GRAVITY INVESTIGATION OF OLDER GRANITE PLUTONS IN GUSAU AREA, SOKOTO STATE, NIGERIA.

BY

AKU, M. O. ***B.Sc (Hons)***

THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, AHMADU BELLO UNIVERSITY, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF:-

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AHMADU BELLO UNIVERSITY,

ZARIA, NGERIA

JANUARY, 1996

DEDICATION

TO MY PARENTS AND FAMILY

DECLARATION

This is to certify that:

(i) the work reported in this thesis was carried out by me, *AKU, M. O.*, at the Geophysics Section of the Department of Physics, Ahmadu Bello University, Zaria, Nigeria.

(ii) this thesis has not been submitted in any form to any institution, body, establishment or organization other than Ahmadu Bello University, Zaria, Nigeria, for the award of the degree of master of science.

(iii) all authors whose works are cited and referenced in this project report are duly acknowledged.



Aku, M. O.

(Author)

CERTIFICATION

This project report entitled 'THE GRAVITY INVESTIGATION OF OLDER GRANITE PLUTONS IN GUSAU AREA, SOKOTO STATE, NIGERIA' by *Aku, M. O.* meets the regulations governing the award of the degree of Master of Science of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Dr. M. N. Umego
Chairman, Supervisory committee — Date: 04/12/96

Prof. S. B. Ojo
Member, Supervisory committee — Date: 24/12/96

Head, Physics Department — Date: 24/12/96

Dean, Postgraduate School — Date: 30/7/98

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A B S T R A C T

Gravity measurements were made at one hundred and ninety-eight gravity stations established at 2 km interval on all motorable roads in an area of approximately 9,975 km2 surrounding the town of Gusau. To aid in interpretations, density determination were made on 129 rock samples.

The result of the survey disclosed that the area is characterized by large negative Bouguer anomaly values between -30 and -70 mGals, with a mean value of -57 mGals for all the stations. The resulting regional trend shows a NE-SW trend which is apparent in the Bouguer anomaly and geologic maps. It is a plane dipping southeast wards with a gradient of 0.44 mGal/km. The residual contour map displays negative closures which correlate well with the granite plutons, thus confirming the acidic (low density) nature of the Older Granites with respect to the host rock, the migmatite gneiss. The resultant second vertical derivative map of the Bouguer gravity corresponds remarkably well with the known surface geology; the elongated zero contours coinciding with most lithological boundaries. Thus a properly designed second vertical derivative map can be a supplement to geologic mapping in the identification of lithological units.

A three - dimensional interpretation of the residual anomaly indicates that the isolated Older Granite outcrops between the Maru and Wonaka - Chafe schist belts in the central region of the survey area probably coalesce at depth into a single big body which is about 55 km in width and extends to a depth of about 5 km.

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CHAPTER ONE

INTRODUCTION

1.1 General Introduction

The significant role of the gravity method as an aid in searching out the mineral resources of the crust and in mapping and understanding the structure and history of the earth is well documented (for example, Grant and West, 1965; Griffiths and King, 1965; Dobrin, 1967 and Telford et al., 1976). The enormous mass of the earth's mantle and core which is regular in shape and smoothly varying in density causes its main gravity field to be smoothly varying too, but superimposed on this smooth field is about 0.05% of the total gravity field due to the uppermost geologic features (Grant and West, 1965). These features are usually those of interest in geophysical surveys. Gravity anomalies met with in prospecting are of the order of a few milligals and have to be measured with an accuracy of better than 0.1 mGal. To separate the changes in gravity field due to the geological features which are being sought from those of different origin therefore, a good density contrast between a body of interest and its host rock should exist for a successful mapping.

The mapping of the earth's gravity field in Nigeria have been confined to limited areas with proven mineral resources and geological objectives. For example, geophysical investigations have been carried out in connection with oil explorations by oil companies in the Niger Delta area. Similar surveys have been done in the Chad Basin for oil and groundwater prospecting. The results of these investigations by

companies are of proprietary nature. However, academic and research institutions have carried out comprehensive geophysical studies in some parts of the country and the results are readily available. Examples of these studies are those of Ajakaiye (1970) on the Younger Granites province, Ojo and Ajakaiye (1976) on the Middle Niger Basin and Umego (1990) on the Sokoto Basin.

The area of the present study lies between longitudes 6° 15' and 7° 00' E and latitudes 12° 00' and 12° 40' N (Fig.1.1). The survey is a follow-up to a gravity survey over the Sokoto basin and parts of the adjoining basement block of Northern Nigeria, extending to part of the present survey area (Umego, 1990). It is one of a series of systematic gravity studies being undertaken by the geophysics group of the Physics Department of Ahmadu Bello University, Zaria within the basement block of Northern Nigeria. Some of the results of these studies have already been published by Gandu et al. (1986), Udensi et al. (1986), Adeniyi (1987), and Oladosu (1987).

1.2 Review Of Previous Geophysical Work Within The Basement Block of Northern Nigeria.

The first comprehensive geophysical work in the area was the aeromagnetic mapping carried out all over the country for the Geological Survey of Nigeria (GSN, 1976). Osazuwa (1985) established a primary gravity network for Nigeria of which base station No. 99046 at Gusau Post Office is within the survey area. All gravity measurements in the

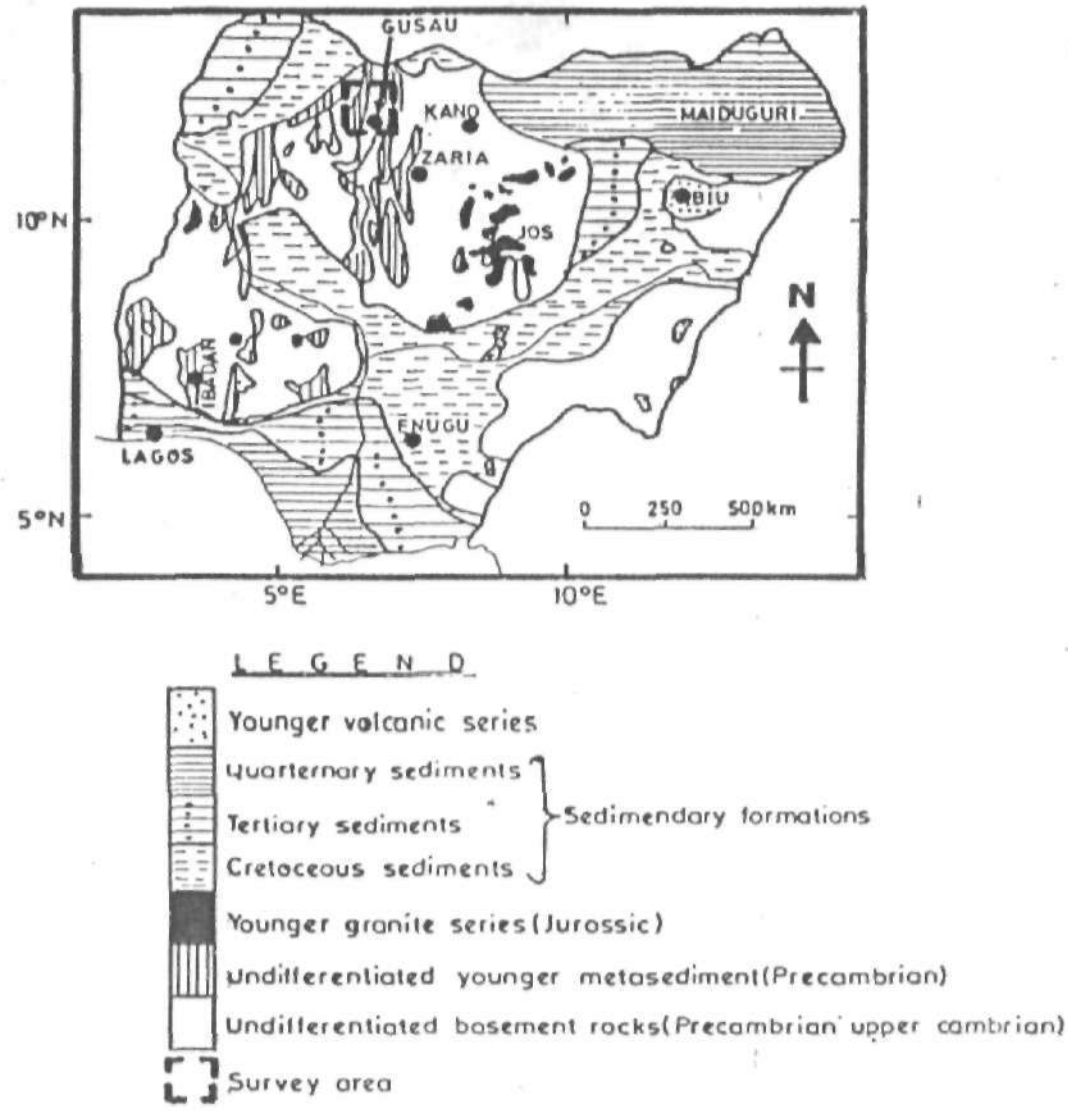


Fig.1.1: Geological map of Nigeria showing the major rock groups and the location of the study area (Adapted from GSN, 1974)

present study were tied to this base station with an absolute gravity value of 978102.755 mGals. Umego (1990) carried out a gravity survey over the Sokoto Basin and parts of the adjoining basement block of North-western Nigeria, extending to part of the present survey area. Other gravity studies over some parts of the basement block include those of Amosu (1979) in the Dutse area; Gandu et al. (1986) in the Malumfashi area; Udensi et al. (1986) in the Minna area; Adeniyi (1987) in the Zaria area and Oladosu (1987) in the Rano area. The studies all confirmed the acidic nature of the granites. Oladosu suggested metasomatism as origin for the granites in the Rano area while the others concluded that magmatic origin was most probable in the other areas. This could mean that the Nigerian Older Granites may vary in their origins and mode of emplacement.

1.3 Objective of Present Survey

This survey forms part of the systematic gravity survey, and in particular is a follow up to an earlier gravity work by Umego (1990) which covered a small portion of the present study area. It was undertaken to investigate the sub-surface structure, the lateral extent and mode of emplacement of the granite plutons in the Gusau area. It was also hoped that the work would reveal the structural relationship between the granite and the surrounding rocks. In addition, it was hoped that this survey would resolve the issue raised by Umego (1990), as to whether the small isolated Older Granite outcrops around Gusau coalesce at depth into one big pluton (Batholith?) still being unroofed at the present time or that the 5 km gravity station spacing used in

that survey was not adequate to resolve the intrusions as distinct small bodies.

The gravity data collected were processed to produce the Bouguer and residual anomaly maps of the area and the residual was further subjected to three-dimensional interpretation. Computer programs available at the Physics department of the Ahmadu Bello University were utilized for the data analysis. The Cyber 932 and IBM PC/AT Computers were used at different stages to analyse and interpret the data.

CHAPTER TWO

GEOLOGICAL SETTING

2.1 Basement Complex of Northern Nigeria

The Nigerian basement complex lies within the Pan-African mobile belt of West Africa and is believed to have a polytecto-metamorphic nature and consequent metamorphism, migmatisation and gneissification have extensively modified the original rocks (Rahaman, 1988).

Relatively detailed reviews of the Nigerian basement complex can be found in McCurry (1976), Ajibade and Fitches (1988), Rahaman (1988) and Ogezi (1988). Three main groups are usually distinguished within the basement complex and these are:-

(i) The migmatite - gneiss complex.

(ii) The metasediments and metavolcanics which form North-South trending schist belts, and

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

2.1.1 The migmatite-gneiss complex

The migmatite-gneiss complex is considered to be the oldest group and the most abundant rock in the Nigerian basement complex. Based on age determination , the migmatite-gneiss complex had undergone four major cycles of deformation, metamorphism and sedimentation corresponding to the Liberian (2700 Ma), the Eburnean (2000 Ma), the Kibaran (1100 Ma) and the Pan-African (600 Ma) orogenies (McCurry and

Wright, 1971; McCurry, 1976; Fitches et al., 1985 and Ajibade and Fitches, 1988).

Banded gneisses and biotite gneisses of varying textures and origins are the principal rock types within the migmatite-gneiss complex. Metasedimentary and metavolcanic rocks now represented by quartzites, marble, calc-silicate rocks and amphibolites occur as relicts within the gneisses or migmatites or are interlayered with them.

2.1.2 The Schist belts

Supracrustal assemblages of low grade metasedimentary and metavolcanic rocks crop out in a series of distinctive essentially north-south trending belts, and they appear to be restricted to the western half of the country. Lithologically, the schist belts are composed predominantly of pelitic to semi-pelitic rocks, psammites, polymict conglomerates, calcareous rocks and mafic to ultramafic igneous rocks (amphibolite complex) Fitches et al. (1985). The age of the schist belts is controversial but recent field and isotopic data have demonstrated that the schist belts are younger than the migmatite-gneiss complex (Ajibade and Fitches, 1988).

2.1.3 The Pan-African (Older) Granites

The term "Older Granite" has been used in Nigeria for a group of discordant, intrusive, late tectonic to concordant, syntectonic bodies varying from small sub-elliptical plutons to large batholiths (Ogezi,

1988). In view of the fact that much older granitic rocks have been found elsewhere in the Nigerian basement (Ajibade and Fitches, 1988; Rahaman, 1988 and Ogezi, 1988), it was strongly suggested that the term 'Older Granite' which was first coined by Falconer (1911), should now be dropped and replaced by "Pan-African Granites" as the rocks yield Pan-African ages (Ogezi, 1988).

The Older Granites which vary from true granites through granodiorites to tonalite gabbros, intrude the rocks of the migmatite-gneiss complex and the schist belts, commonly cross-cutting the boundaries between the two (McCurry, 1976). They are the most obvious manifestation of the Pan-African orogeny in West Africa. In general, the Nigerian Pan-African granites crop out as isolated hills, inselbergs, low whalebacks and granite pavements. Contacts with migmatites and gneisses, where exposed, are commonly sharp, metamorphosed, sheared or migmatised.

Several types of Older Granites can be recognised namely: migmatite or migmatic granite; granite gneiss or anatectic migmatite; early pegmatite dykes and fine-grained granites; homogeneous, medium to coarse grained granites; medium to coarse porphyritic biotite and biotite hornblende granite; slightly deformed pegmatite and aplite dykes and veins; and underformed pegmatites, mica granites and quartz veins (Fitches et al., 1985 and Rahaman , 1988).

2.2 Detailed Geology Of Survey Area

The survey area is entirely underlain by rocks of the Nigerian basement complex. The detailed geological map of the survey area is shown in Fig.2.1. It is represented centrally by the Bungudu migmatites and Bunji migmatite granite-gneiss and is bounded to the east and north east by the Wonaka - Chafe schist belt, and to the west by the Maru schist belt. Between 30 - 40% of the survey area is underlain by Older Granite plutons, mainly minor bodies less than 1km across (Fitches et al., 1985). The major structures are usually composite, comprising combination of the tonalmonzonite, adamellite, granodiorite and granite. The smaller structures are commonly homogeneous and composed of one, rarely two of the above rock types (Rahaman, 1988).

The area is flat-lying and exposures are characteristically visible in most parts and in others, the rocks are being buried under a relatively thick superficial cover (Turner, 1964). The Gusau migmatites and granites are dominantly banded tonalitic gneisses with minor granite gneisses veined by granodioritic to granitic neosomes. Some amphibolite sheets were originally basic dykes which cut the gneissic fabrics and were themselves deformed; they offer a means of beginning to decipher the complex history of the migmatites (Turner, 1983 and Fitches et al., 1985). Mineral assemblages in the gneisses and amphibolites stabilized in the middle amphibolite facies and no traces of higher facies relics have been detected.

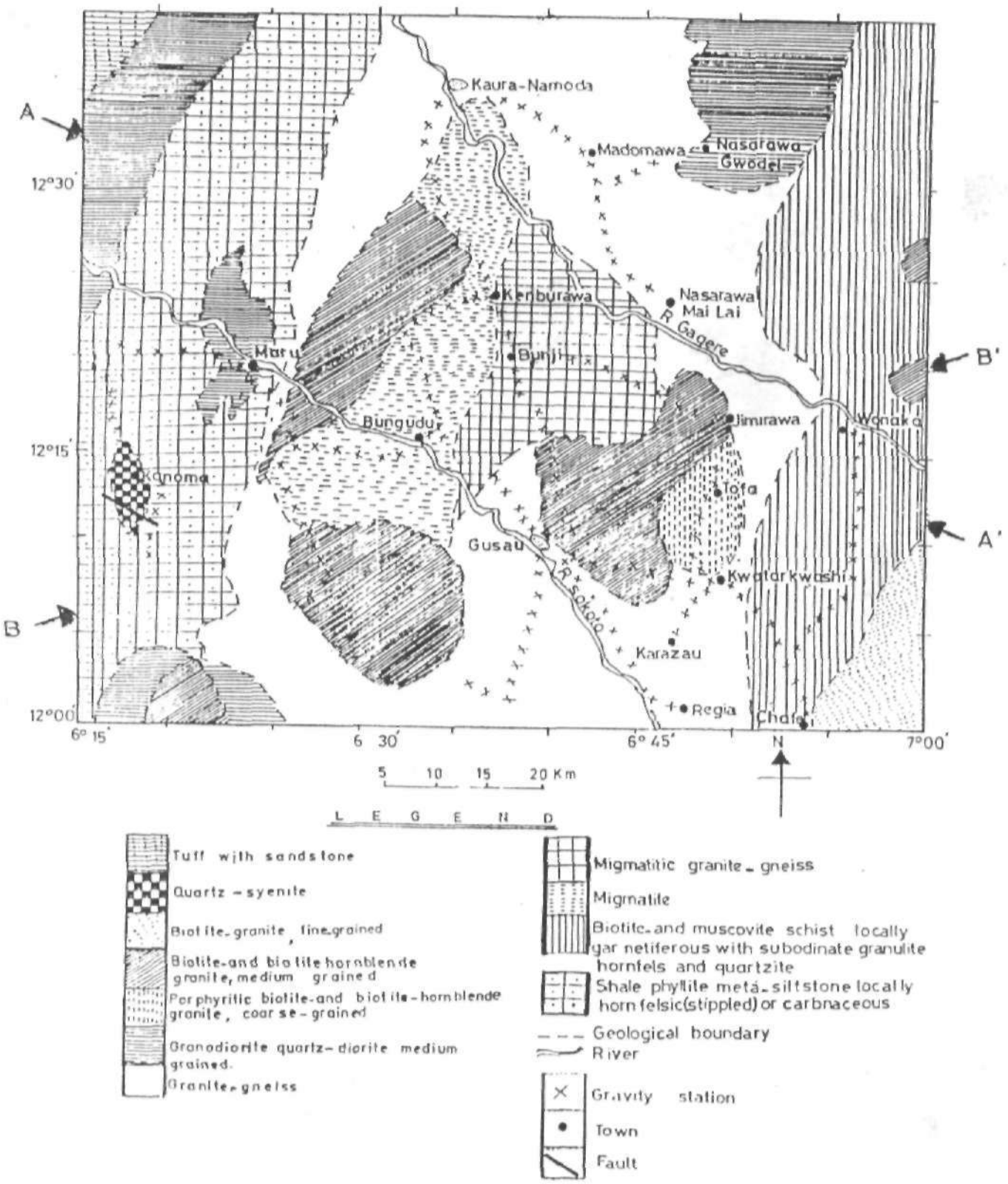


Fig 2.1:Detailed geological map of the survey area (Adapted from GSN, 1:250,000 Series, 1965)

To the west of the central survey area is the Maru schist belt with pelitic rocks dominant mainly as phyllites and slates inter-laminated with siltstones. Banded iron formation containing magnetite and hematite or garnet and grunerite is also present. Impure micaceous quartzites occur near the eastern margin of the belt. Mafic rocks are represented by the amphibolites at several localities (Turner, 1983). The Maru schist belt also
contains internal plutons of granite, granodiorite and syenite. Ogezi (1988) obtained isochron on phyllites from Maru and this dates the belt as Kibaran. The Maiinchi granodiorite intrusive along the western margin of the belt, has given a Pan-African isochron. A similar age was obtained on a single whole-rock sample of the Kanoma syenite in the middle of the belt, although hornblende from the syenite has given a different age, the explanation of which may lie in the perfect concordance of Kibaran and Pan-African folding in the region (Rahaman, 1988).

Syenites are not common in the Older Granite suite in Nigeria and thus an outline description is given of the Kanoma syenite. The syenite at the outcrop is a drop-shaped body 6.5 miles long, a maximum of 2.5 miles wide (Truswell, 1962). A fault cuts across the syenite, and along the North-eastern margin there are numerous large quartz veins in the phyllites. The syenite forms craggy, well pointed hills, exposures being poor only near the northern tip of the mass. The syenite is a uniform-textured fine-to-medium-grained rock.

The Wonaka-Chafe schist belt is distinctive in composition and metamorphism. The main rock type described as hornfelsic schist, forms

a monotonous expanse with constant foliation trends(McCurry, 1976). It is a fine-grained quartz-biotite rock, in places containing sillimanite cordiorite or garnet. Thin beds of calc-silicate rock are widely distributed and in the west, biotite muscovite schists, quartzites and ferruginous quartzites appear (Fargher, 1960). The metamorphism is of a higher temperature and lower pressure type than in other schist belts. This may be due to close association with large batholith masses of granite and granodiorite which almost engulf the schist belt.

2.3 Economic Geology

The largest diamond found in Nigeria, 10 carats, came from the Sokoto river. It is said that it came from near Tsofon Banaga, down stream from Maru. The discovery was made in 1932, and subsequent failure to locate further diamonds in the area may suggest that this stone came from the surrounding meta-sediments, its ultimate origin being unknown (Truswell, 1962).

In the past gold has been worked from several localities, principally from alluvials in streams crossing the Maru schist belt, but in addition, occasionally from veins (Russ, 1957). Iron slag was commonly found adjacent to the ferruginous quartzites and there was local smelting of iron in earlier times. Iron bearing quartzites have been mapped in the south-east of Talata Mafara and in the eastern part of Maru. Mineralogical analyses gave the iron as a magnetite predominant substance.

The Sokoto and Gagere rivers which both take off from the basement areas generally increase their volume downstream. The dissolved contents of these rivers include bicarbonate, sodium, calcium, iron, and manganese. Dams and systems of artificial water recharge are constructed to impound water from these rivers and make it available all the year round for major town supplies and various other purposes.

Presently little or no economic prospecting has been carried out in this area. However the occurrence of lateritic and ferru-ginized sandstone is widespread in the area and have been utilised mainly for purposes of road construction and residential buildings.

CHAPTER THREE

FIELD WORK

3.1 Field Reconnaissance Survey

Relevant topographic and geologic maps of the survey area were gathered and boundaries of all formations delineated. A full reconnaissance of the network of roads and tracks was carried out to ascertain complete coverage of all bodies in the gravity survey area. Survey routes were located and marked on Federal Survey of Nigeria 1:250,000 topographic and geological maps. The positions of field stations along survey routes and field occupational sequences were worked out in preparation for the actual field work.

3.2 Instrumentation

A LaCoste and Romberg gravity meter model G-446, Wallace and Tiernan Aneroid altimeters FA 181 and a psychrometer were the instruments used during the field work and are all available in the Physics Department of Ahmadu Bello University Zaria.

The instruments were checked prior to the field work and the drift characteristics of the gravimeter and altimeters were determined. Fig.3.1 and Fig.3.2. show the diurnal base station drift curves for the gravimeter and altimeters respectively before and after the field work.

The drift rate for the gravity meter before field work along the linear part of the curve is 0.035 meter reading per hour. The amplitude

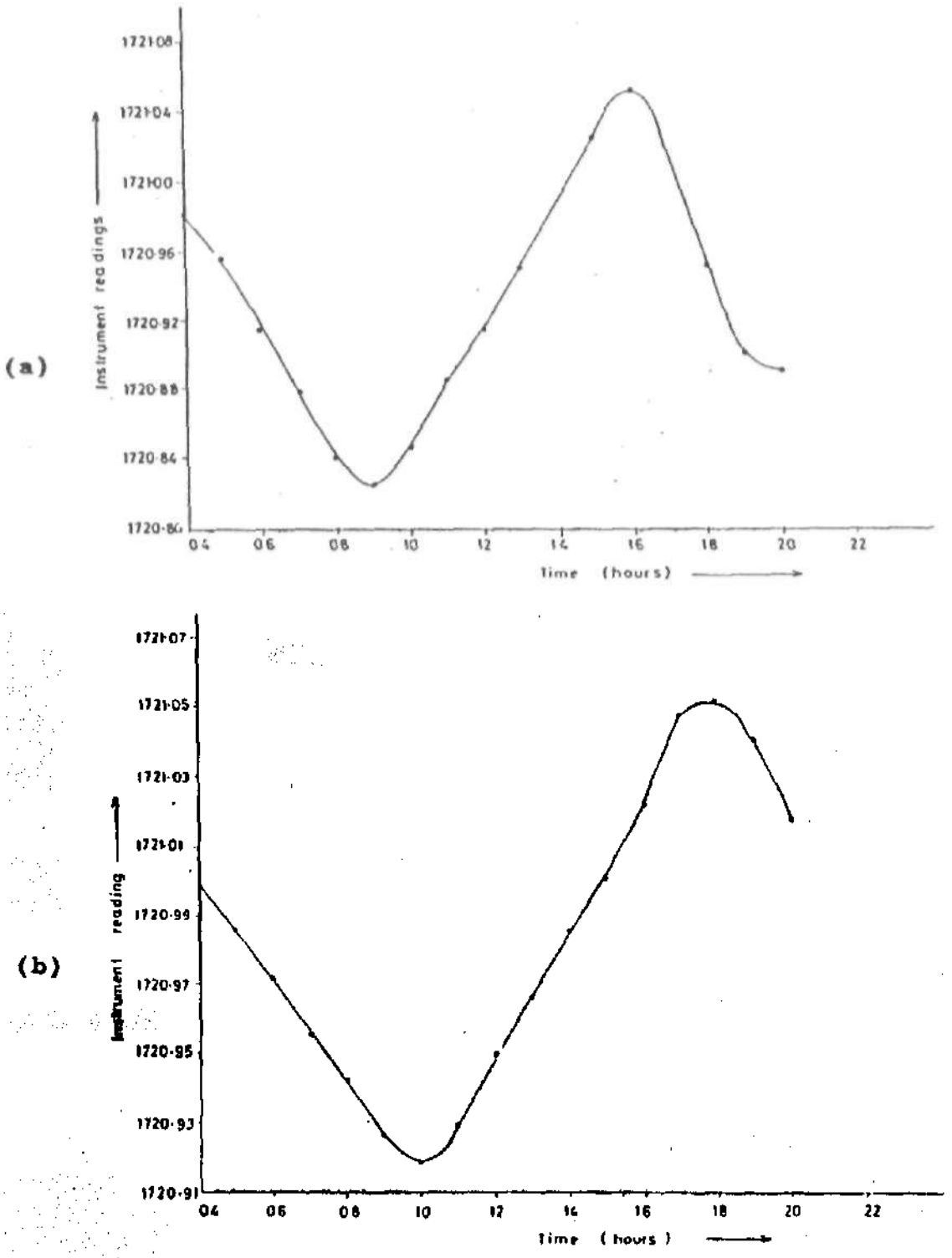


Fig 3.1: Diurnal base station drift curves for the gravimeter (a) before the field work (b) after the field work

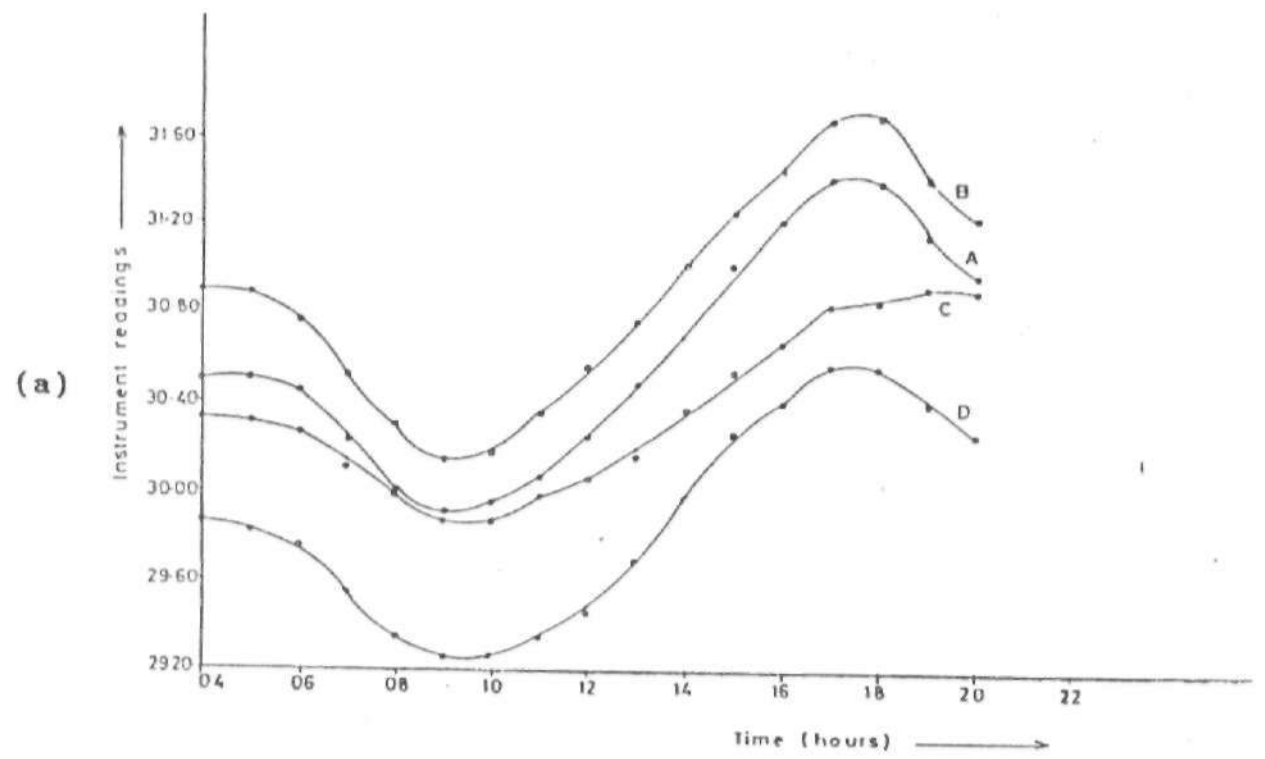


Fig.3.2: Diurnal base station drift curves for the altimeters (a) before the field work (b) after the field work (A B C and D are altimeter identification marks)

of tidal effect is usually not more than 0.03 mGal (Dobrin, 1967) and can usually be corrected for by the field procedure used for the elimination of drift. From Fig.3.2(a), altimeter C appeared to be faulty while drift rates for altimeters A, B and D before the field work are 0.222, 0.219 and 0.218 scale reading per hour respectively. Altimeters A and B were chosen for the actual field work because the linear portions of their plots exhibited the best desirable characteristics for drift correction. Measurements during the survey were restricted to those time ranges where linear drifts were estimated to hold for both the gravimeter and the altimeters, that is, 5.30 a.m. to 9.00 a.m. and 11.00 a.m. to 3.30 p.m., since the gravimetry and altimetry readings were taken simultaneously.

3.3 Field Survey

The actual field survey was carried out in May 1990. A network of 4 base stations was established so that corrections could be made for the drifts of the instruments. A total of 198 secondary stations at 2 km interval along the survey routes were occupied using the single-base method of gravity measurement. To determine the station elevations, altimeter readings were taken simultaneously with gravity readings at any given station. Dry and wet bulb temperature readings were also taken alongside the altimeter readings using the psychrometer for air temperature and relative humidity correction. This correction is required when using Single Base or Leapfrog methods of altimetry. A base station was always visited at the beginning and at the end of each time range where linear drifts were estimated to hold for both

gravity meter and altimeters for each day's work. The gravity data were tied to the first order gravity network base station No 990476 at Gusau Post Office with a value of 978102.755 mGals (Osazuwa, 1985) and station elevations were calculated relative to the Standard Bench Mark (SBM) at Anka junction with absolute height of 399.52 m.

The mode of transportation of instruments between stations was by a Pegeout 504 station-wagon car. The odometer of the car was used to locate station positions with accuracy of 0.1 km and other landmarks like road junctions, rivers, schools, villages, rail crossing, bench marks etc. were also used to affirm station positions. Station positions were carefully marked on the 1:250,000 geologic map of the survey area from which their geographic coordinates were determined. In situations where actual distances by the car odometer did not correspond with those on the map, the affected portions of the map's scale were modified. Fig. 2.1 shows the location and general distribution of field stations over the survey area.

Necessary precautions were taken to shield the instruments from the sun's heat to avoid thermal shock and minimise jerks or mechanical disturbances on the instruments in order to avoid erratic drift (Hamilton and Brule, 1967).

Fresh rock samples from outcrops were collected along the gravity traverses at the end of the survey. A total of 129 rock samples were collected and the location of each collected sample was noted on the geologic map of the area for easy correlation during identification.

3.4 Problems Encountered In The Field

All the topographic and geologic maps available were very old (1960 series) so that some roads indicated as motorable were found not to be in existence at all and some new roads were not shown on the maps. This created problems and errors of locating positions along new roads on the maps.

Developments leading to extension or diversion of roads, change of settlements' names or movement to new locations after production of maps were other problems. Others include abrupt termination of some tracks by big rivers over which there were no bridges. Lack of roads or tracks in some areas contributed to the unevenness of the station distribution in the survey area.

CHAPTER FOUR

DATA REDUCTION AND DENSITY DETERMINATION

4.1 Data Reduction

The gravity data which are usually measured in arbitrary units (scale readings) by the gravimeter must first be converted to their corresponding gravity values in milligals before reduction. This was done with the aid of a simple computer program adapted for use on the Cyber 392 by Osazuwa (1985) using the calibration table contained in the manual for the gravimeter used (LaCoste and Romberg, 1976).

The altimetry data were first corrected for humidity effect using the dry and wet temperatures and the psychrometric chart contained in the manual for the altimeters used (Wallace and Tiernan, Instruction book no. FIA-112-1-3, 1977). The readings were then corrected for drift. The elevations above sea level for each station were calculated manually relative to that of the SBM at Anka junction with an absolute height of 399.52 m. The height values obtained, tallied with those measured during previous surveys in the area (Umego, 1990).

4.1.1 Drift Correction

The readings of all gravity meters drift with time, due to very slow creep in the springs although temperature and pressure changes have been shown to also contribute to it (Griffiths and King, 1965). The gravimeter measurements were carried out with each base station having been occupied twice within the linear portion of the curve (see

Fig. 3.1) such that corrections could be made for the drifts in the meter.

Assuming a linear drift for each complete loop, the drift rate, μ was computed using the formula:

$$\mu = \frac{(\bar{g}_2 - \bar{g}_1) - (g_{02} - g_{01})}{t_2 - t_1} \qquad \text{-------- 4.1}$$

where

$(\bar{g}_2 - \bar{g}_1) = 0$ if terminating stations are the same station and

$$(\bar{g}_2 - \bar{g}_1) - (g_{02} - g_{01}) \left.\begin{array}{l} = 0 \text{ if no drift exists} \\ \neq 0 \text{ if there is drift} \end{array}\right\}$$

where $\bar{g}_1$ and $\bar{g}_2$ are the absolute gravity values of the terminating stations of the loop, g_{01} and g_{02} are the observed gravity values corresponding to $\bar{g}_1$ and $\bar{g}_2$ at time t_1 and t_2 respectively.

The required drift correction to an observed gravity value at any detailed station d at time t_d within the loop is given by

$$\delta_d = \mu(t_d - t_1) \qquad \text{-------- 4.2}$$

4.1.2 Tidal Correction

The attraction of the sun and the moon may change thé gravity value at a station cyclically during the course of a day. The tidal correction can be expressed as

$$TC = P + N\cos\phi(\cos\phi + \sin\phi) + S\cos\phi(\cos\phi - \sin\phi) \qquad \text{------4.3}$$

where P is the correction required at the pole and is usually neglected in gravity surveys, ϕ is the latitude. N and S are corrections at latitude 45° N and 45° S respectively and are usually given on a daily basis at hourly intervals to an accuracy of 5 mGals in tables published yearly by the European Association of Exploration Geophysicists. A computer program available at the Physics Department, Ahmadu Bello University (Osazuwa, 1986) was used to compute the tidal corrections which were added to the observed gravity values.

4.1.3 Latitude Correction

The measured gravity always comprises of a smoothly varying part which reflects the best approximation to the shape of the earth, that is an ellipsoid of revolution with an equatorial radius greater than the polar radius and a part relating to density variations of the uppermost geologic features which are usually those of interest in geophysical surveys. The smoothly varying part is a consequence of the increase in gravity with increasing latitude caused by rotation and flattening of the earth.

The ellipsoid is virtually the sea-level surface and the variations of gravity with latitude over this surface using the 1967 Geodetic Reference System (GRS 67) Formula is

$g_\phi = 978.031846\ (1 + 0.00527889\sin^2\phi - 0.0000234462\sin^4\phi)$ gal

------4.4

where ϕ is the latitude.

4.1.4 Elevation Correction

Since the gravity value at a station varies with height of the station, it is necessary to correct all observations to a datum which is usually but not always sea-level (i.e, the surface of the reference ellipsoid). This correction consists of two parts, the Free-air and Bouguer corrections.

The free-air gradient accounts for only part of the change in gravity with height [i.e. difference in station elevation (h) above the datum plane (Geoid)]. Observed gravity at elevation h is reduced to its sea-level equivalent on the assumption that topographic masses are displaced vertically down to sea level. The free air correction (FAC) is given by

FAC = 0.30877h ------- 4.5

where h is station's elevation in meters. As gravity decreases with height this correction has to be added to the observations to correct to sea level.

Between any elevated station and the datum plane (usually the sea level) there is a slab of rock with thickness equal to the station height (h), exerting a gravitational attraction at the surface which can be considered to be additional to that due to the mass of the earth below the reference ellipsoid. The correction for this factor, called Bouguer correction (BC) is given by

$$BC = 2\pi G\rho h \qquad \text{-------- 4.6}$$

where $G = 6.67 \times 10^{-11} mk^{-1}s^{-2}$ is the universal gravitational constant and $\rho = 2.67 \times 10^{3}\ kgm^{-3}$ is an assumed average crustal density for the slab.

Equation (4.6) is not modified by the Bullard's term because of the relatively small size of the survey area. The Bouguer correction is usually subtracted from the observed gravity to reduce the value to sea level.

4.1.5 Topographic correction

In a rugged area with considerable irregularities of elevation, particularly in the vicinity of a station, the simple assumption of the slab rock in section 4.1.4 is inadequate and further allowance must be made for departure from relatively flat topography.

This correction was not carried out because the topography in the survey area is relatively flat, and the elevation correction was considered to have provided adequate compensation for the topographic effects.

4.2 Gravity Anomalies

After the observed gravity values have been corrected, two basic gravity anomalies, Free-air (FA) and Bouguer (BA) are found and these are given by the following expressions

$$BA = (g_{ob} + FAC - BC) - g_{\phi} \qquad \text{-------- 4.7}$$

and

$$FA = (g_{ob} + FAC) - g_{\phi} \qquad \text{---------4.8}$$

where g_{ob} is observed gravity.

The Bouguer anomaly is therefore that part of the difference between observed gravity (after Bouguer, Free-air and terrain corrections have been carried out) and the theoretical gravity at any point on the earth which is due purely to lateral variations in the density beneath the surface. When only free-air correction is applied to the observed gravity the difference gives the Free-air anomaly.

The gravity anomalies are usually presented as isogal maps which look very much like topographic contour maps. Graphical processing of geophysical data by means of a computer often requires data in a regular grid. A simple computer program was used to grid the gravity data and contouring carried out to produce the Bouguer anomaly map.

4.3 Density Determination

To aid in the interpretation of the gravity anomalies, a knowledge of the densities of the rock types is essential because the actual causes of

small wavelength gravity anomalies are due to the lateral heterogeneity of rock densities in the sub-surface (Grant and West, 1965).

Great effort was made to secure representative samples of the various rock types from the surveyed area. All rock specimens were collected during the survey. Although an attempt was made to exclude weathered specimens, all specimens were taken at the surface and had been affected to some degree by weathering.

Each sample collected was labelled with the station number of the vicinity where it was got for correlation with lithologic units in the geology map. All rock specimens were identified and classified into gneisses, granites and schists by three different geologists. Each rock was weighed in air (dry weight) and then weighed fully immersed in water (water weight). They were then submerged in water for 24 hours and again reweighed in water (saturated weight). Again they were removed, water wiped off them and weighed in air (wet weight). The Mettler balance model P515 with an accuracy of 1.0×10^{-3} kg was used for weighing.

Both the dry and wet densities for each specimen were determined by Archimedes" principles from the formulae

$$\rho(\text{dry}) = \frac{\text{dry weight}}{\text{dry weight} - \text{water weight}}$$

$$\rho(\text{wet}) = \frac{\text{wet weight}}{\text{wet weight} - \text{saturated weight}}$$

The mean of the dry and wet densities were determined and assumed to be the value nearest to the true density of the rock type. The result is given in table 4.1.

Only the schist samples showed any significant higher saturated densities than the dry densities. This is to be expected since igneous and metamorphic rocks have little or no porosity compared to the porous sedimentary rocks. The density of the Older Granite is less than that of the host rock, the migmatite gneiss complex. The density values were found to compare favourably with other values determined for similar rock types in other parts of the basement complex (Gandu et al., 1986; Oladosu, 1987; Adeniyi, 1987 and Umego, 1990).

4.4 Error In Bouguer Anomaly

For the interpretation of local features in the Bouguer anomaly map, it is the relative error that is important not the absolute error itself.

The error in the Bouguer anomaly arise from determination of relative gravity values and errors in elevation. The error in relative gravity values could be associated with several principal factors: For example,

(i) Gravity stations were located on the 1:250,000 geological map to an accuracy of 350 m and the latitudes of these stations obtained could be in error by about 0.001° (100 m). These give a positional error of about 450 m, which will introduce a maximum error of 0.15 mGal in the

Table 4.1: Densities of Rocks Sampled in the Survey Area

Rock Unit	No. of Samples	Density Range ($\times 10^3$ Kg m^{-3})	Mean Density ($\times 10^3$ Kg m^{-3})	Standard Deviation ($\times 10^3$ Kg m^{-3})
Schists	24	2.59 - 2.71	2.67	± 0.01
Gneisses	38	2.55 - 2.80	2.69	± 0.05
Migmatites	19	2.62 - 2.73	2.67	± 0.04
Granites	27	2.53 - 2.68	2.64	± 0.01
Quartzites	15	2.61 - 2.70	2.68	± 0.04
Syenites	06	2.65 - 2.67	2.66	± 0.08

gravity value. There is also an error of 100 m in station location on the ground, contributing an error of about 0.03 mGals.
(ii) Error in station elevation determination by means of the altimeters could be the combination of (a) errors in correcting for drift, (b) reading error and (c) error in calibration of instrument. Error due to elevation has been estimated to be about 0.55 mGals since the station elevations were determined to within 2.5 m accuracy. (iii) There was difference between the true (measured) density of 2.69 Kgm^{-3} of the material above sea-level and the 2.67 x 10^3 kgm^{-3} assumed in making the simple Bouguer corrections. Error arising from this is estimated to be 0.27 mGal.

The error arising from calibration factor of the modern LaCoste & Romberg gravity metres is negligible. This is because the calibration factor depends only on the quality of the measuring screws and the lever system, both of which are accurately calibrated over their entire range (LaCoste & Romberg, 1976). The error in terrain is also negligible for reasons given in section 4.1.5.

It is therefore reasonable to assume a total maximum (standard) error of about 0.93 mGals in each station value of the Bouguer anomaly.

The free-air anomaly is subject mostly to the same error sources as the Bouguer anomaly . The free-air anomaly mainly represents the influences of the topographic features superposed over the effect of sub-surface. It is used for studies on geoidal height determination, crustal thickness variation determination and understanding general problems like isostasy (Murty, 1977).

CHAPTER FIVE

INTERPRETATION

5.1 The Bouguer Anomaly Map

A gravity map is a topographic surface artificially illuminated so as to show up the sub-surface density variations. The randomly spaced Bouguer gravity data were grided at a digitization interval of 1.02 km, and Fig.5.1 shows the Bouguer anomaly contoured at 5 mGal interval. The Bouguer anomaly map is characterized by negative anomaly values between -30 and -70 mGals, with a mean value of -59 mGal for all the stations. This is consistent with negative Bouguer anomalies generally found all over the world in similar environments.

The negative gravity anomalies are normally associated with granites and are caused by the relatively low density of the granite compared with the density of the surrounding rocks (Bott and Smithson, 1967). Granite has a relatively low density because it is composed principally of low-density minerals such as quartz and feldspar and is poorer in dense, dark minerals than most country rocks.

The pattern of the Bouguer anomaly field in the area is a series of more or less NE-SW trending gravity highs and lows and it appears to be influenced by the surface geology. The closures may be associated with different episodes of igneous activity that led to the emplacement of the granite bodies. The closures with relatively lower anomalies correlate with the granite bodies while the areas underlain by metamorphic rocks typically show gravity highs. In order to better isolate these anomalies, the regional gravity component was therefore determined and removed.

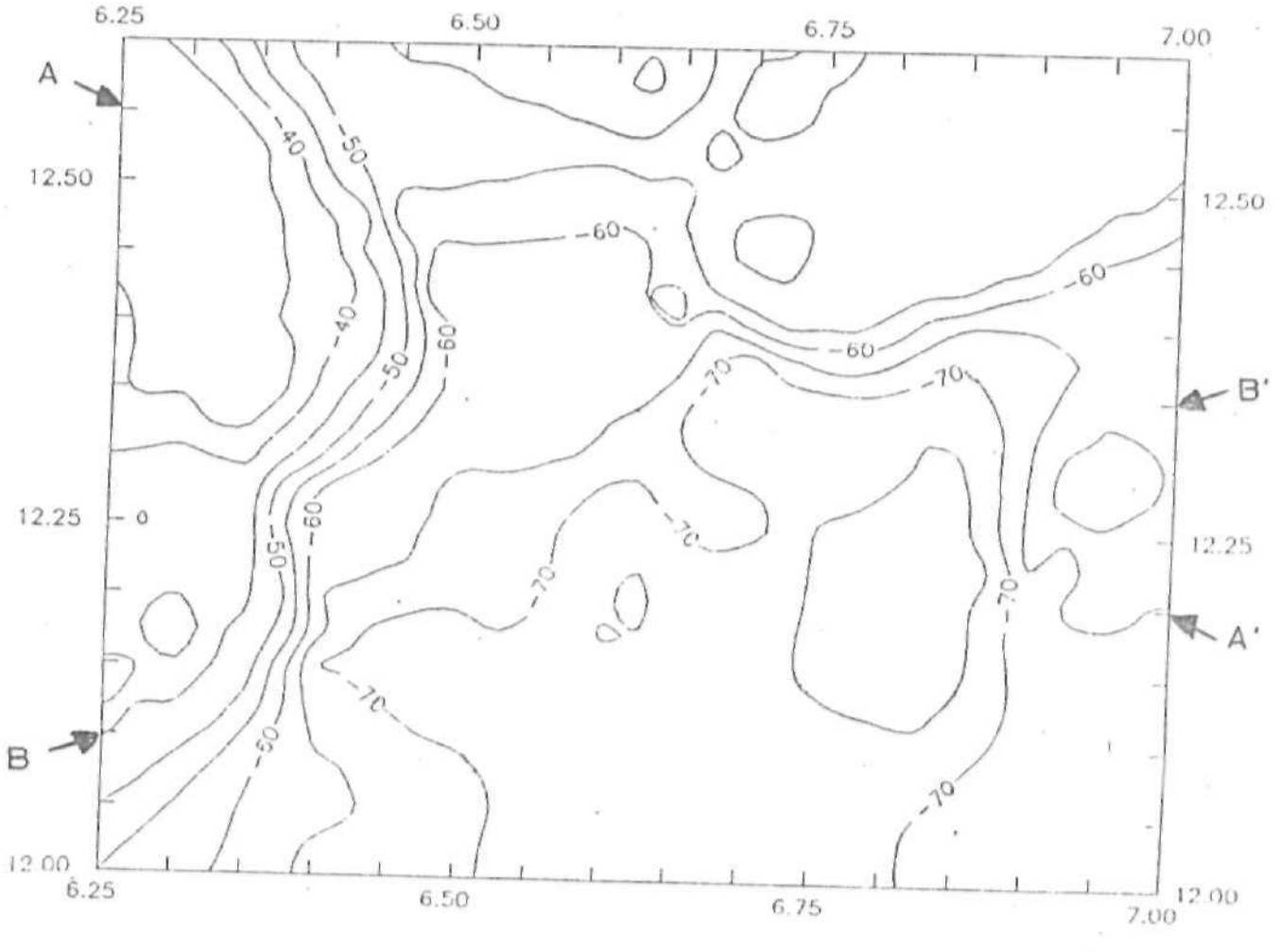


Fig 5.1: Bouguer anomaly map of Gusau area

Contour interval = 5 mGals

5.2 Regional - Residual Anomalies Separation

The observed gravity anomalies usually represent the contribution from all the anomalous masses within a given volume and can therefore be subdivided into regional anomaly due to the deeper and distant regional structures and a residual anomaly due to the effect of local narrow geological features with shallow origin. For this reason, the regional anomalies are usually of long wavelengths (low frequencies) and show a gradual change in value while the residual anomalies, which are due to local effects may show large variations (high frequencies). The residual anomaly is often of interest in most gravity surveys.

There are several graphical and mathematical methods developed for estimating the regional field. Anyone or a combination of the methods can be used for a particular survey in the regional-residual separation depending on the complexity of the Bouguer anomaly map. Each method has its own advantages and disadvantages. The choice of method depends upon

(i) the total labour involved

(ii) the complexity of the gravity map

(iii) the density and distribution of the stations

(iv) the quality of the data.

The method of least squares polynomial surface fitting was used in this survey to estimate the regional effects. This is a purely analytical method in which matching of the regional trend by a polynomial surface of a low order exposes the residual features as random errors. The treatment is based on statistical theory. An advantage of this technique

is that it makes use of the original data points themselves in estimating the regional, thus eliminating the influence of any contouring errors in the Bouguer gravity map, and is also much faster with the availability of a computer. A computer program available at the Department of Physics, Ahmadu Bello University was used to compute the various polynomial surfaces.

First, second, third and fourth degree polynomials were fitted to the data to derive the respective regional gravity fields. Subtracting the regional trend from the observed Bouguer anomaly gave the residual anomaly map. The first degree surface (Fig. 5.2) was chosen as the best surface which depicts the regional trend of the gravity field and its residual correlates suitably well with the known surface geology of the area (Fig. 5.5). Also this is because of the relatively small survey area, and deviations of the regional field from a plane surface are likely to be small. The regional field (Fig. 5.2) shows a NE-SW trend which is apparent in the Bouguer and geologic maps. It is a plane dipping southeastwards with a gradient of 0.44 mGal/km and is consistent with the trend found in the southern part of the basement complex to the surveyed area (Udensi et al. 1986). The residual anomaly map is shown in Fig. 5.3. It has negative contour closures with a minimum of -15 mGal in the central region of the area. The Bouguer, assumed regional and resulting residual anomaly along profiles AA' and BB' are shown in Fig.5.4. The continued rising of the curve on A', B' ends is due to the gravity highs attributed to masses of the schist composition. From the low gradient of the regional field and the large variations in the

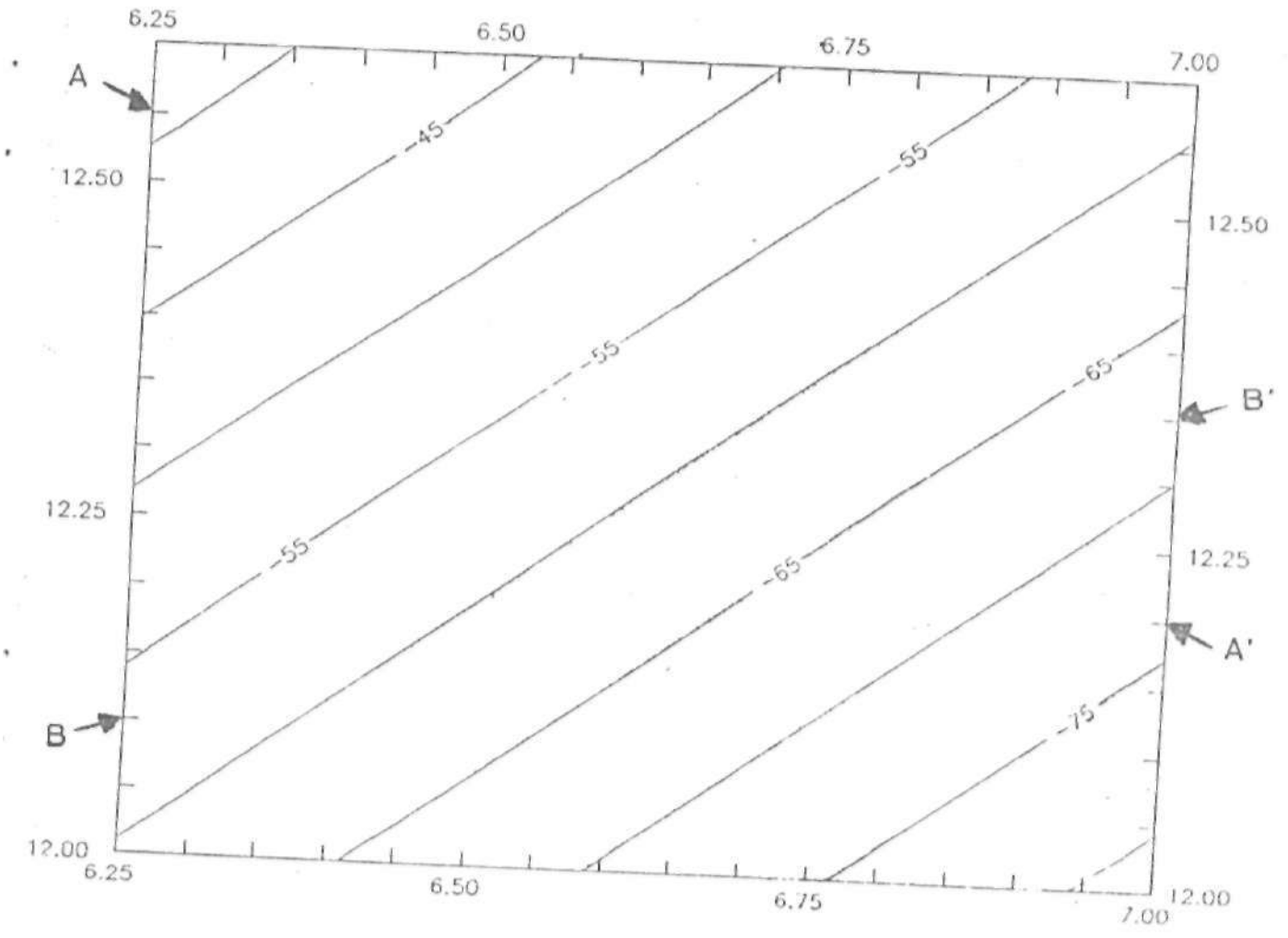


Fig 5.2: Regional gravity field of survey area

Contour interval = 5 mGals

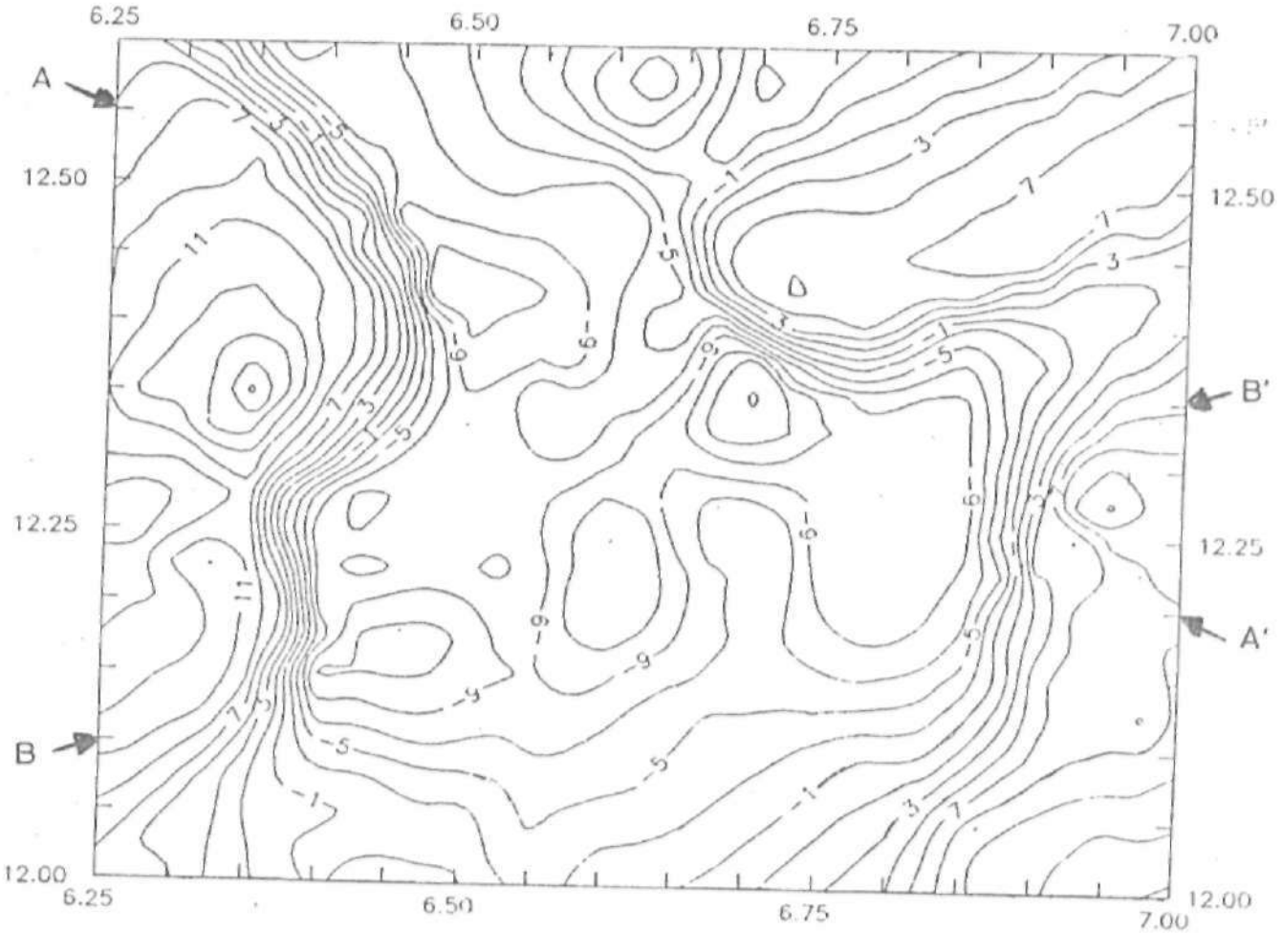
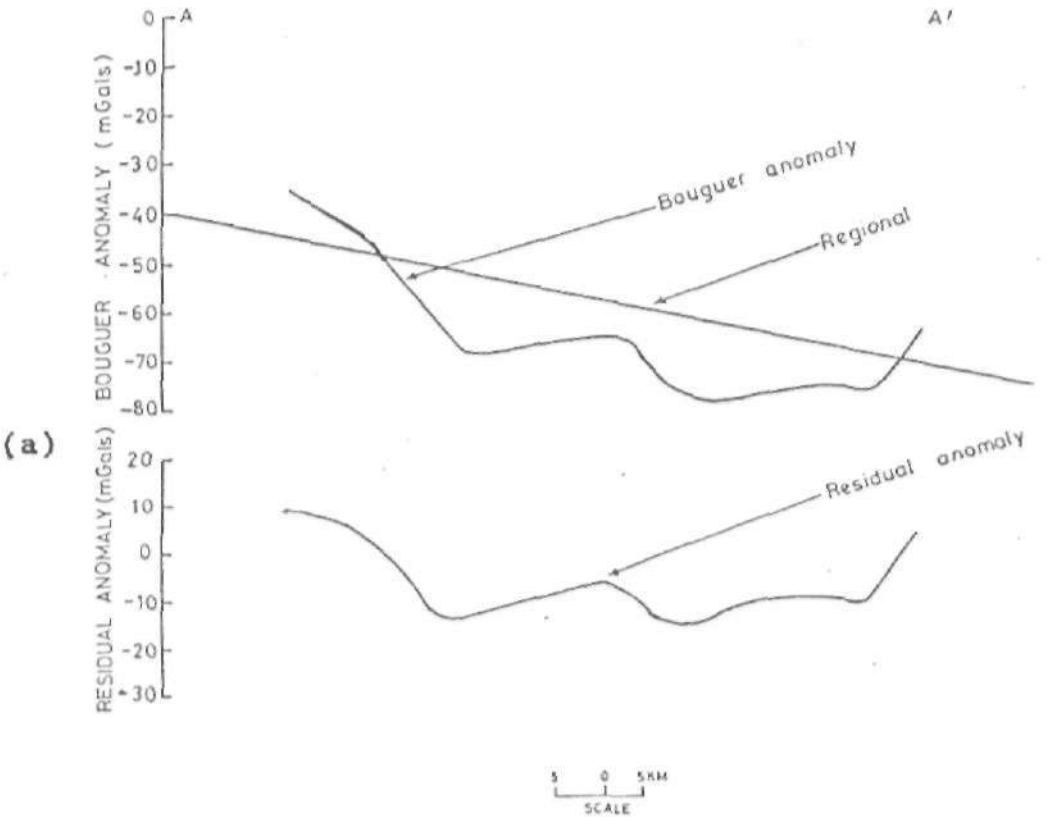
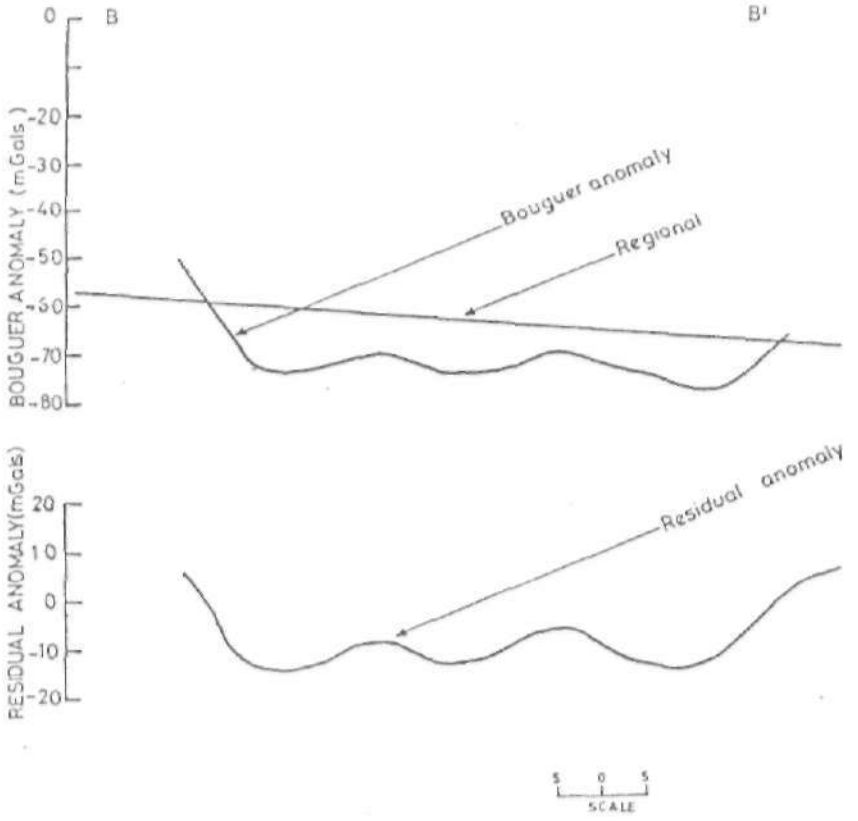


Fig 5.3: Residual gravity map of the survey area

Contour interval = 2 mGals



(a)



(b)

Fig 5.4 Bouguer anomaly, assumed regional effect and residual anomaly (a) along profile AA' (b) along profile BB'

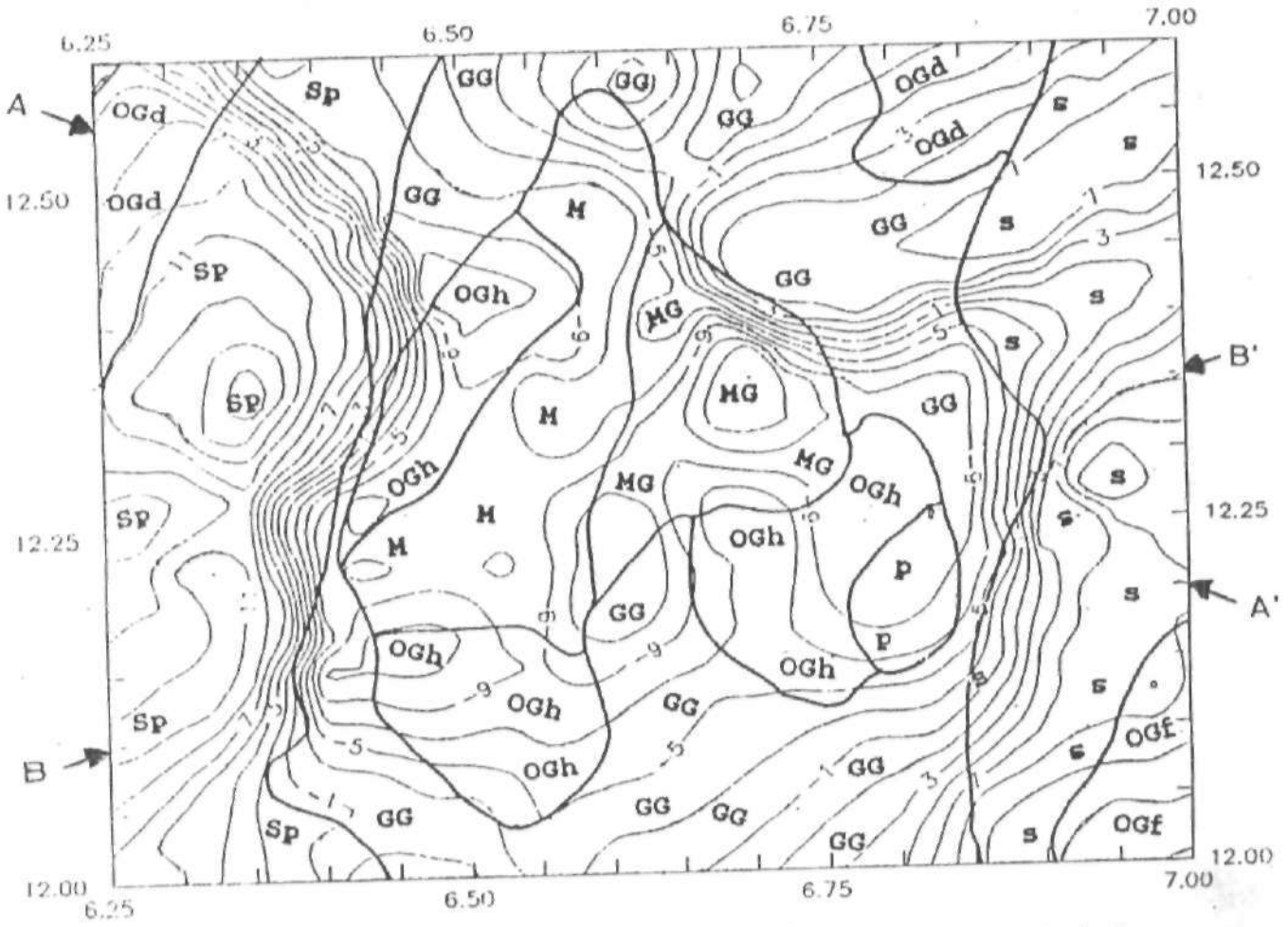
residual values, it can be said that the observed anomalies have in fact been separated into the two parts required: one due to shallow geological features, the Older Granite suite, the other to deeper density contrasts.

5.3 Qualitative Interpretation of Residual Anomaly

The residual anomaly map in Fig. 5.3, got by subtracting the first degree polynomial regional (Fig. 5.2) from the Bouguer anomalies (Fig. 5.1), reveals several prominent negative gravity closures. The residual map was superposed on the simplified geologic map of the area to ascertain any correlation between geophysics and geology (Fig. 5.5) . The closures appear like those caused by a single body at depth. The combined residual and geological map suggests that all the negative closures coincide entirely with mapped Older Granite bodies; the biotite - and biotite hornblende granite, the porphyritic biotite, the migmatite and migmatitic granite-gneiss, situated centrally in the area of survey. The sharp changes in gradient of the anomaly to the east and west which coincide with the Wonaka-Chafe and Maru schist belts respectively tend to confirm that the top of the body responsible for the gravity anomaly is relatively shallow and cannot lie deeper than having its origin in the upper crust.

5.4 The Second Vertical Derivative

The application of the second vertical derivative in gravity interpretation has long been established. The second vertical derivative



——— Contour lines

——— Geological boundaries

OGf	Biotite-granite, fine-grained
OGh	Biotite-and biotite hornblende-granite, medium grained
OGp	Porphyritic biotite-and biotite-hornblende granite, coarse-grained
OGd	Granodiorite, quartz-diorite, medium grained
GG	Granite-gneiss
MG	Migmatitic granite-gneiss
M	Migmatite
S	Biotite-and muscovite schists locally garnetiferous with subodinate granulite hornfels and quartzite
Sp	Shale phyllite, meta-siltstone, locally hornfelsic(stippled) or carbonaceous

Fig 5.5: Residual anomaly map superimposed on geological map of survey area

is often used in gravity interpretation to enhance localized small and weak near - surface features (Gupta and Ramani, 1982). Some gravity anomalies may be distinct on examination of a Bouguer gravity map, while other weak anomalies arising from sources that are shallow and limited in depth and lateral extent may be obscured by the presence of stronger gravity effects associated with deeper features of larger dimensions. The application of the second vertical derivative is to separate the anomalies due to two bodies close together (i.e improving the resolving power of the gravity map) and to suppress the relative importance of the regional anomaly due to deeply buried masses (Baranov, 1975).

The second derivative method can be considered as a type of regional - residual separation technique since it can suppress a second - order regional trend whose curvature is a constant. To obtain the second vertical derivative of the gravity field $\partial^2 g/\partial z^2$, first the second horizontal derivative values; $\partial^2 g/\partial x^2$ and $\partial^2 g/\partial y^2$ are generated. The $\partial^2 g/\partial z^2$ values are then obtained by using the Laplace's equation:

$$\partial^2 g/\partial x^2 + \partial^2 g/\partial y^2 + \partial^2 g/\partial z^2 = 0$$

The horizontal derivatives were obtained with a computer program which employs the method that carries out numerical differentiation using the theory of cubic splines (Pennington, 1965 and Bhattacharyya, 1969).

In this study the second vertical derivative method of analytical regional - residual separation was carried out in order to compare its

results with that of the polynomial method. The resultant second vertical derivative map of the Bouguer gravity over the study area is shown in Fig.5.6. The zero contours are the generated lithological boundaries. The major features are as they are immediately evident on the residual map (Fig.5.3). Fig.5.7. shows the second derivative map of gravity superimposed on the geologic map. There is significant correlation between the vertical derivative and the known surface geology, the zero contours coinciding with the lithological boundaries. In particular, the Older Granite boundaries with the schist belts and granite - gneiss which represent a large mean density contrast are quite accurately outlined by the zero contours. The absence of large number of closures in the central region of the second derivative map could be a supportive evidence that the granite plutons between the Maru and Chafe - Wonaka schist belts coalesce at depth into a single body.

Thus, a properly designed second derivative map, in addition to enhancing weaker local anomalies, can be a supplement to geologic mapping in the identification of lithological units in the study of structures; delineating the contacts of lithologies with contrasting densities. These contacts are reflected by inflection points in the Bouguer gravity map which, while difficult to locate on the Bouguer map, are accurately traced by the zero contours of the second vertical derivative map.

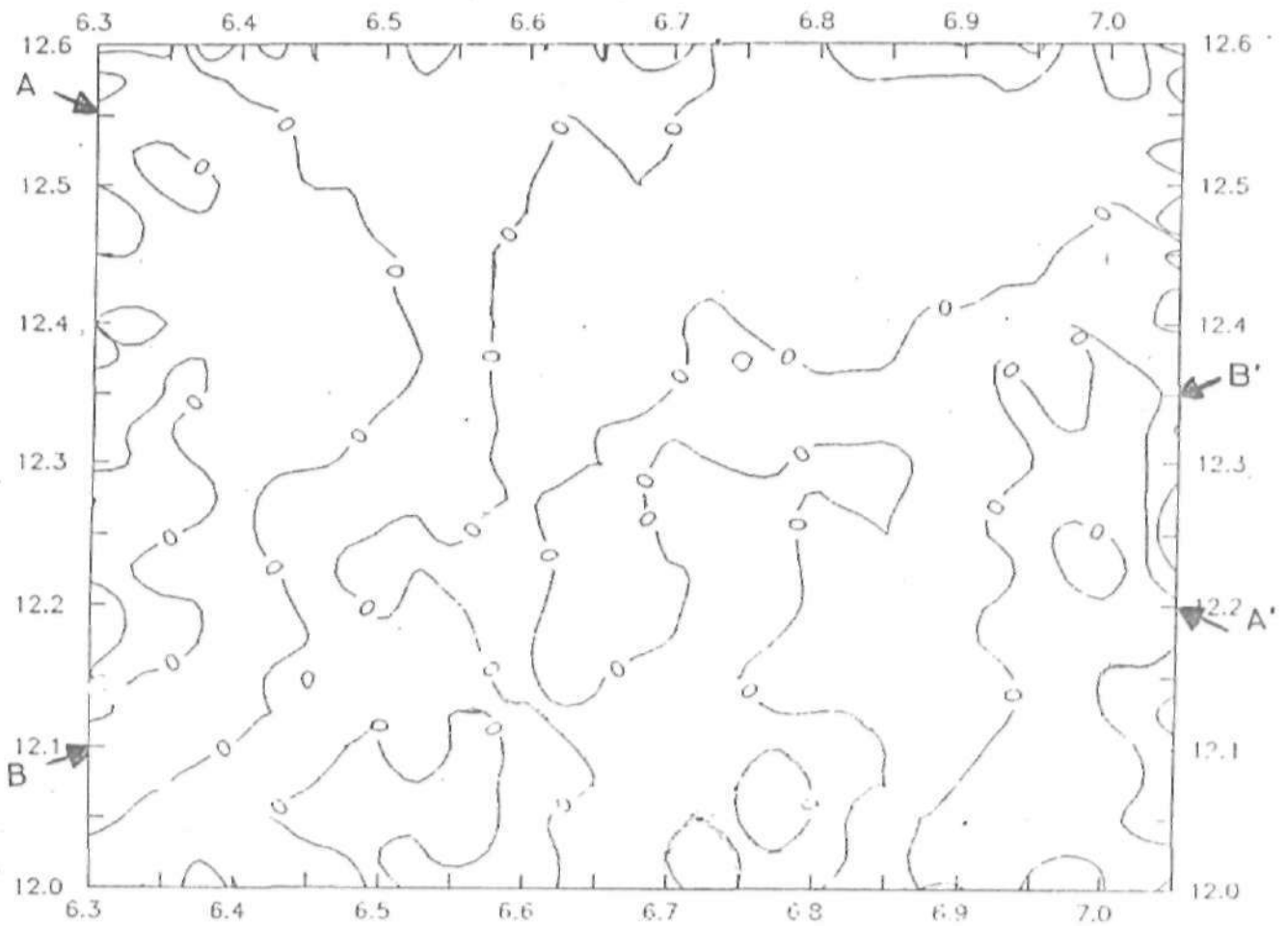


Fig 5.6: Second vertical derivative gravity map of survey area

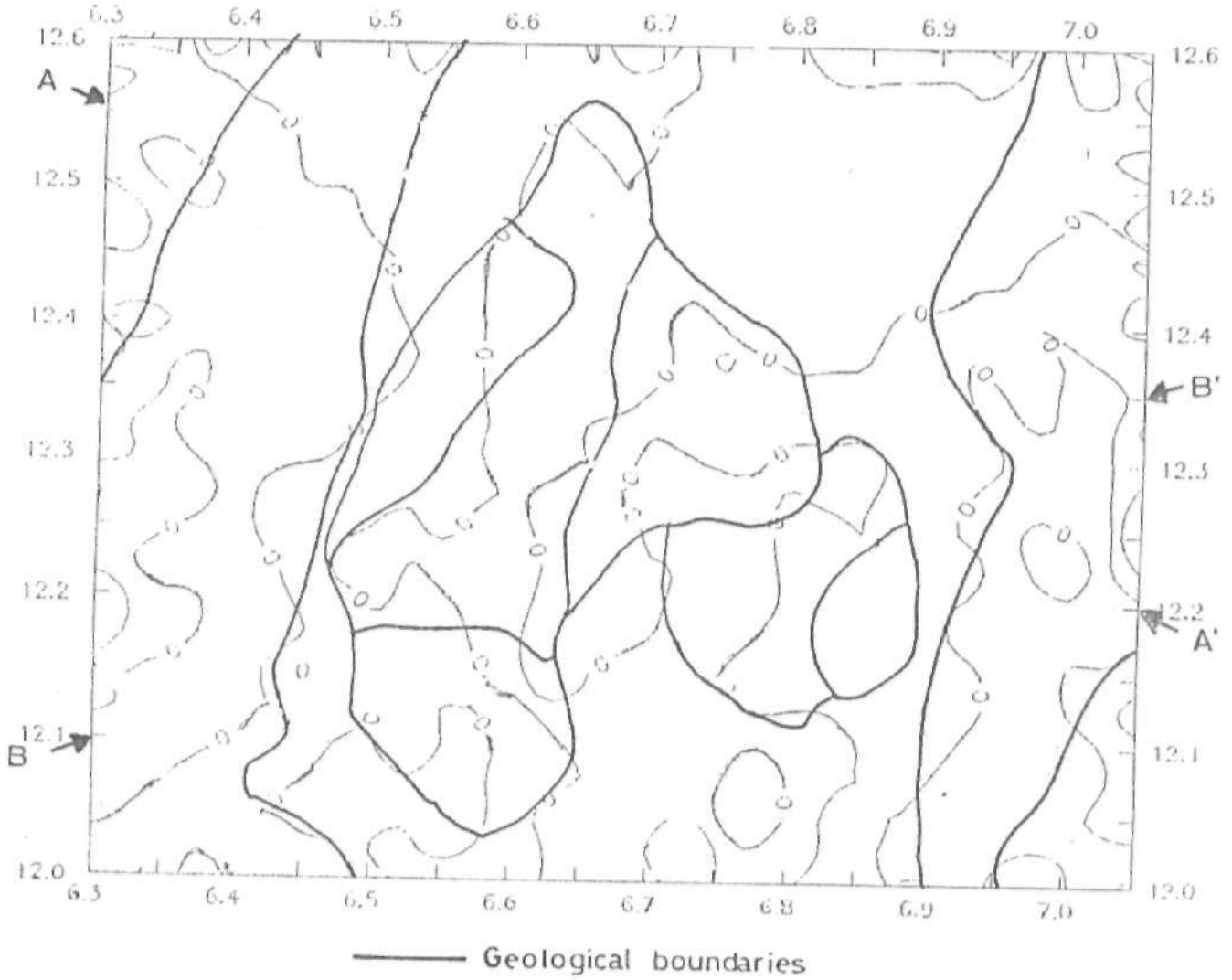


Fig 5.7: Second derivative map superimposed on geologic map of survey area

5.5 Quantitative Interpretation of Residual Anomaly

The problem of gravity interpretation is principally that of using a residual gravity map, which is a topographic surface artificially illuminated so as to show up the sub-surface variations in density, to determine the subsurface source whose gravitational effect has been observed at the surface. The last stage is to estimate the likely parameters of this source such as depth, size, shape and density contrast. Obtaining such a complete solution is rather impossible due to the non-uniqueness of the gravity data interpretation.

The process by which the parameters of the causative body is determined follows one of two routes namely "forward modelling" and "Inverse - modelling". The inverse modelling involves determinig estimates of model parameters given a set of observational data and a general model for their cause (Paterson and Reeves, 1985). This is an over-determined problem as there are usually far more observations than are needed for a single solution, so that the acceptable solution is that which best fits all the available data. Its major advantage is its ability to operate efficiently in multi-parametric space, and ability to produce solutions within a relatively small number of iterations even with poor starting models. The technique however, usually does not allow for user interaction and if such interaction is necessitated by the need to impose some geologic acceptability on the result, the solution is then no longer necessarily the best possible fit in a mathematical sense.

On the other hand, the forward modelling approach involves the following procedures:

(i) Subjective human estimation of an initial model using the known geology.

(ii) Calculating the exact theoretical anomaly values for this model and comparing them with the observed values.

(iii) Judicious adjustment of the model by human interaction and within geologically reasonable limits in the hope of improving the match for an acceptable fit.

(iv) Repeating the process in (ii) and (iii) until the theoretical values match the observed values.

The values of the parameters that give the best match (or fit) of the computed data to the observed points are then adopted as the parameters of the causative anomalous body.

The forward modelling approach was adopted because it has merit in the ease of programming on microcomputers and the human interaction brought in at every iteration which ensures that the model retains geologic credibility.

The shape of the residual anomaly (Fig. 5.3) and the result of the second vertical derivative analysis suggest that the causative body is of three-dimensional nature. A computer program (Talwani and Ewing, 1960) which implements the above procedure was used on the Cyber 392 computer belonging to the Iya Abubakar Computer Centre of the Ahmadu Bello University Zaria. The work was completed using a

version of the program adapted for use on the IBM PC/AT by Umego (1990). The program was modified to plot the observed and computed gravity anomalies automatically after each iteration.

In this method, the program computes the gravity field due to an arbitrarily shaped three-dimensional body using polygonal shaped laminae as the basic modelling blocks. The outline of the body is first defined by polygonal-shaped depth contours, and each contour is then replaced effectively by horizontal n-sided polygonal lamina. The gravity effect (i.e. vertical component of gravitational attraction) caused by each lamina can be determined at any field point and the gravity anomaly of the entire causative body is got by numerical integration with respect to depth. Details of this can be found in Talwani and Ewing (1960).

The theory is summarized in the expression

$$\Delta g = V dz \qquad \text{---------- 5.1}$$

where Δg is gravity anomaly caused by a polygonal lamina of infinitesimal thickness dz, and V is the anomaly caused by the lamina per unit thickness. V can be expressed by a surface integral, the integration being carried out over the surface of the lamina and can be reduced to two line integrals both along the lamina's boundary given by

$$V = G\rho\left[\oint d\Psi - \oint \frac{z}{(r^2 + z^2)^{\frac{1}{2}}}\, d\Psi\right] \qquad \text{--------- 5.2}$$

where G is the universal gravitational constant, ρ volume density of the lamina and z , ϕ and r are the cylindrical coordinates used to define the boundary of the lamina. The total anomaly g_{total} caused by the entire body (evaluated by integrating between Z_{top} and Z_{bottom}, the vertical limits of the massive body) can be obtained by the expression

$$\Delta g_{total} = \int_{Z_{bottom}}^{Z_{top}} V \, dz$$

This integral can be solved graphically or by numerical integration and the possibility that density varies with depth may be easily incorporated by assigning a separate density to each contour.

The body causing the residual anomaly (Fig. 5.3) was modelled by the technique described above. Irregularly shaped polygons representing the assumed three-dimensional body depth contours were fitted as closely as possible at different preselected depth points (Fig 5.8). The X- and Y- coordinates corresponding to longitudes and latitudes respectively of the vertices of the polygons were determined in a horizontal plane and the Z-axis was vertically downward. Field points were chosen at irregular intervals along the profiles A-A' and B-B' and their coordinates as well as observed residual anomalies at these points determined. The input data to the computerised interpretation comprises of the following:

(i) the coordinates of all the field points as well as the observed residual anomaly at these points along the profile chosen and

(ii) the coordinates of the vertices and depths of the polygonal laminae as well as the density contrast for

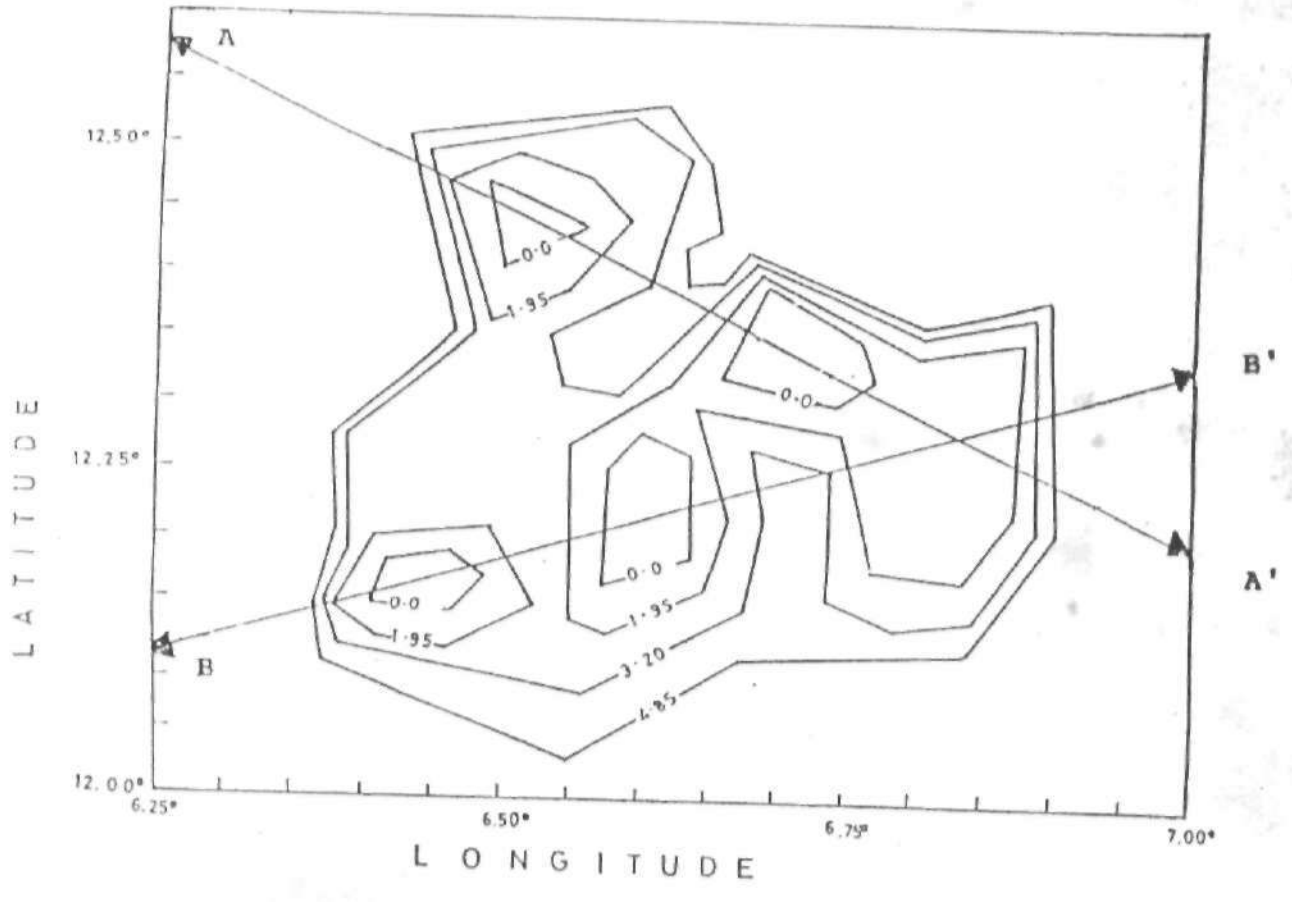


Fig 5·8: Three dimensional model of body used for the residual anomaly (Depth contour values are in km)

each lamina.

The output comprises:

(i) a listing of all the input data which acts as a check,

(ii) the contribution of each polygon at each field point,

(iii) the computed total anomaly (i.e. the result of the numerical integration for each body summed for all bodies) at each point, and

(iv) a plot of the observed and computed anomalies at each field point along the chosen profile.

An infinite number of models is possible in this way, but geological and other constraints would often limit these to only a few acceptable ones.

5.6 Three-dimensional Interpretation of Residual Anomaly

The method of interpretation adopted employs a simple computer program to determine the gravitational attraction along profiles of a certain assumed geometric form, based on available geological information and density contrast from table 4.1 as initial constraints. It was assumed that the density of the rocks measured on the surface do not change appreciably with depth. Two residual profiles A-A' and B-B' were selected to obtain a vertical cross-sectional view of the model shown in Fig 5.8. Gravity values for the given model were computed along the profiles at irregular intervals. The profile A-A', about 75 km long (Fig. 5.8), cuts across the anomaly and runs from the northwestern to the

southeastern part of the survey area on the residual map. The profile B-B', about 77 km long (Fig.5.8) runs over the anomaly from SW to NE.

Gravity values for the chosen model were computed along the profile after several systematic trials and adjustments were carried out in order to obtain the best fit between the computed and observed gravity values. Fig 5.9 shows vertical cross-sectional view of the interpreted model with observed and computed anomalies along the profiles fitting reasonably well. The model indicates that the granite intrusion extends to a depth of about 5 km. The attitude of the contact of the pluton was estimated to be outward sloping with respect to the host rock.

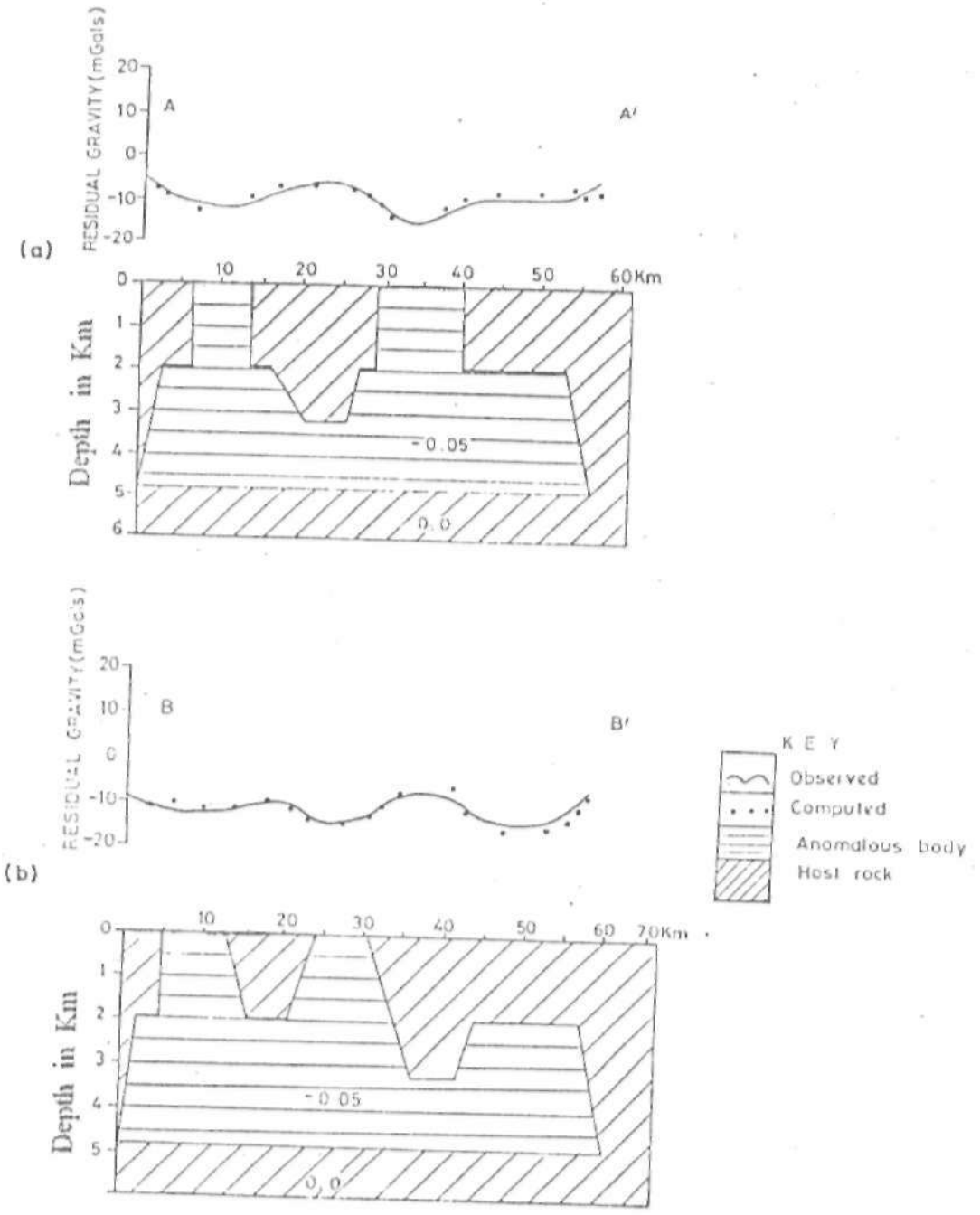


Fig 5.9: Observed and computed residual anomalies (a) along profile AA' (b) along profile BB'

CHAPTER SIX

DISCUSSION AND CONCLUSION

6.1 Discussion

The negative gravity anomalies over granites could be explained by the composition of the granites which are predominantly low-density minerals such as quartz and feldspar and less dense, dark minerals than the country rock, in this case the migmatite - gneiss complex. The prominent gravity lows occur over the mapped Older Granite plutons located between the Maru and Wonaka - Chafe schist belts. Subsurface connection of the individual plutons is suggested by the pattern of the negative anomalies, so that the individual plutons may be regarded as part of one large body at depth. Between the exposed granites, the roof region is still preserved. Fitches et al. (1985) proposed that these plutons are products of magmagenesis at levels substantially below the present exposure level and that some plutons are still being unroofed.

The structural relationship between the different bodies as inferred from the residual (Fig.5.3) shows that the Maru and Wonaka - Chafe schist formations have very steep contacts with the Older Granite suite as is generally the case. The sharp contact between the Older Granite and the host rock, the migmatite - gneiss complex is also prominent in the residual map.

The Nigerian basement complex has suffered polycyclic thermotectonic (orogenic) episodes resulting in common orogenic features that vary in scale from local to regional dimensions, notably the regional

linearments, regional and local folds, thrusts and faults and also the development of tectonites (mylonites). The Older Granite orogeny, now generally recognized as the Pan-African orogeny in Nigeria, is a late-tectonic effect related to the intrusion of granites, aplites and pegmatites into the crystalline complex of gneisses and migmatites, followed by post metamorphic epeirogenic uplift, cooling, fracturing and faulting and high-level magmatic activity.(Oyewole, 1964; McCurry and Wright, 1971; Fitches et al., 1985; Rahaman, 1988 and Ajibade and Fitches, 1988)

Two main divergent hypothesis concerning the origin of Older Granite masses have been suggested for the Older Granites in Nigeria. These are the magmatic origin with subsequent magmatic emplacement or the metasomatic origin whereby sedimentary and metamorphic rocks were converted by metasomatic migration of material. Through chemical analysis and petrological features examination, Older Granites of the Nigerian basement complex were considered to belong to a single magmatic epoch (Russ, 1957; Oyawoye, 1964; McCurry and Wright, 1971; Rahaman, 1976; Grant, 1978; Turner, 1983 and Gandu et al., 1985).

The emplacement of the Older Granites in this area of survey is considered to be due to a cycle of spreading and collision during the late Precambrian times (Fitches et al, 1985). The Older Granite intrusions are high level plutons emplaced by stoping and diapiric processes having sharp and discordant contacts with the host rock, the migmatite - gneiss complex. The granitic magma might have risen

through the weak zones of the country rock before spreading to it's present width possibly due to changes in the temperature and pressure conditions near the surface. Geological analysis reports no evidence of metasomatism at the contacts for Older Granites in NW Nigeria. Ogezi(1977) concluded that the abundance of granitoid plutons of the Older Granite suite is clear expression of late Proterozoic - early Phanerozoic events with ages in the range 750 - 600 MA.

The negative anomalies (i.e low density) confirm the acidic nature of the Older Granite plutons. The presence of several negative closures in the Bouguer and residual anomaly maps strongly indicates a granite parent magma for the Older Granite suite in Gusau area. The shallow depth of about 5 km that the granite has extended to in this work is within the range of 3 to 5 km discovered for other adjacent and near members in the works of Gandu et al. (1986), Udensi et al. (1986), Adeniyi (1987), Oladosu (1987) and Umego (1990). They all proposed magmatic origin except Oladosu that suggested metasomatism for the emplacement of the Older Granite intrusions in the Rano area of Kano state.

The sharp contact of the modelled body with the host rock, coupled with the shallow depth tend to support magmatic stoping as the likely mode of emplacement of the Older Granite intrusions in this area.

With the data at 2 km intervals and the subsequent interpretation, it may be concluded that the small isolated granite outcrops in the survey area coalesce at depth into one big pluton still being unroofed at the present time.

6.2 Suggestions For Further Studies

A comprehensive gravity survey covering a wider area, extending into the Maru and Wonaka - Chafe schist belts in the western and eastern parts of the present survey should be carried out. This will help to map out the Older Granite bodies between the two belts and probably throw more light on their lateral extent and their structural relationship with the host rock. There is need for the Federal Survey Department to update the available road maps and the Geological Survey of Nigeria to update geological maps of the basement complex. These will improve the accuracy of future geophysical surveys within the Nigerian basement complex.

Gravity and seismic refraction surveys over the whole of the Nigerian basement complex will throw more light on the subsurface structures, the lateral extent and mode of emplacement of the granite plutons in this very important region.

6.3 Conclusion

The polynomial fitting method of regional - residual separation employed in this work and the result of the second vertical derivative analysis yielded comparable and favourable results. The results of the density determinations of the major rock types in the survey area show that the migmatite - gneiss, i.e, the host rock has an average density of 2.68 x 10^3 Kgm^{-3} and granites, 2.63 x 10^3 Kgm^{-3}. The survey area is characterized by large negative Bouguer anomalies between -30 to -70 mGals. The relatively low density of the granite bodies, and the negative residual anomalies have confirmed the acidic nature of the Older Granites. The second vertical derivative map highlights remarkably well the granite rock units with the zero contours coinciding with the boundaries of most lithological units. The results of this survey suggest that the small isolated granite outcrops in Gusau area coalesce at depth into one big pluton still being unroofed at the present time. In some of the granites erosion has completely uncovered the roof, but in others, areas of roof are still preserved.

From the model which best fitted the profiles A-A' and B-B', the Older Granite was estimated to have a depth extent of about 5 km and slopes steeply outwards. Sharp contacts between the granites and the migmatite - gneiss strongly suggests a magmatic origin for the granites. Gravity investigation is so far the only method that has given reliable and consistent information on the sub-surface extent of the plutons in Nigeria.

From all the analysis, it is concluded that the Older Granite intrusions in the Gusau area are high - level plutons probably emplaced by stoping and diapiric process, having sharp and discordant outward sloping contacts with respect to the host rock, the crystalline migmatite - gneiss complex.

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