A GRAVITY SURVEY OF THE OLDER GRANITE PLUTONS IN KATABU AREA OF KADUNA STATE, NIGERIA.

BY

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B.&c (Hons) PHYSICS

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A THESIS SUBMITTED TO THE POST GRADUATE SCHOOL AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE, APPLIED GEOPHYSICS

DEPARTMENT OF PHYSICS
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DECLARATION

It is hereby declared that

1. The report presented in this thesis is the result of the original research carried out by the author.

2. This thesis has not been submitted in whatever form to any other institution, organization or body other than Ahmadu Bello University, Zaria, Nigeria for the award of any degree.

3. The works of other authors have been duly referenced and acknowledged.

Anasiudu, F. Emeka

Signed: **Emeka F. Anasiudu.**

CERTIFICATION

THIS THESIS ENTITLED: A GRAVITY SURVEY OF THE OLDER GRANITE PLUTONS IN KATABU AREA OF KADUNA STATE, NIGERIA, BY ANASIUDU EMEKA FIDELIS, MEETS THE REGULATIONS GOVERNING THE AWARD OF THE DEGREE OF MASTER OF SCIENCE, APPLIED GEOPHYSICS OF AHMADU BELLO UNIVERSITY AND IS APPROVED FOR ITS CONTRIBUTION TO KNOWLEDGE AND LITERARY PRESENTATION.

Dr. I.B. Osazuwa. Chairman, Supervisory Committee.	4th August, 1994 Date.
Dr. M. N. Umego. Member, Supervisory Committee.	5th August, 1994. Date.
Prof. S.B. Ojo. Head of Dept.	18/08/94 Date.
Prof. D. Mohammed. Dean, Postgraduate School.	26/1/96 Date.

DEDICATION

To Chief L.E. Anasiudu (KSM)
Okpara Ochendo.

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ABSTRACT

A gravity survey of the Precambrian Older Granite intrusions in Katabu area of Kaduna state, northern Nigeria has been carried out to determine the structure and probable mode of emplacement of the suite. A total of 153 stations were established at intervals of one to two kilometers using a LaCoste and Romberg gravity meter for relative gravity measurements and two altimeters for elavation determinations. Laboratory measurements were carried out on 81 rock samples collected from the area.

Interpretation of the Bouguer anomaly field shows that the area is characterized by prominent residual anomalies of -8 to +6mGal amplitude relative to a N-S trending regional anomaly with an E-W gradient of the order of 0.4 mGal/km. Negative residual anomalies correlate well with granite bodies while positive anomalies are associated with quartz diorites and schists in the area. Two-dimensional modelling of the residual anomalies reveals that the thicknesses of the quartz diorites and granite bodies vary from 2 to 5km and 2 to 7km respectively. It is estimated that the schists in the area have thicknesses of the order of 1 km. The general configuration of the modelled bodies and the pattern of the gravity anomalies suggest that the Older Granites make sharp contact with the country rocks and were magmatically emplaced into the Basement Complex. The Bouguer anomalies observed over the schists have a maximum of only -52mGal. These values are considered too low to allow for the existence of more mafic rocks at depth and the schists in Katabu area are therefore believed to have evolved in an ensialic environment.

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INTRODUCTION

1.1 General

The area studied in this survey is Katabu (fig 1.1). It is bounded by latitudes 10°28'N and 10°52'N and longitudes 7°13'E and 7°46'E and lies within the Nigerian Precambrian belt. It is located within topographic map sheet 32 KADUNA (scale 1:250,000) and has an area of approximately 1,200 sq.km. (Fig 1.2).

The road network in the area consists of two main types: The tarred roads which are well developed and include those linking Katabu to Kaduna, Jos and Zaria. The other type comprises those that can be referred to as tracks. These are often motorable only in the dry season

The area is within a transitional zone between the Guinea Savannah belt characterised by a mixture of grassland and woodland, and Sudan Savannah, a drier less humid climate characterised by grass and thornbrush with baobab trees (Adanu,1991). It forms part of the high plains of Hausaland having an average elavation of 644.96m above mean sea level. It is a rather monotonous, gently undulating erosion surface that reached maturity some time in the late tertiary. Subsequent rejuvenation has reduced this laterite cover to scattered mesas between which is a thin but highly variable succession of wind and water transported sediments. Standing above the general level of the plains are granite inselbergs and quartzite ridges covered by thin gravelly soils (Webb, 1972).

The area has a tropical continental climate having a well defined dry and wet season. The dry season starts in November and ends in March. This is the period of harmattan

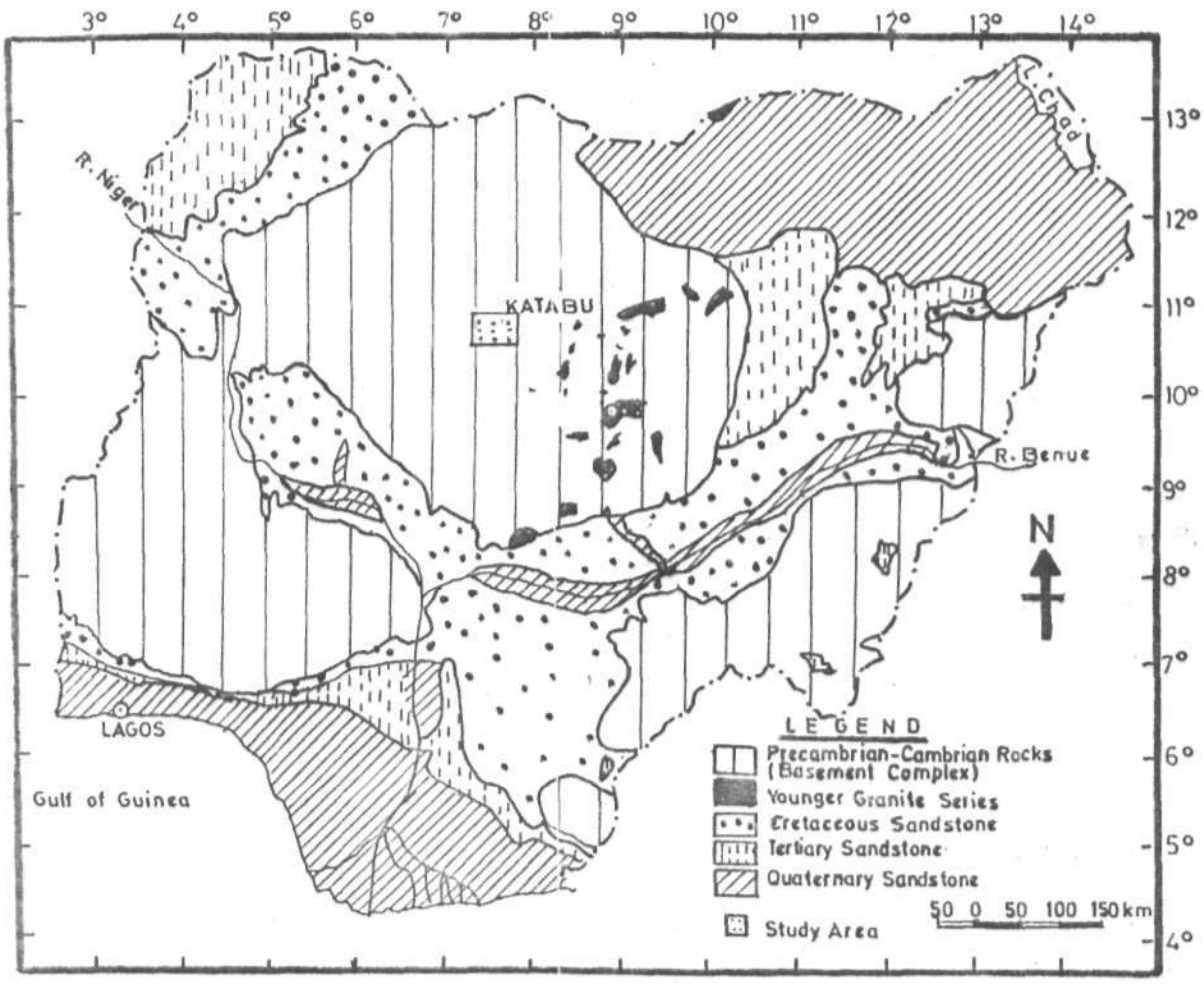


Fig.1.1: Geological sketch map of Nigeria showing study area

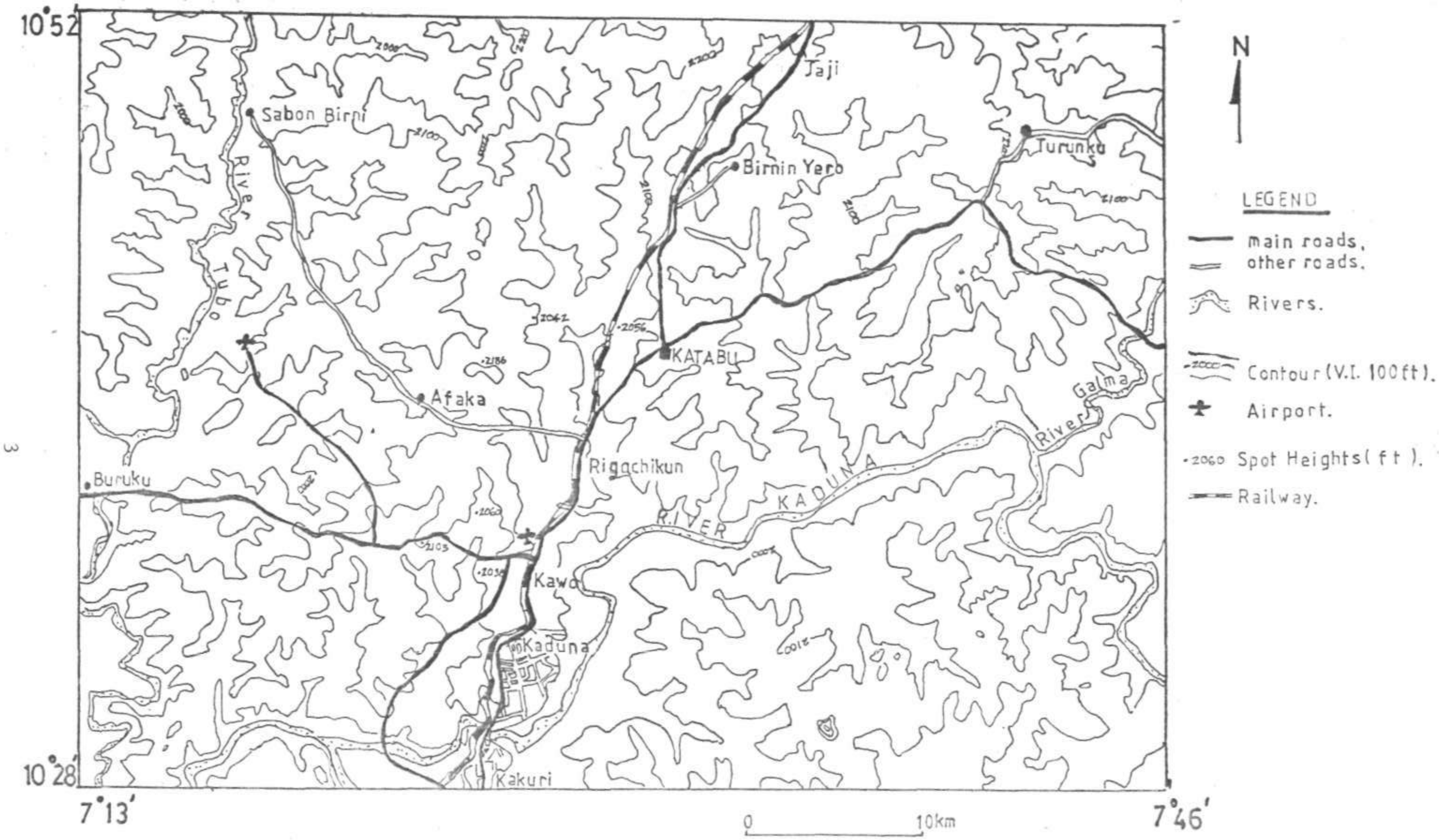


Fig 1.2: Part of topographic map sheet No.32 (KADUNA) showing survey area.

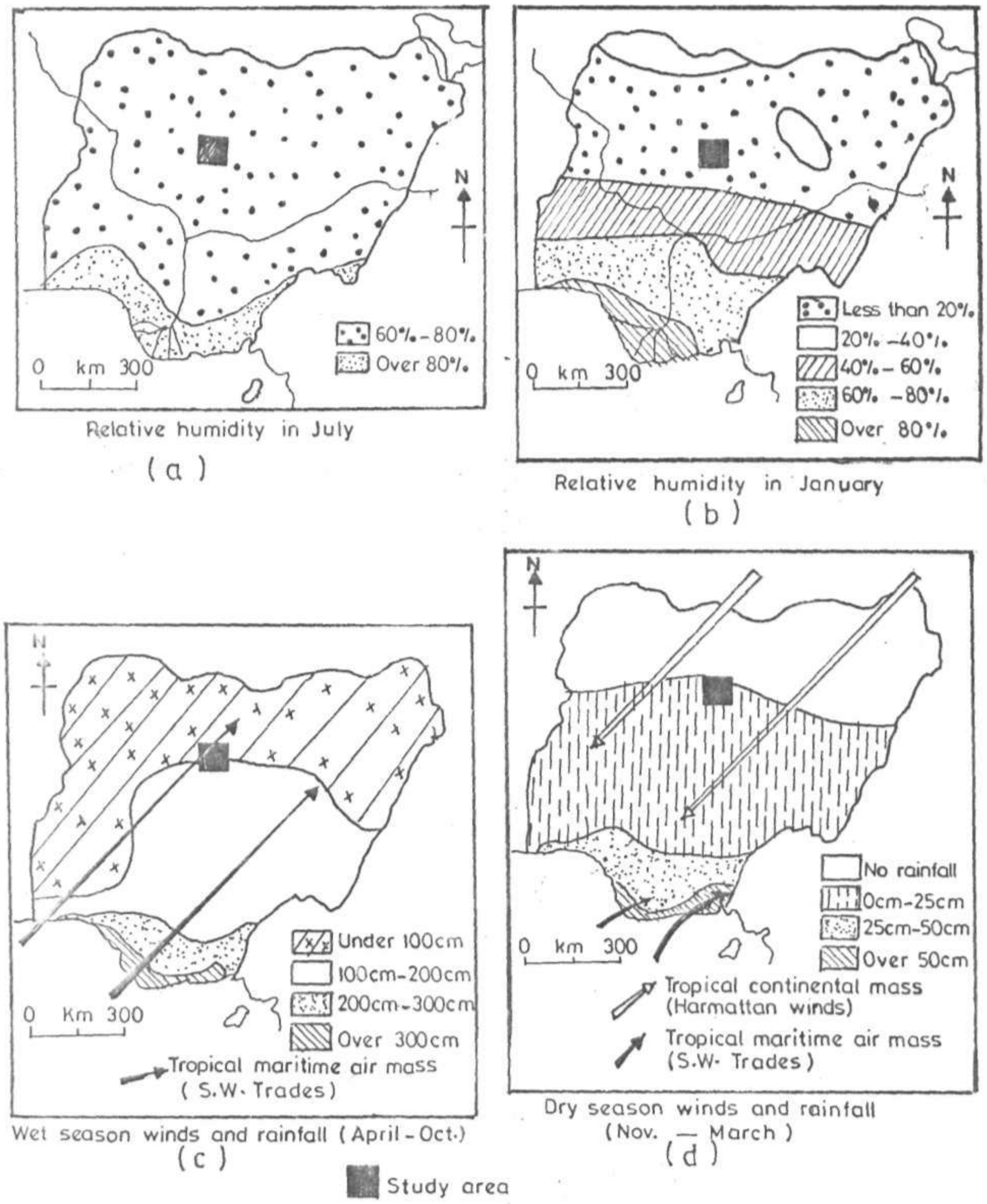


Fig. 1.3: Climatic variations of Nigeria (after Adanu, 1991).

characterised by low humidity, large diurnal range of temperature and absence of convective types of clouds. The surface turbulence caused by the wind produces a suspension cf fine dust particles in the air. The wet season begins in early April and ends in October. The average annual rainfall is about 950mm. Climatic variations are shown in fig 1.3(a,b,c,d). Mean daily temperature rises from about 20°C in January and attains its maximum of 34°C in April. In August the temperature drops to about 27°C and rises again in October to 31°C. (Data supplied by Meteorological unit, IAR (1985) ABU, Zaria).

The drainage pattern in the area is influenced by the rainfall and feeble gradients of the Hausa plains. The major rivers crossing the area originate in areas of higher elevation and, in general, steeper gradients. River Kaduna takes its source from the Jos Plateau-Ganawuri Hills (1528.57m above mean sea level) and flows through a variety of geological formations including the Mesozoic Younger Granites of the Jos Plateau, and the Basement Complex underlying the Hausa plains of northern Nigeria. Rivers Galma, Tubo and Mariga join it at various points. The gradients of these rivers decrease sharply so that large volumes of sediments are deposited in their middle and lower valleys. Consequently channels become aggraded and often subdivided with the result that in the wet season each river, in effect, becomes a wide, shallow, slow-moving sheet of water subjected to enormous losses by seepage and evaporation (Ledger, 1964).

The area became of interest as a result of a regional gravity survey of Kaduna/Katsina states (Ige et al.,1991) which showed a prominent Bouguer gravity high over Katabu. It is suspected that the anomaly may have been due to a basic intrusive into the crystalline basement belonging to the Pan-African Older Granite series.

1.2 Previous work in area.

Related geological work in the area was done by McCurry (1970) and Webb (1972) who studied the Older Granite plutons in the area and considered them to be part of a single batholith subsequently named the Zaria Batholith. Adanu (1991) carried out a ground water survey of the area in the course of which he prepared a tectonic/structural map of the area based on unpublished geological maps (produced by the Geological Survey of Nigeria, Kaduna) and aerial photo interpretation.

The geophysical work done in the area includes the aeromagnetic mapping of the area alongside those of northern Nigeria by the Geological Survey of Nigeria as part of the aero-survey project carried out throughout the country. Adeniyi (1987) carried out a detailed gravity survey over Zaria area in which he traced the Zaria Batholith southwards to the vicinity of Jaji. This massive granitoid body is believed to extend further south and is manifested by outcrops in Katabu area. Ige et al. (1991) carried out a regional gravity survey of Kaduna/Katsina states and produced a Bouguer anomaly map which showed a prominent gravity anomaly over Katabu area. The present work is a follow-up of the survey by Ige et al.(1991).

1.3 Objective and Scope.

The aim of the present work is to carry out a detailed gravity survey over Katabu area with the following objectives:

i) To investigate the vertical and horizontal extent of the Katabu anomaly and other possible members of the Older Granite suite within the area.

ii) To determine the structural relationship, if any, between the Katabu anomaly and the surrounding metasediments and gneisses and

iii) To infer how this can be related to its origin and mode of emplacement.

To achieve these objectives, a gravity survey was carried out. Rock samples were also collected for density determination.

CHAPTER 2

GEOLOGY

2.1 Geology of Katabu area.

Katabu area is underlain by rocks of the Nigerian Basement Complex. The Basement complex rocks are composed predominantly of migmatitic and granitic gneisses; quartzites, slightly migmatised to unmigmatised metasedimentary schists and metaigneous rocks; gabbroic and dioritic rocks; and the members of the Older Granite suite mainly granites, granodiorites and syenites (McCurry,1976; Rahaman,1976.) Geochronological work has shown that the Basement Complex has been through four major orogenic episodes of deformation, metamorphism and remobilization; in the Liberian (2700Ma), the Eburnean (2000Ma), the Kibaran (1100Ma) and the Pan-African (600Ma), (Ajibade and Woakes, 1989). Pan-African granitoids mark the last major event and they have intrusive and/or tectonic relationships with the earlier rock units.

2.1.1 The Migmatite-Gneiss Complex

Large tracts of Katabu are underlain by poorly exposed weathered gneisses with subordinate migmatites while rather infrequent, more resistant facies form low ridges or whalebacks and occupy anticlinal fold cores in the metasediments. In the latter they appear to have sharp contacts with adjacent rocks but elsewhere observable contacts between gneisses and metasediments are gradational. The gneisses vary from equiangular to porphyroblastic in texture and are generally light to dark coloured. The major minerals are perthitic feldspars, quartz and some plagioclase. Biotite and hornblende are the abundant mafic minerals (McCurry, 1970).

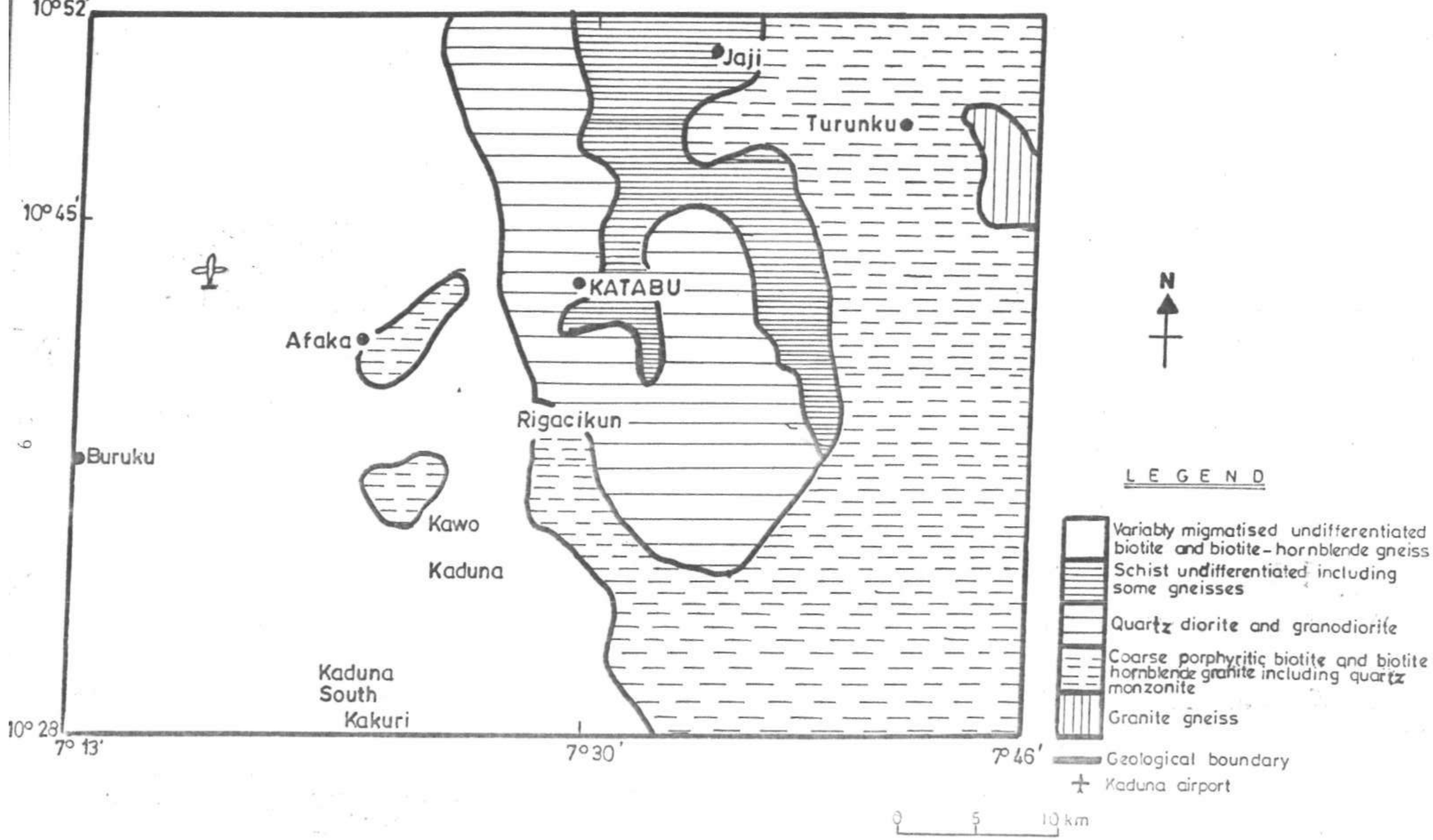


Fig. 2.1: Simplified geological map of Katabu area

Changes from gneiss into migmatite are subtle and gradual and units cannot generally be separated on geological maps. The migmatites include rocks of varying lithology, texture and structure showing differing degrees of granitisation and migmatisation. They are composite rocks consisting of metamorphic host rock and acid injections which may be pegmatitic, feldspathic or granitic material (McCurry, 1976). Truswell and Cope (1963) distinguish between embrechitic migmatites, in which structural features of the original crystalline rocks are wholly or partly preserved, and anatectic migmatites in which original structures have been nearly or completely obliterated so that these rocks approach granite in composition. The embrechites form part of the older metasedimentary sequence while the anatectites are more closely related to granitic rocks. In general, original biotite and hornblende gneisses and metasediments grade into porphyroblastic gneiss, banded gneiss, and embrechitic migmatite to anatectic migmatite and granite (McCurry,1976).

2.1.2 Schists

Schists occupy the central part of the survey area and forms a north-south trending belt. They are low-grade metamorphic rocks underlain by a pre-Pan-African basement of gneisses and migmatites. Pan-African tectonics imposed the north-south structural trend and its magmatism led to the widespread emplacement of granites in the schists (Turner,1983). They are composed mainly of muscovite and muscovite biotite schists and phyllites, interbedded with thin quartzites (McCurry,1970). Gradational boundaries within the schists are ubiquitous and the schists also grade into quartzites within the metasedimentary belt and into adjacent crystalline gneisses. Fresh specimens are difficult to obtain and they are usually only exposed in river valleys where they are deeply weathered (McCurry,1970).

2.1.3 **Quartzites**

Outcrops of quartzite occur in Katabu area. They are muscovite quartzites which form ridges covered by thin gravelly soils (Webb,1972). They are often feldspathic containing highly kaolinised plagioclase and occasional microcline in a finely granular matrix. Graphite, haematite and sillimanite are common accessories and the quartzites are often associated with muscovite-quartz schists. Usually, contact with country rocks is sharp and many of the quartzites show complicated folding and refolding (McCurry,1976).

2.1.4 **The Older Granite Series**

The intense regional tectonism that preceeded and accompanied the emplacement of the Older Granites during the Pan-African orogeny produced a well defined and extensive north-south trend in north-central Nigeria including Katabu area (Russ,1957; Truswell and Cope,1963; Grant,1969). The granitoids have been emplaced into both the migmatite-gneiss complex and the schist belt. They range in size from plutons to batholiths. The forms of the body appear to be related to the environment in which the granite is emplaced. Circular to elliptical bodies occur in schist environment and more elongate bodies in migmatite-gneiss terrains. The Older Granites include rocks of a wide range of compositions: granites, granodiorites, adamellites, quartz diorites and monzonites, syenites, and pegmatites. Granitic-granodioritic compositions are most common (Rahaman,1976). The Older Granite inselbergs, granite pavements and isolated blocky mounds found in Katabu and its surrounding areas are currently regarded as outcrops of a single batholith called the Zaria Batholith (Webb, 1972; Adeniyi, 1987; Ike, 1988). In its present form it is at least 90km long and 22km wide extending from Zaria southwards to the vicinity of Kaduna (Ike, 1988). The main rock type of the batholith is a coarse porphyritic biotite granite which is distinctly foliated. In the field the foliation is broadly oriented north-south and marked by a subparallel alignment of elongate and closely packed feldspar phenocrysts mainly microcline and a corresponding preferred orientation of biotite-mica. Xenoliths of gneisses and micro-diorite, as well as mafic clots in various stages of assimilation also occur in the rock (Ike,1988). Nearer the margin of the batholith, the granite tends to become granodioritic. The granodiorites have similar material content 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 (Alagbe,pers.comm.). In the southern part of the batholith, for example, along the Jos-Kaduna road, outcrops of granite are almost entirely restricted to gullies or low ruwares and isolated boulders. Where exposure is good, contact of the batholith with country rocks is sharp and often exhibits phenomenal interbanding of granite injections with sheets of pre-existing schists and gneisses (Webb, 1972). In summary, Webb (1972) categorized the granites making up the batholith as follows:

a) Characterised by closely packed elongate microcline phenocrysts aligned in parallel fashion and imparting a strong planar fabric to the rock.

b) Another porphyritic type, but with equant phenocrysts, and not so close together.

c) Granodiorite net-veined by later granite of type (d)

d) Medium-to coarse-grained granite, rarely porphyritic and containing xenoliths of (a)-(c)

Minor intrusive bodies consist of microgranite dykes, pegmatites and aplites, and quartz veins. These are essentially late stage occurences (Ike,1988). Table 2.1 shows a generalized chronological sequence of the various rocks types in the area (After Grant,1969, and McCurry,1970).

TABLE 2.1: Generalized chronological sequence of rock typesin survey area.

Period	Rock unit	Rock type
618 - 467Ma Late-Precambrian to Lower-Palaeozoic	Older Granites	Pegmatites, Granodiorites, Granites.
850 - 650Ma Pan African	Metasediments	Schists, Gneisses, Quartzites, Mylonites
2000Ma Eburnean	Metasediments	Feldspathic quartzites, sillimanite gneiss, basic and calcareous rocks
>2000Ma Dahomeyan	Crystalline Complex	Gneisses, Migmatites

CHAPTER 3

FIELD WORK AND DATA REDUCTION

3.1 Logistics and planning

In planning a gravimetric survey, careful consideration must be given to the logistics of the area to be studied, the instrumental factors, and availability of field requirements in order to set up an adequate gravity network. The type of gravity network is determined mainly by the station spacing, accuracy, and internal consistency of observations. The preparation for the field work entailed:

i) Obtaining the relevant topographic maps of the area at the appropriate scales (i.e. 1:50,000, 1:100,000 or 1:250,000) and outlining the boundaries of all formations within the survey area.

ii) Choosing survey routes and producing station identification maps with sketches of base stations to be visited.

iii) Selection of a suitable field observational procedure.

iv) Obtaining and observing the required instruments.

v) Obtaining advance clearance to take measurements at gravity base stations situated in restricted areas.

A logistic problem encountered during planning was the poor road network in the area. Although the federal highways were in good condition, the smaller road tracks (mainly DFRRI roads) were in very poor condition owing in part to the fact that they were largely untarred, and also as a result of the prevailing rainfall at the time of the survey. Another problem was the non-availability of standard topographic maps of the area.

Most of the maps were produced several years ago and did not reflect new roads in the area. The survey routes were chosen with the aid of a 1:250,000 scale topographic map (fig 1.2). The choice of routes was governed by the available road network, their accessibility and motorability and the need for an even spatial coverage over the area. The extent of the survey was determined by the geological information and the necessity to establish an adequate regional field. The field stations were located at intervals of 1 to 2 km along motorable roads. Tentative loop sequences were prepared using the single-base loop method (Osazuwa, 1985) with the main base at Katabu.

3.1.1 Instrumentation

A LaCoste and Romberg gravity meter (model No.G512) and six Wallace and Tiernan aneroid altimeters (model No.FA 181) were studied and put under observation for two days. This was necessary to detect any malfunctioning instrument, identify any peculiarity in instrument behaviour as well as their drift characteristics. Two of the altimeters were selected for the survey and these were adjusted for the correct elavation range using the mean elavation (644.96m above msl) of the area. The responses of the gravimeter and altimeters as a function of time are summarized in figs 3.1, 3.2 and 3.3. The observation revealed a negligible drift rate for the gravimeter and a faulty altimeter (ALT D). The shift of the responses of the altimeters along the reading axis is ascribed to the difference in characteristic behaviour of each instrument (Osazuwa, 1992(a)).

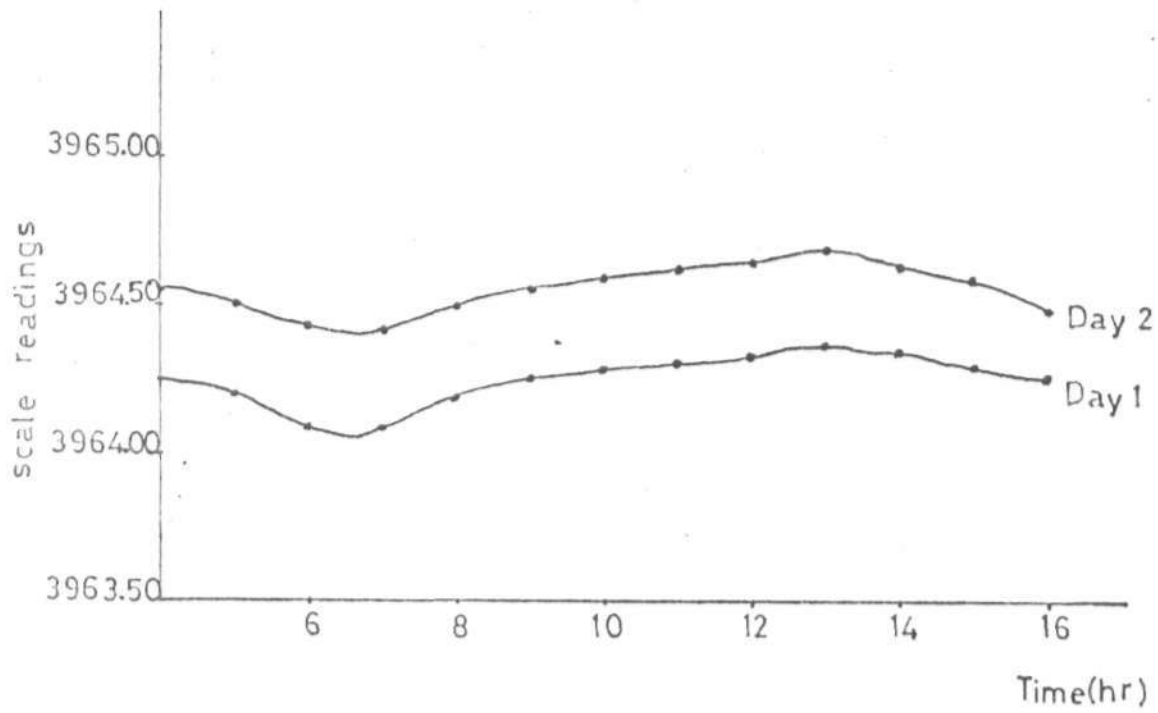


Fig 3.1: Gravimeter drift curves.

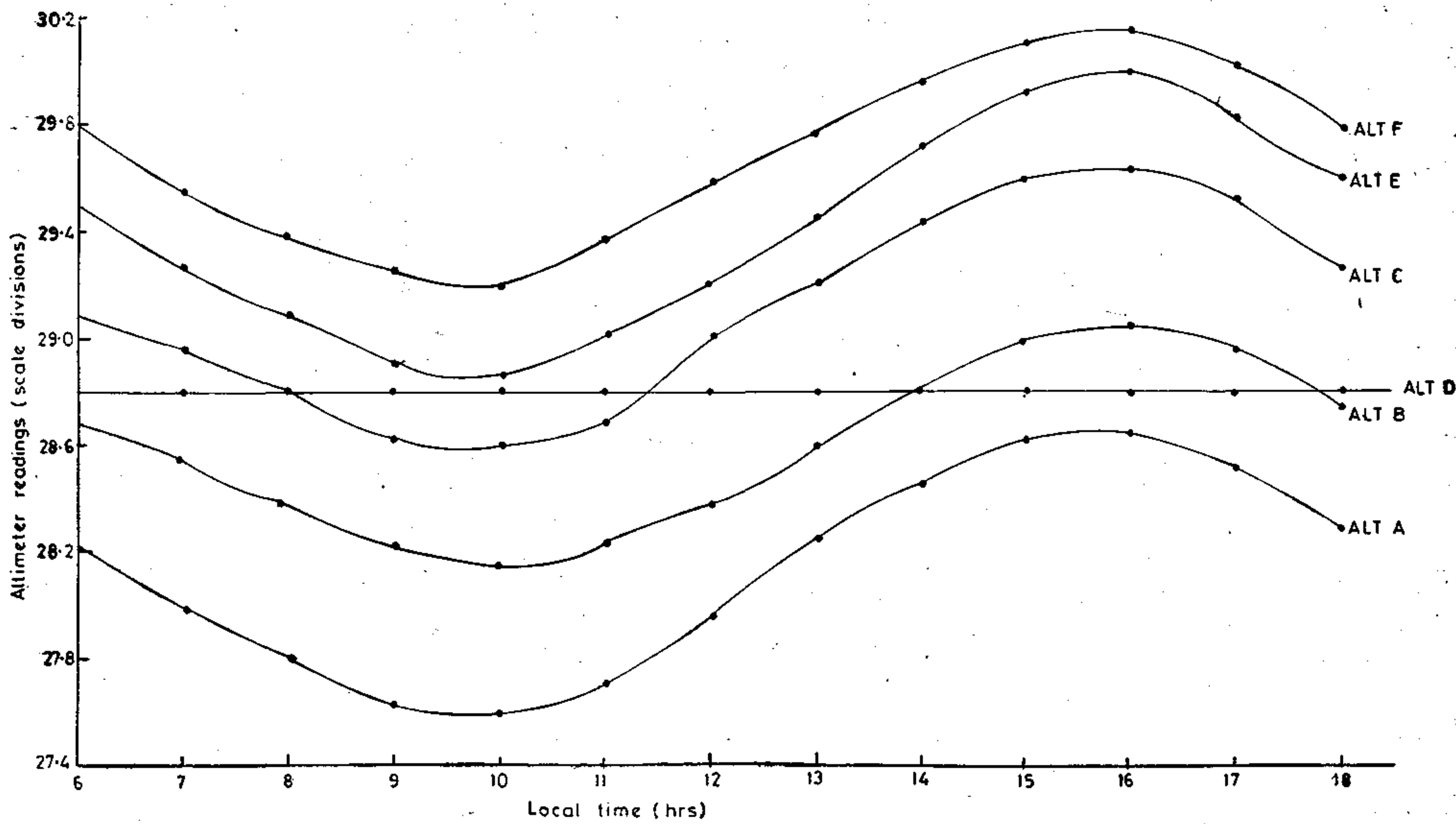


Fig.3.2: Altimeter drift curves day 1

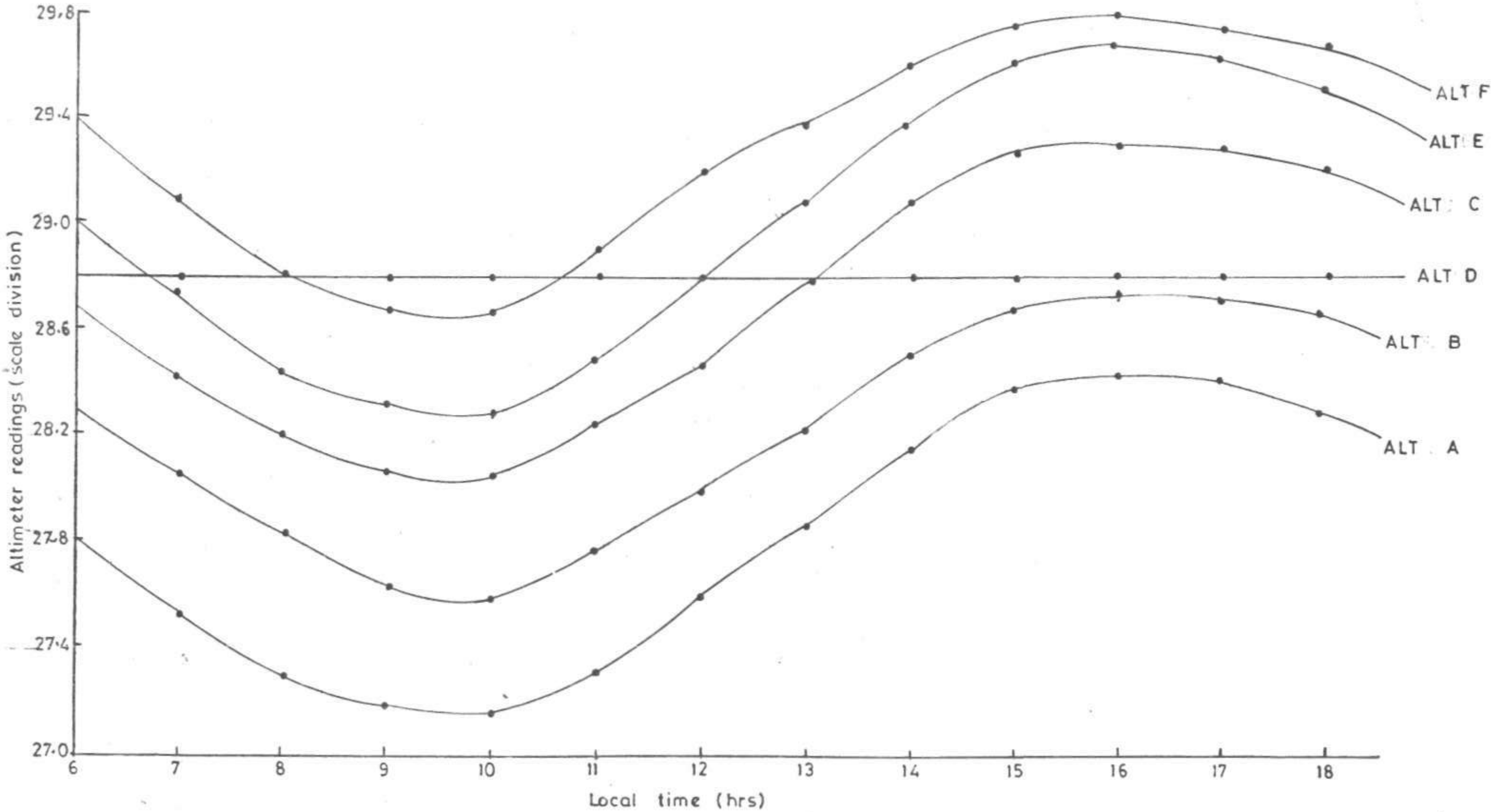


Fig.3.3 : Altimeter drift curves day 2

3.2 **Field Work**

The field work was carried out in July 1992 and in October 1992 (to obtain more altimetric data). Using the odometer of the field vehicle and a field map of the survey area, station positions were located. In addition, other features such as road junctions and milestones were used to affirm station positions and establish new ones. Fig. 3.4 shows the location and general distribution of field stations. Data collected in the field included gravimeter readings, altimeter readings as well as wet and dry bulb temperatures.

All the observed gravity values in the survey were taken relative to the value 978029.737 mGal at the primary gravity network of Nigeria base station (FSN-GMSJ1B) located at the Nigerian Airforce base (Kaduna old Airport), Kaduna, which is tied to the International Gravity Standardization Net, (1GSN, 1971), (Osazuwa, 1985). The LaCoste and Romberg gravimeter (G512) was used to establish a base station in Katabu for the survey. For additional control on the altimetric readings the base station was also tied to a national gravity base station (GMSC4) at the Nigerian College of Aviation Technology, Zaria, and a national gravity base station in the Physics Department building, ABU. For both the gravimetric and altimetric work, the single-base loop method of observational sequence (Osazuwa, 1985) was adopted, with both sets of readings taken simultaneously. Reoccupation at the base stations was, on the average limited to between 2½ and 3 hours. This was aimed at having effective control over the instrument drift and the diurnal tidal and pressure variations where these may not be corrected for. Other noteworthy precautionary steps taken while handling the instruments in the field included:

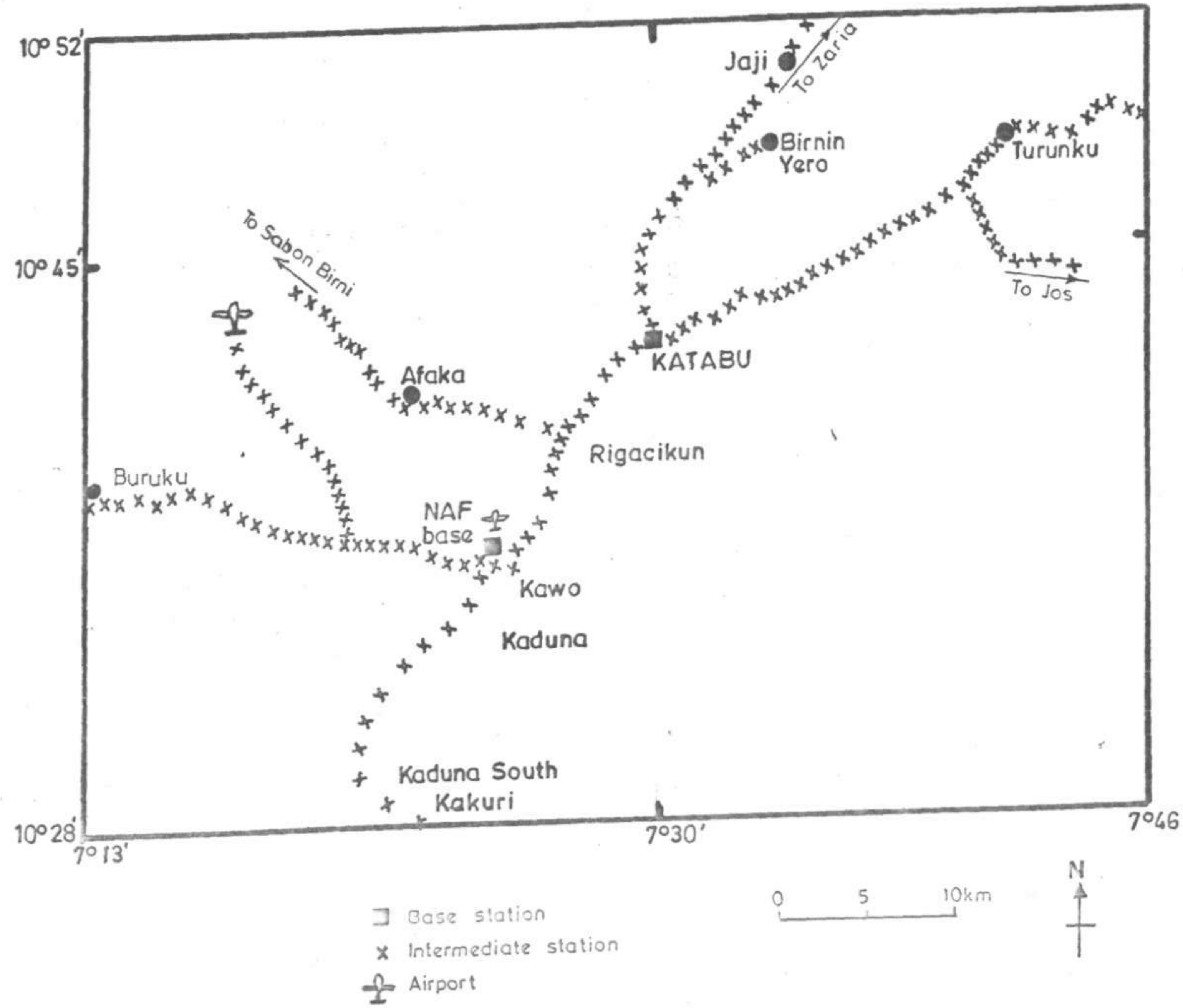


Fig.3.4 :Station distribution map

i) Keeping observation points free from microseismic activities of cities as much as possible.

ii) Maintaining the gravimeter constantly on heat by ensuring constant power supply and recharging the batteries after each days work. This was necessary to avoid spurious readings.

iii) The pointers of the altimeters were allowed to settle before taking readings. At the end of each observation the altimeters were closed to avoid excessive drift during transportation. For the same reason, the beam of the gravimeter was clamped between readings.

iv) The instruments were shielded from direct sunshine and wind to prevent thermal shock as discovered by Osazuwa and Ajakaiye (1982).

v) Care was also taken to minimise jerks or mechanical disturbances on the instruments so that they do not suffer undetectable creep (Hamilton and Brule, 1967).

A total of 153 detailed stations were occupied and these were all tied to the main base. On the average 12 - 30 stations were occupied per day depending on the quality of the road, accessibility, and weather conditions. In addition rock samples were collected from outcrops within the area for density determination.

3.3 DATA REDUCTION

The reduction of the raw data was divided into two parts. The first part dealt with the reduction of the altimetric data. This was done manually. The second part was for the gravity data reduction and was accomplished with the aid of a computer program (Osazuwa, 1986).

3.3.1 Altimeter Data

The altimeter readings were first corrected for relative humidity using psychrometric and relative humidity correction charts provided by the instrument manufacturers. The two altimeters used in the field did not give the same reading for each station. This is understandably due to the characteristic behaviour of each instrument (Osazuwa, 1992(a)). However a statistical test of significance was carried out in order to ascertain if the difference in height between consecutive stations as obtained from each altimeter was significant. Table 3.1 serves to illustrate the test.

TABLE 3.1 Table of Gaussian and standard normal distributions for differences in altimeter readings.

Station	A_1 (ft)	A_2 (ft)	x	f(x)	z	y
*KB 0001JJ	-27.87	-24.68	-3.19	0.071	-0.82	0.2850
KB 0002JJ	39.21	33.12	6.09	0.030	1.57	0.1163
KB 0003JJ	24.02	24.47	0.45	0.099	0.12	0.3961
KB 0004JJ	20.35	15.63	4.72	0.050	1.22	0.1895
KB 0005JJ	-28.94	-21.00	-7.94	0.010	-2.05	0.0488
KB 0006JJ	25.60	26.16	-0.56	0.099	-0.14	0.3951
KB 0007JJ	25.76	24.86	0.90	0.097	0.23	0.3885
KB 0008JJ	-2.48	-2.94	0.46	0.099	0.12	0.3961
90099	-27.61	-26.68	-0.93	0.097	0.24	0.3876

Key

A_1 : Difference in height measured by Altimeter No.1 between consecutive stations.

A_2 : Difference in height measured by Altimeter No.2 between consecutive stations.

x : Difference between A_1 and A_2 (i.e $A_1 - A_2$)

f(x): Gaussian distribution curve given by

$$f(x) = \frac{1}{\sqrt{(2\pi\sigma^2)}} \exp\left[-\frac{(x-\mu)^2}{2\sigma^2}\right] \qquad (3.1)$$

where μ = mean, σ^2 = variance.

z : standard normal score (with mean zero and variance one) given by

$$z = \frac{x-\mu}{\sigma} \qquad (3.2)$$

y : ordinate of z (given in statistical table of standard normal distribution) defined by

$$y = \frac{1}{\sqrt{2\pi}} \exp[-\tfrac{1}{2}z^2] \qquad (3.3)$$

*The height differences for this station were taken with respect to station 90099.

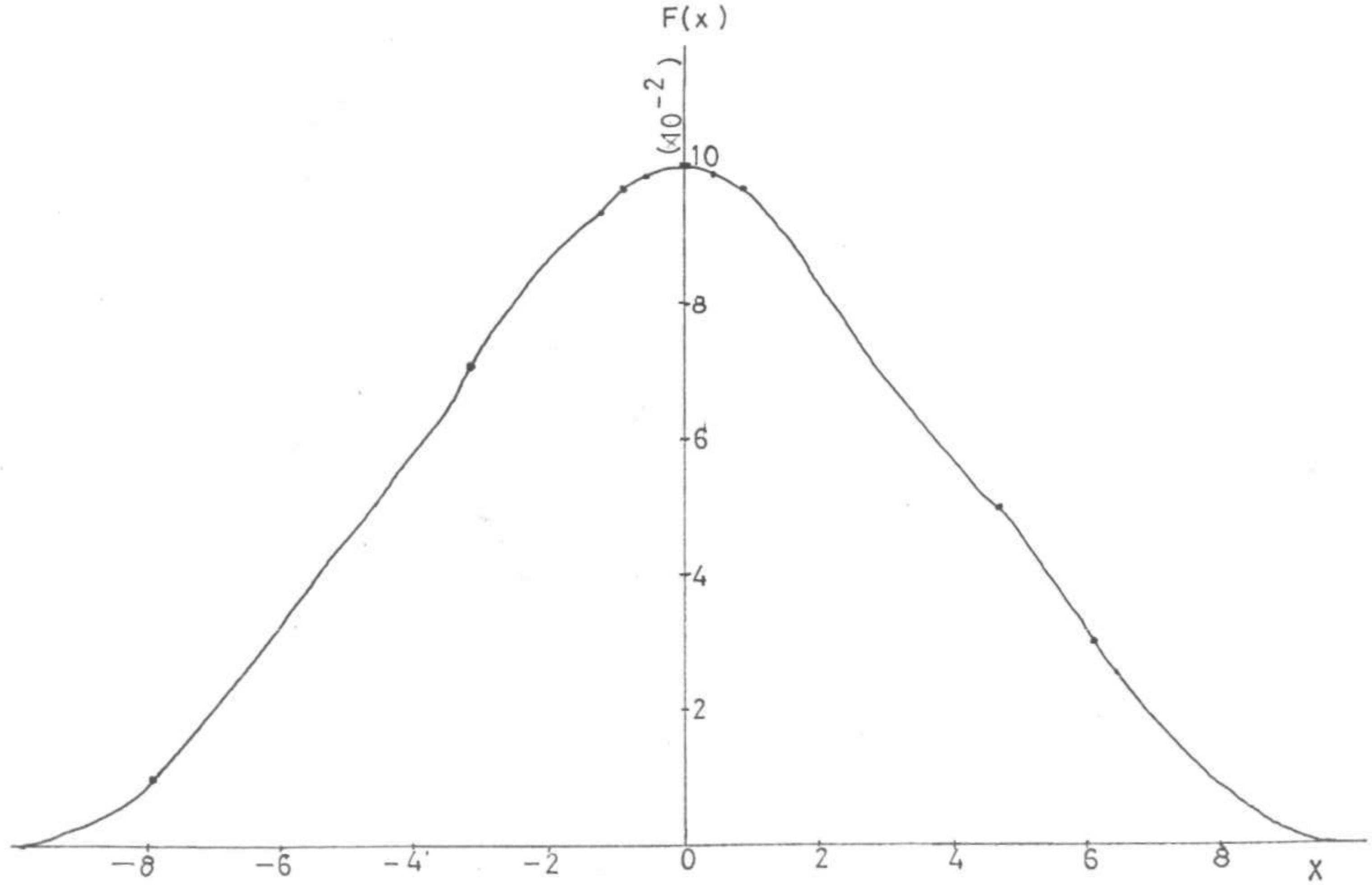


Fig. 3.5 Gaussian distribution curve for difference in altimeter readings.

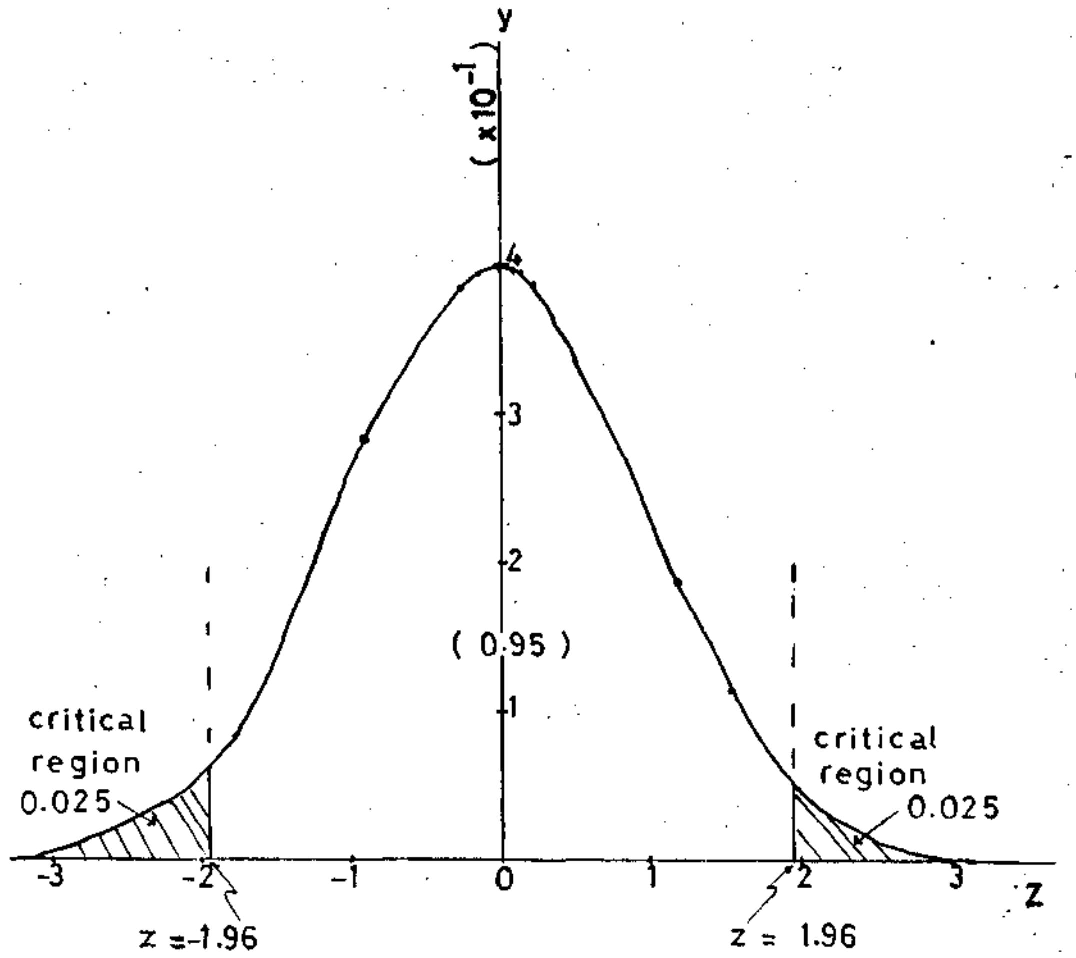


Fig. 3.6 Standard normal distribution curve for difference in altimeter readings.

The differences between altimeter readings, x, were plotted as a variable on a Gaussian distribution (fig 3.5), and this showed that the differences were normally distributed about a zero mean. A standardized normal curve of the distribution (fig 3.6) was plotted with the aid of statistical tables and tested at a 5% level of significance. The areas between z = -1 and + 1, z = -2 and +2, and z $\pm$ - 3 and +3 are equal respectively to 68.27%, 95.45% and 99.73% of the total area under the curve which is one. The total shaded area, 0.05, is the level of significance of the test. The set of z scores outside the range $-1.96 \leq z \leq +1.96$ constitutes what is called the *critical region* while the z scores within the range $-1.96 \leq z \leq 1.96$ is called the *region of acceptance* or *region of non-significance*. In the above test attention is focussed on extreme values of the z score on both sides of the mean i.e in both 'tails' of the distribution. For this reason it is often called a two-tailed test of significance. (see Spiegel,1972); Clark and Cooke,1984 for details) Fig 3.6 shows that most of the z - scores fall within the region of non-significance and thus the differences between altimeter height readings can be considered to be insignificant.

Drift correction was done separately for each altimeter using the Cascade drift model (Osazuwa, 1988). The basic principle of the method is that when all observations in a day are tied to the same time origin during a days work, repeat observations at the same station after drift correction should be equal. The underlying assumption is that drift of the instrument is a linear function of time over a short interval of time.

The absolute elavation for each station was determined for each altimeter using the height of the main base. The average value of the two heights so determined was taken as the absolute elavation of each station. These heights correlate well with the values on the topographic map of the area.

3.3.2 Gravity Data

Two requirements must be satisfied in order to produce useful gravity maps. First, the measuring apparatus must be sufficiently sensitive to detect the effects of local geologic structures on the gravity field, g, of the earth. Second, methods must be used to correct the data for all sources of variations other than the local geology.

For most surveys, gravity values are transformed into Bouguer anomalies to make them represent the variation in subsurface mass distribution which is of geological interest. To this end, the readings must undergo several corrections in order to reduce them to the values they would have on some equipotential datum surface. Such a surface is the geoid or the mean sea-level surface with excess land masses removed and ocean depths filled. The theoretical value of gravity computed for the reference ellipsoid is then compared with the observed field values to obtain Bouguer anomalies. If the earth were an isolated, irrotational, spherical body of constant density with respect to its concentric composition shells, gravity data interpretation would be greatly simplified. Unfortunately the earth is far from being spherical, the density changes considerably from continental material to ocean basin material, and the effects of the sun and moon cannot be overlooked. Inorder to obtain results which are not misleading, one must mathematically isolate, stretch and compress the earth until it conforms to the perfect model. To this end, the following corrections need to be carried out:

The earth tide and drift correction smooths the effect of the sun and moon as well as correcting for the natural drift of the instrument. Tidal tables were employed for the tidal correction while the cascade model (Osazuwa, 1988) was used to remove the instrumental drift. The other corrections can be split into three groups.

i) Corrections involving differences in elevation above the datum surface, the mean sea level in this case.

ii) Corrections involving the material between the actual ground surface and the datum surface.

iii) Corrections for nearby topographic features.

The free-air correction essentially adjusts all readings to a common datum, the mean sea-level in this case. It can be shown from the inverse square law (see Telford et al, 1976) that gravity changes at a rate of 0.3086 mGal/m change in elavation. Therefore if the gravity value at a station is to be transformed downward to a datum plane below it the correction would thus be 0.3086h where h is the difference in elavation between the datum and the station.

The Bouguer correction mathematically removes the effect of the material between the horizontal plane passing through the station and the reference datum plane. The Bouguer correction, $0.04193\rho h$ mGal is opposite in sign to the free air correction and is directly related to it (where ρ is the mean density of the material between the station and the datum plane). For this reason the two corrections are often combined in the elavation correction, E, given by:

$$E = 0.3086h - 0.04193\rho h \qquad (3.4)$$

The Bouguer reduction density, ρ, is usually chosen by one of three methods. The first is to use what could be called traditional or standard density. Most regional maps have traditionally been reduced using a value of 2.67 x $10^3 kgm^{-3}$; the greatest consistency and compatibility with older adjacent or regional surveys is achieved if this value is used. The second method originally suggested by Nettleton (1939) and also Vajk (1956) determines a Bouguer reduction density that minimizes the correlation between the complete Bouguer anomaly and topography. This method is widely used in areas of rugged topography (Gerkens,1989). The method could not be used for this survey because the area is relatively flat.

The third method is to measure the density of representative rock samples. It is however usually difficult to obtain a suite of rock samples that is truly representative (Williams and Finn, 1985). The first method using a density value of 2.67 x 10^3 kgm^{-3} was chosen for the reason given above.

The effect of terrain is that nearby hills rising above the general level of a station give an upward component of gravity attraction that counteracts a part of the downward pull exerted by the rest of the earth. Similarly valleys in the vicinity of a station between station and datum level are responsible for a smaller downward pull than is accounted for by the Bouguer correction. The correction can be made with an accuracy of 0.1 to 1.0 mGal (Hays,1976) by the use of templates and graphical methods (Dobrin,1976; Telford et al,1976). This correction was not carried out because the survey area was relatively flat. The latitude correction adjusts for the earths variation in gravity with latitude. This correction utilises the international gravity formula (IGF) to obtain the rate of change along a north-south line.

The GRS (1967) formula in milligals given in Osazuwa (1985) as

$$g_{\phi} = 978031.846(1 + 0.005278895\sin^2\phi + 0.000023462\sin^4\phi) \qquad \ldots(3.5)$$

was used for the reduction to reference ellipsoid, where ϕ is the latitude of station. The Bullard term correction accounts for the curvature of the earth. The Bouguer anomaly is given by

$$BA = g_o - g_{\phi} + FAC - BC - BTC \qquad (3.6)$$

where g_o is the observed gravity, g_{ϕ} the theoretical gravity, FAC the Free-Air correction, BC the Bouguer correction and BTC the Bullard term correction.

The gravimeter data reduction was carried out using a Fortran 77 computer programme written by Osazuwa (1986). The programme automatically does the conversion of gravimeter scale readings to their corresponding milligal values, tidal correction, drift correction, Free-Air, Bouguer and Bullard term corrections. The program uses the Geodetic Reference System (GRS 67) formula for the computation of the theoretical or normal gravity on the reference ellipsoid. It assumes a value of 2.67 x 10^3kgm^{-3} for the mean density of surface rocks. As stated earlier, this density value and the choice of the GRS'67 formula as recommended by Morelli (1976), is to standardize the result of this survey.

3.3.3 Rock Densities

The significant parameter in gravity exploration - the anomaly source - is a local variation in density. A knowledge of the densities of rocks is essential in petrological and geological studies, and more so for a meaningful structural interpretation of gravity anomalies. For interpretation, it is not the absolute density, but the density contrasts that are important (Dobrin, 1976). The exact determination of Bouguer densities constitutes a major problem because of the heterogeneous nature of the rocks which form the upper crust. The overlapping nature of the rock units implies surface boundaries of the rock units cannot be exact at depths below the surface. Thus the surface rock samples collected for density determination may not be representative and therefore have limited reliability (Osazuwa, 1992(b)). Despite such variations, it is often necessary to assume average densities for survey areas where the geology is known but no densities have actually been measured. These densities help in constraining the models for the subsurface bodies that cause the observed anomalies.

A total of 81 rock samples were collected and labelled during field work. They were obtained from a variety of outcrops along traverses and from rocks exposed as a result of road construction work in the area. The dry and wet densities for each rock obtained from this method assumes that the most acceptable in-situ density of a rock unit is that which lies between dry and wet densities of the rock sample. The formulae used were

$$\rho_{dry} = \frac{dry\ weight\ in\ air}{(dry\ weight\ in\ air) - (weight\ in\ water)} \quad (3.7)$$

$$\rho_{wet} = \frac{saturated\ weight\ in\ air}{(saturated\ weight\ in\ air) - (saturated\ weight\ in\ water)} \quad (3.8)$$

The saturated measurements were made after soaking the samples in water for 48 hours. A Mettler balance (model PS15) was used for sample weight measurement. It has an accuracy of 1.0×10^{-4} kg. Generally the difference in densities obtained between dry and saturated samples were negligible. This negligible difference is to be expected considering the fact that the porosity or permeability of the igneous and crystalline metamorphic rocks in the area are very small. Average densities and standard deviations of the different rocks types based on these samples are given in table 3.2. These densities compare favourably with those determined for similar rock types in other areas (e.g Ajakaiye,1974; Udensi,et al.,1986; Adeniyi,1987; Umego,1990). The average density for all the rock types is $2.688 \times 10^3 kgm^{-3}$. This value was used later to estimate the error in Bouguer anomaly value.

TABLE 3.2: Average densities of rock samples based on laboratory measurements.

Rock type	No of samples	Range of densities $x10^3 kgm^{-3}$	Mean dry density $x10^3 kgm^{-3}$	Mean wet density $x10kgm^{-3}$	Average density $x10^3 kgm^{-3}$	Std. Dev.
Granite	36	2.55-2.67	2.62	2.63	2.63	0.05
Gneiss	16	2.62-2.79	2.70	2.70	2.70	0.03
Migmatite	9	2.64-2.73	2.69	2.70	2.70	0.03
Quartz Diorite	7	2.78-2.80	2.79	2.79	2.79	0.02
Quartzite	13	2.60-2.63	2.61	2.62	2.62	0.03

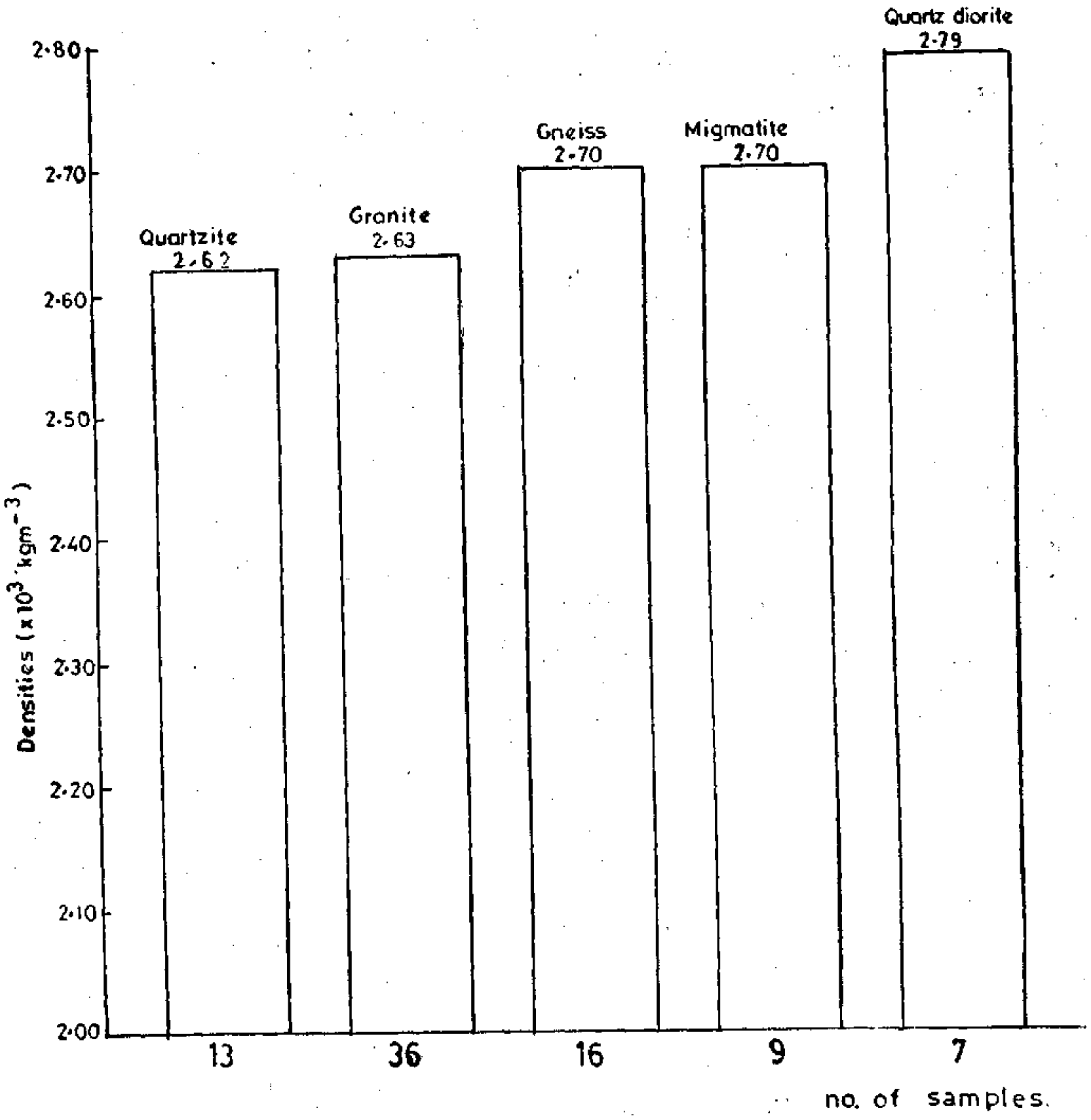


Fig. 3.7 Average densities of rock samples.

3.4 Errors in Bouguer anomalies

The errors in Bouguer anomalies could arise from a variety of sources. These include errors in elavation determination, e_h, errors in assumed reduction density e_ρ, error in station location e_ϕ, error in terrain effect e_t and error in base value e_b. Other errors could arise from mode of observation, non-linear drift of instrument and calibration factor e_o. The total error is given by Murty (1977) as

$$e_T = (e_h^2 + e_\rho^2 + e_\phi^2 + e_t^2 + e_b^2 + e_o^2)^{1/2} \tag{3.9}$$

The error in determining station elavation by means of altimeters could be as much as 5m (Verheijen and Ajakaiye, 1980). This could produce a corresponding error of 0.98mGal in the value of Bouguer anomaly. However, by observing a proper time window for measurement, Osazuwa (1992a) observed that the error in elavation determination could be decreased to less than 1.5m. This would produce a corresponding error of less than 0.5mGal in the Bouguer anomaly.

The mean crustal density used for the Bouguer correction was 2.67 x 10^3kgm^{-3}. The average density determined for all the field samples collected was 2.688 x 10^3kgm^{-3}. There is therefore a density uncertainty of 0.018 x 10^3kgm^{-3} between assumed and actual values. This would introduce an error of 0.048 mGal over the height range of 64m observed during the survey.

The rate of change of gravity with north-south displacement as a function of latitude, ϕ, is given by Parasnis (1973) as 0.00081 Sin2ϕ. The station latitudes of the station were determined to the nearest second by gridding the base map (1:250,000 scale) using a transparent overlay. An estimated maximum location error of 15 seconds of latitude could produce an error of 0.14mGal in the latitude range covered by the survey.

Due to the generally flat nature of the survey area terrain correction was not carried out. However, the maximum error due to terrain effect is estimated to be less than 0.01mGal and this is considered to be insignificant.

The mode of observation error arises from precision and clamping of the instrument. The gravity measurements were made using a LaCoste and Romberg gravimeter. It has a built-in temperature regulator system and a mechanism for clamping the moving parts during transportation. This facility minimizes the instrument 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 observation time window for the gravimeter was restricted to 3 hours. The errors in measured gravity values when observations are restricted to this time interval are negligible and cannot be detected with the gravimeter (Osazuwa, 1992(a). According to Brien et al. (1977), the effect of all these produces a maximum error of 0.01mGal.

For error in base value, Osazuwa (1985) put it at 0.012mGal. The error due to tidal effect was computed for the latitude range of the survey area using tidal correction tables. It is supposed that the mean tidal effect would satisfactorily approximate the estimated error from tidal drift. This in turn has been significantly reduced from a maximum error of 0.31 mGal by the field sequence designed for reoccupation at base within 2½ hours.

From the above analysis, it is therefore, estimated that the total probable error e_T, at any given station would be 1.0mGal for a majority of the stations.

CHAPTER 4

INTERPRETATION

4.1 General.

The gravitational field, g, of the earth has a worldwide average of 980 Gals with a total range of variation of about 5.3 Gals from the equator to the poles (Dobrin,1976). In Nigeria the range of gravity variation is 376.948mGal, of which that anticipated for Katabu area (i.e the Zaria-Kaduna difference) is 1.488 mGal (Osazuwa and Ajakaiye, 1992).

According to Torge (1989), differences in position (Equator-poles) and in elavation (high mountains - deep seas) is largely responsible for the earths range of gravity variation. The earth's departure from sphericity and its rotation cause g to have a maximum value at the poles and a minimum value at the equator. Disturbing masses (deviations from simple earth models) located deeper (crust/mantle) and higher (upper crust) in the earth cause variations in larger and smaller regions of 5×10^{-4} and 5×10^{-5} of g respectively. Periodic tidal effects amount to 3×10^{-7} of g while long term terrestrial mass displacements only cause gravity changes of the order of 10^{-8} to 10^{-9} of g. Mineral ore bodies and geologic structures of interest seldom produce variations in g exceeding a few milligals or about one part in 10^{6} of g.

To calculate details of the size and shape of most geologic structures of interest requires a precision of 0.01 mGals or one part in 10^{8} of g. This precision can be achieved with a LaCoste and Romberg gravimeter which has a sensitivity of ± 10 μgal and it responds to variations in g rather than measuring g directly. The observed gravity values are used directly only in geodetic studies.

In general areas underlain by acidic rocks such as granite plutons have negative gravity signatures whereas more mafic rock types show positive gravity signatures.

4.2 Description of Bouguer and Free-Air anomalies

The Free-air anomaly map is shown in fig (4.1). It is characterised by positive anomalies ranging from a maximum of 37mGal to a minimum value of 3mGal. The computation for the free-air anomaly is independent of whether or not there is any rock material between the sea-level datum and the station elavation and thus has little bearing on the interpretation. It however provides a picture of the influence of topographic features superposed over the effect of subsurface structures. It has more relevance in geoidetic studies and in more general problems like isostacy.

The Bouguer anomaly map of the area is shown in fig (4.2). The area is characterised by negative anomalies ranging from -37mGal to -69mGal with a mean value of -51mGal. The individual station maximum value of -37 mGal occurs near Kakuri while the minimum value of -69mGal occurs near Turunku. The dominant trend of the Bouguer field is not immediately obvious.

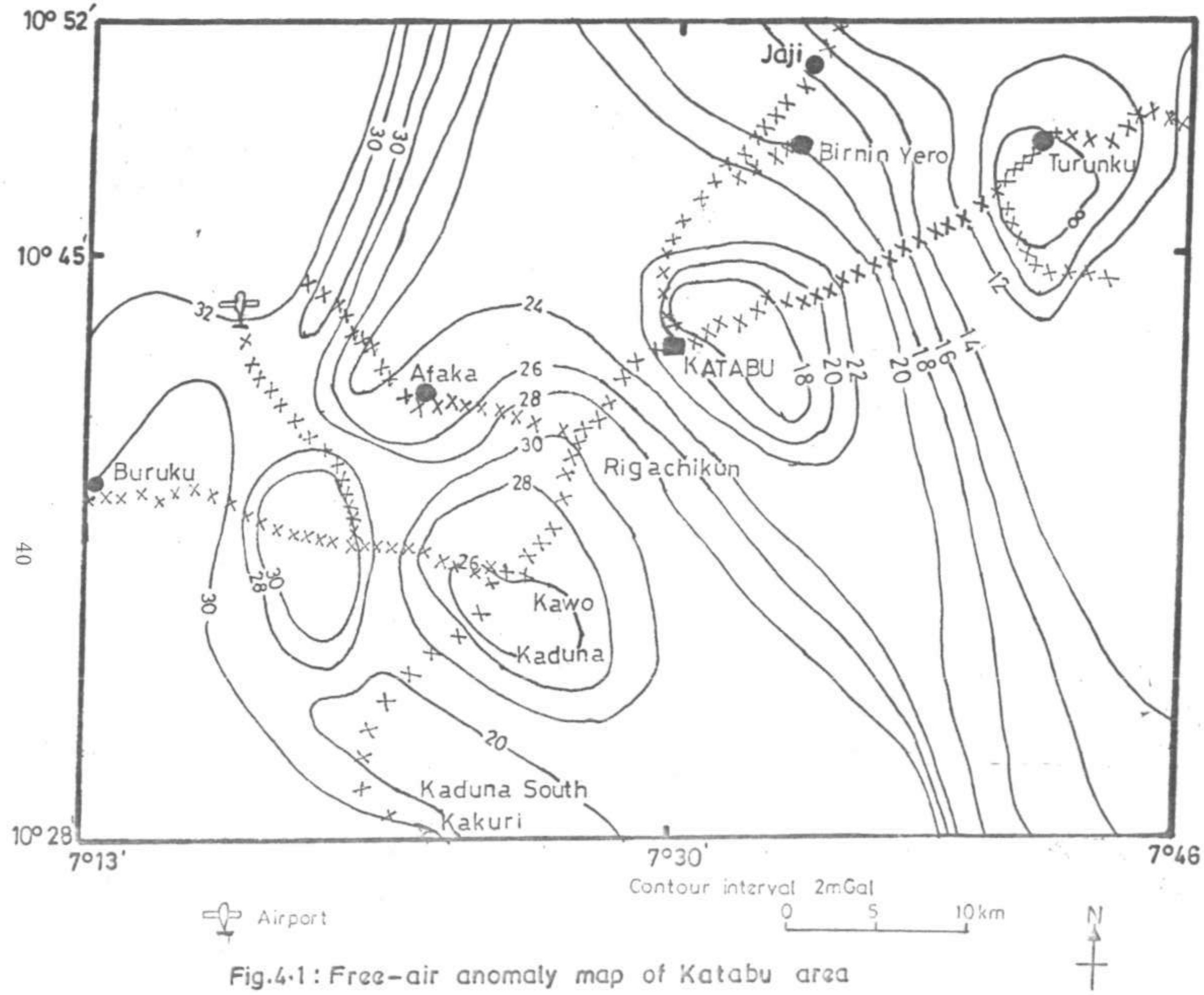


Fig.4·1: Free-air anomaly map of Katabu area

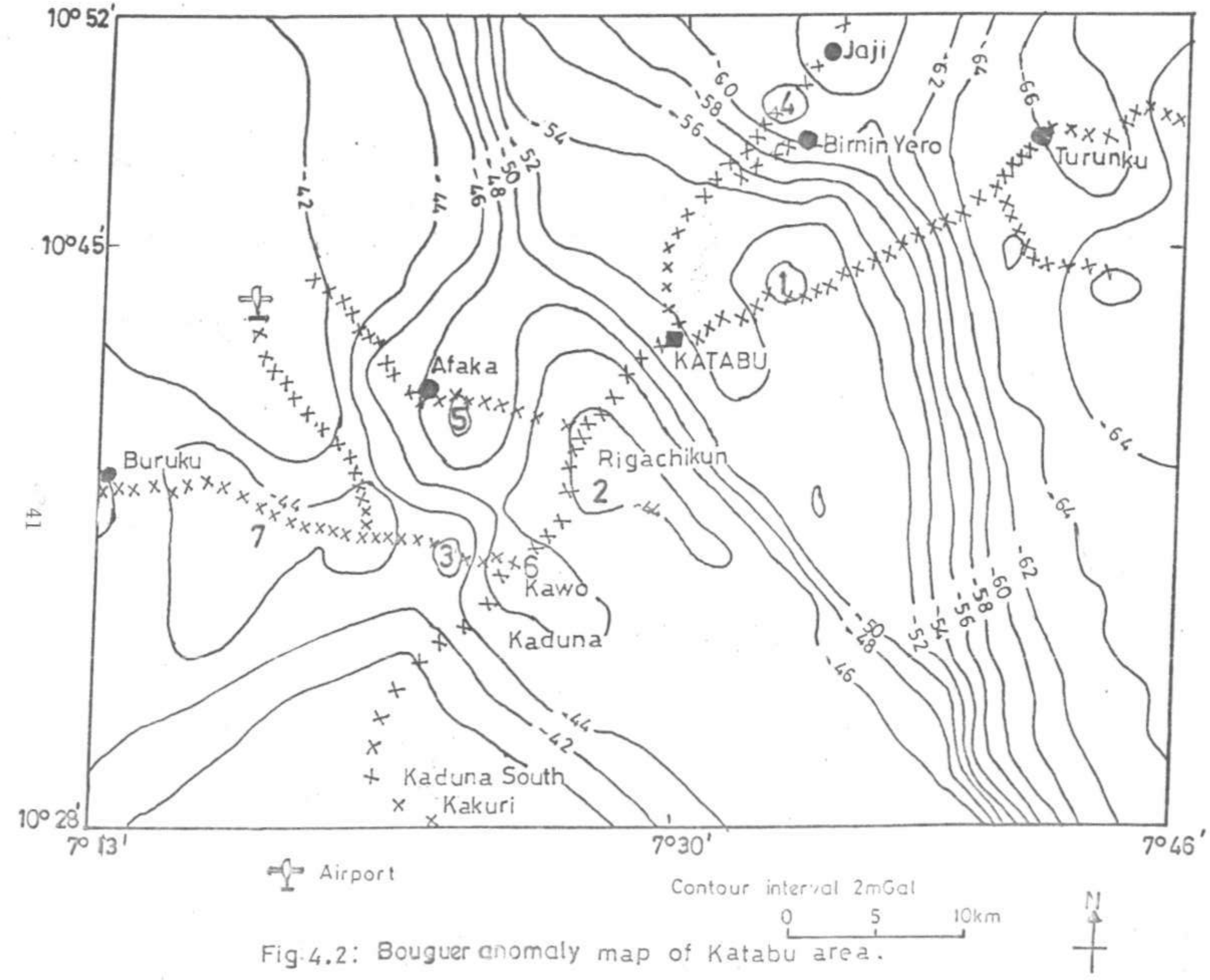


Fig.4.2: Bouguer anomaly map of Katabu area.

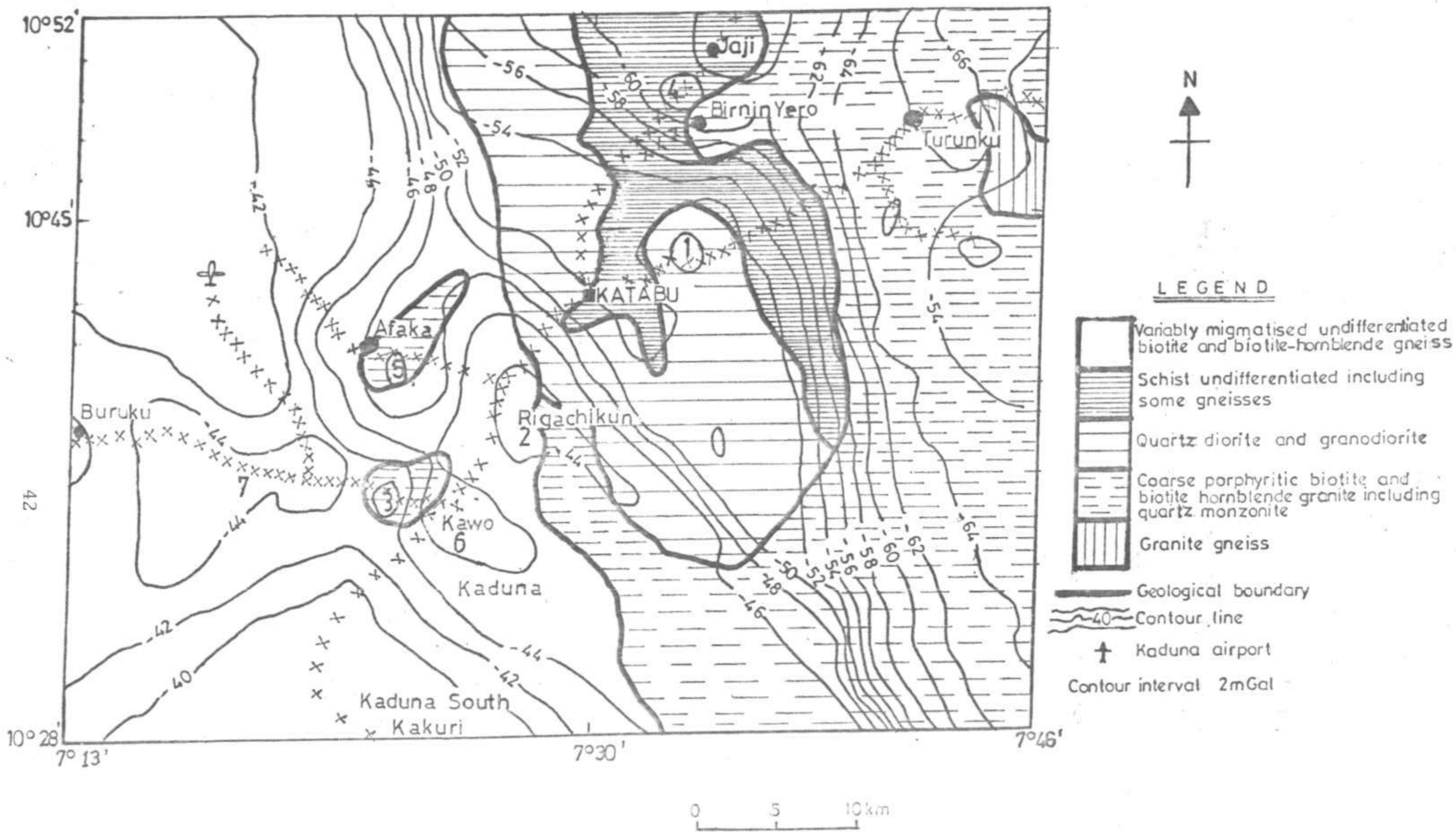


Fig.4.3: Bouguer anomaly map of Katabu area superimposed over geological map of the area

This may be as a result of disturbance from shallow geological structures.

Three relative gravity highs are evident on the map. One of them has a magnitude of -50mGal and ocurs near Katabu. The second one occurs in the vicinity of Rigachikun and has a magnitude of -44mGal. The third gravity high occurs near Kawo and has a magnitude of -42mGal. These have been numbered 1, 2 and 3 for easy identification. There are also a number of relative gravity lows occuring around Jaji (-62mGal), Afaka (-50mGal), Kawo (-46mGal) and Mando road area (-44mGal). These have also been numbered 4,5,6 and 7 respectively. Isolated gravity lows can also be seen around Turunku. Fig. (4.3) shows the geological map of the area superposed over the Bouguer anomaly map. There is good correlation between the Bouguer field trend and the underlying geologic features.

In general, gradients in the Bouguer field are less than 2mGal/km. In areas undelain by gneisses the gradients are even lower, being about 0.8mGal/km. A relatively steep gradient of about 1.7mGal/km occurs in the neighbourhood of Katabu. The relative gravity highs could be ascribed to igneous intrusions of intermediate to basic composition located within older basement rocks. The relative gravity lows may be caused by acidic granitoid intrusives supposedly widespread in the area. The steep gradients could thus be indicative of sharp contact between intrusive granites of low density and more mafic rocks of high density.

4.3 Regional and Residual Anomalies

The picture that usually emerges after making the reductions leading to the preliminary Bouguer gravity map is one that shows the superposition of disturbances of noticeably different orders of size. The larger features generally show up as trends which continue smoothly over very considerable areas and they are caused by the deeper heterogeneity in the earths crust. Superimposed on these trends but frequently camouflaged by them lie the smaller and shallower local disturbances which are generally secondary in size but primary in importance (Grant and West; 1965). The residual anomaly Δg_{res} is expressed as

$$\Delta g_{res} = \Delta g_B - \Delta \bar{g} \qquad (4.1)$$

where Δg_B is the observed Bouguer anomaly and $\Delta \bar{g}$ is the regional effect. The estimation of the regional effect is of critical importance in the sense that it dictates the nature of the residual map. The various schemes that have been developed for regional-residual separation fall into two broad categories viz - the graphical and analytical systems and their operators commonly referred to as 'smoothers' and 'gridders'. The former depend on the judgement of the operator and the latter on empirical assumptions or steps in the mathematical derivation of the numerical factors or coefficients used in the calculation.

Nettleton (1954) reviewed the various graphical and analytical methods and concluded that none of them provides a philosophically sound basis for the separation of a potential field into regional and residual components. The fundamental difficulty is the ambiguity in the source of the potential field and the lack of a clear criterion for separating it into component parts. This fact has been pointed out several times in geophysical literature (Skeels,1947; Vajk,1951; Nettleton,1940;). The ambiguity arises from the mathematical fact that given the distribution of a gravity potential function over a surface, it is not possible to derive a single or unique distribution of mass which will account for that field. The mathematical background of the several systems of derivative calculations used by the 'gridder' does not provide the desired criterion because at certain steps assumptions or empirical choices have to be made and variations in them produce gross variations in the final result when applied to practical data with the usual irregularities from small errors in measurement and from local disturbances.

The polynomial surface fitting method was used for estimating the regional effect. The method entails fitting a low order polynomial - usually not exceeding the second order - to the Bouguer anomaly map, depending on the complexity of the Bouguer field. The regional map obtained for the first order surface is shown in fig. 4.4. It shows a North-South regional trend having an East-West gradient of the order 0.4 mGal/km dipping to the East. This map is not considered to be a good representation of the regional field due to the paucity of the data points, their uneven distribution and the fact that the regional trend would have been better estimated using only the values in the less anomalous part of the Bouguer map. However, the regional trends extrapolated from other surveys in adjacent areas (e.g. Adeniyi, 1987) into the survey area show a N-S orientation and were therefore used in estimating the regional effect.

The first order residual anomaly map is shown in fig 4.5. The map is characterised by both positive and negative anomalies. Three positive anomalies can be found on the map. The first one occurs near Katabu and has a magnitude of 5 mGal.

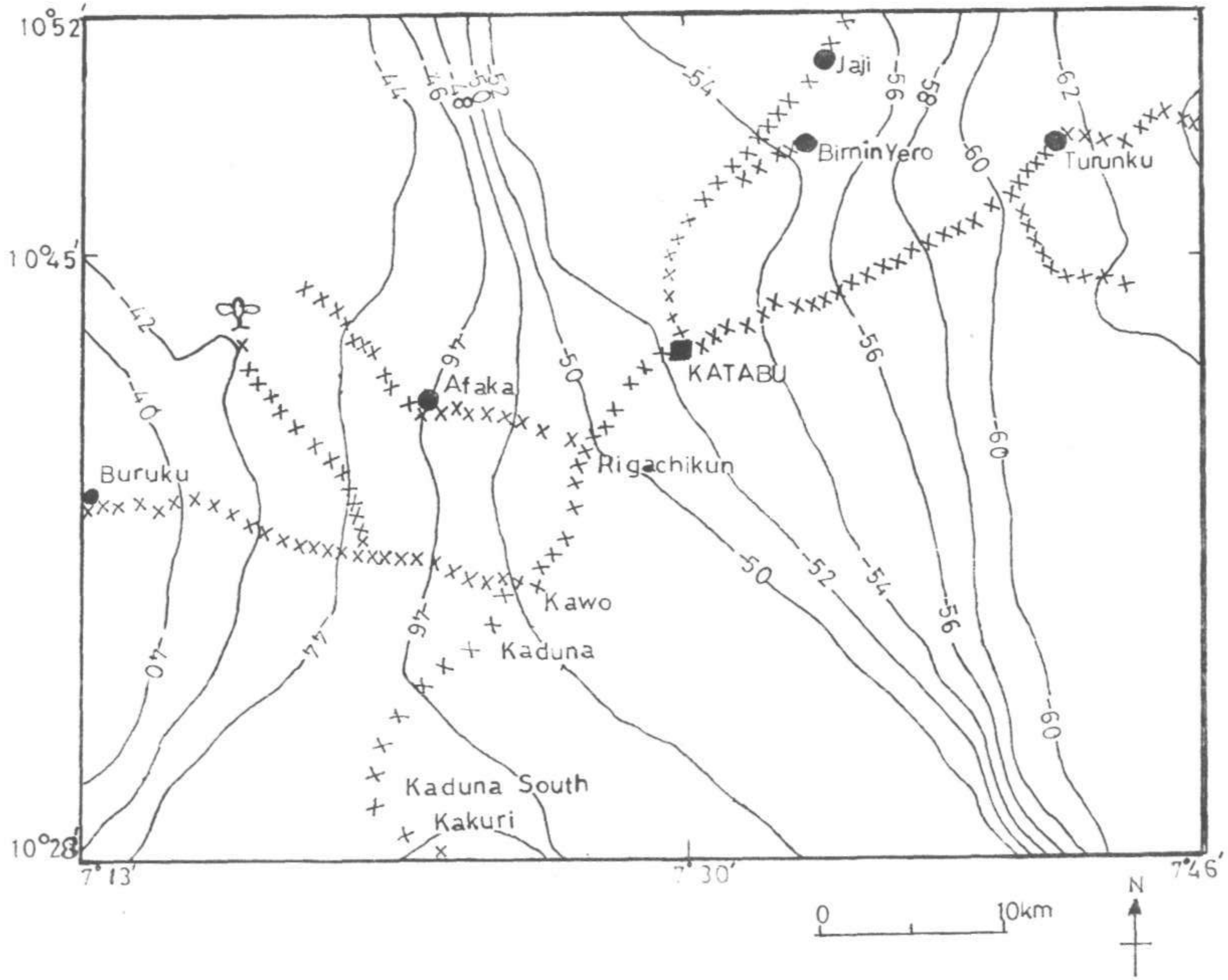


Fig 4.4 Regional anomaly map of Katabu area. (See p.45 for explanation)

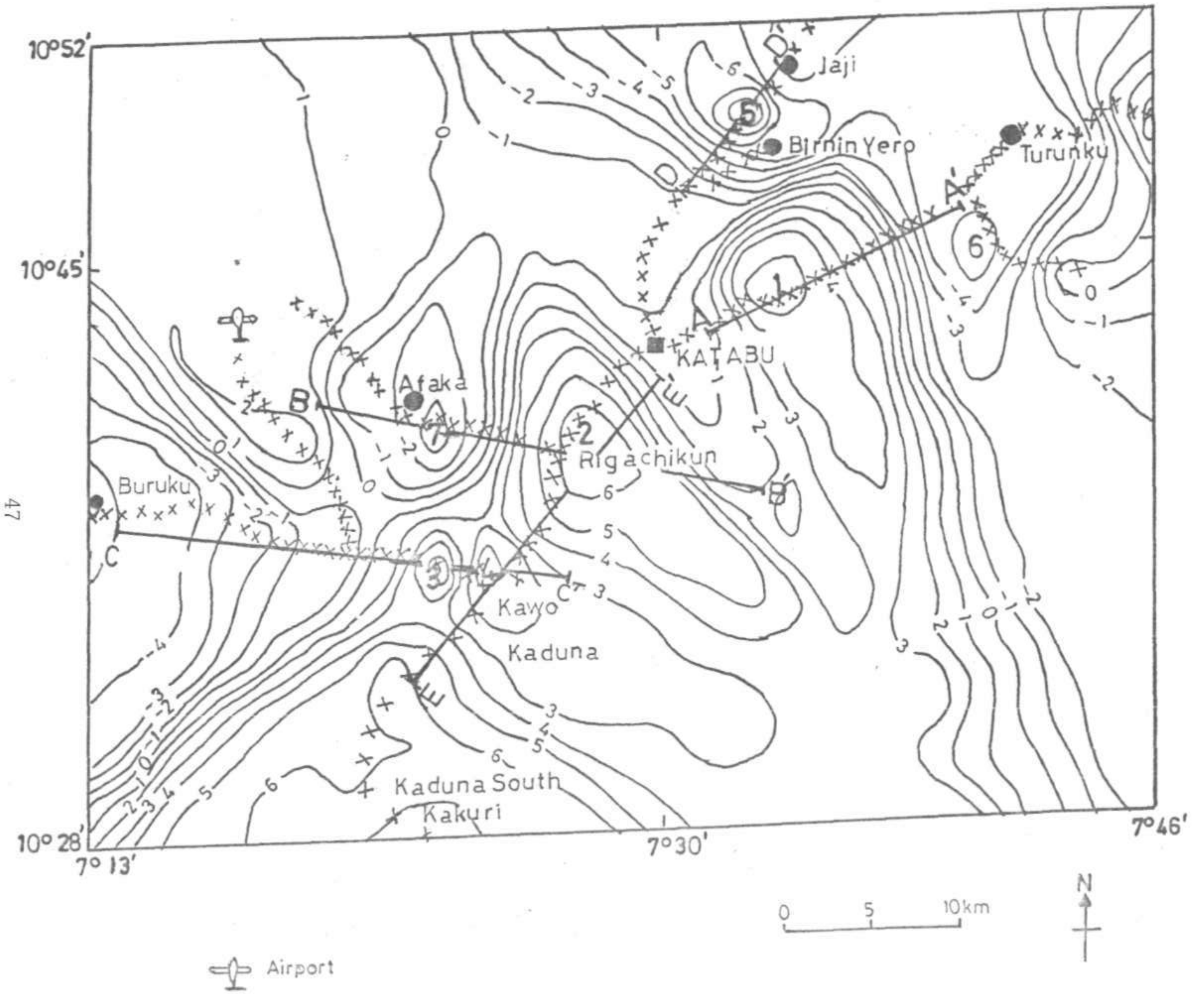


Fig.4.5: First order residual anomaly map of Katabu area

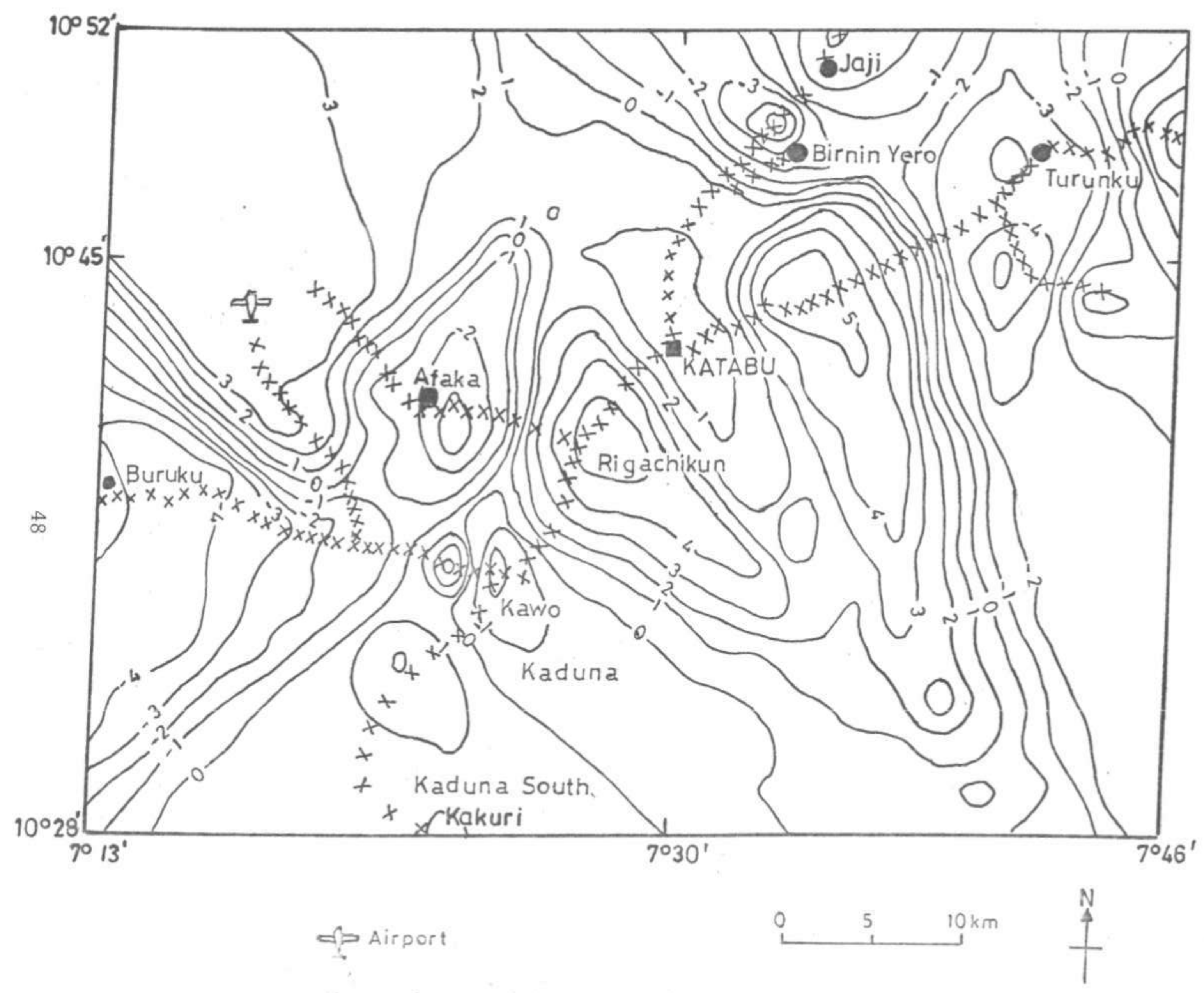


Fig.4.6: Second order residual anomaly map of Katabu area

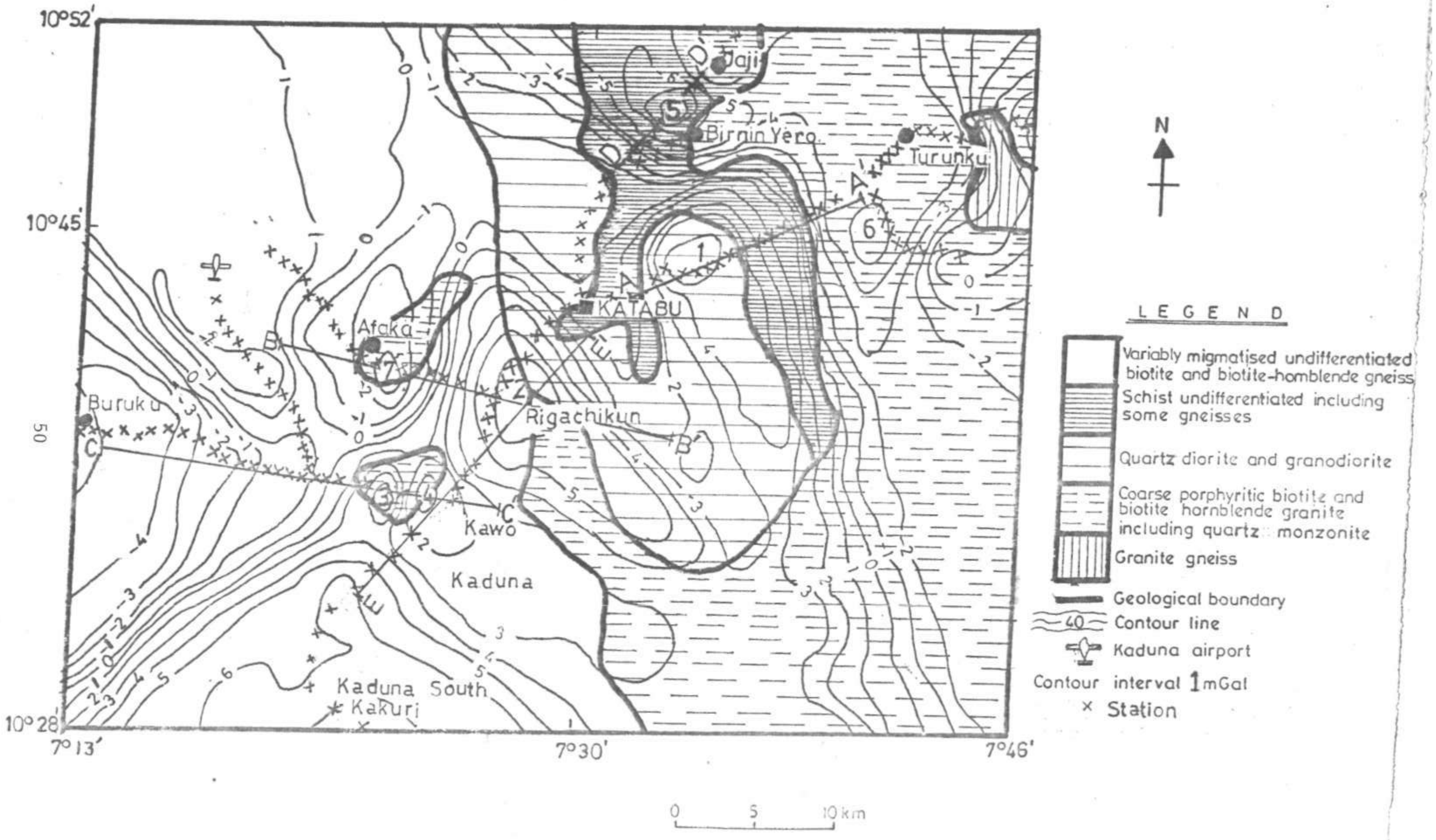
The second anomaly has a value of 6mGal and occurs in the vicinity of Rigachikun. The third anomaly occurs west of Kawo and has a magnitude of 6mGal. This anomaly lies next to a gravity low of 1mGal. These have been numbered 1,2,3 and 4 respectively.

The other gravity lows occur around Jaji (-8mGal), Turunku (-5mGal), and Afaka (-3mGal). These have also been numbered 5,6 and 7 respectively.

A second order surface residual map is shown in fig4.6. Comparison with the first order surface residual map (fig.4.5) of the area shows that the two maps are identical. Usually residuals computed for higher order polynomials may reveal a number of closed features having apparent geological significance which were not discernible on maps of lower-order residuals. This is justified if the survey covers a large area over which the regional has numerous convolutions (Skeels, 1967; Dobrin 1976). However the resemblance of the polynomial surface to the Bouguer map increases with the order of polynomial. Due to the small area covered by the survey and its relatively simple geology, the first order residual surface was chosen for quantitative interpretation.

4.4 Correlation of Residual anomalies with surface geology.

Fig 4.7 shows the 1st order residual anomaly map superposed over the geologic map of the area. The two maps show good correlation with each other. The gravity lows around Afaka and Kawo (anomalies no.7 and no.4 respectively) correspond to granite intrusives into a gneissic basement. The steep gradient between anomalies no.1 and no.6 seems to be a manifestation of contact between granites and the schist-gneiss suite. In general, it appears the area is characterized by both acidic and basic intrusives.



Fig·4·7: Residual anomaly map of Katabu area superimposed over geological map of the area

4.5 Quantitative interpretation of Residual Anomalies.

In quantitative interpretation of gravity data, a subsurface mass distribution is sought whose gravity effect satisfactorily approximates the observed gravity field measured on the surface. This interpretation as earlier stated cannot be unique, therefore the gravity data must be constrained by geologic inferences.

The usual approach to the problem involves a process of trial and error. An initial configuration at some depth is assumed. The gravitational effect of this configuration is calculated and comparison of the calculated with the observed profile indicates where to change the assumed configuration to get a better fit. By judicious adjustment of the configuration within geologically reasonable limits and repeated computation and comparison of the exact theoretical anomaly with the observed anomaly, a new structure is obtained whose calculated effect fits the observed profile. This approach is called forward modelling (Patterson and Reeves, 1985).

4.5.1 Two-dimensional interpretation of Residual anomalies.

On the residual Bouguer map (fig 4.5), five profiles were chosen for quantitative interpretation of the anomalies. The criteria for selecting the profiles interpreted on the residual map were that they crossed the major anomalies in the area as well as many contour closures. In addition they had data points throughout or almost throughout their lengths. Two-dimensional modelling was employed in which the causative body was assumed to be irregularly shaped and its cross-section a polygon with finite number of sides. The parameters used for the assumed bodies are their density contrasts with respect to country rocks and the coordinates of their corner points. Preliminary depth estimates were calculated using the formula (Bancroft, 1960)

$$d = \frac{1}{\pi}\left[\frac{\textit{Anomaly amplitude}}{\textit{maximum gradient}}\right] \qquad (4.2)$$

This gives the maximum possible depth, d, to the top of an anomaly-producing body. Using the available geological information and density contrasts from table 3.1 as initial constraints, bodies were fitted to the anomalies and subsequently adjusted until a good fit was obtained between the computed anomalies and the observed residual anomalies. In modelling each body was assumed to be homogeneous and therefore assumed to be of constant density.

4.5.2 **Profile AA'**

This profile runs in the WSW-ENE direction and cuts across granite-granodiorite, quartz diorite and schist rocks in the central region of fig.4.7. The model (fig.4.8) shows that the bodies have steeply dipping contacts with one another and the host rocks. The quartz diorite body which has outcrops on the surface extends down to a depth of 2.5km. It has outward dipping walls which spread out to a maximum width of 7km. Faulting of the country rocks may have been a factor in the development of this basic intrusion with subsequent progressive inflation of the magma chamber to the proportion of a plutonic mass. The schist body is part of a larger north-south trending metasedimentary belt. It makes contact with the quartz diorite and granite bodies on its south-western and north-eastern flanks respectively. It has inward dipping walls which extend to a maximum depth of 0.8km. Where the schist body makes contact with the granite, it dips at an angle of 60°. A gravity gradient of up to 1.4mGal/km over this contact zone and the high dip angle suggest the probability of faulting.

The granite body extends further north than is shown in this model. It is part of a larger granite mass which lies beyond the length of the profile. The acidic (i.e low density) nature of the granite and the corresponding negative Bouguer anomalies suggest a granite parent magma for the granite suite in the area.

4.5.3 **Profile BB'.**

The model for this profile (fig 4.9) shows that the migmatite-gneiss basement was invaded by basic and acidic intrusives. The granite body which outcrops amidst the gneisses has steep contacts with neighbouring rocks. It extends to a depth of 1km in the northwest before spreading out progressively until it reaches its maximum depth of 2km. In the south-eastern direction, the walls extend to a depth of 0.5km before spreading laterally. It has a width of 7.5km at depth. The granite body makes contact at depth with the basic intrusion and this is the probable cause of the high gravity gradient of about 1.6mGal/km evident in that region. The shape of the body suggests that it may have been initiated by intrusion of a granitic magma along a subhorizontal discontinuity, similar to sill formation. The magma can be viewed as rising from the mantle along a small conduit and

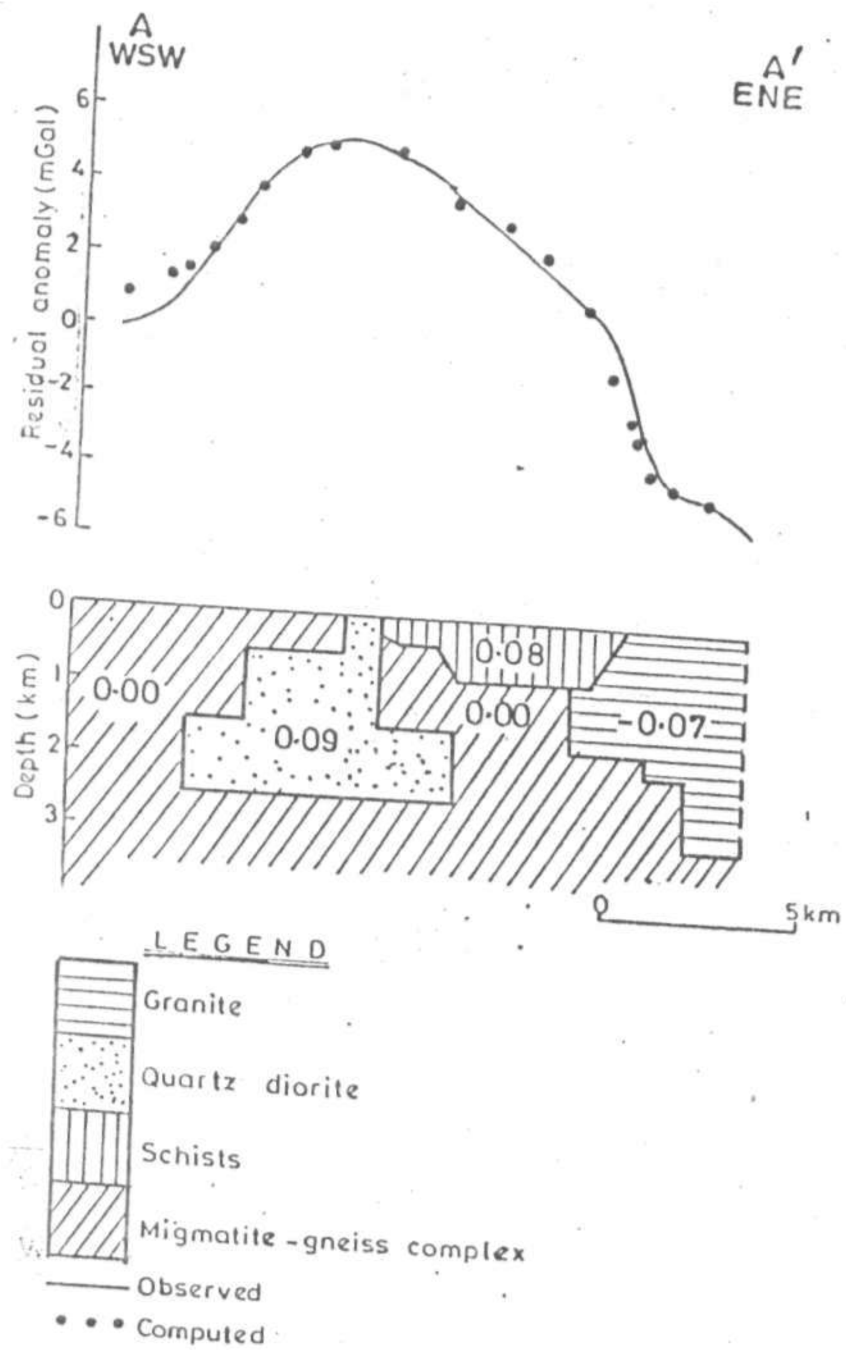


Fig.4.8 :Two-dimensional model of residual anomaly along profile AA'

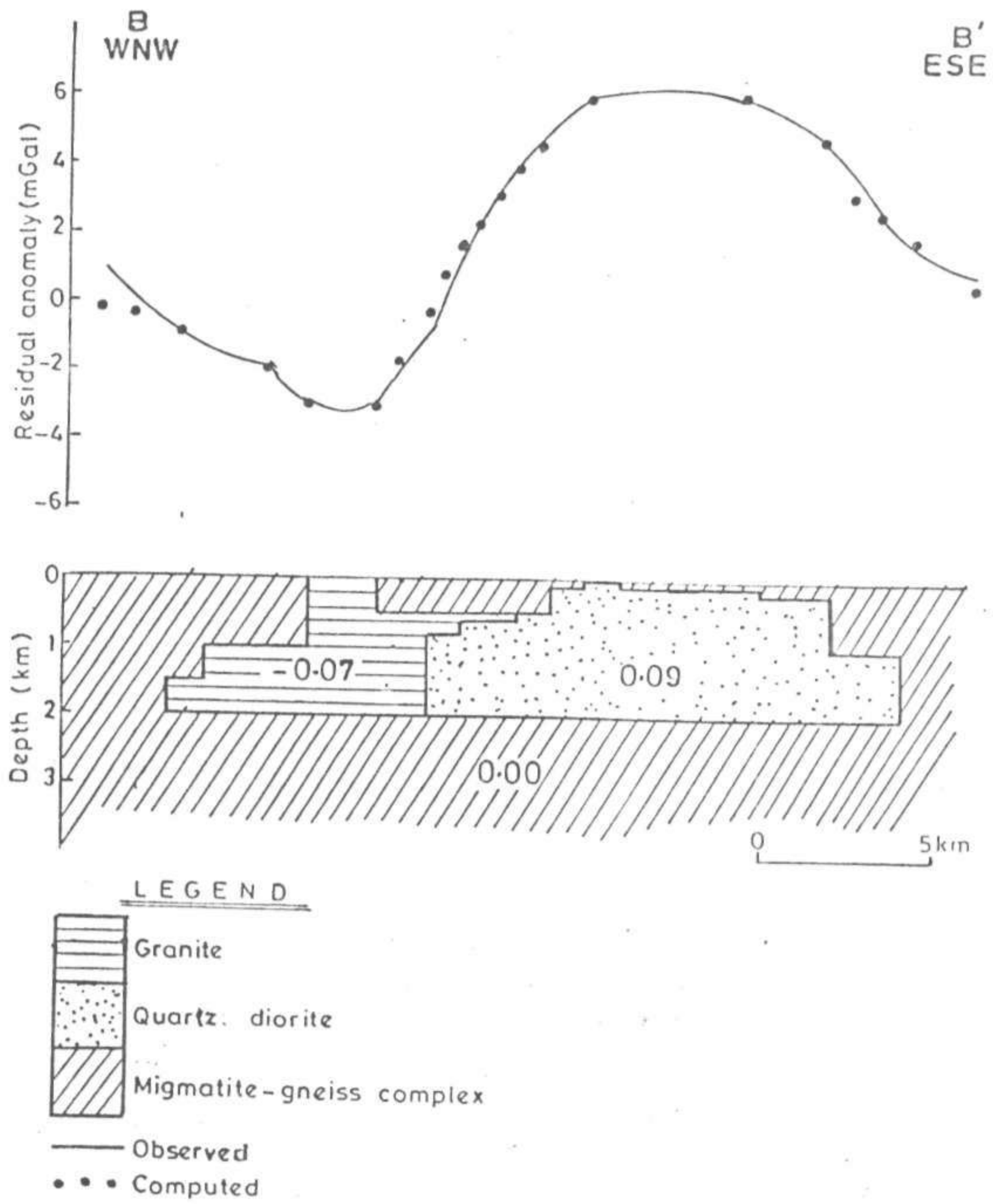


Fig.4.9 :Two-dimensional model of residual anomaly along profile BB'

subsequently spreading laterally at some depth below the surface. On its south-eastern flank, the magma may have found a channel of least resistance at about 0.5km below the surface along a bedding plane producing a concordant intrusion with roof and floor parallel to the adjacent stratification.

The quartz diorite body extends downwards to a maximum depth of about 2km. It has outward dipping contacts with neighbouring rocks and has a width of 14.5km in the WNW-ESE direction. It may have once been a pluton exposed after a long period of time by denudation of the overburden.

4.5.4 **Profile CC'.**

The model in fig (4.10) features a granitic body intruded by a more mafic body at depth. The basic intrusion was assumed to be of quartz dioritic composition. It intrudes into the granite to about 0.2km below the surface. It has outward dipping contacts with both the granite body and the gneissic basement and extends to a maximum depth of 5km. At this depth it has a lateral spread of 5km.

The granite body at the northwestern end of the profile does not outcrop over the area covered by the profile but is required to explain the gravity low observed there. It is believed to be a sill-like extension of a large granite body extending beyond the northwestern end of the profile. Similarly the deep seated quartz diorite body in the southeastern part of the profile is required to account for the increasing gravity in that area. The asymmetry in the ESE part of the profile suggests that the granite body was rotated through about 10^o in the clockwise direction in a vertical plane as a result of the intruding basic rock. The

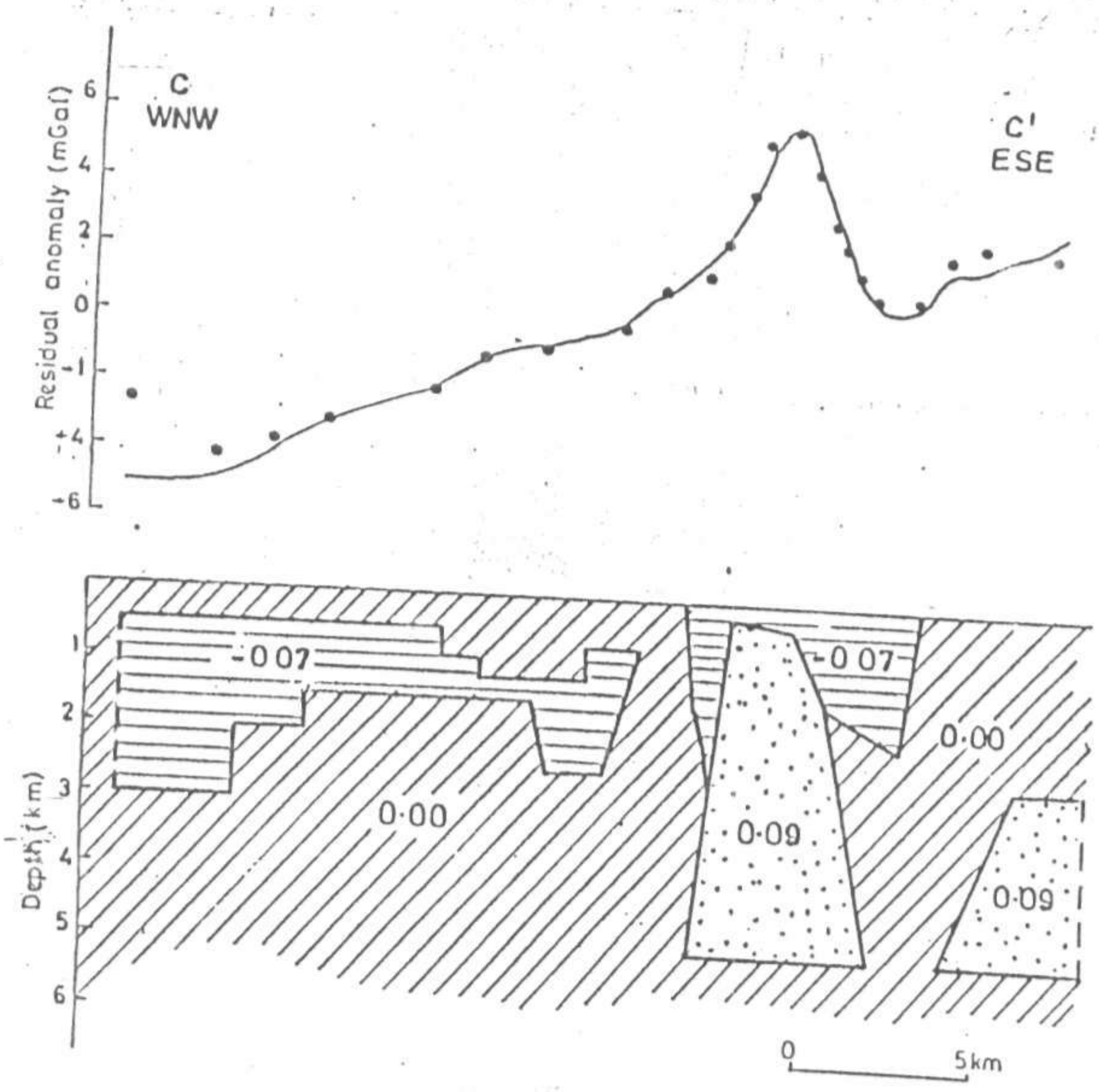


Fig-4.10: Two-dimensional model of residual anomaly along profile CC'

LEGEND

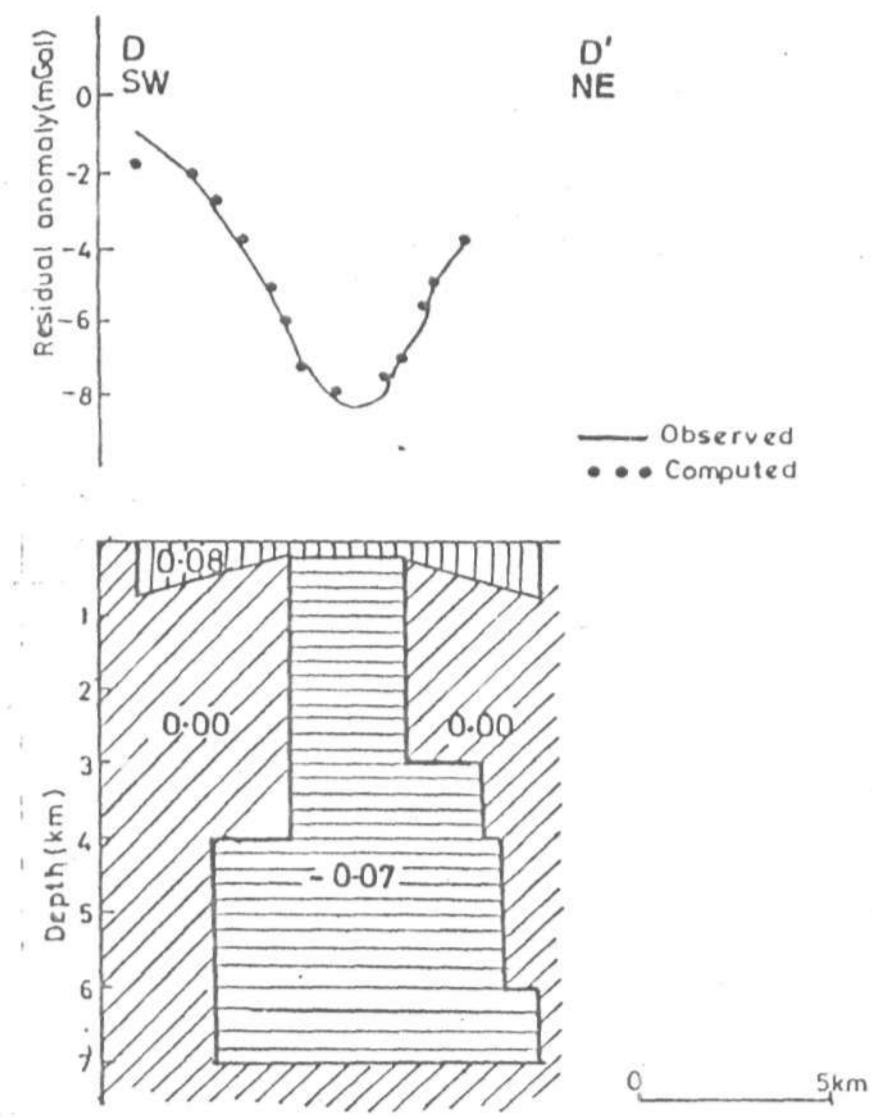
Granite

Quartz. diorite

Migmatite-gneiss complex

Observed

Computed



Fig·4·11: Two-dimensional model of residual anomaly along profile DD'

LEGEND

Granite

Schists

Migmatite-gneiss complex

Observed

Computed

granite shows steep contacts of about 80° with the surrounding gneisses and extends to a depth of about 2.5km on the left flank of the quartz diorite. On the right hand side of the intrusion, the granite extends to a depth of 2km. The granite body has a surface width of about 6.6km.

4.5.5 **Profile DD'.**

Fig 4.11 shows a dyke-like granitic body intruding into an area underlain by schists. The granite extends to a depth of 7km and intrudes to within 0.2km of the surface. The topmost width of the granite is 3km while its maximum width at depth is 8.5km. The body may have been formed by magma ascending through an approximately vertical fissure which on cooling resulted in a granitic body having discordant contact relationships with adjacent rocks.

The schist body lies above the granite intrusive. The upward warping of the schist body floor may be as a result of the pressure generated by the ascending granitic magma which tends to simultaneously lift and bend the overburden (Petraske et al., 1978). The schist has a maximum thickness of 0.8km increasing uniformly from the centre to the flanks of the body. The thickness of the schist may probably be more than this, unfortunately there is no available borehole data which could be used as control for the thickness of the schists in the area.

4.5.6 **Profile EE'.**

This model is described in fig 4.12. The granite body has a steeply dipping ontact of 75° with the adjacent gneisses on the southwestern flank of the body. In the north-east

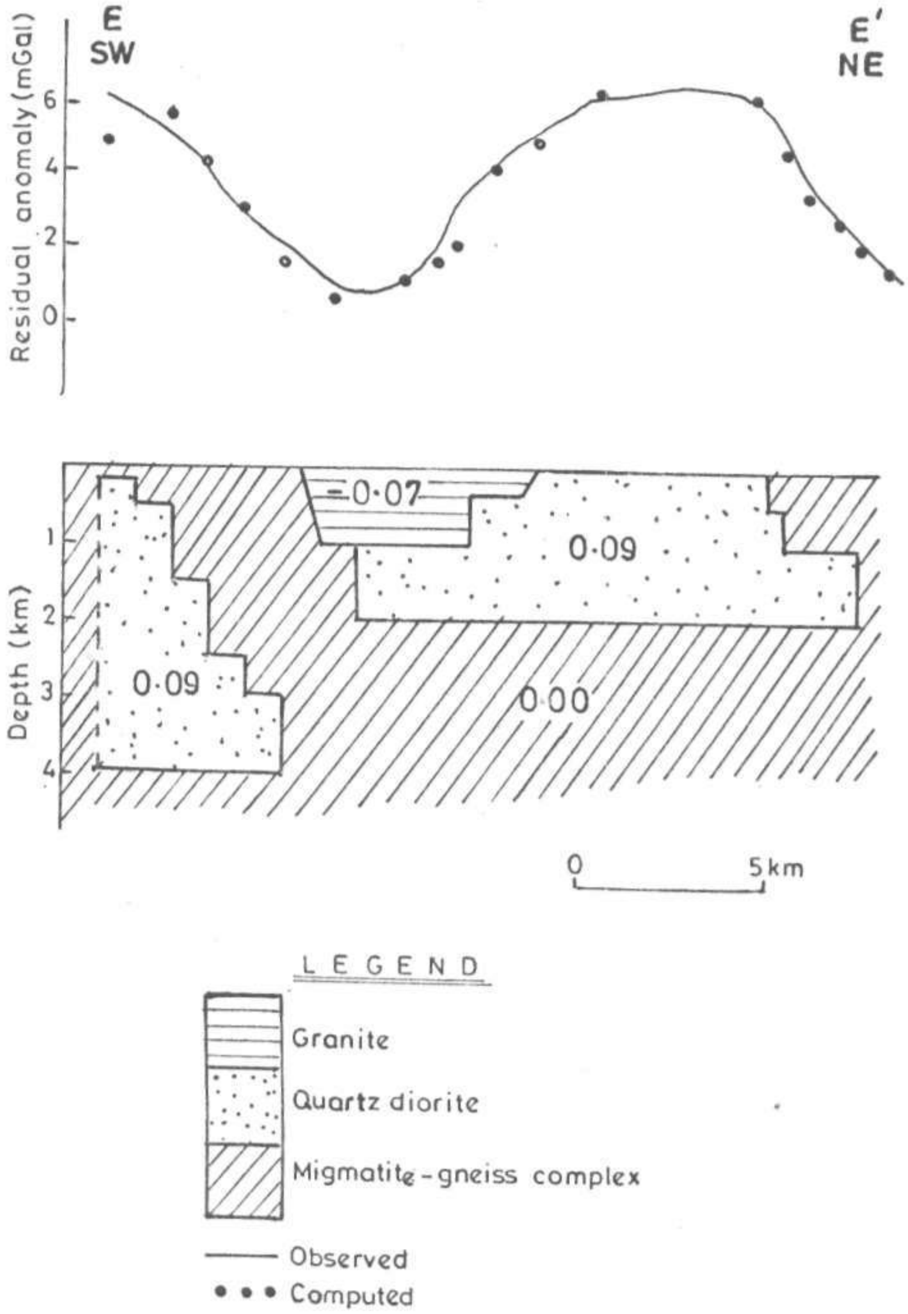


Fig. 4.12 ; Two-dimensional model of residual anomaly along profile EE'

it makes contact with a quartz diorite body having a dip angle of about 50° near the surface and almost vertical contact after a depth of about 0.4km. The general thickness of the granite body over a large area is 1 km. It shows concordant contact with the surrounding stratification at a depth of 0.4km below the surface on the northeastern part of the profile. It has a surface width of 6.5km.

The quartz diorite body on the northeastern part of the profile extends from the surface to a depth of 2km. It has outward dipping contacts which spread to a maximum width of 13.5km at about 2km below the surface. It underlies the greater part of the granite body on the southwestern end. The gravity high in the southwestern end of the profile does not correspond to any visible rock outcrop. It is probably caused by a basic intrusion at depth and has been modelled as a quartz diorite body which may extend beyond the length of the profile.

In general, the high dips and sharp contacts of the granites and quartz diorites suggest that magmatic stoping was the most likely mode of emplacement of the bodies which must have later been drawn out and localised through weak zones in the host gneiss (Petraske et al., 1978).

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 General Discussion

The structural relationships between the different bodies as inferred from the models show that in general the Older Granite intrusives and schist formations in the area have steep contacts with each other and the host migmatite-gneiss complex.

The schists, which form well-defined north-south trending belts are believed to be remnants of a once more extensive supracrustal cover which was folded along with the Basement Complex during the Pan-African Orogeny (McCurry and Wright,1971; McCurry,1976). Turner (1983) categorized the schists into two age groups. The earlier group is thought to belong to the Kibaran Orogeny (1100 $\pm$ 200Ma). This group contains assemblages of mafic igneous rocks, pellitic schists and phyllites. The later group of schist belts is characterized by coarse to fine-grained clastics, insignificant mafic igneous rocks, a simple straight structural style and an absence of internal granite plutons. These schist belts are believed to belong to the Pan-African Orogeny. Kibaran relics in Nigeria are scattered, discontinous and generally overprinted by Pan-African structures and magmatism. Ajibade (1980), Turner (1983) and others have interpreted the Kibaran schists in Nigeria as a largely ensialic event i.e floored by, and terminated within an older continental basement composed mainly of (light) granitic rock types. On the other hand, McCurry (1976) considers the schists to be of ensimatic origin i.e involving deposition on oceanic crust composed of (denser) more basic rock types. However, the high positive Bouguer anomalies in the range of +30 to +80mGal characteristic of essentially ensimatic processes

(Caby et al.,1981) were not observed in this survey. It is therefore concluded that the schists in Katabu area evolved in an ensialic environment.

Rocks belonging to the Older Granite series are widespread in Katabu area. McCurry (1976) divided them into three main groups: basic and intermediate intrusives (represented by small irregular bodies of quartz diorite, pyroxene diorite, and gabbro), migmatities and syn-tectonic to late-tectonic granites. Two divergent hypotheses have been put forward to explain the origin of the Older Granites in Nigeria. These are that the masses have essentially magmatic origin with subsequent magmatic emplacement or alternately, that the masses have an essentially metasomatic origin whereby sedimentary and metamorphic rocks were converted to granites by metasomatic migration of material. Russ(1957), through chemical analysis and examination of petrological features 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 Zungeru region suggested a magmatic origin for the Older Granites. However, Oyawoye (1964) suggested that most of the large masses of granites and quartz diorites in the complex originated through potash metasomatism; while Grant (1978) on the basis of geochronological evidence, also believes that the Older Granites originated through a metasomatic process. Jones and Hockey (1964) have also suggested emplacement partly by intrusion and partly by replacement. These differing opinions are probably the result of regional variations in the tectonism of the Nigerian Basement Complex which could lead to different interpretations of complex textural, mineralogical and physico-chemical field relations (Osazuwa et al., 1992). Rahaman (1988) is of the opinion that attempts to classify the Older Granites can only be valid over short distances.

The presence of several positive and negative closures in the Bouguer and residual anomaly maps resulting in abrupt changes in gravity gradients over the Older Granite suite does not support a metasomatic origin. The high gradients associated with the contours in some areas, especially at the contacts with surrounding rocks and the shape and size of the residual anomalies strongly suggest a magmatic origin. According to McCurry (1970) discordant contacts demonstrate that most of the Older Granite rocks are intrusives and that 'static' granitization has nowhere been identified. She is of the opinion that mobility of the basement caused dense granitoid facies to move from lower to higher crustal levels. The geological evidence in support of this view includes the presence of contact metamorphism of the country rocks (Russ 1957) and the presence of rotated xenoliths in the granites which suggests movement of the granitic material in semi-plastic condition (Webb, 1972). The contact relationship between the Older Granite rocks and the schists also indicate that stoping played an important role in the emplacement of the bodies.

From the foregoing arguments and consideration of the models, it appears the origin of the Older Granites in Katabu area is a compromise between an entirely metasomatic and an entirely magmatic process with more evidence in favour of the latter.

5.2 Summary of Results and Conclusions

The Katabu area is characterised by large negative Bouguer anomalies ranging from -37mGal to -69mGal. It has a north-south trending regional field of the order 0.4mGal/km dipping to the East. The gravity highs and lows correlate well with quartz diorites and granites respectively as indicated on the geological map of the area (Fig 4.7). Thicknesses estimated from two-dimensional modelling were two to five kilometers for the quartz diorites, 0.8km for the schists and two to seven kilometers for the granites.

Sharp contacts between granites, schists and quartz diorites show that such contacts are possibly faulted. Also sharp contacts between Older Granites and the host gneiss as well as the presence of contact metamorphism of the country rock and the presence of rotated xenoliths in the granites, all support the suggestion of magmatic stoping as the mode of emplacement of the Older Granites in the area. The lack of high positive Bouguer anomalies over the schists in the area confirms the geological evidence for the schists having evolved in an ensialic environment.

5.3 Recommendations.

It is recommended that more geophysical work should be carried out not only in Katabu area but over the entire Nigerian basement in order to get a better understanding of the origin and mode of emplacement of the Older Granites and the processes of evolution of the Nigerian Schist belts.

The importance of proper density information in gravity data interpretation cannot be overemphasised. It is recommended that more intensive sampling be carried out both in the area and the Basement Complex in general in order to make density data available.

The existence of batholithic granite masses in the Nigerian basement may be investigated as possible sites for toxic waste disposal.

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APPENDEX II

B	C_B	X_B	$Y_1 (= \alpha_1)$	$Y_2 (= \alpha_2)$	…	$Y_k (= \alpha_k)$	…	$Y_n (= \alpha_n)$	$Y_{n+1} (\beta_1)$	$Y_{n+2} (\beta_2)$	…	$Y_{n+m} (\beta_m)$	Mini Ratio
y_{n+1}	$c_{B_1} = 0$	$x_{B_1} = b_1$	$y_{11} = a_{11}$	$y_{12} = a_{12}$	…	$y_{1k} = a_{1k}$	…	$y_{1n} = a_{1n}$	**1**	**0**	…	**0**	
y_{n+2}	$c_{B_2} = 0$	$x_{B_2} = b_2$	$y_{21} = a_{21}$	$y_{22} = a_{22}$	…	$y_{2k} = a_{2k}$	…	$y_{2n} = a_{2n}$	**0**	**1**	…	**0**	
y_{n+r}	$c_{B_r} = 0$	$x_{B_r} = b_r$	$y_{r1} = a_{r1}$	$y_{r2} = a_{r2}$	…	$\boxed{y_{rk} = a_{rk}}$	⋮	⋮	⋮	⋮		⋮	
y_{n+m}	$c_{B_m} = 0$	$x_{B_m} = b_m$	$y_{m1} = a_{m1}$	$y_{m2} = a_{m2}$	…	$y_{mk} = a_{mk}$	…	$y_{mn} = a_{mn}$	**0**	**0**	…	**1**	
$Z = C_B X_B$ $= 0$		x_j	x_1 0	x_2 0	…	…	…	x_n 0	x_{n+1} b_1	x_{n+2} b_2	…	x_{n+m} b_m	
		c_j	c_1	c_2	…	…	…	c_n	0	0	…		
		Δ_j											

Starting Simplex Table

		c_j^*	c_0^*	c_1^*	$c_2^* \ldots$	c_n^*	c_{n+m}^-	
$\mathbf{B}_1$	$\mathbf{C}_{B_1}^*$	$\mathbf{X}_B^{(1)}$	$Y_0^{(1)}$	$Y_1^{(1)}$	$Y_2^{(1)} \ldots$	$Y_n^{(1)} \ldots$	$Y_{n+m}^{(1)}$	θ Mini $\left\{\frac{\mathbf{X}_B^{(1)}}{\mathbf{Y}_K^{(1)}}\right\}$
$Y_{n+1}^{(1)}$	-1	b_0						
$Y_{n+2}^{(1)}$	-1							
$\vdots$	$\vdots$							
$Y_{n+m}^{(1)}$	-1							
$Z^* =$	$\mathbf{C}_{B_1}\ \mathbf{X}_B^{(1)}$	x_j	$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$	
		Δ_j^*	$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$	
$Z_w = \sum_{j=0}^{m} b_j w_j$		w_{sj}						

Starting Primal dual Table