GRAVITY INVESTIGATIONS
IN THE
MIDDLE NIGER BASIN AREA, NIGERIA

BY

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ABSTRACT

Gravity measurements carried out in the Middle Niger Basin area show that the area is characterised by negative Bouguer anomalies ranging in value from -67 mgal to +15 mgal. The free-air anomalies are distributed about a mean value of approximately +5 mgal. which suggests that the area is approximately compensated. A regional anomaly ranging in value from about -20 mgal in the sourthern parts of the area to about -20 mgal in the northern parts of the area is correlated with a gradual thickening of the crust from the South to the North. Major negative residual anomalies centred on the basin are explained by the presence of thick Cretaceous sedimentary rocks in the area. Positive residual anomalies also occur over parts of the basin and these are attributed to a high-density metamorphic basement, and to masses which are probably of scirest composition.

From two dimensional modelling based on gravity profiles it is estimated that the maximum possible thickness of the 6retaceous sediments is generally of the order of 2km, and is nowhere considered to exceed 2.7 km.

The gravity pattern at the boundaries of the basin indicates that the contacts at the edges of the basin are probably not faulted. The basin is therefore thought to be an area of local subsidence.

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CHAPTER I

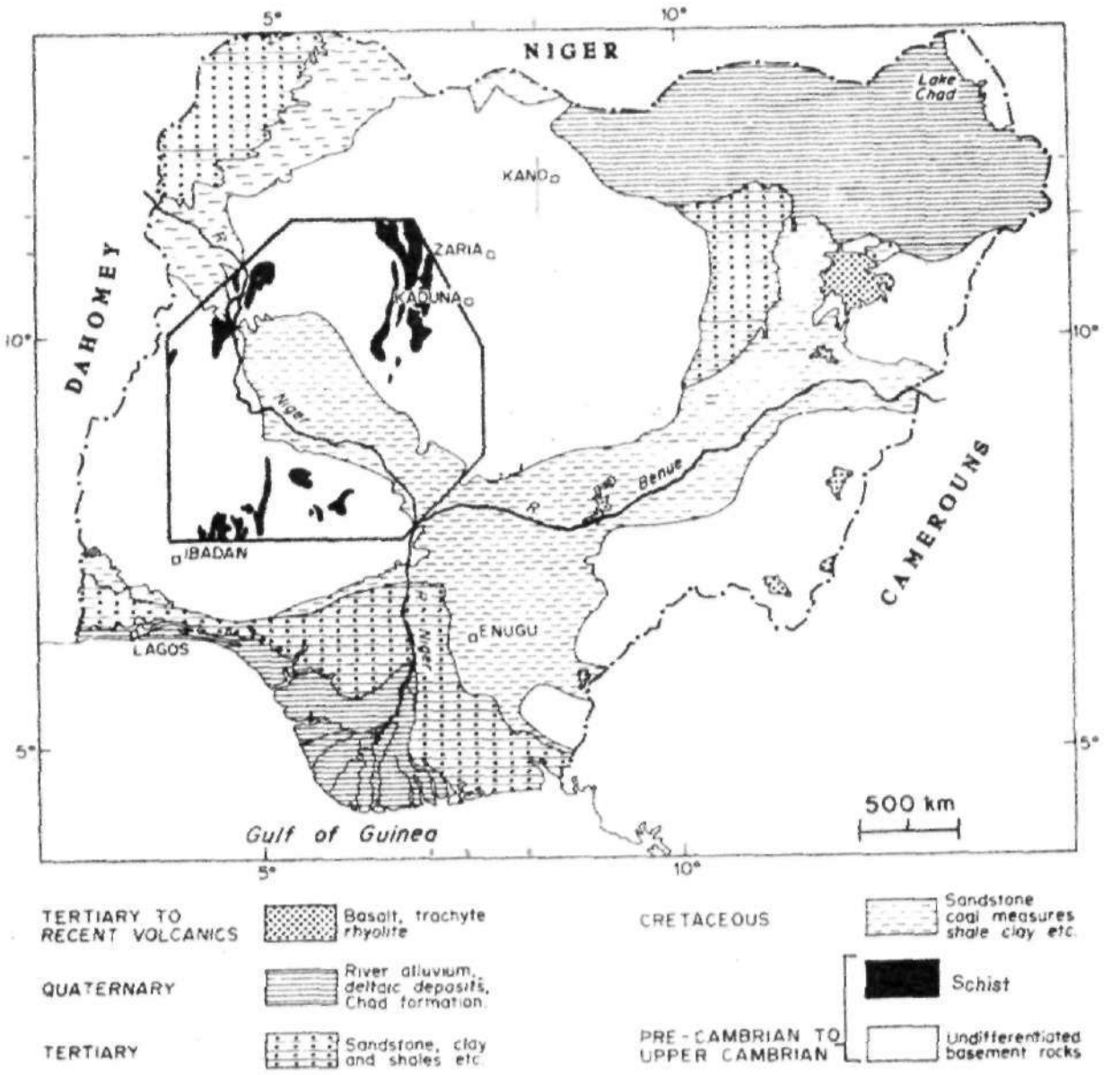
INTRODUCTION

1.1 General Introduction

The area covered by the gravity survey described in this thesis is located in the central region of the western half of Nigeria (Map 1). It lies between latitude 7°30'N and 11°30'N and between longitude 3°40'E and 8°00'E and covers approximately an area of 180,000 km^2. of parts of the North-Western, North-Central, Kwara, and Western States.

Two distinct rock types are located within the surveyed region. They are the rocks of the Basement Complex, and the sedimentary sandstones of the Middle Niger Basin also known as the Nupe Basin. The Nupe Sandstones are Cretaceous rocks which show occasional gentle folding and are underlain by the Pre-Cambrian to Upper Cambrian Basement Complex consisting mainly of Older Granites, migmatites, and various gneisses. Overlying these are the Younger Metasediments consisting of various low-grade schists, quartzites, phyllites and amphibolites.

The region was notable during the first half of this century for its major contribution in gold production, but this has shown decline in recent years. The primary aim of this survey is therefore of a structural rather than economic interest. It was hoped that from this survey, the maximum thickness of the sedimentary strata of the Middle Niger Basin would be determined and that it



Map 1. Simplified geological map of Nigeria showing the gravity survey area.

would be possible to find out the general geometry of the basin. It was also hoped that the survey would throw some light on the origin of the basin and provide a base network for the Middle Niger Basin Area which would serve as a basis for a more detailed gravity study and subsequently other geophysical studies in the area.

The field work was done during a five-week period in March and April, 1972, a five-day period in June, 1972 devoted mainly to the collection of rock samples, and a three-week period in January 1973. Emphasis was placed on establishing as many gravity stations as the road network would permit. In all, 720 stations were established, frequently at 1 to 4 km. intervals. The region is covered by a network of tarred and dry-season roads and all stations were established along these roads.

The results obtained show that the gravity method is not completely adequate to deal with the problems encountered during the course of this survey. It is therefore considered that the results of other geophysical methods especially the seismic method would be valuable for the interpretation of the data collected.

1.2 Previous Geophysical Work in the Area

Very little previous geophysical work has been done in the whole of Nigeria in general, and in this area in particular. A few results have however been published for work done in the

basement areas north and south of the Nupe Basin, but none for the basin itself.

To the north of the basin, an aeromagnetic survey for mineral deposits in the northwest of Nigeria was carried out by the United Nations during the period from December, 1964 to March, 1967. The areas north of 10°45'N of the squared portion of Map.1 were included in the Survey. The project included aeromagnetic, aero-electromagnetic, electrical and magnetic (ground) methods. The general conclusion drawn from the survey was that no important primary deposits of precious or base metals were to be found within the area and no further major programmes of mineral exploration in the area would be justified on the basis of the project results.

South of the basin, a resistivity survey was carried out by Cole, in 1958 for water supplies in the Ihima district, near Okene in Kabba Province. Resistivity depth probes were made at seventeen sites with one self-potential traverse. The results showed that the bedrock in most of this district was too shallow for water yields in the weathered material to be very good.

CHAPTER II

FIELD PROCEDURES AND CORRECTIONS

2.1 Field Work

The gravity survey was carried out during three periods in March and April 1972, June 1972, and January 1973 on the principal roads and tracks in the area. In all, nine weeks were spent collecting data including a week in June devoted mainly to collecting rock samples.

The instrument used was a Worden gravimeter, No.135 with a scale constant of 0.08829 mgals/division. The instrument was carried by Landrover over roads and tracks, twice by a motorised ferry and once in a canoe when base stations across the R. Niger had to be linked at Rofia, Jamata and Pategi respectively. Stations were established at 1-4km. intervals except between base station 9511 and 9581 where the observed gravity gradient permitted an 8 km. interval.

Prior to the field work, the instrument drift was observed for five days inside a room in the Physics Department Building. The readings showed slightly erratic drifts so the instrument levels were readjusted and the instrument observed for a further five days (See Fig.1). The maximum mean drift was 0.37 mgals in ten hours with a maximum of 0.26 mgal/hour. The largest total drift observed on the field was 0.62 mgals over 3.25 hours. In view of this low value, it was felt justifiable to allow as much as four hours to elapse between the reoccupation of a base station

GRAVIMETER DRIFT CURVES

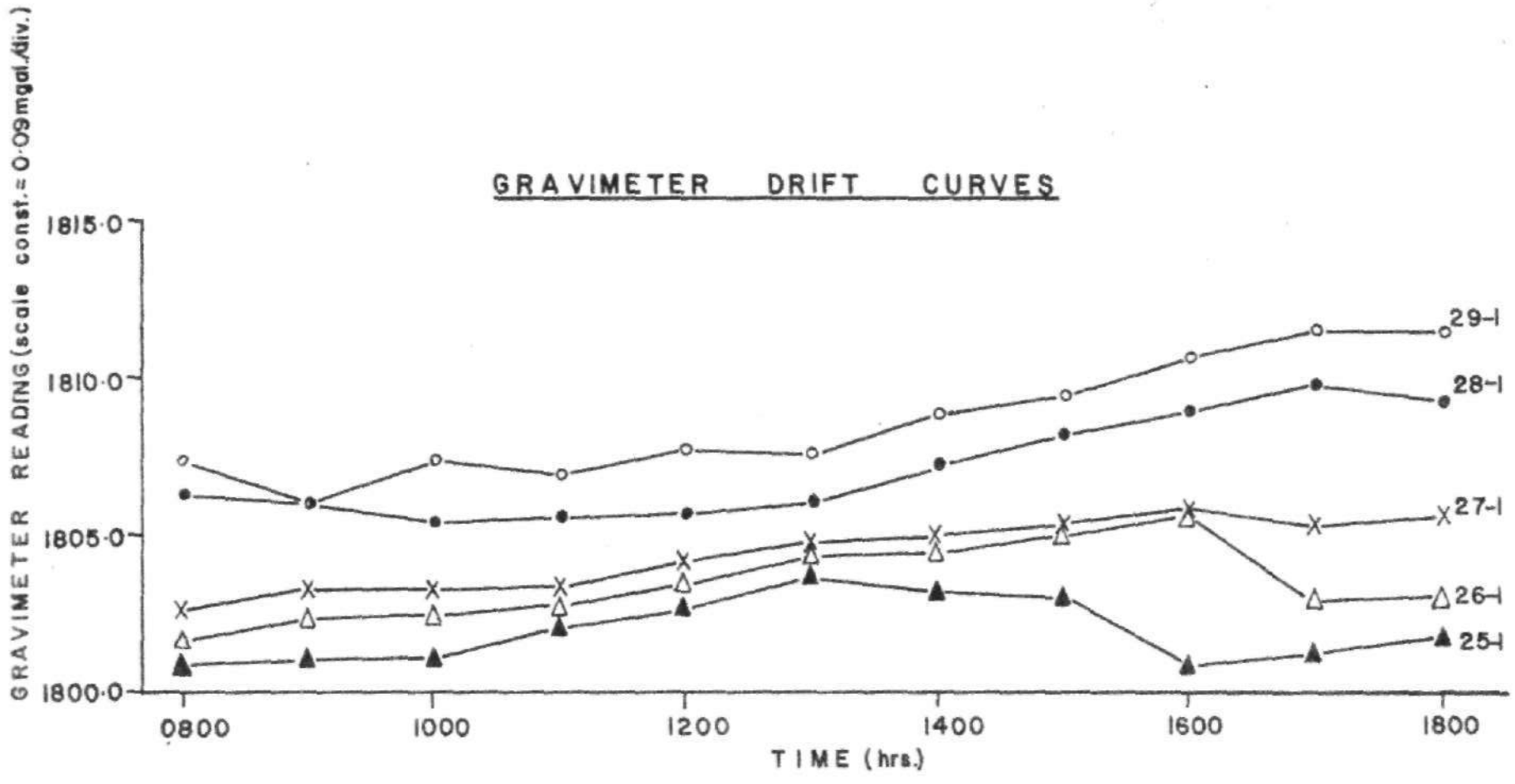


FIG. 1

whenever this became unavoidable. However, most loops were completed in less than three hours. The instrument constant was roughly checked by taking readings on the ground, first and second floors of the Physics Department Building. The check showed that the constant could be in error by as much as .002 mgal.

About one-half of the total number of stations were established on benchmarks whose heights were supplied by the Survey Division of the Federal Ministry of Works and Surveys. The other stations were established wherever possible at mileposts and at road junctions. The heights of the latter stations were determined by means of three Wallace and Tiernan altimeters. One altimeter was placed at a benchmark of known height and the reading taken every five minutes, while the other altimeters were transported to the stations whose heights were required and their readings taken. Wet and dry bulb thermometer readings were taken at each point to correct the altimeter readings for humidity and air temperature.

2.2 The Base Station Network

The base station network is shown in Fig.2. and their principal parameters are given in Appendix I. They were established by the technique of "looping" usually in the form ABABCBCACA (Nettleton, 1940). They were interconnected to form 8 closed loops. A ninth loop which would have included bases 9535 and 9541 could not be completed because of lack of adequate roads. From the closure errors around these loops, it was possible

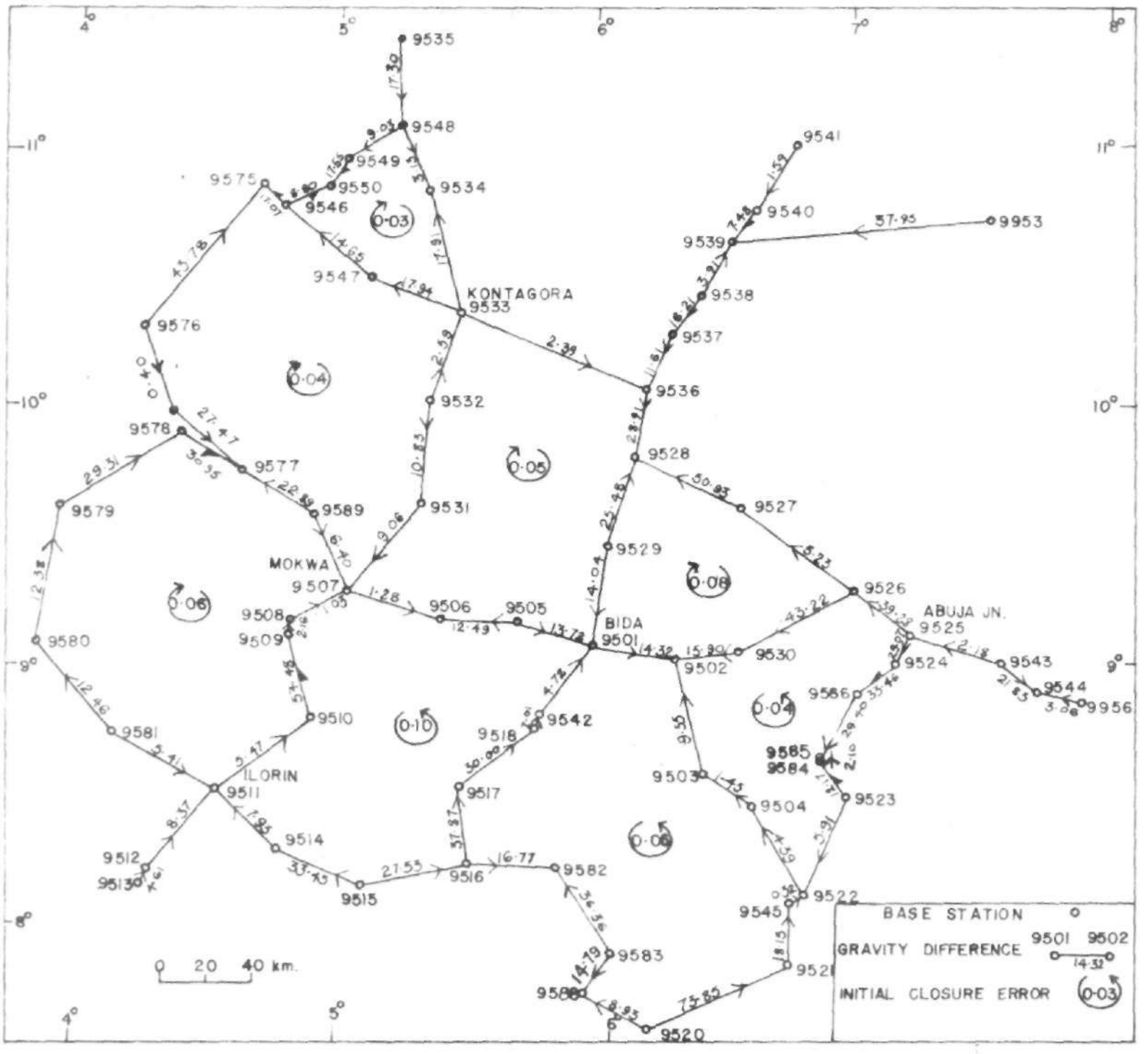


FIG. 2 - Base Network

to estimate the accuracy of the observations. For each leg of the network, a value of the unadjusted ΔR was obtained and corrected for the combined effect of diurnal change and instrument drift by assuming a linear change between repeat readings at base stations. The adjusted ΔR's were multiplied by the scale constant of the gravimeter 0.08829 mgal/division to obtain the values of Δg in mgal.

2.3 Adopted Base Value and Ties to other Surveys

All the observed gravity values in this survey are relative to the value 978074.39 mgals at a standard bench mark in Keffi. This Figure was obtained from a tie by D. E. Ajakaiye(1970) to the Benue Valley Survey by Cratchley and Jones (1965). The network for that Survey was in turn connected to the O.R.S.T.O.M. base at Lagos via a Shell-BP network, and also tied to the O.R.S.T.O.M. base in Fort Lamy via a Chad Basin network established by the British Overseas Geological Surveys in 1959. Another station at the Kaduna/Jos Road junction established by Ajakaiye (1970) was also reoccupied. Agreement was to within 1.12 mgal. The discrepancy is probably due to the fact that the exact position of the base station could not be located due to a new road construction in the area.

2.4 Reduction of the Data

All the gravity data were reduced to Bouguer and Free-air anomaly values at the Gravity Division of the Dominion Observatory, Ottawa, Canada, using a computer-oriented system described by Tanner and Buck (1964).

The drift curves were plotted for the base stations and the relative differences in gravity (Δg) between two neighbouring control stations were calculated manually. These and the other relevant parameters of the base stations were punched on cards and together with detail station cards were then used to calculate the Bouguer and Free-air anomalies.

The vertical gradient of gravity was assumed to be 0.3086 mgal/metre and the crustal density was assumed to be 2.67 gm/cc. Bouguer anomalies were computed assuming the topography to have the form of an infinite sheet having thickness equal to the height of the gravity station above sea level.

The equations used to obtain the observed gravity values from the gravimeter readings, the Free-air and Bouguer anomalies are:

(a) Temperature effect on Worden Instruments. When these instruments are operated without a temperature-control unit the scale constant varies with temperature as follows:

$$K = K_{cal} - 0.000072(75-T)K_{cal} \qquad (1)$$

where K is the corrected scale factor, K_{cal} the instrument constant determined from the calibration line or tilt table, and T the instrument temperature in degree Fahrenheit.

(b) Drift rate. For the computation of the drift rate a linear relationship with time is used. For precise work the time interval between readings at control station is usually kept to less than

three hours.

$$\sigma = \frac{(R_1 - R_2) - \frac{(g_1 - g_2)}{K}}{t_2 - t_1} \qquad (2)$$

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

(c) Observed gravity for detail stations

$$g_s = g_1 + K\left((R_1 - R_s) + \sigma(t_s - t_1) \right) \qquad (3)$$

where g_s is the observed gravity value, R_s is the reading, and t_s is the time of reading at the particular detail station.

(d) Theoretical gravity or latitude effect. The reference spheroid used is the International ellipsoid of 1930 given by the equation

$$\gamma_t = 978.049(1 + 0.0052884 \sin^2\phi - 0.0000059 \sin^2 2\phi) \qquad (4)$$

where γ_t is the theoretical value of gravity and ϕ is the latitude of the station.

(e) Free-air anomaly. This anomaly is computed by taking the difference between the measured value (g_s) at the topographic surface and the theoretical value (yt) which is extrapolated from the reference ellipsoid and correcting it for the vertical decrease of gravity with increase of elevation. The general expression is given by the equation

$$\Delta g_{FA} = g_s - (\gamma t - \frac{dg}{dz} h)$$

where Δg_{FA} is the Free-air anomaly, dg/dz is the vertical gradient of gravity and h is the station elevation above sea level.

(f) Bouguer Anomaly. The Bouguer anomaly is determined using the equation

$$\Delta g_B = g_s - \gamma_t + \frac{dg}{dz} h - 2\pi G\rho_c h$$

where Δg_B is the Bouguer anomaly, ρ_c is the assumed crustal density, G is the universal constant of gravitation and $2\pi G\rho_c$ is the Bouguer correction for the attraction of the material between a reference (usually sea level) elevation and that of the individual station. This material is approximated to an infinite horizontal slab of thickness h and density ρ and the gravitational attraction of such a slab on a unit mass is 0.04191 ρ mgal per metre.

2.5 Error in the Bouguer anomalies

The Bouguer anomalies contain several sources of errors, but most of them are of very small magnitude. The sources include errors due to non-linear drift of the instrument, instrument and operator precision, error in calibration factor of the gravimeter and that arising from using a wrong density in the Bouguer reduction. Others are errors from latitude correction arising from errors in determining station latitudes, errors due to the terrain effect, and errors in the determination of station elevation.

The drift rate of the instrument was quite small as earlier indicated. In all loops (Fig.2), the closure error was less than 0.10 mgals and the error in dial constant (2%) was assumed to be insufficient to cause significant error of more than 1.6 mgal in the observed values (a range of 80 mgal.). Although a crustal density of 2.67 $g.cm^{-3}$ is generally assumed and was used in the Bouguer reduction, density investigations in the area show a much higher value (2.70 $g.cm^{-3}$) than this for the basement. Woollard (1969) and Smithson (1971) have infact suggested that ρ = 2.74 $g.cm^{-3}$ is a more correct average crustal density. Over the elevation range of this survey which is 570 metres, a cumulative error of 0.71 mgal is obtained using a density uncertainty of 0.03 $gm.cm^{-3}$, for ρ = 2.70 $g.cm^{-3}$ instead of 2.67 $g.cm^{-3}$.

Most of the maps used were on a scale of 1:50,000, and the latitude of a given station could be determined to the nearest 0.01 minute with accuracy and precision. If the latitude correction were determined to an accuracy of 0.1 mgal., in the latitude range covered by the survey, this would result in an error of less than 0.2 mgal. in any particular station.

Errors due to inaccurate station elevation are perhaps the most significant in the survey. Elevations of stations at Federal Survey bench marks are accurate to better than 3 centimetres.

But elevations determined by altimeters could sometimes have errors as much as 8 metres. This would lead to an error of about 1.5 mgal. over the elevation range of 550 metres.

No terrain corrections have been applied to the data partly because not all the maps used were contoured and partly because a few corrections made showed that the terrain corrections were sufficiently small to be insignificant. For instance the terrain corrections calculated for station 9526 which was located in an area surrounded by hills, as high as 300 metres above the station was 0.2 mgal. One could therefore conclude that terrain corrections in this area are not large and would not exceed 1 mgal. If the maximum possible error was made in all determinations at any one station, the maximum Bouguer anomaly error for that station would not exceed 5 mgal; and for a majority of the stations established on bench marks it would be less than 2 mgal.

CHAPTER III

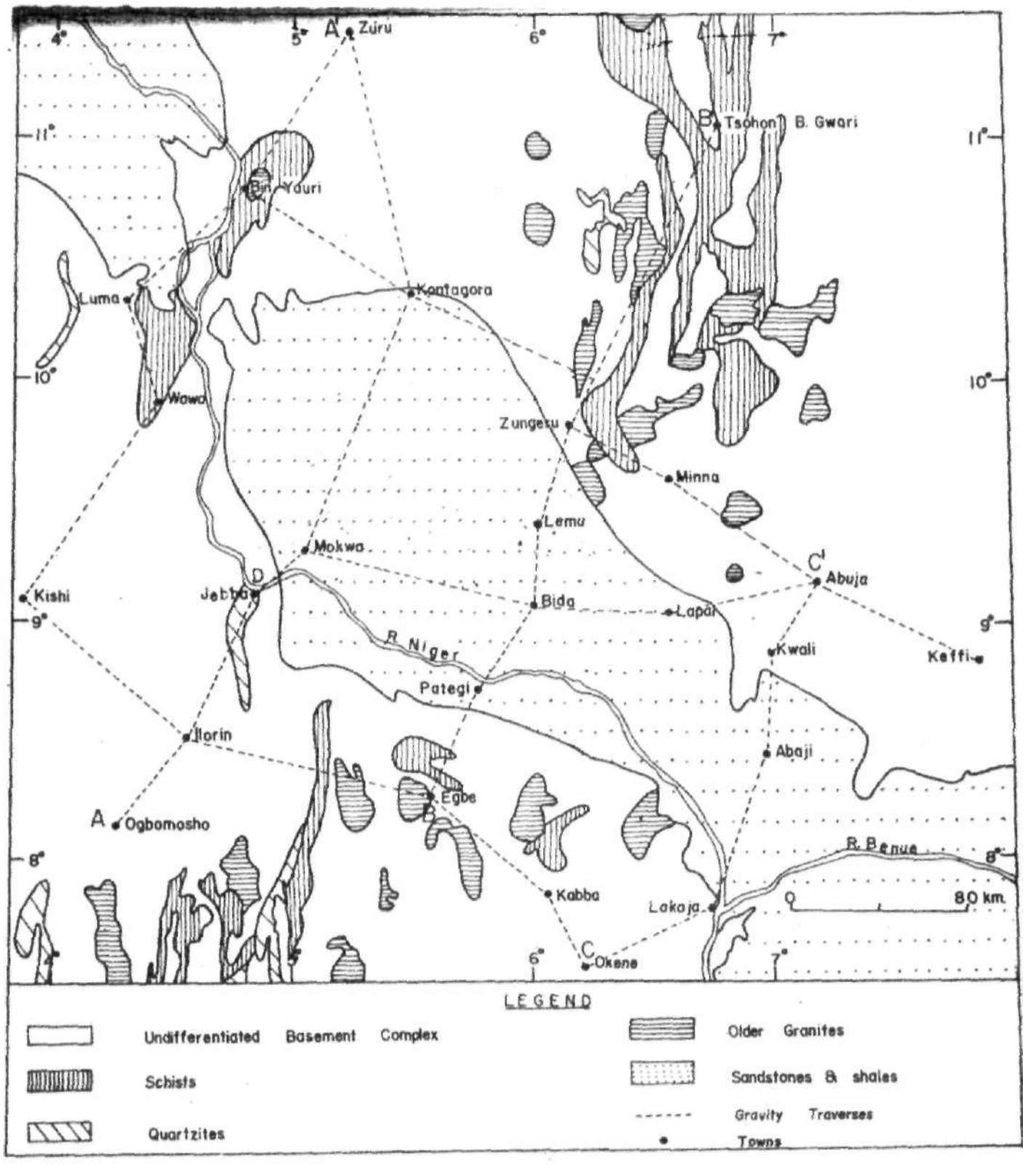
THE GEOLOGY OF THE MIDDLE NIGER BASIN AREA OF NIGERIA

3.1 Introduction

The geology described here covers an area of approximately 187000 km^2. Included are the areas surrounding the Middle Niger Valley as far north as latitude 11°30'N and as far south as latitude 7°30'N (see Map 1). The Nupe Basin, filled with Upper Cretaceous rocks and bounded on all sides by crystalline basement is contained within this area. Also included is a schist belt which runs along the west-central part of Nigeria in an approximately north-south direction.

In the north, the country slopes gently south-westward towards the Niger river and in the south, the slope is north-eastward towards the river. Conspicuous because of their heights (up to 300m.) are the isolated or sometimes grouped inselbergs of Older Granite, while the schists generally form smooth low ranges. Drainage in the area is by the Niger, Kaduna, Chanchagga, Gurara, and Oshun rivers and a host of other small rivers.

The available geological map of the area is perhaps too generalized, but adequate material has been obtained from both published and unpublished reports to give a fair insight into the geology of the area. For the purpose of this study, the area has been divided into three regions: the northern Basement Complex, the southern Basement Complex, and the Nupe Basin. Map 2 is a geological



Map 2. Geological sketch map of the survey area showing the gravity traverses.

sketch map of the area.

3.2 General Stratigraphy

The general stratigraphy of the area has been described by Russ (1957), and King& de Swardt (1949), and is summerised in Table 1 and Table 2. With the exception of Recent, Tertiary and other superficial deposits and of a small number of late dolerite dykes, all rock types in the area belong to the Upper Cretaceous and the Precambrian.

The earlier periods of sedimentation and intrusion in the Precambrian represents a complex and vast period in the history of the area. The majority of the original sediments and minor intrusive rocks may have been subjected to several periods of metamorphism (Russ, 1957). Among the Precambrian rock types gneisses and migmatites predominate. Sediments which have not been so greatly altered include quartzites, quartz schists, and quartz-sillimanite rocks. Orthogneisses, which intruded the gneissic rocks, and were subsequently folded with them, are recognised as a distinct unit(Russ,1957).

After the formation of the gneisses, there followed a period of sedimentation during which predominantly fine-grained rocks were deposited, probably in moderately deep water. During the episode of compression which followed sedimentation, these beds were isoclinally folded and largely converted to schists. Later erosion has removed most of the schist and only the deepest parts of the synclines have been preserved (Russ, 1957). The stresses associated with this

TABLE 1.

General Stratigraphy of the Middle Niger Valley Area, Nigeria

(after Russ, 1957)

AGE	SUCCESSION	ROCK TYPE
Recent and Tertiary	Superficial deposits	Laterite, alluvium, terrace and terrestrial gravels and sand.
Upper Cretaceous	Nupe Sandstone	Sandstones
Precambrian	Older Granite Cycle	Quartz veins, Dolerite intrusions. Pegmatitic, aplitic and granitic dykes. Granites and related rocks.
	Orogenic phase	Formation of schists. Folding, faulting and intrusions of auriferous quartz veins
	Sedimentary cycle	Mudstones, siltstones, quartzites, etc., later converted to paraschists.
	Earlier periods of sedimentation, intrusion and metamorphism.	Orthogneisses. Orthoschists. Paragneisses and schists. Quartzites, quartz schists etc.

folding episode gave rise to two sets of faults, one with shatter belts, trending north-north-east and the other aligned in an east-south-easterly direction (Russ, 1957).

After the folding of the sediments and the formation of the schists, there followed a period of granitic intrusion, the Older Granite cycle known throughout Nigeria. The numerous granites and gneisses of this cycle vary considerably in their petrology and chemical composition, but all belong to one intrusive cycle (Russ, 1957). Within the gneissic complex south of the Nupe Basin, another granite cycle, characteristically composed of a medium-grained biotite or biotite-hornblende granite-gneiss, has been recognised (King & de Swardt, 1949). There is a close inter-relationship between cycles of granitisation and periods of deformation, more especially with compressional slip thrust faulting or shearing.

The surface on which the Nupe Sandstones were laid down in Upper Cretaceous times comprised many different rock types, often of a medium to high-grade metamorphism. These rocks once lay deep in the earth's crust and considerable erosion took place before the Upper Cretaceous beds were laid down (Russ, 1957). The Nupe Sandstones, which consist of shallow water sandstones and pebble beds, probably once were continuous with the Upper Cretaceous beds of Sokoto Province (See Map 1). Tertiary earth movements imparted low dips to this formation, leading to its erosion over wide areas. The youngest deposits in the area are laterites and alluvial terrace and terrestrial deposits of Tertiary and Recent age (Russ, 1957).

TABLE 2

Various rock types in relation to the general time sequence and processes

(after King & de Swardt, 1949)

CYCLE	PRODUCTS etc.	TECTONICS	PROCESSES
PORPHYRITIC GRANITE CYCLE	Quartz veins, Latest Pegmatites, Latest Aplites.	Tensional Rebound(Jointing).	
	1st Post-Granite Pegmatites, Late Leucocratic Granite	Alternating Periods of compression and	Pegmatisation and Aplitisation
	1st Post-Granite Aplites. Granite Porphyry and Aplo-Granite	Relief (with waning regional stress)	
	Coarse Porphyritic Granite, Early Granites.	Main Period of E-W stress (with shearing movements)	Main Granite Phase Granitisation and Pegmatisation
	Pre-Granite Pegmatites Post-Gabbro Aplites & Pegmatites		
		Minor Deformation	Metamorphism of Gabbros
GABBROS	Gabbro (now metagabbros)		Intrusion of Gabbros
GRANITE-GNEISS CYCLE	Older Aplites and Pegmatites Granite-Gneiss (Granodiorite Semi-Confromable Leucocratic Veins (in part)	Deformation	Pegmatisation and Aplitisation
		Major Periods of Deformation (shearing) Several periods of Deformation (with shearing movements)	Granitisation, Pegmatisation etc.
'SECONDARY' GNEISSES	Granitic and Banded Gneisses and Biotite and Hornblende schists.		Periods of Granitisation etc.

3.3. The Northern Basement Complex

The rocks of this area form part of the igneous and metamorphic crystalline basement which outcrops over more than half the surface area of Nigeria. They are undifferentiated and consist of various gneisses, migmatites, older granites, quartzites and several low-grade schists of the younger metasediments. They are probably the oldest members of the Precambrian in the area. The schists are considered to have been highly metamorphosed and recrystalized, and may represent an ancient sedimentary series.

3.3.1 The Younger Metasediments

These rocks are widespread within the complex and include the phyllite and gold-bearing quartzites which occur in the Niger Province and in Ilorin to the south. Also included are marbles and low-grade schists in Kabba Province, Kwara State and Sokoto Province, North-Western State. They are probably the youngest rocks of the Basement Complex and form relatively large exposures. The quartzites form impressive topographic features and sometimes show complex folding which is not often easy to interprete due to lack of continuous exposure (Oyawoye, 1964). They are not affected by migmatisation and granitisation.

3.3.2 The Older Granites

Very common in this group are the granodiorites and the various granites. Their occurrence is widespread and their variation in texture and structure are considerable. The majority of inselbergs,

which are so characteristic of the landscape, are composed of Older Granite (Russ, 1957). Their characteristic form is a smooth, bare exfoliation dome.

Textures vary from coarsely porphyritic to microgranitic. The contacts between individual textural types are always gradational. A gneissose structure is common and foliation consists of a parallel alignment of feldspar phenocrysts, or of biotite folise, or of both.

3.3.3 Principal Rock Types

The gneisses predominate. They include rocks whose origins differ considerably and show a wide variation in chemical composition, mineralogy and field occurence. Biotite gneiss occurs widely and is of variable grain size. It is characterised by abundant oligoclase and little microcline. Migmatites range from coarsely mixed gneisses to more lineated and banded gneisses. They are very uniform in character and the foliation strike is remarkably constant in direction. The migmatites often grade into the gneisses with indistinct transitional zones. Granites are common and although they have a small range of chemical composition, minor chemical compositions result in important mineralogical differences and distinct granite types can be recognised. They fall into two bread groups: the biotite, hornblende granites and the granite-gneiss or granodiorites.

The schists in the area fall into two groups, namely the paraschists and the schists of heterogeneous origin. The paraschists have been derived from a group of ancient sediments by dynamic metamorphism and they post-date the underlying gneisses, and appear

to be the infolded remnants of a sedimentary succession which once covered the area (Russ, 1957). They are mostly fine-grained and probably originated in deep-water conditions. The schists of heterogenous origin are much less common than the paraschists, and include orthoschists. They usually occur in intimate association with the gneisses.

3.3.4 Minor Intrusions

The great majority of the minor intrusions which can be directly related to the gneisses are, as in the case of the Older Granites, of an acid nature, and are composed mostly of granite, aplite, quartz and pegmatite. These ramify through the gneisses and sometimes form composite acid dykes. Successive intrusions may cut one another, and at least three generations of pegmatites and quartz veins have been recognised (Russ 1957). In addition to the quartz veins, massive veins of vitreous quartz are of widespread occurence within the gneisses. They are not known to contain minerals presently of economic value.

3.4 The Southern Basement Complex

This area comprises the area south of the Nupe Basin. Table 2 summarises the various rock types in relation to the general time sequence and processes that were operative. All the successions described in the table are of the Precambrian era.

The rocks in the area consist essentially of schists, gneisses, granites and various basic intrusives. The granitic types fall into two groups: The Older Granite, usually biotite and hornblende granite

and the Granite-Gneisses. The gneisses are invaded by a series of sheeted bodies that are presumed originally to have been gabbros, but which are now represented by plagioclase-hornblende-biotite-quartz rocks (metagabbros) (King and de Swardt, 1949).

3.4.1 The Gneissic Complex

The country rocks within which the metagabbros and porphyritic granites have been emplaced, comprise a varied series ranging from banded and granite-gneisses to granodiorites. Though structurally forming part of this complex, the granodiorites and associated aplites and pegmatites are the products of the earliest recognisable cycles of granitisation (King & de Swardt, 1949).

The banded gneisses are composed of layers ranging in composition from medium to fine-grained quartz-feldspar rocks to biotite schists. Individual bands vary greatly in thickness and contacts are gradational to sharply demarcated. The biotite and biotite-hornblende gneisses and schists are widely distributed but are quite insignificant in areal extent. The granodiorites are well represented in the area and often grade into true banded gneisses. Though the same components are present, a pronounced schistosity is sometimes found in place of banding. Generally, they have a uniform appearance, are relatively constant in composition and are medium-grained.

3.4.2 The Metagabbros

These are largely found within the granites or along its contacts. They form somewhat irregular, interconnecting, sheet-like

bodies generally occuring along the margins of the granite and approximately parallel to the strike of the adjacent gneisses. The central parts of the larger sheets are usually formed of a medium-grained, dark greenish-grey rock, composed essentially of white or grey plagioclase, hornblende, biotite and subordinate quartz. As the margins are approached, they assume a gneissic foliation and ultimately become a fine-grained schistose rock in which biotite predominate over hornblende (King & de Swardt,1949).

3.4.3 Pegmatites and Late Dolerite Dykes

Two varieties of pegmatites are recognised in the Osi area: the equigranular, biotite-poor pegmatite and the coarse-grained magnetite-bearing quartz-feldspar-biotite pegmatites, (King and de Swardt, 1949). The former are moderately coarse-grained, leucocratic rocks which form straight or irregular dykes rarely more than thirty centimeters in width, and occur both in the granite and host-rocks. The latter group occurs principally as coarse-grain dykes characterised by regularity in strike and lateral persistence, and are found both in granites and adjacent gneisses, but are markedly less abundant away from the granite margins.

Small dykes, up to a metre in width, of fine-grained dolerite are occasionally found in the area. They are very much younger than any of the rocks already described and judging by their petrographic character, are not Precambrian in age (King &de Swardt,1949). They consist largely of diverse laths of plagioclase, up to a

millimeter in length and vary from very pale brown to a distinct purplish-brown in small granules, anhedral plates or small subhedral prisms. The textures may generally be described as intergranular; the augite is commonly found as granular aggregates between the feldspar laths. Finer grained chilled margins have been seen in cases where the entire width of the dyke is exposed. The development of chilled margins and sharp contacts and the absence of any sign of deformation or metamorphism of the dykes may be regarded as indicating that they were formed by the simple dilation of fissure walls as a result of magmatic injection at no very great crustal depth (King & de Swardt, 1949).

3.5 The Nupe Basin

These rocks were first described by Falconer (1911) who included them in his "Lokoja Series" which he considered to be of Eocene age. He used the "Lokoja Series" to indicate sediments outcropping over the area stretching along the Niger from Idah, south of Kontagora and up the Benue from Lokoja to the Doma Hills. Russ (1930) described the Nupe sandstones as the rocks of the central part of the belt around Bida. The Nupe Basin now indicates the whole series of sedimentary rocks occupying the Middle Niger Basin between Kontagora and Lokoja. It has been generally accepted that the sandstones of the northern part of this belt around Kontagora are equivalent to the Illo group of Southern Sokoto which Brynmor-Jones (1948) believed to be Senonian or older, and which Kogbe (1970) considered to be as thick as 210 meters.

3.5.1 Structural features and Principal Rock Types

A notable feature of the sandstone basin is the widespread occurrence of surface and subsurface ironstone and ferruginous sandstones. The material occurs principally as a lateritic crust or capping on the rocks and in some areas it forms thick sheets extending continuously for many square kilometres. The most striking characteristic of the ironstone is the fact that it has formed almost exclusively on the sedimentary rocks, and rarely on those of the surrounding Basement Complex. Shale beds occur near the base of the laterite capping in several places (Jones, 1951).

Another notable feature of the sandstones is the occurrence of many scattered thin layers of them several kilometers from the main body (Russ, 1957). Some of these series lie as far north as Birnin Gwari (Map.2), which suggests that the sandstones probably once extended over the whole of the area north of the basin. Widespread erosion during the Tertiary (Russ,1957) resulted in its present outline.

The sandstones consist in general of soft, buff and red-brown sandstone and conglomerates. At Mokwa, there are pale red-brown, false-bedded sandstones and in the river banks near Lafiagi, there are coarse and fine-grained sandstones with mottled red-brown and white, massive sand clays. Near Koton Karifi, the dominant rock type is a brown, rusty sandstone which is fairly easily crushed and is generally ill-sorted. Records of bore-holes at Mokwa and Badeggi indicate the presence of clays and sandy silts at depths of up to 150 metres.

In the Bida area, four rock units have been distinguished (Adeleye and Dessauvagie, 1970). Bottom to top, Bida Sandstone, Sakpe Ironstone, Enagi Siltstone, and Batati Ironstone. The Bida sandstone is a coarse sandstone locally current bedded. The Sakpe Ironstone is an oolitic-pisolitic horizon restricted to a zone 45km. long by 5km. wide by 3m. thick between Bida and the R. Niger. The Enagi Siltstone consisting of siltstones, mudstone and fine sandstones conformably overlies the Bida Sandstone except where the Ironstone intervenes and is estimated to be 70m. thick or more. The Batati Ironstone 5m. thick is predominantly an oolitic ironstone with a silty-clayey matric (Adeleye and Dessauvagie, 1970).

Two types of Ironstones have been distinguished in the Agbaja Plateau area of Kabba Province (Jones, 1955): the lateritic ironstone which varies greatly in appearance, hardness and composition, and the oolitic and pisolitic ore. The upper part of the lateritic ironstone forms a hard rock where it is exposed but at deeper levels, it is softer and grades into a clay-like substance. The oolitic ore varies from a dark, hard and heavy compact rock to a light, porous, yellow earthy rock.

3.5.2 Origin of the Ironstone

Various possibilities for the origin of the ironstones have been proposed by Falconer (1911); du Preez (1952); du Preez and Jones (1953); Jones (1955); and some others. The interbedded oolitic ironstone seems to be of sedimentary origin, with the iron possibly

introduced after deposition. The upper oolitic ironstone may, in part, have a lateritic origin and may therefore occur at different levels above the siltstone. The presence of marine fossils at a few localities, however, suggest deposition of marine sediments under conditions similar to those of the lower oolitic horizon (Adeleye and Dessauvagie, 1970).

3.6 Tectonics

The periods of deformation in the area south of the Nupe Basin are mainly of Precambrian age. The tectonics can be inferred by analogy with those operative during the granite-gneiss and porphyritic granite cycles. Plastic and semi-plastic shearing appears as the critical feature, which, developing in response to regional stress, produced regular, parallel and relatively straight banding in the rocks. The occurrence of parallel zones in which the gneisses are alternately crumpled and evenly banded is ascribed to the operation of shearing along numerous sub-parallel planes with the redevelopment of uniform straight banding (King and de Swardt, 1949).

Although the location of many of the post-Older Granite aplite and pegmatite dykes demonstrate a relationship to fracturing and shear movements, to which the rocks responded by sharp dislocation as if they were in a brittle condition, there is evidence that the rocks were also capable of deformation of plastic type. Indication of the latter are seen where the relative lateral displacement on

either side of a dyke show rapid variations both in magnitude and direction (King & de Swardt, 1949). As with the metagabbros, their location within the granites and along their contacts, and the displacement of the host granites indicate that they are related to the granite emplacement and that they are late stage products of granite intrusion. The dolerite dykes are not Precambrian in age but are much later than the metagabbros and pegmatite dykes. This is indicated by the development of chilled margins at the sharp contacts of the dolerite dykes.

The earth movements which affected the Precambrian rocks north of the Nupe Basin are mainly of pre-Cretaceous age. Some minor movements took place in the Tertiary (Russ, 1957). The gneisses and schists in the north exhibit foliation with a north-north-east strike which have been ascribed to pre-Cretaceous age. Subsequent to folding, faulting occured along two directions, trending north-north-east and east-south-east respectively. The north-north-east faults are shatter belts and the other probably are tear faults. The Tertiary earth movements were responsible for warping of the Upper Cretaceous beds and, subsequently, the more elevated portions were removed by erosion and the Precambrian exposed (Russ, 1957).

3.7 Economic Consideration

Gold is widely distributed throughout the area of crystalline rocks and the bulk of the gold in Nigeria has been produced from here.

Table 3 (Russ, 1957) shows a summary of the production from north-western Nigeria as compared to production from the whole of Nigeria for the period 1932 to 1955. Occurence is usually in quartz veins and alluvial deposits, and traces have been found in most rivers in the area, but lodes are very uncommon. By far the greatest proportion has come from alluvial sources. The explanation for this is that the schists, which contain most of the gold-quartz veins were subjected to erosion during vast periods in the Palaeozoic era and the gold derived from the eroded rocks concentrated in the changing river patterns of the Palaeozoic and Mesozoic eras. In Cretaceous time, shallow-water sandstones and conglomerate were deposited over most of the Middle Niger Valley area and the gold deposited in these beds. Many of the pegmatite dykes around the Egbe district have been worked for tin and tantalite and one of them for beryl. Those dykes associated with quartz-veins have also been worked for gold.

The Ironstones of the Nupe Basin may contain sufficient reserves of Iron to make feasible the establishment of an Iron and Steel industry in the area. For instance, in the Agbaja plateau area of Kabba Province, ironstone averaging 50% iron and 9 metres in thickness under an overburden of laterite, itself a low-grade ironstone of approximately 35% iron with an average thickness of 5 metres, has been estimated to have a reserve of about 30 million tons of the 50% material (Jones, 1955). Reserves of similar magnitude existing in some other parts of the ironstone region might therefore suggest a bright future for the Iron Industry.

TABLE 3

NIGERIAN GOLD PRODUCTION 1932-55

(after Russ, 1957)

YEAR	Production from north-western Nigeria in Ozs. troy	Total Nigerian Production in Ozs. troy
1932-35	95,126	96,403
1936-39	96,081	110,439
1940-43	53,595	108,686
1944-48	16,354	29,553
1949-55	1,306	10,578

CHAPTER IV

DENSITY MEASUREMENTS

4.1 Introduction

The actual cause of small wavelength gravity anomalies is the lateral heterogeneity of rock densities in the upper crust (Sweeney, 1972). A knowledge of the densities of rock formations is therefore important in the interpretation of gravity anomalies. Tables of densities for some of the rock types found in the earth's crust have been published by various authors (Dobrin, 1960; Jakosky, 1960; McLean, 1961; Hatherton and Leopard, 1964; Gibb, 1968; Smithson, 1971), but these tables only afford a general survey of rock densities. Since the accuracy of the interpretation of gravity anomalies depends greatly on the assumed density contrasts of the rocks, which are usually small, the density differences between the various rock types in the particular study area must be known in order to appropriately restrict density contrasts used in model computations. The best values of densities are obtained from fresh, unweathered rock samples.

4.2 Sampling Techniques

201 rock samples were collected from outcrops close to the gravity stations during the course of the field work. Wherever possible, the samples were collected from fresh surfaces of outcrops or from recent blasting by road construction workers.

TABLE 4

Densities of Lithologic Units

GROUP NAME	ROCK TYPE	NO OF SAMPLES	RANGE	MEAN DENSITY	STANDARD DEVIATION
BASEMENT	Biotite Granite	32	2.60-2.71	2.65	±0.024
COMPLEX	Granite Gneiss	14	2.56-2.75	2.68	±0.046
(Pre-Cambrian)	Migmatite	45	2.62-2.85	2.72	±0.047
	Granodiorite	32	2.62-2.69	2.66	±0.019
	Quartz Diorite	4	2.74-2.77	2.76	±0.009
	Mica Schist	12	2.72-2.79	2.76	±0.021
	Metamorphosed-Rhyolite	4	2.62-2.67	2.66	±0.018

All the rock samples were weighed dry in air (dry weight), and the rocks of the crystalline basement were then weighed in water (water weight). All the rock samples were then submerged in water for 24-28 hours in the case of the basement rocks, and for 48 hours in the case of the sedimentary rocks after which they were weighed in water (saturated weight). The excess water was then wiped off the rocks after removal from the water, and they were weighed in air (wet weight). The dry density was obtained from the formula:

dry density = dry weight/(wet weight-saturated weight)

and the saturated density from the formula:

Sat density = wet weight/(wet weight-saturated weight).

In general, samples of igneous and metamorphic origin showed saturated densities slightly higher than the dry densities but rocks of sedimentary origin sometimes showed considerably higher increase in density after saturation. In all cases the mean of the dry and saturated densities was assumed to be the value nearer the "true" density of the rock.

Although most samples weighed over 700 gm, some weighed about 200 gm. Since the balance has an accuracy of ± 0.2g, calculated density values are accurate to better than ± 0.02 g.cm^{-3} for the lighter samples, and ± 0.005 g.cm^{-3} for the heavier samples.

4.3 Densities of Basement rocks in the Area

The mean values for the dry and saturated densities for each rock type were divided into class intervals of 0.02 or 0.05 g.cm^{-3}, depend-

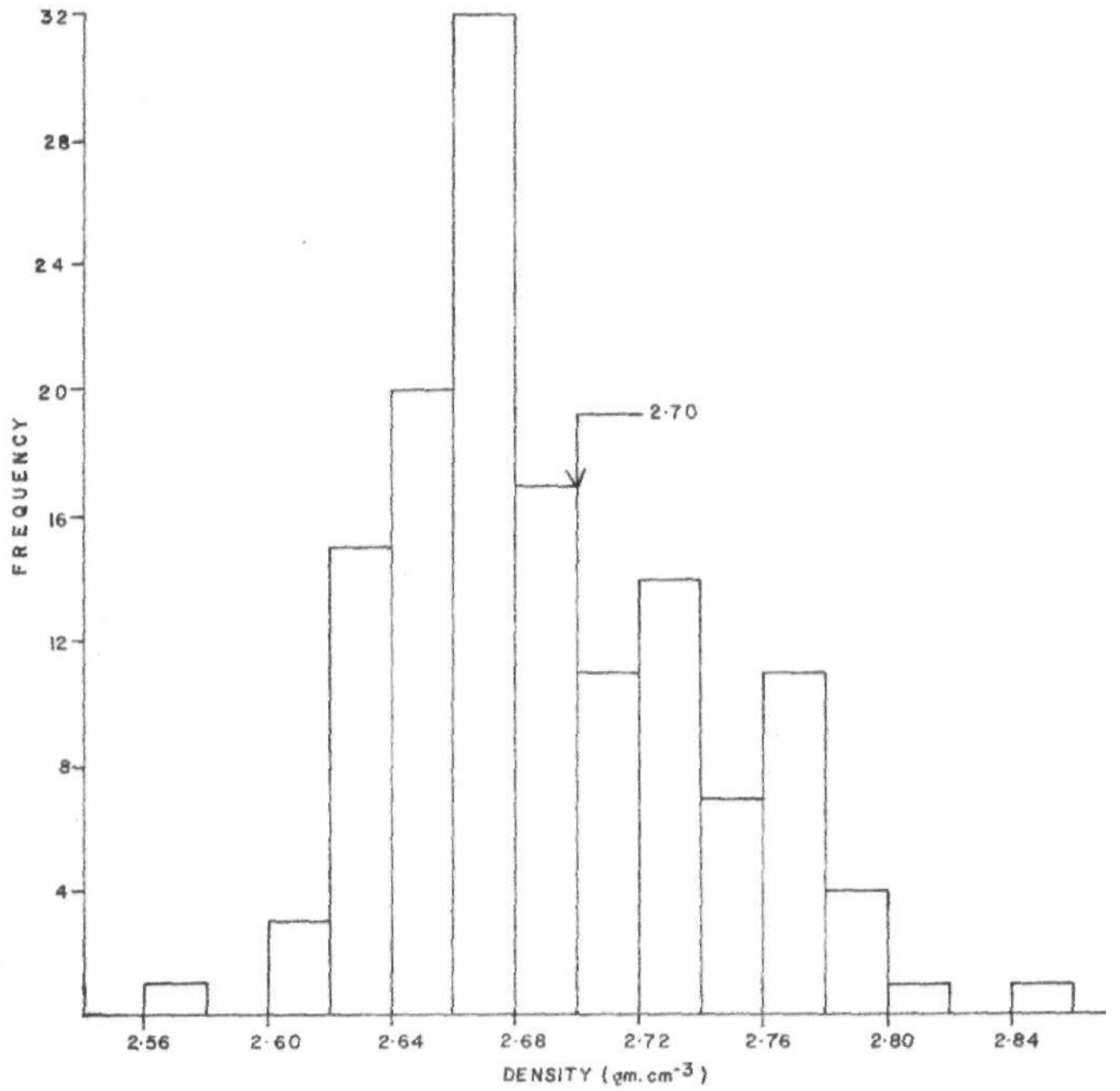


FIG.3 Combined histogram of Basement rocks

ing on the range of the distribution. Histograms of these mean values were plotted to permit a study of the distribution of the densities.

Mean densities range from 2.65 g.cm^{-3} for biotite granite to 2.76 g.cm^{-3} for biotite-schists (Table 4). The increasing densities reflect changes in chemical composition and the diversity of the rock types within each group of rocks forming the Basement Complex. Fig.3 shows the combined histogram for the densities of rocks of 143 samples belonging to the Basement Complex. The calculated mean density for these rocks was 2.70 g.cm^{-3} with a standard deviation of the mean, $\pm$0.052 g.cm^{-3}. The frequency distribution is positively skewed which indicates the presence of heavier mafic rocks. The mode of the distribution is 2.670g.cm^{-3}.

4.3.1 Biotite Granite

The histogram of densities of 32 samples of biotite granite from different outcrops in the area is shown in Fig. 4(a). The calculated mean density for this group was 2.65 g.cm^{-3} with a standard deviation of $\pm$0.02 4 g.cm^{-3}. The frequency distribution is negatively skewed and the mode of the distribution is 2.670g.cm^{-3}.

4.3.2 Granite Gneiss

14 samples of this rock type were collected and analysed and the histogram of their densities is shown in Fig. 4(b). The calculated mean density was 2.68 g cm^{-3} and the slightly high standard deviation of $\pm$0.046 g.cm^{-3} is an indication of the large dispersion around the mean.

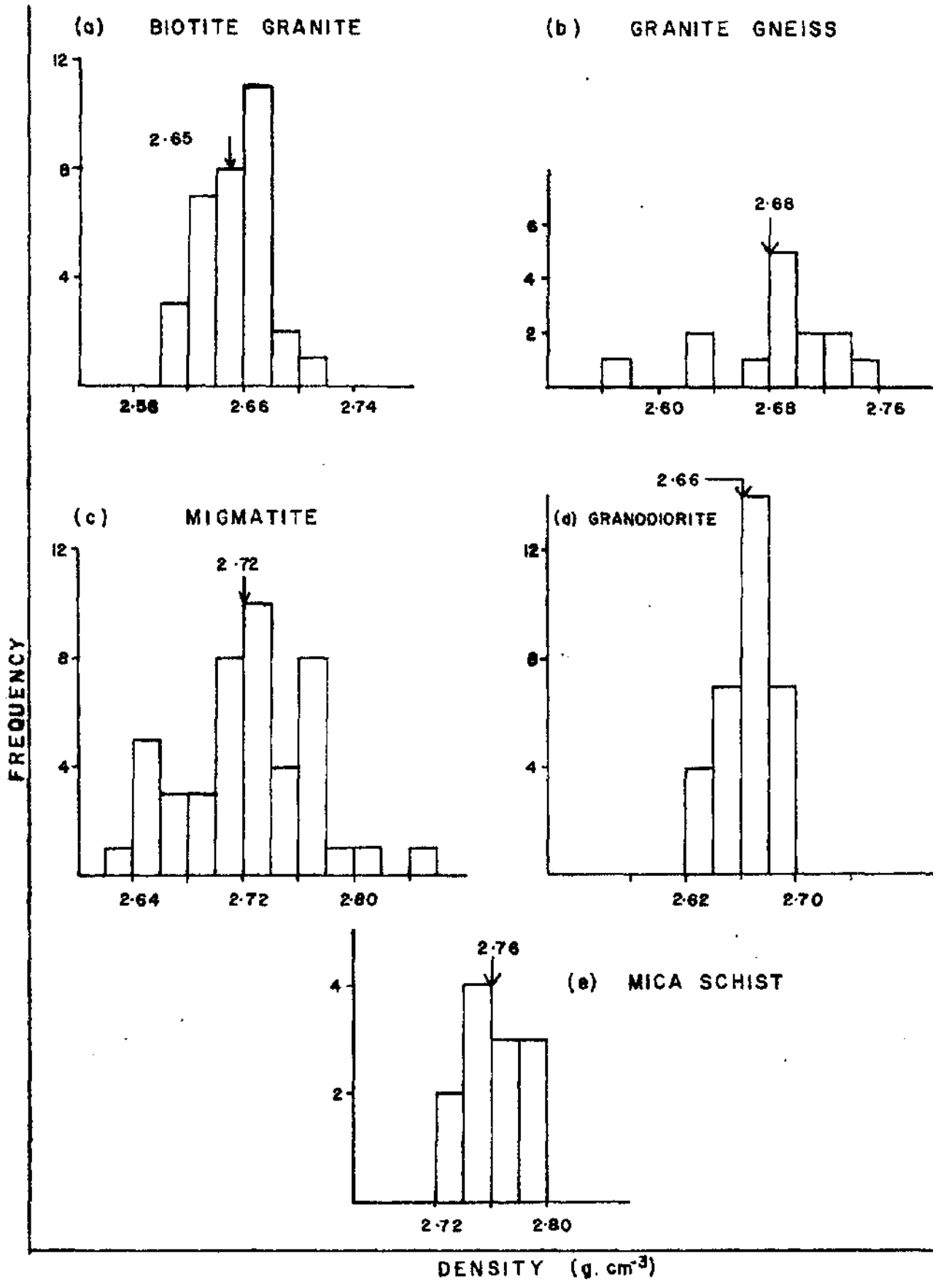


FIG. 4 Histograms of Basement rocks

.3 Migmatite

Fig. 4(c) shows the histogram of densities for 45 samples of migmatite collected at different locations in the area. The frequency distribution is approximately bi-modal and the calculated mean density is 2.72 $g.cm^{-3}$. with a standard deviation of ± 0.047 $g.cm^{-3}$. The slightly high standard deviation indicates a slightly large dispersion around the mean. The mean, 2.72 $g.cm^{-3}$ is comparable to 2.70 $g.cm^{-3}$ (Ajakaiye, 1970) obtained in the Nigerian Younger Granite Province.

4.3.4 Granodiorite

32 samples were collected and analysed and the histogram of their densities is shown in Fig.4(d). The frequency distribution is near normal, and the calculated mean density was 2.66 $g.cm^{-3}$ which is near the mode of the distribution, 2.670$g.cm^{-3}$. Standard deviation of the mean is ± 0.019 $g.cm^{-3}$. The calculated density is however low when compared with the published value, 2.72 $g.cm^{-3}$ (Jakosky, 1960) and the range 2.62-2.69 $g.cm^{-3}$ is also low when compared with published value, 2.69-2.79 $g.cm^{-2}$(Dobrin, 1960).

4.3.5 Quartz Diorite

Only 4 samples were collected and hence no histogram is shown. The calculated mean density of 2.76 $g.cm^{-3}$ is comparable to the value 2.75 $g.cm^{-3}$(Gibb, 1968) obtained for samples in some other parts of the world.

4.3.6 Mica Schist

12 samples of schists from 2 locations were collected and analysed. Six samples from one location consist predominantly of muscovite while

TABLE 5

Densities of Sedimentary Rocks

GROUP NAME	ROCK TYPE	NO OF SAMPLES	RANGE	DRY DENSITY	SAT. DENSITY	MEAN DENSITY	STANDARD DEVIATION
SEDIMENTARY ROCKS OF THE NUPE BASIN (Upper Cretaceous)	Ferruginous Standstone	20	1.95-2.24	2.01	2.17	2.09	±0.100
	Ferruginous Sandstone with high % of Iron	12	2.50-2.79	2.59	2.69	2.64	±0.069
	Ferruginous Siltstone	4	2.12-2.41	2.11	2.42	2.27	-
	Ironstone	22	2.50-3.04	2.81	2.91	2.86	±0.136

4.3 the other six from the other location was rich in biotite. A combined histogram for the two types is shown in Fig. 4(e). The calculated mean density was 2.76 $g.cm^{-3}$ and the standard deviation about the mean is ± 0.021 $g.cm^{-3}$.

4.3.7 Metamorphosed Rhyolite

4 samples were collected and analysed. The calculated mean density for this group of rocks which was 2.66 $g.cm^{-3}$ is similar to the value 2.66 $g.cm^{-3}$ (Gibb, 1968) obtained for similar rocks in other parts of the world, and is comparable to 2.64 $g.cm^{-3}$ (Ajakaiye, 1970) obtained for rhyolites in the Nigerian Younger Granite Province.

4.4 Densities of Sedimentary rocks in the Nupe Basin

The sedimentary rocks in the Nupe Basin have a greater porosity than the rocks of the Basement Complex. The "true" densities obtained from the dry and saturated densities for 58 samples of sedimentary rocks collected from various locations were sub-divided into intervals of 0.05 $g.cm^{-3}$ because of the wide range of these densities.

Fig. 5 shows the combined histogram of all the different sedimentary rock types collected. The frequency distribution is positively skewed which is an indication of the large occurence in the samples collected of rocks containing a fairly high percentage of iron. The calculated mean density for ferruginous sandstones and siltstones was 2.12 $g.cm^{-3}$, while that for ferruginous sandstones with a high iron content was 2.64 $g.cm^{-3}$. Ironstones have a calculated mean density of 2.86 $g.cm^{-3}$, and a further consideration of Fig.5 shows that the sandstones with high iron content grade into the ironstones.

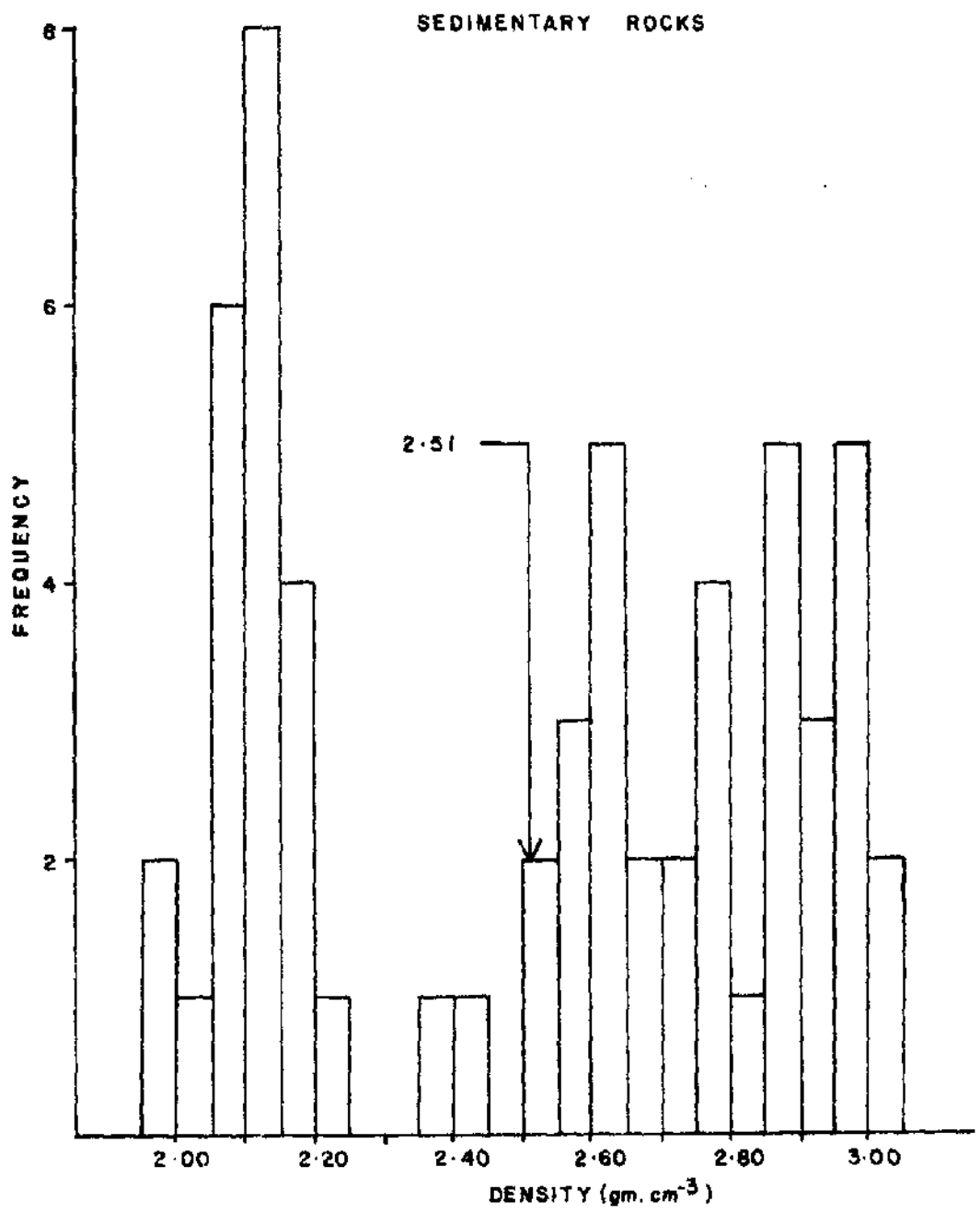


FIG. 5 Combined histogram of sedimentary rocks

The calculated mean density for all the sedimentary rock types was 2.51 $g.cm^{-3}$ with a high standard deviation of the mean, ± 0.348 $g.cm^{-3}$, which indicates the large dispersion about the mean. A summary of the densities of the various groups is presented in Table 5.

4.4.1 Ferruginous Sandstones and Siltstone

20 samples of Ferruginous sandstone from two locations and 4 samples of Ferruginous siltstone from another location were collected and analysed. The combined histogram of the densities for these two rock types is shown in Fig. 6(a). The frequency distribution is near-normal with a mode of 2.125 $g.cm^{-3}$ which is close to the calculated mean density of 2.12 $g.cm^{-3}$. The standard deviation of the mean is ± 0.100 $g.cm^{-3}$.

4.4.2 Ferruginous Sandstone with high content of Iron

12 samples were collected from 2 locations in the area. Their densities were grouped in classes at intervals of 0.05 $g.cm^{-1}$, yielding a near-normal frequency distribution with a calculated mean density of 2.64 $g.cm^{-3}$ and a standard deviation of ± 0.069 $g.cm^{-3}$ (Fig.6(b)). The mode of the distribution which is 2.625 $g.cm^{-3}$ is close to the calculated mean.

4.4.3 Ironstone

22 samples of ironstone were collected from 2 locations and analysed. Fig. 6(c) shows the frequency distribution of their densities. The calculated mean density was 2.86 $g.cm^{-3}$ with a standard deviation of the mean ± 0.136 $g.cm^{-3}$.

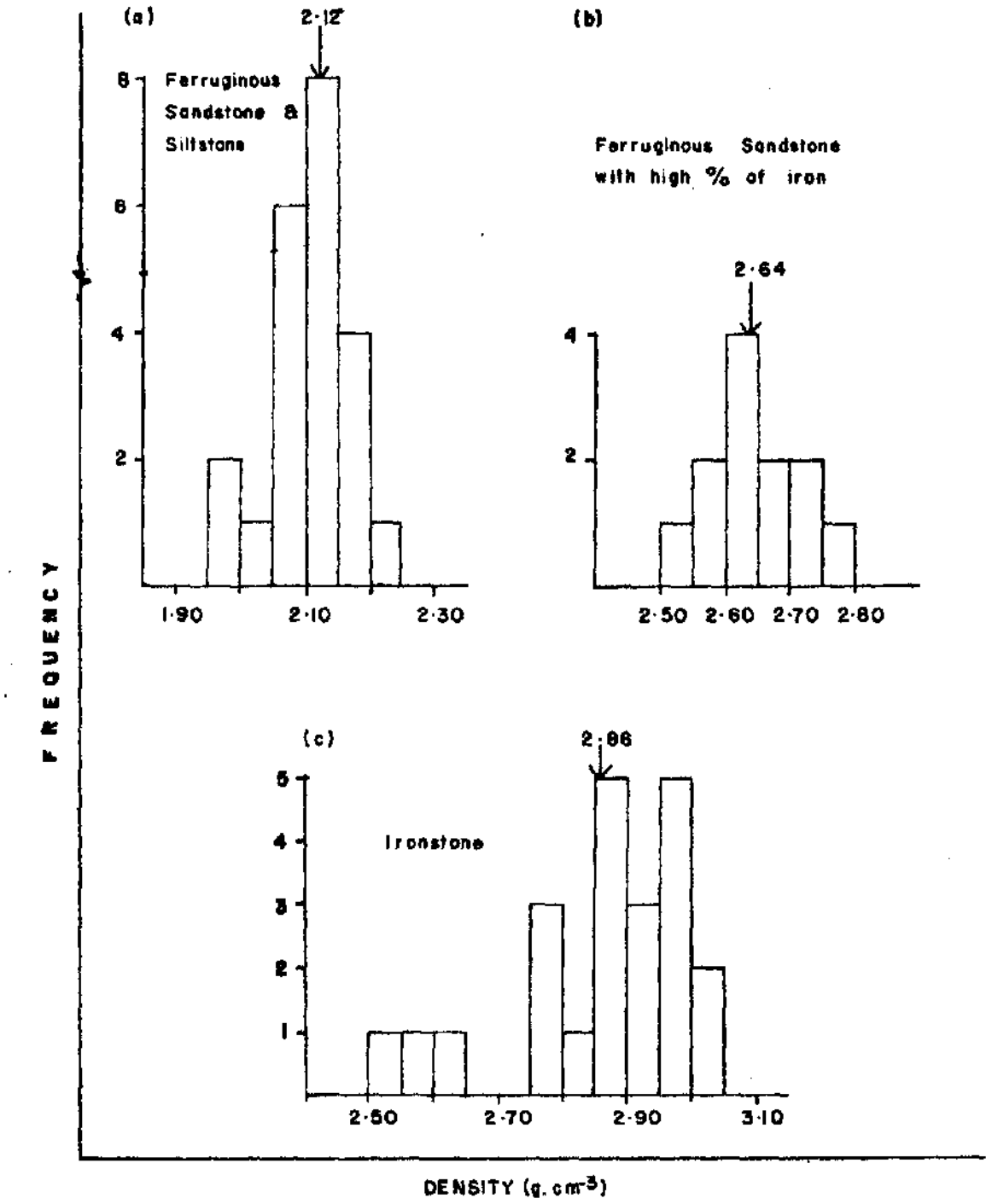


FIG. 6 Histograms of sedimentary rocks

4.5 Rock Densities Accepted for Models

A summary of the densities accepted for use in models on the basis of the density determinations carried out is shown in Table 6. A value of 2.70 $g.cm^{-3}$ was accepted as being the mean for the basement rocks. This value exceed that of the Bouguer density by 0.03 $g.cm^{-3}$, and the error due to this (of a magnitude less than 1 mgal for the elevation range in the Middle Niger Basin) is not likely to affect the models significantly.

As explained earlier on a mean value of 2.51 $g.cm^{-3}$ was calculated for the sedimentary strata. This value was not thought to be very representative of the typical Nupe sandstone at depth because rock specimens of this rock type could only be obtained from the ferruginous sandstone which appears to cover the sandstone area extensively. Structural investigations in various parts of the basin as well as data from bore-holes have indicated that the ferruginous sandstone capping is not likely to exceed a thickness of 50 meters at its maximum thickness. For this reason, a density of 2.40 $g.cm^{-3}$ for the sedimentary strata was thought to be more reasonable and was used in the models.

TABLE 6

Summary of the Density of Rock Types used in Models

ROCK TYPES	NO OF SAMPLES	RANGE	MEAN DENSITY	STANDARD DEVIATION
Biotite Granite Granite Gneiss Migmatite Granodiorite Quartz diorite, Schist & Rhyolite	143	2.56-2.85	2.70	±0.052
Ferruginous Sandstones Ferruginous Siltstones Ironstone	58	1.95-3.04	2.51	±0.348

CHAPTER V

A GENERAL DESCRIPTION AND INTERPRETATION OF THE BOUGUER ANOMALIES

5.1 Introduction

The Bouguer values have not been contoured owing to the large areas covered by the survey and the comparably low station density. A high station density has not been possible mainly because of lack of adequate roads in the area. The present study should therefore serve only as a preliminary investigation of the area and it is hoped that it would be possible in the future to further extend the work.

Interpretation of the anomalies in the area has therefore been based on Bouguer profiles drawn from traverses primarily chosen so as to run across the Nupe Basin in several places. The traverses are, however, sufficiently many and cover a relevant fraction of the area to permit a study of the major gravity variations in the area.

5.2 Estimation of Regional Anomalies and Gradient

In the interpretation of any gravity anomalies, one of the major problems is in separating the effects of shallow origin from those of deeper origin. These are the residual and the regional anomalies respectively. No unique determination of the regional effect is possible and no mechanical method for its removal can be found (Nettleton, 1954; Skeels, 1967).

The methods for separating them can be broadly divided into two, namely: the Mathematical trend frequency analysis or grid calcula-

tion systems, and the graphical method. As Nettleton (1954) pointed out, any grid calculation, once set up, is automatic. It is an advantage in that the system being automatic, is not subjected to the judgement of an operator. It is a disadvantage in that it is not easily adaptable to changing situations. In the graphical method, the choice of a regional is largely empirical. This is usually done by drawing smooth contours and subtracting this set of contours from those of the observed map to contour the residual features. A more refined method is to plot profiles along lines perpendicular to the direction of regional geological trends and to draw smooth regional curves on these lines. Vajk (1954) has indicated that there is a large "personal factor" in the form of the geological background of the interpreter in the determination of the regional gravity by the graphical method. This includes "all the geological data known to him, and all sound geological theories and assumptions he accepts or develops". This might therefore have its advantages.

In estimating the regional anomaly trends, the graphical method of separating the regional from the observed gravity value has been used. This method has been preferred to the mathematical trend frequency analysis because the station distribution is not adequate and not on a regular grid. Moreover, there are several gravity traverses in the survey which run across the major structural feature (the Nupe Basin) in the area to permit a fairly good graphical analysis. Four profiles were drawn along various

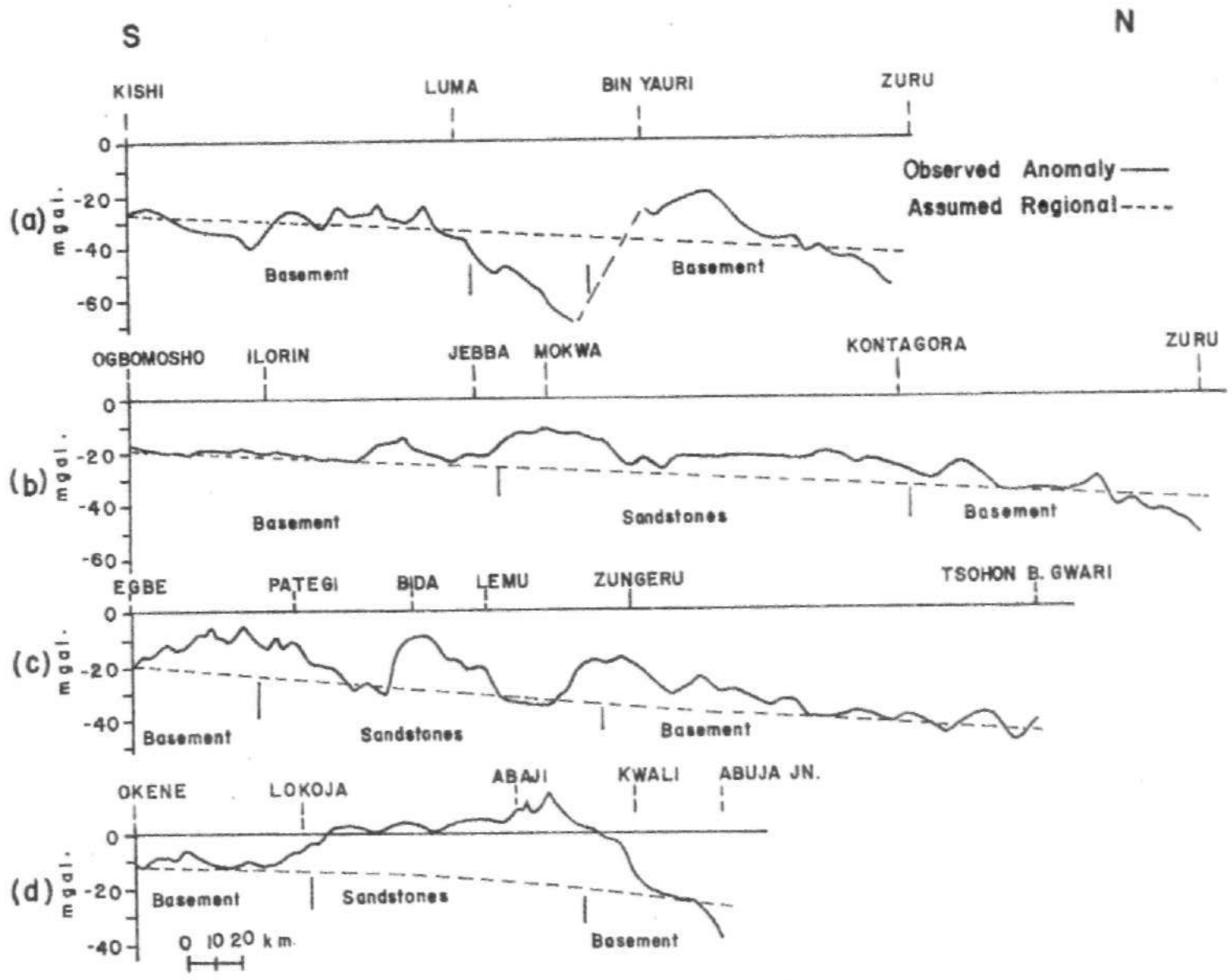


FIG. 7. Observed Bouguer Anomalies and regional curves for north-south profiles.

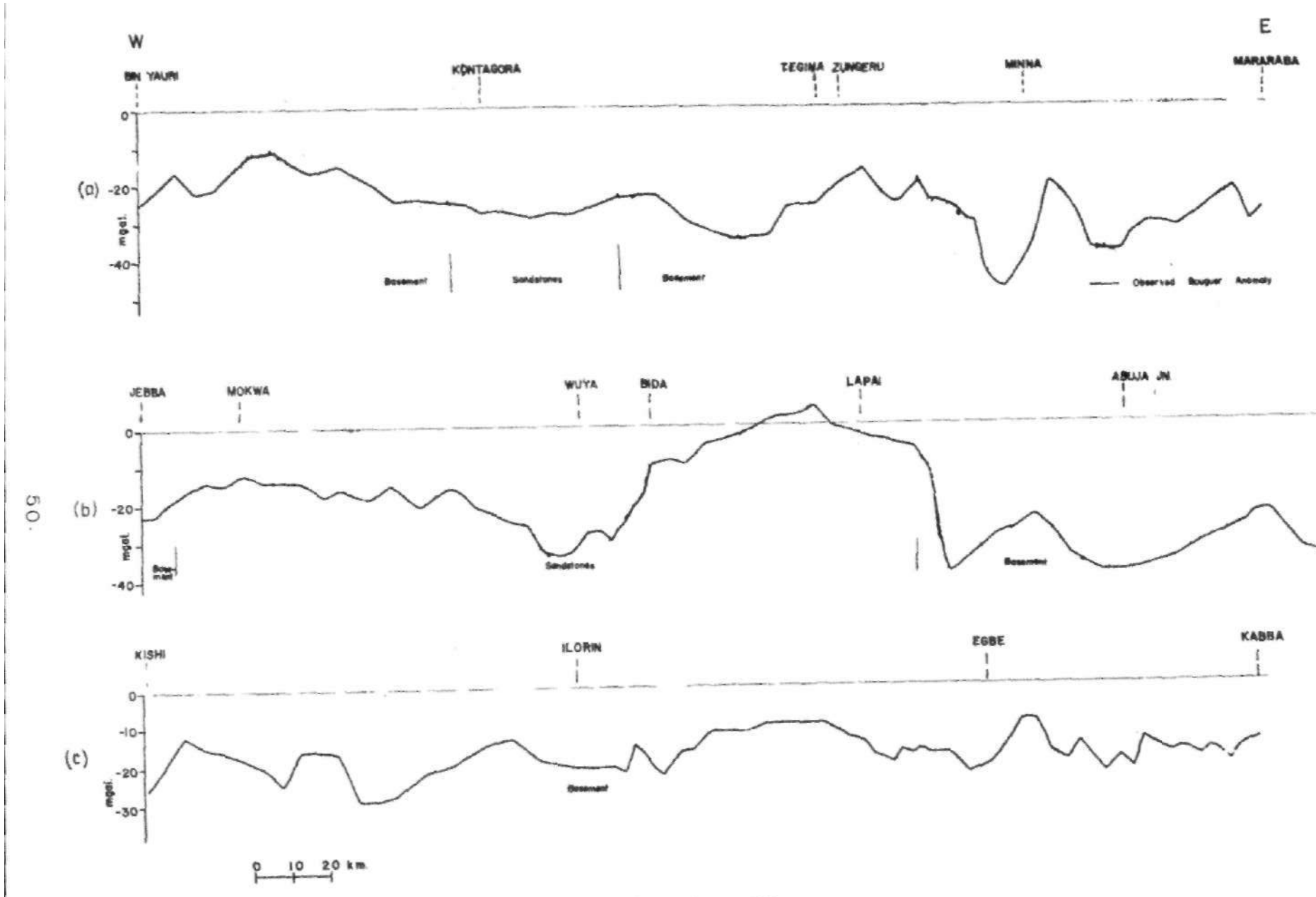


FIG. 8. Observed Bouguer Anomalies for east-west profiles.

traverses in the north-south direction and another three were drawn along traverses in the east-west direction. The four north-south profiles were particularly suitable for estimating the regional curves because they run fairly parallel to one another, and they extend into the basement area far beyond the boundaries of the basin. They were therefore aligned and the regional curves drawn along them using the parts of the profiles over the basement area as controls. Fig. 7 shows the north-south profiles and the regional curves while Fig.8 shows the approximately east-west profiles. The gradients of the regional curves do not exceed 0.15 mgal km^{-1} in the north-south direction and the general indication is that the regional plunges to the north.

5.2.1 Interpretation of the Regional Anomalies

A preliminary investigation of the Bouguer anomalies reveals that there is a general correlation between Bouguer anomaly and height. This is readily seen (Fig.9 and Fig.10) by the way in which the Bouguer values tend to decrease as the higher ground is approached. A plot of the computed mean Bouguer anomaly against mean elevation for stations grouped according to their elevation in 100 feet intervals (Fig.11) indicated that the relation is approximately:

$$\text{Bouguer Anomaly} = -7 \text{ mgal.} - 0.01979\ H$$

where H is the elevation in feet. Similarly, a plot of the computed mean free-air anomaly against mean elevation indicated

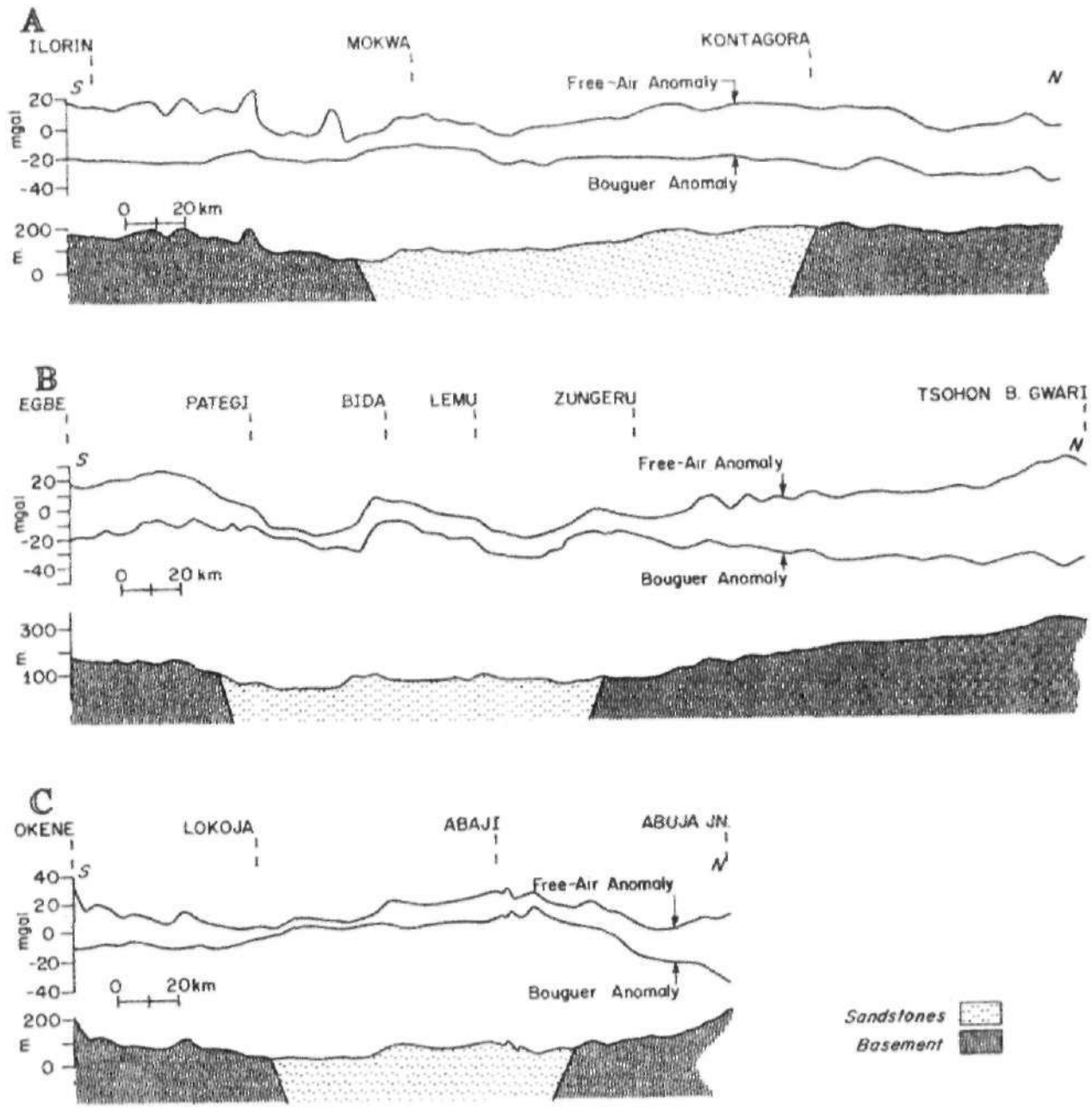


FIG. 9. Bouguer anomalies, Free-air anomalies and Elevations.

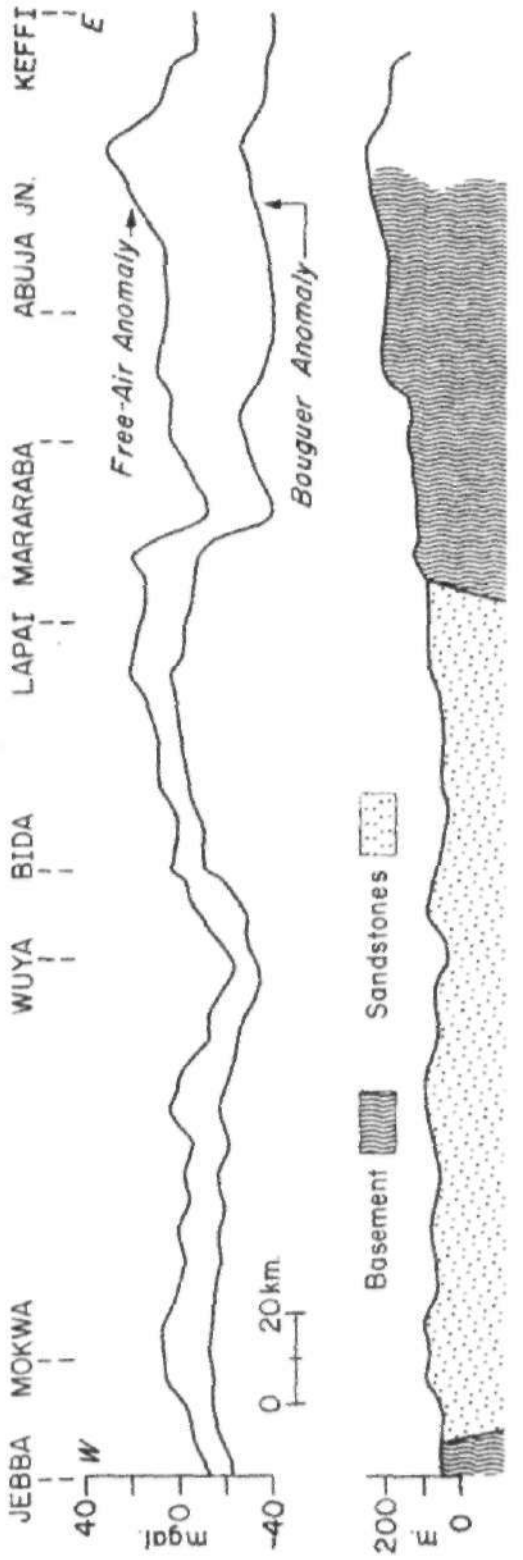


FIG.10. Bouguer anomalies, Free-air anomalies and Elevations.

that there is a correlation between elevation of ground surface and the mean free-air anomalies. The relation is approximately:

$$\text{Free-air Anomaly} = -7 \text{ mgal.} + 0.01438\ H$$

where H is the elevation in feet. The elevation in this area varies from 60 metres to almost 600 metres. As would be expected, the two curves converge to the same value (-7 mgal) at sea level (zero elevation).

A negative regional gravity anomaly extends over the whole area with a maximum negative value to the north. This negative anomaly that characterises the Middle Niger Basin area is consistent with the negative regional obtained in the Younger Granite Province Survey (Ajakaiye, 1970) and the Benue Valley Survey (Cratchley, and Jones, 1965). This dominant gravity feature of central Nigeria probably reflects the distribution of low density material within the earth's crust.

The gentle gradient of the regional curves (a maximum of 0.15 mgal. km^{-1}) indicates that it is of a deep origin. Its continuous plunge to the north is an indication that the crust is probably thicker in the north than in the south of the area. The plunge represents an increase of about 20 mgal. within a distance of 360 km. from the north to the south of the area. Assuming a density contrast of 0.40 $g.cm^{-3}$ at the crust-mantle boundary, a computed value of 1.6 km. was obtained as the increase in thickness of the crust required to produce a change of 20 mgal, from the north to the south of

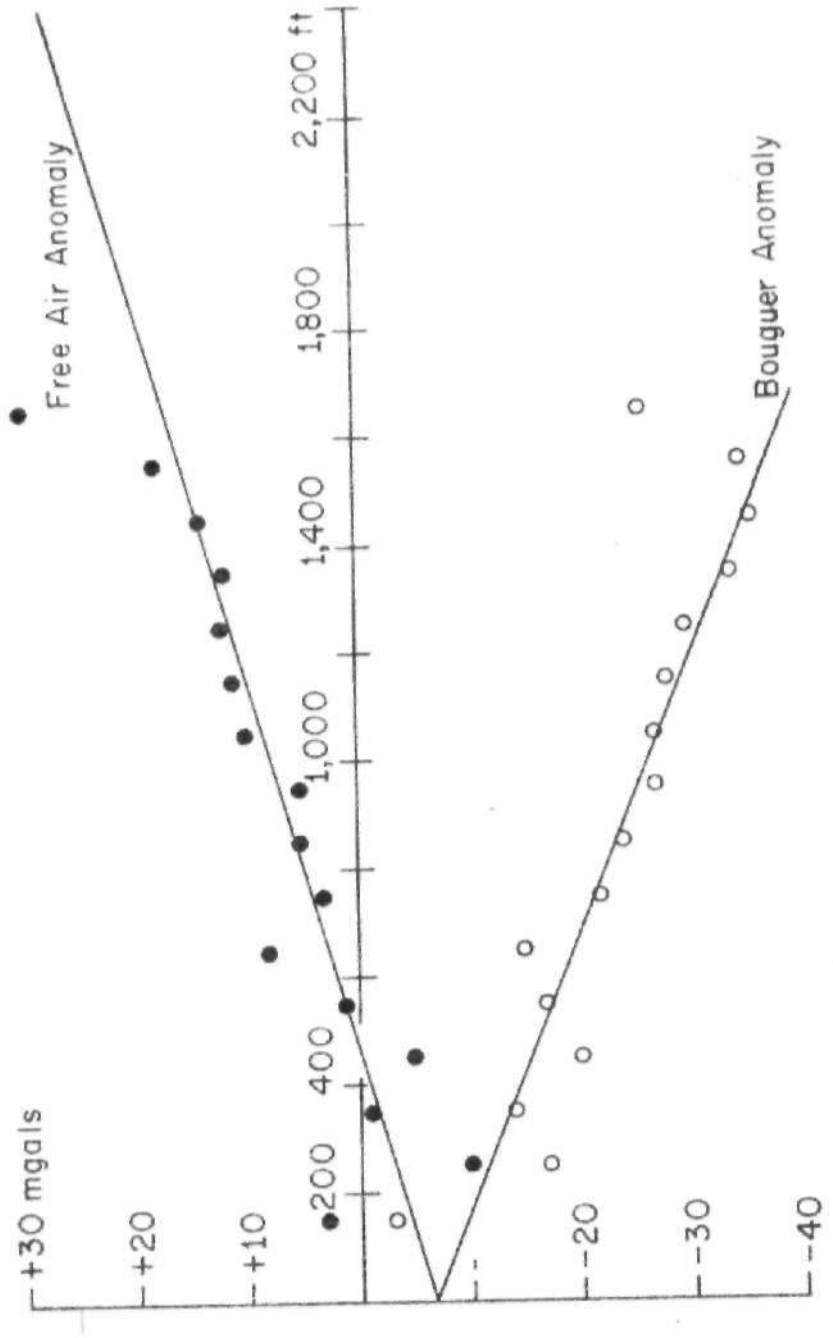


FIG. 11. The relation between Bouguer anomaly, Free-air anomaly and Elevation in the Middle Rio Grande Basin Area.

the area. The general pattern of the Bouguer values increasing over the basin and decreasing away from it is attributed to a thinning of the crust beneath the basin as compensation for the lighter sedimentary rocks in the basin. The feature is particularly pronounced in the Abaji area (Fig. 7d) and is probably due to the fact that this profile crosses an area close to the confluence of the Niger and Benue rivers where the Nupe Basin joins the Benue Valley and where considerable deposits of sedimentary rocks were probably deposited.

In the absence of any other geological or geophysical evidence, the main conclusion to be drawn from a preliminary investigation of the Bouguer and regional anomalies is that, the crust is thicker in the north of the area than in the south and that it is thinner under the basin than under the surrounding Basement Complex.

5.3 Isotasy in the Middle Niger Basin Area

The idea that elevated regions of the earth's surface are compensated by mass deficiencies at depth is not new. Quantitative studies date from those made by Pratt and Airy in the nineteenth century, on the plumb line deflections observed during the survey of India. These deflections proved to be less than would be predicted by calculation of the direct attraction of the Himalayas, and both Pratt and Airy suggested that the mountains were compensated.

The fact that the earth is close to a state of isostatic equilibrium is now supported by many facts, deduced especially from studies of the earth's gravitational field and studies of the structure of the earth's deep interior by the methods of deep seismic sounding and seismology (Artem'yev and Artyushkov, 1967). Density heterogeneities of the earth's crust are expressed both in the diversity of the surface topography and in the existence of rocks of different densities in the crust. These heterogeneities are compensated mainly by changes in the position of the lower boundary of the crust, the Mohorovicic discontinuity. Heterogeneities in the crust may therefore be compensated by changes not only in the position of its lower boundary, but also in the density of the upper parts of the mantle between the lower boundary of the crust and the top of the Mohorovicic discontinuity.

The modern concept therefore implies that a state of hydrostatic equilibrium exists between the surface irregularities of the earth's crust whereby the apparent excess of matter represented by a mountain or the apparent deficiency of matter in an ocean basin is compensated by variations in the underlying crustal materials. The tendency of the Bouguer anomaly to go to large negative values in elevated regions is evidence of compensation by concealed mass deficiency. If the effects of these deficiencies were added to the Bouguer anomaly, a new value close to zero

is obtained if compensation were nearly complete. The extent, therefore, to which these new values - the isostatic anomalies - tend to zero is a measure of the isostatic equilibrium of the area. The Isostatic anomaly is not unique, but depends on the parameters such as density, and depth of compensation of the model chosen (Garland, 1971).

5.3.1 Estimation of the Isostatic Anomalies

Approximate isostatic anomalies were calculated for the region by finding the difference between the observed Bouguer values at some stations along the profiles, and their theoretical values calculated on the assumption of complete isostatic compensation of the surface topography, using the Airy-Heiskanen principle. The crustal thickness is assumed to be 30 km. and a "root" of thickness H' at the base of the crust due to an elevation H of the station above a median height X for the traverse is calculated using the formula:

$$H \times 2.70 = H' \times 0.4$$

where the mean density of the rocks above the median height was 2.70 $g.cm^{-3}$, and the assumed density contrast between the upper mantle and crust was 0.4 $g.cm^{-3}$. The isostatic effects at sea level due to these "roots" were then determined by calculating the gravitational attraction of a two dimensional body at the depth of the "root" and thickness equal to H' (Nagy, 1964). To these values were added the gravity attraction due to an infinite

block of mass of thickness X and density 2.70 g.cm^{-3}. For instance, the median height for the Jebba-Keffi traverse was approximately 122m. and the height of 9507 -72 (Mokwa) above this median height was 39m. The equivalent "roots" thickness was therefore 263.25m. which gave a calculated isostatic anomaly of -3.65 mgal. at sea level. The gravitation attraction due to an infinite block, 122m. thick and density 2.70 g.cm^{-3} was -13.81 mgal. The total isostatic effect at Mokwa was therefore -17.46 mgal. The observed Bouguer anomaly at Mokwa was -11.69 mgal. The residual isostatic anomaly which is the difference between the observed and calculated anomaly is therefore approximately +6 mgal. Similarly, the residual isostatic anomaly at 9501 -72 (Bida) which is in the centre of the basin is approximately +4 mgal. But the mean free-air anomaly for the area is +5 mgal. Since in the essentially lowland areas of the basin, the free-air anomalies should approximate to isostatic anomalies (Cratchley and Jones, 1965), it would appear, therefore, that the area is approximately isostatically compensated since the isostatic anomalies calculated for Mokwa and Bida are close to the mean free-air anomaly value.

5.4 Correlation of the Bouguer Anomalies With the General Geology

In general, there is good correlation between Bouguer anomalies and the mapped geology of the area, but some positive

anomalies were observed over the basin and these have no clear correlation with the geology of the basin.

In the Kishi-Zuru profile (Fig. 7a), the Bin Yauri positive anomaly has a magnitude of about 20 mgal. It occurs over basement area and is directly related to mapped bodies of schist. Also associated with scattered exposures of schists are the positive anomalies (Fig.7c) observed between Egbe and Pategi and just south of Zungeru.

The Bida positive anomaly (Fig. 7c), however, has no clear correlation with known geology of the area over which it was observed. It is perhaps the most prominent of the positive anomalies and extends north of Bida for 40 km. and east of Bida (Fig. 8b) for 80 km. In the Lapai area (Fig. 8b) it has a residual value of about +25 mgal and in the Bida area (Fig. 7c), it has a residual value of about +18 mgal. Also observed over the basin and similarly not correlated with known geology is the Mokwa positive anomaly (Fig. 7b). It averages about +10 mgal. and extends northwards towards Kontagora (Fig. 7b) and eastwards for 60 km. (Fig. 8b).

In most instances, the negative anomalies can be related to thick sediments in the basin area; for instance, the Lemu negative anomaly (Fig. 7c) and the Wuya negative anomaly (Fig. 8b) are correlated with sandstone deposits of the Nupe Basin. The

Wuya negative anomaly is flanked by the Mokwa positive anomaly and the Bida positive anomaly, and has a residual value of about -6 mgal. The Lemu negative anomaly lies north of the Bida positive anomaly and has a residual value of about -5 mgal.

Also associated with mapped sedimentary deposits is the negative anomaly which lies between Luma and Bin Yauri (Fig.7a). It is correlated with the sandstones of the Illo Formation of southern Sokoto. Details of the northern part of the anomaly are unavailable owing to the lack of adequate maps of the area during the field work, but details shown in Fig.7a indicate that the anomaly has a residual value of about -25 mgal. An assumed density contrast of 0.30 $g.cm^{-3}$ with the basement rocks should therefore give an estimated thickness of 1.9 km. for the sandstones in this area of the Sokoto Basin. It would appear that the thickness obtained here is greater than thicknesses to be expected in most parts of the Nupe Basin, by comparing the values of the negative anomalies observed in both areas.

A prominent negative anomaly with a residual value of about -20 mgal. observed over basement area near Minna (Fig.8a) cannot be correlated with known geology of the area. Exposed intrusions of Older Granite rocks are observed about 30 km from the area. This anomaly may therefore be associated with subsurface intrusion of the same granite suite.

5.5 Main Gravity Feature of the Basin

The general indication from the three north-south profiles that cross the basin is that, positive residual anomalies are centred on the basin around Abaji (Fig. 7d), Bida (Fig. 7c), and Mokwa (Fig. 7b). They decrease in magnitude from Abaji westwards to Mokwa with a value of about 25 mgal. at Abaji, 18 mgal. at Bida, and about 15 mgal. at Mokwa. In the central basin region at Bida (Fig. 7c), the anomaly is flanked to the north and south by two negative anomalies.

The east-west profile (Fig. 8b) indicates a central negative anomaly flanked by two positive anomalies which are the Mokwa and Bida positive anomalies. It also indicates that the Mokwa positive anomaly extends as far as 60 km. east of Mokwa, and that the Bida positive anomaly extends as far as 80 km. east of Bida. It would therefore appear from the east-west profile that the positive anomalies observed in the three north-south profiles do not form one continuous trend. They may therefore be associated, at least at shallow depth, with separate origins.

CHAPTER VI

THE RESIDUAL ANOMALIES

6.1 Introduction

Residual anomalies are obtained by subtracting the regional anomaly from the observed Bouguer values for the profiles. In this respect, the final results derived from these residuals would to a certain extent depend on the assumed regional.

The modelling principle normally used in interpreting the residual anomalies is to compare the residual Bouguer values with anomaly values calculated for a hypothetical set of bodies extending into the subsurface with different shapes and density contrasts with the surrounding basement rocks. When the difference between the observed and calculated gravity values is small throughout the region of comparison, the model configuration constitutes a possible representation of mass distributions which exist in the upper crust. In theory, an infinite number of model configurations will generate the observed anomaly pattern but the restrictions imposed by surface lithologic distributions and structures, and general physical and chemical considerations will eliminate most of the models.

Only two dimensional models were calculated using a computer programme (Nagy, 1964) adapted by the writer to suit the ICL 1901 computer of the Computer Unit at the Ahmadu Bello University (Appendix II). The programme uses the polygon

approxination nethod of determining the gravitation attraction over a cross-section of a polygonal body which extends infinitely in a direction perpendicular to the cross-section. Although the basin is a three dinensional structure and a three dinensional model would therefore have been preferable, it was felt that the difference in depth estimates made by a two dimensional and a three dimensional model would be small enough to justify the use of two dimensional models, and two dimensional models can be made to fit the residual gravity profiles nore exactly.

Of all the seven profiles, Profiles A-A', B-B', C-C', and D-C' (Map.2) cross the basin substantially. Three of the latter profiles run in a north-south direction while the fourth runs in an east-west direction. The sections of the profiles which run over the basement far away from the basin were used in estimating the regional curves, and only the sections which cross the basin and its immediate surroundings have been studied in the subsequent models described later in this Chapter.

6.2 General Description and Preliminary Interpretation of the Residual Anomalies

As mentioned above, the area of particular interest is the Nupe Basin and its contacts with the basement. The basin is characterised by positive residual anomalies which are observed

in the profiles that cross the basin (Fig.7b-d). In the central basin region of Profile B-B' (Fig.7c), a central positive anomaly is flanked to the north and south by two negative anomalies. These and other negative anomalies which are observed over the basin are most reasonably ascribed to great thicknesses of the Cretaceous strata in the basin.

The positive anomalies on the other hand can be produced by the following hypotheses:

I. Considerable thicknesses of the ironstone capping which characterises the basin.

II. A significant rise of the order of 2-3 km. in the Mohorovicic discontinuity.

III. A shallow basin floor coupled with a zone of basic igneous intrusives occuring predominantly within the basement.

IV. Extremely shallow basin floor which is underlain by predominantly highly metamorphosed rocks of intermediate composition of the schist or amphibolite type.

On the assumption of I, thicknesses of the order of 3km. or more would be required to produce the positive anomalies observed in the Lapai area (Fig.8b); but records of boreholes in the Nupe Basin (Geological Survey Nigeria records) and various geological reports of the area (Jones, 1948; Jones, 1955; Adeleye and Dessauvagie, 1972) have shown that nowhere

in the area does the ironstone capping exceed a thickness of 50m. It is therefore considered that this hypothesis is not probable.

With reference to II, while the positive anomalies between Lokoja and Kwali (Fig. 7d) may be explained by a rise in the Mohorovicic discontinuity, it seems unlikely that this is the case for the Bida positive anomaly (Figs. 7c and 8b). At the eastern margin of the Bida positive anomaly (Fig. 8b), the gravity gradient is about 6 mgal.km^{-1} which implies that the anomalous body that causes it is at a shallow depth. An estimate of the limiting depth of the anomalous body (Bott and Smith, 1958) gave a value of 3.6 km. as the maximum depth to the top of the body. Since the depth of the Mohorovicic discontinuity is of the order of 30km. in the area, hypothesis II cannot completely explain the positive anomalies.

Several models calculated based on hypothesis III showed that the basic igneous intrusion required to explain the positive anomalies would be fairly massive (70 km. long and 9 km. deep in Fig. 12-A). While an intrusion of this dimension is possible, it would be expected that some geological evidence for it within the basin and beyond the margins of the basin should be present. In the absence of such evidence, hypothesis III is considered unlikely.

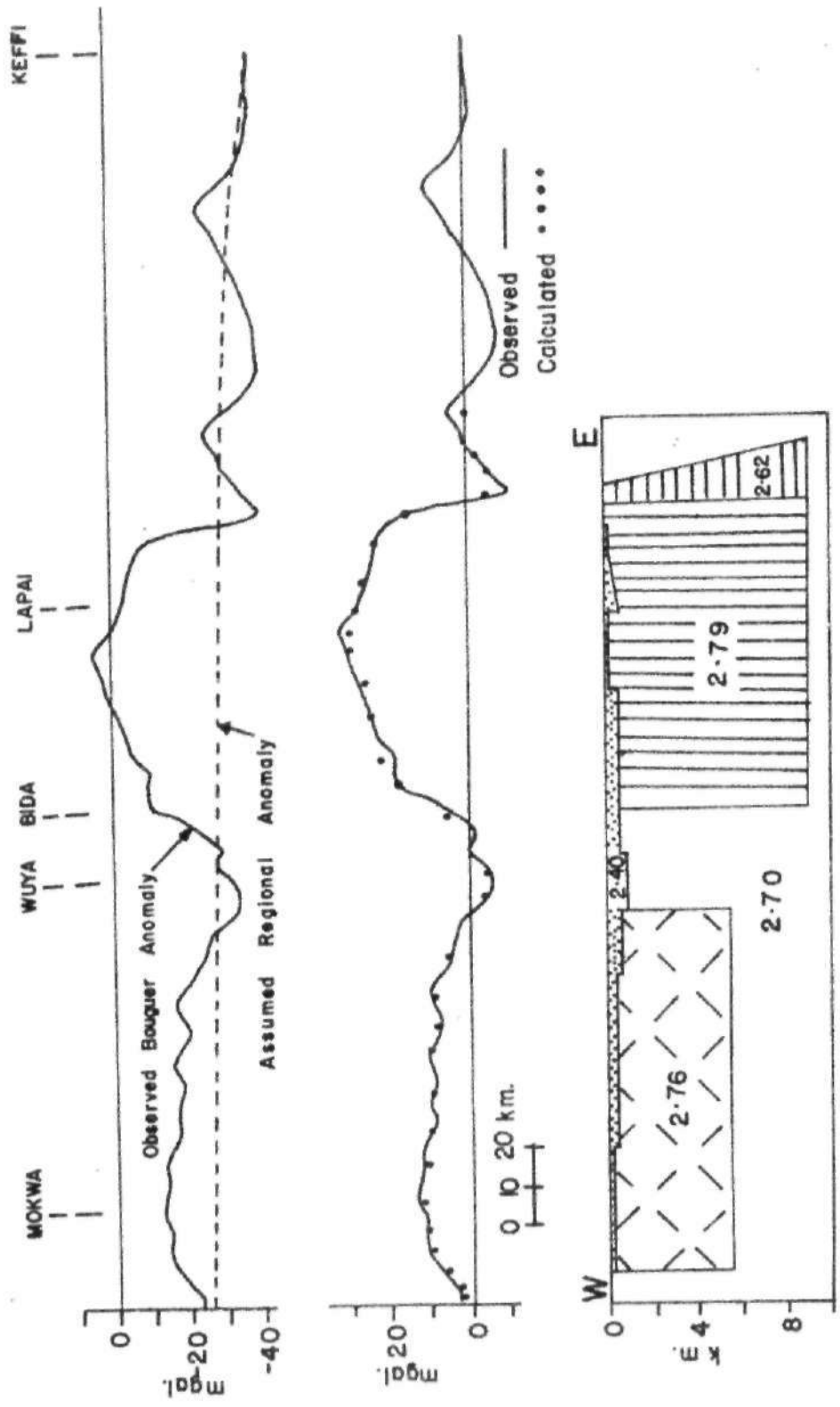


FIG. 12-A Two dimensional model of Profile D-C'
assuming an igneous mass under Lapai.

In consideration of IV, the following observations were taken into account:

(a) The Lapai area is covered fairly extensively by basal conglomerate which suggests that the basement is probably close to the surface in this area.

(b) Most of the rivers in the basin are perennial and have been observed to contain water all the year round. This probably suggests a fairly thin deposit of sandstones.

(c) The Nupe basin cuts across a zone of schist belt (Map.1) which extends in an approximate north-south direction and which predates the basin. Schist samples were also collected from outcrops close to the edges of the basin south of Zungeru and north of Abaji (Map.2). Furthermore, Russ (1957) inferred that, since the gold-bearing Pre-Cambrian rocks occur in a north-south belt down the western side of Nigeria, a considerable area of auriferous Pre-Cambrian rocks, in particular schists, must be concealed beneath Cretaceous strata in the Niger Basin.

One may therefore conclude that a shallow basement floor of metamorphic origin and intermediate composition, probably schist, is the most probably cause of part of the positive anomalies observed over the basin.

In view of the geological evidence in support of hypothesis IV, and the fact that hypothesis II appears possible, the interpreted models presented in the remainder of this Chapter have therefore been restricted to these two hypotheses.

6.2.1 Two dimensional model of Profile A-A'

This profile runs from Ogbomosho to Zuru (Map.2) and crosses the western side of the basin. The residual anomalies for the section that cross the basin (Fig.12) are positive and maintains a fairly constant amplitude (10 mgal.) between Mokwa and Kontagora except for a "low" of about 8 mgal. 30km. north of Mokwa.

The model shown in Fig.12 indicates an area underlain by a mass with a uniformly high density of 2.76 $g.cm^{-3}$ which extends to a depth of 5.5km. Overlying this mass is a deposit of sandstones (2.40 $g.cm^{-3}$) which is very thin under Mokwa (0.1km.) and deeper (0.3km.) northwards towards Kontagora. A maximum thickness of 0.7km. was estimated about 30km. north of Mokwa. Farther north, the separate mass of high density material (2.76 $g.cm^{-3}$) shown in the model north of Kontagora has not been observed on the surface. It may therefore lie under a thin cover of basement rocks. A uniform density of 2.70 $g.cm^{-3}$ was assumed for the basement rocks on the basis of density measurements of samples collected.

This model is very tentative because the residual anomalies are entirely positive over the basin, and it is felt that no

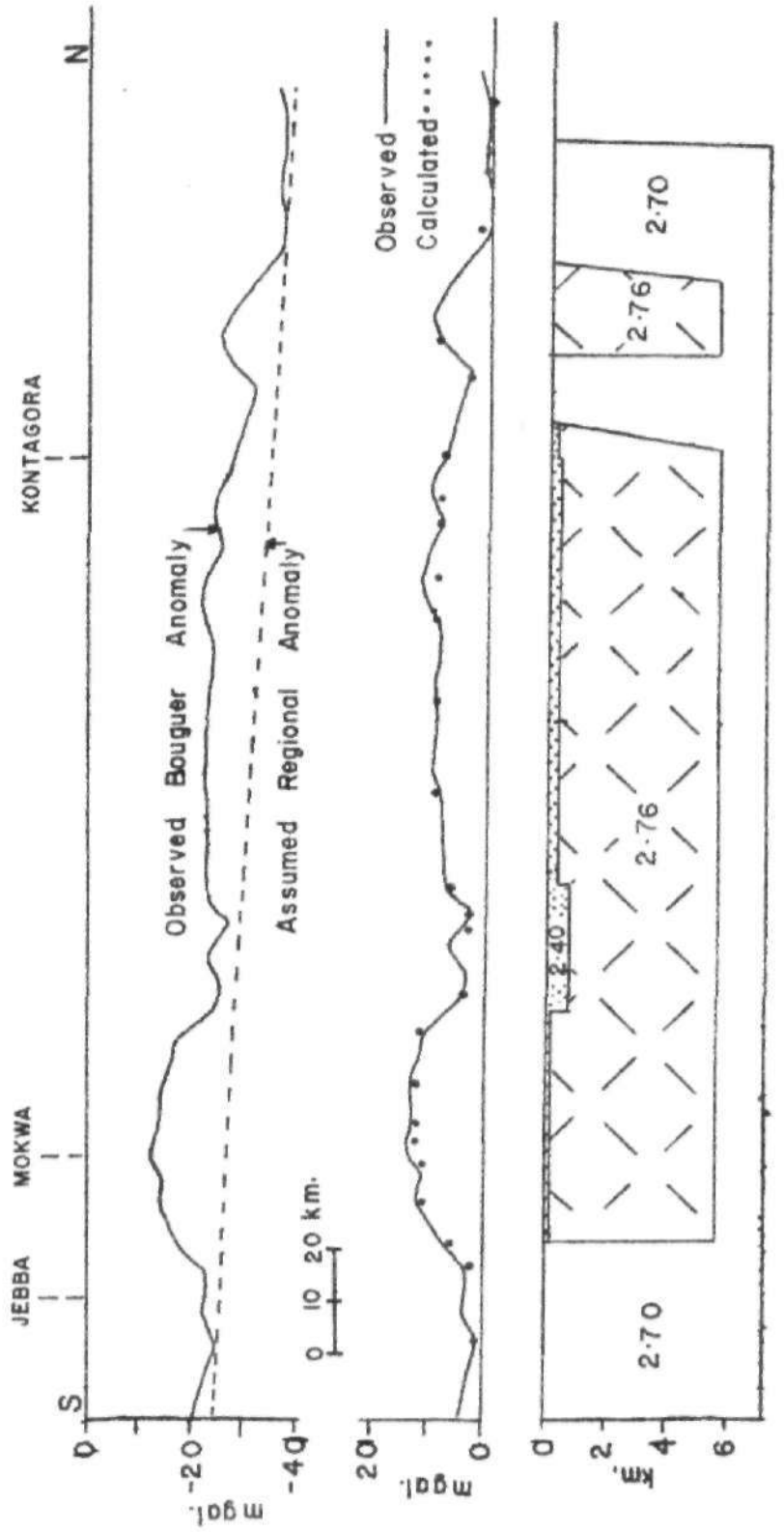


FIG.12. Two dimensional model of Profile A-A'

unique model is possible without some other information from drilling or other geophysical methods, in particular, the seismic method.

6.2.2 Two dimensional models of Profile B-B'

This is the Egbe-Birnin Gwari profile (Map.2). The residual anomalies (Fig.13) show that a central positive anomaly over the the basin is flanked on either side to the north and south by two negative anomalies. The profile is representative of the central Middle Niger Basin and is perhaps the best suitable for study because apart from crossing the centre of the basin, it provides the best three dimensional picture of the centre of the basin since one other profile intersects it almost at right angles. In addition, the regional curve for the profile is reasonably good because the profile extends far beyond the boundaries of the basin. It also runs far away from the Benue Valley in the east and the Illo Basin in the west whose gravity influence would therefore be negligible.

The model in Fig.13 shows Basement Complex with a uniform density of 2.70 $g.cm^{-3}$ overlain by varying thicknesses of Cretaceous strata with a uniform density of 2.40 $g.cm^{-3}$. The greatest thickness of sediments for the model is 0.5 km. and is restricted to two areas which lie south of Bida and north of Lemu. The central positive anomaly in the Bida area was

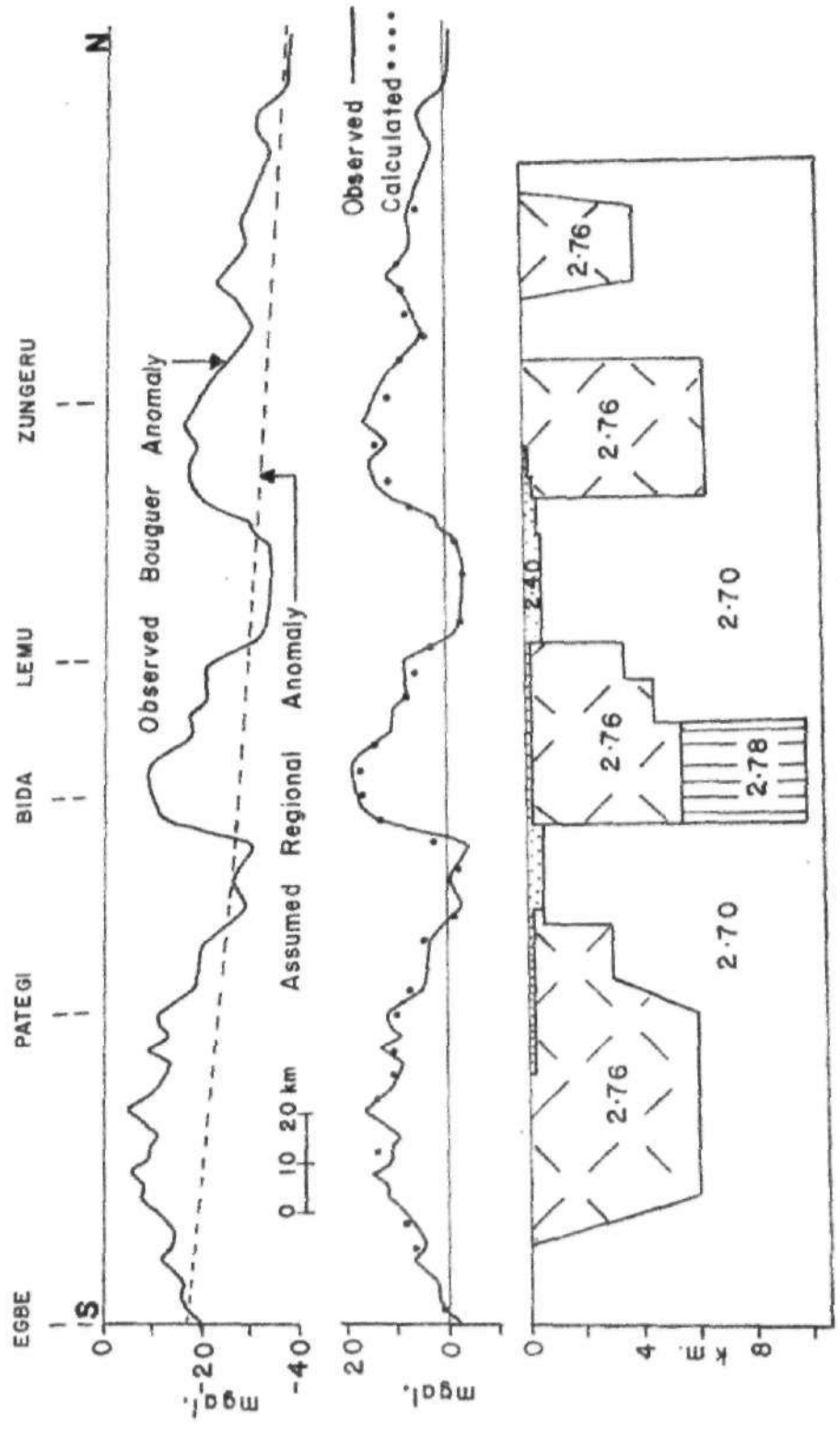


FIG. 13. Two dimensional model of Profile B-B'.

explained by a shallow basin floor (0.3 km.) underlain by two high density masses with density of 2.76 $g.cm^{-3}$ and 2.78 $g.cm^{-3}$ respectively. The two high density masses represent a single mass whose density increases with depth. The depth to the bottom of the combined mass is 10km. The positive anomalies to the north (around Zungeru) and the south (around Pategi) are also explained by masses of density 2.76 $g.cm^{-3}$. A density of 2.76 $g.cm^{-3}$ was ascribed to the masses on the basis of density determinations made on schist samples collected near Zungeru. Since schist bodies are also mapped north of Egbe, the conclusion is that the high density masses shown in the model are probably of schist composition.

The maximum possible thickness of the sediments in the central region of this profile would be obtained if the largest value of the negative residuals was assumed. This value of the residual was obtained assuming the regional curve shown in Fig.14. It is possible to explain this regional curve by assuming a thinning of the crust under the basin as compensation for the lighter sediments. One would then expect the Bouguer values to rise over the basin as a result of the rise in the crust-mantle boundary.

Fig.14(a) shows a model whose calculated anomalies gave a good fit with the residual anomalies. The central positive

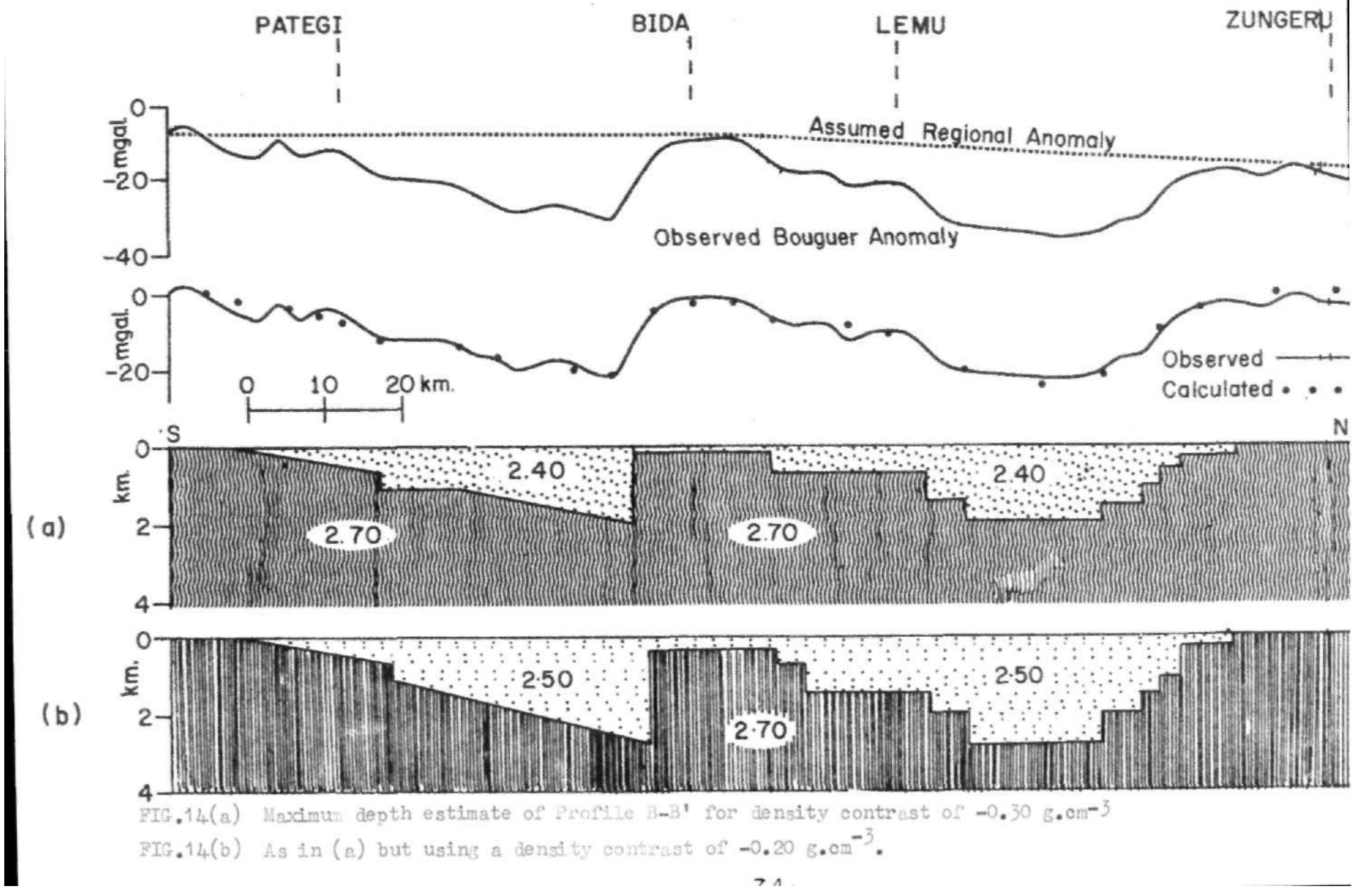


FIG.14(a) Maximum depth estimate of Profile B-B' for density contrast of -0.30 g.cm^{-3}

FIG.14(b) As in (a) but using a density contrast of -0.20 g.cm^{-3}.

anomaly was entirely ascribed to very shallow floor of the basin (0.1km.). The maximum thickness of the sediments with a uniform density of 2.40 $g.cm^{-3}$ is 2.0 km. and is restricted to two areas south of Bida and north of Lemu. Fig. 14(b) is similar to Fig.14(a) but a density of 2.50$g.cm^{-3}$ was ascribed to the sediments. This density gave an estimated maximum thickness of 2.7km. for the sediments assuming a density of 2.70$g.cm^{-3}$ for the basement. The depths of 2.0km. and 2.7km. are maximum estimates, and should not be considered as typical depths because it was difficult to correlate these two models with the models calculated for the other profiles.

The last model for this profile is shown in Fig.15 and is similar to the model in Fig.13 but with a significant difference which is the omission of the high density mass in the south. The assumed regional curve lies between the two extreme regional curves of Fig.13 and Fig.14 and this model may therefore be considered as a median interpretation of the profile. The estimated maximum depth of the sediments in this case was 1.0km.

6.2.3 Two dimensional model of Profile C-C'

The profile crosses an area close to the Niger-Benue confluence and is shown in Fig.7d. It has a predominantly positive residual anomaly and as in Profile A-A', it was felt that no unique model is possible without other geophysical data.

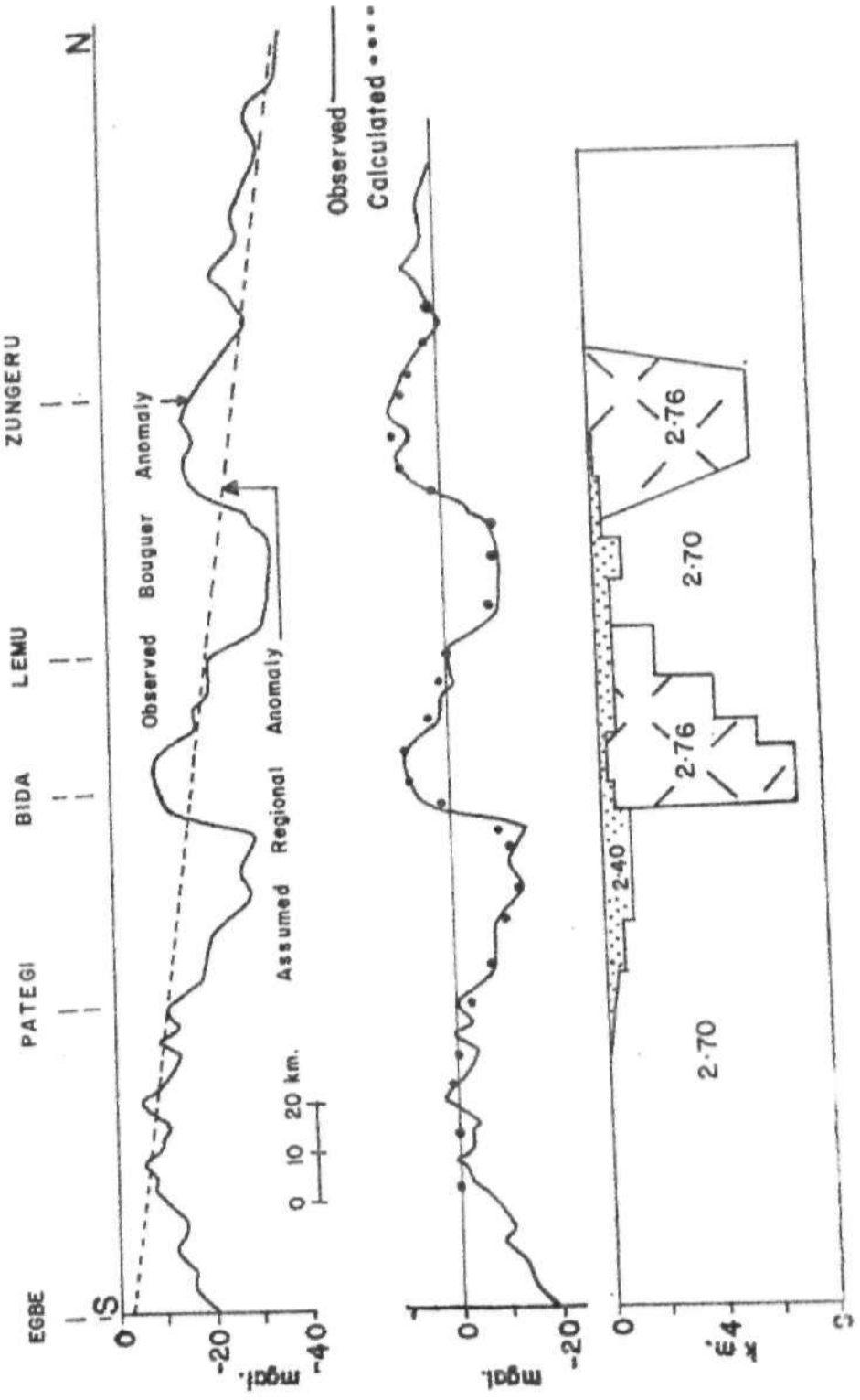


FIG.15. As in 13 but using a different regional curve.

The model with calculated anomalies that best fitted the residual anomalies is shown in Fig.16. The regional curve in the figure was drawn on the assumption of a thinning of the crust under the basin as compensation for the lighter sedimentary rocks. A local rise of about 2.0km. in the crust-mantle boundary would account for the rise in the regional curve.

The model shows basement with a uniform density of 2.70g.cm^{-3} overlain by Cretaceous sediments with a uniform density of 2.40 g.cm^{-3}. A uniform thickness of 0.7km. is shown for the sediments except in two areas where the thickness increases to 1.0km. The northern end of the sediments is underlain by a mass with a density of 2.76 g.cm^{-3}, and 3.5 km. deep which is considered to be of schist composition because schist samples were collected close to the edge of the basin in this area.

6.2.4 Two dimensional model of Profile D-C'

This is the east-west profile that crosses the basin in the central region. An attempt has therefore been made to correlate the model in Fig.17 with the north-south models where they intersect. It was however difficult to draw a suitable regional curve for this profile mainly because more than half of the profile lies over the basin. For this reason, the model shown in Fig.17 is considered to be very hypothetical.

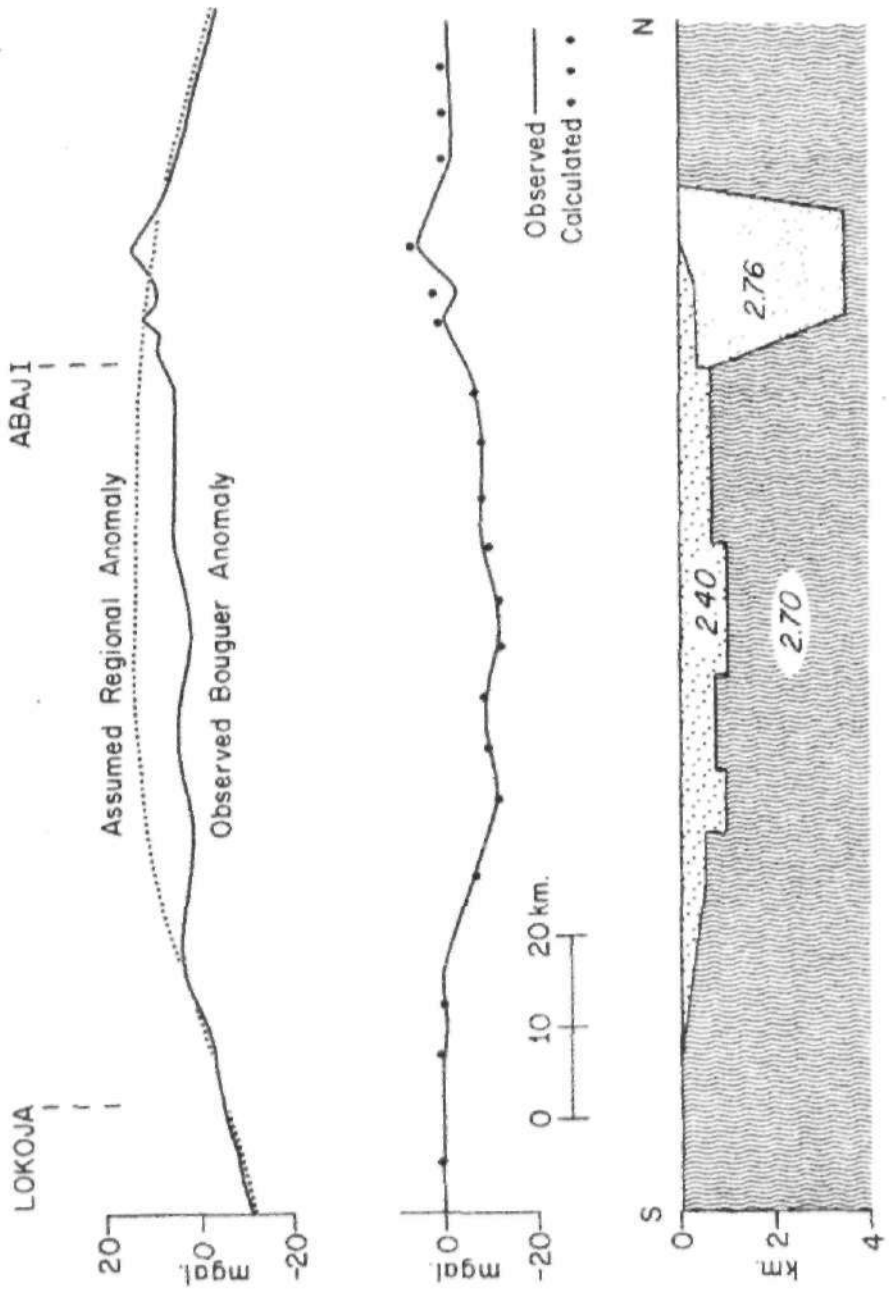


FIG.16. Two dimensional model of Profile C-C'.

The model shows varying thickness of light sediments (2.40 $g.cm^{-3}$) underlain predominantly by high density material (2.76 $g.cm^{-3}$) except in the Wuya area where the sediments are underlain by basement rocks with a mean density of 2.70 $g.cm^{-3}$. Greatest thickness of the sediments is 0.7 km and is restricted to the Wuya area. A greater thickness would be obtained in this area if the mass with a density of 2.76 $g.cm^{-3}$ was assumed to extend below the Wuya area, but the resulting model would not correlate with the models of the intersecting profile (B-B'). The sediments in the Lapai area are very thin and probably do not exceed 0.1 km; the high density masses under the same area represent a single mass whose density increases with depth.

The negative anomaly 25km. east of Lapai was also difficult to explain. The magnitude of the anomaly (about -10 mgal.) and the steepness of the sides of the anomaly suggest that it is caused by a very light material close to the surface. If a density of 2.40 $g.cm^{-3}$ was ascribed to the material, it would require a thickness of the order of 2.0km. to explain the anomaly. This possibility was discarded since a density of 2.40 $g.cm^{-3}$ would suggest a sedimentary rock type and since no outlier of the Nupe Sandstones has been observed in the area. Rock samples collected in the area and the geology of the area however indicate that the rock types are of the Older Granite

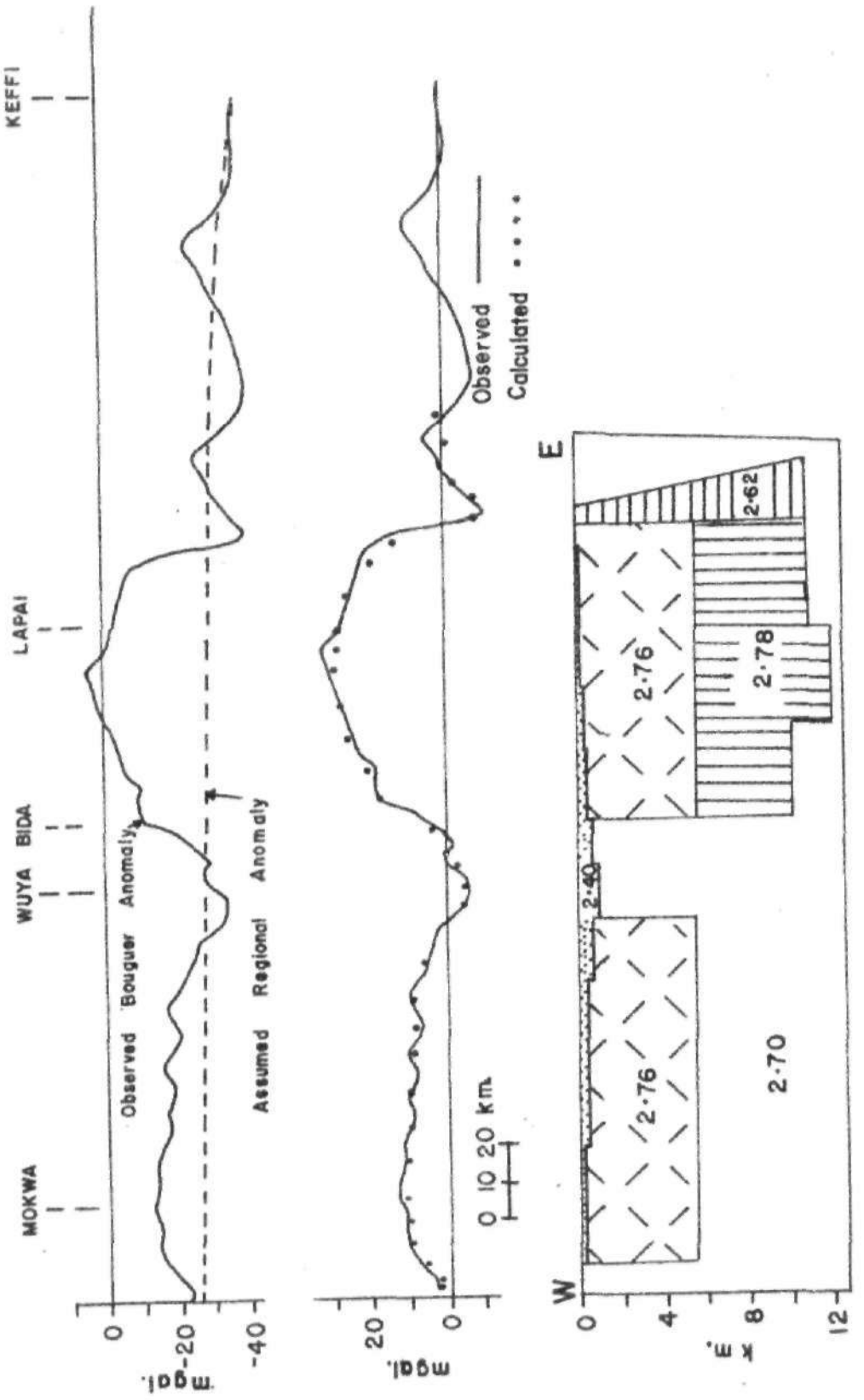


FIG.17. Two dimensional model of Profile D-D'.

type. On this basis, a mass with a density of 2.62 g.cm^{-3} (Fig.17) was considered a probable cause of the negative anomaly, and anything more than this tentative interpretation was considered unjustifiable in the absence of any other information.

6.3 Interpretation of the Residual Anomalies and Models

One of the pre-requisite for the interpretation of gravity data is good geological control and an accurate knowledge of the density contrasts of the various lithologic units in the area. This was lacking in this survey and in addition, the interpretation of the residual anomalies have been based on models where the rock types have uniform densities. Since variations in densities, even within one rock type, are possible for the size of masses calculated in the models, and since for two dimensional models, the infinite extent perpendicular to the cross sections makes depth estimates less than is actually the case for a three dimensional structure, the calculated depths and extent of the masses obtained in the models are tentative.

It is clear from all the models that the sediments in the Niger Basin are fairly thin in most places, and that the floor of the basin is irregular in shape. Considerable thicknesses however occur on the western side of the basin, north of Mokwa (0.7km); in the Wuya area (0.7km.), and in the Lemu area and south of Bida (0.5km.). On the eastern side, considerable thicknesses are also to be found south of Abaji (1.0 km.). A maximum

possible thickness of 2.7km. was calculated in the Lemu area and south of Bida. It would therefore appear that the sediments in the Middle Niger Basin are thinner than the sediments in the Benue Valley whose maximum thickness have been estimated to be 5.5 km. by Cratchley and Jones (1965).

The sediments in the basin are in most places underlain by rocks of a higher density than the mean density of the Basement Complex. The high density masses which account for the irregular shape of the floor of the basin, appear to extend down to depths of upto 5.5 km. under the western side of the basin and upto 10.0km under the eastern side of the Basin. They have been related to the schist bodies exposed to the north and south of the basin and the densities ascribed to them in the models were based on density determination of samples collected from these schist bodies.

Some minor variations of the Bouguer anomalies which were superimposed over some of the positive anomalies (for example, the Mokwa positive anomaly in Fig.17) have not been taken into consideration in the models. They are probably a reflection of slight foldings of the Cretaceous strata, with anticlines forming local positive anomalies and synclines local negative anomalies due to the increased densities of the lower layers of

sediments. They may also reflect changes in the thicknesses of the ironstone capping.

The positive anomalies which characterise the basin area have to a large extent made it difficult to find out much about the contacts between the basin and the basement. Most of the steep gravity gradients observed were associated with the margins of the high density masses shown in the models, and the gradients are such that faulting could have occurred at these margins. The steep gradients also suggest shallow structures which would not be consistent with deeper features associated with rifts. It is therefore unlikely that the basin originated as a rift valley.

CHAPTER VII

CONCLUSIONS

7.1 Introduction

The gravity survey described in this thesis should be regarded as a preliminary investigation of the hitherto unsurveyed Middle Niger Basin area. Although the gravity stations are sufficiently detailed (1-4 km. intervals in most places), the large area covered and the inadequate road network resulted in widely spaced traverses. Consequently, it was felt that no suitable Bouguer or Free-air anomaly map of the area could reasonably be produced with the station distribution, and no very simple correlation of the profiles could therefore be expected. It is hoped that further work in the area will make the production of a map possible because, apart from allowing a better study of the structures in the area, a Bouguer map of the Niger Basin area would fill a substantial part of the gap in the only available Bouguer gravity map of Nigeria (Ajakaiye and Burke, 1973) which covers only about 40% of the area of Nigeria.

The primary aim of the survey was to determine the maximum thickness of the sediments in the basin, and the general geometry of the basin. Normally, the subsurface shape of sedimentary basins (and most structures in general) can readily be determined from the gravity anomalies they produce if the density contrast between the sediments and the surrounding rocks is known, and

if there is good control from known geology and other geophysical data. However, there is very little published data on the geology of the Middle Niger Basin area, and no data from any other geophysical method was available to the writer. In addition, positive anomalies were observed widely over the basin where one would normally have expected negative anomalies. Density determination for the sandstones were also probably not representative of the typical Nupe Sandstones at depth due to the fact that, samples which did not contain iron were difficult to find because of the fairly extensive occurrence of ironstone capping. A limitation was therefore placed on the interpretation possible owing to these difficulties, and the conclusions drawn here are tentative.

7.2 Origin of the Middle Niger Basin

Two probable hypotheses are the rift hypothesis and the isostatic subsidence hypothesis. The general shape of the basin does not, however, support the rift hypothesis. Typical rift valley (Holmes, 1965) have widths of about 50 $\pm$ 13 km. but the Middle Niger Basin has a maximum width of about 160km. Furthermore, most of the phenomena of rifts such as igneous intrusion, shearing and intermittent uplift as well as, and in particular, volcanic activity are absent in the Niger Basin. The adjacent

Benue Valley, for instance, which is believed to be a rift valley shows evidence of widespread volcanic activity, and numerous igneous intrusions are distributed throughout the valley (Cratchley and Jones, 1965). There is also evidence of intermittent uplifts in the Benue Valley. It is therefore unlikely that the Niger Basin originated as a rift valley.

A geophysical interpretation of the origin on the basis of the Bouguer anomalies leads to the same conclusion. Positive residual anomalies were observed in several places, but only one profile shows a steep gravity gradient close to the edges of the basin east of Lapai (Fig.17). Although a few gradients in the Bida area (Figs. 13 and 17) and in the area east of Lapai (Fig.17) suggest faulting, they appear to be related to shallow structural features and not with deeper features normally associated with rift valleys. It is therefore concluded that rifting is probably absent in the Niger Basin. A rifting origin should not however be entirely ruled out because the gravity effect of the shallow structural features might have obliterated the effect of the deeper features. Further geophysical work, in particular a seismic reflection survey, may therefore throw more light on the crustal structure of the area and resolve the problem.

The isostatic subsidence hypothesis is supported by the tectonic activities associated with the Benue Valley and the

adjacent Younger Granite Province. Intermittent regional uplifts which took place in the Benue Valley and the Younger Granite Province probably resulted in the outflow of material from the lower part of the crust of the Niger Basin area and other surrounding areas. On the assumption of this outflow from beneath the Niger Basin area, subsidence of the basin-floor would result. This outflow is explained as an isostatic response to the uplifts in the Benue Valley and the Younger Granite Province as a means of restoring equilibrium. The uplifted regions were later partially eroded and the sediments deposited in the Middle Niger depression. The fact that the sediments in the Niger Basin are younger than most of those in the Benue Valley is evidence that the Middle Niger depression appeared at a later stage.

Although the sediments in the Niger Basin appear to be continental sediments and although the oolitic ironstone horizons probably indicate a brief transgression of a shallow sea into the area (Adeleye and Dessauvagie, 1970) the deeper sediments may be marine. It has in fact been suggested that the sediments of the Niger Basin were derived as a result of the sea entering the Niger Valley after being displaced from the Benue trough by folding movements in the trough (Wright, 1970). The forces which caused folding movements in the Benue trough could also have contributed to the depression in the Middle

Niger Basin.

7.3 Comparison with the Neighbouring Benue Valley

A gravity survey of the Benue Valley (Cratchley and Jones, 1965) showed that the Benue Valley is characterized by Bouguer anomalies with a similar pattern to those obtained in the Middle Niger Basin. The Benue Valley survey revealed a central zone of positive anomalies which is flanked over most of the 'Middle Benue' by two elongated negative anomalies. The central Niger Basin area also revealed (Fig. 7c) a central positive anomaly flanked by two negative anomalies, but this pattern does not appear to extend over the whole length of the Niger Basin. The profiles are, however, too widely spaced to make the above impression conclusive. Generally common to both valleys is the widespread occurrence of positive anomalies over the basins. The positive anomalies of the Benue Valley were ascribed to a zone of intrusion in which the oldest Cretaceous rock of Albian age (about 105 million years) are close to the surface and contain igneous material of intermediate to basic composition. There was also a close association between the lead-zinc mineralization belt and the zone of positive Bouguer anomaly. The positive anomalies of the Niger Basin are on the other hand ascribed to a shallow metamorphic basement of high density and intermediate composition. These rocks are thought to consist mainly of schist because the Niger Basin cuts across a zone of schist belt

which runs down the western section of Nigeria from the north to the south (Map.1).

A maximum depth of 5.5 km. of Cretaceous rocks was estimated for the Benue Valley while the maximum possible depth for the Niger Basin is thought to be generally of the order of 1.0km. and nowhere exceeding 2.7km. The Benue sediments are therefore much thicker than the Niger sediments. The Benue sediments are also older dating from Lower Cretaceous age (about 65-105 million years) while the Niger sediments are believed to be of Upper Cretaceous age (about 65-90 million years) (Russ, 1957; Adeleye and Dessauvagie, 1970).

7.4 Other Geophysical Methods

While closer spaced gravity traverses and a higher station density would improve the interpretation of the Bouguer values, the ambiguity inherent in the theory of gravity interpretation and the various problems mentioned earlier on still make it desirable to obtain information from other geophysical methods. Results from two other methods would throw more light on the sub-surface structure of the area.

An aeromagnetic survey across the basin with north-south flight lines spaced at about 20km. and at a height of about 200m. should delineate the regions of shallow basement from

areas of great sedimentary thicknesses. The objection to an aeromagnetic survey would be the cost of such a survey and the fact that the effect of the ironstone capping might obliterate the effect of the basement.

Probably more useful would be the results of a seismic refraction survey. The shooting of short seismic refraction lines at various places where the gravity survey has indicated probable shallow basement should yield useful results. If a few depths of the basin floor are known, more reliable gravity models can be calculated and the various profiles can be better correlated. Refraction lines placed near the edges of the basin would yield more information about the contact between the basin and the basement. In addition, a more representative velocity of the sandstones can be determined from their velocities and the density so determined used for calculating the gravity models.

In contrast to an aeromagnetic survey, a seismic refraction survey would be fairly cheap to carry out with a portable seismogram. Deep seismic sounding may also indicate if the basin is a rift valley.

7.5 Conclusions

In spite of all the limitations discussed in detail above, several general conclusions are possible. The area is characterised by negative Bouguer anomalies with a range of about 70 mgal.

A considerable fraction of this in the form of residuals could be explained by changes in the sub-surface geology and the remainder is thought to be due to a regional effect. A northward plunging of the regional curves has been interpreted as being caused by a thickening of the crust to the north of the area. A thickening of 1.6 km. to the north was estimated over a distance of about 360km. The general pattern of the Bouguer anomalies increasing over the basin and decreasing away from it on most of the profiles was attributed to a thinning of the crust beneath the basin as compensation for the lighter sedimentary rocks in the basin. From the point of isostasy, the area appears to be in approximate isostatic equilibrium. The mean free-air and mean Bouguer anomalies are approximately +5 mgal. and -25 mgal. respectively.

The Bouguer profiles show that the central Middle Niger Basin area has a positive anomaly which is flanked on both sides to the north and south by two negative anomalies. The profiles are however too widely spaced to indicate whether this pattern is continuous along the whole central basin area. Rather, the western and eastern profiles show positive residual anomalies along the length of the basin so that the general picture is of a basin characterised by widespread positive residual anomalies.

The positive anomalies were ascribed to a shallow metamorphic basement and high density masses. Stratigraphical evidence had shown that the surface on which the Nupe Sandstones were laid down comprised of rock types of a medium to high grade metamorphism. Observations made from rock samples collected and the fact that the basin cuts across a zone of schist belt which runs down the western section of Nigeria from the north to the south, led to the conclusion that the high density masses are probably of schist composition.

The negative anomalies were ascribed to relatively great thicknesses of sediments. Considerably thicknesses were estimated south of Abaji (1.0km.), north of Nokwa (0.7km.), in the Wuya area (0.7km.), in the Lemu area (0.5km.) and south of Bida (0.5km.). The maximum thickness of the sediments was estimated to be generally of the order of 1.0 km. and nowhere exceeding 2.7km.

The general geometry of the basin is irregular and there is a close association between the irregularity of the floor of the basin and the high density masses which underlie the basin.

The sandstone beds were laid down in Upper Cretaceous times and the present distribution of the sedimentary strata has been greatly affected by Cainozoic earth movements which imparted low dips to the formation, leading to its erosion over

wide areas. The sandstones are covered in many areas by an ironstone capping and borehole records showed that the capping is thin and typically less than 50 metres. Some of them are however believed to contain concentration of iron with such reserves as to be of economic importance.

Although the general indication is that the basin is an area of local subsidence, the gravity pattern does not completely rule out rifting as a possible origin.

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APPENDIX I

PRINCIPAL PARAMETERS OF BASE STATIONS

STATION NO	ELEVATION	LATITUDE	LONGITUDE	OBSERVED GRAVITY	FREE-AIR ANOMALY	BOUGUER ANOMALY
9501-72	414	9051	6007	978142.48	4.18	-9.98
9502-72	345	9008	6194	978156.80	13.98	2.18
9503-72	184	8366	6253	978147.25	0.32	-6.02
9504-72	179	8268	6351	978145.80	2.59	-3.53
9505-72	449	9134	5438	978128.76	10.32	-25.61
9506-72	410	9118	5242	978141.25	-0.66	-14.66
9507-72	526	9176	5033	978139.97	6.28	-11.69
9508-72	282	9084	4488	978138.94	-13.33	-22.99
9509-72	311	9075	4492	978136.78	-12.33	-22.98
9510-72	1195	8488	4565	978082.30	24.92	-15.83
9511-72	1053	8285	4351	978076.83	15.23	-20.72
9512-72	1116	8128	4172	978068.46	19.44	-18.62
9513-72	1188	8077	4142	978063.85	23.89	-16.68
9514-72	1240	8162	4481	978068.90	30.07	-12.21
9515-72	1709	8089	5058	978035.45	43.76	-14.47
9516-72	1180	8133	5306	978062.98	19.56	-20.32
9517-72	926	8310	5305	978100.76	66.88	-5.10
9518-72	400	8436	5445	978130.76	42.85	-11.31
9519-72	1194	7423	5584	978061.17	31.91	-8.77
9520-72	1299	7329	6141	978049.09	33.51	-10.79
9521-72	244	7476	6442	978122.94	2.32	-6.03
9522-72	178	8069	6471	978141.41	6.58	0.50
9523-72	530	8270	6563	978135.51	25.24	7.15
9524-72	1009	9022	7104	978086.87	5.81	-28.60
9525-72	1350	9065	7129	978057.80	6.88	-39.17
9526-72	956	9167	6597	978097.68	5.11	-27.54
9527-72	818	9366	6329	978102.91	-12.56	-40.47
9528-72	401	9484	6091	978153.84	-6.56	-20.32
9529-72	441	9278	6017	978128.36	-18.24	-33.32
9530-72	566	9027	6344	978140.90	18.02	-1.32
9531-72	662	9382	5213	978130.91	-0.03	-22.62
9532-72	1029	10024	5243	978120.08	11.46	-23.64
9533-72	1110	10241	5283	978122.67	10.34	-27.53
9534-72	876	10487	5216	978140.58	-7.17	-37.04
9535-72	1283	11258	5142	978120.15	-10.43	-54.14
9536-72	928	10039	6111	978124.93	6.04	-25.62
9537-72	1140	10183	6188	978113.32	6.89	-32.12
9538-72	1355	10250	6241	978097.11	7.34	-39.11

STATION NO	ELEVATION	LATITUDE	LONGITUDE	OBSERVED GRAVITY	FREE-AIR ANOMALY	BOUGUER ANOMALY
9539-72	1419	10393	6320	978101.02	9.57	-39.09
9540-72	1607	10479	6382	978093.54	15.07	-40.10
9541-72	1764	11009	6472	978091.95	21.00	-39.60
9542-72	198	8469	5477	978137.76	-12.50	-19.18
9543-72	1545	9042	7280	978055.62	24.19	-28.53
9544-72	953	8535	7422	978077.45	-4.86	-37.36
9545-73	136	8034	6463	978141.09	3.85	-0.76
9546-73	733	10470	4479	978155.26	-4.95	-24.77
9547-73	1067	10293	5088	978140.61	21.57	-14.85
9548-73	1127	11060	5154	978137.48	+3.69	-34.73
9549-73	907	10586	5052	978146.50	-3.76	-29.61
9550-73	741	10525	4577	978164.05	1.58	-18.53
9575-73	437	10445	4424	978172.33	-14.39	-23.93
9576-73	801	10174	4176	978128.54	-9.41	-36.49
9577-73	497	9505	4352	978156.41	4.10	-12.88
9578-73	861	9540	4244	978125.47	5.40	-24.16
9579-73	991	9375	3577	978096.16	-3.37	-37.47
9580-73	1128	9057	3509	978083.78	12.49	-26.38
9581-73	1126	8436	4096	978071.32	9.96	-28.50
9582-73	967	8109	5530	978079.76	17.47	-15.09
9583-73	1442	7498	6044	978041.64	34.52	-14.49
9584-73	348	8402	6565	978147.68	14.51	+11.60
9585-73	305	8403	6565	978149.78	12.52	+12.10
9586-73	597	8530	7000	978120.38	4.92	-15.27
9587-73	902	10142	5511	978134.62	7.88	-22.88
9588-73	1247	7424	5585	978058.19	33.94	-8.32
9589-73	666	9341	4564	978133.52	5.13	-17.71
9590-73	796	9568	4203	978128.94	1.32	-25.99
9953-68	2134	10417	7309	978044.19	18.60	-54.10
9956-68	979	8506	7523	978074.39	-4.21	-37.57

Bases 9582, 9583 and 9588, located on bench marks, were connected to the rest of the network (Fig.2) by ties to three other temporary stations (not shown) established when the bench marks could not initially be located.

APPENDIX II

TWO DIMENSIONAL GRAVITY PROGRAMME

The Programme was written in Fortran for an ICL 1901 computer with card input and line-printer output. The formulation used basically follows that of Talwani (unpublished paper) with a rearrangement of the formula (Nagy, 1964) to avoid singularities. The formula used in the programme is as follows:

$$\Delta g = 2G\rho \sum_{i=1}^{n} \frac{x_i z_{i+1} - x_{i+1} z_i}{\Delta x^2 + \Delta z^2} \left[\frac{1}{2} \Delta z \ln \left(\frac{x_{i+1}^2 + z_{i+1}^2}{x_i^2 + z_i^2} \right) + \Delta x \left\{ tg^{-1} \left(\frac{x_{i+1}}{z_{i+1}} \right) - tg^{-1} \left(\frac{x_i}{z_i} \right) \right\} \right]$$

where $\Delta x = x_{i+1} - x_i$ and $\Delta z = z_{i+1} - z_i$. x_i, z_i, x_{i+1}, z_{i+1} are the cartesian coordinates of successive vertices of the body in clockwise order (see Fig. 18); G is the Gravitation Constant and ρ is the density or density contrast of the body; and n is the number of body points for the body. Other notations used in the programme are: M, the total number of field points (points of measurement); FX(K), FZ(K), the x and z coordinates of the field points; L the total number of bodies; LNO, the body number; N, the total number of body points for each body; RHO, the density contrast in $g.cm^{-3}$ for each body; and X(I), Z(I), the coordinates of each body point for each body.

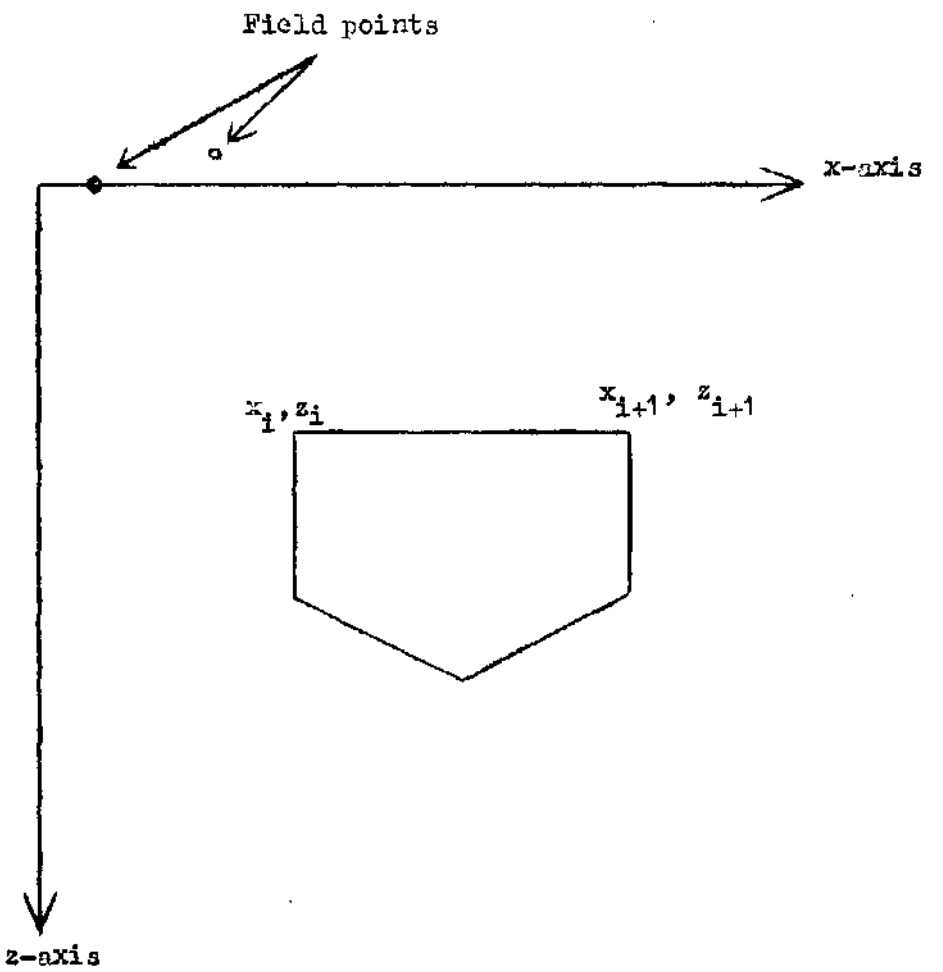


Fig.18 Illustration to Appendix II

The computer programme is as follows:

```
C       TWO DIMENSIONAL GRAVITY PROGRAMME

        DIMENSION FX (50), FZ(50), X(100), Z(100), TOT(50)
 21     FORMAT (I5, 3F10.3)
 22     FORMAT(6H      M=,I5)
 23     FORMAT(I5)
 24     FORMAT (6H     L=,I5)
  3     FORMAT (2F10.5)
  4     FORMAT (2I5, F10.3)
  5     FORMAT (//6H   LNO=I5, 6H  N=I5,10H   RHO=F10.3)
  6     FORMAT (/35H     K       FX(K)    FZ(K)  ANOMALY)
        READ(1,23) M
        WRITE (2,22) M
        READ(1,3) (FX(K), FZ(K), K=1,M)
        WRITE(2,3) (FX(K), FZ(K), K=1,M)
        READ(1,23)L
        WRITE(2,24)L
        DO 600 K=1,M
        TOT(K)=0
600     CONTINUE
 60     READ(1,4) LNO,N,RHO
        WRITE(2,5) LNO,N,RHO
        READ(1,3)(X(I),Z(I),I=1,N)
        WRITE(2,3)(X(I),Z(I),I=1,N)
        WRITE(2,6)
        CPI2=1.5707963
        DO   420  K=1,M
        S=0
        DO   50 I=1, (N-1)
        X1=X(I)-FX(K)
        Z1=Z(I)  -FZ(K)
        X2=X(I+1)-FX(K)
        Z2=Z(I+1)-FZ(K)
        C= X1*Z2-X2*Z1
        IF  (C)72, 71, 72
 72     DX=X(I+1)-X(I)
        DZ=Z(I+1)-Z(I)
        A=C/(DX*DX+DZ*DZ)
        ALN=(X2*X2+Z2*Z2)/(X1*Z1+Z1*Z1)
        IF(Z2)10,12,10
 10     ARC2=ATAN(X2/Z2)
 40     IF(Z1)100, 120, 100
100     ARC1=ATAN(X1/Z1)
400     ARCTAN=ARC2-ARC1
```

```
      DEL G=13.34*RHO*A*(.5*DZ*ALOG(ALN)+DX*ARCTAN)
540   S=S+DEL G
      GO TO 50
 71   DEL G=0
      GO TO 540
 12   IF(X2)47,48,48
 47   ARC2=-CPI2
      GO TO 40
 48   ARC2=CPI2
      GO TO 40
120   IF(X1)57,58,58
 57   ARC1=-CPI2
      GO TO 400
 58   ARC1=CPI2
      GO TO 400
 50   CONTINUE
      TOT(K)=TOT(K)+S
      WRITE(2,21) K,FX(K),FZ(K),S
420   CONTINUE
      IF(L-LNO)430,430,60
430   WRITE(2,6)
      DO 333 K=1,M
      WRITE(2,21)K,FX(K),FZ(K),TOT(K)
333   CONTINUE
      STOP
      END
```