APPENDIX A.1

GRAVITY SURVEY OF DUTSE COMPLEX
IN
KANO STATE

BY

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APPENDIX A.2

DECLARATION

This is to certify that the work reported on this thesis was carried out by me:-

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ABSTRACT

A gravity survey was carried out over Dutsu Complex, Kano State for a total of six weeks during the months of October and November 1977, February, July and August 1978.

The observed Bouguer anomaly showed that the area is characterised by negative values ranging from -350 gu to -c230 gu. The pattern of the contours on the Bouguer anomaly map suggested that the anomaly might have been due to a plug-like body, thus a computer programme for three dimensional mass modelling was used for the interpretation.

It was also observed that the Dutse Complex is made up of typical rocks of the Younger granite suite such as riebeckite granite and rhyolite with characteristic low density values.

The three dimensional model studies suggest that the riebeckite granite is a pluton which is 4km in thickness and about 14km in diameter buried at shallow depth of about 0.5km. The surface expression of this pluton is a series of small cylindrical pipes of different radii which serve as outlets of the magma at depth. The rhyolite is probably the volcanic phase following the intrusion of the peralkaline granites extruded through one of the pipes within the granitic pluton.

ACKNOWLEDGEMENT

I wish to express my gratitude to the Director, Geological Survey of Nigeria for sponsoring me through this course and making available, as well, facilities necessary from time to time.

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GRAVITY SURVEY OF THE DUTSE COMPLEX KANO STATE OF NIGERIA

CHAPTER ONE

INTRODUCTION

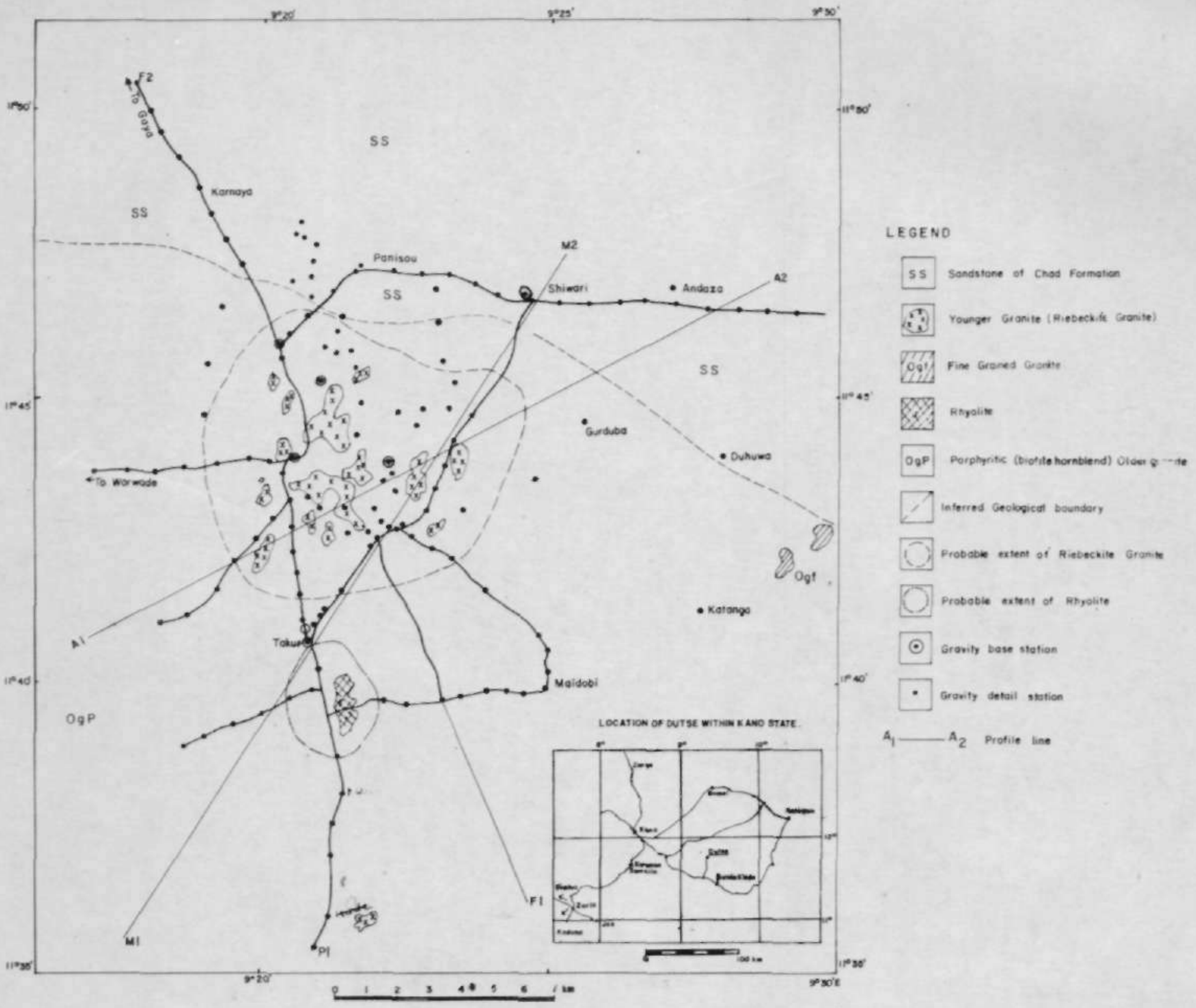
The area covered by the gravity survey described in this thesis lies between latitudes 11°36'N and 11°51'N and longitudes 9°17' and 9°25'E. It covers an area of 150 sq km in the Kano State. This area is centred on the Dutse complex which is located about 134 km east-south-east of Kano in fig.1.

Three distinct groups of rocks were found in the area. These were rocks forming the basement complex, the Younger Granite series and the sandstone (fig.1).

The Basement Complex consists mainly of quartzites and are said to be of Precambrian age (Okorun, 1976).
The Jurrasic Younger Granites consist of rhyolites,porphyritic riebeckite micro-granite, and the coarse grained and fine grained riebeckite granites (Turner, 1976).
The sandstones belong to the Chad formation of pleistocene age (Matheis, 1976). Outcrops of this latter group are scarce in the area.

GEOLOGICAL MAP OF DUTSE AREA

FIG. 1



(After Okosun, 1976)

The Younger granites have attracted a lot of geological interest from as early as 1902 mainly because of the occurence of minerals associated with them; examples of which are tin, columbite, wolfram, monazite and zircon. Several geologists have carried out detailed studies of different parts of the province and by 1922, the characteristic features of the area have been recognised. These publications are summarised in Bulletins 32 and 33 of the Nigeria Geological Survey (Macleod . Turner and Wright, 1971; Turner and Jacobson 1977).

The studies indicate that the Younger granites of the Jurrasic ring complexes comprising mainly of peralkaline graintes, syenites, porphyries and rhyolites intrude into the Precambrian to Upper Cambrian basement complex terrain consisting mainly of migmatite and porphyritic biotite granite. The biotite granites in the Jurrasic ring complexes have been recognised by Falconer(1911) as the source of tin and columbite which are still being mined in commercial but decreasing quantities.

Previous Geophysical Work In The Area

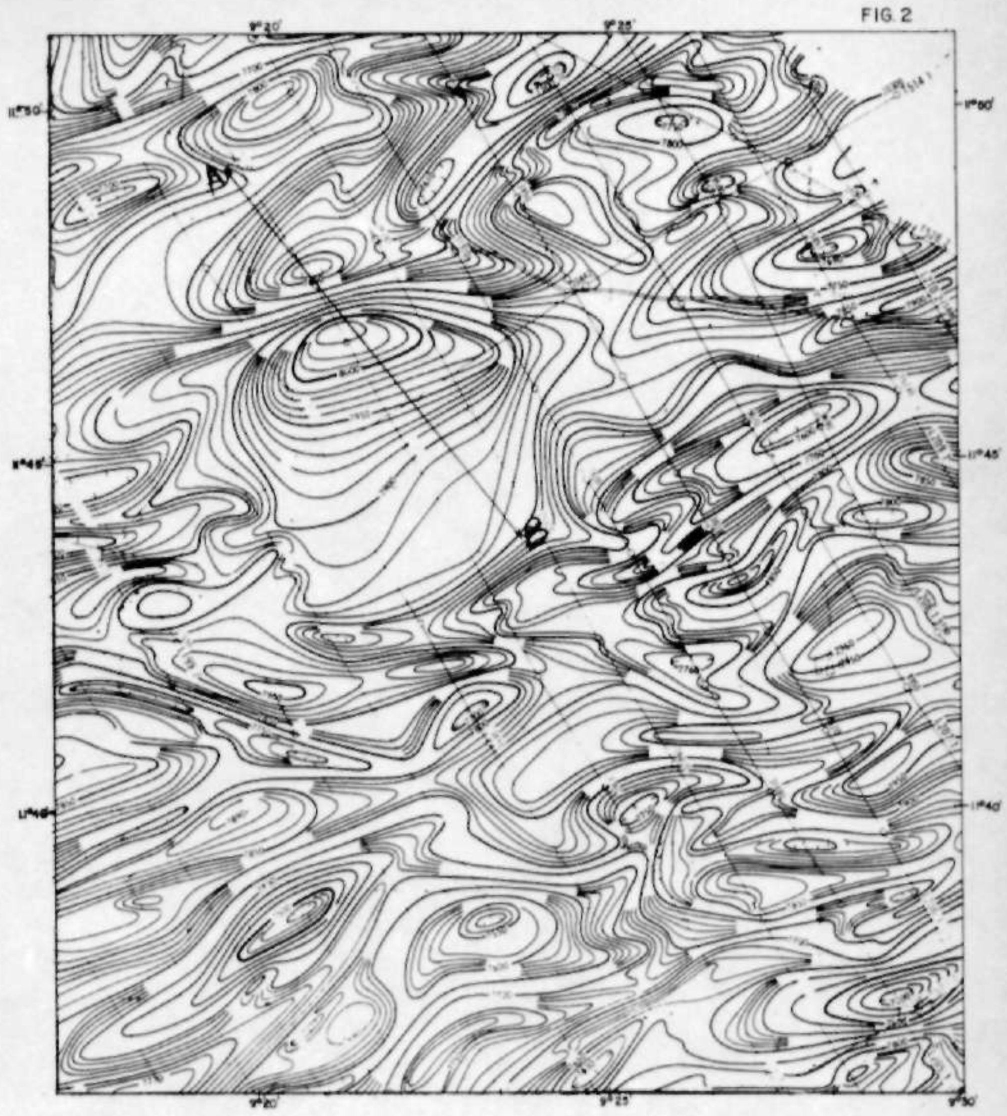
Very little geophysical work has been done in the whole of Nigeria in general and virtually none has been done in this area in particular.

An aeromagnetic survey of sheet 82, Gaya, on scale of 1:100,000 was flown on behalf of the Geological Survey of Nigeria by Huntings Geology and Geophysics in 1974. This survey revealed an anomaly of up to 8000 gammas at the north central part of the survey area, shown in fig.2.

This anomaly was found by the author to be due to veins of magnetite each about one metre thick and aligned parallel to the prevailing trend of the Younger Granite outcrop. These were found in the sandstone region north of the granitic outcrop. There is also evidence that the veins were intruded after a period of faulting since fracture patterns were observed on the granites. Some breccias were also enclosed as xenoliths in the magnetite veins even though the main riebeckite granite body itself was totally intact.

At the northwestern corner of the area, a resistivity survey had been carried out by Ige (1967) for water investigation in the Gaya district.

FIG. 2



Aeromagnetic Map of Dutse Area (After G.S.D., 1975)

1:100,000

The report of this was not available during the period of this present survey.

A gravity survey had also been conducted across the Chad formation - Basement contact areas of Kano State with station spacings of approximately 5 km on all motorable roads in the area of the present Survey. (Ajakaiye and Verheijen, 1977). The Bouguer anomaly values were found to be much higher in the Quaternary formations than in the Basement areas of the region. A negative Bouguer anomaly was also located, by these workers, north of Birnin Kudu which they associated with a Younger Granite complex which could be the Dutse Complex.

Aims of the Present Survey

The primary aim of the present survey is structural rather than economical, since biotite granite commonly considered to be associated with mineralization is not present at Dutse. It is thus hoped that by this study:-

(i) The depth, mode and structural factors contributing to the emplacement of the younger granites in this area will be determined.

(ii) The link between the Nigerian Younger Granites and those of the southern Niger Republic would be more firmly established (fig.3). This has become necessary since conclusions regarding petrogenesis and the mode of emplacement of several ring complexes within the Nigerian Younger Granite Province have been based primarily on geological mapping, structural and petrological studies (Turner, 1963, 1972; Oyawoye, 1968; Brown and Bowden, 1973; Jacobson and Macleod, 1977).

Geochronological (Van Breemon and Bowden, 1973) studies have also been employed to explain their origin and emplacement, while gravity measurements have also been conducted to determine their subsurface geometry (Ajakaiye, 1970, 1973).

It is hoped that this present study will provide additional evidence against which the existing emplacement theories (based exclusively on surficial evidence) may be tested.

CHAPTER TWO

GEOLOGY

2.10. Regional Geology: The general geology of the Younger Granite complexes in Nigeria and southern Niger and also the location of the Dutse complex with respect to the rest of the Younger Granite province are shown in fig.3.

In the central part of Nigeria, the Younger Granites and the volcanics intrude into the Precambrian basement complex rocks; on the other hand the Younger Granites in Niger are found spatially associated with the Cretaceous and post Cretaceous sediments(fig.3).

In the project area, the basement complex rocks can be found in the south, the Younger Granites in the central part and the sediments of the Chad formation in the north.

2.11. The Basement Complex: This can be divided into two main groups:those termed by Oyawoye (1964) as ancient metasediments, which consist of granulitic gneiss, migmatites and various schists which are now considered to be older than 2220 million years (Grant,1969) and a group comprising migmatite, granite gneiss and older granites which are about 467 - 618 million years(Grant, 1969).

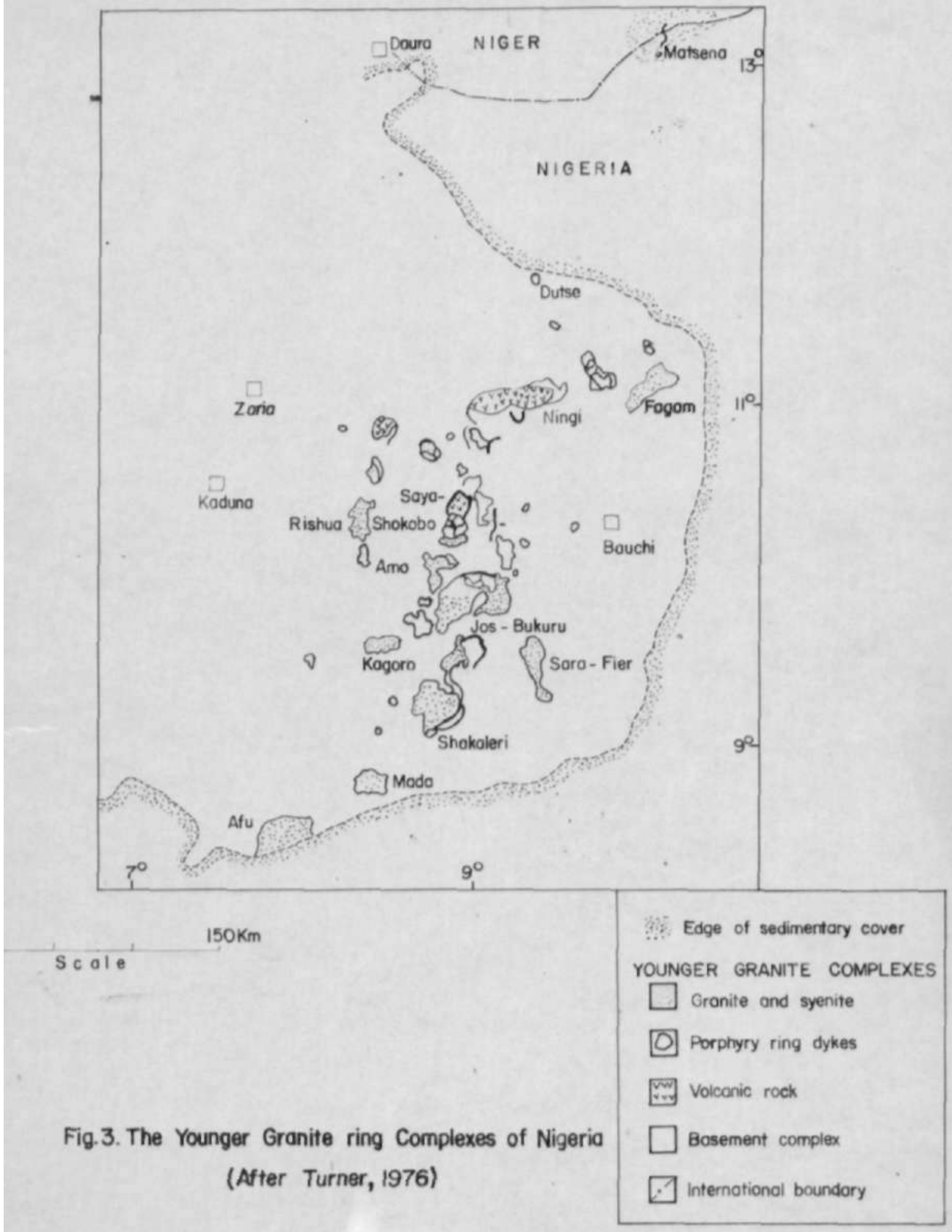


Fig. 3. The Younger Granite ring Complexes of Nigeria (After Turner, 1976)

These two groups have been further subdivided into three (Ajibade, 1976) thus:-

(a) The crystalline gneiss and migmatites of generally amphibolite facies metamorphism which include migmatites, granite gneiss, banded gneiss, augen gneiss and biotite gneiss.

(b) Linear belts of metasediments and metaigneous rocks of generally green schists and lower amphibolite facies metamorphism.

(c) Granitic rocks of the Older Granite suite which include porphyritic and coarse-porphyritic biotite granites, fine and medium grained biotite and biotite muscovite granite, granodiorite, diorite, gabbro and quartz syenite.

2.12. **The Younger Granite Province:** These are a group of discordant alkaline granites first recognised by Falconer in 1911 in Nigeria (Turner, 1976). They are thought to have been intruded into the Basement rocks in Jurassic time (Jacobson et al, 1963). They form distinctive rocky hill masses both in the central Nigeria and the southern Niger. They are situated along the central zone of the Pan African Orogenic belt and form a northernly continuation of the continental margin of the southern Africa.

Turner (1973) believes that the Younger Granites lie on an extension of the ancient rift structure developed during the separation of the south America and southern Africa on a zone of incipient faulting along which crustal separation did not take place but along which magmatic activity was concentrated.

The Younger Granites are composed usually of several intrusions with different petrographic characteristics; Ring dykes and arcuate intrusions are common.

Their age is around 160-170 million years whilst the Older Granites and accompanying metamorphism of the basement rocks are dated at about 500-600 million years (Van Breeman and Bowden, 1973); (Jacobson et al, 1964, Oghezi, 1978). However it seems likely that the emplacement of the Younger Granites was associated with epeirogenic uplift. Indirect evidence of this is the lack of sediments associated with volcanic rocks of the Younger Granite age which are apparently erupted on to a land surface undergoing erosion not deposition (Turner, 1976). The mode of emplacement of the Younger Granites is by ring-fracture and cauldron subsidence.

The Younger Granite series consist mainly of biotite granites, riebeckite granites, syenites, and their corresponding porphyries. The Younger Granites of Nigeria, especially those of the Jos Plateau, are associated with rich alluvial cassiterite deposits. The frequency of these deposits decrease northwards and hence those in the southern Niger have little or no economic mineralisation. It has also been discovered (Turner,1976) that the quantity of sodic amphibole increases from the southern boundary of the Younger Granites in Nigeria to the north in the southern Niger whilst the biotite granites decrease steadily along the same trend. This probably explains the absence of cassiterite deposits in the Younger Granites of southern Niger since these deposits are often associated with the biotite granites.

2.1.3. The Sediments: These are represented by the Chad formation (Barber, 1955). The formation is a variable sequence which includes all Quaternary sediments of lacustrine and fluviatile origin (Durotoye, 1976). It rests unconformably on the basement in the west and the south east near the Cameroun border with Nigeria. Information on the thickness has been obtained from wells and boreholes (Matheis , 1976).

The data obtained indicate a gentle dip eastwards towards lake Chad and maximum thickness of about 840 m around Baga on the western shore of Lake Chad. The formation varies lithologically and vertically. Towards the centre of the basin, lacustrine clays are predominant but near the margins, fluviatile sand, grits and gravels become more important. It is essentially argillaceous among which impersistent **arenacious** horizons occur. The clays represent deposition under less turbulent conditions and the sands are thought to have been laid down as lake margin deposits or as alluvial fans and deltas.

Dating of the Chad Formation is based on vertebrate remains (Matheis 1976). These remains are of lower Pleistocene age. However a considerable thickness of the formation is found below this fossil bearing horizon in Nigeria; this suggests that part of the rock may be pliocene in age.

2.20. Geology of the Dutse Complex

The Dutse Complex is found at the central part of the project area. It is approximately 36 sq km in area.

It forms a series of hills roughly circular in pattern (fig.1). It consists of riebeckite bearing granites and fine grained rhyolite. The riebeckite granites have been classified on the basis of texture and colour into three types. The three classes of riebeckite granite identified are:

(a) the coarse grained
(b) the fine grained
(c) the porphyritic

The granites vary in shades of pale grey to greenish grey to pink while the texture ranges from fine-grained to coarse grained some of which are porphyritic. In some places, the granite is cut through by small fine-grained dolerite dykes and magnetite bearing veins, especially in areas of minor faults and joints. These magnetite bearing veins are post faulting, since crushed breccias of host rock are found as pseudoxenoliths within the magnetite rich veins.

The coarse grained riebeckite granite: forms the greater percentage, over 70%, of rocks in the area. It is greyish in colour and sometimes pinkish. It may also be porphyritic. The rock occurs as circular massifs and magnetite veins and dolerite dykes have been found in them.

It is being quarried for road construction.

The fine grained riebeckite granite is found as the top layer of the coarse grained type and has the same mineralogical composition as the latter. This rock is presumably the chilled roof zone of the coarse variety since the observation at some quarries show that they both belong to the same pluton.

The porphyritic riebeckite microgranite is greenish grey in colour with phenocryst of alkali feldspar interspersed in the microgranite matrix. The greenish colour, which tends to dominate the rock is due to amazon stone which forms the phenocrysts. The quartz grains are fairly large (about 1.5cm diameter) and are of the smoky type; the combination of the amazon stone and the quartz gives the rock a greyish green colour. The rock compares favourably with others found in the Mada complex near Akwanga in Nigeria (fig.3). This type of rock has been located in Australia (Olatunji, personal communication). The rock has the same mineralogical composition with the other ones listed above and occurs between the coarse grained granite in the east and the rhyolites on the south western side of the complex.

2.21. The rhyolite is greyish to red in colour. It is found at the southern end of the complex. It is believed to be younger than the granites because xenoliths of the latter are found in it. The rock is deeply weathered into white clay. Flow bands can be observed on the weathered surfaces of the rhyolites and this indicates the degree of fluidity of the lava during the period of emplacement.

It is not impossible that the Dutse complex forms a link between the Nigerian Younger Granites and those at Zinder. This could be so since the entire belt of the ring complexes of the Nigeria-Niger province lie on a north-south belt of about 1,300km. long related to the major features of the African continent. This belt stretches from the northern Air region of the Niger Republic to the margin of the Benue Valley in Nigeria. The major features which happened within the continent are the north-south trending Pan-African Orogenic belt and the northernly continuation of the continental margin of southern Africa. The unpublished K-Ar determinations (around 295 million years) quoted by Black and Girod (1970) on granites from the northern region of Air and the ages determined for other complexes by Bowden (1973) suggest a sequential age trend along a north/south line of 0.76 cm/year for the Younger granites. The liruei complex was determined to be 177±3m.y(Bowden, 1973), the author has also estimated that the Dutse Complex, which is more northernly than the former, is older than 190m.y.

It has also been discovered that the rocks are predominantly alkaline granites and this predominates in the Younger Granites from the south to the north.

2.22. Economic Geology: The Younger granites at Dutse are basically peralkaline and hence do not have cassiterite mineralisation associated with them as is the case with the biotites on the Jos Plateau. However there are magnetite veins which can be further investigated to ascertain their lateral extent and possibly determine their economic viability.

(i) The Magnetite Veins: are lenticular in shape and are scattered on one of the outcrops. The lenses are about3-4 cm in diameter and it is believed that they perhaps extend beneath the adjacent Chad formation. If this is so then it means that they may be Pre-Pliocene in age. They may have occured as epigenetic veins through the fractures created during the emplacement of the granites. Also associated with magnetite are other trace elements like gold, manganese, titanium, niobium, cobalt etc. Since the last three have been found in the southern granites, associated with cassiterite, it is not impossible that they would be found associated with the magnetite veins.

Thus further work can be done to trace the distribution, lateral and in depth extent of the magnetite veins.

(ii) The riebeckite granites are being quarried for road construction and residential buildings. The quartzites as well as the sands of the Chad formation are also being used for the building industry.

(iii) The rhyolites, weathered into kaoline, are being used for pottery. Since the rhyolites are only concentrated in the southern area of the survey and are not very extensive, it would be necessary for the kaolinitic clay to be sampled to determine its suitability for the ceramic industry. The extent of kaolinitisation and reserve estimation would also be useful.

The rhyolitic rocks weather down into alkaline elements which enrich the soil for farming.

CHAPTER THREE

Field Procedure and Data Reduction

3.1. **Field work**: The gravity survey was carried out in a total of 6 weeks during three periods in October/November, 1977, February, 1978 and July/August, 1978 on the available tracks in the area.

The instrument employed was a worden Gravimeter No.135 with dial constant of 0.683 (3) g.u/division. Two Wallace-Tiernan altimeters and one psychrometer were used to determine the heights. All the instruments were transported in a landrover during the first and third trips and in a peugeot 504 station wagon during the second field trip along the motorable roads in the survey area. Other stations were established on foot. The stations were located at approximately one kilometre interval and at the junctions of the numerous footpaths which connect the villages in the area. This facilitated location of the points on the map which was based on a 1976 topographical survey of the area on a 1:50,000 scale.

The gravity meter was read twice at three minutes interval in each station, after the instrument has been levelled.

More readings were taken whenever the difference between the first two readings were more than 0.1 division (about 0.1 g.u) on the gravimeter scale. The altimeters were also read in the interval of time between the gravimeter readings at any particular station. The second set of readings of the altimeters were taken after the final reading of the gravimeter at each station. Every precaution was taken to ensure that the altimeters attained the pressure of the surroundings at each station by, for example, opening the altimeters on arrival at a station to allow the instruments to settle down to the pressure of the surroundings. Readings of the psychrometer were also taken along with those of the altimeters at each station.

The altimeters were found to behave much more irregularly between the hours of 1400 and 1600 local time due to metereological conditions and hence were not used during this period throughout the survey.

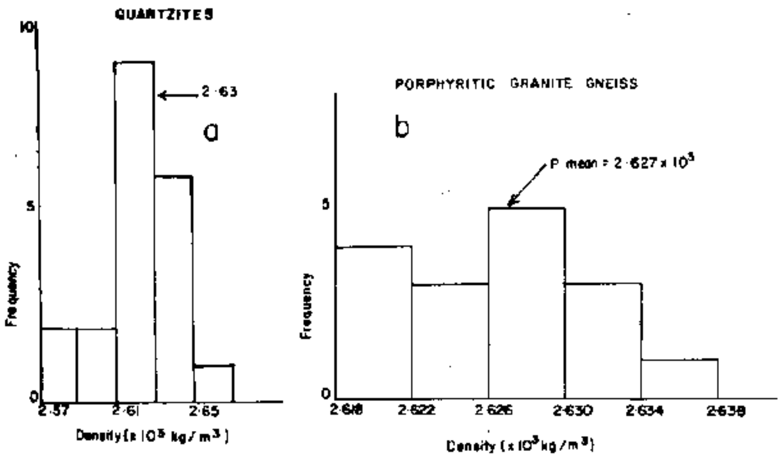
3.2. The Base networks: The absolute gravity value and height of a school at Takur (fig.1) about 0.5 km north of base station A_1 used were 9781246.80 g.u. and 441.5 meters respectively (Ajakaiye, 1977).

The heights and gravity values of the base stations at A_1 and A_4 were tied to this known value by the usual method of base looping. All other stations in the survey, were then tied to these two bases. The base station locations and network are shown in fig.1 and 4. A tie between two base stations was established by the technique of "looping" in the form of A B A B C (Nettleton, 1940). The bases were interconnected to form seven loops. The computer programme for linear drift least squares error adjustment (P.J.T. Verheijen, personal communication) was used for both the gravity meter and altimeter base network.

The altimeter base network was established using the same field procedure as the gravity base network. Corrections for humidity effect were applied to the altimeter readings.

The method employed for the detailed stations was that of returning to the base after every two hours, that is, of the form A, 1,2,3,4,5, A where the numbers in between the base stations are the detail stations. The estimated error for each of the gravity base station is about 2.5 g.u. This can be subdivided into the reading error which is 0.5g.u. and the closure error of 2.0g.u. in the base network.

Fig.5·3 HISTOGRAM OF THE ROCK DENSITIES IN THE AREA



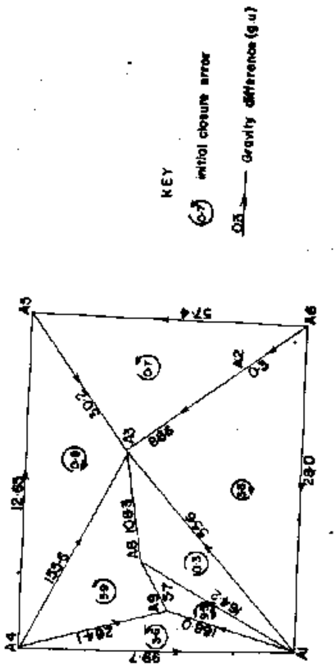


FIG. 4. GRAVIMETER BASE LOOPS

The estimated error in the altimeter base network is about 8ft (2.4 metres). This error is made up of that due to the instrument, 1.0m (Ajakaiye and Verheijen, 1978), temperature and humidity affects and it was estimated by least square programme mentioned earlier (Verheijen,personal communication). The various sources of errors in the height determination with altimeters probably explain why there are large closure errors (up to 4.3 metres in one sector).

The average temperatures for each loop in the detail stations were used to correct for the humidity effect. The estimated error in the height for each detailed station is 2.4 metres.

3.3. <u>Data Reduction</u>: From the field measurements the Bouguer and free air anomaly values were calculated for each of the base and detail stations. The average differences in gravity values determined from the drift curves were adjusted with the kbown value(47) at the school to determine the absolute gravity values for each station.

All the altimeter readings were also converted to heights after applying the temperature - humidity corrections.

3.4. Corrections applied to the observed readings

(a) Theoretical Gravity and Latitude effect

The reference spheriod used is the international ellipsoid of 1973 given by the equation

$g(\phi) = 9780318.5(1+0.005278895 \sin^2\phi + 0.0000023462 \sin^4\phi)$. Where $g(\phi)$ is the theoretical value of gravity, in gravity units, and ϕ is the latitude of the station (Jacobs, 1974). The theoretical value takes account of the latitude effect at the observation point whose latitude is ϕ.

(b) Free Air anomaly This anomaly is computed by taking the difference between the measured value $(g)_s$ at the topographic surface and the theoretical (g_ϕ) which is extrapolated from the reference ellipsoid, and correcting it for the vertical decrease of gravity with increase in elevation. The general expression is given by the equation

$$\Delta g_{FA} = g_s - \left(g_\phi - \frac{dg}{dz} \cdot h\right).$$

where Δg_{FA} is the Free air anomaly; $\frac{dg}{dz}$ is the vertical gradient of gravity (which is taken to be 3.086 g.u./m) and h is the station elevation in metres above the sea level.

(c) The terrain correction This correction allows for surface irregularities in the vicinity of the station, that is, hills rising above the gravity station and valleys below it. Both affect gravity measurements in the same sense by reducing the magnitude of the observed readings hence the correction is added to the observed measurement at the station. The correction is estimated from a topographic map(scale 1:50,000) using a template or zone chart. The Hammer zone chart (Hammer, 1939) was used at first to calculate the corrections for twenty randomly chosen stations round the complex. Since the corrections were found to be significant, about 10 g.u. in one station which was the highest judging from the fact that the maximum anomaly was 130 g.u., all other stations' terrain corrections were then calculated.

It was observed that the terrain correction (Tc) was affected by:

(i) absolute height difference between the station located at the centres of the peak of the complex and the station at which the correction is being made; that is ΔH:
The greater the value of DH, the lower the gravimeter reading.

(ii) the distance between the station X_1 located at the centre of the peak and the station on which correction is being made (X_2).

(iii) the angle between the stations (θ). (see diagram below)

The first term comes essentially as a "correction" to the Bouguer Correction, where a piece of slab thickness $|\Delta H|$ is taken off the Bouguer correction and thus becomes an addition.

The second term takes the shape of a mountain into account as a mass and because only the vertical component plays a role

$$\frac{GMm\theta}{R^2} \simeq \frac{GMh}{R^3}$$ where GMh is represented by β.

It was found that $|\Delta H|$ was the main contributing factor. From the use of Computer programme supplied by P.J.T. Verhsijen for the adjustment of least square fitting the suitable formula

$$T_c = \frac{|\Delta H|^{\alpha}}{\beta/R}$$

was deduced for the calculation of each station where

$\alpha = 0.00002$, $\beta = 0.0029$

are constants. It was found that $|\Delta H|^{\alpha}$ was the main contributing factor.

3.5. Bouguer Anomaly is determined using the equation

$$g_B = g_s - g_\phi + \frac{dg}{dz} h - 2\pi G \rho_c h + T_c$$

where g_B is the Bouguer anomaly, ρ_c is the assumed crustal density, G is the universal constant of gravitation, T_c is the terrain correction 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_c and the gravitational attraction of such a slab on a unit mass is 0.4191 g.u./metre.

3.6. Error analysis The error in the Bouguer anomaly is due to errors in the determination of the relative gravity values, errors in terrain corrections and errors in height determinations, that is

$$\Delta_B = \Delta g + \Delta T_c + \Delta h$$

Error in relative gravity values is due mainly to non-linear drift of the instrument. These have been estimated to 3.0 g.u. for the base stations and 4.0 g.u. for the detail stations.

Error arising from using a wrong density in the Bouguer correction is estimated to be 2.7 g.u. This was calculated using a density contrast of 0.07 x 10^3 km/m^3 and a maximum elevation difference of 94 metres between the stations.

The error due to elevation has been estimated to about 7.5 g.u. since the station elevations were determined to within 2.4 metres accuracy.

Error in the latitude correction may be due to inaccuracies in the location of station on the topographic maps. This has been estimated as 1.0 g.u. for the maps used which were on scale of 1:50,000.

The error in terrain correction for each station is estimated to be 1.0 g.u. Thus it is reasonable to assume that the total maximum error in each of the Bouguer anomaly values is about 9.6 g.u.

Similarly the Free air anomaly is subject to the same error sources as the Bouguer anomaly and thus a combined error of 14 g.u.

It is obvious that the major error source is associated with the height determination. If this could be substantially reduced, then the errors will lie in the order of a few gravity units only, say, 6.0 g.u.

CHAPTER FOUR

Density Measurements

4.1 Introduction: The actual causes of small wavelength gravity anomalies are the lateral heterogeneity of rock densities in the Upper Crust. A knowledge of the densities of rock formations is therefore important in the interpretation of gravity anomalies. Since the accuracy of the interpretation of gravity anomalies depends greatly on the assumed density contrasts of the rocks, which are usually very small, density differences between various rock types in the particular study area must be known in order to appropriately restrict density contrasts used in model computations.

4.2 Sampling Techniques: 157 rock samples were collected from outcrops within the area of survey during the course of the fieldwork. Most of the samples were collected from the quarries and the rest were from outcrops. Care was taken to collect "fresh" and unweathered samples.

All the rock samples were weighed in air (dry weight) and they were then weighed in water (water weight). They were then submerged in water for 26 hours after which they were again weighed in water (saturated weight). The rocks were removed from the water, the excess water was then wiped off and the rocks were then weighed in air (wet weight). The dry density was obtained from the formula

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

using Archimedes principle. The saturated density was determined thus:-

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

Only the rhyolite samples showed significantly higher saturated densities than the dry densities. This indicated that the rhyolite samples had higher porosity than the other samples. In all cases, the mean of the dry and saturated densities was assumed to be the value nearer the true density of the rock. A compilation of the results is given in table 2. Taking the average weight of the samples to be 0.8 kg (some of the samples weighed as much as 2.0 kg. while the least weight is 0.4 kg) and the accuracy of the balance to be ± 0.001 kg, the calculated density values are accurate up to 0.001×10^3 kg/m^3 for the heavier samples and 0.003×10^3 kg/m^3 for the lighter ones.

The fresh rock samples collected in the field might not have been unweathered but they were the best that could be collected in the area. The error in the density determination could be caused by minor changes in the degree of freshness of the rock samples.

4.3 Density of the basement rocks:

36 samples of rocks of the basement complex were collected from the porphyritic granite gneiss and quartzite veins in the area. The 16 granite gneiss samples were collected at Kwanan Sumaila (fig.1; inset) about 50 km from the area since there were no outcrops of this rock type in the survey area. The 20 samples of the quartzite veins were collected at about 0.6 km north of Kude (fig. 1) south of the complex.

The densities of the samples were determined and a histogram was plotted for each of the rock types to permit the study of the distribution (fig. 5.3 (a) and (b). The calculated mean densities of the basement rock types indicated in the histograms show higher mean densities than any of the Younger granite series of rocks; Nevertheless, the mean density of 2.63×10^3 kg/m^3 obtained for the rock types is rather too low to be considered representative of the density of the granite gneiss (basement rocks) in the area;. This could be due to the fact that the samples could only be collected from one distant location. Other reasons could be due to weathering and absence of basement outcrops in the area. Ajakaiye (1970) obtained a density of 2.68×10^3 kg/m^3 for the basement rocks in the Younger Granite province from 392 basement rocks in the Younger granite province just south of the area and 70 samples from areas covered by topographic maps, sheets 97 and 98 (1:100,000). This value is very close to the value of 2.67×10^3 widely used in literature to represent the crustal density. A density of 2.67×10^3 kg/m^3 was therefore adopted to be the density of the basement rocks in the area of investigation. The mean density (2.63×10^3 kg/m^3 agrees favourably with the values obtained by Ajakaiye (1970, 1974) for the Older Granite within the central region of Nigeria and also with the value of 2.65×10^3 kg/m^3 obtained by Osazuwa (1978) for the granite samples collected in the Upper Benue area of Nigeria.

The frequency distribution of the quartzites shows a normal distribution. However this rock type only occurs in minor veins and has no significance for this survey.

The calculated mean density of 2.629×10^3 kg/m^3 for the quartzite samples compares favourably well with the values of 2.59×10^3 kg/m^3 obtained by Osazuwa (1978), 2.60×10^3 kg/m^3 (Telford et al) 1976.

4.4 Densities of the Younger Granite Series:- The rocks of the Younger Granite Series in this complex are basically of one type, that is, riebeckite granites and have only been differentiated on the basis of texture and colour.

The mean density of each rock type was calculated (Table 2) and histograms were plotted to permit the study of distribution of the densities. (fig. 5,4, (a) to (d). In general, the histogram for each rock type, shows a near normal distribution which is what one would expect for igneous rocks of magmatic origin having conditions close to homogeneity (Ajakaiye 1970).

4.4.1 Rhyolite:- The histogram of 24 samples is shown in fig. 5.4.a. These samples were collected from various parts of the only rhyolite hill in the area. The distribution is positively skewed due to variation in composition within the specimens which have affected the rate of weathering in the hill. The low density, 2.5 x 10^3 kg/m^3 which corresponds to the density of kaolin suggests that the samples might have been weathered.

4.4.2 Granites and Porphyries:- The granites have been divided mainly on the basis of texture into fine Grained, coarse grained, and porphyritic riebeckite micrograntes. The

HISTOGRAM OF THE ROCK DENSITIES IN THE AREA

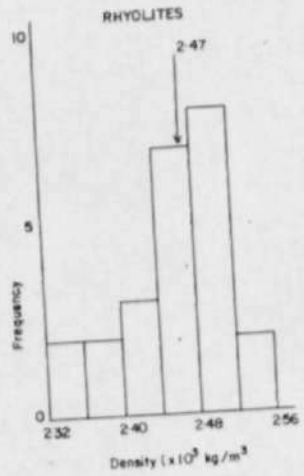


FIG 5 4a

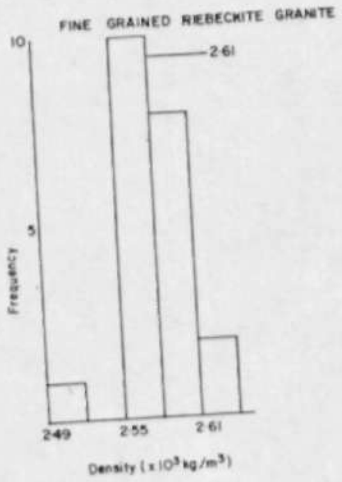


FIG 5 4b

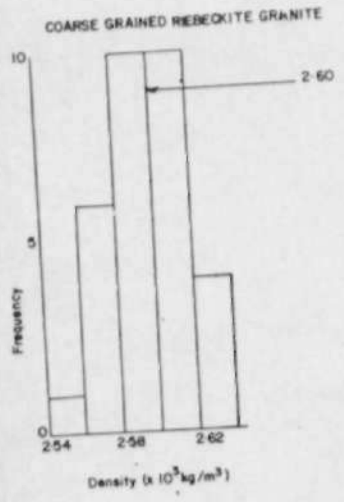


FIG 5 4c

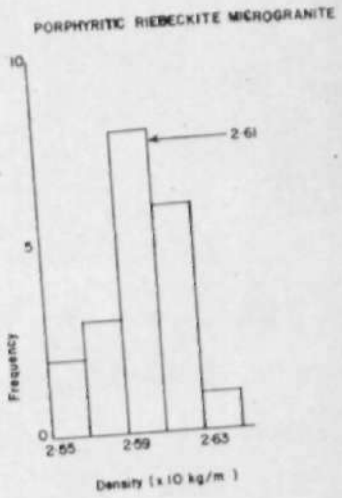


FIG 5 4d

histograms for these rocks are shown in figs. 5.4.b, to 5.4.d. respectively and they show normal distributions. The average value of 2.6 x 10^3 kg/m^3 agrees with the values of 2.6 x 10^3 kg/m^3 (Ajakaiye, 1970) and 2.64 x 10^3 kg/m^3 (Telford et al 1976) for riebeckite granites.

4.4.3. The magnetite containing rocks:- These were collected at the central part of the area. Only ten samples were collected here since the extent of the occurence of the veins is very small and scattered. The densities of the samples are very variable and this shows the varying degree of concentration of the magnetite content. The average density is 2.76 x 10^3 kg/m^3 and the histogram is negatively skewed as shown in fig. 5.5 (a). This probably shows that the quantity and the quality of the magnetite content in the rocks are poor and hence many samples are not mineralised.

4.5. Densities of the sedimentary rock in the area:

The only sedimentary rock is the unconsolidated sands of the Chad formation which is found in the northern part of the area, fig. 1. The measured density of this formation is shown in table 1. The rock varies in grain size

HISTOGRAM OF THE ROCKS COLLECTED IN THE AREA

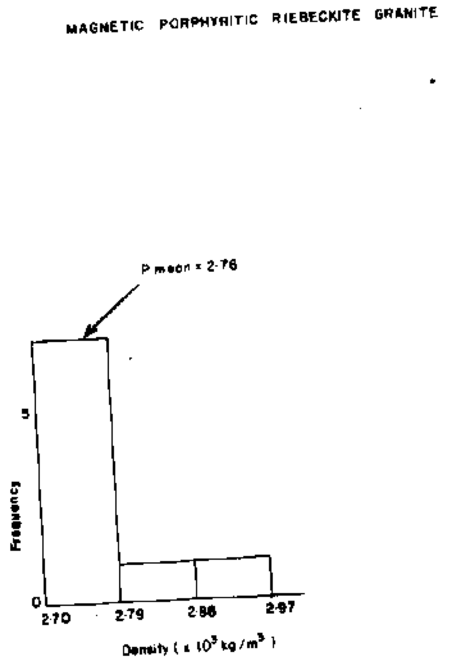

MAGNETIC PORPHYRITIC RIEBECKITE GRANITE

FIG.5·5a

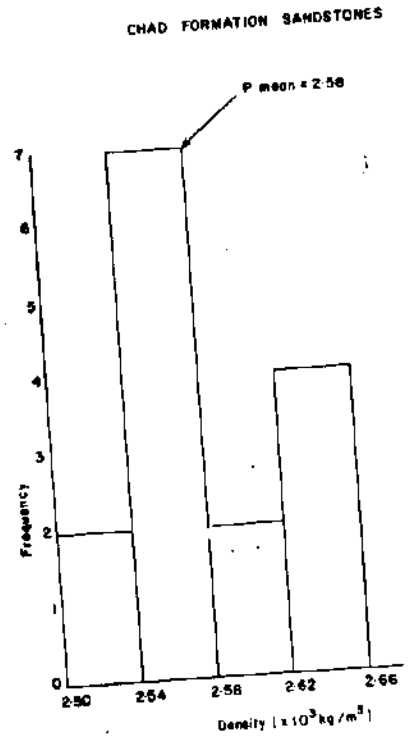

CHAD FORMATION SANDSTONES

FIG 5·5b

TABLE I:

Densities of Lithologic Units (x 10^3 kg/m^3)

Group Name	Rock type	NO. of Samples	Range	Meandensity	Standard devation
Basement Complex (Precambrian)	Porphyritic Granite Quartzite	16 20	2.618-2.635 2.572-2.647	2.627 2.629	0.005 0.023
Younger Granites (Jurrassic)	Coarse Grained Riebeckite Granite	31	2.539-2.637	2.597	0.022
	Fine Grained Riebeckite Granite	21	2.494-2.627	2.588	0.027
	Porphyritic Riebeckite Microgranite	20	2.555-2.641	2.607	0.024
	Rhyolite	24	2.323-2.531	2.466	0.053
	Magnetite rich Riebeckite Granite	10	2.703-2.967	2.761	0.087
Standstone (Pleistocene	Chad Formation	15	2.502-2.662	2.580	0.043

considerably. The overall mean density, fig. 5.5.b, is $(2.58 \pm 0.043) \times 10^3$ kg/m^3. Which is fairly high compared to 2.0×10^3 kg/m^3. The rather high observed value suggests the presence of magnetite in the unconsolidated sands; Also since the colour of the sands vary from whitish to reddish brown and the sands contain some clay minerals, it is not impossible that the increase in the density might also be due to the presence of clay minerals in the formation.

The histogram is negatively skewed and may be due to the fact that the true mean density lies in the region of low density samples. Thus density contrasts of $- 0.07 \times 10^3$ kg/m^3 and $- 0.20 \times 10^3$ kg/m^3 were used for the modelling of the riebeckite granite and the rhyolite bodies respectively, table 2.

TABLE 2.

Expected density contrasts for the rocks in the Study area assuming the density of the basement rocks to be 2.67×10^3 kg/m^3

Rock type	Density x 10^3 kg/m^3	Density Contrast x 10^3 kg/m^3
Riebeckite Granite (Younger Granite)	2.597 ± 0.009	-0.07
Rhyolite	2.466 ± 0.053	-0.20
Magnetite bearing Riebeckite Granite	2.761 ± 0.087	-0.09
Sandstone (unconsolidated) (Chad formation).,	2.580 ± 0.043	-0.09

CHAPTER FIVE

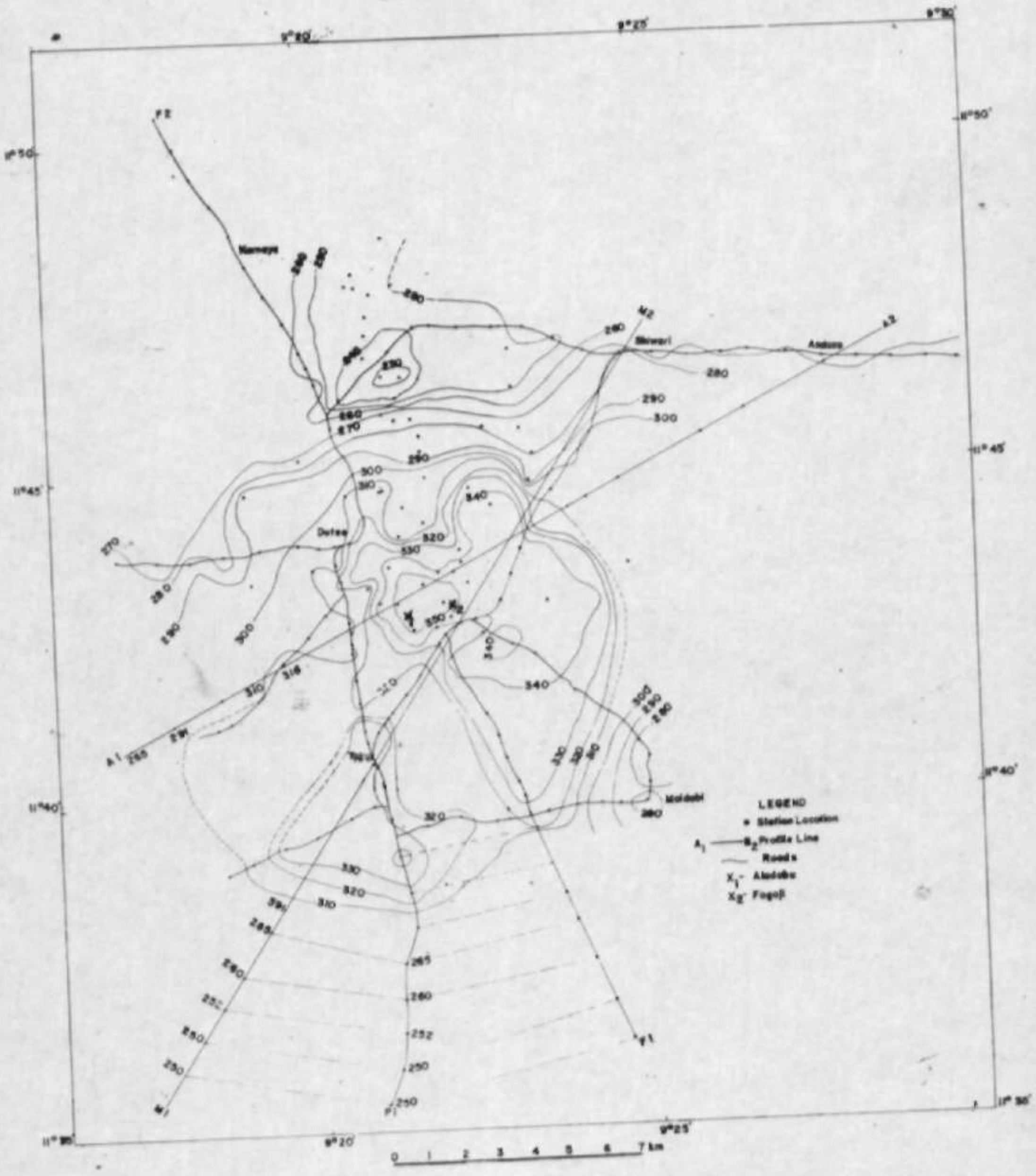
5.1. General Discussion and Interpretation

The geological map (fig.1) shows the four distinct rock types: the quarzites, the younger granites, the rhyolites and the sandstones recognisable on the field. Porphyritic granite gneiss are not exposed in the area but their occurence have been deduced from results of borehole data (Okosun, 1976). The quartzites occur as veins in the basement rocks at the southern portion of the area whilst the riebeckite granites and the rhyolites outcrop in the central portion of the area. The sandstones cover the northern part of the area.

The Bouguer anomaly map (fig.6) indicates negative values ranging from -230 g.u. in the north to a minimum of about -350 g.u. around the central portion. The northern portion is characterised with relative high gravity value. The high positive anomaly particularly at the contact between the sandstone and the granites, has been correlated with the presence of small magnetite veins, lenticular in shape, found within the northern area of the complex. It is believed that these veins may extend to the neighbouring sandstones of the Chad formation.

FIG. 6 BOUGUER ANOMALY MAP OF DUTSE COMPLEX KANO STATE

(Values in gravity units)



The aeromagnetic anomaly interpretation map suggests the positive anomaly to be due to the igneous - sedimentary contact (Huntings Surveys, 1976). The central portion of the area is characterised by a pattern of circular negative anomaly contours. The lowest Bouguer values in the project area are found here, that is in the Aladabu-Fagoji area, (fig.6). This is the area where the centre of the Dutse complex is assumed to be on the basis of surface geological mapping (Okosun, 1976).

The negative anomaly in the southern area is due to the rhyolite hills exposed at Takur (fig.1).

5.2. The Regional Anomaly: The estimation of the regional anomaly was done using the data collected along four long traverses, $F_1 F_2$; $P_1 F_2$; $A_1 A_2$ and $M_1 M_2$ marked in the Bouguer anomaly map (fig.5). Profiles $F_1 F_2$ and $M_1 M_2$ are roughly perpendicular to each other and whilst the former passes through only the riebeckite granite, the latter passes through the granite and the rhyolite bodies. The former was chosen because it passes through the centre of the body. Profiles $A_1 A_2$ and $P_1 F_2$ are also nearly perpendicular to each other and were chosen for the reasons stated above for profiles $F_1 F_2$ and $M_1 M_2$.

The regional was removed graphically by drawing straight lines through the extended sections of these profiles. Adequate care was taken that at the crossing between these profiles, the regional had the same value. Thus, for the whole area, the regional was supposed to be a first order surface and this was subtracted from the observed anomaly along the profile.

5.3 Description of the residuals: Profile 1 (F_1 F_2,fig.7) runs from the southeast to approximately north-north-west of the area as it passes through the centre of the complex. The only prominent anomaly, about -85 g.u. on this profile has been attributed to the Younger Granite pluton of the Dutse complex. The complicated pattern of the anomaly indicates that the pluton causing this anomaly could be irregular in shape and inhomogeneous.

Profile 2 (M_1 M_2 fig.8) is roughly perpendicular to profile 1 and thus runs approximately southwest - northeast. It does not pass through the centre of the complex but cuts through the basement, the rhyolite, the riebeckite granite and the sandstones.

GRAVITY PROFILE ACROSS SECTION F2 F1

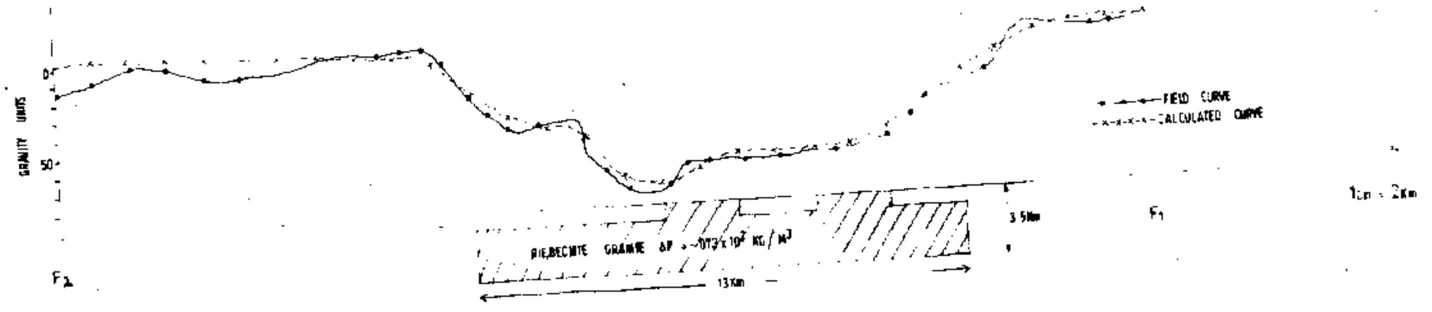
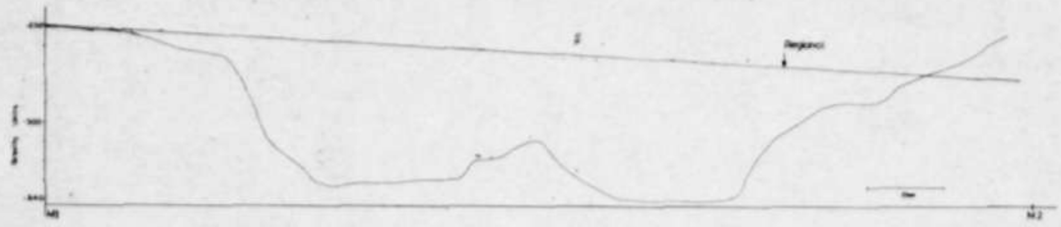


FIG. 7

DIAGRAM SHOWING THE INTERPRETATION MODEL



Gravity profile across section M1 M2

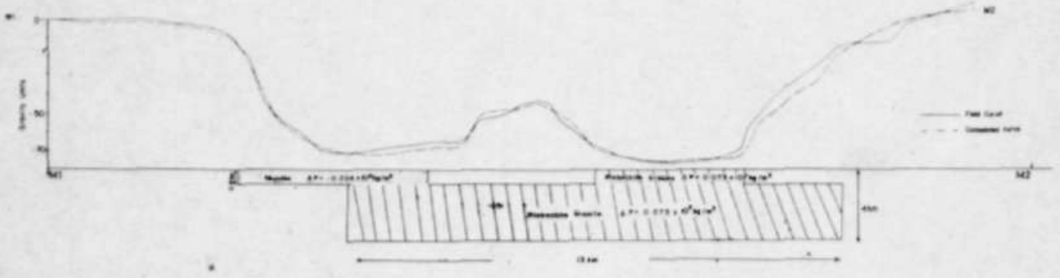


Diagram showing the interpretation model

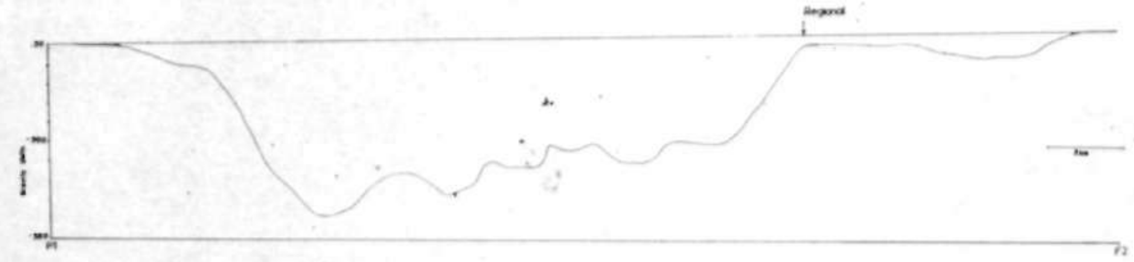
FIG - 8

The rhyolites (fig.1) here have been interpreted as giving rise to an anomaly of -65 g.u. whilst an anomaly as much as -70 g.u. has been attributed to the riebeckite granites. From this profile, it appears the contact between the rhyolite and the riebeckite granite is very sharp even though none was observed on the field.

Profile 3, (P_1 F_2 fig.9) runs approximately from the south to the north but does not pass through the same rock types as profile 2. It has two prominent negative anomalies of 90 g.u. and 80 g.u. attributed to the rhyolite and the riebeckite granite. The variations in the values along the profile might be due to the inhomogeneous nature of the rhyolite and riebeckite plutons. Profile 4 (A_1 A_2,fig.10) is also nearly perpendicular to profile 3 and approximately southwest-northeast. This passes through the centre of the riebeckite granite body, the basement and sandstone. The magnitude of the negative anomaly at the centre of the body, along this profile, 80 g.u. is attributed to the riebeckite granite.

5.4. Quantitative Interpretation:

This was carried out for the two main intrusive bodies, the riebeckite granite and the rhyolite. Each of these bodies was assumed to be cylindrical in shape and the parameters of



Gravity profile across section P1 F2

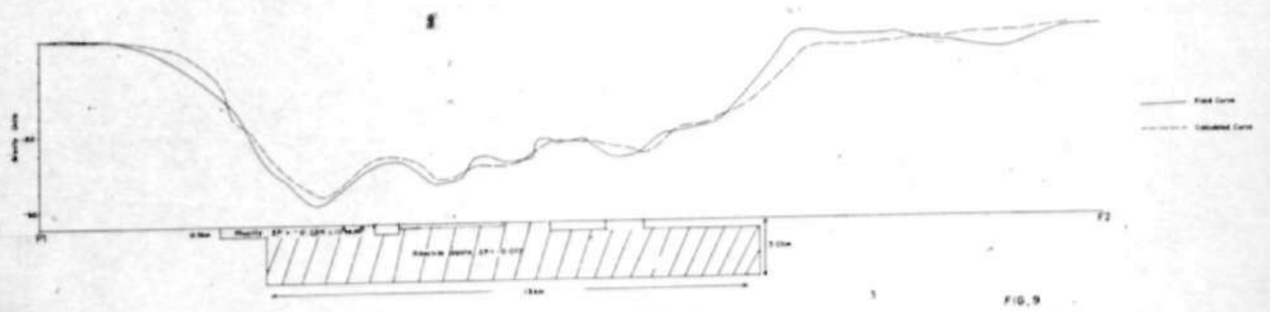
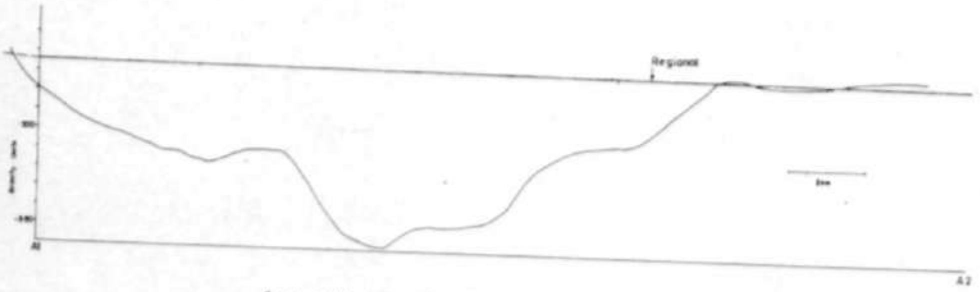


Diagram showing the interpretation model

FIG. 9



Gravity profile across section A1 – A2

FIG 10

Diagram showing the interpretation model

the assumed cylinder were amended in order to obtain a fit to the observed gravity data. The vertical cylinder was chosen as the nearest model, as the Younger granite bodies have previously been presented as either dykelike bodies or cones cutting across the country rock. (Ajakaiye, 1970; Turner, 1976).
Field evidence also confirmed the choice of a vertical cylinder model for the rhyolite bodies.

A first estimation of the thickness of the body was determined by using the Bouguer formula for a thin slab

$$\Delta g = 0.42 \Delta\rho H$$

Where $\Delta\rho$ = density contrast
= -0.204×10^3 kg/m^3 for the rhyolite body
= -0.073×10^3 kg/m^3 for the riebeckite granite
H = radius of the cylindrical body

The radius was determined from

$\Delta g_{max} = 2\pi G \Delta\rho R \times 0.486$ (Telford, 1976) where G is the universal gravitation constant and R is the radius in metres.

The thicknesses and radii of all bodies encountered in the four profiles were then determined and these were used for the initial models for the quantitative interpretation using a computer programme developed by Nagy (1965) and modified by

Ajakaiye and Ojo in 1974. Of the several models considered, the computed profiles with the best fits are shown in figs.7 to 10.

Thus from the models, it could be deduced that the anomalous bodies can be reasonably represented by a series of cylinders. The models also indicate the main cylindrical body of riebeckite granite extends to a depth of 4 km and has many pipes through which it intruded. This main granite body is also the source of the rhyolite hills only that the level of emplacement is quite different from those of the granite bodies. The depth extent of the main granite body is very small of about 4 km compared with its areal extent which is about 13 km in diameter. The centre of the main body is situated around Dutse town.

The rhyolite body probably has only one vein through which it extruded from the main body but spread out as lava flows on the surface extending farther away from the source of extrusion. It should thus be emphasized that the values of "h" (the approximate thickness from the top) and "R" (the approximate radius) of the body for each profile were carried out on the assumption that the causative body was made up of either a homogenous riebeckite granite or a rhyolite cylindrical mass. The method used consisted of fitting a set of cylinders resting on top of each other but having different diameters to interprete any anomaly due to a particular body.

CHAPTER SIX

MAGNETIC INTERPRETATION

The magnetic anomaly interpreted in this chapter occurs in the northeastern section of the aeromagnetic map of the project area (fig.2). A profile AB was taken perpendicular to the strike of the body and this was plotted to be able to determine the quantitative parameters of the causative body.

The profile is shown in fig.11. The shape of the profile represents a plate like body, possibly a dyke, with the south pole nearer the surface of the ground.

The strike lenght of the body was determined by taking the derivatives of the profile up to the third degree when two negative peaks only were present (Koefoed, 1971). The middle of these peaks were marked and the distance between them was recorded as 3.8 km.

The depth of the causative body was determined using koefoed's methods as described below:-
Choosing regular points along the profile and finding the difference between these points and the maximum value (in gammas) of the anomaly.

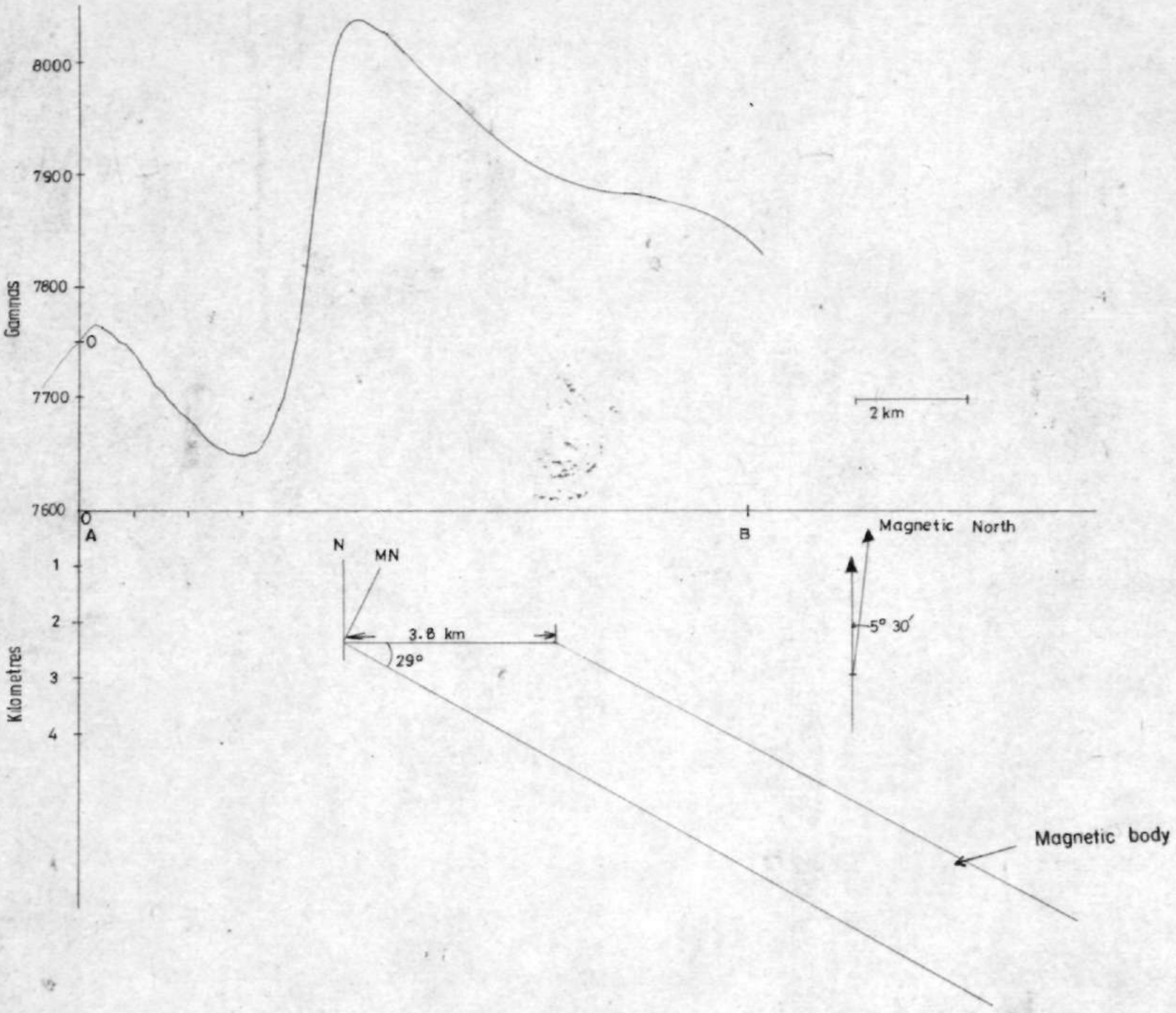


FIG. 11

THE PROFILE ACROSS AB AND THE CALCULATED BODY

(b) Plotting these differences against the distances of these regular points on a bilogarithmic paper.

(c) Matching of the observed curve so produced with standard curves prepared by keofoed and working out the ratios for a dyke like body as the original profile AB suggests the causative body to be.

The strike of the body was determined from the orientation of the contours of the map. The general strike angle of the body was measured from the map with respect to the Earth's magnetic east using Moo's (1965) method. The dip of the body was also determined by using the master curves of J.K. Moo (1965).

(a) Strike length = 3.8 km.

(b) Depth = 2.5 km.

(c) General strike = 24° 30' (with respect to the magnetic east measured in the clock wise direction. The magnetic north is 5° 30 east of the true north as indicated on the Aeromagnetic map provided).

(d) Magnetic susceptibility = 15.13×10^{3} S.I units.

(e) Dip of the body = 60°.

From the above determinations and the observations in the map and the profile AB (fig.11) the direction of the inclination of the dyke was chosen. The profile shows a maximum and a minimum with the maximum very much greater than the minimum; this suggested that the body instead of being vertical, dips towards the east.

The dyke is believed to have been magnetised in the direction of the earth's magnetic field. This assumes that the form of magnetisation is by induction since there is no evidence of remanent magnetisation determined.

The magnetic contour gave the direction of the general strike of the body.

The polarity of the body was determined from the nature of the anomaly bearing in mind that the readings were taken in the northern hemisphere. The occurence of the magnatite rich granite at the northern part of the Dutse complex may be due to introduction of iron rich solution within the weak zones during the late magmatic stages of the granitic intrusion. This idea is more supported by the presence such iron rich solutions in other complexes as discovered by Macleod, W.N.et all (1971) in G.S.N. Bulletion 32. Vol.1. The magnetic body's occurrence near the contact with the sedimentary chad formation also lends credence to the idea of intrusion through a weak zone and its probably non violent mode of introduction.

CHAPTER SEVEN

CONCLUSIONS

7.1 Summary of results: The density of the riebeckite granites has been determined to be 2.60 x 10^3 kg/m^3 whilst that of the magnetite rich riebeckite granite is 2.76 x 10^3 kg/m^3. The magnetic susceptibility of the latter was measured to be 15.13 x 10^3 S.I. units. The density of the quartzites was found to be 2.63 x 10^3 kg/m^3 whilst that of the porphyritic granite gneiss was 2.63 x 10^3 kg/m^3. The average density of the sandstones of the Chad formation was determined to be 2.58 x 10^3 kg/m^3.

From the models which best fit the profiles, the younger granite pluton was estimated to extend to a maximum depth of 4 km in thickness (Profile M_1 M_2, Fig.8). The results from the cross sections F_1 F_2, M_1 M_2, and P_1 F_2 and A_1 A_2 (figs. 7-10) which were taken perpendicular to each other for a three dimensional interpretation of the causative body show that the pluton extends in diameter to about 14 km and it is buried at shallow depth of about 0.5 km. The surface expression of this pluton is a series of small cylindrical pipes of different radii which serve as outlets of the magma at depth.

[redacted]

The rhyolite body is probably the volcanic phase following the intrusion of the peralkaline granites extruded through one of the pipes within the granite pluton as xenoliths of the granites are found in some of the samples observed in situ.

The iron rich veins found within the riebeckite granite may be similar to those found in some other younger granites by previous workers and may be due to late stage of magmatic intrusion (Macleod, W.N. et al 1971), G.S.N. Bulletin 32 vol. 1. Its local occurance in weak contact zone of the granite pluton and the sedimentary formation gives credence to a quiet mode of intrusion.

7.2 Conclusions:- This work has established that the Dutse complex is a member of the Younger Granite suite which are often associated with negative Bouguer anomalies. It has also been confirmed that the Dutse Complex is a pluton of high level magmatic origin on the basis of the shallow depth of 3 to 4 km to the base of the density contrast as have been discovered for other members within the Jos area. (Ajakaiye, 1970; 1974), results of the gravity survey of Dutsen Wai and Banke complexes in the Younger granite province of Nigeria confirm this observation.

In the Banke Complex, it was discovered by Ajakaiye (1974) that the pluton becomes wider as it gets deeper; this has also been found for the Dutse complex (figs.7 to 10). The complex, as has been discovered in other Younger granite area, has a sharp contact with the surrounding rocks of the basement complex. The association of the Dutse granite with the rhyolites also comfirms it to be of intrusive origin. The method of intrusion might be by cauldron subsidence since no chilled margin (evidence of contact metamorphism) was observed on the field. The magnetite observed in the northern part of the complex, extending into the sandstones might have been products of magmatic segregation or late stage magmatic activity as has been reported in some other members of the Younger Granite complexes (Jacobson et al, 1971). It is also possible that the part of the younger granite might have extented beneath the sandstone boundary, obtained from model studies.

It could then be suggested that the Dutse Complex is the link between those of the southern Niger and the Jos Plateau. Further work may be needed on the complexes in the Southern Niger to determine more fully the relationship between these complexes and those on the Jos Plateau.

7.3 Suggestions for further work: As a preclude to further work, photogeological mapping of the area should be carried out to be able to determine other outcrops of the complex which may be farther away from the complex centre so as to define precisely the extent of this and possibly other complexes in the project area.

A comprehensive gravity survey should be carried out to cover a wider area in the project area so as to be able to determine precisely the Bouguer anomaly field in this project area. The proposed gravity survey should cover an area of at least a radius of 20 km from the centre of mass estimated by the author. This can also help in mapping out any other rhyolite bodies not outlined in this survey. Levelling should also be carried out. This will help to eliminate most of the errors introduced in the present survey due to elevation determinations by the use of altimeters. A close spacing of stations at 0.5 km within the 20 km radius of the complex and a gridded pattern are suggested, using the centre determined by this present work.

It will also be interesting to investigate the depth extent of the veins especially at the younger granite/ sedimentary sandstone contact, which corresponds to the magnetic anomaly on the aeromagnetic map. (fig. 2). The present survey could not do this due to the limited area of the project and time constraints. Detailed ground magnetic and gravity surveys are recommended along this contact zone with station separation of 0.2 km.

The Younger Granites are known to be rich in radioactive minerals as discovered in Jos Plateau. To establish further, the link between this complex and those in the Jos Plateau, aero-radiometric as well as geochemical surveys across the Dutse complex are suggested. The geochemical survey will be useful in determining the presence of other minerals associated with magnetite such as sulphides and gold.

Seismic refraction survey could be useful to map the top surface of the buried bodies as deduced from the results of the present work; Traverses should be about 2 km apart from each other. Each traverse should be 10 km long on both sides of a north-south line passing through the centre of the body determined in this present work.

TABLE 3

PRINCIPAL PARAMETERS OF BASE STATIONS

STATION NUMBER	ELEVATION (Metres)	LATITUDE	LONGITUDE	OBSERVED GRAVITY (g.u.)	FREE AIR (g.u)	BOUGUER ANOMALY (g.u.)
A1	449.7	11°41.44'	9°20.33'	9781216.03	169.97	-335.03
A2	464.42	11°43.41'	9°21.13'	9781186.37	170.10	-349.60
A3	445.43	11°44.07'	9°20.11'	9781272.46	194.00	-304.40
A4	507.63	11°45.52'	9°20.77'	9781116.49	222.25	-345.75
A5	465.52	11°45.04'	9°21.44'	9781243.04	220.19	-300.71
A6	469.12	11°44.24'	9°21.63'	9781186.58	183.95	-340.95
A7	441.50	11°41.63'	9°20.24'	9781246.80	169.89	-324.21
A8	421.74	11°46.82'	9°20.04'	9781380.50	211.33	-260.57
A9	420.40	11°47.44'	9°24.12'	9781279.87	202.73	-267.74

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