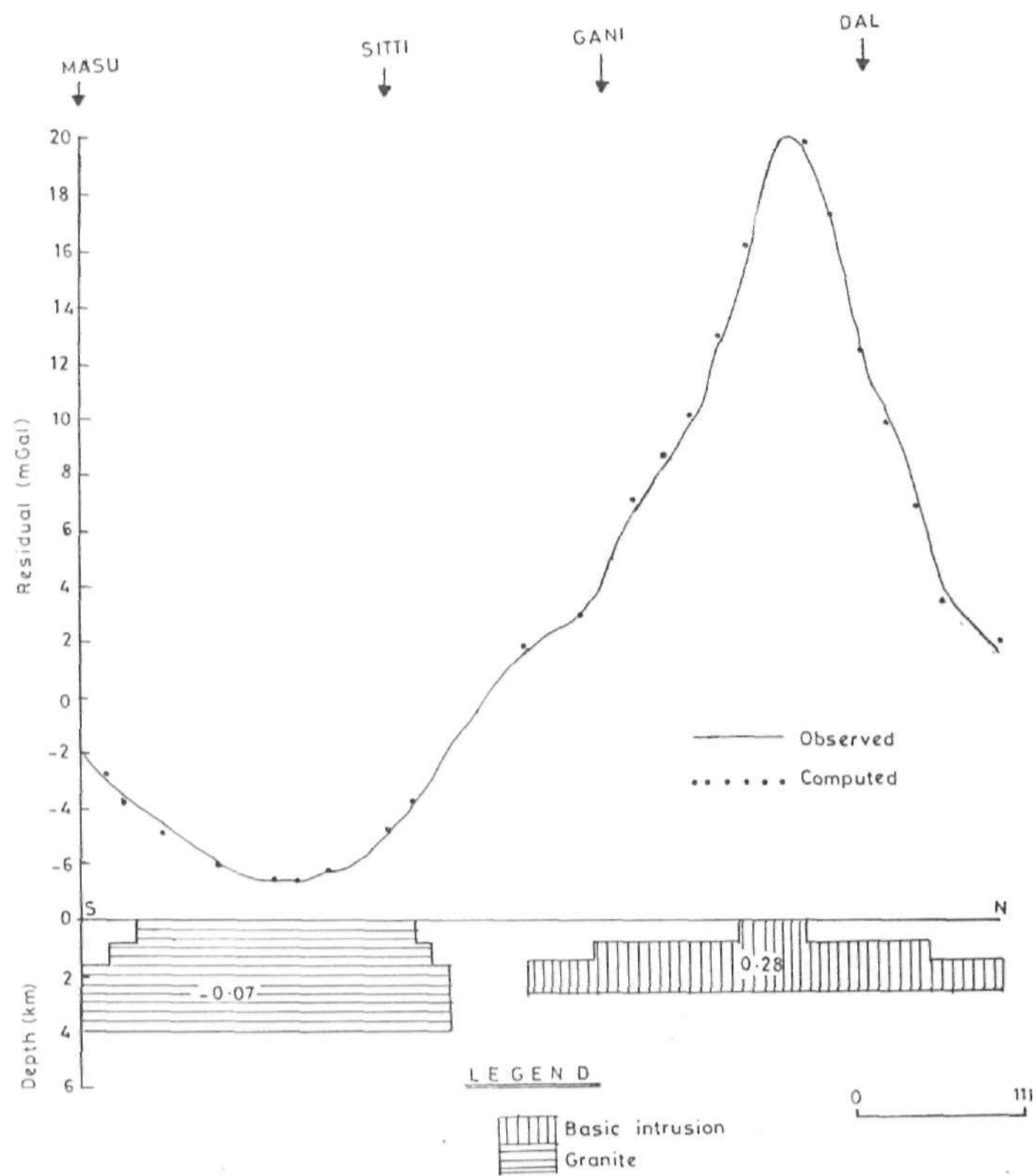


FIG.5.5b; THREE DIMENSIONAL MODEL OF RESIDUAL GRAVITY ALONG PROFILE A — A

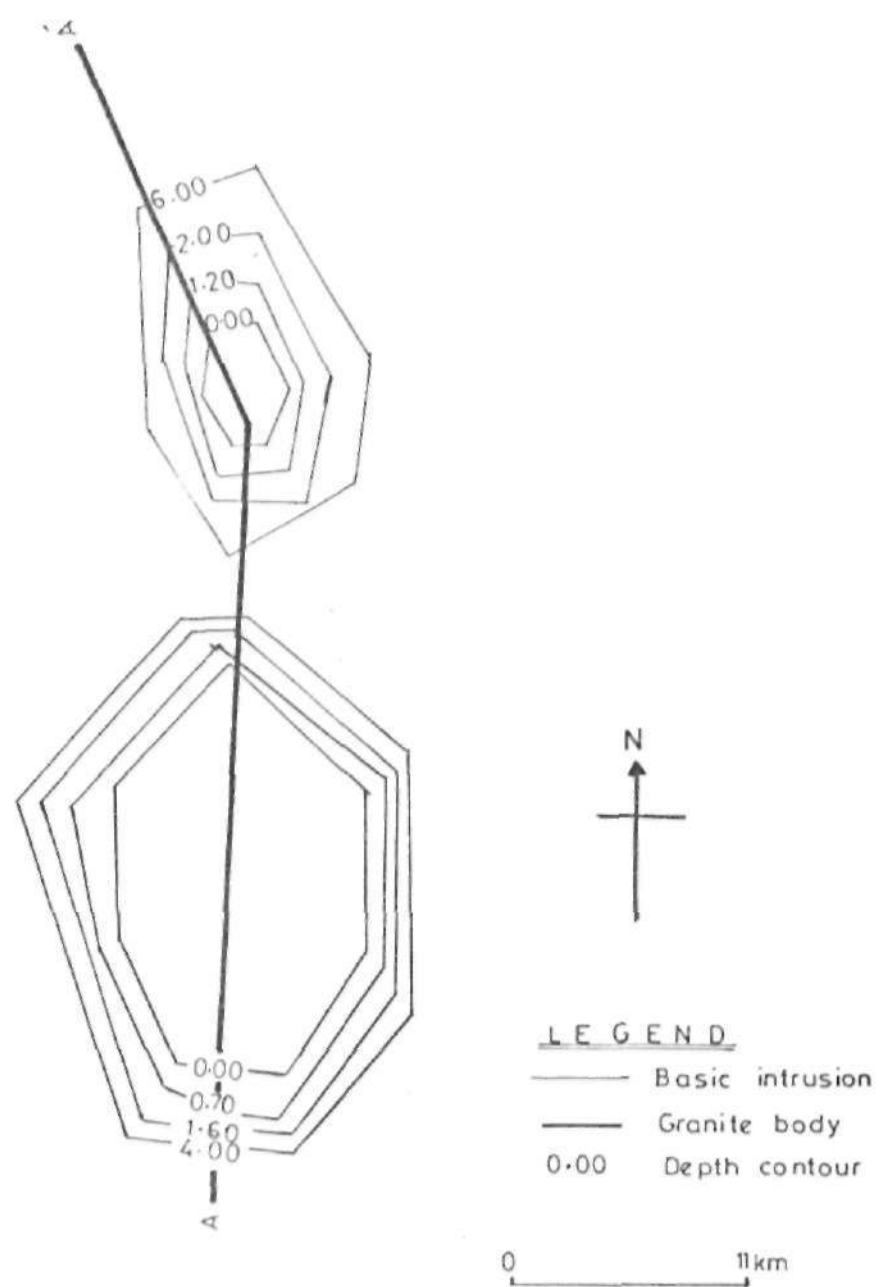


FIG. 5.6a: ALTERNATIVE BODY CONTOURS AND DEPTH ALONG PROFILE A-A'

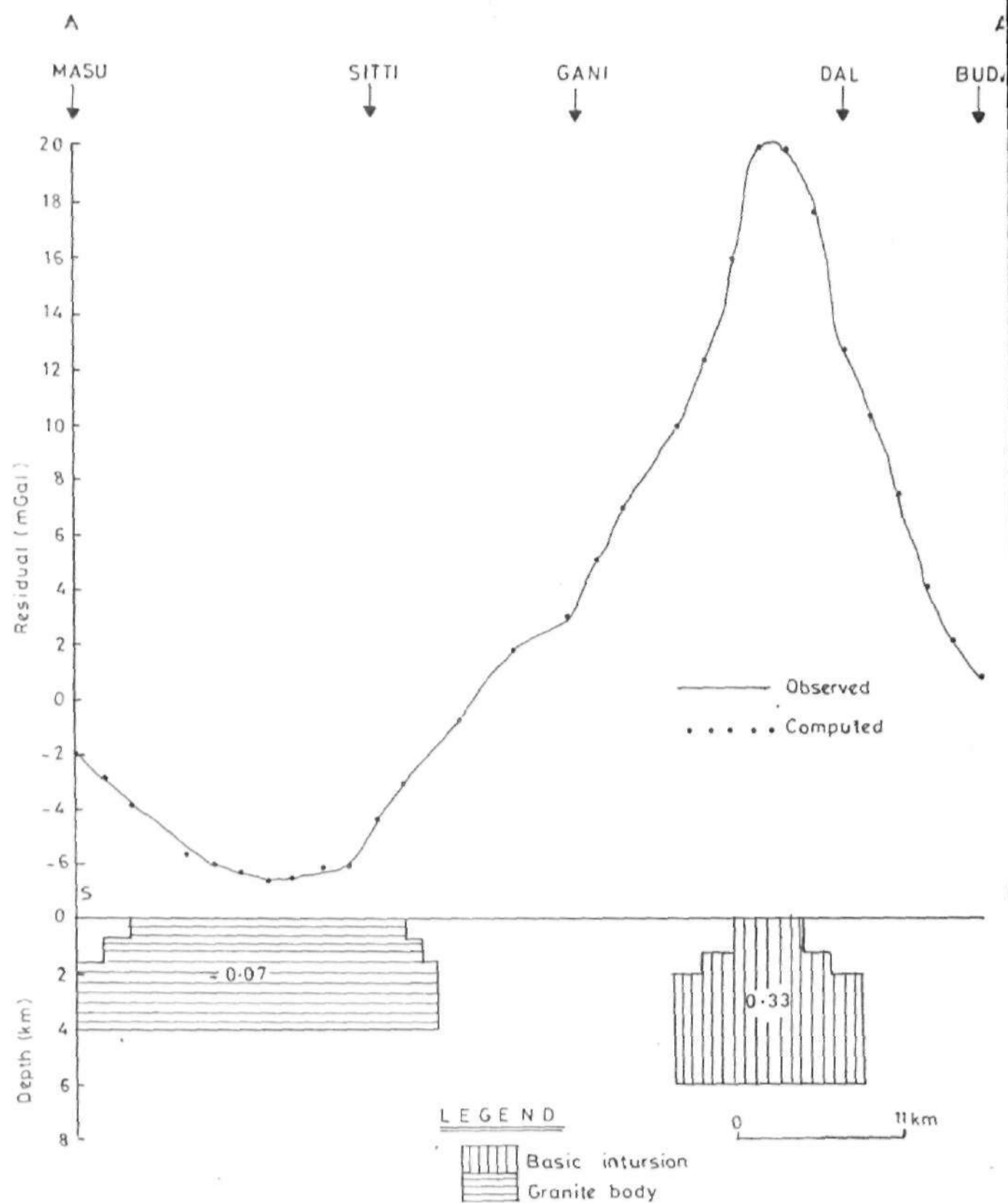


FIG.5.6b: ALTERNATIVE THREE - DIMENSIONAL MODEL OF THE RESIDUAL GRAVITY
ALONG PROFILE A - A'



Profile B-B'

This profile which is about 68 km long with four branches along the data points runs along the western part of the area. It begins south of Gana and runs through Chiromawa and terminates at Karfi (Fig. 5.4). The residual gravity along this profile has a minimum with amplitude of -4 mGal located between Rurum and Gana which coincides with the mapped granite. There are two maxima with amplitudes of 6 mGal each located close to Karfi and southeast of Chiromawa respectively (see also Fig 5.7b). These two maxima are uncorrelated with the surface geology and are considered to be basic intrusive bodies which have not outcropped. The two possible models interpreted for this profile are shown in Figure 5.7a, b and Figure 5.8a, b respectively. Density contrasts are the same as those for the models on profile A-A', and as with that profile, while the computed values for the model shown in Figure 5.7b fitted the observed values, the model was nevertheless considered unsuitable on the basis of the size of the basic intrusion.

Therefore, the alternative model of Figure 5.8a with the corresponding cross section (Fig. 5.8b) were obtained. The interpreted model shows that the granite body has a surface width of 11 km with corresponding depth of 3 km and the basic intrusive bodies have a maximum depth of 5 km.

Profile C-C'

This profile which is about 24 km long runs from southeast of Chiromawa through Rano and terminates at Buda

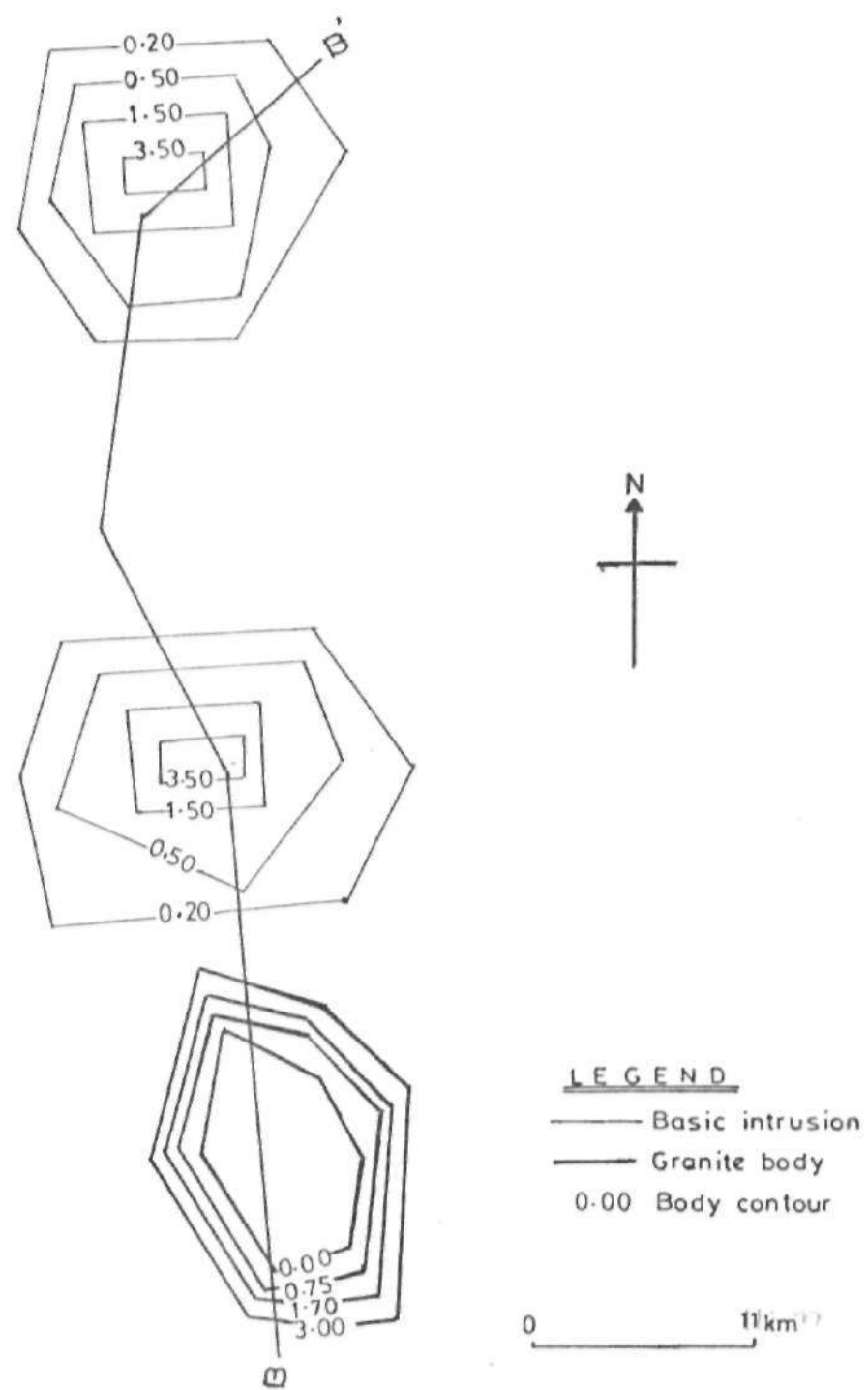


FIG. 5.7a: BODY CONTOURS AND DEPTH ALONG PROFILE B - B'

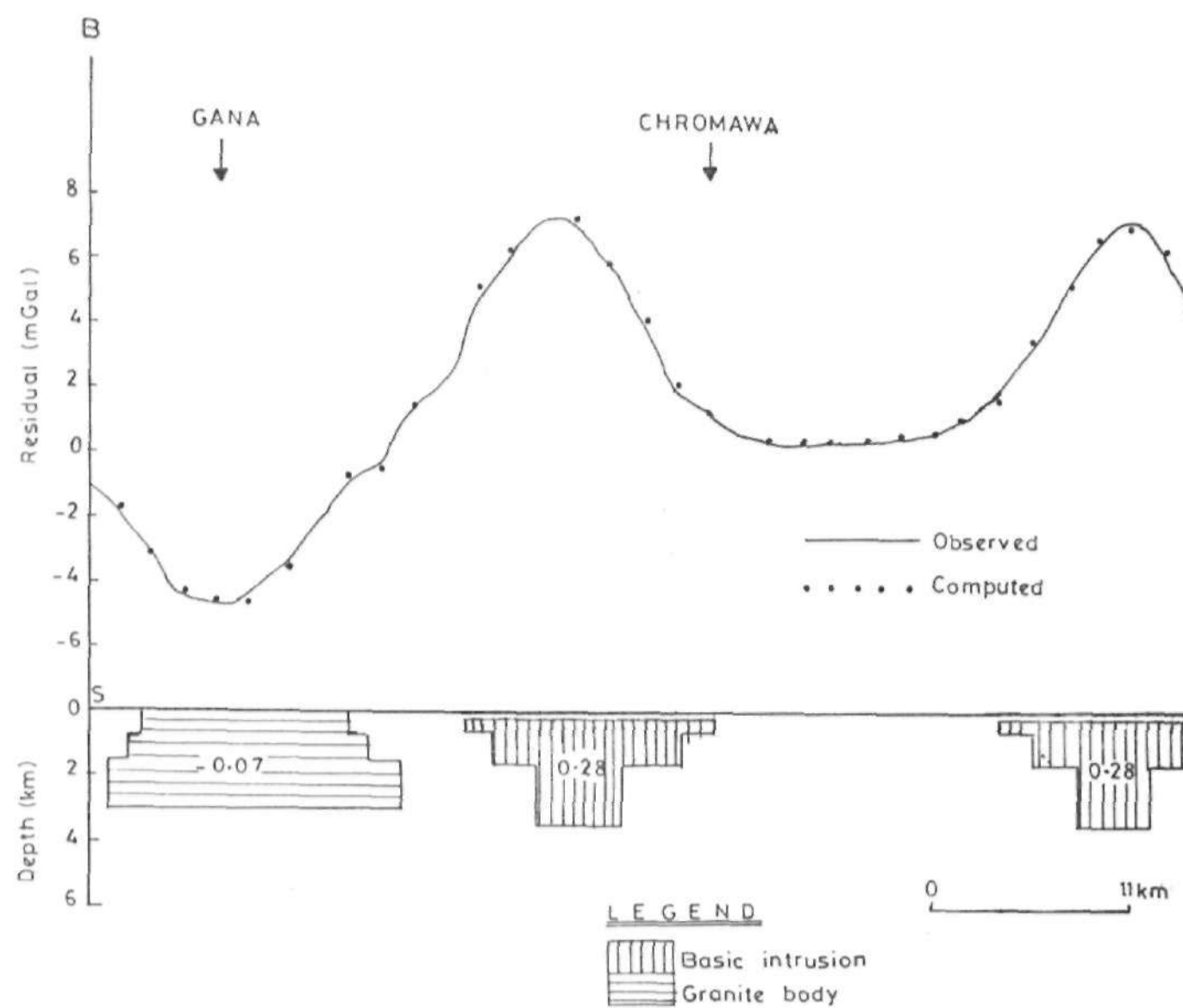


FIG. 5.7b ; THREE - DIMENSIONAL MODEL OF RESIDUAL GRAVITY ALONG PROFILE B -

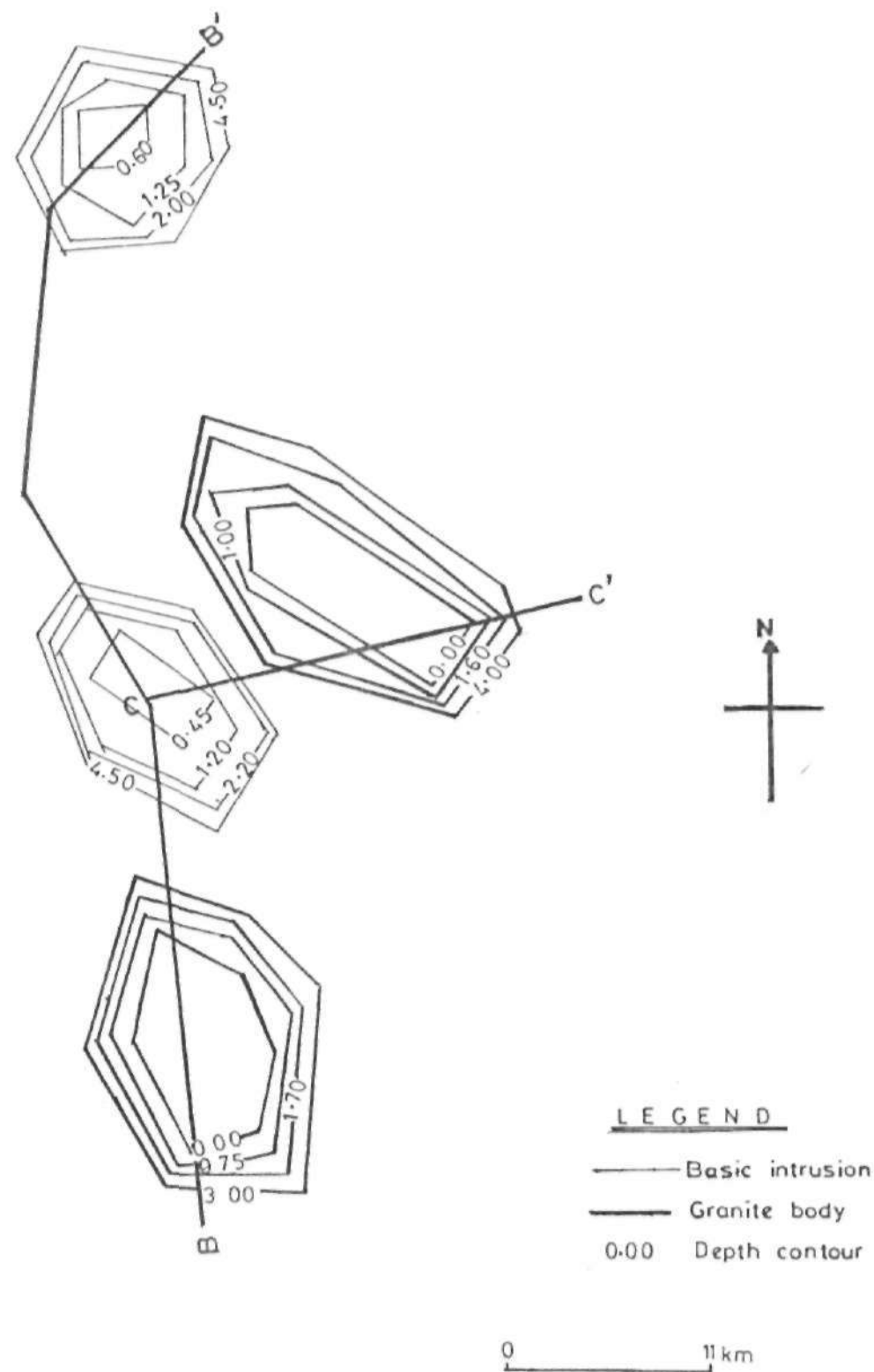


FIG. 5.8a: ALTERNATIVE BODY CONTOURS AND DEPTH ALONG PROFILE
B - B' AND C - C'

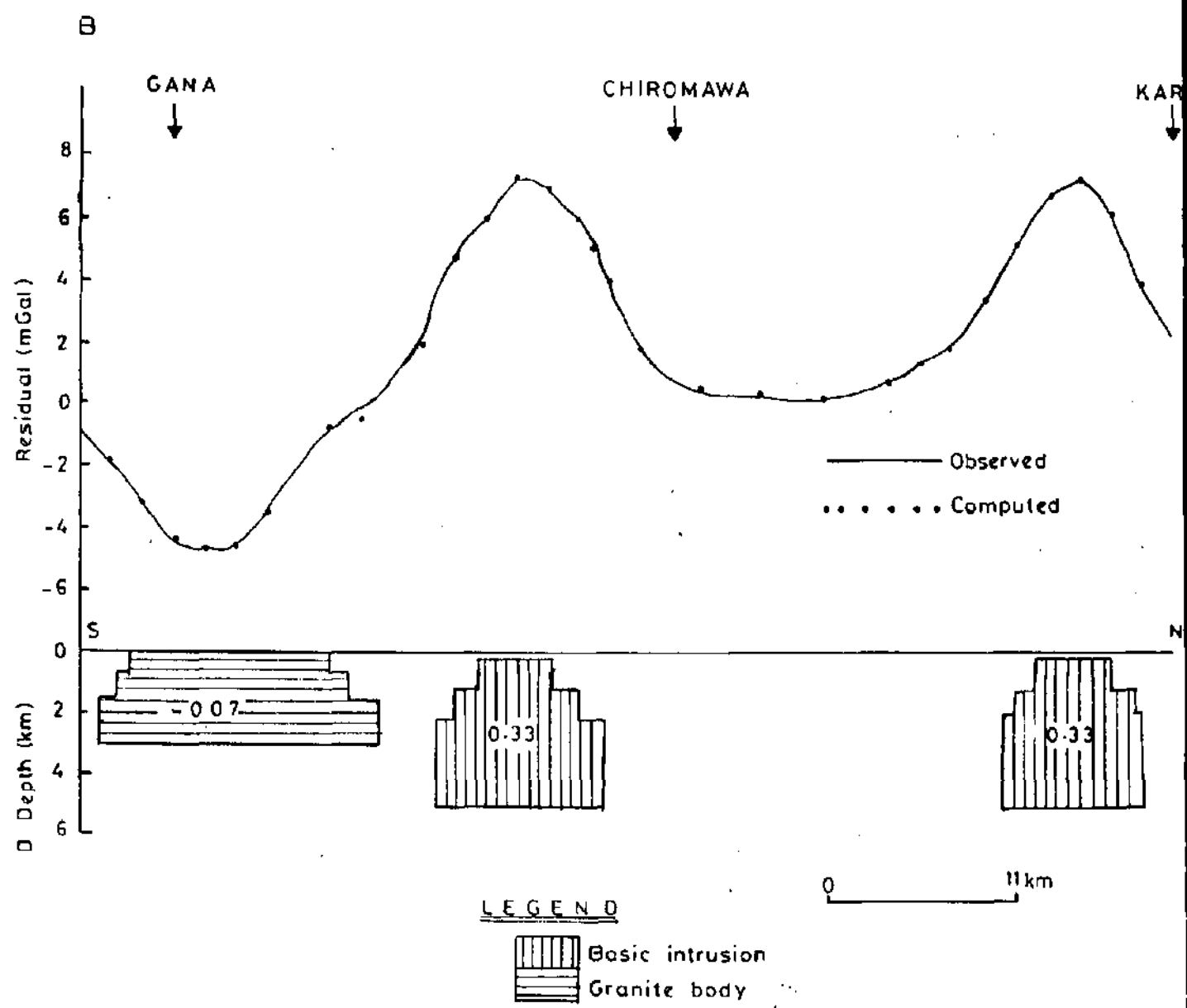


FIG. 5.8b. ALTERNATIVE THREE - DIMENSIONAL MODEL OF RESIDUAL GRAVITY ALONG PROFILE B - B'

(Fig. 5.4). The interpreted depth contours are shown in Figure 5.8a with the corresponding cross-section in Figure 5.8c. The basic body is the same as that which occurs along profile B-B' and extends to a depth of 5 km; the granite body extends to a depth of 4 km. However, it is noted that the geological map shows that two isolated granite bodies were mapped at Rano and north of Rano (Fig. 5.4) which is inconsistent with both the residual map and the model. It would therefore appear that both mapped bodies may be one granite body rather than two distinct bodies and the geological boundary might have been inaccurately mapped probably due to accessibility problems.

5.4.2 Summary of Models

In summary, the depth contours of all the bodies along the three profiles were superimposed on the geological map of Figure 2.1 and the resulting map is shown in Figure 5.9. The depth contours and the mapped bodies show fairly good correlation with the exception of the granite bodies at Rano and north of Rano, a discrepancy which was explained above. It should be noted that the model shown in Figure 5.9 represents one possible configuration that fits the observed data well. Nevertheless, other possibilities exist because of the ambiguities usually inherent in gravity interpretations (Nettleton, 1940). The model shown in Figure 5.9 seem to be consistent with presently available geological data.

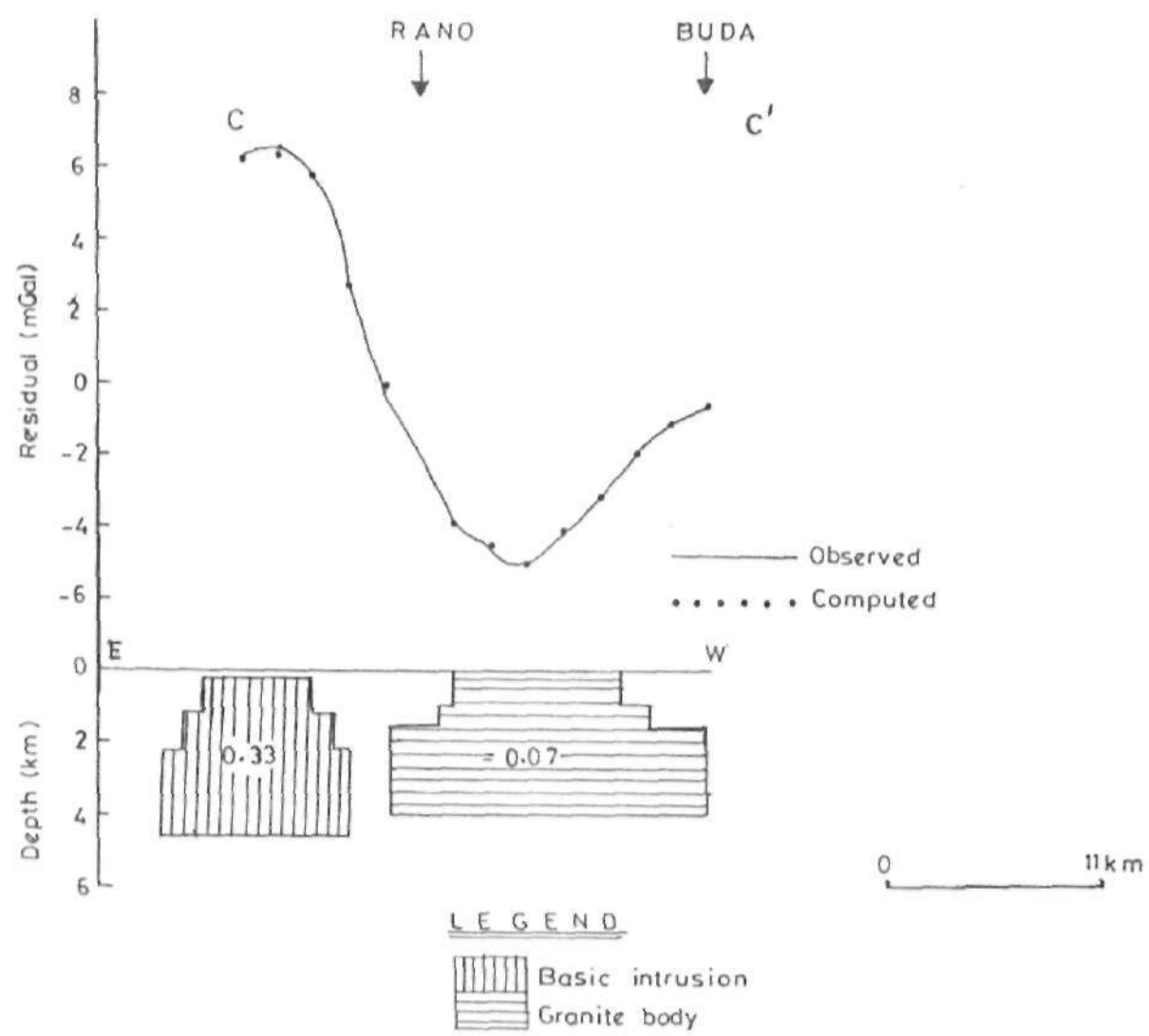


FIG.5-8c ; THREE - DIMENSIONAL MODEL OF RESIDUAL GRAVITY ALONG
PROFILE C - C'

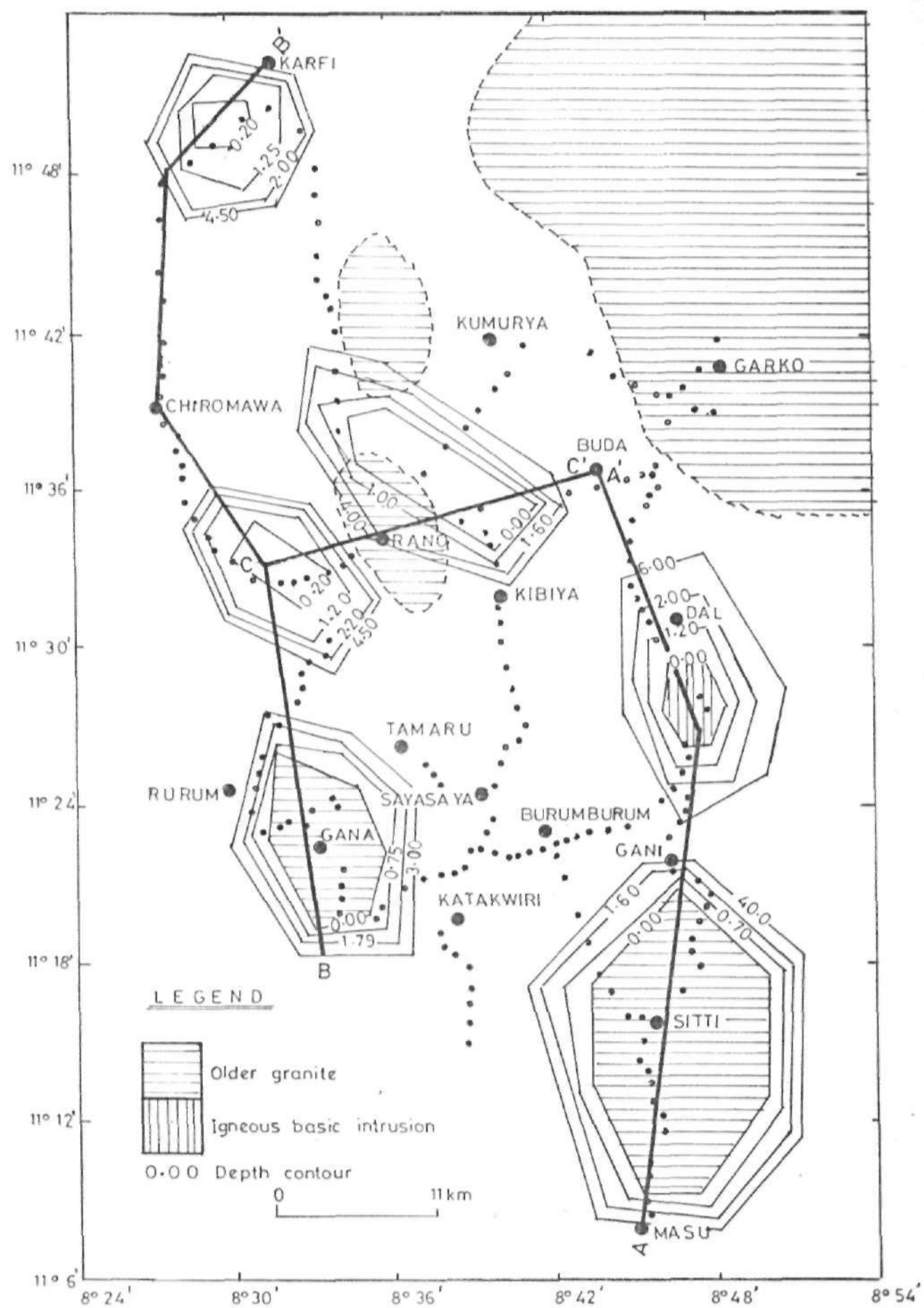


FIG. 5.9: BODY DEPTH CONTOURS SUPERIMPOSED ON THE SIMPLIFIED GEOLOGICAL MAP

CHAPTER 6

CONCLUSION

6.1 Summary of Results and Discussion

This study shows that Rano area is characterised by negative Bouguer anomalies in the range of -38 mGal to -68 mGal. The Bouguer anomalies are distributed about a mean of -56 mGal. The northwest plunge of the regional curves with a low average gradient of only 0.16 mGal/km suggests that it is of deep origin.

The Bouguer anomaly with amplitude of about -38 mGal and associated gradient of about 5 mGal/km in the eastern part of the area is centred on a mafic igneous intrusion which is poorly exposed. The sharp contact suggested by this high gradient is a departure from the prevalent gradational contact in the area. Two other positive residual anomalies each with amplitudes of 6 mGal at Karfi and Chiromawa uncorrelated with the surface geology were interpreted to be due to basic igneous intrusions which did not outcrop. These basic intrusions which abound in the Nigerian basement complex are not believed to have much significance in terms of origin and mode of occurrence with respect to the tectonic evolution of the area (M. Woakes, pers. comm.). However, some of these basic intrusions with high densities may be indicative of a source of economic minerals because of the variational composition in their mineral contents. Some of these basic intrusions with

densities in the range of $4 \times 10^3 \text{ kg m}^{-3}$ may contain minerals such as ilmenite and magnetite, and could have significant magnetic signatures. However, the lack of a good road network for adequate control of data points as well as inadequate geological information make our present interpretation tentative, although this survey has confirmed the existence of isolated positive anomalies in the Rano area.

On the other hand, negative closures of the residual anomalies have been fairly well correlated with the granite bodies in the area. The minimum residual anomalies with amplitudes in the range of -4 mGal and -6 mGal confirm the low density and hence the acidic nature of the granites. The origin of the Nigerian Older Granites has always been a subject of controversy among authors who have worked extensively on the Nigerian Basement complex. (Russ, 1957; Oyawoye, 1964; Grant, 1978; and Ajibade, 1980). The divergent opinions include whether the Older Granites originated essentially through magmatism with subsequent magmatic emplacement or essentially through metasomatism whereby sediments and metamorphic rocks are converted to granites by metasomatic migration of material. These various opinions are as a result of different interpretations of field relations, textural, mineralogical and physico-chemical evidence.

From chemical analysis and examination of petrological features, Russ (1957) proposed a single magmatic epoch for the Older Granites. Rahaman (1975), on basis of the mode of occurrence of the charnokites in Ibadan; Ajibade (1980) on

basis of field relation in Zungeru region, and Turner (1983) from comparison of granite concentration in the Kibaran Schist belts of south-western Nigeria with those in the Pan African schist belts in northwestern Nigeria, also proposed magmatism.

However, while reviewing the geology of the basement complex, Oyawoye (1964) suggested potash metasomatism as the origin of the Older Granites. Grant (1978) from geochronological studies; Wright and McCurry (1970) after collating areas mapped by Truswell and Cope (1963) and that mapped by McCurry (1970), suggested boron metasomatism.

The problem of the origin of the Nigerian Older Granites cannot be resolved from this survey, partly because of the limited nature of the survey and the preliminary geological information. Nonetheless, the study confirmed the acidic nature of the granite with its characteristic gravity "low" as a result of its low density. Furthermore, the Bouguer anomaly map (Fig. 5.1) does not indicate the existence of sharp contacts between the granites and the country rock where they occur together; rather the gradients are moderately low and the models suggest that the bodies are not very deep in extent. These findings are in contrast with recent studies by Gandu *et al.* (1986), Udensi *et al.* (1986), and Adeniyi (1987) in Malumfashi, Minna and Zaria areas respectively which all showed that the granites were relatively deep in extent and the contacts were sharp. This study is therefore in agreement with the proposals of geologists who mapped the

Rano area, that metasomatism must have reached an advanced stage in the area (GSN, unpublished geological reports) and thus suggests that the Nigerian Older Granites may vary in their origin.

6.2 Recommendation for further work

As pointed out in this study, some portions of the area could not be reached due to lack of roads; consequently, a uniform data coverage of the entire project area was not possible. It is however hoped that accessibility would improve because of the strategic location of the Rano Local Government Headquarters at Rano. In the light of this, further detail gravity investigation as well as magnetic measurements should be carried out over the positive anomaly between Buda and Gani in order to reveal the lateral extent of the basic intrusion and hence throw more light as to its economic importance if any. In addition, the coverage of this work should be extended in order to define the boundaries of the peripheral anomalies properly.

REFERENCES

- Adeniyi, O.O. (1987). Gravity Survey of the Older Granite Plutons in Zaria area of Kaduna State, Nigeria. Unpublished M.Sc. Thesis, Ahmadu Bello University, Zaria, Nigeria.
- Ajakaiye, D.E. (1974). Densities of rocks in the Nigerian Younger Granite Province. Journ. Min. Geol. Nigeria, 11:33-43.
- Ajakaiye, D.E. and Verheijen, P.J.T. (1977). Gravity Survey across the Quaternary basement areas of Kano State. Journ. Min. Geol. Niger., 14: 55, (abstract).
- Ajibade, A.C. (1980). Geotectonic Evolution of the Zungeru Region, (Unpublished Ph.D. thesis) University of Wales 303 pp.
- Appel, B.A.N.C. (1974). The quality of some Two-dimensional Filters in separating Regional and Local Gravity Anomalies. Geophysical Prospecting, vol.22, pp.601.
- Dobrin, M.B. (1976). Introduction to Geophysical Prospecting McGraw-Hill, Book Co., Inc., New York, London, 630 pp.
- Elkins, T.A. (1951). The second derivative method of gravity interpretation. Geophysics vol. 16, pp. 29-50.
- Fairhead, J.D. (1976). The structure of the Lithosphere beneath the Eastern Rift, East Africa, Deduced from Gravity Studies. Tectonophysics vol.30, pp. 269-298.

- Falconer, J.D. (1911). The Geology and Geography of N. Nigeria. MacMillan and Co. Ltd., London.
- Gandu, A.H., Ojo, S.B. and Ajakaiye, D.E. (1986). A gravity study of the precambrian rocks in the Malumfashi area of Kaduna State, Nigeria. Tectonophysics, 126: 181-194.
- Garland, G.D., Kanasevich, E.R. and Thompson, T.L. (1961) Gravity Survey over the Southern Rocky Mountain Trench Area of British Columbia. Journal of Geophysical Research vol.82 pp 2295-2305.
- Grant, F.S. (1953). A theory for the regional correction of potential field data. Geophysics vol.19 no.1, pp 23-45.
- Grant, F.S. and West, G.F. (1965). Interpretation Theory in Applied Geophysics. McGraw-Hill Book Co. Inc. New York, London 584 pp.
- Grant, N.K. (1978). Structural distinction between a metasedimentary cover and an underlying basement in the 60 m.y. old Pan African domain of northwestern Nigeria, West Africa. Geol.Soc. Am. Bull. vol. 39, pp 50-58.
- Grant, N.K., Rex, D.C. and Burke, K.C. (1969). The Geological sequence and geochronology of old basement rocks from Ibadan, Nigeria. Ann. fac.sci.clermont-Fd; no.41 geol. mineral, fasc. 19, p.84.
- Gupta, V.K. and Ramani, N. (1980). Some aspects of regional -residual separation of gravity anomalies in a

- Precambrian terrain. Geophysics vol.45, no.9,
pp 1412-1426.
- Holt, R., Egbuniwe, I.G., Fritches, W.R. and Wright, J.B.
(1978). The relationships between low grade metasedimentary belts, calc-alkaline volcanism and the Pan-African orogeny in N.W. Nigeria. Geol. Rundsch.,
vol. 67, pp. 631-646.
- Jones, H.A. and Hockney, R.D. (1964). The geology of part of southwestern Nigeria. Bull.Geol.Surv.Niger.
no. 31.
- Krubein, W.C. (1950). Trend surface analysis of contour type map with irregular control point spacing.
Journal of Geophysical Research, vol.64, no.7,
pp 823-834.
- Lafehr, T.R. (1965). Estimation of the Total Amount of Anomalous Mass by Gauss' Theorem. Journal of Geophysical Research vol.70, pp 1911-1919.
- McCurry, P. (1970). The geology of degree sheet 21 (Zaria). M.Sc. Thesis, Ahmadu Bello University, Zaria, 139 pp.
- McCurry, P. (1976). The geology of the Precambrian to Lower Palaeozoic Rocks of Northern Nigeria - A Review
In: Kogbe, C.A. (Ed.), Geology of Nigeria.
Elizabethan Press Pub. Co. Ltd. pp 15-39.
- Nettleton, L.L. (1940). Geophysical Prospecting for Oil.
McGraw-Hill Book. Co. New York.
- Nettleton, L.L. (1954). Regional, residuals and structures.
Geophysics vol.19, no.1, pp. 1-22.

- Ojo, S.B. (1974). Preliminary Interpretation of Gravity Measurements in the Middle Niger Basin Area, Nigeria. Unpublished M.Sc. Thesis, Ahmadu Bello University, Zaria, Nigeria.
- Osazuwa, I.B. (1985). The Establishment of a Primary Gravity Network for Nigeria. Unpublished Ph.D. Thesis, Ahmadu Bello University, Zaria, Nigeria.
- Osazuwa, I.B. and Ajakaiye, D.E. (1986). Gravity Meter Calibrations Ranges in Nigeria. Paper presented at the 3rd International Conference, Association of Geophysicists in Exploration and Research in Africa, 1-5 December, Jos, Nigeria.
- Oyawoye, M.O. (1964). The geology of the Nigerian basement complex. Journ. Nig. Min. and Geol. vol.1, pp. 87-102.
- Parasnis, D.S. (1973). Mining Geophysics. 2nd revised updated edition, Elsevier Scientific Publ. Co., Amsterdam, Lond., New York.
- Paul, M.K. (1967). A method of computing Residual Anomalies from Bouguer Gravity map by applying Relaxation Technique. Geophysics vol. 32, pp. 708-719.
- Pick, M., Picha, J. and Vyskocil, V. (1973). Theory of the Earth's Gravity Field, Elsevier Publishing Company.
- Rahaman, M.A. (1975). Review of the basement geology of southwestern Nigeria. In: Kogbe, C.A. (Ed.) Geology of Nigeria. Elizabethan Publ. Co., Lagos, Nigeria. pp. 41-58.

- Romberg, F.E. (1958). Key variables of gravity. Geophysics vol. 23, pp. 684-700.
- Roy, A. (1961). On some properties of Residuals and Derivatives. Journ. of Geophysical Research. vol. 66, pp. 543-548.
- Russ, W. (1957). The geology of parts of Niger, Zaria and Sokoto Provinces with special reference to the occurrence of gold. Bull. Geol. Surv. Nigeria, no. 27.
- Skeels, D.C. (1967). What is Residual Gravity. Geophysics vol. 32, pp. 872-876.
- Talwani, M. and Ewing, M. (1960). Rapid computation of gravitational attraction of three dimensional bodies of arbitrary shape. Geophysics, 25: 203-225.
- Telford, W.M., Geldart, L.P., Sheriff, R.E. and Keys, D.A. (1976). Applied Geophysics, Cambridge Univ. Press, London 860 pp.
- Truswell, J.F. and Cope, R.N. (1963). The geology of parts of Niger and Zaria Provinces, Northern Nigeria. Bull. Geol. Surv. Nigeria. No. 29.
- Turner, D.C. (1983). Upper proterozoic schist belts in the Nigerian sector of the Pan-African Province of West Africa. Precambrian Research, vol. 21 pp 55-79.
- Udensi, E.E., Ojo, S.B. and Ajakaiye, D.E. (1986). A three dimension interpretation of the Bouguer Anomalies over the Minna batholith in Central Nigeria. Precambrian Research, 32: 1-15.
- Vajk, R. (1951). Regional Correction of Gravity Data. Geophysics Pure and Applied, vol. 19, pp. 129-143.
- Van Breeman, O., Pigeon, R.T. and Bowden, P. (1977). Age

and isotopic studies of some Pan African granites from North Central Nigeria. Precambrian Research 4: 307-319.

Verheijen, P.J.T. and Ajakaiye, D.E. (1978). A Gravimeter Calibration Line, Nigeria. Survey Review, vol. 24, no. 190, pp. 373-380.

Verheijen, P.J.T. and Ajakaiye, D.E. (1980). Analysis of errors in barometric elevations in Northern Nigeria. Geophysics vol. 45, no. 7, pp. 1144-1152.

Webb, J.S. (1972). Recent research on the geology between Zaria and Kaduna. Savanna, vol. 1, no.2, pp 241-243.

Wright, J.B. and McCurry, P. (1970). Geological map of the Zaria area (sheet 102 SW), In: Zaria and its Region, Dept. of Geog. A.B.U., occ. paper no.4 pp. 5-12.