A GRAVITY PROFILE OF THE LOWER BENUE TROUGH OF NIGERIA

By

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ABSTRACT

Gravity measurements were made along a roughly east-west profile across the lower Benue trough, with the main objectives of investigating the nature and configuration of the basement beneath the trough and determining the thickness of the sedimentary cover rocks.

187 gravity stations were established at 2-4km intervals and standard corrections were applied to the observed gravity values. A Bouguer gravity map of the whole Benue trough is compiled from the results of these measurements and data obtained from previous works. The map shows that the positive anomaly along the axis of the trough is a most prominent regional feature that extends over the whole length of the trough. The abrupt truncation of the positive anomalies along a NNE-SSE line may represent the Cretaceous continental margin.

The axial positive is ascribed to the doming of the basement underlying relatively dense Albian Shales and their associated intermediate to basic intrusives along the trough axis as a result of tectonic processes. "Growth" of the positive anomaly towards the South is attributed to the

basement being at a shallower depth in the lower Benue than in the upper Benue trough and to the probability that oceanic crust underlies the sediments at the south-western end of the trough.

The negative anomalies are due to thick sedimentary sequences which fill the flanks of the trough. The sediments are estimated to have a maximum thickness of 4.25km in the surveyed area of the lower Benue trough.

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CHAPTER I

INTRODUCTION

General Statement

The Nigeria's Benue Trough, located at the Gulf of Guinea re-entrant on the West Coast of Africa (Fig. 1) comprises a linear sedimentary basin which is filled by deformed volcanic and Cretaceous rocks whose ages range from middle Albian to Maastrichtian.

The trough is bounded on the east and west by granite and gneisses of Precambrian age. The study of the tectonic evolution of the Benue rift has, of late, attracted considerable attention especially with regards to the continental separation of South America from Africa and the opening of the South Atlantic Ocean during early Cretaceous times. (Fig. 1 inset).

For the purpose of this project, the Lower Benue Trough is considered as that area of the Benue depression which is bounded by longitudes $6^{\circ}.30'E$, $9^{\circ}.00'E$; and latitudes $6^{\circ}.00'N$, $7^{\circ}.30'N$ in the 1:500,000 map of Nigeria.

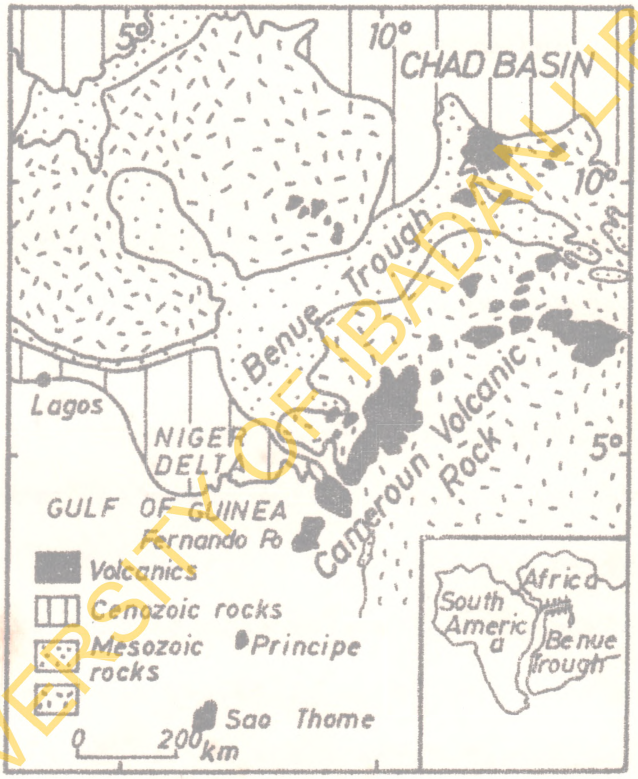

Fig. 1: Location of the Benue Trough and the Cameroun volcanic line. Inset: the Benue Trough as one of a Cretaceous (rrr) triple junction.

Economic interest in the lower Benue Trough is centred around the lead-zinc mineralization and salt deposits that are almost all localised in the older Cretaceous sedimentary rocks in the trough. Despite the considerable work on the general tectonic setting and geology of the lower Benue trough, to the writer's knowledge, no detailed geophysical studies of this area have been undertaken.

Previous Geophysical Work

Geophysical work in the Benue trough has been minimal. Apart from the limited number of gravity surveys, the other geophysical work was an aero-electromagnetic measurement across known lead-zinc lodes conducted in 1965 by the United Nations (under its technical aid programme) to study the electromagnetic response of the ore-bodies. Partly, due to the flight height of about 400ft and partly due to the presence of saline water which tended to saturate the shale host rock, it was difficult to differentiate the sulphide ore bodies from the conductive background (Norris, 1966). Orajaka and Nwachukwu (1968) undertook a ground follow up using electromagnetic and geochemical methods over a proven lode to test the suitability of these methods. From the result of the measurements, Orajaka and Nwachukwu suggested that despite the conductive background of the lead-zinc ores it is still possible to outline the ore bodies using both electromagnetic and geochemical methods.

Another geophysical work carried out in the Benue valley was a magnetometer survey across part of the Cretaceous - basement boundary near Shendam (Cole, 1958), and some magnetometer traverses across the basin at rather widely spaced station intervals (Cratchley, 1960).

The first recorded gravity work in the Benue valley was that undertaken by the Shell B.P. Development Company of Nigeria in 1948 and 1953 over the area of the Niger Delta and Oturkpo as part of its programme of exploration for oil. The instruments used in this survey were North America Gravimeters. Hospers (1965) used the data collected from the Shell B.P. survey to interprete the gravity field of the present Niger Delta and parts of the lower Benue trough. In 1960 and 1965 Cratchley and Jones carried out gravity measurements using a World-Wide gravimeter in the north-eastern part of the valley to determine whether or not the Benue basin was a rift valley. From their investigation, Cratchley and Jones concluded that the trough is a rift valley of Cretaceous age. In 1973, Ajakaiye and Burke published a compiled Bouguer Gravity Map of part of Nigeria from four previous networks

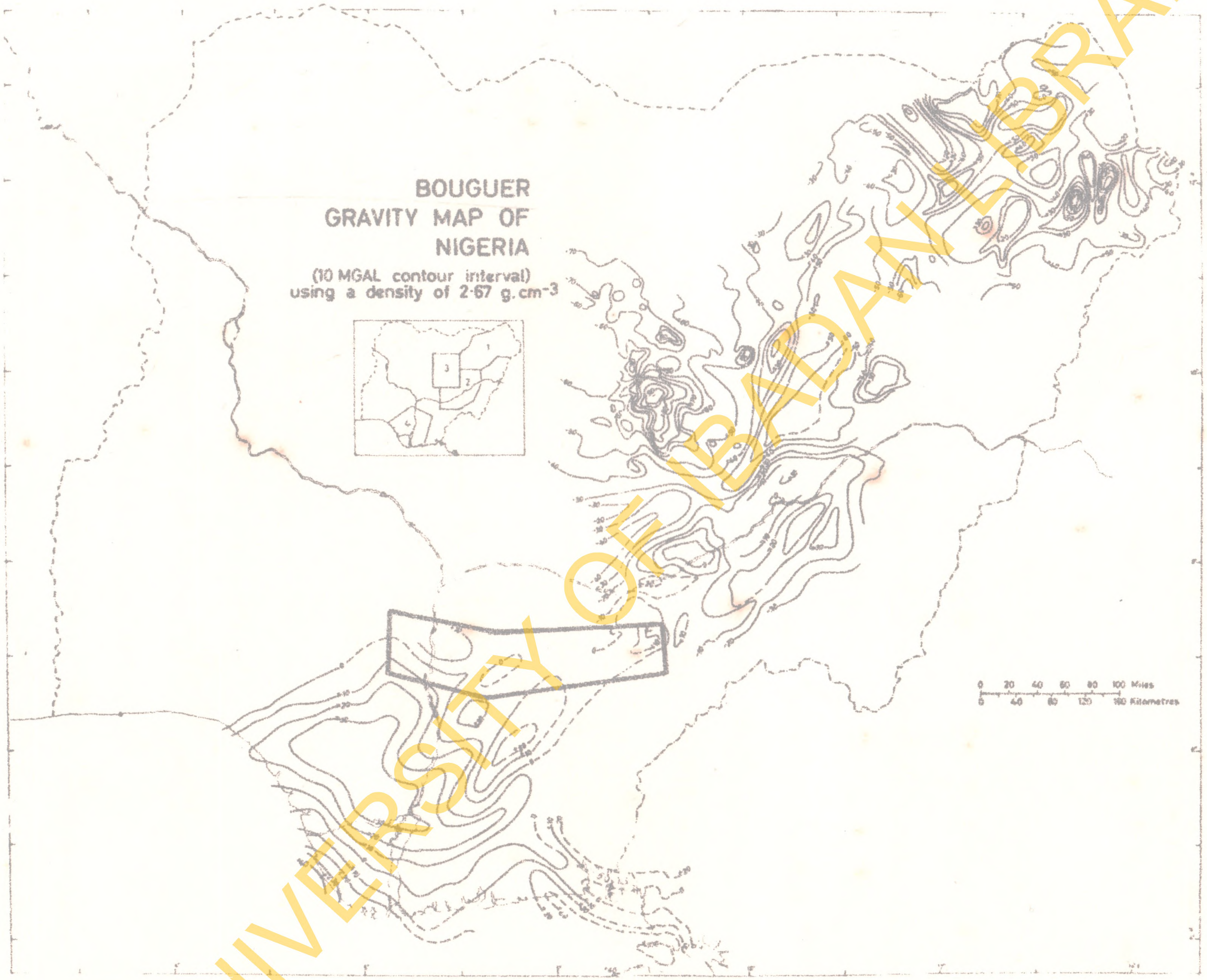

Fig. 2: Bouguer map of Nigeria showing the surveyed area (after Ajakaiye and Burke, 1973)

covering about 40% of the area of Nigeria. This map has a blank between latitudes 6° 30'N and 7° 30'N which is our present area of interest in the Benue Trough (Fig. 2).

Objectives and Scope of Project

With the recent development of contemporary ideas of plate tectonics, the evolution and geology of rift systems, especially failed rifts (aulacogen) that developed along trilete plate junctions, have been of considerable interest (Olade, 1975; Grant 1971; Nwachukwu 1972). It is hoped that from thorough geophysical studies of the Benue Trough, its evolution, geology, structure and tectonics will be better understood.

The present gravity work is aimed at

(a) investigating the configuration of the basement underlying the trough;

(b) determining the thickness of the sedimentary rocks along the present gravity profile;

(c) attempting to fill up the blank in the Bouguer Anomaly Map of the Benue trough (Fig. 2).

The present survey involved gravity measurements along a major roughly east-west trending profile in an area which

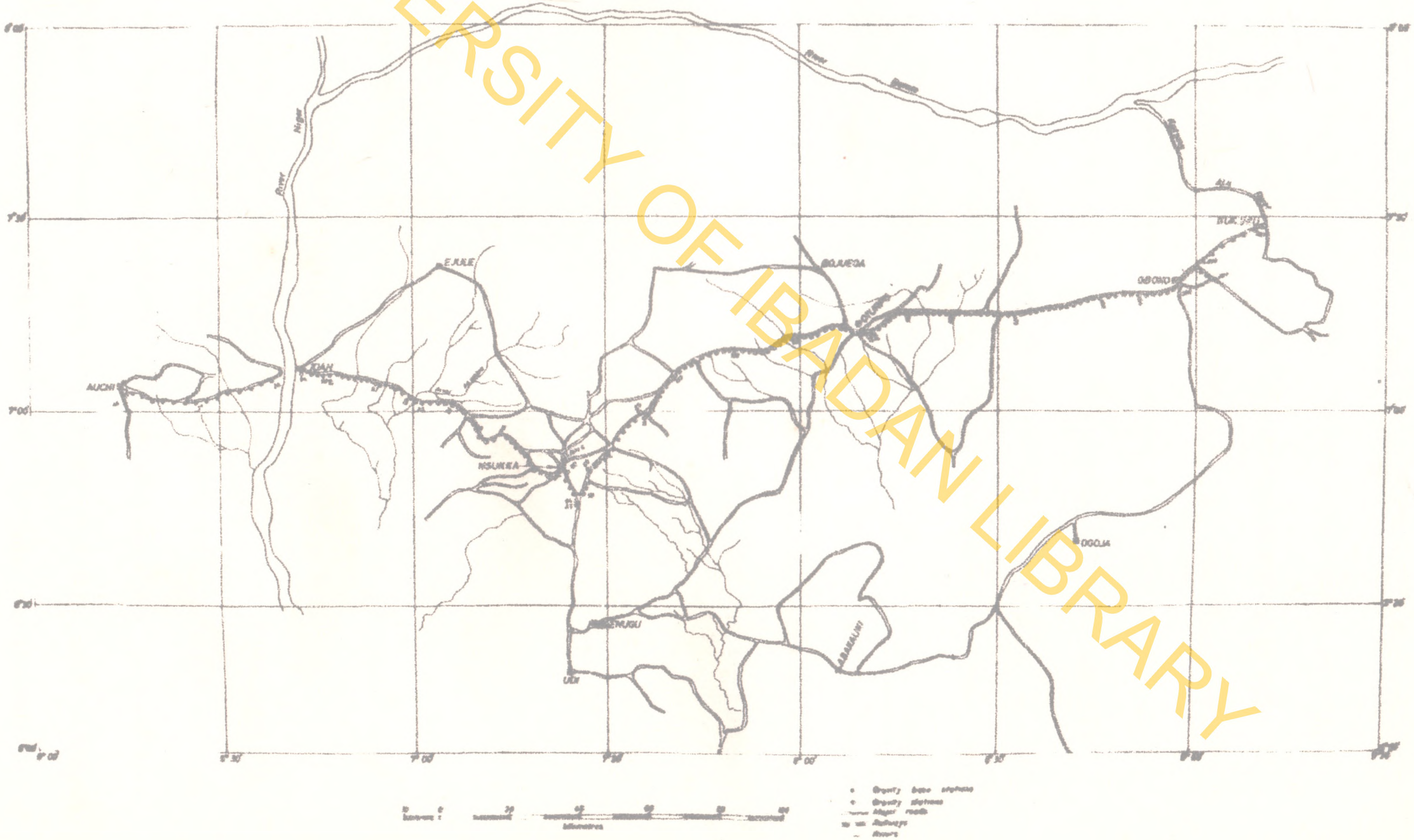

Fig 3 LOCATION MAP OF THE TRAVERSED AREA

lies approximately between longitudes $6^{o}E$ to $9^{o}E$ and latitudes $6^{o}N$ to $8^{o}N$ (Fig. 3). This particular profile was chosen in order to provide the necessary gravity information needed to fill up the gap in the Bouguer anomaly map which is one of the aims of this project. The traversed areas are easily accessible by motorable roads from various parts of the country (Fig. 3).

187 gravity stations were established at 2-4km interval. The densities of available rock samples were accurately determined and checked with the values obtained by earlier workers. Necessary non-isostatic corrections were applied to all the gravity data and the interpretation was based on a two dimensional scheme.

Physiography

The study area is composed of the Benue plains; the Enugu escarpments and the Udi plateau (Fig. 4).

The Benue plain is a long low-lying tract bounded in the south by the Okigwi ridge and Afikpo hills, and in the west by the Enugu escarpment. The plain can be traced to the north and northeast along the Benue valley, and extends westwards to the area around Lokoja. In the northernmost

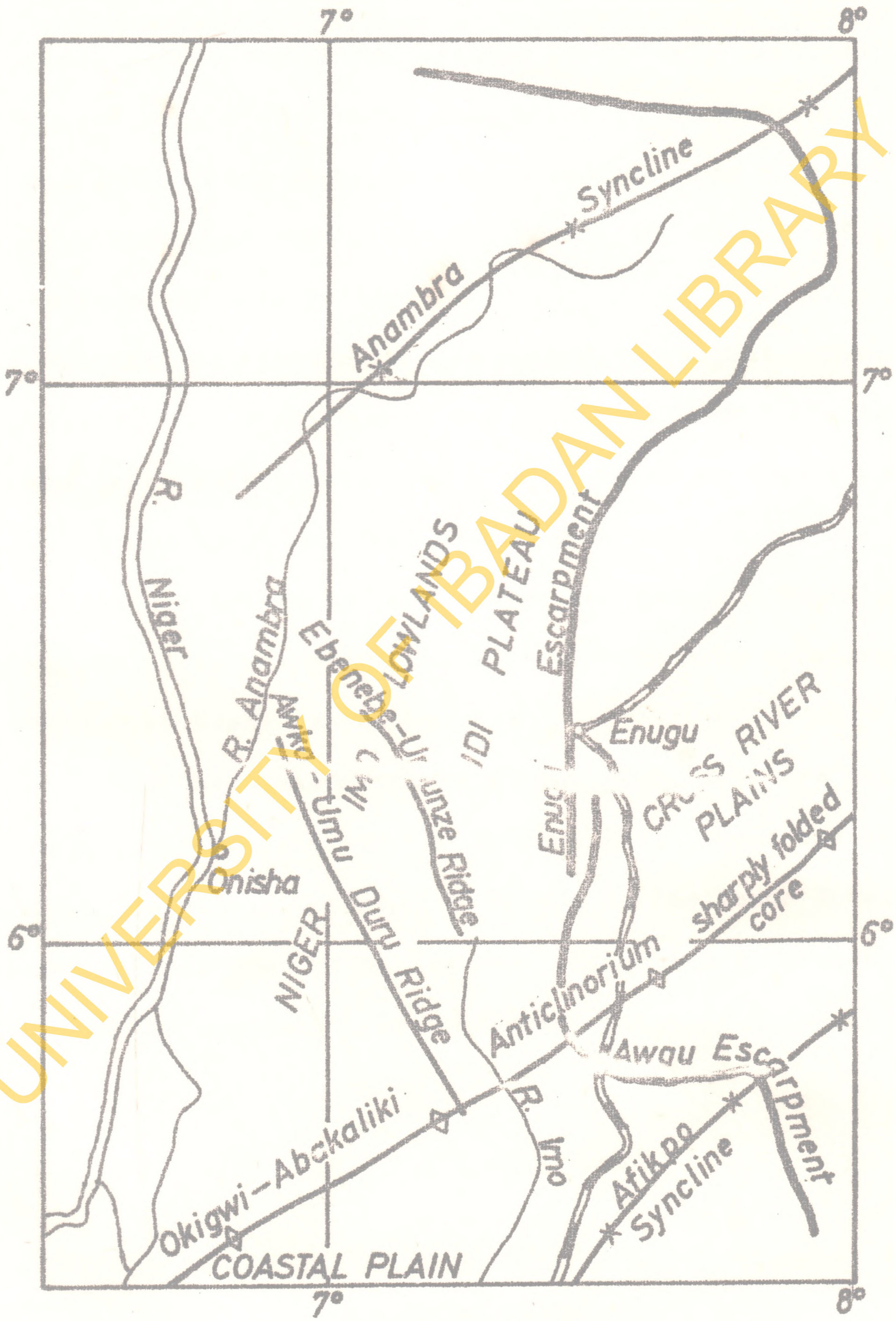

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Fig. 4: Part of Southern Nigeria showing relief forms and principal fold axes

portion there are many steep-sided sandstone hills and ridges; otherwise there are few topographic features of note. West of the Enugu escarpment is the resistant Awgu sandstone ridge which in some places reaches a height of 450m above sea level. To the north, the escarpment is much indented by deep valleys.

The Udi Plateau is also marked by several broad, dry valleys that stretch west and southwest from the crest of the Enugu escarpment. The plateau rises to nearly 600m above sea level and then slopes west towards the Anambra lowlands. In Nsukka area, there are numerous flat laterite-capped hills which owe their preservation to relatively resistant basal sandstone.

The three main reviers in the study area are the Niger, the Anambra and the Katsina Ala. There are small relic patches and strips of forest in the Benue depression, mainly following water courses. Otherwise the vegetation is of the savannah type consisting of small to medium trees.

CHAPTER II

GEOLOGIC SETTING OF THE LOWER BENUE TROUGH

REGIONAL GEOLOGY

The graben forms an abandoned arm of a Cretaceous trilete (rrr) rift system (including the South Atlantic and Gulf of Guinea) that failed to open into a proto-ocean and was filled with sediments (Burke and Whiteman, 1971). The trough is bounded on both sides by granite and gneisses of probable Precambrian age which make up the crystalline basement. The regional geology of the Benue trough has recently been summaried by Olade (1975).

Stratigraphic Evolution

Uzuakpunwa (1974) has shown that the oldest rocks within the Lower Benue depression are Aptian mafic volcanics and volcaniclastic rocks (Abakaliki Pyroclastics of Okezie, 1965) that underlie and interfinger with a thick transgressive sequence of marine argillites limestones and evaporites (Nwachukwu, 1972; Orajaka 1972a) of the Albian Asu River Group (Reyment, 1965). These rocks grade northward into shallow marine platform carbonates of the Middle Benue (Arufu and Gboko Formations) (Reyment, 1965). An early episode of deformation during the Cenomanian generated a marine regression that confined carbonate sedimentation (Odukpani Formation) only to the Calabar flank. (Nwachukwu 1972, 1975).

A second sedimentary cycle (Murat, 1972) was initiated by an extensive Turonian regression which deposited a thick unconformable sequence of argillites and carbonates of the Ezeaku Formation. Lateral equivalents of this formation are, an unnamed succession of shales and carbonates in the Middle Benue. (Burke et al 1972). A few remnants of sediments belonging to this cycle include shales of the Awgu Formation overlying the Ezeaku Formation which is mapped in the Abakaliki area. Syn- and post- deformational sediments include sandstones and shales of Nkporo, Mamu, and Nsukka Formation in the southern part of the depression (Reyment, 1965).

Structural History

At least two episodes of deformation have been recognised in the Benue depression: (1) an earlier Cenomanian episode which affected only Albian sediments; and (2) a later Senonian phase which affected all pre-Santonian sediments within the depression. Structural features associated with the latter phase are well preserved, and consequently are well documented (Farrington, 1952; Reyment 1965; Short and Stauble, 1967; Wright, 1968). In contrast, the Cenomanian episode has been obscured by later sedimentary and deformational processes. However, Nwachukwu (1972; 1975) presented evidence in support of the Cenomanian episode. This includes the presence of an unconformity between Albian and Turonian sediments (Ogbukagu, 1974), restriction of Cenomanian sediments to the Calabar flank; greater relative intensity and polyphase deformation of Albian rocks; structural features of Pb-Zn mineralization; and lastly ammonite biostratigraphy.

The Senonian deformation was characterized by compressive folding, generally along a NE-SW direction, parallel to the trough margine. Folds are unique, comprising aggregates of small axes that commonly occur en echelon (Olade, 1975). Faults are generally normal or slightly reverse. Closely associated with the Senonian

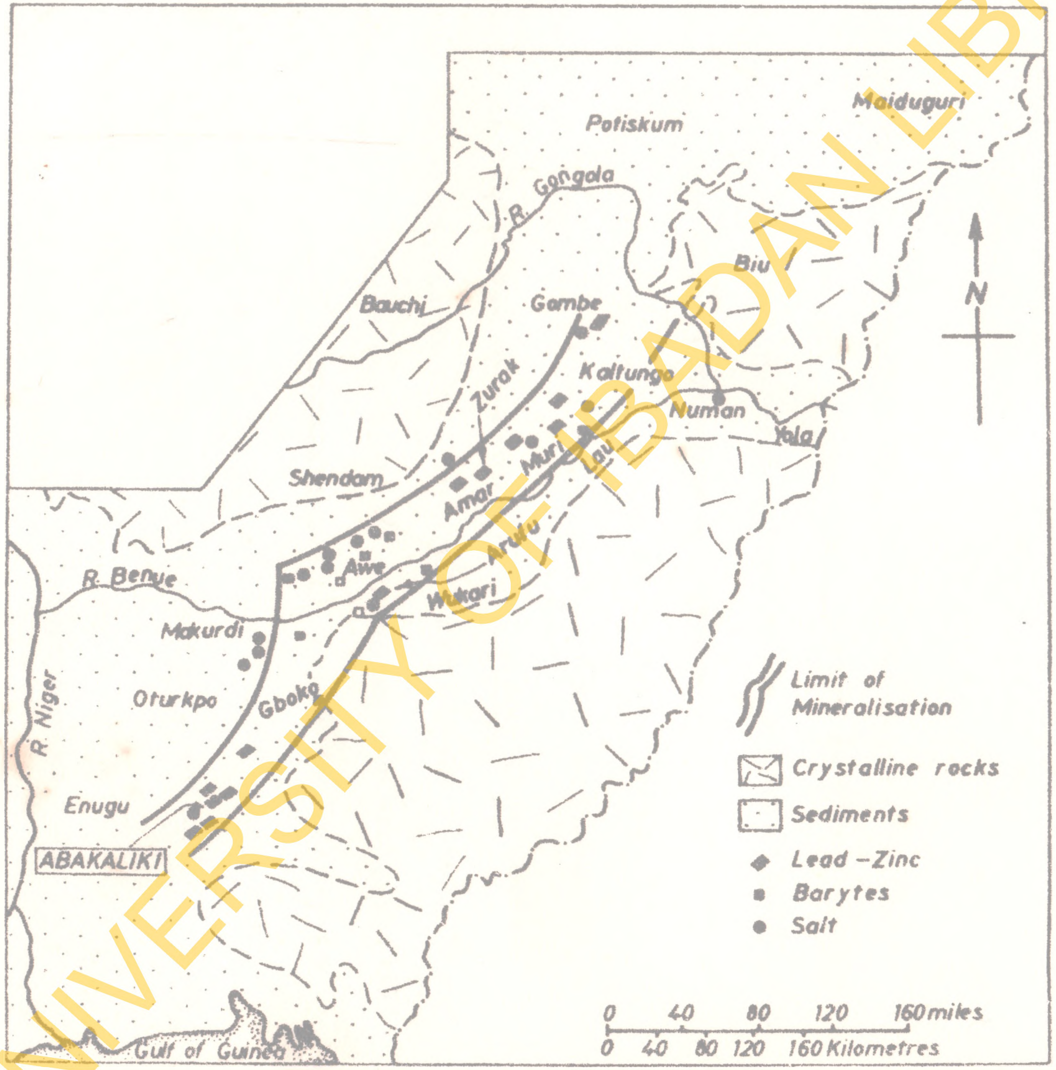

Fig. 5: Belt of mineralization in the Benue Trough

deformation were igneous activities such as mafic intrusions and eruption of alkaline or cal-alkaline lavas and tuffs (Murat, 1972; Wright, 1968).

Mineralization, Intrusion and Volcanism

A notable feature of the Benue trough is the occurrence of lead-zinc mineralization in a narrow belt 80km wide and about 600km long extending from southwest of Abakaliki to beyond Muri in the north east. (Fig. 5). The Pb-Zn deposits occur exclusively within sedimentary rocks of Albian age (Orajaka, 1972) ranging from shales near Abakaliki, carbonates in Arufu and Akwana lodes, to sandstones at Zurak and Gombe (Rockingham and Mackay, 1933; Mackay 1946, 1950). Mineralization occurs dominantly as open-space fillings within en echelon tensional steeply dipping fracture systems, commonly astride anticlinal axes (Farrington, 1952).

There are occurrences of salt springs at various localities in the Asu River Group sediments. Nwachukwu (1972) suggested that these salt springs have salinities which range from 5% to 10%. The igneous rocks present in the Cretaceous sediments are in the form of small dykes, sills and irregular mafic intrusions. They occur principally in the Asu River Group, along the axis of the anticlinorium. The larger basic masses occasionally produce contact metamorphism in the sediments. Southwest of Gboko, other larger masses are known to be close to the ground surface. In the Abakaliki area, small mafic intrusions are abundant. Most of them occur in the folded sediments, though some are present in their unfolded extension around Oturkpo. There is evidence of widespread but sporadic volcanic activity throughout the Cretaceous; but its distribution only infrequently coincides with areas of igneous activity.

GEOLOGY OF THE SURVEYED AREA

Generally, the surveyed area has a flat to gently undulating topography, rising to a maximum of 500m, about 20km east of Nsukka. Vegetation is of the savannah type except for some strips of forest mainly along the river valleys.

The geology of the surveyed area can be described under two broad headings: Precambrian basement complex,

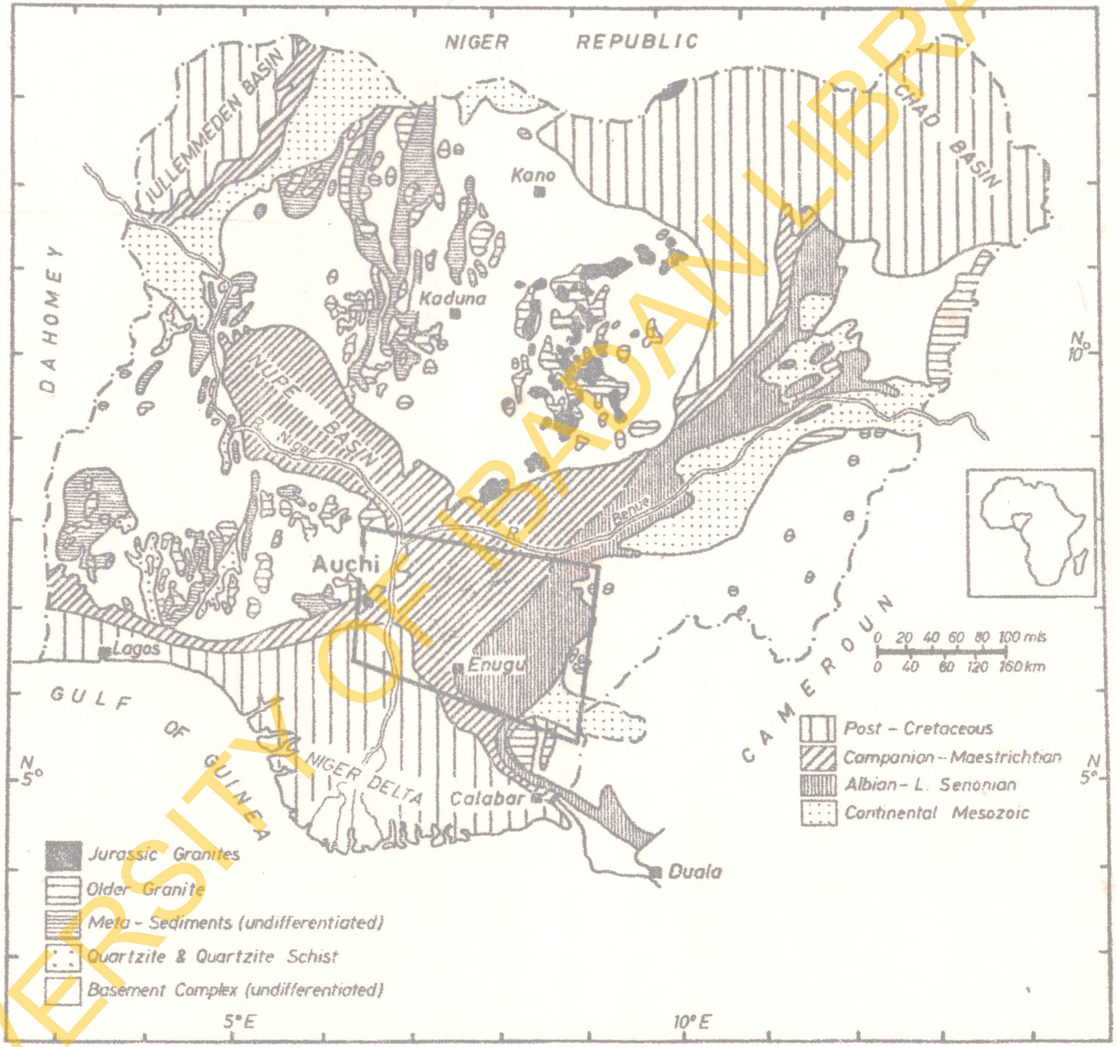

Fig. 6: Generalized geological map of Nigeria showing the Lower Benue Trough

and the Cretaceous sedimentary rocks (Fig. 6). Outcrops are generally meagre to scarce except in Nsukka and Gboko areas where they are moderately common.

Basement Complex

In the surveyed area, rocks of the basement complex crop out only in the area around Gboko. These are mainly the granite gneiss and migmatite groups with a few isolated bodies of the Older Granite suite. Generally, the granite gneiss and migmatite groups show strong foliation, in which quartzo-feldspathic and mafic minerals form alternating bands. The Older Granite rocks are easily distinguished because of the presence of large microcline phenocrysts in a fine to medium grained matrix. Other constituent minerals are plagioclase, quartz, hornblende and biotite.

Cretaceous Sedimentary Rocks

The oldest sedimentary rocks within the trough are of Albian age and consist of thick well-stratified beds of shales and siltstones with subordinate sandstones.

In places the shale and siltstone sequence is intercalated with medium-grained sandstones and lenses of grey limestone The sequence is generally known as the Asu River Group which unconformably overlies the basement complex. Outcrops of the Asu River Group are observed along a narrow belt that runsfrom Abakaliki to the south of Gboko where the formation consists of a thick series of fissile shales (commonly carbonaceous) with thin beds and lenses of limestone.

Overlying the Asu River Group is the Ezeaku Formation which consists of flaggy calcareous shale and siltstone. In the surveyed area, the formation crops out along Oturkpo - Aliade road where the calcareous shales grade into thick sandstone bodies. Further southwards the Ezeaku Formation crops out as bluish grey, well bedded shales with intercalations of fine grained calcareous sandstone.

East of the Enugu escarpment, the Enugu shales are found underlying the plains. South of Enugu the shales are greyish to dark grey mudstones with occasional beds of sandstone. To the northwest of Enugu the shales are poorly exposed and gradually replaced by thick sandstone beds.

Overlying the Enugu shale is the Ajali-sandstone, which is medium to fine grained white sandstone and silt-sone with intercalated mudstone and shale. The sandstone body crops out north of Oji River where it is found in the higher slopes of the Enugu escarpment.

Stretching from Nsukka through Idah to Auchi is the fine grained well bedded sandstone of the Nsukka formation, which occasionally alternates with fine textured dark grey clay ironstone as is the oase in Ugwuaka 24km northwest of Nsukka, (along Idah road, Fig. 3).

The igneous rocks present in the surveyed area are in the form of small dykes and sills which occur principally in the Albian Asu River Group. A few doleritic rocks crop out along river channels southwest of Gboko and around Oturkpo. The size and attitude of the doleritic rocks are difficult to measure because of some sedimentary overburden and vegetation cover.

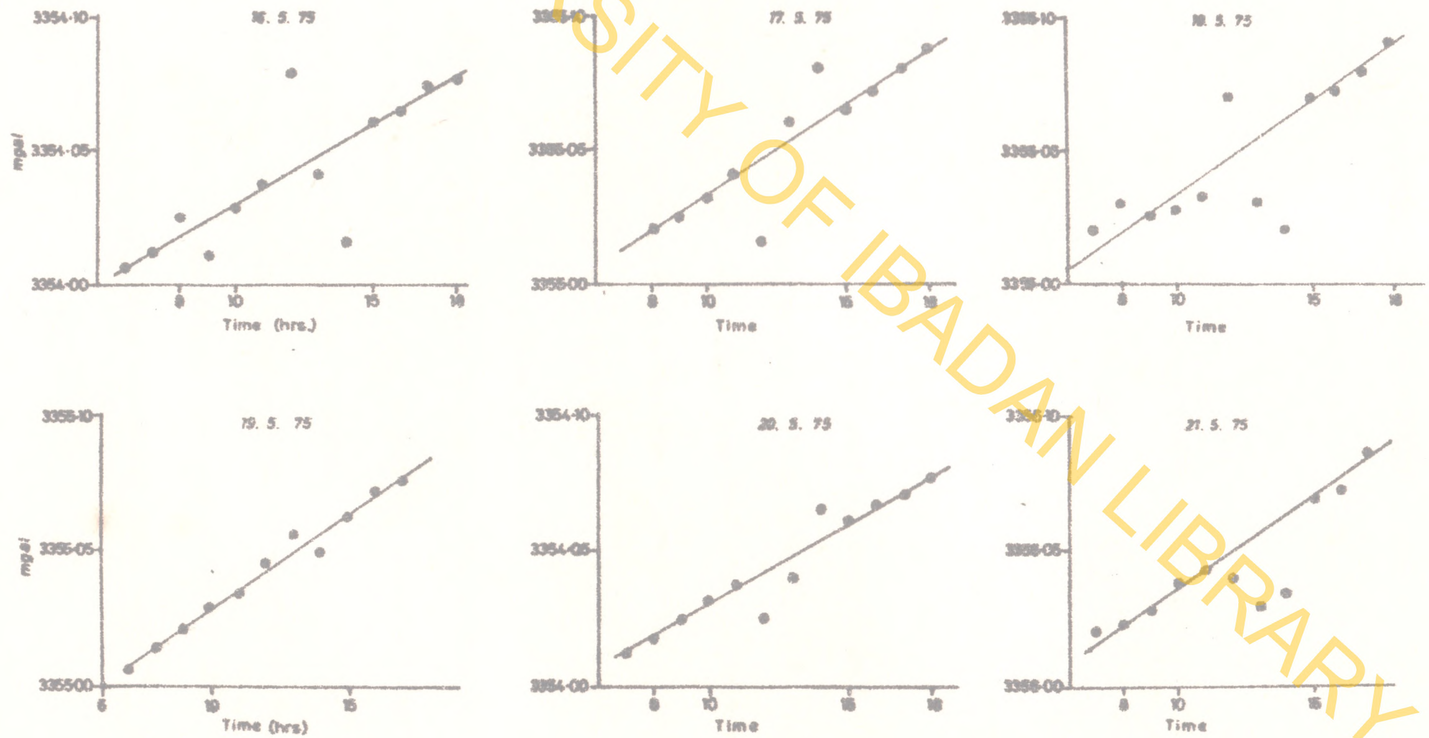

Fig. 7: Plots of the Gravimeter Drift in the laboratory

CHAPTER III

GRAVITY MEASUREMENTS

Gravimeter

We used the Canadian Scintrax C-G2 gravimeter which belongs to the Department of Geology, University of Ibadan. It is measurable to the order of 0.01 milligals and has an instrumental constant of 0.10071mgal/div. The instrumental constant was checked by methods described by the manufacturer before commencing the survey and found unchanged from the original value. The gravimeter was set up in the laboratory for two weeks before the survey in order to check the instrumental drift. From the observation, the drift was found to vary linearly with time, and is normally less than 0.005mg/hr. (Fig. 7).

Field experience has shown that the instrumental reading can be affected by a few physical conditions for which adequate precautions were taken:

(i) About mid-day, usually between 12.30 and 2.00 p.m. when the temperature is maximum, the reading of the instrument changes rapidly and measurements were stopped during this period.

(ii) The spring system of the instrument were allowed time, at least, 10 minutes to stabilize after

(a) the big scale dial is changed; or

(b) transporting the instrument on a rough road;

<u>Altimeter</u>

Out of the 92 known heights in the surveyed area supplied by the Federal Surveys Department of Nigeria, only 18 stations of known heights were found in the field because road reconstruction in parts of the area has led to the removal of many of the bench marks. Heights of other stations were established by using the two American Paulin system altimeters of our Geology Department in connecting the stations of known heights. The readings of the altimeters were taken simultaneously with gravimeter station. The height above the ground of the tripod base usually about 0.3m, on which the gravimeter was set up was always added to the altimeter reading.

The dial of the altimeter is calibrated for a temperature of 50°F at the factory, that is, it will measure true differences in altitude at this mean air temperature (assuming no change in barometric pressure due to factors other than change in altitude). When the average of the two temperature readings at two successive stations is above or below 50°F, a correction must be applied to compensate for the change in pressure of the air column as a result of temperature change.

The temperature correction formula for the altimeter is derived here in a little different way from that in the manual given by the manufacturer. Consider a column of air from a height H_1 to H_2, the height of the column being H (Fig. 8).

Fig. 8: Air Column for deriving the Temperature Correction Formula.

From the fundamental equation for a simple gas,

$$DT = K \quad .. \quad .. \quad .. \quad .. \quad (3.1)$$

in which D is the density of the air column, T its absolute temperature, and K a constant.

$$\frac{\delta D}{D} = -\frac{\delta T}{T} \quad .. \quad .. \quad .. \quad .. \quad (3.2)$$

Since D is proportional to the pressure P and in turn to the observed height H_{obs}, $D = C\,H_{obs}$, C being a constant. If D has a change δD, H has a change δH, $D+\delta D = C(H+\delta H)$ or $\delta D = C\delta H$. Dividing by $D = CH$

$$\frac{\delta D}{D} = \frac{\delta H}{H} \quad .. \quad .. \quad .. \quad .. \quad (3.3)$$

From eqns (3.2) and (3.3) $\frac{\delta H}{H} = -\frac{\delta T}{T}$ .. .. (3.4)

The temperature T of the air column, is taken as the mean temperature between T_1 and T_2, i.e. $T = \frac{T_1 + T_2}{2}$, where T_1 and T_2 are the temperatures at H_1 and H_2 respectively. If the observed temperature decreases by δT from the normal temperature T, which is taken as $50^\circ F$ or $460+50 = 510^\circ$ Absolute Temperature, the height difference H_2-H_1 may be observed falsely as $H+\delta H$; here H is the correct height difference and δH is the correction to be subtracted from the falsely observed height due to the decrease of temperature. When $\delta T = 1^\circ F$, $\frac{\delta T}{T} = 0.00196$.

This holds for a simple gas. For air, the constant is determined experimentally to be 0.00204. Therefore from eqn (3.4)

$$H = -\left(\frac{T_1 + T_2}{2} - 50\right) 0.00204.H \quad .. \quad (3.5)$$

where observed height is used in place of H.

Error in using the American Paulin system altimeters is introduced from

(i) the graduation which may give a reading error of ± 0.3m.

(ii) as is shown in equation (3.5) the greater the difference in elevation (H) between the known height and the height we wish to determine the greater will the correction δH, so the error arising from the correction becomes larger. In this survey, however, the maximum difference (H) is less than 100m; the error introduced by using the altimeter may not exceed ±0.3m.

Method of Measurement

During May-June 1975, gravity measurements were made at 167 stations, of which 16 stations on bench marks were selected as the local base stations. The gravimeter was transported in a car whose speedometer was also used in fixing the station interval.

The methods of observation used in the field involved (i) at first taking the gravimeter reading at a base A (ii) then readings were taken at 2km interval until the next base B was reached. Normally the latter base was established at about a distance of 20km from the previous one, thus allowing for about 9 gravity stations between two bases. (iii) The instrumental drift was calculated from the two readings at two bases A and B. After the reading at base B, we returned directly to base A to repeat the reading at A in order to check the instrumental drift.

It took an average of two hours between the first and repeat readings at a base. Usually the repeat reading never differed from the initial reading by more than 0.07 milligal.

All the gravity measurements were taken along motorable roads that permitted the car to travel at normal speed without shaking violently the gravimeter. Throughout the survey, the gravimeter was transported in its carrying-case which was mounted on a foam rubber pad on the triangular base provided for avoiding shock. Moreover, to prevent the instrument from tilting, it was hand-carried when being transported in the car. The time of reading and the temperature are always recorded.

The first gravity reading was taken at station LBM 6 in Nsukka (Fig. 3). The subsequent readings were taken westwards along the Nsukka-Idah road. Measurement on this road was terminated at station number 26 by the bank of the Anambra River because there was no ferry service then at the river. We had to return to LBM 6 to take measurements eastwards to Gboko. The rest of the Nsukka-Idah stretch was measured two weeks later, when the Anambra River was crossed by using a barge. Since the river was calm the instrument was not upset during this crossing. At the end of the May-June (1975) measurements it was observed from calculations that the drift increased as we moved away from the original station at Nsukka.

In January 1976, it was decided to extend the profile in the west from Idah to Auchi and in the east from Gboko to Buruku. This was intended to enable us to take measurements on or near the basement complex. In all, 20 new stations were established at 4km interval. Apart from establishing these new stations the primary objectives of the January 1976 project were:

(i) to connect the gravity readings to the Shell B.P. absolute gravity station (BJ 1811) at Boju Ega (24km northwest of Oturkpo);

(ii) to repeat measurements at 16 selected base stations along the entire profile.

Measurements were taken at base station A, then at B 20km away, repeated at A to check the instrumental drift, then the next measurement was made at base C, and so on. Since the time interval for a repeat reading at a base station was on the average of 1 hour, drifts were very small - about 0.01mgal/hr and were mostly eliminated together with the tidal effect.

The River Niger which is about 2km wide along our traverse, separates station No. 30 (Agenebode) from station No. 84 (Idah). In order to tie No. 30 to No. 84, it took two hours to cross the river by a ferry. Usual precautionary methods were taken to insure that the gravimeter was not violently shaken during the journey across the river.

Absolute Value of Gravity

The gravity values in this survey are tied to the absolute gravity base station at Boju Ega (BJ.1811) which was originally established by the Shell B.P (1948, 1953) via the (O.R.S.T.O.M) base at Lagos. However, Cratchley and Jones (1965) applied a correction factor of -4.3mgal to the published O.R.S.T.O.M. values and thereby obtained a corrected value of 978.0864mgal, which is 4.3mgal less than the Shell BP value for Boju Ega. Accordingly, our values should be consistently less than Shell BP values by 4.3mgal.

In order to tie in the absolute gravity station at Boju Ega with our gravity station No. 100 at Oturkpo two return measurements were made; the result of the measurements is given in Table 1. Gravity station No. 100 is established on the bench mark 46/69 which is on the right side of the rail line, 200m to the Oturkpo railway station, and is near mile post 232 along Oturkpo-Makurdi road. Station 100 was therefore taken as the fundamental gravity station for our survey. For the calculation of the absolute gravity value at this station the method of least squares was used for determining the instrumental drift which was found to be 0.21mgal/hr. The absolute value of 978.08377 gal obtained at station 932 Oturkpo by Cratchley and Jones (1965) is comparable to our value of 978.08361. Cratchley and Jones probably established their station on any one of the three bench marks located in Oturkpo, (BM 46!67; BM 46!70; SBM Oturkpo) but which we could not trace in the field.

Rock Densities

Extensive sampling of rocks in the surveyed area for density measurements was limited by the scarcity of outcrops. When the rocks crop out densities often varied even within the same rock type. This variation in density has been attributed to the effects of weathering on the rock bodies. The same rock body will be affected to various degrees by weathering depending on the physical conditions of the environment. Even seemingly fresh samples have varying porosities which have resulted from differential weathering of the same rock type.

Another factor that affects the density of the sedimentary rocks is the "facies changes" observed in the lithologies. Thus, it is observed that an outcrop of shale of a particular density changes to sandy shale of a different density within a few metres.

Since it is known that the rock formations are gently dipping, it is possible that a rock cropping out on the surface may not have the same lithologic features a few metres deeper in the ground, e.g. sandstone outcrop of some particular density may become shaly and denser at depth. It is therefore noted that the densities of surface samples of sedimentary rocks may not necessarily be the true densities of the rock type. Moreover, if all the possible densities from one lithology to another are considered, the resultant Bouguer anomalies will be too complicated to be interpreted. For the reasons outlined above, and considering that the present project is a regional survey, it is more convenient to take the average value of the densities of sedimentary rocks.

From hand specimens and core samples Cratchley and Jones (1965) calculated the following densities for sedimentary rocks in the Benue valley:

Albian shale	$2.65gcm^{-3}$
Cenomanian shale	2.48 "
Turonian-Senonian shale	2.53 "
Turonian-Senonian sandstone	2.45 "

The mean $2.53 \pm 0.12gcm^{-3}$ has been adopted for the density of the sedimentary rocks in our surveyed area. In adopting this mean density it is noted that since shale densities increase with depth owing to compaction, a maximum value of $2.65gcm^{-3}$ is reasonable for Albian shales, which are the oldest rocks in the trough. Despite the high density of the Albian shales the mean density of $2.53gcm^{-3}$ is still acceptable because the high density shales occupy only a very narrow belt in our surveyed area. This mean density was checked in our laboratory with samples collected at

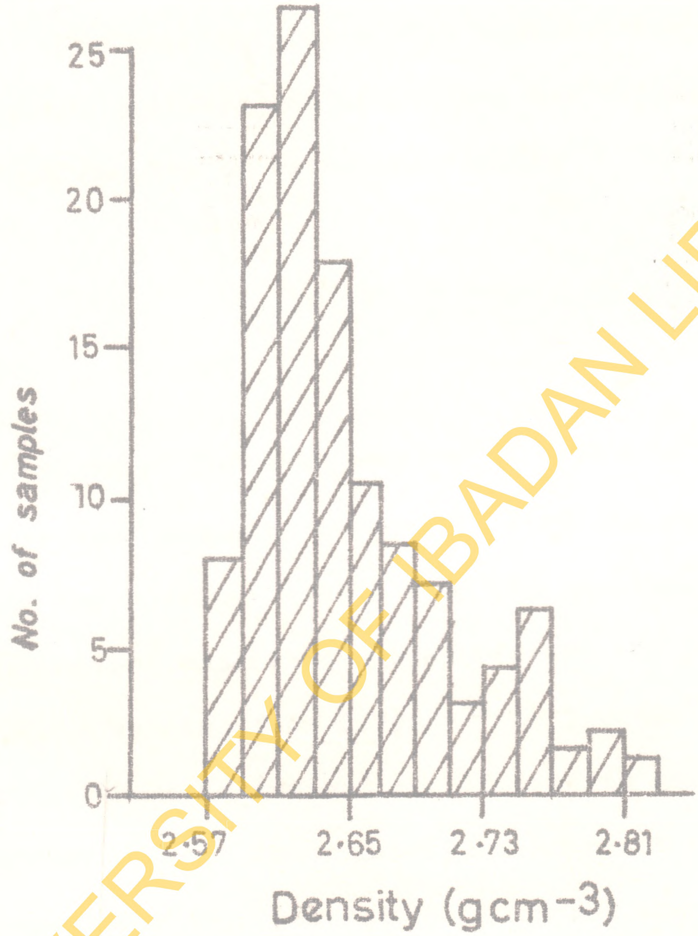

Fig. 9(a): Histogram of density variation in the basement rocks. mean density = 2·70 ± 0·05 g cm^{-3}

several different localities around our traverse, the result obtained being $2.50 gcm^{-3}$.

The mean density of the basement complex comprising of granite gneisses and migmatites was easily obtained from fresh samples by using the formula

$$\frac{\text{Weight of Sample in air}}{\text{Weight in air - weight in water}}$$

(Fig. 9a). The mean density of $2.70 \pm 0.05 gcm^{-3}$ which we have used compares favourably with the value calculated by Ojo and Ajakaiye (1975) from 143 samples. The igneous intrusions described around Oturkpo and Gboko have density values varying from $2.75 gcm^{-3}$ to $3.00 gcm^{-3}$ (Fig. 9b). Since these intrusions are limited in quantity in our surveyed area, their densities have not been considered separately from that of the basement complex.

Reduction of the Observed Gravity

All the necessary corrections were applied to the observedgravity to obtain the free-air anomaly and the Bouguer anomaly.

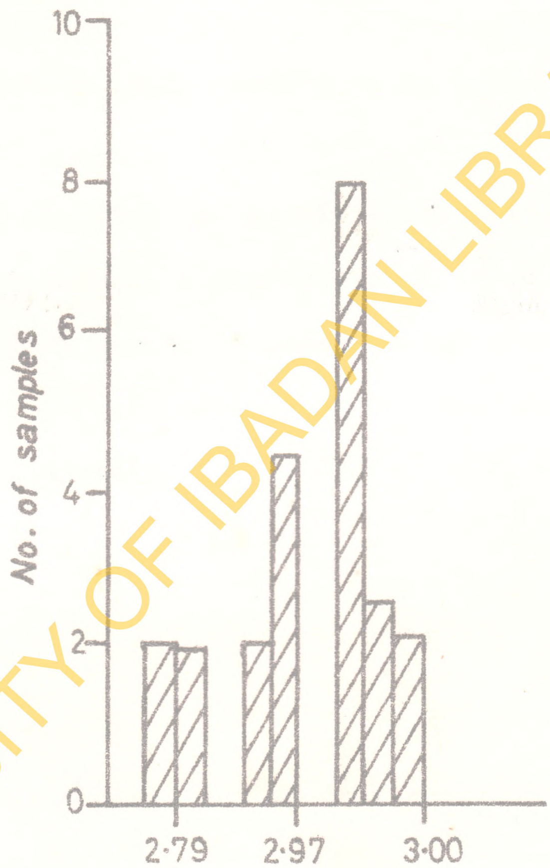

Fig. 9(b): Histogram of density variation of igneous intrusions

Free-air Correction

Since all our gravity stations are less than 700m above sea level, the formula

$$0.3086\ H \text{ mgal, where } H \text{ is in metres,}$$

was used in calculating the free-air correction. Normally in very high altitudes, especially high mountains, a second term of expression should be added to the above formula. The calculated free-air correction δ_{gf} for all the stations are given in Appendix A.

Bouguer Correction

The general formula for Bouguer correction δ_{gB}, is given as

$$\delta_{gB} = 2\pi G\sigma H$$

If $\pi = 3.1416$; $G = 6.67 \times 10^{-8}$ cgs

then the formula becomes

$\delta_{gB} = 0.04191\ \sigma H$; where σ is the density of the intermediate disc of infinite radius between the sea level and the horizontal plane passing the observation station. Usually in geodetic surveys an average density of 2.67gcm^{-3} is assumed for the Bouguer correction. In this survey a density value of 2.53gcm^{-3} was used since the surrounding topographies are mostly Cretaceous sedimentary rocks. However, for comparison purposes, the Bouguer anomalies values using 2.53gcm^{-3} and 2.67gcm^{-3} were calculated from the formula:

$$(\Delta_{go}'')_{2.67} - (\Delta_{go}'')_{2.53} = -2\pi GH(2.67 - 2.53)$$

$$(\Delta_{go}'')_{2.67} = (\Delta_{go}'')_{2.53} - 0.0058H.$$

(The derivation of this formula is given in appendix C). (Δ_{go}'') means the Burguer anomaly using the density 2.53gcm^{-3}. The values obtained are given in Appendix A.

<u>Topographic Corrections</u>

We used Lukavchenko's Tables for the topographic correction. Generally, the topography of the surveyed area is flat to gently undulating. Consequently, the intermediate zone chart for a map on scale 1:50,000 was used in

TABLE 1

Topographic Correction Values Calculated by Lukavchenko's Tables

Stn	mgal
44	0.02
30	0.00
84	0.00
26	0.00
12	0.04
9	0.06
5	0.07
LBM 6	0.10
60	0.08
61	0.08
79	0.03
130	0.01
100	0.00
175	0.00
204	0.06
205	0.15
206	0.10
207	0.11
208	0.09

computing the topographic correction. The innermost zone has a radius of 200m, and the outermost zone, 5km. The limitation of the calculations to 5km radius is due to the even topography which gives negligible topographic effects beyond this distance.

On the basis of the 1:50,000 topographic maps of the area along the entire profile 20 gravity stations which seem to have appreciable effect of topography were selected. The result of the computation for these stations is given in Table 1. It is observed that the corrections remain below 0.03mgal except for stations around Nsukka and Gboko where the values range from 0.10 to 0.15mgal. As a result of their low values, topographic corrections are not applied to the observed gravity in this survey.

The international gravity formula (1930)

$$\gamma_o = 978.490(1+0.0052884 \sin^2\phi - 0.0000059 \sin^2 2\phi)$$

was used in computing the normal gravity values.

γ_o is the theoretical gravity value at latitude ϕ. The gravity anomalies were calculated using the following formulae

$$\Delta g_o = g_{obs} + \delta g_f - \gamma_o$$

$$\Delta g_o'' = g_{obs} + \delta g_f - \delta g_B - \gamma_o$$

Δg_o means free air anomaly

TABLE 2

Gravity values of local base stations

Stn No.	Locality	ϕ^{o}N	λ^{o}E	H(m)	Gravity gals
044	Auchi	7.06	6.25	194.73	978.07894
030	Agenebode	7.08	6.65	34.63	978.12544
084	Idah	7.10	6.72	31.33	978.12253
099	Igabado (W)	7.03	6.99	42.37	978.12506
026	Igabado (E)	7.02	7.01	32.89	978.12505
012	Ugunaka	6.95	7.23	218.99	978.08010
LBM 6	Nsukka	6.88	7.39	447.60	978.01888
079	Orokam	7.00	7.59	463.57	978.02640
117	Ajide	7.15	7.88	194.43	978.08787
100	Oturkpo	7.20	8.18	194.77	978.08361
173	Aliade	7.25	8.50	158.25	978.09855
175	Awajir	7.25	8.55	178.31	978.09532
189	Akpagher	7.30	8.77	162.31	978.10281
194	Akwarra	7.30	8.86	160.32	978.10850
203	Gboko	7.36	9.00	230.76	978.09198
206	Yandev	7.35	9.03	226.68	978.09326
213	Buruku (W)	7.48	9.18	121.16	978.10966
	Boju Ega	7.37	8.03	185.94	978.08640

Boju Ega: Fundamental station for our survey.

CHAPTER IV

RESULTS AND INTERPRETATION

Gravity Values of Local Base Stations

Gravity values of selected base stations are presented in Table 2. These values were tied to the Shell B.P. base at Boju Ega which was itself connected to the O.R.S.T.O.M. base at the Lagos airport.

As mentioned in the preceding chapter, a correction of -4.3mgal was applied to the O.R.S.T.O.M. value. 978.08640gal for Boju Ega is the result. Consequently, the values in our area are less than the O.R.S.T.O.M. values by 4.3mgal. Site descriptions for the local base stations are given in the Appendix B.

Where the localities of the gravity stations in this study overlap those of Cratchley and Jones, the observed gravities were compared, and are presented in Table 3. The differences noted in the values may be attributed to the following:

(a) Where the disparity in the values is comparatively small e.g. Oturkpo and Aliade, the differences may be due to the use of different gravimeters (Cratchley and Jones used World-Wide gravimeter)

(b) In localities having differences of up to 1.4mgal, it is probable that there has been a change in the altitude of the localities resulting from excavation or road reconstruction work in the area.

(c) The site description for stations established by Cratchley and Jones is not available and it may well be that our stations do not coincide in point, although they may be close.

However, it is inferred that one or a combination of the above reasons could be responsible for the observed differences in the gravity values.

Table 3

Comparison Between the Writer's Values And Cratchley & Jones Values for Selected Stations

Locality	Gravity Values from present Survey	Gravity Values by Cratchley and Jones
Oturkpo	978.08361	978.08377
Aliade	978.09855	978.09815
Gboko	978.09035	978.08948
Yandev	978.09326	978.09447
Buruku (W)	978.10966	978.11106

Fig. 10: Free-Air Anomaly and Bouguer Anomaly profiles

General Features of Gravity Data

The free air anomaly profile has a value ranging from +0.1 to +48milligals (Fig. 10). The maximum value of the free air anomaly is located 50km east of Nsukka and corresponds to the highest elevation in the surveyed area. The free air anomaly profile is more or less parallel to the Bouguer anomaly profile except in the area around Nsukka where a slight departure from the parallel trend is marked by an increase in the gap between the two profiles (Fig. 10). This gap is attributable, probably to the thick sediments which are composed of sandstone of density much less than $2.53gcm^{-3}$.

Although quantitative isostatic corrections were not applied, it is inferred, from the generally low topography of the area, and from the relatively small free air anomalies that probably an isostatic condition prevails i.e.

$$\Delta gi = \Delta go$$

The most conspicuous feature of the Bouguer anomaly profile is its alternating series of negatives and positives. The main positive Bouguer anomalies are observed at Idah, Adoru, Obokolo and Gboko; negatives are at Auchi, Nsukka, Oturkpo and Buruku areas (Fig. 10).

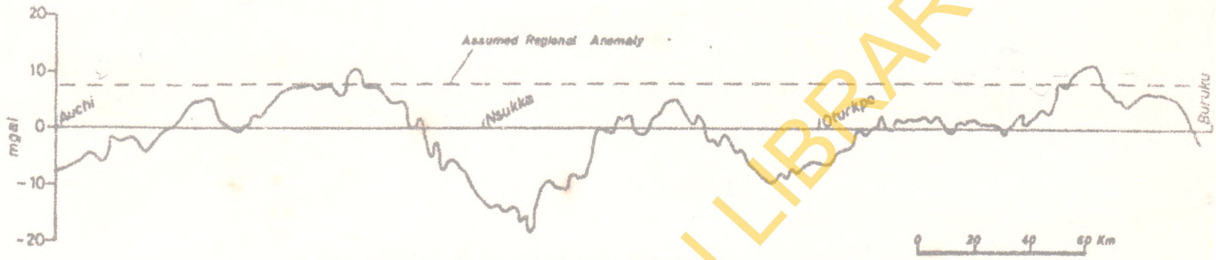

Fig. 11(a): Unsmoothened Bouguer Anomaly profile showing Assumed Regional Anomaly

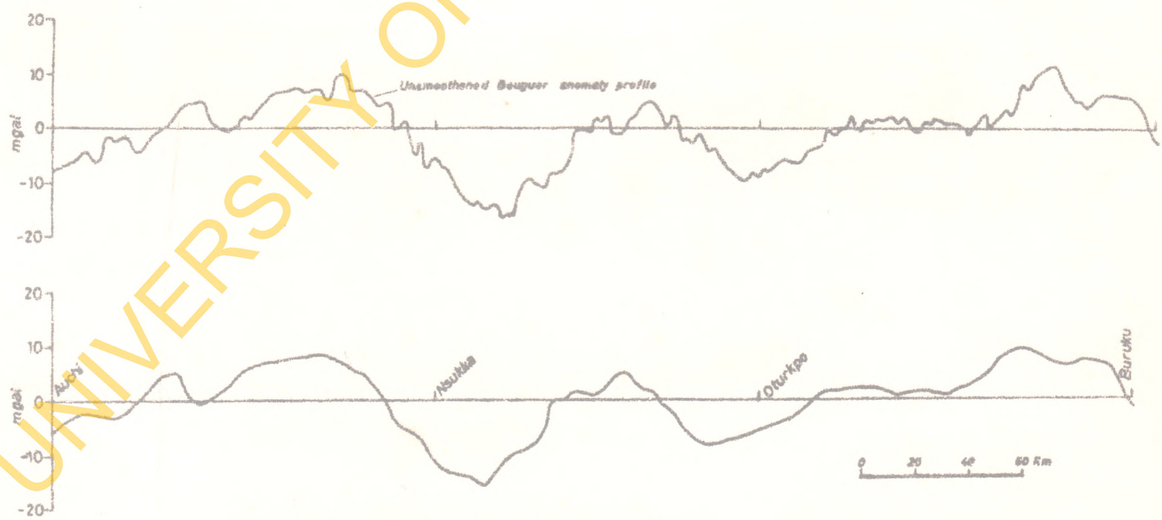

Fig. 11(b): Smoothened Bouguer anomaly profile

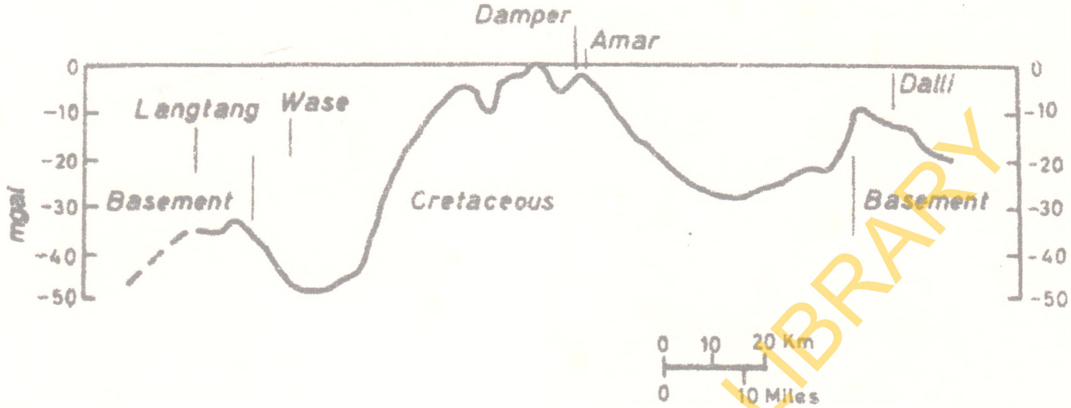

Fig. 12(a): Bouguer anomaly profile across the Amar anomaly (after Cratchley & Jones) 1965

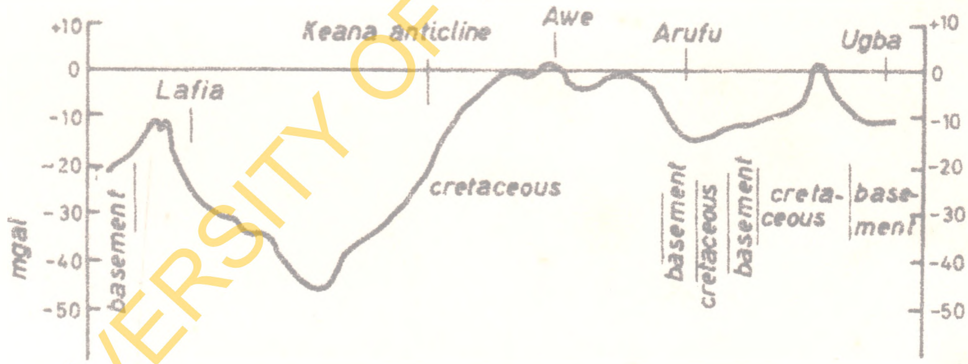

Fig. 12 (b): Bouguer anomaly profile across the Awe anomaly (after Cratchley & Jones

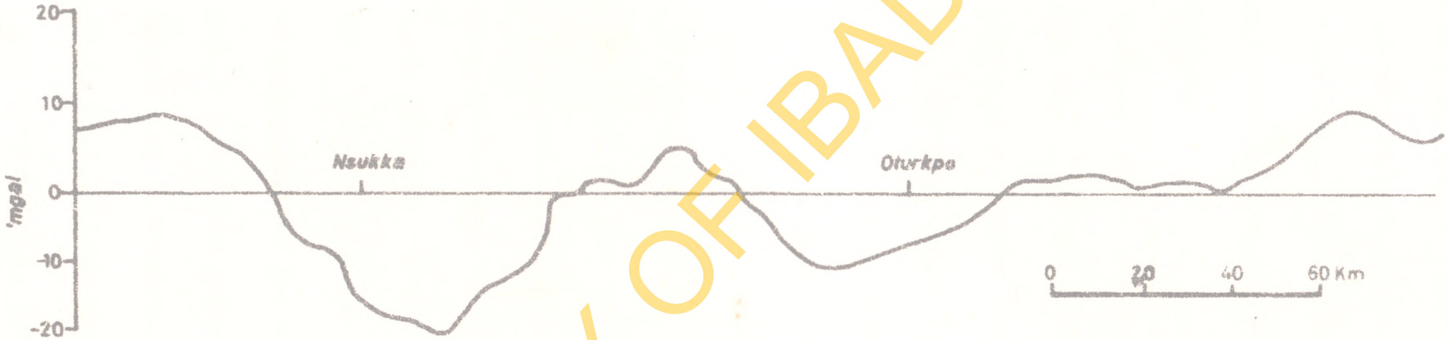

Fig. 12(c): Bouguer anomaly profile from the present survey

The figure shows that the River Niger area is marked by a positive Bouguer anomaly which falls steeply to a value of -8mgal at Auchi. North-east of Gboko the Bouguer anomaly has a value of 5mgal around Yandev but decreases steeply to -2.5mgal near Buruku.

A comparison between the Bouguer anomaly profiles of previous workers and the present work reveals some similarities. Two profiles taken from Cratchley and Jones work (1965): the one, in the upper Benue trough, from Dalli (latitude 8°15'N, longitude 10°31'E), to Wase (latitude 9°15'N, longitude 10°E) Fig. (12a); the other, in the middle Benue trough from Lafia (latitude 8°30'N, longitude 8°30'E) to Ugba (latitude 7°30'N, longitude 9°25'E) (Fig. 12b) are compared with the profile of the present survey, (Fig. 12c). The three profiles commonly reveal a central positive anomaly with negative anomalies on both flanks. The depression of the negative anomaly in the western end is deeper and narrower than the depression on its eastern side.

From the three profiles it is apparent that the amplitude of the axial positive anomaly increases from the northeast to the southwest. Similarly the width of the axial positive, and therefore the wavelength of the depressions increases towards the southwest.

DATA INTERPRETATION

The observed Bouguer anomaly (Fig. 11a) is made up of regional and local sources. In order to remove the local perturbations, a smooth profile method was used. Even though it has its intrinsic limitations because of its subjective nature, it is nevertheless suitable for a regional investigation.

The smoothened profile is shown in Figure 11b. This figure is used for subsequent interpretations.

Thickness of the Trough Sediments

To get a first order estimate of sediment thickness we used the gravity effect of an infinite sheet, applying the formula

$$(\Delta g)z - (\Delta g)_o = -2\pi G\sigma z$$

where z is the depth to the basement; σ, the density contrast, $0.17 gcm^{-3}$, G the gravitational constant; $(\Delta g)z$, the Bouguer anomaly at a given station where z is required; and $(\Delta g)_o$, the Bouguer effect when the region is supposedly composed of granitic bed rock. $(\Delta g)_z - (\Delta g)_o$ must be originated from the effect of the Cretaceous sediments overlying the bedrock. In the east, from the gravity stations around Gboko where the basement complex crops out the value obtained was 7.99 milligals. In the west, the mean of the Bouguer anomalies at station numbers 19 to 91 was taken. Around these stations the basement complex is very close to the surface. $(\Delta g)_o$ has been considered to change linearly from Gboko in the east, to Adoru-Oforoachi in the west. Beyond this interval, 7.99 milligal was taken to the east and 7.35 milligal to the west.

The above formula was used to derive an estimate of basement

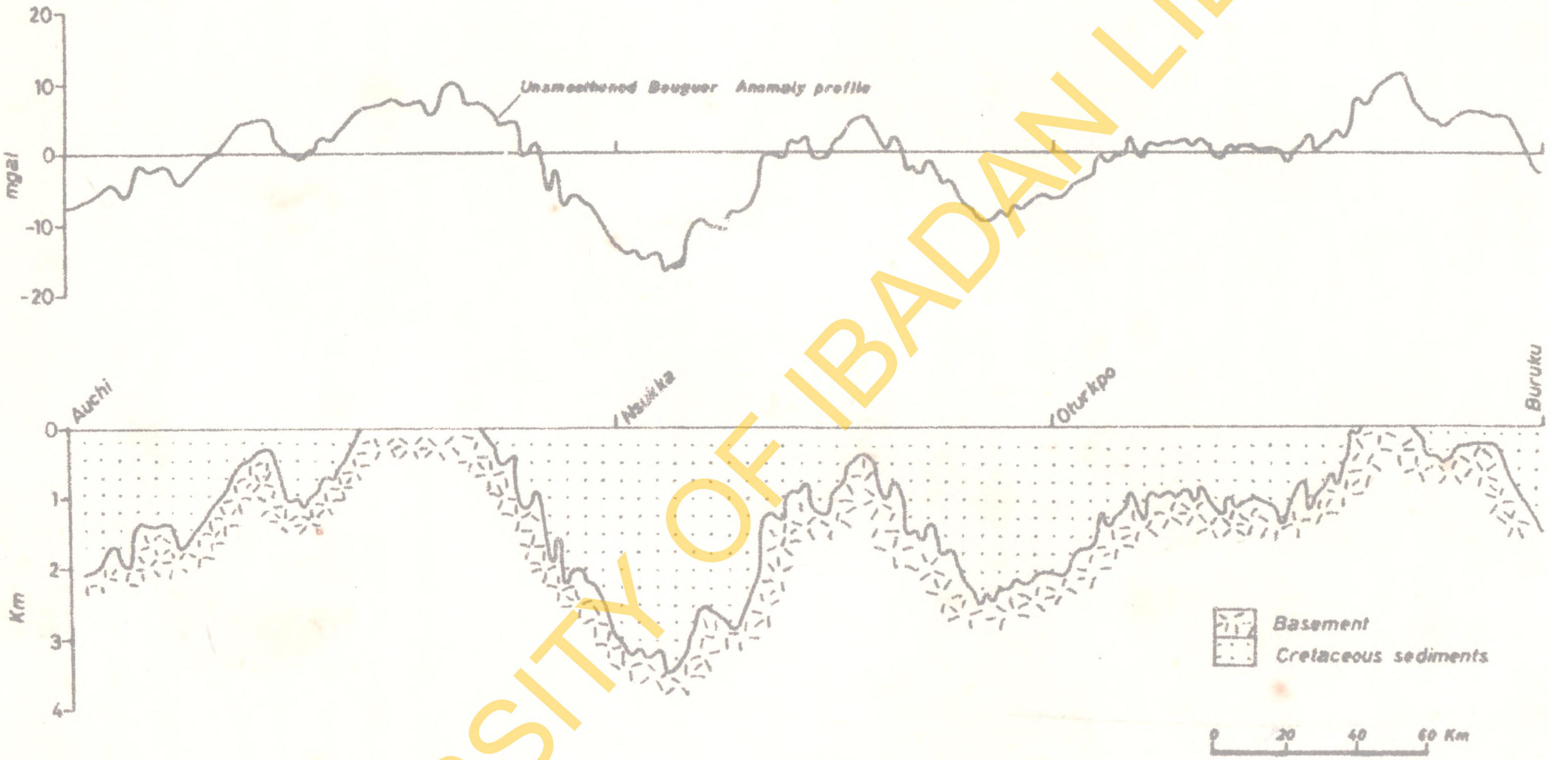

Fig. 13: Interpreted unsmoothened configuration of the basement

configuration or variation in sediment thickness along the line of profile. This technique though not rigorous allows a quick derivation of a working model for detailed interpretation.

The result of depth determinations reveals the characteristic configuration of the basement complex, i.e. along the axis of the trough the basement approaches the surface and on the east and west sides of this high, depressions of the surface have been found. The maximum thickness of the sedimentary cover rocks has been tentatively determined as approximately 3.60km (Fig. 13).

The formula used in determining the above thicknesses of the sedimentary rocks assumes that the trough extends indefinitely in all directions whereas the trough most probably extends in a north-south direction only. Although the calculation was made with the said simple method, the result obtained gives a general configuration of the surface of the basement complex.

In order to test the accuracy of our model and evolve a realistic shape of anomaly source a two dimensional graticule was used for this purpose. The construction of graticules have been adequately described by Nettleton (1940). Briefly the technique involves superimposing the template over the model and calculating the gravity response at various positions along the traverse - comparing observed calculated - adjusting anomaly parameters and repeating the exercise till discrepancy between observed and calculated were reduced to the minimum. The final configuration thus obtained is illustrated in Fig. 14 together with the calculated anomaly response curve and the observed. From this result, it is found that the maximum depth of the western depression is 4.25 km and that of the eastern depression, 3.30 km; the whole trough being filled with Cretaceous sediments of

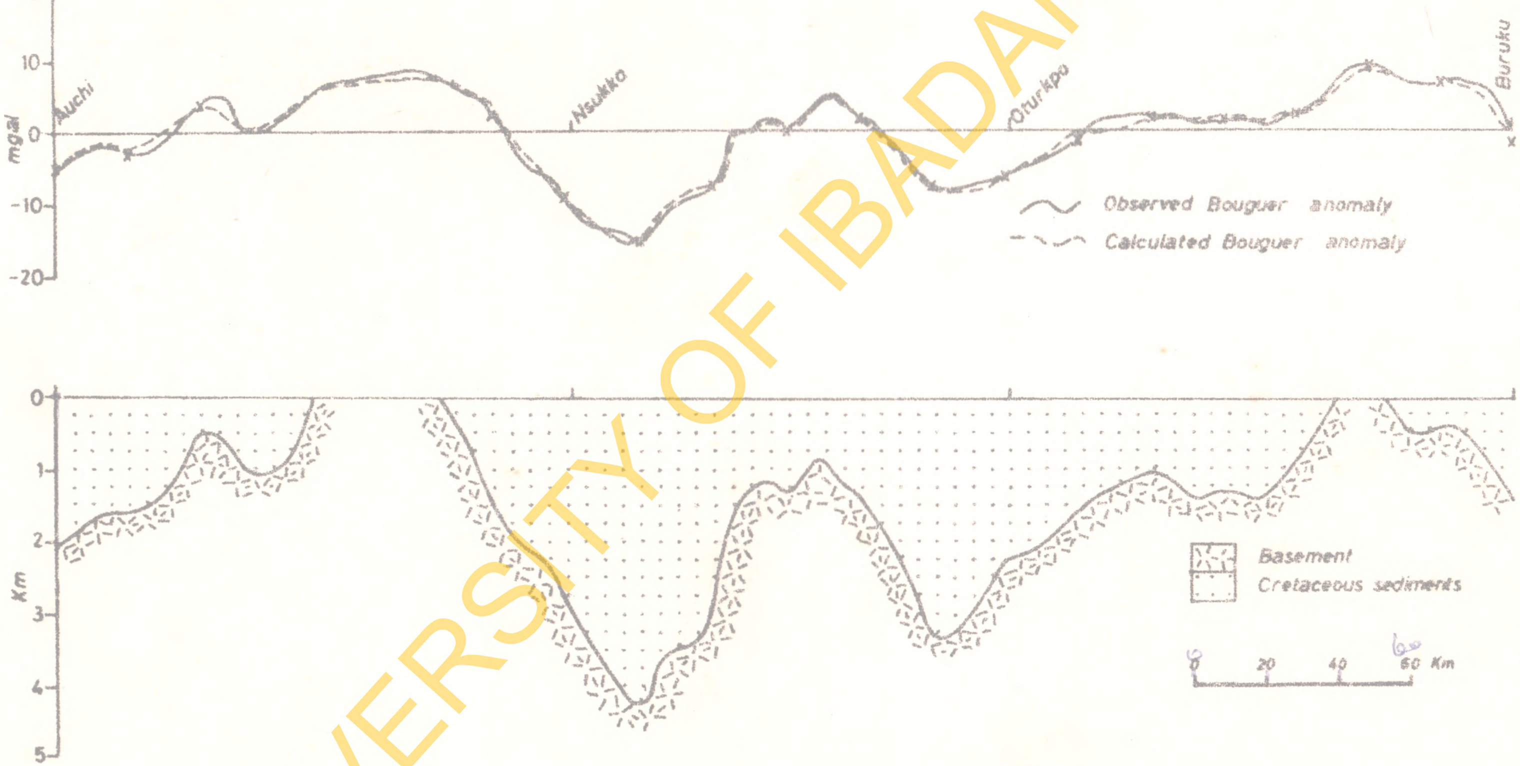

Fig. 14 : Interpreted smoothened Basement configuration

mean thickness 2km, (Fig. 14). The basement underlying the trough axis approaches to the ground surface only to a depth of 0.8km.

Configuration of the Basement and Cover Rocks

From the estimations of the depths to the basement complex underlying the trough, it is observed that the basement is shallower near the central axis than in both flanks which form conspicuous depressions on the surface of the basement. This is attributed to the uplift or doming of the basement complex about the present axis of the trough due to tectonic processes (Nwachukwu, 1972; 1975). Uplifting was accompanied by the thinning of the crust in the affected area. However, as a whole the Benue depression has taken an aspect of a typical rift basin which was deepened by continuous accumulation of sediments along the linear valley.

Local variations in gravity anomalies may be attributed to the basic dykes mapped in the area, or to folding; anticlines forming local positive anomalies and synclines, local negative anomalies. The series of anticlines and synclines observed from the Bouguer profile show similar fold amplitudes as those of the Abakaliki anticlinoriun located just south of the present profile (Nwachukwu, 1972). It is envisaged that the Cretaceous rocks were originally deposited on a fairly even to smooth basement. Later, earth movements, especially the Santonian event resulted in the folding of both the basement and the sediments. An alternative explanation is that the basement was initially corrugated due to differential erosion, and that the sediments were deposited in an already folded basement.

Faulting is possibly assumed from the Bouguer profile which shows steep gravity gradients. The condition is found at the boundary between the basement and Cretaceous sediments. Unfortunately geological mapping has not confirmed faulted boundaries for the trough, although it is suggested that any evidence of faulting must have been covered up by later sedimentary processes (King, 1950).

Width of the Sedimentary Basin

Assuming that the depressions on both sides of the axial anomaly mark the flanks of the trough, it can be inferred from their separation that the trough is probably wider in the surveyed area than in its northern extension.

Furthermore, considering the supposition that the trough is bounded in the east and west by the basement complex, and by the indication from our Bouguer profile that the basement crops out near Gboko and Adoru (east and west, respectively Fig. 13), it is estimated that the lower Benue depression is possibly 240km wide. This hypothesis is supported by the evidence that the Niger Delta prograded southwards down the Benue trough about the Campanian (Burke, 1972). Obviously, surplus upper Cretaceous sediments from the delta must have filled the trough and probably spilled into the adjacent basins.

Adjacent Areas of the Trough

It is observed from the configuration of the basement complex that the River Niger is underlain by a shallow bedrock that rises up to 0.5km near the ground surface. West of the River Niger, towards Auchi, the sediments overlying the basement become thicker and attain the maximum thckness of 2km around Auchi area.

In the eastern extremity of the profile around Buruku, the negative anomaly indicates that sedimentary rocks having thickness ranging from 0.5km to 1.3km overlie the basement complex. This fact is consistent with Cratchley and Jones'(1965) views that the Cretaceous sedimentary rocks in the Buruku-Katsina Ala River area could be about 1km thick.

CHAPTER V

GRAVITY FIELD OF THE BENUE TROUGH

General Statement

In discussing the gravity field of the Benue trough we have used data obtained from:

(i) Cratchley and Jones' (op cit) measurements in parts of the upper Benue trough covering an area between latitudes 7°N and 9°N; longitudes 8°30'E and 11°E;

(ii) Hospers' work (1965) covering part of the Niger delta area between latitudes 5°N and 7°N; longitudes 6°E and 8°E;

(iii) gravity values on a single line profile between areas (i) and (ii) above, obtained in the present survey.

In addition, a Bouguer gravity map of Nigeria had previously been published by Ajakaiye and Burke (1973).

However, we have compiled a Bouguer map of the Benue trough, after applying the following adjustment to the data used by the earlier workers mentioned above.

Cratchley and Jones (1965) tied their gravity values via the Shell B.P. bases at Boju Ega and Damaturu to the

O.R.S.T.O.M. base at the Lagos airport for which a value is given of 978, 132.4mgal.

The absolute values of gravity at Boju Ega and Damaturu used by Cratchley and Jones were given as 978,086.4 and 978,143.9mgal respectively. These values were obtained after a correction of -4.3mgal was applied to the published O.R.S.T.O.M. value in Lagos (Cratchley and Jones, 1965, p. 10). On the contrary, no similar corrections were applied to the Shell B.P. data in the delta. It follows therefore, that Cratchley and Jones values should be consistently less than those of Hospers by 4.3mgal. Since the present survey was tied to Boju Ega base, our values must be accordingly less than Hospers' values by 4.3mgal. This was checked by comparing the Bouguer anomaly values at our stations numbers 30 and 21 which coincide with (or are near) Hospers' station numbers 2 and 3 respectively, Table 4.

It is observed that our values are consistently lower than Hospers' values by a value which is close to 4.3mgal. The remaining differences of 0.3mgal and 1mgal may be due either to the use of different gravimeters or the fact that the locations of the stations do not exactly coincide. The difference in their elevations may rise to a few metres

TABLE 4

Comparison of Bouguer Anomalies In Overlap Stations

	Stn	go "mgal	Stn	go "mgal
Hospers	3	11.4	2	10.3
Present work	21	6.8	30	5.0
Cratchley and Jones	Oturkpo	7.00	Gboko	9.00
Present work	Oturkpo	7.70	Gboko	9.03

In the north-east the writer's Bouguer anomaly values agreed approximately with Cratchley and Jones values where the stations overlapped at Oturkpo and Gboko, Table 4.

Thus, in drawing the Bouguer map, we subtract 4.3mgal from the gravity values in the delta area to harmonize them with our values.

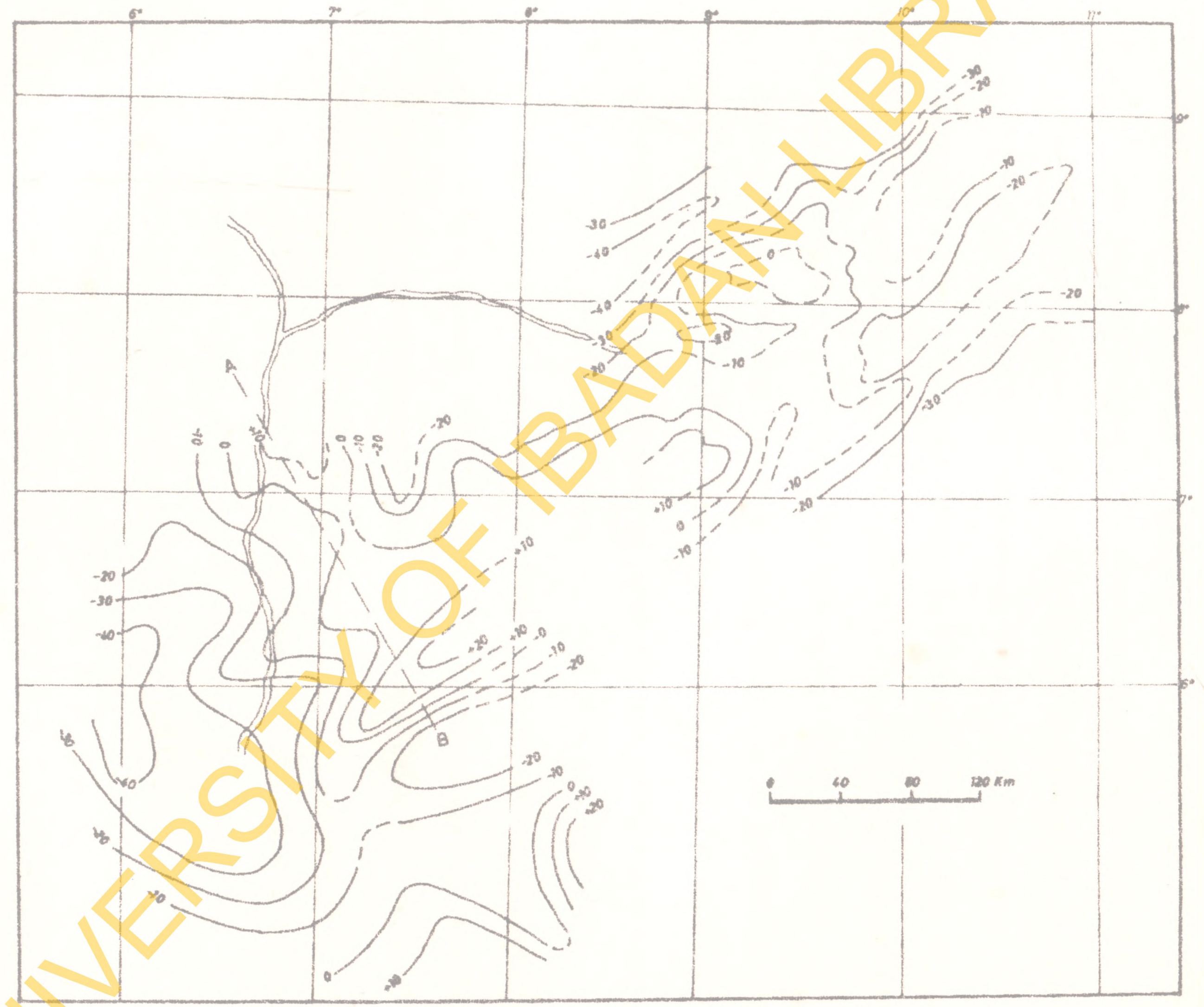

Fig. 15: Bouguer Anomaly map of the Benue Trough (10 mgal contour interval using a density of 2·67 g cm⁻³)

General Features of the Bouguer Map

The special features of the map which has been drawn using a contour interval of 10mgal are outlined as follows:

The entire axis of the Benue trough which trends linearly along NE-SW direction is marked by positive Bouguer anomaly. The axial positive anomaly is observed to "grow" from the north east to the south west where it is widest - the general pattern being that of an inverted "V". The value of the anomaly also tends to increase from near zero mgal in the northeast to over 15mgal in the southwest. The positive anomaly is observed to terminate abruptly towards the southwestern end where high negative values seem to take over. At this end, it is possible to draw a line AB trending NNW-SSE that demarcates high positives and high negatives (Fig. 15).

Negative anomalies are observed on both flanks of the axial positive along the entire trough. The negative anomalies in the western flank are generally bigger than those in the eastern flank.

Discussion

In our profile, the central positive anomaly spreads over a distance of 50km between Ajide and Orokam (Fig. 13) and has a value of 5mgal. The negative anomalies are located in the east, around Oturkpo; and in the west around Nsukka; their values being -10mgal and -16mgal respectively.

The negative anomalies are probably due to the thick Cretaceous rocks that fill the trough. Larger negative Bouguer anomalies in the western flank could be ascribed to the thicker sediments in the west. In the investigated profile, sediments have a maximum thckness of about 4.25km in the west, and 3.30km in the east. It is suggested that thicker sedimentation in the western part of the trough must be due to the surplus sediments supplied by the delta which was prograding southwards by the late Cretaceous times. This excess load of sediments must have caused the sagging of the basement in the western depression.

Towards the southwestern boundary of the trough the very large negative anomalies are attributed to either a very thick sequence of deltaic sediments and Cretaceous rocks, underlain by oceanic basement, or a moderate thickness of less dense tertiary sediments which accumulated in a sedimentary basin. It is the writer's view that the negative anomalies are probably due to a combination of the above reasons.

Furthermore, from Cratchley and Jones' (1965) report, the Cretaceous rocks in the upper Benue trough may be considered to have a thickness of up to 6 km, while from the result of the present survey, it is suggested that the Benue trough may be shallower in the south than in the north. However, it is most probable that the sedimentary rocks which fill the trough in the northeast are of Cretaceous age, and towards the southwest the sediments grade into the lower Tertiary.

Several factors could be responsible for the axial positive anomaly. These include

(i) extensive basaltic lava flows;

(ii) a zone of intermediate to basic intrusives either within the Cretaceous sediments or within the basement;

(iii) basement occurring at very shallow depth;

(iv) uplift of the mantle at great depth.

Although basaltic sills occur in a number of localities in the Benue trough, the general habit is small cones and lava sheets, that seldom exceed a few square kilometres in extent e.g. the sill around Makurdi. In the profile which we investigated, no basaltic or volcanic rocks were mapped. Some of the cones, which are evidences of volcanic activities, have had most of their surrounding lavas removed by erosion. It is therefore unlikely that basaltic lavas can cause the axial positive which is known to persist through the entire trough axis.

There is evidence to support the intrusive theory. Intrusive rocks are widely distributed in the Benue trough. There are more occurrences of these intermediate to basic intrusives in the south western than in the northeastern parts of the trough (Farringtom, 1952). Careful examination around Gboko and Oturkpo discloses doleritic rocks that do not outcrop or are slightly exposed. The igneous intrusions are associated with the oldest Cretaceous rocks especially Albian shales that crop out in the south around Abakaliki and in the middle Benue southewest of Gboko. These shales are known from the result of measurements to have density approaching that of basement rocks. The belt of positive anomaly coincides remarkably with these Albian shales in the southwest. The fact of this coincidence suggests that the high density Cretaceous rocks with their associated intrusives are, at least, partly responsible for the positive anomaly. The positive anomaly in fact apparently peters out in the northeast where the Albian shales have not been known.

Close to the southwestern boundary of the trough no lower Cretaceous rocks have been mapped, rather upper Cretaceous rocks, directly overlie the basement in some localities, e.g. Idah-Adoru areas. In our traverse, the zone of axial positive is associated with areas of shallow depth of the basement which we calculated as about 0.8km from the surface. The basement that underlies the Niger in the surveyed area was calculated as less than 0.5km from the surface. The doming of the basement about the trough axis is attributable to tectonic processes associated with the upwelling of the upper mantle. It is inferred that the uplifting of the basement also led to the uplifting of the overlying Cretaceous rocks, and the combined effect of the basement and the high density Cretaceous rocks contributed largely to the observed positive anomaly.

The high positive region at the southwestern end is ascribed probably to the oceanic crust which underlies the sediments in the delta area. Hospers (1971) showed evidence that the delta lies on an oceanic crust.

Generally, the pattern of the positive anomaly in the Benue trough can be attributed to a combination of the effect of oceanic crust, in the southwestern boundary with the delta; shallow basement, igneous intrusives and dense Cretaceous shales. The tendency for the positive anomaly to decrease towards the northeast is probably due to the following reasons:

(i) There is evidence that there is a greater concentration of intrusives in the southwest than in the north east ~~e~~ (Farrington 1952).

(ii) Dense Albian shales that are mineralized with lead-zinc are present in the lower Benue trough.

(iii) The Benue trough has thicker sedimentary rocks in the northeast, about 6km (Cratchley and Jones) than in the southwest. This means that the basement is closer to the surface in the lower Benue than in the upper Benue.

(iv) It is highly probable that some oceanic crust is exposed in the southwest Benue trough.

The evidence that an axial positive anomaly with negative anomalies on the flanks stretches along much of the trough is an indication that the trough probably has essentially the same structural pattern throughout its length.

Structural patterns of the gravity anomalies of some rifts in Africa are outlined and compared to the Benue rift: The Gregory rift in East Africa is an active rift with axial positive anomaly within a broad negative anomaly. Similarly the Mid-continent rift, U.S.A; Ngoteur rift, Chad; Great Dyke rift, Rhodesia; - all are inactive rifts with axial positive anomaly flanked by negative anomalies attributed to miogeochinal sediment wedges (Burke, 1973). From the above, it is obvious that most rift systems have similar structures which may be related to their origin and evolution.

The regional positive anomaly associated with the Benue trough bears a close resemblance to that observed in the Red Sea region (Drake and Girdler, 1964). The axial positive anomaly associated with the Red Sea has a value of 150mgal and is suggested to be due to the large exposure of oceanic crust intruding through the downfaulted basement rocks of the Arabian-Nubian Sheild (Girdler, 1958). For the Benue trough, its axial positive is attributed to basement relief resulting from tectonic processes, rifting and intrusion of substratum.

A characteristic feature observed in the Bouguer map is the abrupt truncation of the high positive anomaly along AB (Fig. 15). The line tends to separate the high positives from the high negatives around the delta. This feature is structurally important as it probably marks a tectonic feature in the history of the Benue trough and the Niger delta. Another possible inference from this major feature is that it could be the boundary of the Benue trough, probably at the continental margin. The opinion that the trough extends from the continental margin onto the continental platform is supported by many authors, (Burke, et al., 1971; Grant, 1971; Nwachukwu, 1972; Hoffman, et al., 1974). It is imagined that detailed geophysical work in this area will give an insight into the structure of the area, and perhaps the tectonic evolution of the Benue trough.

CHAPTER VI

SUMMARY AND CONCLUSIONS

From a consideration of the known geology of the Benue depression, and from results of the gravity measurement the following conclusions are drawn.

1. The Benue trough is a rift valley which is filled with sedimentary rocks of Cretaceous age. The normal faults which marked the basement - Cretaceous boundaries have either been obliterated probably by post deformational sedimentation, or have evolved into an asymmetric downwarp.

2. Thicknesses of Cretaceous rocks in the upper Benue were reported to reach 6km (Cratchley and Jones 1965). The present survey reveals that the maximum thickness of the sediments in the lower Benue is 4.25km. It is therefore inferred that the Benue trough is shallower in the south than in the north.

3. The sediments in the western part of the trough are thicker than in the eastern side. In the lower Benue trough the sediments have a thickness of 4.25km in the

western, and 3.3km in the eastern end. That thicker sediments accumulated in the west is ascribed to the surplus load carried into this part of the trough by the delta in the late Cretaceous times.

4. The Bouguer gravity map reveals that the trough is characterised by an axial positive anomaly which "grows" from the northeast to the southwest. The axial positive is attributed to the doming of the basement underlying relatively dense Albian shales and their associated intermediate to basic intrusives along the trough axis as a result of tectonic processes. The high positive in the southwest end of the trough is probably due to the oceanic crust that underlies the sediments in parts of the delta frame work. The axial positive has negative anomalies on both flanks and are likely due to the thick sequences of Cretaceous sedimentary rocks which fill the trough.

5. The tendency for the axial positive anomaly with its marginal negative anomalies to stretch along the entire trough is evidence that the depression is structurally consistent over most of its area.

6. When compared with other rifts, the Benue is found to be typical in that most rifts whether "active" or "inactive" are marked by an axial positive flanked by negative anomalies. However, unlike the Red Sea where the larger

axial positive has been interpreted as due to exposed oceanic crust, the smaller axial positive anomaly of the Benue trough is considered as the result of the basement relief underlying both the Cretaceous rocks in the Benue depression and the upper Cretaceous-Tertiary sediments of part of the Niger River Basin.

Suggestions for Further Work

1. There is need for a more detailed coverage of the gap that exists in the Bouguer anomaly map compiled (1973) by Ajakaiye and Burke in order to close up the isogals more accurately.

2. In order to investigate the nature of basement complex in the western end of the present area of investigation, profiles need to be extended beyond Auchi to where the basement outcrops, probably in Igarra.

3. There is need to map accurately the basement-Cretaceous boundary. For this reason, it is necessary to make more detailed measurements where the boundaries are presently inferred around Gboko in the east, and Adoru in the west.

4. The depths to the basement obtained from the present work need to be further investigated by other geophysical methods especially, the seismic method.

5. Present economic interest in lead-zinc mineralization of the Albian shales demands an investigation of the nature and extent of anomalies associated with the known lodes, and its implications in geophysical prospecting.

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APPENDIX A

FIELD DATA, FREE AIR AND BOUGUER ANOMALIES

KEY

*Gravity Base Station

*B Gravity Base Station established on bench mark.

Bouguer Corrections, δ_{gB}; Free air corrections, δ_{gf} in mgals;

Δgo, $\Delta go''$ in mgal

g, g_o, g_o'' in gal

Station is numbered according to longitude from the western to the eastern end.

Stn No	ϕ^{o}N	λ^{o}E	H_m	g_{gal}	δ_{gf}	$\delta\delta_{gB}$	$g_{o}gal$	g_o'' gal	Δg_o mgal	$\Delta g_o''$ mgal	$(\Delta g_o'')2.67$
* 44	7.06	6.25	194.73	978.07894	60.09	20.65	978.13903	978.11838	+12.24	-8.41	-9.55
43	7.05	6.27	214.02	.07547	66.05	22.69	.14152	.11883	+14.95	-7.74	-9.00
42	7.04	6.30	172.65	.08453	53.28	18.31	.13781	.11950	+11.46	-6.85	-7.86
41	7.03	6.32	93.11	.10262	28.73	9.87	.13135	.12148	+ 5.21	-4.66	-5.21
40	7.03	6.35	84.94	.10214	26.21	9.01	.12835	.11934	+2.21	-6.80	-7.30
39	7.03	6.38	83.69	.10688	25.83	8.87	.13271	.12384	+6.57	-2.30	-2.79
38	7.03	6.40	82.10	.10690	25.34	8.71	.13224	.12353	+6.10	-2.61	-3.09
* 37	7.03	6.43	65.09	.11066	20.09	6.90	.13075	.12385	+4.61	-2.29	-2.67
36	7.03	6.47	42.93	.11272	13.25	4.55	.12597	.12142	-0.17	-4.72	-4.97
35	7.04	6.50	52.23	.11316	16.12	5.54	.12928	.12374	+2.93	-2.61	-2.92
34	7.05	6.53	41.37	.11735	12.77	4.39	.13012	.12573	+3.55	-0.84	-1.08
33	7.05	6.55	42.93	.11887	13.25	4.55	.13212	.12757	+5.55	-1.00	+0.75
32	7.06	6.58	38.75	.12289	11.96	4.11	.13485	.13074	+8.06	+3.95	+3.72
31	7.07	6.62	41.07	.12356	12.67	4.35	.13623	.13188	+9.22	+4.87	+4.63
* 30	7.08	6.65	34.63	.12544	10.69	3.67	.13613	.13246	+8.90	+5.23	+5.03
* 84	7.10	6.72	31.33	.12253	9.67	3.32	.13220	.12888	+4.53	+1.21	+1.03
83	7.10	6.73	53.86	.11658	16.62	5.71	.13320	.12749	+5.53	-0.18	-0.50
82	7.09	6.75	58.22	.11568	17.97	6.17	.13365	.12748	+6.13	-0.04	-0.38
81	7.09	6.77	55.50	.11542	17.13	5.88	.13255	.12667	+5.03	-0.85	-1.18
80	7.09	6.78	51.02	.11750	15.74	5.41	.13324	.12783	+5.79	+0.38	+0.08
85	7.09	6.79	59.80	.11605	18.45	6.34	.13450	.12816	+7.05	+0.71	+0.36
86	7.09	6.81	61.78	.11751	18.82	6.55	.13633	.12978	+8.88	+2.33	+1.97
87	7.08	6.82	62.48	.11662	19.28	6.62	.13590	.12928	+8.60	+1.98	+1.61
88	7.08	6.83	65.11	.11752	20.09	6.90	.13761	.13071	+10.31	+3.41	+3.03
89	7.08	6.85	65.81	.11824	20.31	6.98	.13855	.13157	+11.32	+4.34	+3.95
90	7.08	6.87	66.51	.11942	20.52	7.05	.13994	.13289	+12.71	+5.66	+5.27

Stn	$\phi^{o}N$	$\lambda^{o}E$	H_m	g	δgf	δgB	g_o	g_o''	Δgo	$\Delta go''$	$(\Delta_{go}'')_{2.67}$
91	7.08	6.88	76.08	978.11798	23.48	8.07	978.14146	978.13339	+14.23	+6.16	+5.71
92	7.07	6.90	71.81	.11933	22.16	7.61	.14149	.13388	+14.48	+6.87	+6.45
93	7.07	6.91	64.62	.12074	19.94	6.85	.14068	.13383	+13.74	+6.89	+6.51
94	7.07	6.92	57.70	.12194	17.81	6.12	.13975	.13363	+12.81	+6.69	+6.35
95	7.06	6.93	50.78	.12421	15.67	5.38	.13988	.13450	+13.01	+7.63	+7.33
96	7.06	6.95	40.08	.12655	12.37	4.25	.13892	.13467	+12.05	+7.80	+7.56
97	7.05	6.96	44.10	.12463	13.61	4.68	.13824	.13356	+11.59	+6.91	+6.65
98	7.04	6.98	46.21	.12420	14.26	4.90	.13846	.13356	+12.07	+7.17	+6.90
*99	7.03	6.99	42.37	.12506	13.08	4.50	.13814	.13364	+11.93	+7.43	+7.18
*26	7.02	7.01	32.89	.12505	10.15	3.49	.13520	.13171	+9.28	+5.79	+5.60
25	7.02	7.03	45.05	.12391	13.90	4.78	.13781	.13151	+11.93	+5.63	+5.37
24	7.02	7.05	59.38	.12301	18.32	6.30	.14133	.13503	+15.45	+9.15	+8.80
23	7.02	7.07	60.90	.12376	18.79	6.41	.14255	.13609	+16.67	+10.21	+9.85
22	7.02	7.08	66.81	.12219	20.62	7.08	.14281	.13573	+16.93	+9.84	+9.45
21	7.01	7.10	38.71	.12493	11.95	4.10	.13688	.13278	+11.11	+7.01	+6.78
20	7.01	7.12	64.74	.12021	18.98	6.86	.13919	.13233	+13.53	+6.67	+6.29
19	7.00	7.13	59.25	.12065	18.29	6.28	.13894	.13266	+13.46	+7.18	+6.83
18	6.98	7.15	58.58	.11999	18.08	6.21	.13807	.13186	+13.02	+6.81	+6.47
17	6.97	7.16	80.68	.11403	24.90	8.55	.13893	.13038	+14.17	+5.62	+5.15
16	6.95	7.17	97.87	.10879	30.20	10.38	.13899	.12861	+14.59	+4.21	+3.64
15	6.93	7.17	133.05	.10156	41.06	14.11	.14262	.12851	+18.58	+4.47	+3.69
14	6.92	7.18	149.23	.09836	46.05	15.82	.14441	.12859	+20.66	+4.84	+3.96
13	6.93	7.21	189.01	.08559	58.33	20.04	.14392	.12388	+19.95	-0.09	-1.20
*B12	6.95	7.23	218.99	.08010	67.58	23.22	.14768	.12446	+23.35	+0.13	-1.16
11	6.93	7.24	170.29	.09107	52.55	18.06	.14362	.12556	+19.58	+1.52	+0.52
10	6.92	7.25	252.68	.07056	77.98	26.79	.14854	.12175	+24.82	-1.97	-3.45
9	6.91	7.27	206.96	.07618	63.87	21.94	.14005	.11811	+16.55	-5.39	-6.60

Stn	ϕ^{o}N	λ^{o}E	H_m	g	δ_{gf}	δ_{gB}	g_o	g_o''	Δg_o	$\Delta g_o''$	$(\Delta g_o'')_{2.67}$
8	6.90	7.28	242.44	978.07099	74.81	25.71	978.14580	978.12009	+22.55	-3.16	-4.58
7	6.89	7.29	249.99	.06468	77.15	56.51	.14183	.11532	+18.83	-7.68	-9.15
6	6.87	7.30	275.33	.06063	84.97	29.19	.14560	.11641	+22.99	-6.20	-7.82
5	6.85	7.32	287.98	.05764	88.87	30.54	.14651	.11597	+24.33	-6.21	-7.90
4	6.84	7.33	299.71	.05397	92.52	31.78	.14649	.11471	+24.41	-7.37	-9.13
3	6.84	7.35	336.44	.04612	103.82	35.67	.14994	.11427	+28.00	-7.67	-9.64
2	6.85	7.37	372.80	.04931	115.05	39.53	.16436	.12483	+42.46	+2.93	+0.74
1	6.88	7.38	444.89	.02019	137.29	47.17	.15748	.11031	+35.30	-11.87	-14.48
*BLBM6	6.88	7.39	447.60	.01888	138.13	47.46	.15701	.10955	+34.22	-13.24	-15.87
B60	6.85	7.40	459.36	.01551	141.76	48.07	.15727	.10856	+35.09	-13.62	-16.32
B61	6.83	7.40	508.35	.00385	156.88	53.92	.16073	.10683	+39.01	-14.89	-17.87
B62	6.81	7.41	488.56	.00837	150.77	51.80	.15914	.10764	+37.80	-14.00	-17.87
63	6.79	7.41	489.20	.00681	150.97	51.87	.15778	.10591	+36.76	-15.11	-17.98
64	6.77	7.42	503.04	.00325	155.24	53.34	.15849	.10515	+37.93	-14.65	-17.60
65	6.76	7.42	494.48	.00587	152.60	52.43	.15847	.10604	+38.05	-14.38	-17.28
66	6.79	7.44	514.20	.00013	158.68	54.52	.15881	.10429	+37.79	-16.73	-19.75
67	6.81	7.45	485.88	.00675	149.94	51.52	.15669	.10517	+35.59	-16.17	-19.02
68	6.82	7.46	465.03	.01342	143.51	49.31	.15693	.10262	+35.38	-18.93	-21.66
* 69	6.85	7.46	433.85	.02097	133.89	46.00	.15486	.10886	+32.61	-13.39	-15.94
70	6.86	7.47	434.55	.02367	134.10	46.08	.15777	.11169	+35.23	-10.85	-13.62
71	6.87	7.48	433.36	.02510	133.74	45.95	.15884	.11289	+36.09	- 9.86	-12.39
72	6.88	7.49	462.11	.01887	142.61	49.00	.16148	.11248	+38.51	-10.49	-13.11
73	6.90	7.51	461.25	.01931	142.34	48.91	.16165	.11274	+38.33	-10.58	-13.21
74	6.91	7.52	481.77	.01446	148.67	51.08	.16313	.11205	+39.66	-11.42	-14.17
75	6.93	7.53	456.10	.02284	140.75	48.36	.16359	.11523	+39.55	-8.81	-11.19
76	6.95	5.55	480.46	.01844	148.27	50.94	.16671	.11577	+42.31	-8.63	-11.45
77	6.97	7.56	471.56	.01302	145.52	50.00	.15854	.10854	+33.78	-16.22	-18.99

Stn	ϕ^oN	λ^oE	H_m	g	δgf	δgB	g_o	g_o''	Δgo	$\Delta go''$	$(\Delta go'')2.67$
78	6.98	7.58	476.01	978.02072	146.90	50.47	978.16762	978.11715	+42.57	-7.90	-19.69
*79	7.00	7.59	463.57	.02640	143.06	49.15	.16946	.12031	+43.98	-5.17	-7.89
140	7.00	7.61	379.75	.04781	117.19	40.27	.16500	.12473	+39.52	-0.75	-2.98
139	7.00	7.62	394.53	.04514	121.75	41.83	.16689	.12506	+41.41	-0.42	-2.74
138	7.01	7.63	425.38	.03862	131.27	45.10	.16989	.12479	+44.23	-0.87	-3.37
137	7.02	7.63	413.83	.04296	127.71	43.88	.17067	.12679	+44.82	-0.94	-3.37
136	7.03	7.64	439.28	.03858	135.56	46.58	.17394	.12736	+47.91	+1.75	-0.83
135	7.03	7.64	412.58	.04421	127.32	43.75	.17153	.12778	+45.32	+1.57	-0.85
134	7.05	7.65	381.24	.05167	117.65	40.42	.16932	.12890	+42.75	+2.33	-0.09
133	7.04	7.66	403.34	.04585	124.47	42.77	.17032	.12755	+43.45	-0.42	-2.79
132	7.07	7.67	428.83	.03938	132.65	45.58	.17203	.12645	+44.95	-0.63	-3.15
131	7.08	7.67	416.60	.04229	128.56	44.17	.17085	.12668	+43.62	-0.55	-3.00
*130	7.09	7.68	440.31	.04005	135.88	46.69	.17593	.12924	+48.55	+1.86	-0.72
129	7.10	7.69	385.91	.05191	119.09	40.92	.17100	.13008	+43.33	+2.41	+0.14
128	7.11	7.71	292.97	.07300	90.41	31.06	.16341	.13235	+35.55	+4.49	+2.77
127	7.12	7.73	245.03	.08319	75.62	25.98	.15881	.13285	+30.77	+4.79	+3.35
126	7.13	7.74	229.82	.08676	70.92	24.37	.15768	.13331	+29.46	+5.09	+3.74
125	7.13	7.75	254.11	.08129	78.42	26.94	.15971	.13277	+31.30	+4.36	+3.82
124	7.15	7.77	208.27	.08924	64.27	22.08	.15351	.13143	+24.73	+2.65	+1.43
123	7.15	7.78	187.91	.09158	57.99	19.92	.14957	.12965	+20.79	+0.87	-0.23
122	7.15	7.80	211.78	.08820	65.36	22.46	.15356	.13110	+24.78	+2.32	+1.08
121	7.15	7.82	218.08	.08593	67.30	23.12	.15323	.13011	+24.38	+1.26	-0.02
120	7.15	7.83	203.45	.08504	62.79	21.57	.14783	.12626	+18.98	-2.59	-3.78
119	7.15	7.85	185.32	.08888	57.19	19.65	.14607	.12642	+17.22	-2.43	-3.52
118	7.15	7.87	195.86	.08594	60.44	20.77	.14638	.12561	+17.53	-3.24	-4.39
*117	7.15	7.88	194.43	.08787	60.00	20.62	.14787	.12725	+19.09	-1.53	-2.67
116	7.15	7.90	205.74	.08426	63.49	21.82	.14775	.12593	+19.05	-2.77	-3.98

	$\phi^o N$	$\lambda^o E$	H_m	g	δg_f	δg_B	g_o	g_o''	Δg_o	$\Delta g_o''$	$(\Delta g_o'')_{2.67}$
115	7.15	7.92	179.89	978.08744	55.51	19.07	978.14295	978.12388	+14.25	-4.82	-5.88
114	7.16	7.93	156.06	.09298	48.16	16.55	.14114	.12459	+12.44	-4.11	-5.03
113	7.17	7.95	138.53	.09456	42.75	14.69	.13731	.12262	+8.53	-6.16	-6.97
112	7.18	7.96	127.44	.09582	39.33	13.51	.13515	.12164	+6.00	-7.51	-8.26
111	7.18	7.98	133.17	.09414	41.10	14.12	.13524	.12112	+5.79	-8.33	-9.11
110	7.19	7.99	146.73	.09014	45.28	15.56	.13540	.11984	+5.88	-9.68	-10.54
109	7.19	8.02	134.39	.09395	41.47	14.25	.13542	.12117	+5.83	-8.42	-9.21
108	7.19	8.03	104.67	.09926	32.30	11.10	.13156	.12046	+1.89	-9.21	-9.82
107	7.20	8.05	107.78	.09989	33.26	11.43	.13315	.12172	+3.48	-7.95	-8.58
106	7.21	8.07	111.16	.09924	34.30	11.79	.13354	.12175	+3.72	-8.07	-8.72
105	7.21	8.08	134.11	.09583	41.39	14.22	.13722	.12300	+7.18	-7.04	-7.83
104	7.21	8.11	145.24	.09313	44.82	15.40	.13795	.12255	+7.76	-7.64	-8.49
103	7.21	8.13	149.75	.09237	46.21	15.89	.13858	.12269	+8.46	-7.43	-8.31
102	7.21	8.14	184.28	.08536	56.87	19.54	.14223	.12269	+12.19	-6.42	-7.50
101	7.20	8.17	191.84	.08476	59.20	20.34	.14396	.12362	+14.14	-6.20	-7.33
*B100	7.20	8.18	194.77	.08361	60.11	20.65	.14372	.12307	+13.83	-6.58	-7.72
150	7.20	8.20	199.13	.08297	61.45	21.11	.14442	.12331	+14.45	-6.66	-7.83
151	7.21	8.22	183.06	.08670	56.49	19.41	.14319	.12378	+13.00	-6.41	-7.48
152	7.22	8.23	145.36	.09595	44.86	15.41	.14081	.12540	+10.47	-4.94	-5.79
153	7.23	8.23	132.44	.09967	40.87	14.04	.14054	.12650	+9.98	-4.06	-4.84
154	7.24	8.24	129.97	.10052	40.11	13.78	.14063	.12685	+9.80	-3.98	-4.74
155	7.25	8.26	117.62	.10386	36.30	12.47	.14016	.12769	+9.15	-3.32	-4.01
156	7.25	8.27	127.41	.10490	39.32	13.51	.14422	.13071	+13.21	-0.30	-1.05
*157	7.25	8.28	115.40	.10593	35.61	12.24	.14154	.12930	+10.53	-1.71	-2.39
158	7.25	8.29	102.96	.10942	31.77	10.92	.14119	.13027	+10.18	-0.74	-1.34
159	7.25	8.36	101.86	.11020	31.43	10.80	.14163	.13083	+10.62	-0.18	-0.78
160	7.25	8.32	100.55	.11075	33.03	10.66	.14378	.13312	+12.77	+2.11	+1.52

Stn	ϕ^oN	λ^oE	H_m	g	δ_{gf}	δ_{gB}	g_o	g_o''	Δg_o	$\Delta g_o''$	$(\Delta g_o'')_{2.67}$
161	7.25	8.33	107.11	978.10942	33.05	11.36	978.14247	978.13111	+11.46	+0.1	-0.53
162	7.25	8.34	135.06	.10277	41.68	14.32	.14447	.13013	+13.44	-0.88	-1.67
163	7.25	8.36	127.79	.10678	39.44	13.55	.14622	.13267	+15.21	+1.66	+0.91
164	7.25	8.38	130.42	.10597	40.23	13.83	.14620	.13237	+15.19	+1.36	+0.59
*165	7.25	8.39	158.25	.10090	48.84	16.78	.14974	.13296	+18.73	+1.95	+1.02
166	7.25	8.40	149.50	.10231	46.14	15.85	.14845	.13260	+17.44	+1.59	+0.71
167	7.25	8.42	138.87	.10447	42.86	14.72	.14733	.13261	+16.32	+1.60	+0.78
168	7.25	8.43	160.14	.10081	49.42	16.98	.15023	.13325	+19.22	+2.24	+1.30
169	7.25	8.45	166.09	.09836	51.26	17.61	.14962	.13201	+18.61	+1.00	+0.03
170	7.25	8.46	166.12	.09991	51.26	17.61	.15117	.13356	+20.16	+2.55	+1.57
171	7.25	8.48	183.52	.09518	56.63	19.46	.15181	.13235	+20.80	+1.34	+0.26
172	7.25	8.49	153.01	.09981	47.22	16.22	.14703	.13081	+16.02	-0.20	-1.10
173	7.25	8.50	158.25	.09855	48.84	16.78	.14739	.13061	+16.38	-0.40	-1.33
174	7.25	8.53	150.82	.10172	46.54	15.99	.14826	.13227	+17.25	+1.26	+0.37
*B175	7.25	8.55	178.31	.09532	55.03	18.91	.15035	.13144	-19.34	+0.43	-0.62
176	7.25	8.57	172.67	.10158	53.29	18.31	.15487	.13656	-23.86	+5.55	+4.54
B177	7.25	8.58	166.76	.10275	51.46	17.68	.15421	.13653	+23.20	+5.52	+4.54
178	7.25	8.59	154.32	.10052	47.62	16.36	.14814	.13178	+17.05	+0.69	-0.22
179	7.26	8.60	138.65	.10380	42.79	14.70	.14659	.13189	+15.39	+0.69	-0.12
180	7.26	8.62	113.39	.10908	34.99	12.02	.14407	.13205	+12.76	+0.74	+0.07
181	7.27	8.63	113.51	.10875	35.03	12.04	.14378	.13174	+12.39	+0.35	-0.32
182	7.27	8.65	109.97	.10783	33.94	11.66	.14177	.13011	+10.38	-1.28	-1.93
183	7.27	8.67	110.37	.10922	34.06	11.70	.14328	.13158	+11.82	+0.12	-0.53
184	7.27	8.68	129.54	.10694	39.98	13.74	.14692	.13318	+15.38	+1.64	+0.88
185	7.28	8.70	140.24	.10606	43.28	14.87	.14934	.13447	+17.76	+2.89	+2.07
186	7.28	8.72	162.15	.09934	50.04	17.19	.14938	.13219	+17.60	+0.42	-0.53
187	7.29	8.73	168.80	.09919	52.09	17.90	.15128	.13338	+19.36	+1.46	+0.47

Stn	ϕ^{o}N	λ^{o}E	H_m	g_{gal}	δgf	δgB	g_o	g_o''	Δgo	$\Delta go''$	$(\Delta g_o'')_{2.67}$
188	7.29	8.75	165.93	978.10063	51.21	17.59	978.15184	978.13425	+19.85	+2.33	+1.36
*B189	7.30	8.77	162.31	.10281	50.09	17.21	.15290	.13569	+20.83	+3.62	+2.67
190	7.30	8.78	158.25	.10263	48.84	16.78	.15147	.13469	+19.33	+2.55	+1.62
191	7.30	8.80	157.49	.10519	48.60	16.70	.15379	.13709	+21.65	+4.95	+4.03
192	7.30	8.83	150.24	.10985	46.36	15.93	.15621	.14028	+24.07	+8.14	+7.26
193	7.30	8.84	154.11	.10825	47.56	16.34	.15581	.13947	+23.67	+7.33	+6.43
*194	7.30	8.86	160.32	.10850	49.47	17.00	.15797	.14097	+25.83	+8.83	+7.89
195	7.30	8.88	169.47	.10818	52.30	17.97	.16048	.14251	+28.34	+10.37	+9.38
196	7.30	8.90	166.39	.10922	51.35	17.64	.16057	.14293	+28.43	+10.79	+9.81
197	7.31	8.92	147.49	.11358	45.52	15.64	.15910	.14346	+26.81	+11.17	+10.30
198	7.31	8.93	157.46	.11217	48.59	16.70	.16076	.14406	+28.43	+11.73	+10.81
199	7.31	8.95	154.23	.11121	47.60	16.35	.15881	.14246	+26.29	+ 9.94	+9.03
200	7.32	8.97	168.58	.10585	52.02	17.87	.15787	.14000	+25.20	+7.33	+6.33
201	7.35	8.98	180.08	.10356	55.57	19.09	.15913	.14004	+26.48	+6.84	+5.78
202	7.35	8.99	199.83	.09801	61.67	21.19	.15968	.13849	+26.32	+5.13	+3.96
203	7.36	9.00	230.76	.09198	71.21	24.47	.16319	.13872	+29.61	+5.14	+3.79
204	7.37	9.02	234.73	.09035	72.44	24.89	.16279	.13790	+29.05	+4.16	+2.78
205	7.38	9.03	226.56	.09256	69.92	24.02	.16248	.13846	+28.97	+4.95	+3.62
206	7.35	9.03	226.68	.09326	69.95	24.03	.16321	.13918	+29.93	+5.90	+4.57
*207	7.35	9.05	211.53	.09644	65.28	22.43	.16172	.13929	+28.44	+6.01	+4.77
208	7.38	9.05	238.35	.10369	73.55	25.27	.17715	.15188	+43.19	+17.23	-
209	7.41	9.05	217.57	.10712	67.14	23.07	.17426	.15119	+39.61	+16.54	-
210	7.43	9.08	237.96	.09371	72.53	25.23	.16624	.14101	+31.13	+ 5.90	+4.5
211	7.45	9.10	222.81	.09387	67.91	23.62	.16178	.13816	+26.20	+2.58	+1.27
212	7.46	9.13	175.38	.10156	53.46	18.60	.15502	.13642	+19.21	+0.61	-0.42
*213	7.48	9.18	121.16	.10966	36.93	12.85	.14659	.13374	+10.32	-2.53	-3.24

APPENDIX B

The gravity stations have been numbered, though not in numerical order from the western to the eastern end of the profile.

Station No.

44	Located in Auchi town at the road junction to Igarra. Eastwards from No. 44 stations are established every 4km along the old road from Auchi to Agenebode. Station No. 37 coincides with mile post 16 on Auchi-Agenebode road.
30	Established on the west bank of the River Niger, 100 metres from the Agenebode Police post.
84	Sited in the eastern bank of the River Niger, 20 metres to the ferry post in Idah. From Idah waterside stations are marked every 2km, along Nsukka road to the west bank of the Anambra River where station 99 is located.
99	Egabado village. West bank of the Anambra River at the point the car is loaded onto a barge.
26	Established on the eastern bank of the Anambra River just as you step off the barge. The river is 50m wide in this area. Stations 25 to 12 are marked every 2km.
12	Ugwuaka market; established on bench mark No. 25/22, 16 metres from the provincial boundary pillar and mile post 39½ Idah-Nsukka road. Station Nos. 11 to 1 are established every 2km until station LBM6.
LBM6	Sited in the centre of Nsukka town on local bench mark No. 6 in front of the Bishop Shanahan Hospital. Stations 60 to 64 are established every 2km beginning from LBM6 along Nsukka-Opi road. No. 65 is exactly at the junction of Nsukka road to Enugu-Oturkpo road.

Station No.

Station No.	
	Along Opi-Oturkpo road, all the stations are 2km apart. No. 079 is sited on the right hand side of the Opi-Oturkpo road exactly 0.5km from the first store in Orokam market.
117	Located at the main entrance to Ajide St. Michael's Catholic primary School, No. 104 is located on the left side of the Opi-Oturkpo road, 0.5km from the Lokoja junction.
100	Fundamental Base Station. Established on BM 46/69 by the railway line 200m to Oturkpo railway station.
	Station Nos. 150-172 are located at 2km interval along Oturkpo-Makurdi road. Station Nos. 172 to 200 are along the untarred road from Aliade to Gboko. No. 174 is established on BM93/21 near mile post 29 along Aliade-Gboko road.
175	Located 2km from No. 174, on the standard bench mark in Awajir junction. Stations from Nos. 175 to 189 are established every 2km.
189	Located on bench mark 93/13 near mile post 47, Oturkpo-Gboko road. No. 189 to 207 are marked every 2km. No. 203 is at the main entrance to Gboko Ministry of Works and Surveys. No. 207 is near the Yandev-Makurdi road junction.
208-213	Station 208 is located 4km from No. 207 along Yandev-Buruku road. Similarly stations 208-212 are marked along Buruku road at intervals of 4km. Station 213 is at the west bank of River Katsina-Ala, just at the petrol depot.

APPENDIX C

Derivation of Formula for Obtaining Δ_{go}'' Using a density of $2.67 gm.cm^{-3}$

$$(\Delta_{go}'')_{2.67} = g_{obs} + \delta_{gf} - (\delta_{gB})_{2.67} - \gamma_o$$

$$(\Delta_{go}'')_{2.53} = g_{obs} + \delta_{gf} - (\delta_{gB})_{2.53} - \gamma_o$$

$$(\Delta_{go}'')_{2.67} - (\Delta_{go}'')_{2.53} = -(\delta_{gB})_{2.67} + (\delta_{gB})_{2.53}$$

$$= -2\pi G(2.67)H + 2\pi G(2.53)H$$

$$(\Delta_{go}'')_{2.67} - (\Delta_{go}'')_{2.53} = -2\pi GH(2.67 - 2.53)$$

$$= -(2\pi G \times 0.14)H$$

$$= -0.04191 \times 0.14 \times H$$

$$= -0.00587.H$$

$$\therefore \quad (\Delta_{go}'')_{2.67} = (\Delta_{go}'')_{2.53} - 0.00587 H.$$