DETAILED GRAVITY STUDY OF THE DANGE ANOMALY IN SOKOTO STATE, NIGERIA

BY

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DECLARATION

The original work on this project is mine. It has not been submitted in parts or whole to any media/wireless for transmission/publication or award of any type of certificate than the postgraduate school of Ahmadu Bello University, Zaria for the award of an M.Sc degree in Applied Geophysics.

All literature used during the course of this work to the best of my knowledge are true and duly acknowledged.

.... 28/09/2000

G. N. EGWUONWU.

CERTIFICATION

This thesis entitled "Detailed gravity study of the Dange anomaly in Sokoto State, Nigeria" by G. N. Egwuonwu meets the regulations governing the award of the degree of Master of Science of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

I dedicate this project to my dear Parents Mr & Mrs R.N. Egwuonwu and the entire family who sacrificed almost all they had to see the successful end of this project.

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First, my profound gratitude goes to God Almighty whose leading and guidance has brought me successfully to the end of this work.

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ABSTRACT

A detailed gravity survey of the Dange area within the Sokoto Basin, North-western Nigeria has been carried out to determine the structure and probable mode of emplacement of the causative body of Dange aeromagnetic anomaly. One hundred and ninety five gravity stations were occupied at one kilometer interval using a LaCoste and Romberg Model G gravimeter for the relative gravity measurements and two Wallace and Tiernan Aneroid Altimeters for the elevation determination. Density measurements on one hundred and ninety six rock samples were carried out to aid the interpretation of the gravity data.

The Bouguer gravity in the area is characterized by negative anomaly with relative values ranging in amplitude from -58mGal to -32mGal. The regional field is a plane dipping at about 10° northeastwards with a gradient of 0.38mGal per km. The residual anomaly map of the area is characterized by a prominent positive anomaly of +10mGal amplitude located at the southeastern portion of the survey area. This positive residual anomaly corresponds well in it's location with the prominent Dange aeromagnetic anomaly which earlier workers have attributed to an intra basement intrusion underlying the sediment in the region.

A two and half-dimensional modeling of the residual anomaly suggests a body which is probably schistotic with depth extent of about 10.0km. It is located at a depth of about 2.0km with inward dipping contrasts ranging from 20° to 48° in the underlying basement. This body has probably resulted from a metamorphic process which is believed to have taken place during the middle Eocene uplift which gave rise to some synclinal structures and general irregularities of the basement surface in the area.

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ABRREVIATIONS

m	meter
km	kilometer
N	North
S	South
NW	Northwest
NE	Northeast
SE	Southeast
SW	Southwest
SSW	Southsouth west
SSE	Southsouth east
kg	Kilogram
G.S.N.	Geological Survey of Nigeria
m.y.a.	Million Years Ago
S.I.C.	Sokoto Investment Company
SI	System International
CCN	Cement Company of Nigeria
SSP	Single Super-Phosphate (Fertilizer)
m.s.l.	Mean Sea Level

CHAPTER ONE

INTRODUCTION

1.1 GENERAL INTRODUCTION

Gravity prospecting involves the measurement of variations in the gravitational field of the earth. It is a natural source method in which local variations in density of rocks near the surface cause minute changes in the main gravity field. Gravity method has some similarities with magnetic method. Both of them attempt to measure small differences in a force field which is relatively huge. Since in both cases the main field vary more with position and less with time, it is possible to determine the absolute fields.

Density variations are relatively small and uniform compared with changes in magnetic susceptibility, therefore gravity anomalies are smaller and smoother than magnetic anomalies. In other words, magnetic map such as total field or vertical component, is generally more complex and variations in field more erratic and localised than the gravity map (Nettleton, 1971). Thus the precise interpretation of magnetic field data is much more difficult than for gravity data. In mineral exploration, gravity method has usually been employed as a secondary method and recently very useful for detailed follow-up of magnetic and electromagenetic anomalies especially during integrated base-metal surveys (Murty, 1977; Patterson and Reeves, 1985).

In Nigeria, the mapping of the earth's gravity and magnetic fields has had a long and distinguished history as part of the investigations of the structure and petrologic variation within the earth's lithosphere. A few geophysical investigations has been recorded in Sokoto (Fig. 1.1) despite the fact that there was no proven economic mineral resources and the prevailing advert climatic conditions in the area, these include the nation wide aeromagnetic

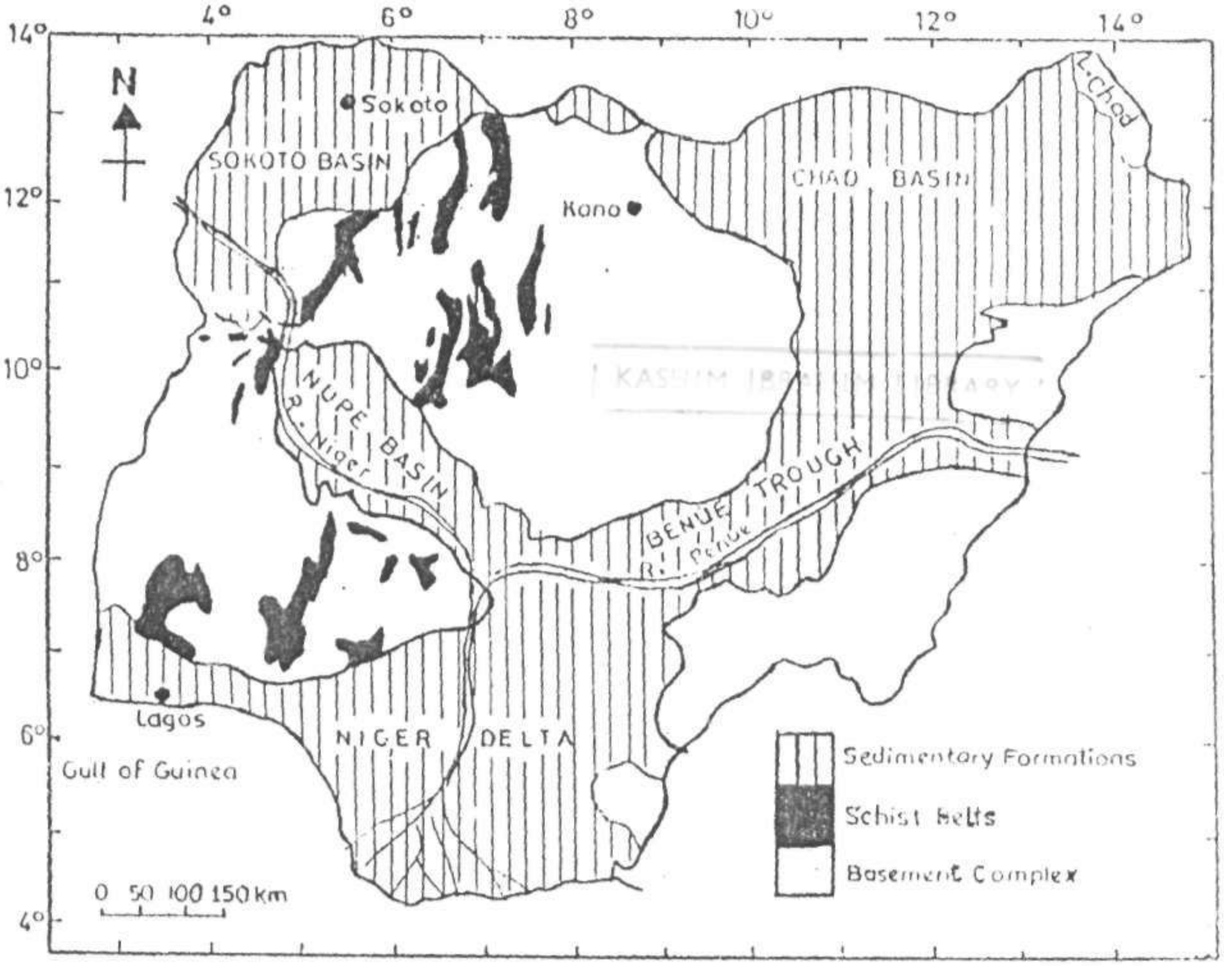


Fig 1.1: Simplified Geological Map of Nigeria showing Sokoto Basin
(Source; GSN, 1979)

and aeroradiometric coverage, electrical resistivity and seismic refraction surveys for ground water by the Geological Survey of Nigeria (GSN) as well as the recent gravity and magnetic investigations by Umego (1990), Sambo(1994) and Haruna (1996). Kogbe (1978, 1979) and Wright (1979), carried out ground geological mapping which they considered adequate. Based on the geological investigations, it was recommended that an intensive programme of both geological and geophysical investigations should be carried out over the basin.

The present work which is a detailed gravity investigation of the Dange area located between latitude 12.77°N and 12.95°N and longitudes 5.25°E and 5.50°E (fig. 1.2) is intended to complement the geophysical information of this area.

1.2 PREVIOUS GEOPHYSICAL STUDY OF THE AREA

The first comprehensive geophysical investigation in the area was the aeromagnetic mapping carried out by Hunting Geology and Geophysics Ltd in June, 1975 for the Geological Survey of Nigeria (GSN). From the survey, the aeromagnetic maps for the area was compiled in 1976. A large negative aeromagnetic anomaly centered roughly at lat.12.80°N and long.5.38°E almost at Dange town (Fig 1.3)was identified in the 1:100,000 aeromagnetic map Dange sheet No. 29 which is in custody of the Geological Survey of Nigeria.

Uwah (1984), carried out an investigation of aeroradiometric anomalies in Sokoto basin using nuclear methods. He suggested that uranium enrichment seems to have taken place in an iron deposit, which altered the magnetic properties of the iron mineral in the NE of Dange sheet between latitude 12.78°N and 15.91°N and longitudes 5.33°E and 5.47°E.

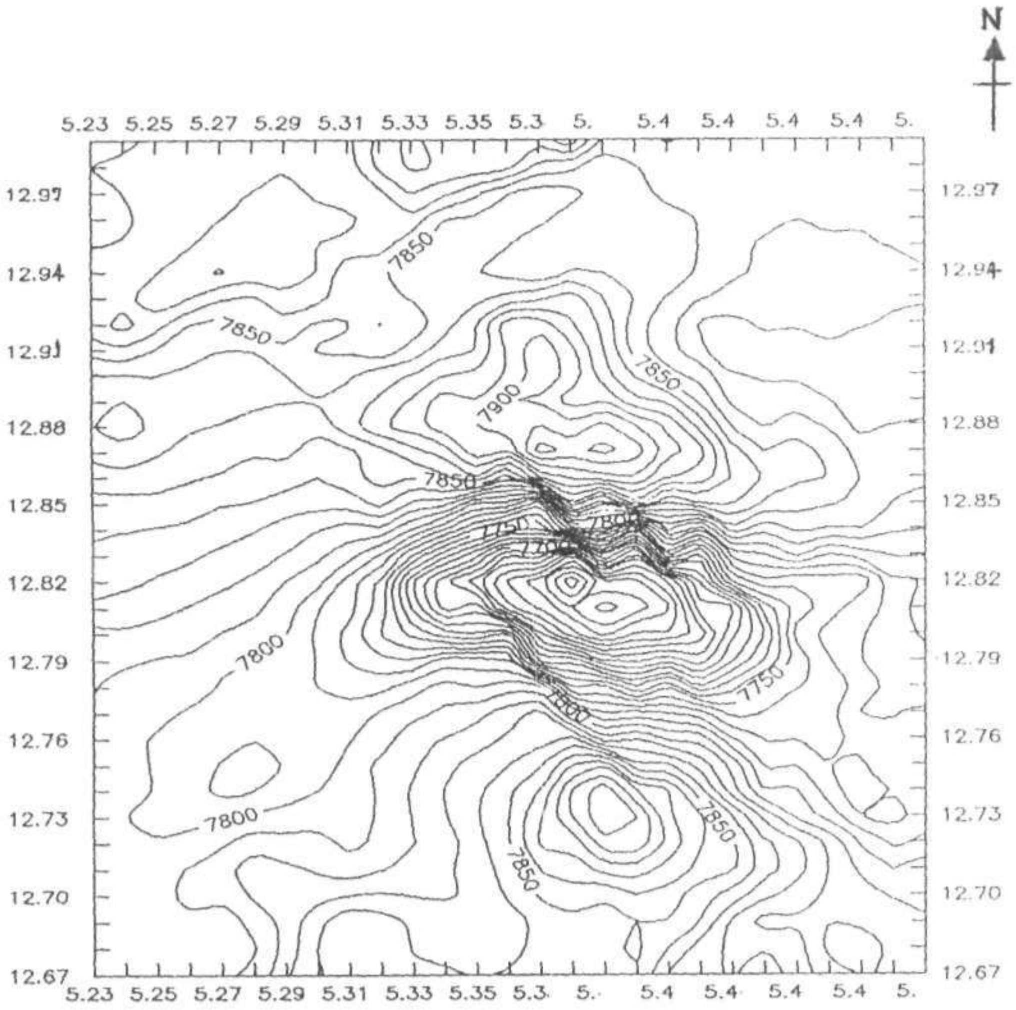


Fig 1.3: Total field aeromagnetic map of the study area (Contour values (in gamma) are relative to a value of 2500nT)
(Source: Hunting geology and geophysics Ltd, 1976)

Thus he linked the prominent magnetic anomaly in Dange area with uranium mineralization or enrichment since uranium carrying fluids could alter the magnetic properties of a subsurface mineral deposit. Nevertherless, the above statement cannot be conclusive until the magnetic anomalies in the area are investigated by other non-radiometric geophysical techniques such as resistivity, gravity and magnetic methods.

Osazuwa (1985) established a primary gravity network for Nigeria of which five base stations were located within the Sokoto basin. Of the five, one was particularly located very close to the study area, and was reoccupied as a base station in this present survey. Umego (1990), carried out a structural interpretation of both gravity and aeromagnetic anomalies over the basin. In the course of the investigation, station spacing of 2.0km was used for gravity data collection and the Wener deconvolution technique was used for interpretation of the aeromagnetic data. The Bouguer map obtained from his survey did not indicate any gravity anomaly in Dange area where the prominent aeromagnetic anomaly was observed and the present survey is aimed at investigating this apparent discrepancy. Sambo, (1994) using the same aeromagnetic data and spectral method for interpretation, estimated the average depth to the basement to be about 1.85km. Both however, agreed that the depth to the basement at the site of the prominent anomaly is about 1.4km.

A three dimensional interpretation of the same prominent aeromagnetic anomaly was carried out by Haruna (1996). The causative body was interpreted as an intrabasement body of basic igneous composition with a high magnetic susceptibility of 0.0730 (System International (SI) Units). A model of best fit was obtained which was represented by a prismatic body having dimensions (10.11 x 2.9 x 3.32)km^3 at a depth of about 1.65km. He drew a conclusion that a geodynamic process must have resulted to of the emplacement of the causative body which was penetrated by dipiric intrusion of mantle rocks, and must have been followed by ascension to the lower and upper crust which on cooling probably had forced a downward deflection of the crust by the virtue of it's increased density.

From the foregoing, it is obvious that no comprehensive detailed gravity survey has been carried out in Dange area of the basin prior to this present survey.

1.3 OBJECTIVES AND SCOPE OF THE PRESENT SURVEY

The present survey is primarily aimed at resolving the discrepancy in the results of earlier surveys. The gravity survey by Umego(1990) did not record any significant anomaly at the location of the Dange magnetic anomaly which Haruna (19900 interpreted to be caused by a high density material at depth. It is also aimed at satisfying the need to confirm the location, depth, and possible mode of emplacement of causative body responsible for the prominent magnetic anomaly in Dange using a more detailed gravity survey. However, seismic method of investigation is another good and even a better approach to this survey but it is more expensive to carry out, secondly the equipment for the method was not readily available during the period of this work. Gravity method of investigation is cheaper and can be good enough for this work because anomalies obtained can be readily used to determine the shape of subsurface structures and the density contrast between the structures and their host rock, and approximate mode of emplacement of the intrusions. The survey will thus complement the previous gravity surveys which has involved this area and is specifically designed to;

(i) confirm the presence or otherwise of the Dange anomaly from both gravity and ground magnetic measurements,

(ii) determine the lateral and depth extent of the causative body of Dange anomaly and

(iii) investigate the probable mode of emplacement of the intrusive body

1.4 LIMITATIONS

Certain limitations were encountered during the course of the survey which either slowed down the project or necessitated modifications in the original survey plan. The first of these problems which faced the author was associated with the very old topographic map produced by GSN which was used for the station location. Part of the road network indicated on the map had long been reconstructed and some new roads in the area were not on the map. This map was later complemented with another map sketched for Dange/Shuni local government by the Survey Division, Sokoto. Roads such as Gusau-Sokoto road had been reconstructed, the new roads include those linking Wababi and Hetereti, Majia and Bolere, Amanawa and Dange-Danchadi road (fig.3.1). The southwestern part of the survey area was found void of motorable roads hence little or no gravity station could be established there. The reconstruction of the Gusau-Sokoto road also contributed to much delay in the location of the bench mark used for the survey, since the description of the bench mark was done using the very old map.

The survey was undertaken at a period when the atmospheric conditions were rather unstable due to the interplay of the dust-laden north easterly winds and the moisture-laden south westerly winds. Measurements were thus interrupted any time the weather was unstable or when there was excessive high temperature as these were bound to affect the gravimeter and altimeters. The survey periods were thus limited to morning and late evening hours to avoid the erratic drift of the instruments. Hence the number of days initially stipulated for the field work was increased to make up for the skipped hours of each day.

In the rock sampling exercise, two major problems were encountered. The first was that the area being sedimentary, it was difficult to find representative formations because while some areas were covered by thick sandy and clayey topsoil, other areas were largely covered by thick lateritic ironstone (Kogbe, 1979). Some samples (especially shales) collected even around the type locality were weathered, making precise determination of bulk density almost impossible. In other places, it was difficult to obtain fresh (unweathered) samples of some of the main rock types. Nevertheless it is the bulk density values eventually obtained for the samples that were averaged for the modelling in this survey.

CHAPTER TWO

GEOLOGY AND GEOMORPHOLOGY OF THE STUDY AREA

2.1 TOPOGRAPHY AND DRAINAGE

The study area is in the sedimentary basin of northwestern Nigeria. It consists predominantly of a gentle undulating plain with average elevation varying from 250 to 400meters above sea level. The monotonous plain is occasionally interrupted by steep-sided, flat-topped hills. A low enscarpment which was named "Dange Scarp" by earlier workers, is the most prominent feature in the basin. The best outcrops of the Paleocene strata are confined to the face of the enscarpment, the slopes of its outliers and to its gentle slope facing westwards. The enscarpment retains a marked NNE-SSW trend which approximately parallels the regional strike. "Dange Scarp" becomes non recognizable as it extends to Gwandu Emirate (Kogbe, 1970).

In this northwestern Nigeria sedimentary basin, the character of the landscape is determined by the lithological differences among the rocks and the widespread occurrence of lateritic ironstone forming resistant cappings to weaker rocks. The regional dip is very gentle in most places less than 2° and trending northwest (Kogbe 1972a).

The drainage in the area is dominated by the Sokoto River which flows southwards to join the River Niger. The main tributary of the Sokoto River is the Rima River. Numerous small streams flow from a spring line on the face of the Dange Scarp but these are all dry during the dry season. During rains and the early part of the dry season springs are very common. The springs are most numerous along the valley slopes where the water table in the laterites intercept the surface. The generally small springs issuing from the Kalambaina formation usually last longer into the dry season (Kogbe, 1976).

There are few lakes and ponds of importance in the basin of which some ponds fall within the study area. Prominent ones in the area, called Surkandu Ponds, are located around Surkandu, Wababi, and Bolere villages (fig 3.1). The lakes and ponds occur in a string (probably six or more perhaps during the rains) along an old water course where sand dunes have settled, cutting off portions of the river. The existence or survival of these lakes is probably due to active erosion of the river valley during wet seasons. The valley has completely cut through the Kalambaina limestones so that the water rests on the impermeable Dange clays but the seepage is from the Kalambaina (Kogbe, 1979).

2.2 CLIMATE, VEGETATION AND SOIL

Rainfall in the area is concentrated in a short wet season which extends from mid-May to mid-September. While the dry season lasts for more than six months; October to March/June, the rainfall is characterized by its intensive showers of short duration which contribute to the amount of run-off as well as gully erosions in the area. (Udoh, 1970). During the dry season normal vegetative growth ceases, daytime temperatures are very high and nights are often very cold. During harmattan, the wind coming from the desert, is not only dry but also dust-laden. Soils in this area show a rather sandy topsoil and a clayey subsoil in which concretions are common. Once the vegetative cover is removed through over cultivation, overgrazing and bush burning, the topsoil are readily washed off by rainwater.

2.3 GENERAL GEOLOGY OF SOKOTO BASIN

Sokoto Basin is located at the southeastern part of Iullemmeden Basin. The entire Iullemmeden Basin covers the major part of Niger Republic, some part of Benin Republic, Mali and Algeria. The basin has been affected by series of marine transgressions. These transgressions took place during the Palaezoic, Mesozoic and Tertiary. They progressively affected the greater portion of the basin in a southward direction. This implies that tertiary transgression was the most extensive and covered a considerable portion of the basin. The marine environment which existed during the Palaeocene and lower Eocene was immediately replaced by a return to continental conditions within which the sediments of the continental terminal were deposited as indicated by Kogbe and Sowunmi (1975).

In northwestern Nigeria, the sediments of the Iullemmeden Basin was also deposited during the three main phases of deposition: Continental, Mesozoic and Tertiary phases, with an intervening marine Maastrichtian to Palaeocene phase (Grant, 1969). Overlying the Precambrian basement uncomformably are, the Illo and Gundumi Formations, made up of grits and clays, form part of "Continental Intercalaire" of West Africa. They are overlain uncomformably by the Maastrichtian Rima Group, consisting of mudstones and friable sandstone (Taloka and Wurno Formations), separated by fossiliferous shaly Dukamaje Formation. The paleocene Dange and Gamba Formation (mainly shales) are separated by calcareous Kalambaina Formation. The overlying continental Gwandu formation (continental terminal) is of Tertiary age. These sediments dip gently and thicken gradually towards the northwest, with a maximum thickness of over 1,000meters near the frontier of the Niger Republic (Kogbe, 1979). They were deposited on the south-eastern flank of the

Iullemmeden basin which is a large synclinal structure trending NW-SE (Kogbe, 1972b). Table 2.1 summarises the sequence in the northwestern Nigeria sedimentary basin.

2.4 THE BASEMENT

Sokoto basin is believed to have been underlain by the basement. The basement consists of gniess, migmatites and metasediments of Precambrian age which have been intruded by a series of granitic rocks of late Paleozoic age.

The rocks have been variably metamorphosed and granitised through at least two tectono-metamorphic cycles so that they have been largely converted to migmatites and granite gneiss. Younger Metasediments, believed to be upper Proterozoic in age, were deposited on this granitised basement and folded along with it during the Pan-African Orogeny. They are of low metamorphic grade and are now in north-western Nigeria.

Intrusive into both the basement rock, and the younger Supracrustal cover is a series of basic, intermediate and acid plutonic rocks known as the older granites. The youngest rock in the area belong to the suite of volcanic rock introduced into Older granite bodies during lower pelaeozoic epeirogenic uplift following the Pan-African Orogeny.

At least two phases of tight isoclinal folding have been recognised in both the Younger Metasediment and the basement gneiss. The deformation episode were accompanied by progressive regional metamorphism, and separated and followed by a phase of static metamorphism.

Accompanying migmatization and granitisation of the basement gneisses resulted in the intrusion of a suite of syn-to late tectonic granites. The closing stages of Orogeny were marked by cooling, uplift and fracturing, and by the intrusion of high level volcanic rocks.

Available evidence suggests the Pan-African Orogeny was the result of the opening and closing of a small ocean comparable in size top the Red sea.

2.5 PRE-MAASTRICHTIAN DEPOSITS

The Pre-Maastrichtian sediments are of fluviatile and lacustrine origin. They belong to the Gundumi and Illo formations which extend northwards into the Nigeria Republic. These deposites belong to the upper part of the "Continental Intercalaire" which comprises of a group of poorly fossiliferous sediments covering a very extensive area, bounded on the west by the crystalline basement rocks of the Niger Republic, and on the east by the Quaternary sands of the Chad Basin.

The Gundumi Formation lies uncoformably on the basement and consists of basal conglomerates, and gravels with sand and vari-coloured clays increasing upwards; the maximum thickness is about 350 meters. The Illo Formation includes interbedded clays and grits, with an intermediate pisolitic and nodular clay member, and attains over 240 meters in thickness. The continental period represented by the Gundumi and Illo Formations was terminated by a Maastrichtian Marine transgression. The sea penerated the interior of the continent both from the north, and from the south through the mid - Niger Basin.

2.6 MAASTRICHTIAN DEPOSITS

The second phase in the depositional history of the north-western Nigeria Basin began during the Maastrichtian, when the Rima Group was deposited uncomformebly on Pre-Maastrichtian continental beds. The type sections of the three Maastrichtian formations are at Taloka, Dukamaje and Wurno Formations.

The lower sandstones and mudstones of the Rima Group (Jones, 1948); belongs to the Taloka Formation, with a maximum thickness of about 100meters. The formation consists essentially of white; fine-grained, friable sandstones and siltstones, with thin intercalated mudstones and carbonaceous mudstones or shales. On the northern side of the Rima villey, the Taloka Formation occupies the base of a high scarp feature which is the northern terminal of the "Dange Scrap", a prominent topographic feature which runs southward toward Dange village. The upper levels of the enscarpment are occupied by younger formations. The hills near Goronyo on the southern side of the Rima valley are of lower elevation and the greater part of the hill is made of Taloka Formation sediments, with the overlying Dukamaje Formation poorly developed. The Wurno Formation is only represented at the summit where it is preserved by a layer of laterite.

Dukamaje Formation consists predominantly of shales with some limestones and mudstones. The shales contain numerous fragments of vertabrae and limb bones. A bone bed very richly fossiliferous lies near the base. The Dukamaje formation over lies the Taloka formation comformably through the bone-bed. The contact is sharp. The bone-bed is an excellent marker horizon in the field and was used as the index horizon for mapping at Taloka.

The sediments consist of pale coloured, friable, fine-grained sandstones, siltstones and intercalated mudstones. In boreholes, the sediments of the Wurno Formation are dark in colour. This is due to the presence of carbonaceous material and finely divided iron sulphides. Good outcrops of the formation are rare outside the type locality at Wurno. The loosely consolidated nature of the sediments make them very easily suscpetible to weathering.

2.7 SOKOTO GROUP

The Sokoto group of sediments is of Upper Paleocene age. The group consists of three formations; Dange formation which is the oldest, Kalambaina formation and Gamba formation which is the youngest in the group. These formations form an outcrop band that is about 16km wide near the border with Niger Republic. Southwards, the outcrops narrow rapidly and at Jega almost no outcrop occurs. Fig. 2.1 shows the geological map of Dange area.

Dange formation consists of slightly indurated bluish-grey shale. It is interbeded with thin layer of yellowish brown limestone. In surface outcrops, the maximum thickness of about 22meters has been recorded near Sokoto, but in subsurface wells, it attains a thickness of over 45meters (Kogbe, 1979). Generally outcrops of the formations are restricted to the slopes of the "Dange Scarp".

Table 2.1 : Summary of Geological Sequence in Northwestern Nigeria Sedimentary Basin

(After Kogbe, 1979)

AGE	FORMATION	GROUP	ENVIRONMENT
Quaternary	Sandy drifts laterites	-	Continental
Eocene to Miocene	Gwandu Formation	Continental Terminal	Continental
Upper Paleocene	Gamba formation Kalambaina formation Dange formation	Sokoto group	Marine
	UNCONFORMITY		
Maastrictian	Wumo formation Dukamaje formation Taloka formation	Rima group	Brackish water with brief intercalation
	UNCONFORMITY		
Lowermost Cretaceous or Older	Illo and Gundumi formations	"Continental intercalaire"	Continental
	UNCONFORMITY		
Precambrian	Basement Complex		

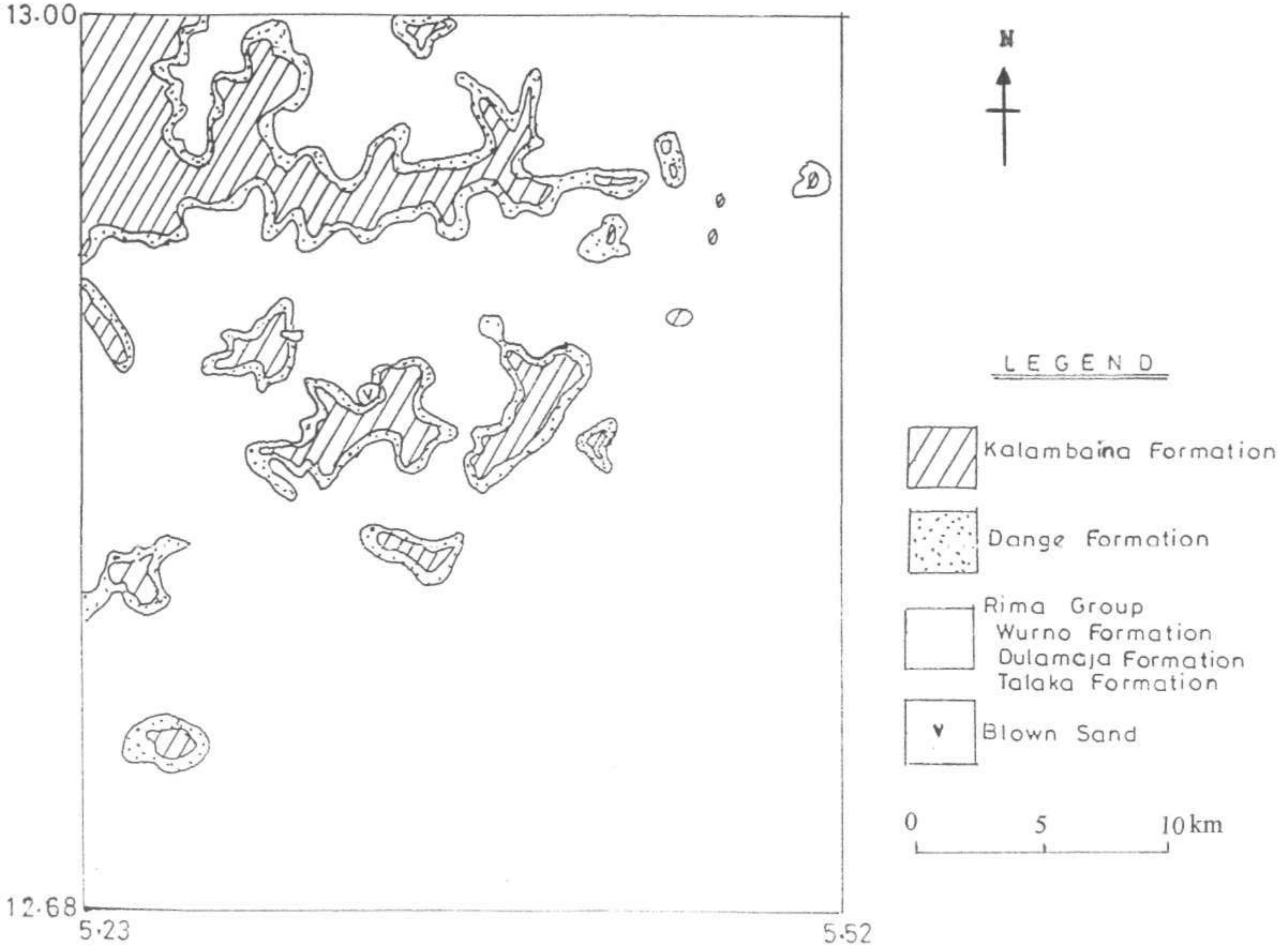


Fig. 2.1: Geological Map of Dange Area

The shale includes bands of fibrous gypsum with a large number of irregular shaped phosphatic nodules. The nodules are characteristically marked with irregular striations, and have a dirty colour externally but bluish grey internally. The type locality of Dange formation is in Dange village about 26km off Sokoto and type section is at the road cut on Gusau-Sokoto road (fig. 2.2), and the photograph of part of the road cut taken during this present work is shown in (Appendix II). Specimen analysed by Jones (1948), were found to consist largely of calcium phosphate, which is most probably derived from the abundant vertebrate fossil assemblage as described by White (1934).

The limestone intercalations are located mostly towards the base of the formation where they occur in two or three bands, these are usually unfossiliferous. There is a conformable contact of Dange formation with the overlying Kalambaina formation.

Better exposure of Dange formation can be seen at Wurno behind the village where the search for gypsum for Sokoto Cement Factory has resulted in a miniature open-cast mine. Dange formation attains a thickness of 9 meters in Kaloye, 50 meters in Balle, 4 meters in Argungu and 21 meters in Sokoto (Kogbe, 1979).

Kalambaina formation consists of white clayey limestone and shale. Good exposure of the formation are scarce except in the quarry of the cement factory and in well sections. The type locality is at Kalambaina and a type section is at the cement quarry near Sokoto (Kogbe 1972c). The rocks of the Kalambaina and Gamba formations are well exposed in the quarry of the Sokoto Cement Factory. The profile consists of the Kalambaina formation at the base, overlain conformably by the Gamba formation which in turn is succeeded by an ironstone unit. Figure 2.3 shows detailed description of the sequence. Outcrops are confined to the upper slopes of the "Dange Scarp" and the slope of the enscarpment are

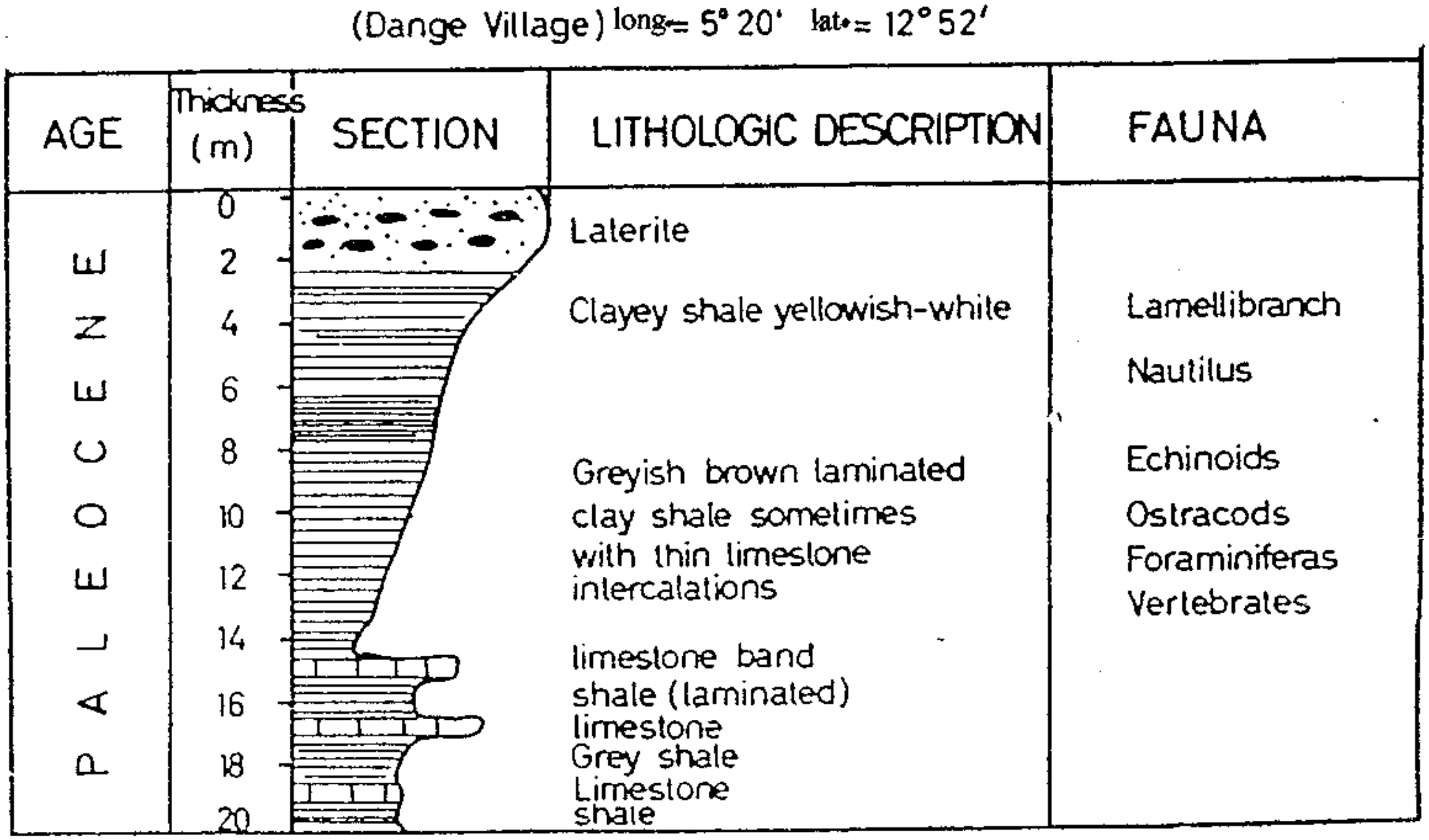
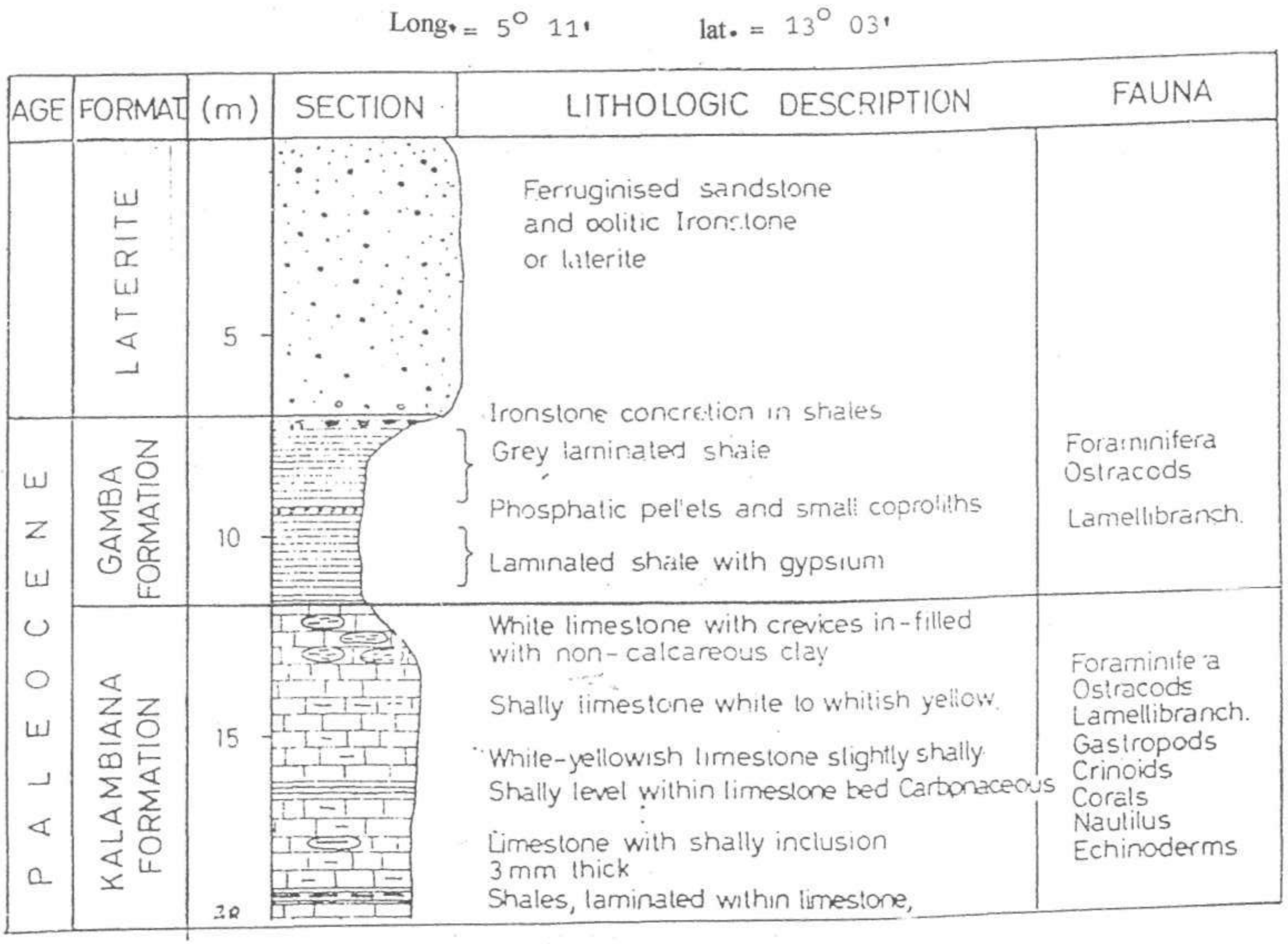


Fig. 2.2 : Section through the Dange formation at the type locality
(After Kogbe, 1979)



F.g. 2.3: Section through the Kalambaina formation at the type locality in Kalambaina. (After Kegbe,1979).

often littered by limestone cobbles, shale and invertebrate fossil. The maximum thickness of Kalambaina formation recorded from the borehole is below 20 meters, however, the subsurface removal of the calcarous beds by solution, causes a substantial reduction in thickness. The formation is rich in invertebrate fossil mainly echinoids, corals, nautilus, lamelibranch and gastropods (White, 1934; Russ, 1957).Forminifera from the formation have been described by Rayment (1965) and Kogbe (1972b). The limestone is often white in colour and is separated by irregular non-calcareous clay.

Gamba formation consists of grey shale overlying the Kalambaina formation. The upper part of the shales consists of small phosphatic pellets varying in size from 1mm to 1cm (Kogbe, 1979). The shales appear to be folded due to the removal by solution of the underlying limestone and the slumping of the overlying beds. Except when overlain by the Gwandu formation, the formation is covered by a mantle of lose sand and laterite (Weaver,1958; Ramsey, 1961). The laterite usually 1.5m to 3m thick often passes down into oolitic ironstone 3m to 5m thick (Raeburn and Tattam, 1930; Kogbe, 1979).

2.8 CONTINENTAL TERMINAL

Continental terminal marks the upper and lower boundaries which are determined by geodymanic events. Although the events are not strictly synchronous over the whole of North and West Africa, they are considered to have been caused by related stress patterns of supra-regional validity. Continental terminal is represented in Sokoto Basin by the Gwandu Formation. Throughout the sedimentary Basin of North-Western Nigeria, the tertiary marine sediments of the Sokoto Group are overlain discoformably by a thick series of deposits consisting predominantly of red and mottled massive clays with sandstone intercalations. These sediments belong to the Gwandu formation, with the type section and the type area in the Gwandu Emirate of Northern Nigeria (Kogbe, 1972b). Outcrops of the formation cover over 21,739 square kilometers in northwestsern Nigeria. It contains a member of prominent ridges and gorup of flat-topped, steep-sided hills capped by ironstone. Other hills covered with ironstone debris occur in all stages of demolition, rising out the sandy plain over which the products of erosion have been on the hillsides where, however, they are usually small and obscurred by rain-wash and ironstone scree.

2.9 MINERALOGY AND ECONOMIC GEOLOGY

There are some dominant economic minerals and rocks which are industrial raw materials found in the study area. These include phosphates, gypsum, limestone, kaolin and clay.

2.9.1 Phosphates

This is one of the most vital economic minerals found in the area. Its major industrial application lies in the production of Single Super Phosphate fertilizer (SSP). The types of phosphates very common in the area are florapatrites and chlorapatites but flourapatites are more common. They frequently occur in cavities as well-developed in-growth or overgrowth of crystals. They are commonly found to be colourless or emerald-green, light blue, yellow, brown or violet in colour. They are vitreous and greasy in lustre. They are brittle and fractures unevenly, this implies that their cleavage is imperfect (Cleaveland, 1978). They have specific gravity between 3.18 and 3.21. Phosphate is one of the magmatic minerals therefore it could occur in the grains of many igneous rocks or in veins of some hydrothermal deposits. Many deposits of calcium phosphate are formed in marine sedimentary rocks through a complex biochemical process and are confined to definite stratigraphic horizons.

The principal use of apatites and phosphorites is for the production of fertilizers. Apatites in particular are source of phosphoric acid and various salts as well as of phosphorus. It is also an important material for safety matches.

2.9.2 Gypsum

This is another prominent mineral in the area. It occurs in beds of the Dange formation. It is largely located in areas like Amanawa, Gidan - Gara and Ganiyabo which were all within the study area. Gypsum generally is white in colour and if its individual crystal is studied it may appear colorless and water transparent. It may also appear grey, honey yellow, red, brown and black depending on the color of the impurities trapped during crystallization.

Gypsum is very brittle and can easily be scratched with the finger nail. It is an article of manure in the cultivation of grasses, roots and grains. It can be employed in the native and ornamental arts. Gypsum when mixed with a certain quality of quicklime forms a good cement. When finer it can be used for casting status busts in moulds for taking impression on metal and other ornamental works. In all these works, when dry, it is susceptible to polish.

Gypsum is currently mined locally for the consumption of Cement Company of Northern Nigeria Plc. (CCN) and other consumers in the country (Sokoto Investment Company (SIC), 1996). Apart from its usage as a raw material for cement, it is also found useful in production of fibre board, fertilizer, plaster of paris, chalk, pharmaceuticals, and tiles.

2.9.3 Limestone

This is a very important economic resource in the study area. It results from irregular crystallization. It is both foliated and granular in structure. Its grain ranges from a coarse to very fine. It varies vastly in its hardness and cohesion of its grains. Its specific gravity usually lies between 2.71 and 2.84. It is more or less translucent, its color is most commonly white or grey, often snow white and sometimes greyey black (Betekhtin, 1975).

They are exclusively found in primitive rocks and commonly occur in beds which are of considerable extent in width and thickness and sometimes more or less stratified. They can be burnt to prepare mortar, or employed and appropriated to statuary decoration in architectural and other ornamental works and in this respect they are susceptible to polish.

Limestones are currently mined and utilized by the Cement Company of Northern Nigeria Plc in the production of cement. Generally, limestone is also processed and used as flourine stone for iron smelting, as a hydrated lime for water treatment and other chemical based products.

2.9.4 Clays

The most common clays found in the area are kaoline (pocelain clay) $Al_2O_32SiO_22H_2O$ and potter's clay. Kaoline is located in substantial quantity at the hilly side of Amanawa (fig 3.1) and associated with gypsum deposits. It occurs in the veins or beds associated with granite and sometimes with gneiss. Kaoline may be greyish in colour or more often white. It retains its colour in fire. It is dry to touch, and is very useful in the production of pots for melting glass. Kaolin has specific gravity ranging from 2.23 to 2.40 (Betektin, 1975).

Potters clay on the other hand is abundant in the study area. It is a compact mineral in texture and considerably solid in other cases, it is more or less friable, it is smooth or a little unctuous to the touch. Its fracture is dull earthy or uneven. It is gray, grayish white or nearly white. Under the action of fire or heat it gets more or less fusible due to the presence of lime in it (Cleaveland, 1978).

While kaolin is applied in the production of pharmaceuticals, paints, industrial fillers and petrochemicals, potters clay on the other hand has been useful in the massive production of local pots and varieties of ceramics in Dange area (S.I.C., 1996).

CHAPTER THREE

FIELD PROCEDURE, DATA REDUCTION AND CORRECTIONS

3.1 GENERAL WORKPLAN

In gravimetric surveys, definite procedures are laid down which must be adopted if the results of the survey are to be relied upon. This often necessitates reconnaissance field trips to the study area, pre-field monitoring of all instruments, and procurement and study of all topographic and geologic maps of the area.

A reconnaisance field trip was made to the study area , and this brought to light the inadequacy of the only available topographic map, of the 1970 Federal Survey of Nigeria map series. The survey division of the State Ministry of Works, Sokoto was visited and a more up to date road map of the area was obtained (Fig. 3.1). The network of gravity stations was then planned taking into account the conditions of the roads. The stations were located at 1 km intervals along all motorable roads in the area.

In the same trip the gravity base station (Osazuwa, 1985) located near survey area (Appendix I) was sought out and located as well as the Standard Bench Mark (SBM) at Dange market square. Other logistic problems such as accomodation and transportation were also arranged.

The instruments used for the field work includes gravimeter, altimeter, psychrometer, magnetometer and magnetic compass. The type of gravimeter used is Lacoste and Romberg (LCR) model G geodetic gravity meter No. G446. It has a reading precision of 0.01mGal and a drift rate less than 1 mGal per month (model G446 manual). A pair of Wallace and Tiernan Aneroid Altimeters model No. FA181 was used for relative elevation measurements. For three days before the field trip, a prefield calibration of the gravimeter and the two altimeters were carried out at the physics department of Ahmadu Bello

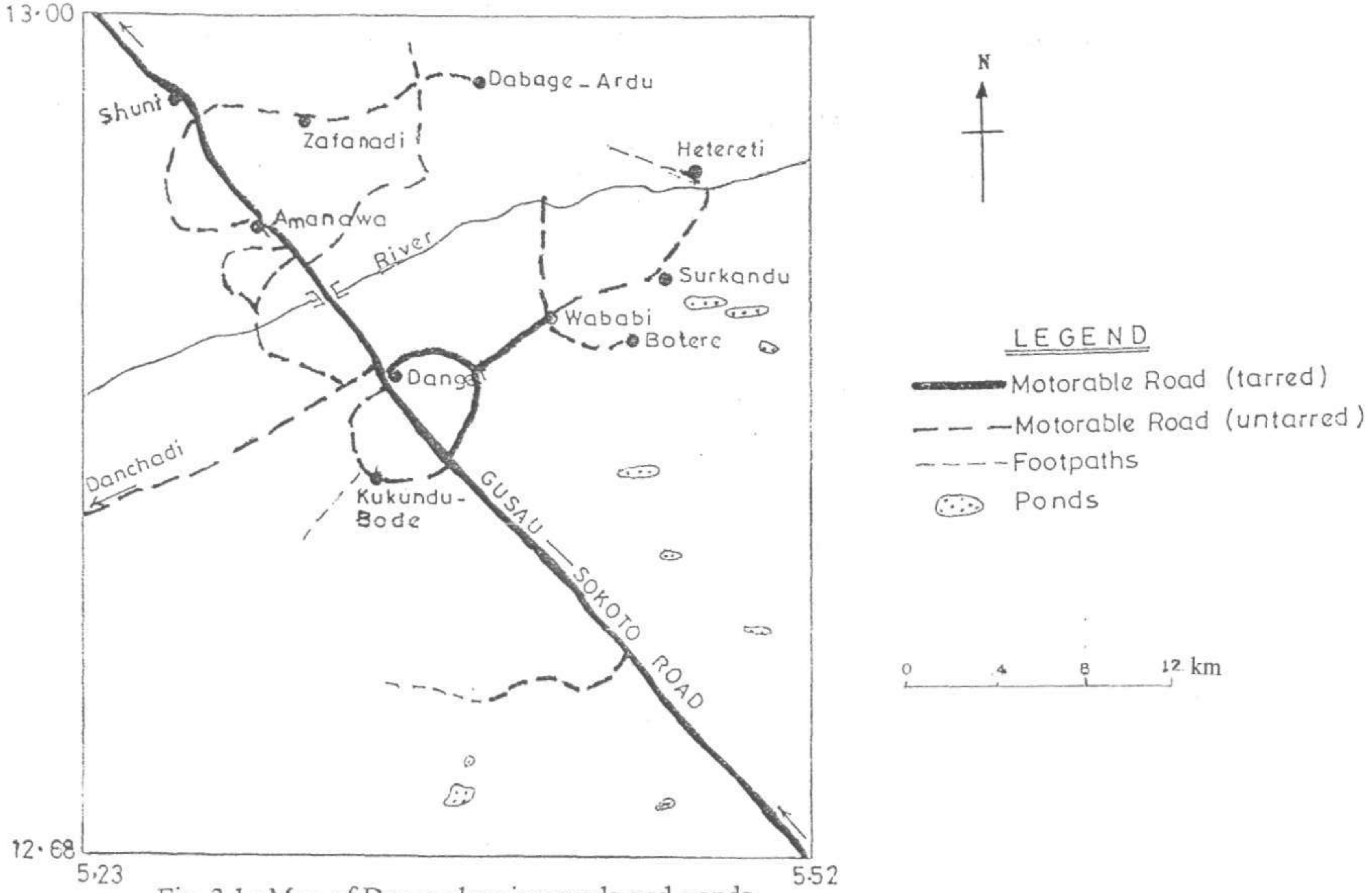


Fig. 3.1 : Map of Dange showing roads and ponds.
(Source; Survey Division, Ministry of Works, Sokoto)

University (A.B.U.), Zaria between the hours of 0600 and 2300 (local time). Measurements were also made along some roads within the University premises, to further check the behaviour of the instrument. All necessary routine checks on level adjustments and sensitivity of gravimeter were carried out as described in gravimeter manual.

After the field work, similar (post field) observations were made on both the gravimeter and the altimeters for two days. This was to confirm that the instruments still retain their earlier characteristics as before the field work. Figures 3.2 and 3.3 show the plots of the instrumental responses during the two epochs of test observations. The figures show the instrumental drifts curves resulting from the tidal effects of the sun and moon. From fig 3.3a it can be observed that the pre field observation revealed altimeter D of the second pair of altimeters labeled A' and D was faulty. Therefore the first pair consisting of altimeters labeled A and B were chosen for the field work since they gave a better representation of the linear windows.

The shift in the responses of the altimeters can be ascribed to the difference in characteristic behavior of each instrument (Osazuwa, 1992). There are two time segments of the drift curve which indicate approximate linear drift, and these are 1000-1300 and 1600 - 2000 hours. The readings in the field were confined to these time windows because linear drift is assumed in the computation of drift rate.

3.2 FIELD WORK

The first field trip was made in June/July 1998, and data was collected. More data was collected in September 1998 when the second but shorter field trip was made. The data collected in the field includes magnetometer, gravimeter and altimeter readings as well as psychrometer readings of wet and dry bulb temperatures and the times for the various

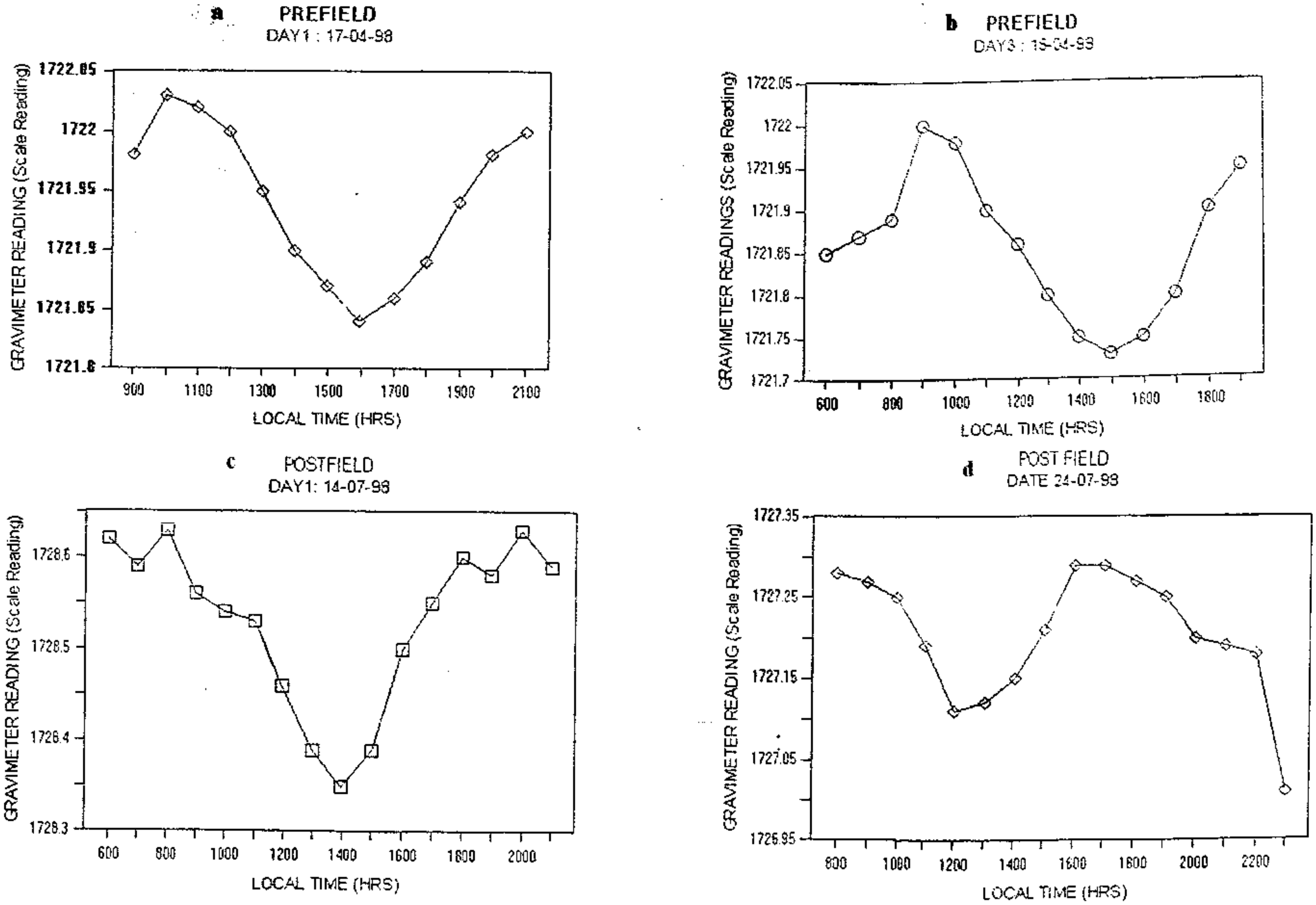


Fig. 3.2 : Pre-field and Post-field Gravimeter drift curves

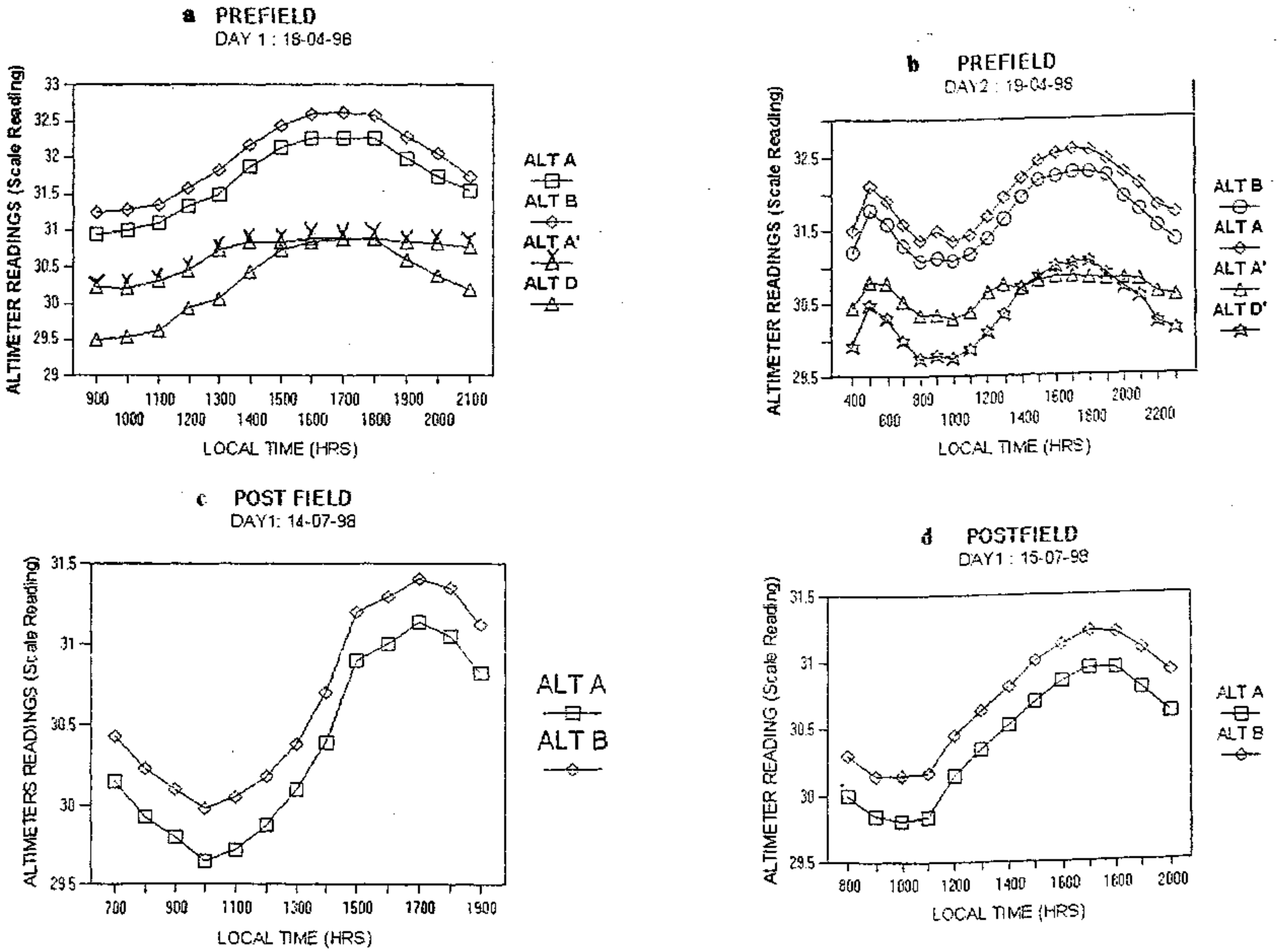


Fig. 3.3 : Pre-field and Post-field Altimeter drift curves.

readings. The method adopted for the data collection is leap-frog method of observational sequence (Osazuwa,1985).

Hitherto, all studies of the prominent Dange magnetic anomaly (Uwah, 1984; Umego, 1990; Sambo, 1994 and Haruna, 1996) had been with aeromagnetic data. It was therefore one of the objectives of the present survey to comfirm the presence or otherwise of this anomaly as located on the aeromagnetic map. To achieve this it was planned to take readings along the main Sokoto-Gusau road. Consequently ground magnetic readings were taken at 1 km intervals with the Proton Magnetometer (model MP-2) during the first two days of the field work.

The magnetometer, gravimeter and altimeter readings were taken simultaneously until after the first two days when the sufficient data for ground magnetic had been collected. It was ensured that the readings were confined within the selected time windows of the drift curves which on the average was limited to three hours. This was to ensure that there was effective control over the instrumental drift. All the gravity readings were tied to the first order gravity network of Nigeria base station (GMSb1A) No. 97105901, located at Air Force Base in Sokoto via a main base station GSB1 established at a strategic junction in the study area Fig (3.4). All the altimeter readings were similarly tied to the standard Bench Mark SBM15 with a height of 336.834m above mean sea level and located near Dange village market. A total of 195 detailed stations were occupied using the equipments with exception of the magnetometer which was used only along the Gusau-Sokoto road.

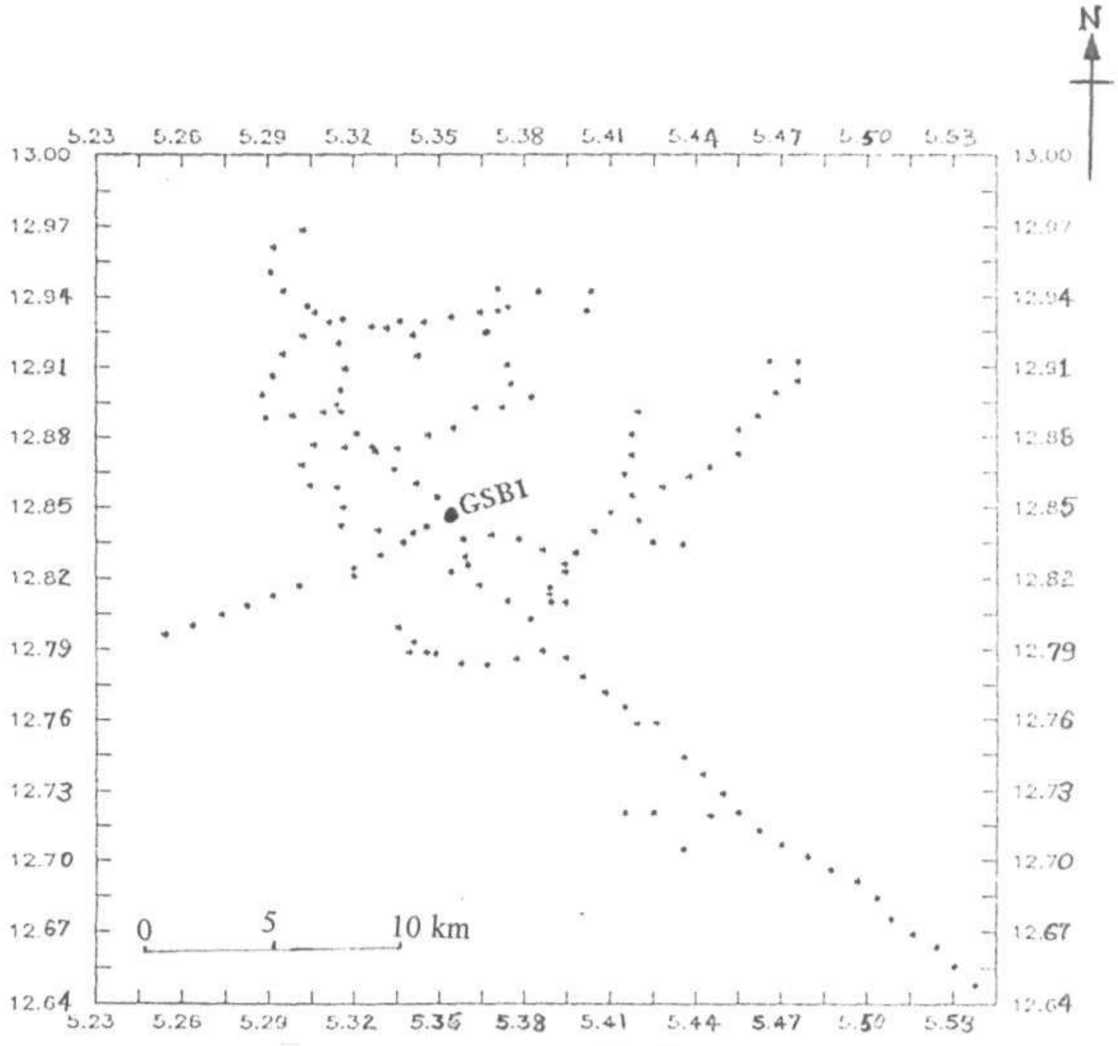


Fig.3.4: Station Distribution Map.

3.3 PRECAUTIONARY MEASURES TAKEN ON INSTRUMENTS

It was ensured that readings were not taken from any of the instruments used while it was raining or drizzling, and after the rainfall, enough time was allowed before data collection was resumed. This was to allow for the normalization of ambient temperature and pressure conditions. Care was taken to minimize jerks or mechanical disturbances on the instruments especially while conveying them in and out of the vehicle and while moving from one station to another. This prevents the instruments from suffering undetectable creep (Hamilton and Burle, 1967). The instruments were also shielded from direct sunshine and wind to prevent thermal shock as discovered by Osazuwa and Ajakaiye (1992).

3.3.1 Gravimeter

It was ensured throughout the period of the field work that the gravimeter was constantly maintained on heat. This precaution helped to ensure that the gravimeter did not give spurious readings (model G446 manual). Secondly, it was ensured that the beam of the gravimeter was always clamped well after each reading in order to avoid excessive drift during transportation.

3.3.2. Altimeter

In order to avoid excessive drift during transportation, it was ensured that after each reading, the altimeters were closed tightly. Before taking any reading, the pointers of the altimeters were allowed to settle well and parallax error was avoided while taking the readings. Nevertheless in order to avoid erroneous reading at the various stations, the altimeters were always placed on a horizontal platform before the readings were taken.

3.3.3 Magnetometer

The same technique of data collection for gravity was adopted for ground magnetics in order to conform with the linear drift assumption. Although the magnetic readings were taken simultaneously with gravity, it was ensured that all magnetic materials were removed from the body of observer before the magnetic readings were taken. High tension power lines were avoided and a distance over 50 meters were kept from them. Others features which were avoided include wire fencing, rail lines, vehicles and motorcycles parked by the roadside. The magnetometer was held at a distance not less than 1m above the ground while the readings were taken.

3.4. DATA REDUCTION AND CORRECTION

The results of gravimeter measurements are gravity differences between an arbitrary reference point and a series of field stations. The measured values at each station have some influences which completely mask the desired effect if they were not removed. Therefore before gravity measurements may be useful as possible indications of subsurface conditions, the observed gravity differences must be corrected for those various large influences. The necessary correction include the following.

i. Instrumental drift correction

ii. Latitude effect

iii Free-air correction

iv. Bouguer correction.

v Tidal correction

vi Terrain correction

In the present survey, tidal correction was not made because loops were closed at interval of about two hours or less. Also, since the area is relatively flat, there was no need considering excess mass or mass deficiency, hence terrain correction was not carried out.

Lacoste and Romberg model G gravimeter have no constant scale factor for conversion of the counter readings to gravity values. Therefore it is very necessary to convert the instrument reading to its gravity value in milliGal unlike other gravimeters such as worden gravimeter.

The gravity data collected were reduced to Bouguer anomaly and free air anomaly values by the use of an executable file of a FORTRAN 77 computer program (Osazuwa, 1986), which was also modified by him to suit the observational sequence adopted in field works such as that of the present survey (Akolisa, 1998). The program automatically converts the gravity scale readings to their corresponding milliGal values. Other corrections carried out with the program are drift correction, free-air and Bouguer correction. The program uses the Geodetic Reference System 1967 (GRS 67) for the computation of the theoretical (or normal) gravity on the reference ellipsoid as recommended by Morelli *et al.* (1971). It assumes a value of $2.67 \times 10^3 kgm^{-3}$ for mean density of surface rocks. A theoretical background of the various corrections is given below.

3.4.1 Drift Correction

In the reduction of gravity data, the removal of drift which occurs as a result of elastic creep in the spring of the instrument is very necessary. The instrumental drift of the gravimeter used in this survey was removed using cascade model routine of Osazuwa, (1988). It is assumed that there is a linear relationship of the drift with time as given by the drift rate which is expressed as;

$$\mu = \frac{(g_2-g_1)-(R_2-R_1)}{t_2-t_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

where g_1 and g_2 are absolute gravity values at the two end stations of a loop while R_1 and R_2 are the observed reading (converted to milliGal) at times t_1 and t_2 respectively at those stations.

If the same station is reoccupied, then $g_2 - g_1 = 0$ therefore equation 3.1 becomes;

$$\mu = \frac{-(R_2-R_1)}{t_2-t_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

Repeated computation for loops continued until all observations are referred to an initial time The drift correction for any intermediate station referred to the initial time $t0$ thus becomes;

$$\sigma_i = \mu(t_i - t_o) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

With the assumption that drift of the instrument is a linear function of time over a short time interval, it was ensured that all observations in a day were tied to the same time origin during a day's work and the repeat observations at the same station after drift correction was equal to the former. Drift correction was done separately for each altimeter height value using the same cascade drift model

The absolute elevation for each of the stations were determined for each altimeter using the height of the Bench Mark No BM15 to which they were tied. Due to the characteristic behaviour of instrument (Osazuwa, 1992), the field values recorded from the altimeters for each station were varying. It was observed that the height obtained approximately correlate with the values on the topographic map of the area. The observed gravity value at the detailed station is given by;

$$g_{obs} = g_1 - K[(R_o - R_s) - \mu(t_s - t_o)]mGals \ldots\ldots\ldots\ldots(3.4)$$ where

g_1 is the absolute gravity value at the first base station, K is the meter constant. R_0 and R_s, t_1 and t_s are the readings and times at the first base station and detail station respectively

3.4.2 Latitude Effect

Both the rotation of the earth and its slight equatorial bulge produce an increase in gravity with increase in latitude. Therefore it becomes necessary to apply latitude correction for stations at different latitudes. The formula for latitude effect is the 1967 Gravity Reference System (GRS67) whose Chebychev approximation form is

$$g_{lat} = 978031.85(1 + 0.005278895 Sin^2\Phi + 0.000023462 Sin^4\Phi)mGal \ldots\ldots\ldots\ldots(3.5)$$

where Φ is the latitude of the station concerned in degrees.

3.4.3 Free Air Correction

Free air anomaly is obtained from the difference between the measured or absolute gravity of a station, gobs at the topography surface and its theoretical gravity, glat, extrapolated from the reference ellipsoid and correcting it for the free air effect.

The final result of the free air anomaly is given as;

$$\Delta g_{FA} = g_{obs} - (g_{lat -} \frac{dg}{dz} h) \ldots\ldots\ldots\ldots(3.6)$$

where $\frac{dg}{dh}$ is the vertical gradient and h is the station elevation above mean sea level in meters and its value is 0.3086mGal m^{-1} (Parrasins, 1962).

3.4.4 Bouguer Correction

This is the difference between the observed gravity and the theoretical gravity at any point on the earth corrected for the mass of materials between the point and the datum plane. The equation for Bouguer gravity at a point after all the necessary preceding corrections have been applied can be written as;

$$g(B_{grav}) = g(obs) - BC \quad \ldots\ldots (3.7)$$

Where BC is the Bouguer Correction.

$$g_{(BA)} = g(B_{grav}) - g(Theoretical) \quad \ldots\ldots (3.8)$$

Hence the Bouguer Anomaly is determined using the expression

$$\Delta G_{BA} = g_{obs} - g_{lat} + \frac{dg}{dz}h - 2\pi\rho Gh \quad \ldots\ldots (3.9)$$

where $\pi\rho$ is the assumed crustal density value which is 2.67 x 10^3kgm^{-3} or Bouguer density and G is the universal gravitational constant. The term $2Gh$ is the Bouguer correction which is the additional attraction exerted on a unit mass by a slab of rock material of density between a station and reference datum-mean sea level (m.s.l).

3.5 ACCURACY OF THE BOUGUER GRAVITY ANOMALY

The computed Bouguer anomalies could have several errors introduced to it. Errors could be as a result of incompleteness of the formulae used and the correctness of the numerical values of the constants occuring in them (Umego, 1990). The calibration factor of the mordern LaCoste and Romberg gravimeter depends only on the quality of the measuring screws and the lever system. Errors which could arise from the calibration factor is thought to be negligible because, the calibration factor does not change perceptibly with time, which eliminates the need for frequent checks of calibration (LaCoste and Romberg, 1976). At each station, errors could arise from several sources. These include; errors in elevation determination eh, errors in terrain effect et, errors in base value e_{ϕ}, errors in assumed

(1976) which recommended that the most likely in situ densities of subsurface rock lies between the dry and the saturated densities. The summary of the results for the various rock types identified in the area are shown in table 3.1.

Table 3.1 : Summary of Rock Densities

Rock Type	No. of Samples	Range of Densities x 10^3 kgm^{-3}	Mean Densities x 10^3 kgm^{-3}	Standard Deviation
Limestone	83	1.88-2.94	2.53	0.12
Clay	15	1.57-2.54	2.31	0.03
Shales	32	1.67-3.20	2.51	0.04
Ironstone (finegrained)	23	1.75-2.60	2.11	0 .02
Ironstone (coarse)	43	1.67-2.01	1.91	0.05
Total Number of Rock Samples	196			

Bar chart for each rock type was plotted using mean density values for different rock types which in all, range from 2.11 x 10^3 kgm^{-3} for laterites to 1.91 x 10^3 kgm^{-3} for limestone. A total of 83 samples of Limestone were obtained and their density distribution shown in figure 3.5.1a The calculated mean density for the group is 2.53 x 10^3 kgm^{-3} with standard deviation of 0.10 x 10^3kgm^{-3}. A mean density of 2.30 x 10^3 kgm^{-3} was obtained for 15 samples of clay (fig.3.5.2c). Others were represented in the chart as in figures 3.5.1 and 3.5.2. Various authors have published densities of rock types encountered in different parts of the world such as Telford *et al.* (1976) and Dobrin (1976).

3.7 BOUGUER REDUCTION DENSITY

There are three methods of selection of Bouguer reduction density; one is a "traditional" or standard density with which most regional maps have traditionally been reduced using a value of 2.67 x 10^3 kgm^{-3}. The second is by determining a Bouguer reduction density which minimizes the correlation between the computed Bouguer anomaly and topography. This method is widely used in areas of rugged topography (Gerkens, 1989) and which was originally suggested by Nettleton (1939) and Vajk (1956). This second method was not used in this survey because the area is relatively flat. The third method is to measure the density of representative rock samples just as described for this survey. The fact is that it is usually difficult to obtain a suite of rock samples that is truly representative, (Williams and Finn, 1985). Therefore in order to ensure consistency and compatibility with other regional gravity surveys in adjacent areas, the standard density value of 2.67 x 10^3 kgm^{-3} was used for reduction in this survey.

3.8 DENSITIES ACCEPTABLE FOR MODELS

The proper density values used for gravity interpretation will depend upon the depth of formation in relation to the water table, which will inturn depend on whether the climate is arid or moist. The age and depths of sediments depend on how long they are buried. If the period is long enough, the sediments usually consolidate and lithify, resulting in a reduction in porosity and increase in density. Limestones and sandstones which are found in the study area increase in density by infiltration of cements without volumetric change (Cleaveland, 1978). Clays and shales which are compacted clays are the most highly compressible of all sedimentary rocks and they therefore show the greatest amount of compaction. If sandstone and limestones on the other hand are subjected under the same environment, they experience smaller density change (Grant and West, 1965).

From the table 3.1, it can be seen that the range for the rock density in Dange area is from about 1.5 x 10^3kgm^{-3} to 3.5 x 10^3kgm^{-3} and their respective mean densities approximately agree with the published values for similar rock types from other places (Keary and Brooks, 1984); Telford *et al.* (1976)). Considering the results from Telford *et al.* for example, the

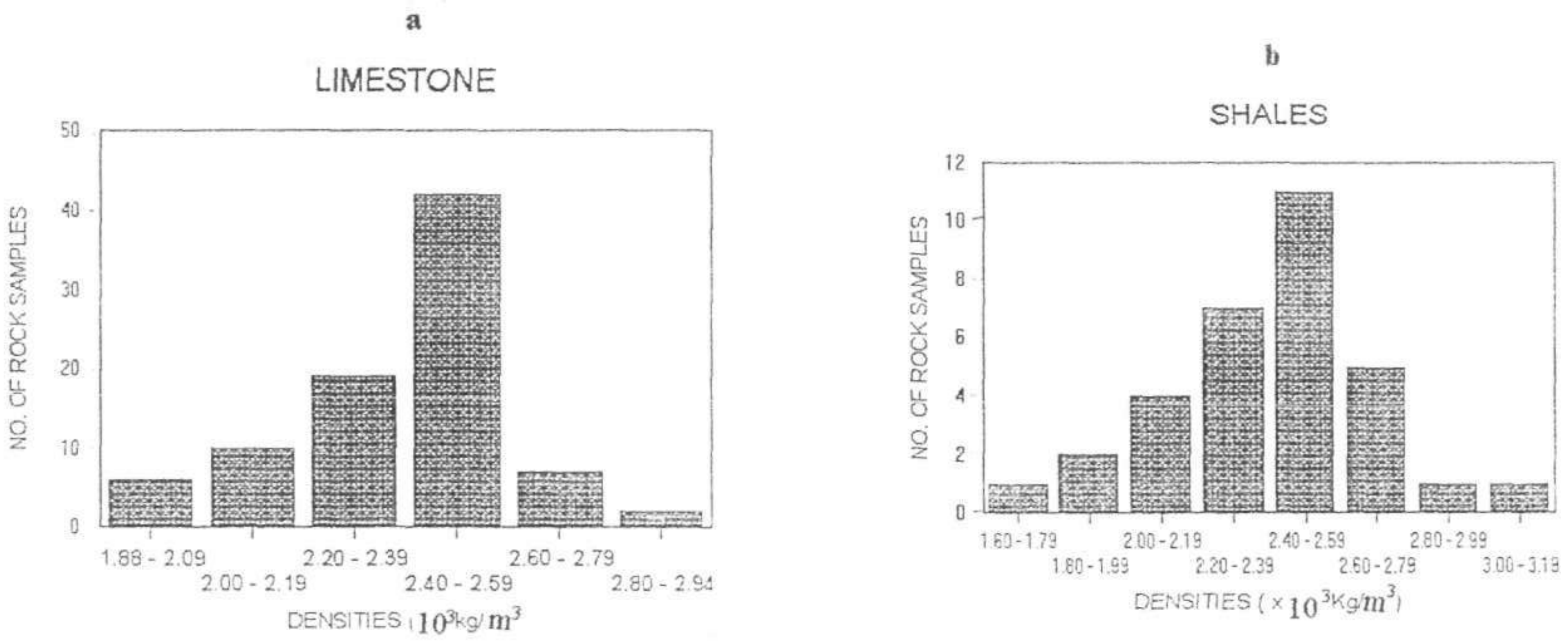


Fig 3.5.1 : Bar Charts of Density Measurements for Limestone and Shales

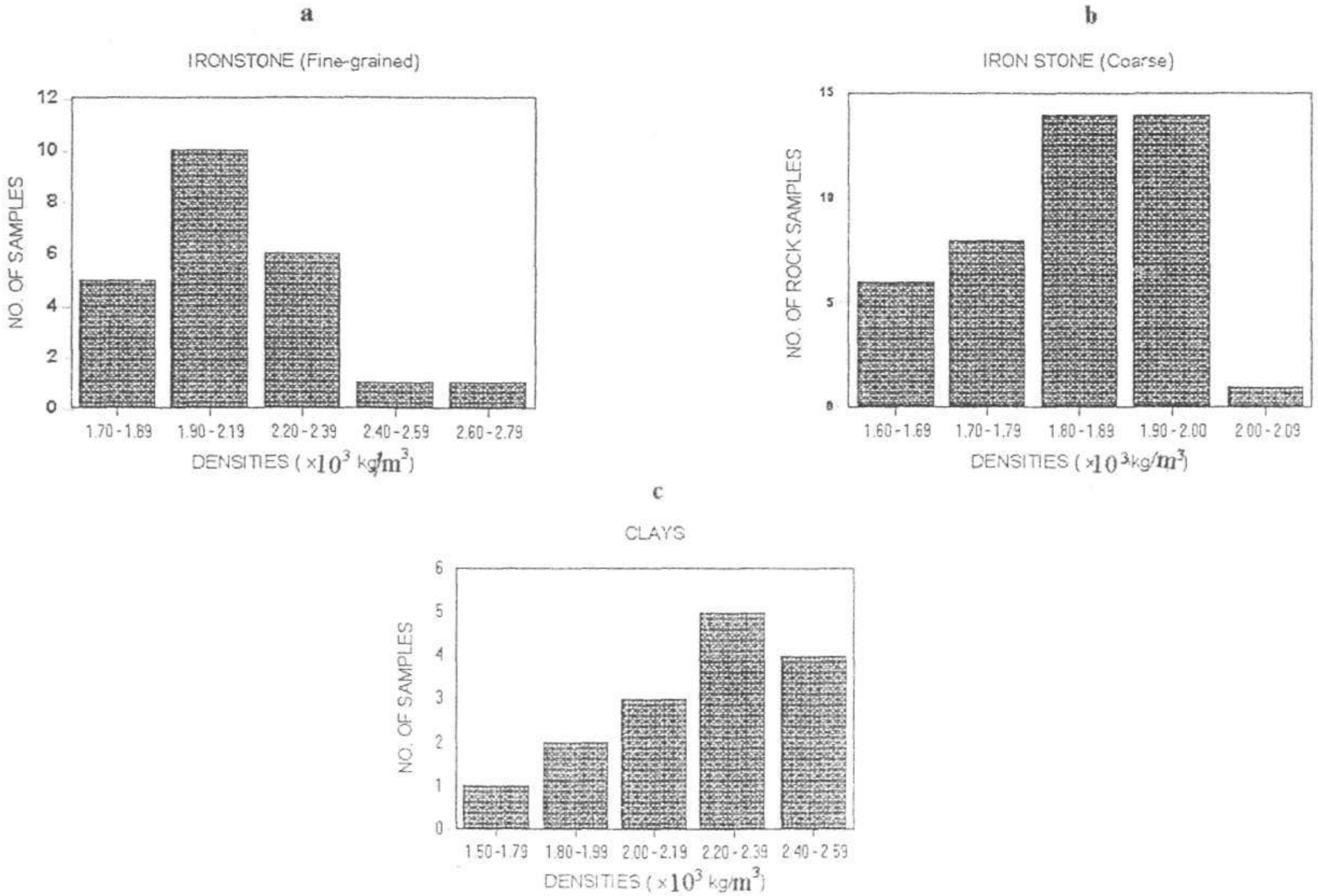


Fig 3.5.2 : Bar Charts of Density Measurements for Ironstones and Clays

mean densities for limestone, clay, shales, and laterites are (2.55, 2.21, 2.40 and 2.15) x 10^3 kgm^{-3} respectively and from the table, the same set of rocks have their density values ranging from 1.88 x 10^3 kgm^{-3} to 2.40 x $10^3 kgm^{-3}$. Since limestone and laterites are the dominant rocks in the study area, density values within this range were used as that of the sediments during interpretation.

Generally, the common rocks of the basement are gneisses, granites, phyllites and quarzites. Their densities range from 2.5 x $10^3 kgm^{-3}$ to 2.9 x $10^3 kgm^{-3}$ and their average densities are (2.80, 2.64, 2.74, and 2.77) x $10^3 kgm^{-3}$ as mentioned above respectively (Telford *et al.,* 1976). Therefore the average density of the earth crust (2.67 x 10^3 kgm^{-3}) was then used as that of the basement.

CHAPTER FOUR

INTERPRETATION OF BOUGUER AND RESIDUAL ANOMALIES

4.1 FREE AIR ANOMALY MAP AND TOPOGRAPHY

Free-air correction essentially takes care of the vertical decrease of the gravity with increase of elevation and no account of the materials between the station and the datum plane taken. The variation amounts to -0.3086 mGal/m. The relationship between the free-air anomaly and heights was investigated and explained in section 3.4.3. The result of both the observed elevation and the free air anomaly of the area are shown in figures 4.1 and 4.2 respectively. The free-air anomaly map indicates values ranging from a maximum of 10mGal to a minimum of -20mGal and a contour interval of 2mGals was used for the map. A careful study of the map reveals that its strike is generally in NE-SW direction with exception of few anomalies located at the northern side of the area which strike NW-SE or N-S.

4.2 BOUGUER ANOMALY MAP

The Bouguer anomaly values obtained from random distribution of the detail stations in the survey area was first of all transformed to regular grid. This was achieved with the aid of a FORTRAN 77 computer program written by members of the geophysics group of the physics department, Ahmadu Bello University, Zaria. The data was used to produce the Bouguer map which is shown in figure 4.3. A contour interval of 2 mGal was used for the map as well as for residual map. The area is characterised by negative Bouguer anomalies ranging from -32 to -56mGal with mean value of -44mGal. The minimum value of -56mGal occurs westward of Dange village towards Danchadi, whereas the maximum value of

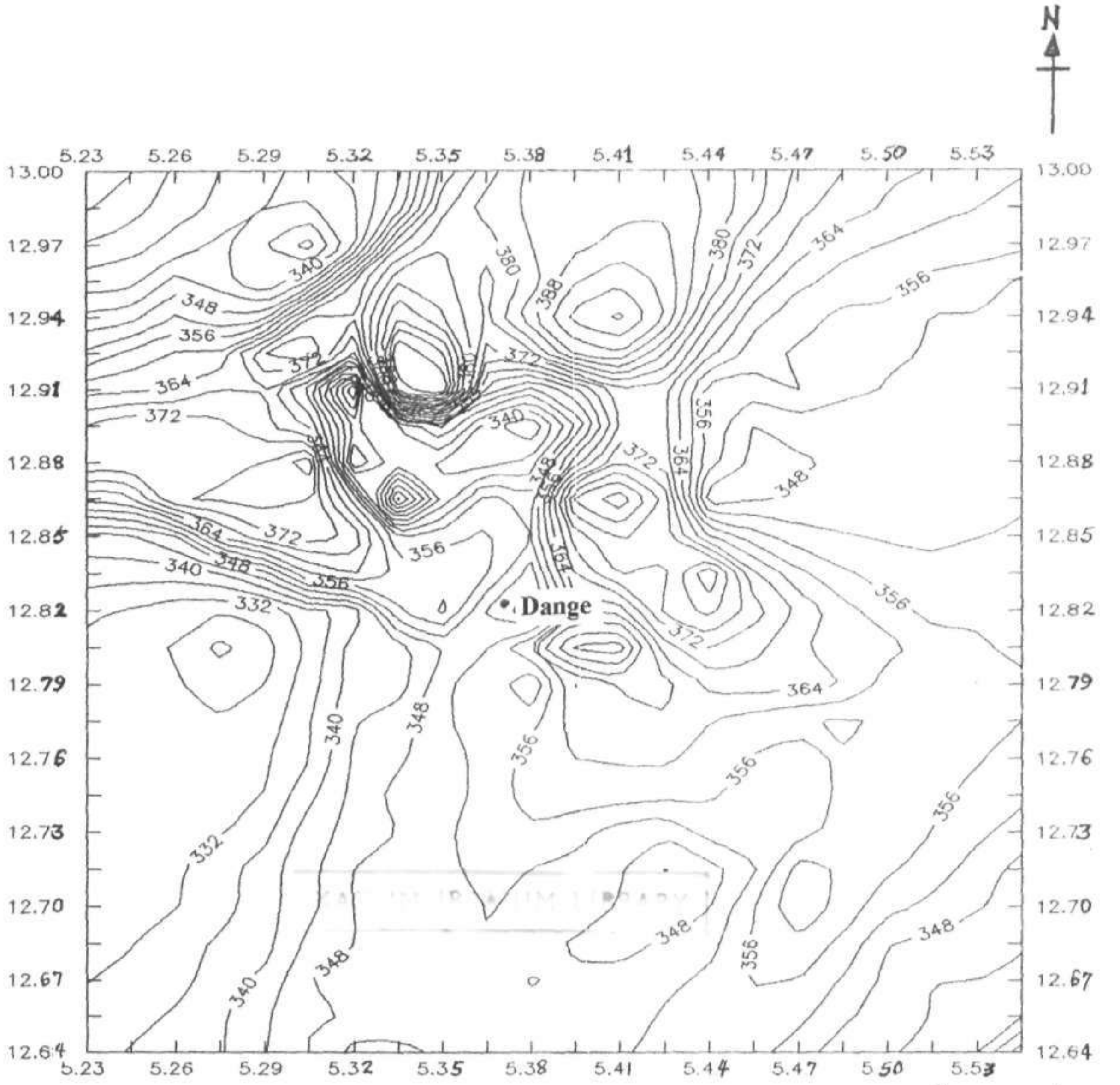


Fig 4.1: Contour Map of the observed Elevation in the Study Area

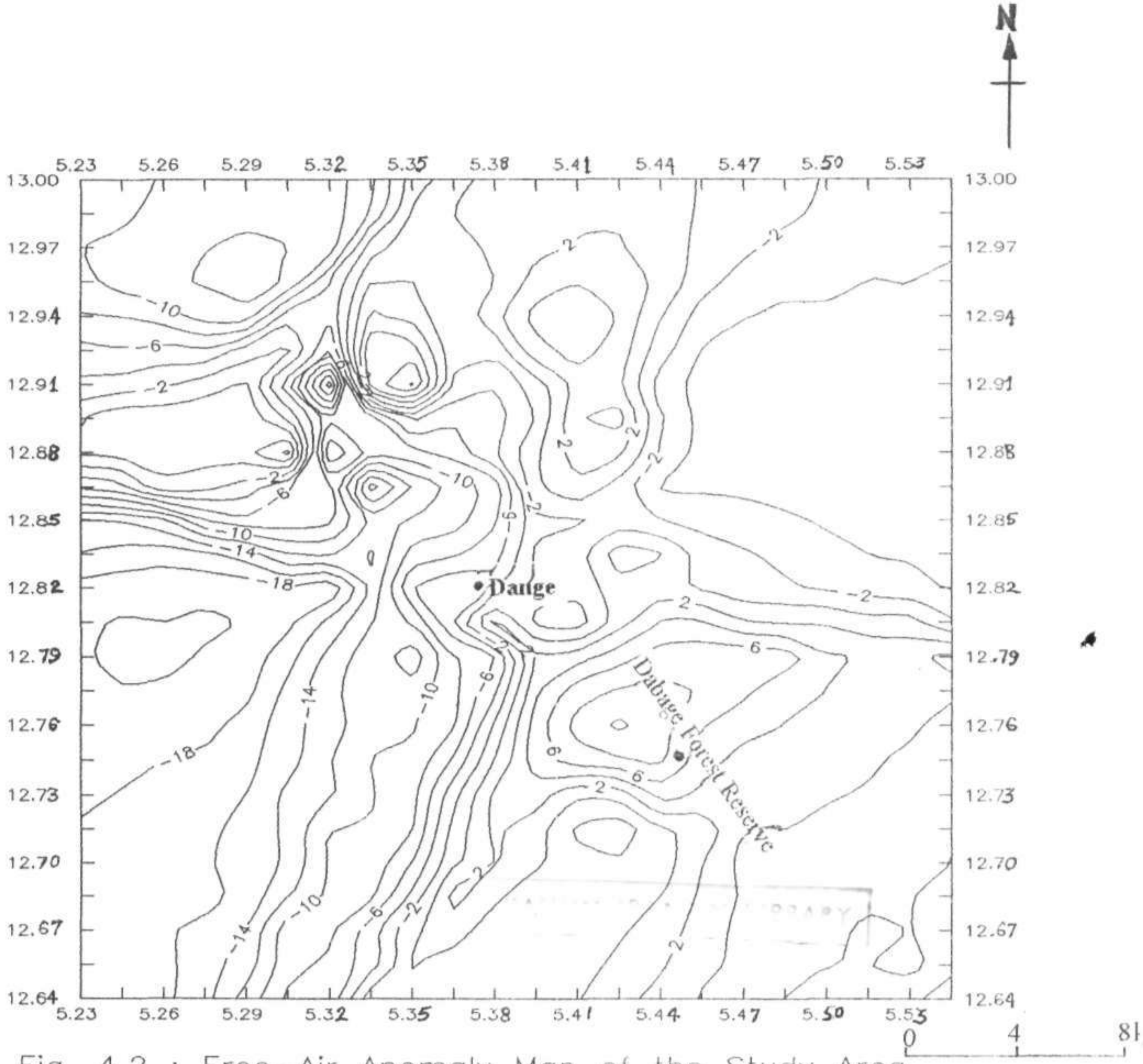


Fig. 4.2 : Free-Air Anomaly Map of the Study Area

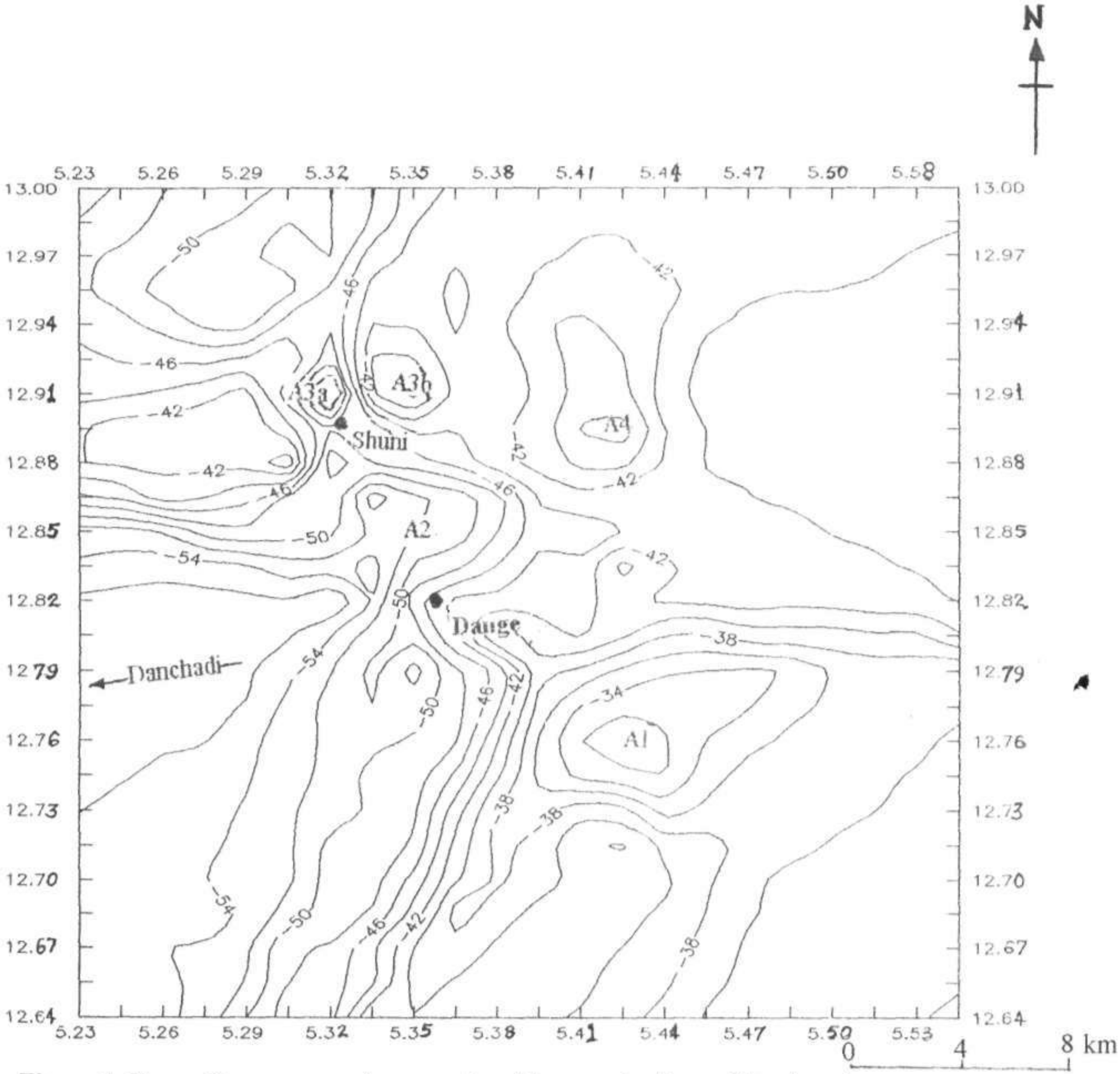


Fig. 4.3 : Bouguer Anomaly Map of the Study Area.

32mGal is located near Dange village (long 5.41°, lat 12.78°) There is roughly NW-SE. striking relative gravity high located at the S-W coner of the map. Two prominent closures found in the map are both relative highs and are located at the SE and NW coners of the map.

4.3. REGIONAL ANOMALY FIELD

Few interesting anomalies could be noticed from the Bouguer map (fig. 4.3). The anomalies frequently may be masked by deep-seated structures. It shows the super position of disturbances of noticeably different orders of magnitude. The larger features generally show up as trends which continue smoothly over very considerable areas, and they are caused by the deeper heterogeneity of the earth's crust. Superimposed on these trends, but frequently camouflaged by them, lie the smaller, local disturbances, which are secondary in size but primary in importance. These are the residual anomalies, which may provide the direct evidence for reservoir - type structure or mineral bodies. But in order to interpret these anomalies, it is important to separate them anomalies from the regional background (Grant and West, 1965).

The regional effect correspond to low frequencies therefore the anomalies are usually of long wavelength showing a gradual change in value while the residual anomalies which are due to local effects may show larger variations.

There are several methods of removing the unwanted regional. Some approach is entirely graphical while others are analytical. In some cases the graphical methods are incorporated in the analytical methods (Gupta and Ramani, 1980). In the present study, a purely analytical method was used in which matching of the regional by a polynomial surface of low order exposes the residual features as random errors. A first order polynomial surface was considered adequate for estimating the regional effect. The regional field (fig 4.4) is a plane dipping gently in a northwesterly direction with a gradient of about 0.4 mGal/km.

4.4 RESIDUAL ANOMALY FIELD

The residual anomaly at any point is then the difference between the observed Bouguer anomaly g_B and the regional effect g at that point and this is expressed as;

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

The residual anomalies at all the points were gridded and contoured. The resulting map (fig 4.5) shows the gravitational effect of the near surface and local structures in the study area.

4.5 QUALITATIVE INTERPRETATION

4.5.1 Free-Air Anomaly Field

The free-Air Anomaly map shown in figure 4.2 is characterized by values ranging from -20mGals to +10mGals. The anomalies represent the influence of topography over the effect of the subsurface structures. Comparing this anomaly field with Bouguer anomaly, it can be observed that where there is Bouguer gravity high, free-air anomaly is also high and where Bouguer is low, free air it is low as well. Areas of high free-air occur exactly where elevation is low such as southeast of Dange where most prominent gravity high (at Dabage Forest Reserve) occurs. The free-Air anomaly provides a broad assessment of the

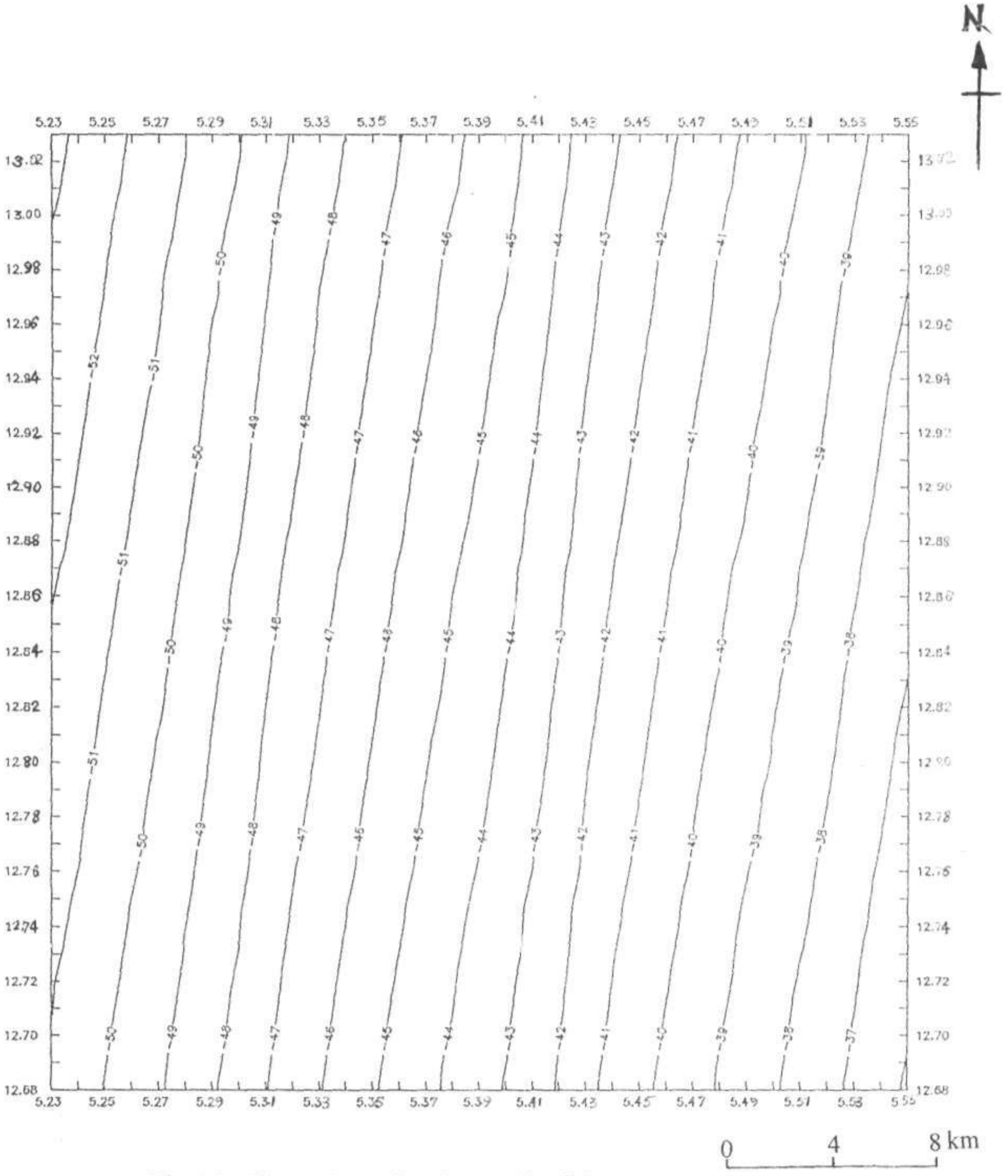


Fig 4.4: First order regional anomaly of the area

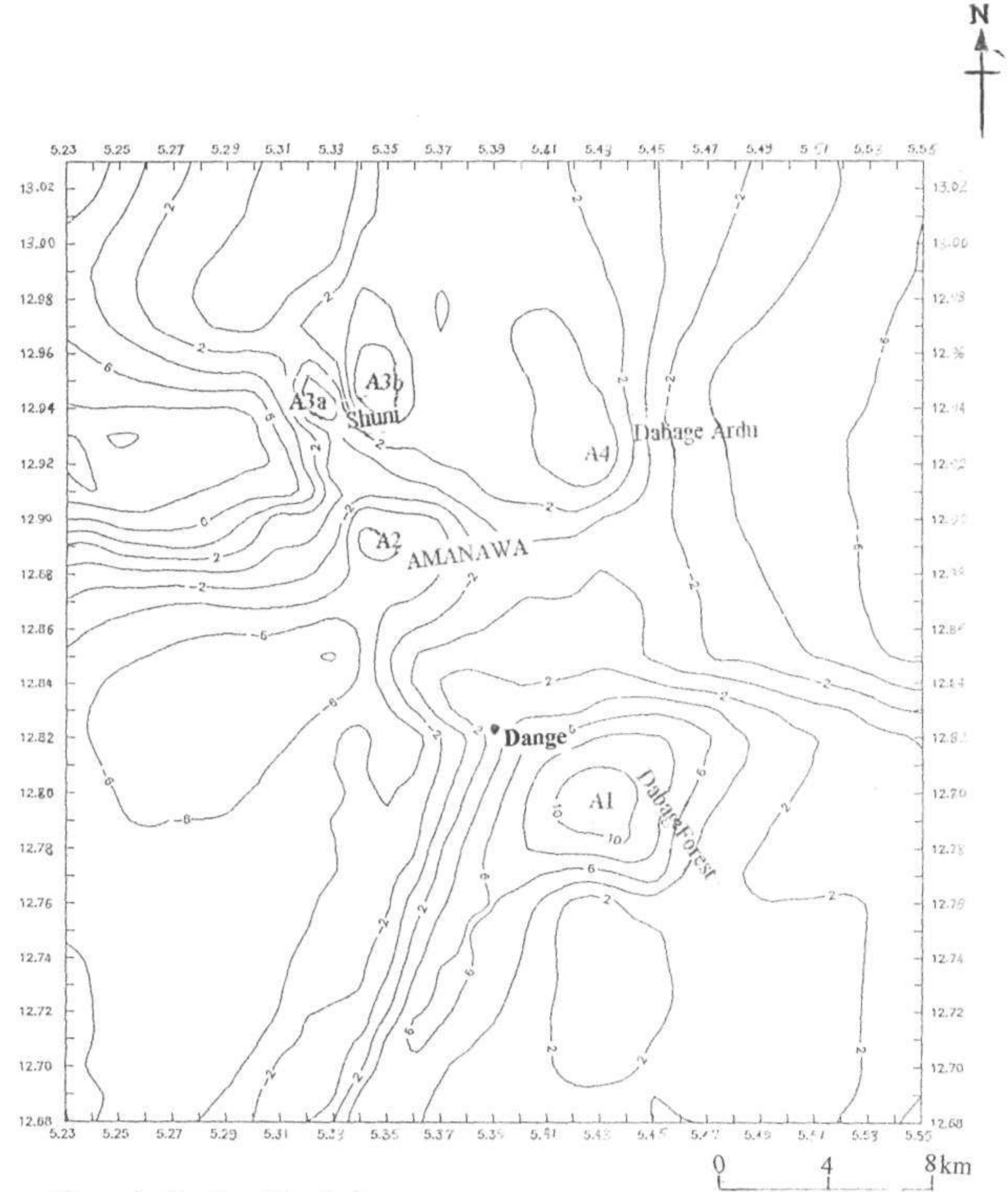


Fig. 4.5: Residual Map of the Study Area.

degree of isostatic compensation of an area. (Keary and Brooks, 1984).

4.5.2 The Bouguer Anomaly Map

The Bouguer anomaly map Fig (4.3) shows values ranging from -32mGal located at the southeastern part of the area to -56mGal located almost at the western part of the study area. The major and the most prominent gravity high labeled 'A1' occurs near Dange village and is centered completely on Rima group of rocks outside the region where Dange/Kalambain formation spread.

The relative gravity high at this part of the study area could not be associated with the sediments such as clays, shales limestones but must be due to a high density intrusion probably in the underlying basement. The center of this gravity high is at (log. 5.41o lat 12.78°) and this corresponds exactly with the center of the peak of magnetic low on the aeromagnetic anomaly map (Fig 1.3). Other closures worth noting in the map include those labeled A2, A3a, A3b and A4. These were considered because they were all well constrained by gravity stations.

4.5.3 Residual Anomaly Field

The residual map (fig. 4.5) generally trends NW-SE. It is characterized by both positive and negative anomalies. The anomalies occur at the same position where the corresponding Bouguer anomalies occur.

The residual anomalies also marked A1, A2, A3a, A3b and A4 just as in Bouguer were located at Dabage forest , (near Dange), Amanawa, Shuni town and near Dabage-Ardu respectively. The anomaly A1 has amplitude +10mGal, while the anomaly A2 at Amanawa is a gravity low with an amplitude of -6mGals. Anomalies A3a and A3b located almost at

Shuni village are gravity low and high with amplitudes of -2mGal and +6mGals respectively. Anomaly A4 located near Dabage-Ardu has a slight positive anomaly of amplitude +4mGal. Figure 4.6 shows the residual anomaly map superimposed on the geologic map of the area. The gravity high near Dange village can be said to be directly located over a subsurface with positive density contrast with respect to its surrounding (host) rocks or the basement. Gravity lows observed in the areas correspond either to the thickened sediments of Dange formations or to the presence of older granite intrusions. Hence, there is slightly a good correlation between the residual anomaly map and the geological map.

The most prominent gravity high A1 just as also observed in Bouguer map is centered on the Rima group of rocks which is completely outside the region where Dange/Kalambaina formations spread. The relative gravity high could be associated with high density intrusion probably in the underlying basement. The relative gravity low could be an indication of abundance of sediments though one should not completely rule out the fact that the cause could be the presense of a low density intrusive rock such as granite. The hilly area around Amanawa has over the years recorded both local and mechanised mining of some economic rocks and minerals whose source are in the Dange formation. (S.I.C., 1996).

The gravity low of A3a could also be associated with the abundance of Dange sediments. Of course from the geological map it is obvious since the anomaly lies almost at the junction where Sokoto group formations begins to widen northwestwards. A slight gradient of about 1mGal/km is indicated from the anomaly A3a to A3b. This steep gradient

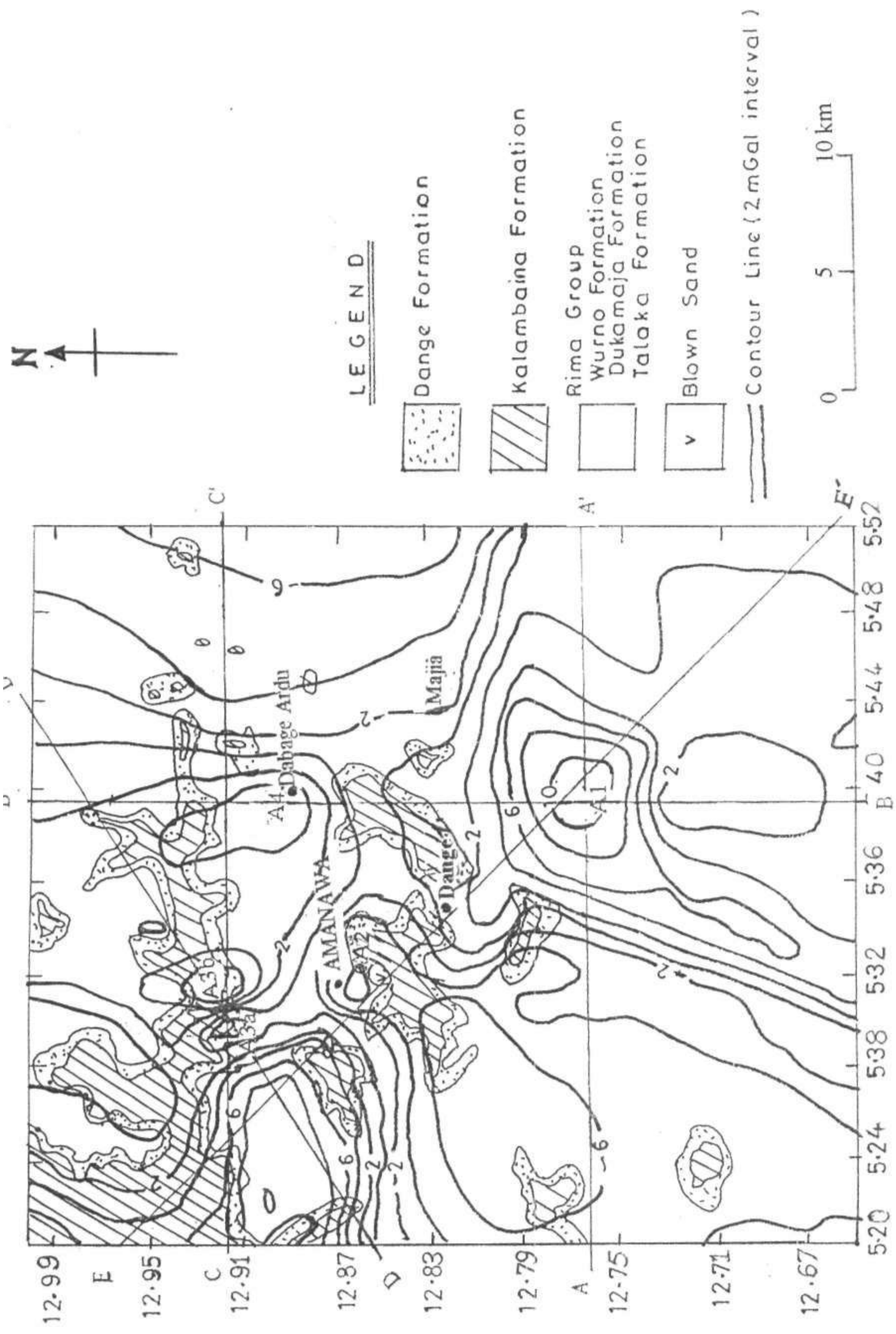


Fig. 4.6 : Residual Map of Dange Superimposed over Geological Map.

suggests a sharp geologic contact or possibly may be suggestive of faulting. There is also gravity low around Dabage-Ardu and Majia. This could be a slight indication of granitic intrusion since there is less of Dange /Kalambaina formations in those areas as indicated in the geological map. Observing the mid southern part of the map, a gradual gravity gradient of about 1mGal/km could be noticed which also may be suggestive of faulting. All the speculations made above over the study area, are based solely on the results obtained.

4.6 QUANTITATIVE INTERPRETATION OF THE RESIDUAL ANOMALIES

4.6.1 Introduction

In quantitative interpretation of gravity data, the objective is to estimate a subsurface structure whose calculated gravity effect satisfactorily approximate the observed gravity field measured on the surface. The magnitude of gravity anomaly caused by any structure depends directly on its volume times its density contrast. Secondly, the amplitude of the anomaly decreases as the depth of the structure causing it increases. If the shape of the structure is irregular or diffused, the observed gravity will be expected to reduce in sharpness and in magnitude. Nevertheless, if a structure is not sufficiently well isolated from other structures whether similar to it or not, its own gravity anomaly cannot be resolved from those of the other structures (Hay, 1976).

Quantitative interpretation, generally is hardly unique or precise as it is always based on geologic inferences. Thus, sufficient and adequate information about the geology of the study area becomes indispensable for a meaningful interpretation. The study area falls into the sedimentary basin of this country, and the particular sediments found from the surface (Dange formation) which is of the paleocene age have average density of about $2.5\text{x}10^3$ kgm^{-}

^{3} considering the lithologic sequence downward to depth of about 80m. Underlying it with a slight unconformity are the Wurno, Dukamaje and Taloka formation which are of Maastrichtian age which have average density of about 2.3×10^{3} kgm^{-3}. These deposits extend to the depth of about 270m (Kogbe, 1979). Below this occurs continental deposits (fluvial) which were of lower cretaceous or pre-maastrichtian age (Chukwuike, (1978) and Grant, (1978)). The formations at this depth (about 700m) which were Illo and Gundumi formation have average density of 2.5×10^{3}kgm^{-3} (Burk and Dewey,1972). Considering the ages of deposits above, a mean density of 2.4×10^{3}kgm^{-3} was estimated by the author and it was used for all the sediments overlying the basement rocks. This density value was used as the density of the sediment while modeling the profiles. The estimated density value has a negative density contrast of -0.20×10^{3}kgm^{-3} with respect to the average density of the basement (2.67×10^{3} kgm^{-3}) used. Therefore almost all the gravity lows in the study area were accounted for by the thickening of the sediments. In the interpretational procedures, the gravitational effect of any assumed initial model is calculated and compared with the observed effect. Changes are made as necessary on the assumed model in order to get a better fit. The common changes usually involve volume, shape and density contrasts. This process is repeated within geologically reasonable limits until a new structure whose calculated effect best fits the observed effect was obtained. This approach is refered to as forward modeling (Patterson and Reeves, 1985).

Five profiles; A-A', B-B', C-C', D-D' and E-E' (fig.4.7.1 and 4.7.2) were chosen based on the criteria that each crossed at least one of the major anomalies identified earlier for interpretation. Also it was ensured that each of the profiles was chosen to be at right angle with the strike of the anomalies and that each has data points surrounding or close to it.

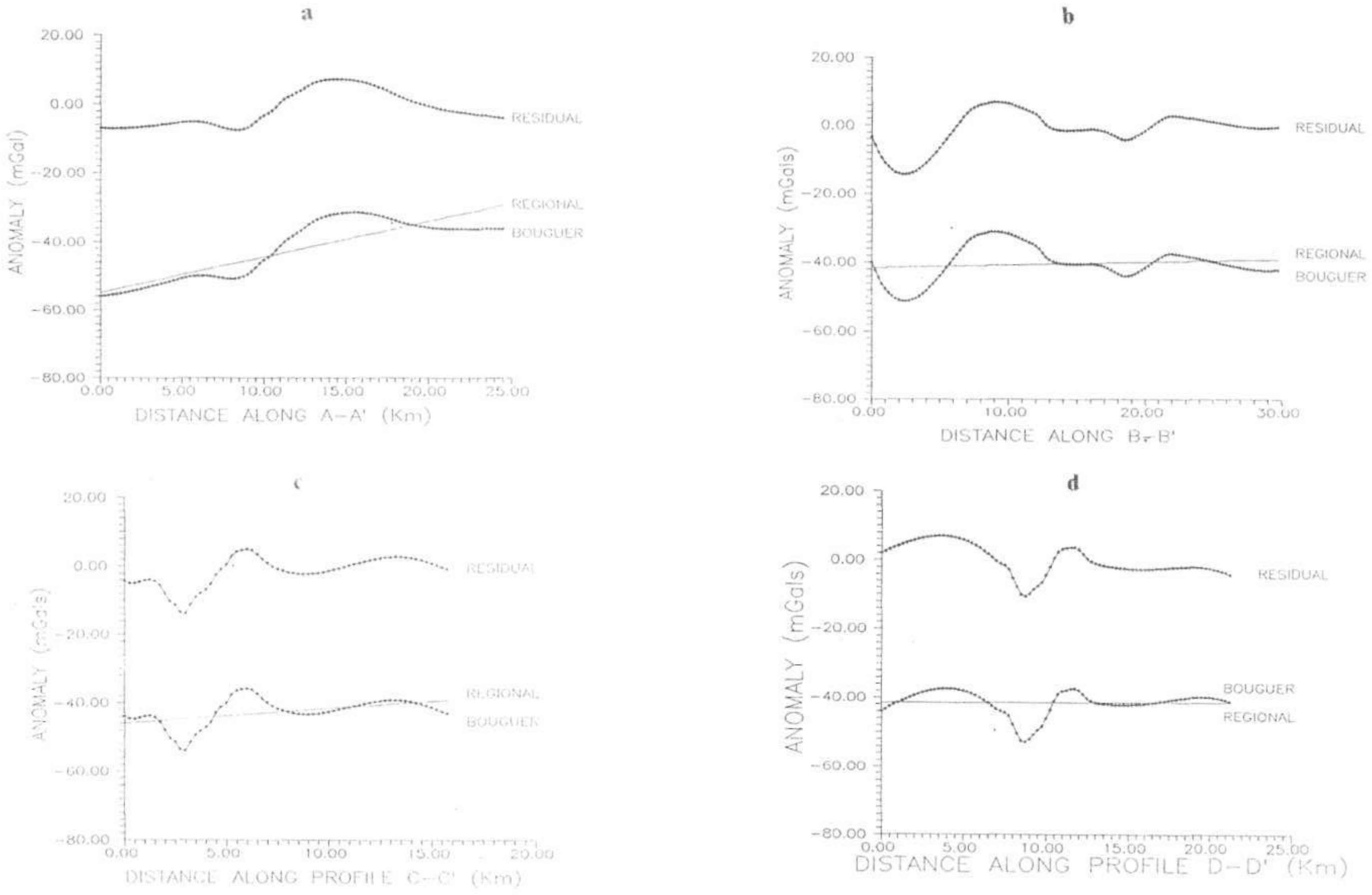


Fig.4.7.1. Bouguer, Regional and Residual Anomalies along profiles A-A', B-B', C-C' and D-D'

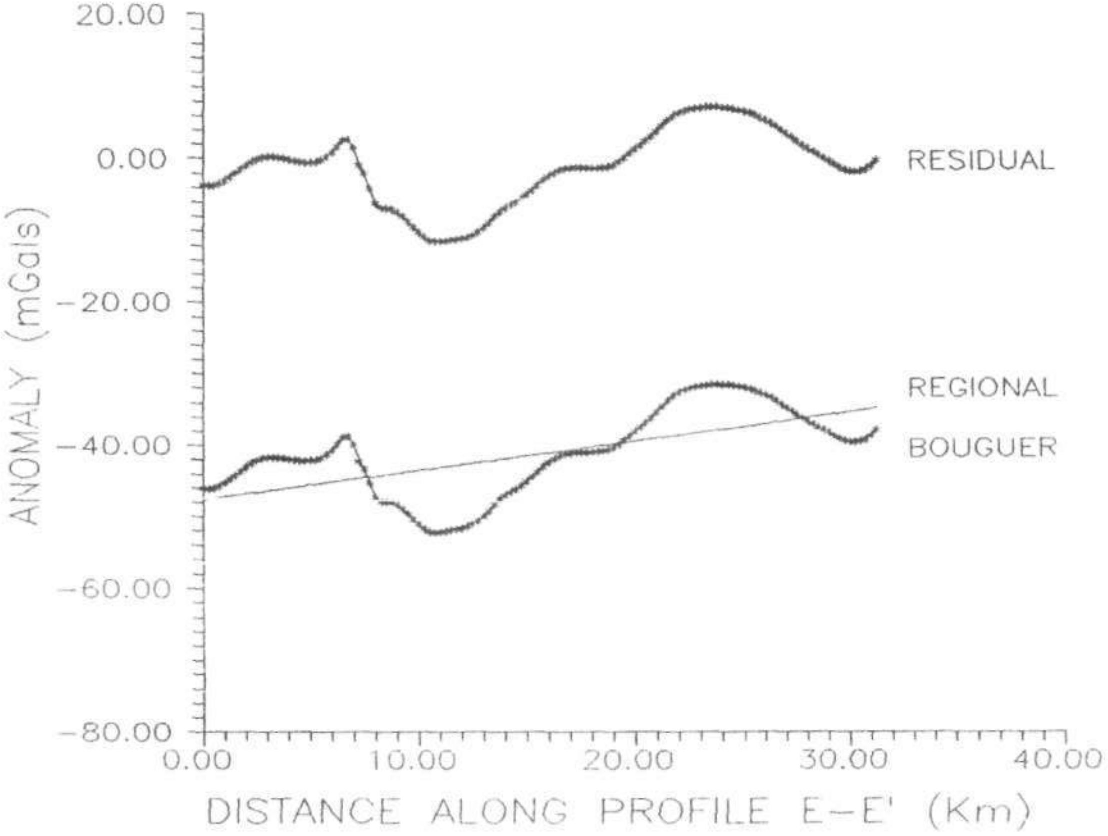


Fig4.7.2: Bouguer. Regional and Residual Anomalies along profile E-E'

Despite the fact that the method of interpretation is used in this work is subject to all the ambiguities in potential field data, it is still good since there are some geological and geophysical constraints to depend upon which will keep most ambiguities within manageable limits (Dobrin, 1976). A dimensional gravity/magnetic software (GMSYS) written by Mike *et al.* (1991) based on Rasmussen and Pederson (1979) courtesy Osazuwa, 1992, was used to model the profiles.

The total magnetic field along Sokoto-Gusau road with its corresponding regional and residual anomalies are shown in fig. 4.7.3. The profile which was produced fron ground magnetic data indicates a prominent magnetic low at a location which corresponds exactly with the prominent Dange magnetic anomaly in the north eastern portion of Dange sheet 29 of the air born geophysical series. It thus attests to the accuracy of the air borne geophysical series in both the location and magnitude of this anomaly. The profile is almost collinear with profile E-E' of the gravity data. It can be noticed that the prominent magnetic low occurs almost at the same location with the prominent gravity high in profile E-E' (fig. 4.7.2). The same method of interpretation and computer program used for gravity was also used for quantitative interpretation of this manetic profile (fig. 4.8.6). This interpretation reveals that the prominent Dange magnetic anomaly and gravity anomaly have a common origin.

4.6.3 Profile A-A'

This profile runs in the W-E direction and cuts across anomaly A1 (fig. 4.6). While modelling, an intrusion I_1 with density contrast 0.09 was introduced in the basement at about 15.0km along the profile before a fit of the computed with the observed was obtained

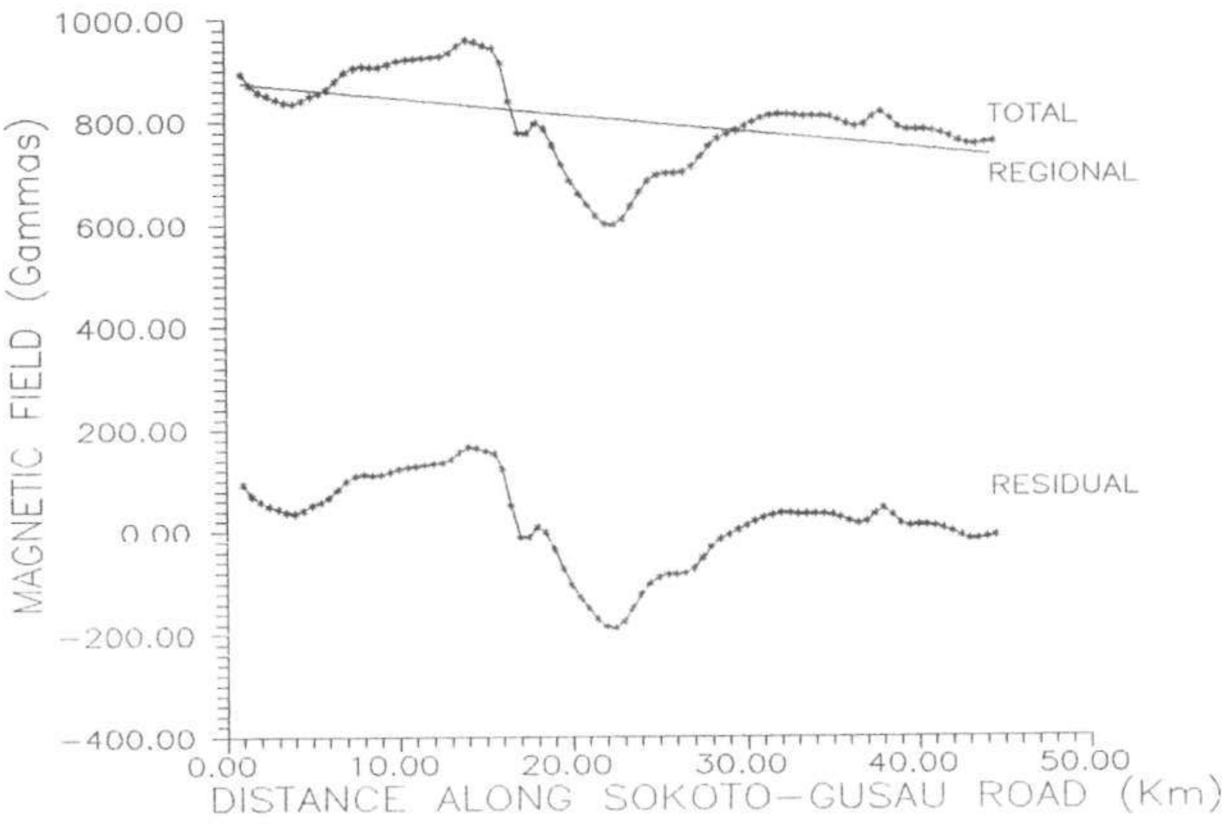


Fig.4.7.3: Total, Regional and Residual Anomalies along Sokoto-Gusau Road.

(fig 4.8.1). While the low gravity at the western side of the of the profile was accounted for by thickened sediments which has density contrast of -0.20 x 103kgm^{-3}. The maximum and minimum depths to the top of the basement along this profile are 3.0km and 1.0km respectively. The body I_1 has inward dipping walls and the dips are 48^0 and 25^0 on its western and eastern flanks respectively. The maximum depth extent of the intrusive is about 10.0km from the surface of the earth. The high density intrusive I_1 (0.09 x 10^3kgm^{-3}) is probably a continuation in the underlying basement of the rocks of the schist belt of northwestern Nigeria notably schists, phyllites or quartz whose outcrops are common in the odjoining Maru schist belt.

4.6.4 Profile B-B

This profile runs S-N across the anomalies A1 and A4 (fig 4.6). Three intrusions were modeled at distances 2.5km, 10.0km and 25.0km along the profile. The intrusion I_2 has a negative density contrast of -0.10. It complements the sedimentary beds which has average density contrast of -0.20 to account for the gravity low at this end of the profile. This intrusion has a slight inward dipping contacts of 10^0 and 30^0 at its southern and northern flanks respectively. The depths to the top and bottom of I2 are about 1.0km and 6.0km respectively. It is suspected to be a granite intrusion because of its low density.

The intrusion labelled I_3 is the same as that labelled I_1 in profile A-A' (fig. 4.8.1). The intrusive dips inwards at about 32^0 and 20^0 at its southern and northern flanks respectively. The average depths to the top and bottom of this intrusion are 2.0km and 10.0km respectively. A third intrusion I4 occurs at the northern end of this profile. The average depths to the top and bottom of the intrusion are 2.0km and 7.0km respectively. The I

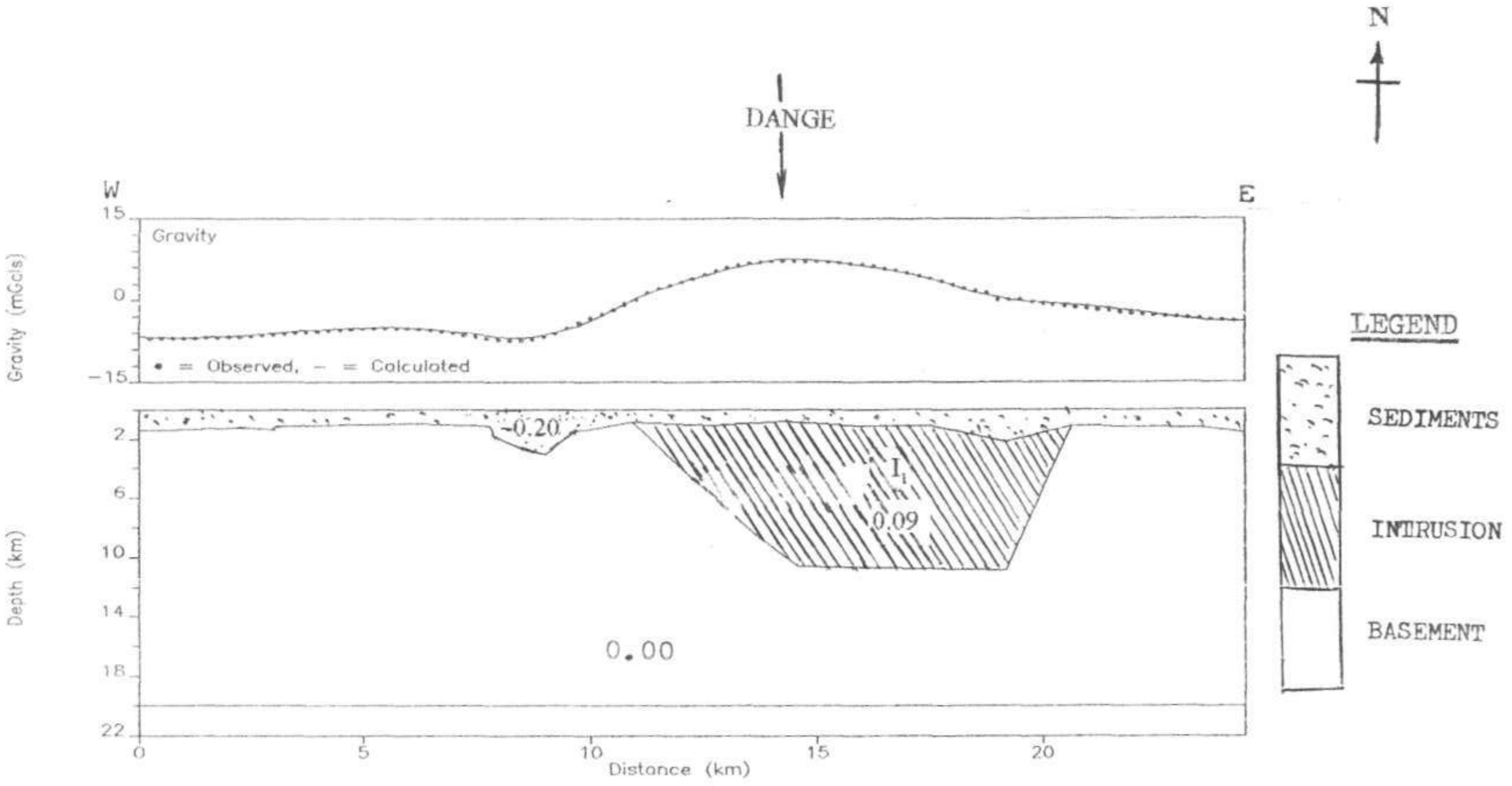


Fig 4.8.1 : 2 1/2 Dimensional Model of Profile A-A'

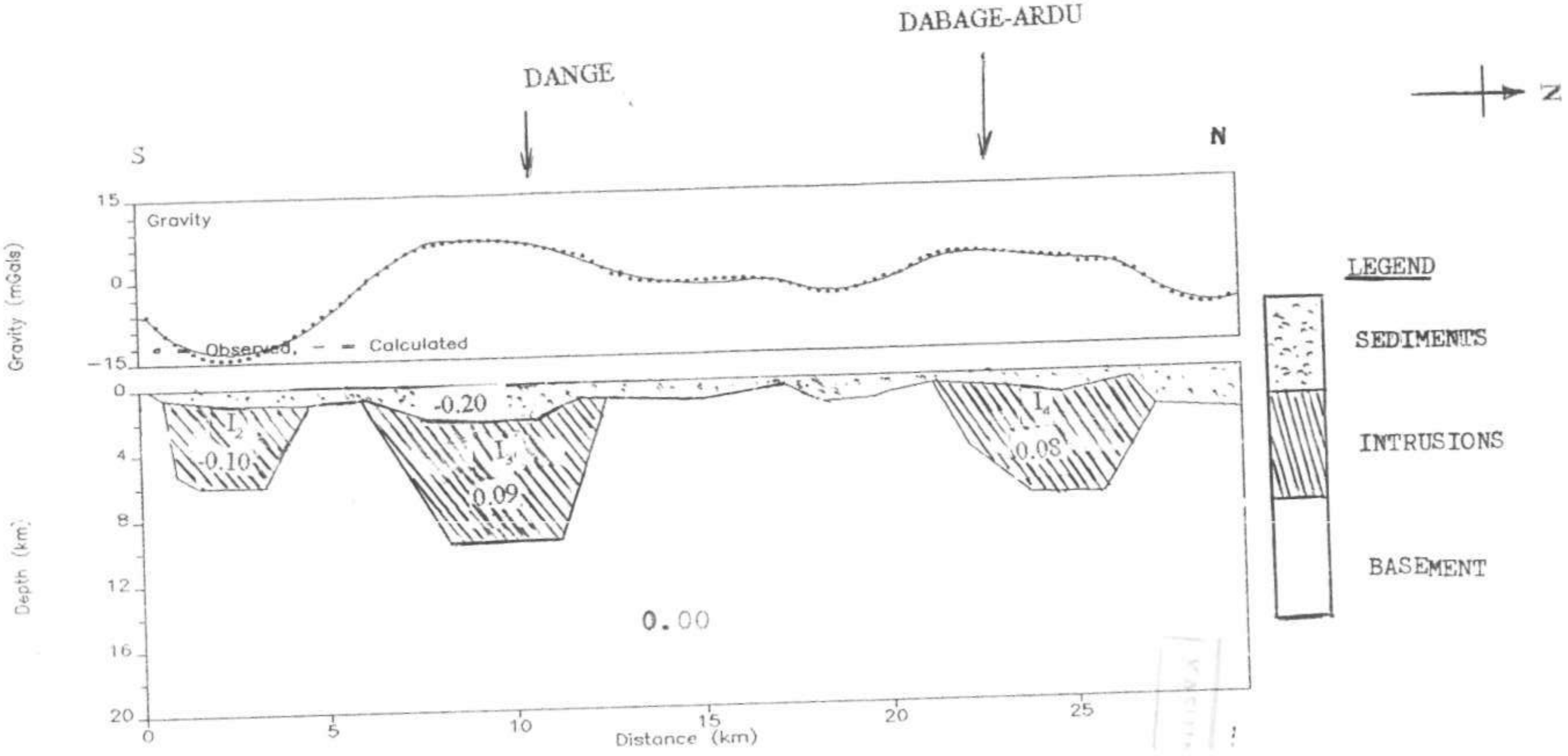


Fig 4.8.2 : 2 1/2 Dimensional Model of Profile B-B'

ntrusion has an inward dipping contact with the basement at about 35^0 and 20^0 at its southern and northern flanks respectively. This intrusion is believed to have almost similar properties with that of I_3 having a positive density contrast of 0.08 which is very close to 0.09 of I_3. Hence the body could also be a schist. The gravity low at the extreme northern end of this profile is accounted for by the sediments which thickened to about 2.5km. In all, the maximum and minimum depths to the top of the basement were 2.5km and 0.5km respectively.

4.6.5 Profile C-C'

This profile runs W-E across anomalies A3a, A3b and A4 as shown in fig. 4.6. It is characterised by a gravity low at 3km distance from the western end of the profile and two gravity highs at 6.0km and 13.0km respectively. The intrusions along this profile were labelled I_5, I_6 and I_7 from the western end of the profile fig. (4.8.3).

The intrusion I_5 is suspected to be granite having density contrast of -0.08. It accounts for the gravity low at this western end and can be observed to have dipped towards the western side of the profile at an angle of about 200 to the vertical. Its maximum depth is about 8.3km.

The other intrusions I6 and I7 have almost common density contrast of 0.07 and 0.08 respectively. While I6 dips inwards at angles 12^0 and 15^0 at its western and eastern flanks, I7 dips which dips at about 5^0 and 30^0 at its eastern and western flanks respectively. I7 could be observed to be the same as intrusion I4 of profile B-B' (Fig 4.8.2). The maximum and minimum depths to the basement along this profile are 2.5km and 0.5km respectively.

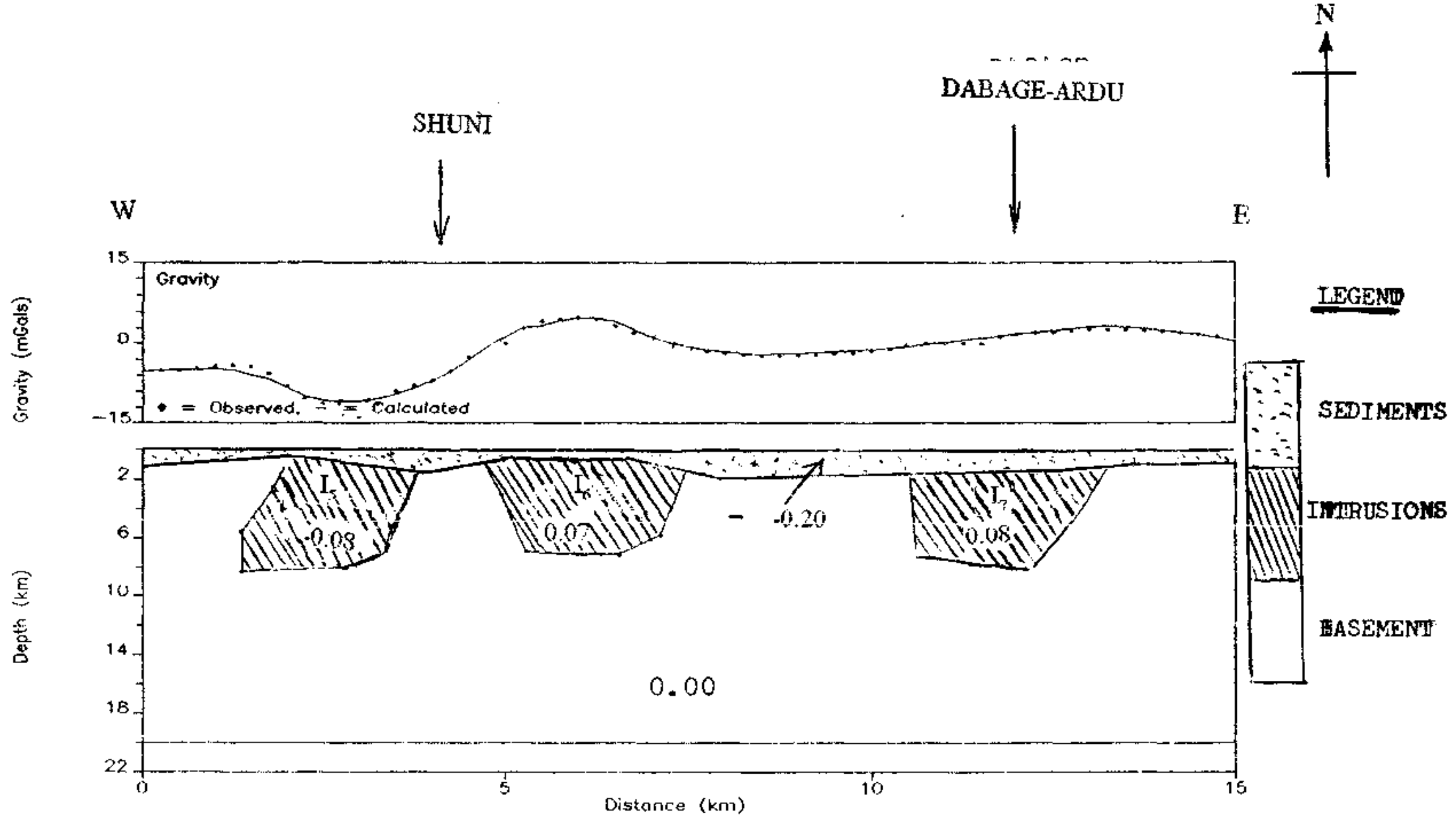


Fig 4.8.3 : 2 1/2 Dimensional Model of Profile C-C'

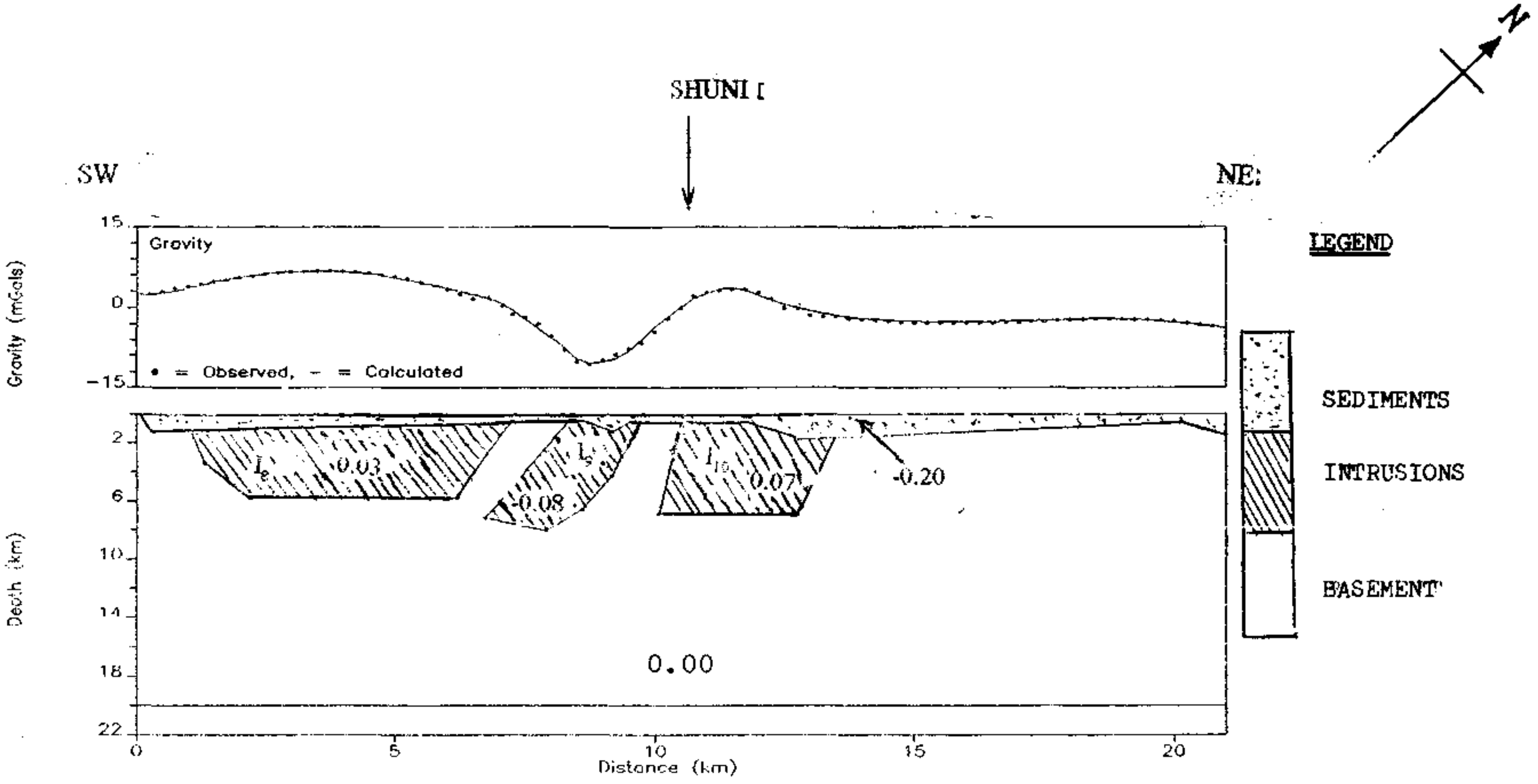


Fig 4.8.4 : 2 1/2 Dimensional Model of Profile D-D'

4.6.6 Profile D-D'

This profile runs in SW-NE direction across anomalies A3a, and A3b (fig. 4.6). It is characterised by two gravity highs at about 5.0km and 11.0km distances and a gravity low at about 8.5km distance, all measured from the southwestern end of the profile While the sedimentary beds had density contrast of -0.20, three intrusions labelled I_8, I_9 and I_{10} were introduced to account for the gravity highs and the low (fig. 4.8.4).

The causative body I_8 at the SW end of the profile has a density contrast of 0.03. The body extends to about 6.0km along this profile. It dips slightly inwards with an angle of about 35_0 at both flanks of it and its depth extent is about 6.0km.

Next to this is the intrusion I_9 which accounts for the gravity low along the profile. It has density contrast of -0.08 hence can be observed to be same intrusion as I_5 since they not only occur at the same place but are similar both in density and mode of emplacement (fig. 4.8.3 and 4.8.4). The maximum depth extent could be observed from both profiles to be 8.5km from the ground surface. The intrusion I10 has the same density contrast and depth extent with I6 as shown in fig. 4.8.3 which are 0.07 and 6.0km respectively. In all, the maximum and minimum depths to the top of the basement along this profile are about 2.0km and 0.5km respectively.

4.6.7 Profile E-E'

This profile runs in NW-SE direction and is the longest of all the profiles (fig. 4.8.5). It cuts across Dange village, Amanawa village and Shuni town. This is to say that it is the most reliable profile of all since it has enough data points almost all along it. Two gravity

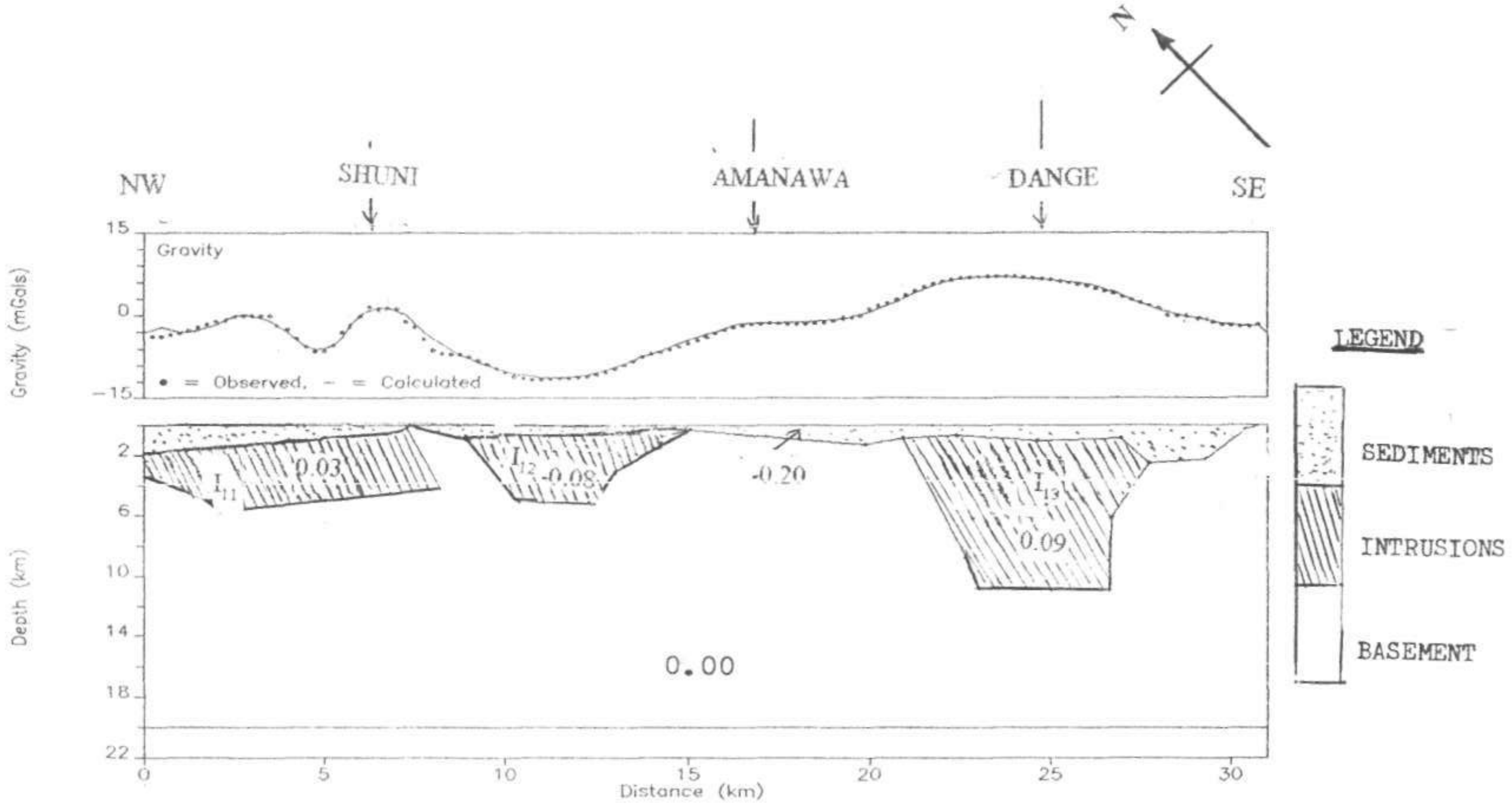


Fig 4.8.5 : 2 1/2 Dimensional Model of Profile E-E'

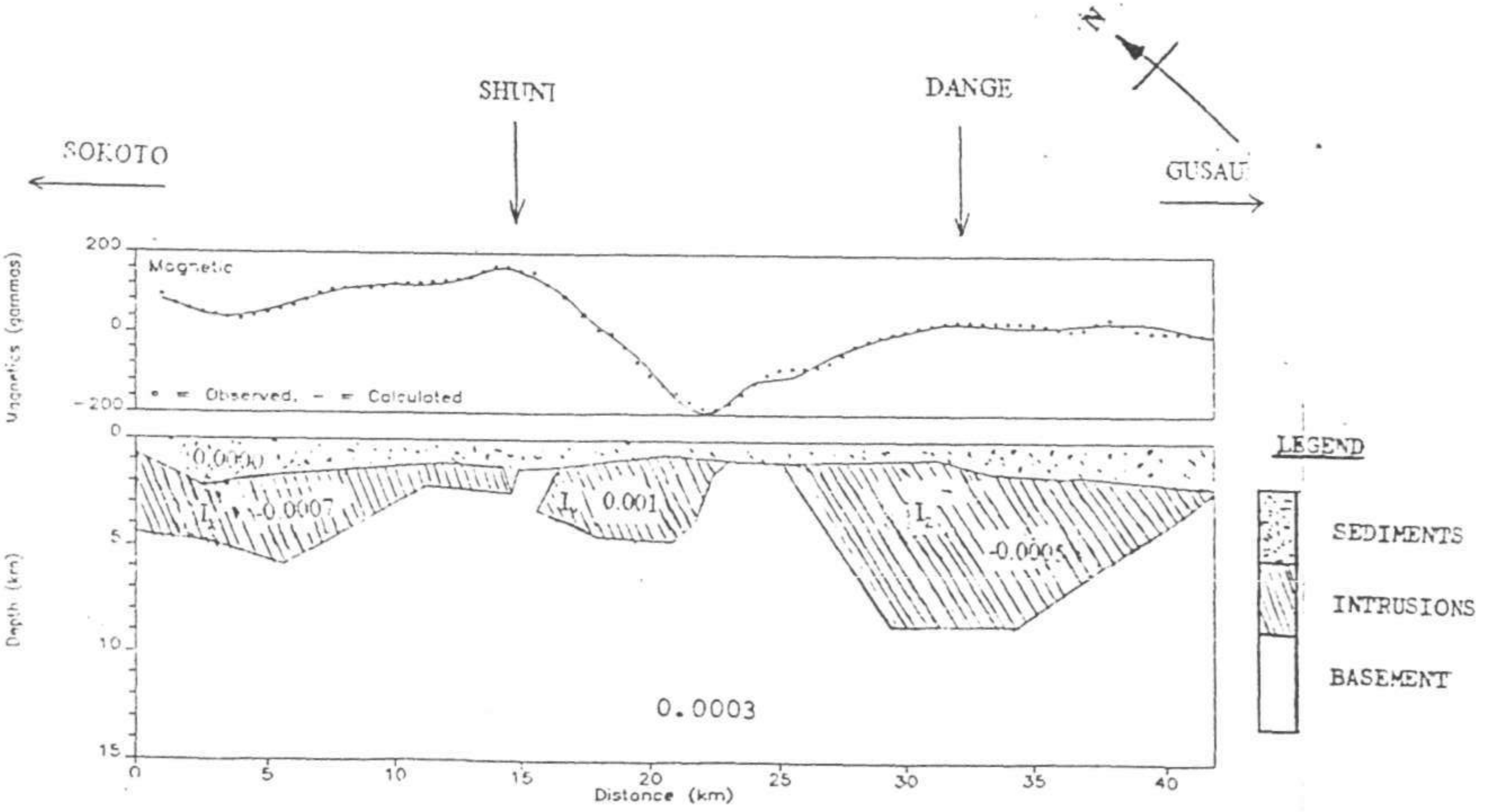


Fig 4.8.6 : 2 1/2 Dimensional Model of the Residual Magnetic Anomaly Along Sokoto-Gusau Road.

or both E-E' and the present profile is owing to the complexity and variations in magnetic field which is more erratic and localized than in gravity. Secondly, while profile E-E' of gravity is a straight line, the magnetic profiles was taken along Sokoto-Gusau road which is neither straight nor of the same length with E-E'.

While Iy has magnetic susceptibility contrast of 0.001c.g.s, Ix and Iz have negative susceptibility contrast of -0.0007c.g.s. and -0.0005c.g.s. respectively. It can be observed that while Ix and I_{11} appear to unify with the basement almost at the same depth of 6.0km Iy and I_{12} similarly unify with the basement at the depth of about 5.0km, but I_Z and I_{13} for some of the reasons mentioned above do not agree in depth extent. While I_{13} unifies with the basement at the depth of about 10.0km, Iz appears to unify with it at lesser depth of about 8.5km.

CHAPTER FIVE

DISCUSSION AND CONCLUSION

5.1 DISCUSSION

The crystalline basement rocks which are of Precambrian age include gniesses, granites, phyllites and quarzites. These are all metamorphic rocks with exception of granites which are igneous. Although there are several intrusives suggested in this work, non of them could be as reliable as those obtained along profile E-E' since it is the only profile that has data points almost throughout its length. While the ground magnetic data confirms the presence of the Dange aeromagnetic anomaly, the location of the most prominent gravity anomaly A1 (fig. 4.6) revealed that it is the same causative body for the gravity high that is also causing the prominent magnetic low (fig. 4.8.5 and 4.8.6)

The body with its high density contrast is suggested to be schistotic since schist is the most abundant intrusive even in the basement complex neighboring the study area. The uplift movement at the margin of the Iullemmeden basin which resulted to a mild deformation of almost all the upper Cretaceous and Tertiary formations in the basin first can be said to account for the irregular surface of the basement along the profiles taken in this work. Secondly, the uplift obtained was probably accompanied by the downward warping resulting to synclinal structures in the basin (Woakes *et al*, 1987)

5.2 SUMMARY OF RESULTS AND CONCLUSION

From the lithological information about the study area, the results, and the detailed interpretation, the following conclusion can be drawn from the entire survey;

1. The gravity field is characterized by large negative Bouguer anomalies ranging from -32mgals to -56mGals.
2. The prominent Dange aeromagnetic anomaly has been confirmed by both gravity and ground magnetic data collected in this survey.
3. From the results of the models, the density of the causative body responsible for gravity high is about 2.75 x 10^3 kgm^{-3}. This indicates that the major intrusion accounting for the anomaly is more likely to be a schist.
4. The average depth to the top of causative body causing anomaly A1, on the residual map isabout 2.0Km. The major intrusive causing anomaly A1 has its dip estimates ranging from20° to 48° considering profiles A-A', B-B' and E-E'. The lateral extents of this body along this profiles are 10km, 6.5km and 17km respectively. Generally the intrusion has inward dipping (convergent) walls down to the depth of 10.0km where its density unifies with that of the host rock.
5. The body has probably resulted from increased density due to the metamorphic process which must have taken place during the middle Eocene uplift (a geodynamic event) which also accounts for some synclinal structure and general irregularities of the surface in the basin.

5.3 RECOMMENDATIONS

It is recommended that more geophysical work should be carried out in Dange area. If another detailed geophysical work will follow this, emphasis should be laid on the parts where fault scarps were partially revealed. Secondly if there will be motorable roads available in the NE and SW zones of the area, a more detailed gravity work should be carried out over them for clearer picture of gravity field there.

Although the preliminary ground magnetic data collected along Gusau-Sokoto road confirms the existence of the Dange aeromagnetic anomaly, yet a more detailed ground magnetic work should be carried out in the area for better picture of the anomalous body.

There have not been any record of geophysical work in the area using electromagnetic or electrical resistivity method. The author recommends these methods so that in addition, layers of different conductivities could be mapped out. An on going research in the area has involved sampling of rocks in some wells around Dabage-Ardu village. The rock samples include some dark ones containing carbonaceous materials and possessing the properties of reservoir rock common in petroleum environment (Alagbe, personal communication).

Further investigation could be carried out around the faults in the study area. Hence resistivity and other electrical methods, magnetelluric and telluric, VLF and well logging will not be of any disadvantage when carried out in the area for mor detailed information.

These recommendations will not be complete if seismic method is not mentioned. It is more reliable to locate and map synclines, anticlines, faults and reefs if there is any in the study area. Seismic refraction method in particular will be effective and economical in covering larger area in shorter time than reflection method although it would give a less precise information than the later. It could also be used to show depths and shape of the basin specifying their lithologies and reveal throws of faults in any high-speed formation such as dense limestones where they possibly occur in the study area.

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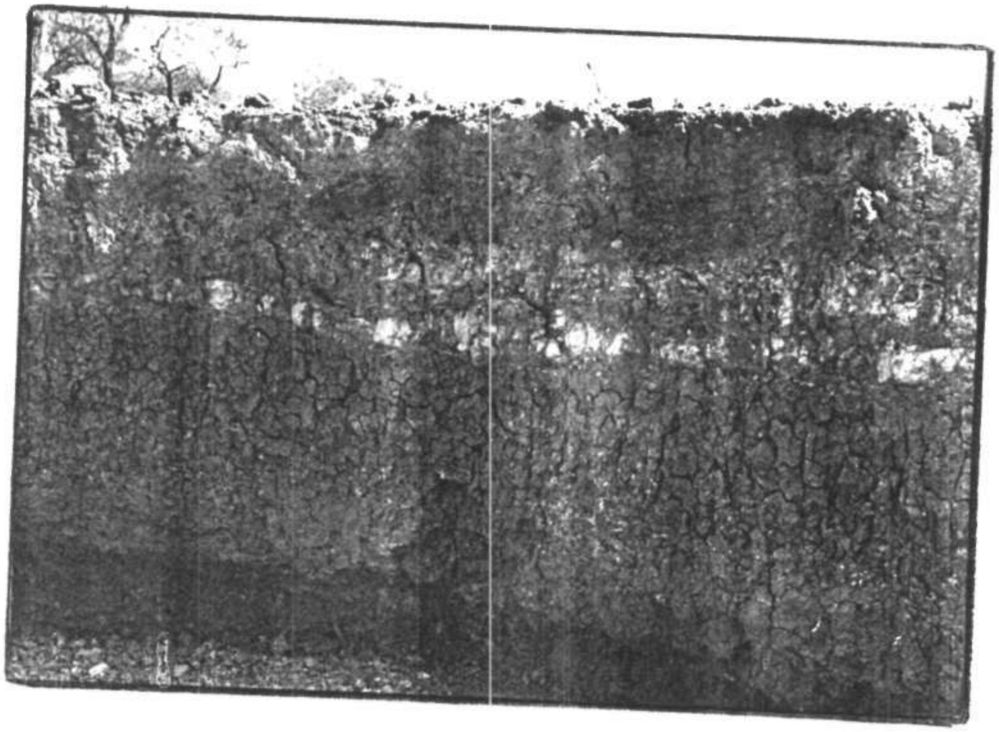

Appendix II: Road-Cutting Showing the Layers of Sokoto Group of Sediments.