GRAVITY SURVEY AROUND THE WUSE-AKIRI SALT SPRING AREAS IN THE MIDDLE BENUE VALLEY

BY

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D E D I C A T I O N

This work is dedicated to my parents, Mr. & Mrs. Ibibo Boma Ekine, for all their struggles and to my brothers who still sally-forth for the trident of the turbulent high seas. Ahoa!!!

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ABSTRACT

Gravity investigation was carried out within the Wuse-Akiri area in the Cretaceous sedimentary sequence of the Middle-Benue Valley to delineate and locate areas of possible salt deposits. The area of about 48 km square is bounded by latitude 8° 21.5'N and 8° 24.7'N, and longitudes 9° 17.8'E and 9° 21 'E.

Gravity measurements were made along traverses on a 400 x 800 square metre grids, using the LaCoste - Romberg gravimeter, model G-446. The area is characterised by dominant WSW to ENE trending negative Bouguer anomalies ranging between -230 to -165 gravity units. Negative residuals of the order of 2.0 to 7.0 g.u. were obtained in the area. The major negative closure of 7 g.u. is located in the southeastern part of the survey area. Small, positive closures of about 2.0 g.u. were also obtained located at areas of mapped baryto veins.

Since the Keana formation which underlies the whole of the survey area is known to be impregnated with salt beds, the causative body of the observed negative anomalies has been assumed to be a small salt dome intruded by irnonstones which overflow in the south eastern direction. The cylindrical models obtained for the structure have mean radia of 880 m for the salt dome and 270 m for the intrusive ironstones. The depth to the top of those models is about 415 m. An estimated mass of 2.4×10^9 tonnes of salt was obtained for this major anomaly. The Akiri salt spring in the area owes its origin to the contact between transit ground-water and the salt body, and issues at convenient points through fractures and fissures in the Keana formation flanking the anticlinal axis.

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C H A P T E R 1

1.1 INTRODUCTION: In recent times, geophysical methods of exploration, have played increasingly, important role in the search for mineral deposits, and with the improvements in geophysical instrumentation and techniques, the gravity method has come to play an increasingly significant role in the exploration for ores and saline deposits. Gravity survey, though expensive in terms of skill, operation time, and field equipment, is much cheaper as a reconnaissance tool in most geophysical explorations.

The gravity method is applied particularly to mineral exploration to aid in quantitative studies of both magnetic and non-magnetic ore bodies; in the search for non-magnetic ores; and as a reconnaissance tool in the study of regional structures that are favourable for the occurence of such ores. These studies include the determination of the areal and subsurface extent, the attitude and structure of the body. In this application, the gravity method is used primarily in conjunction with other geophysical methods and geological studies. In the search for dissiminated mineral ores, seismic and gravity methods have not been very favourable, but however, in the search for mineral deposits and the delineation of bedrocks the application of gravity, seismic and resistivity surveys have yielded very precise and detailed results.

The success of the gravity method in quantitative studies is strongly dependent on the limitations imposed by the results of these other methods. However, inspite of the inherent ambiguities and lack of precision in

gravity surveys, they can impose very definite limits on geological interpretation and can thereby make specific contribution to the overall exploration picture.

1.2 PREVIOUS STUDIES IN THE AREA:

There has been no record studies, either geological or geophysical, that has been carried out within the area of the present survey. The only surveys and studies around the area were:

(i) A regional geophysical survey of the Benue Valley by Cratchley and Jones (1965). The results of this survey showed Bouguer isogals that are generally parallel to subparallel to the boundaries of the cretaceous crystalline basement, with a medial zone of gravity high which is flanked on either sides by narrow elongated gravity lows. They also attempted a stratigraphic correlation of the Benue Valley. The indicated anomolous features elongated in a NE - SW direction were along the occurences of brine springs which correspond to a series of folds and fractures related to several Tertiary intrusions.

Cratchley and Jones' survey included only two gravity stations within the present area of survey (fig.1) and so is not adequate enough to indicate the presence of any salt dome or any such local structures.

(ii) Offodile (1974) carried out a detailed geological mapping of Lafia Sheet 231 and a reconnaissance survey of part of Akiri Sheet 232 towards the north of Makurdi on a scale of 1:100,000. (fig. 2(a).

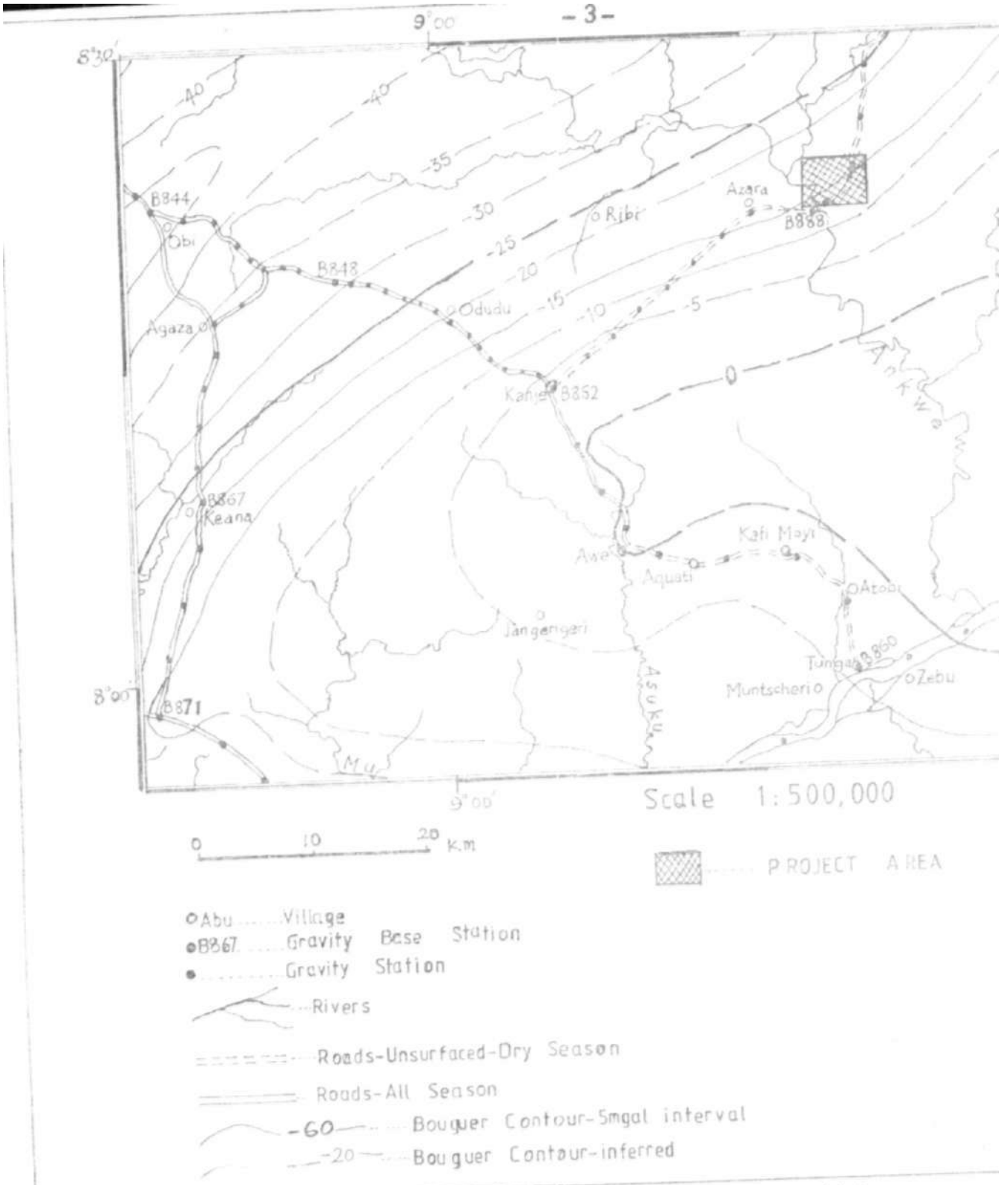


Fig. 1 Bouguer Gravity Contour Map Of The Benue Valley
(After Cratchley and Jones, 1965)

(iii) Ajakaiye and Ajayi (1977) carried out a regional gravity survey of the salt springs zone in Lafia division within sheets 231 and 232.

Other geological studies that have been undertaken within the middle - Benue valley are the works of Falconer (1911), and later a sketchy account, in relation to lead - zinc exploration by McConnell (1949). Farrington (1952) and Bogue also did some work on the Nigerian brine springs. Reyment (1965) did a stratigraphical summary of the Middle - Benue using field programmes (1950) and palaeontological monographs (1955). Esso West Africa Inc. (1967) made a photogeological interpretation of the Middle - Benue valley and the surrounding areas. Finally, Offodile et al (1977) carried out geological studies of the Azara baryte deposits.

1.3 AIM AND SCOPE OF THE PRESENT SURVEY:

Ajakaiye and Ajayi (1977) carried out a regional gravity survey within the Middle half of the area on topographic map sheets 231 and 232 (fig.2(b)). The gravity measurements were along all motorable roads and tracks, with gravity stations located at 1 km intervals except along main roads where stations were on benchmarks at 1.6 km intervals. The survey indicated low gravity values in the vicinities of known salt springs, viz: Awe, Azara, Kanje, Keana and Ribi. The Akiri salt springs are about 12 km east of Azara and so lies closely within the area of the regional survey.

The present work is to carry out a more detailed survey around the Akiri salt pits, in response to the request by the Nigerian Mining

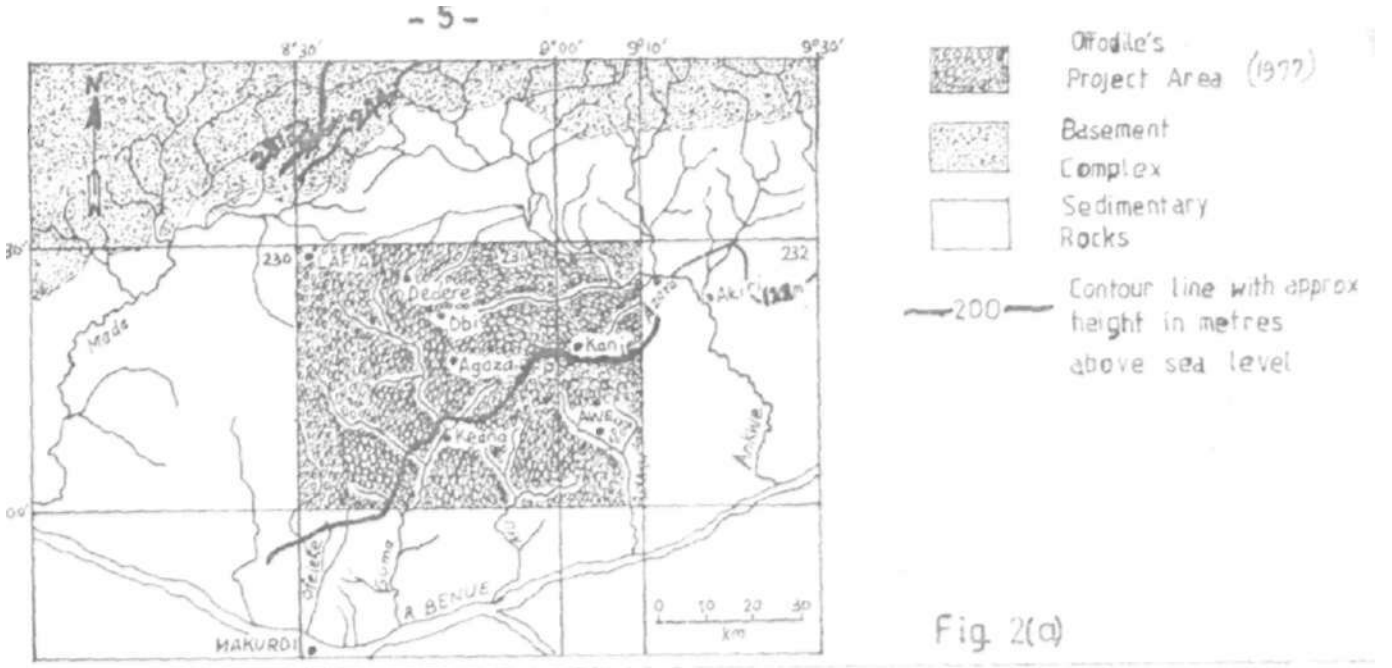


Fig. 2(a)

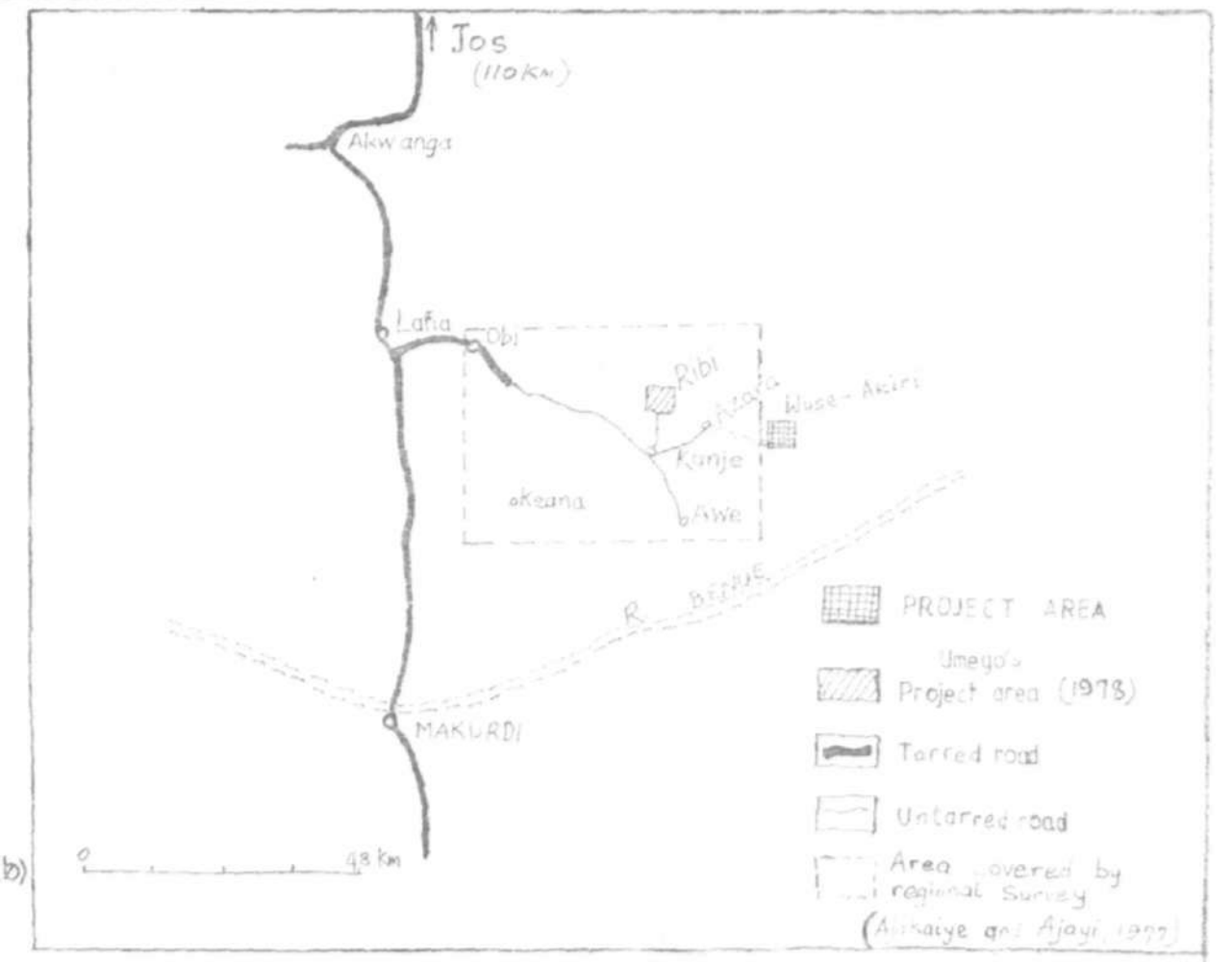


Fig. 2(b)

Fig. 2 (a) Topography Of Keana - Awe Area
(b) Sketch Map Of Previous Survey Areas

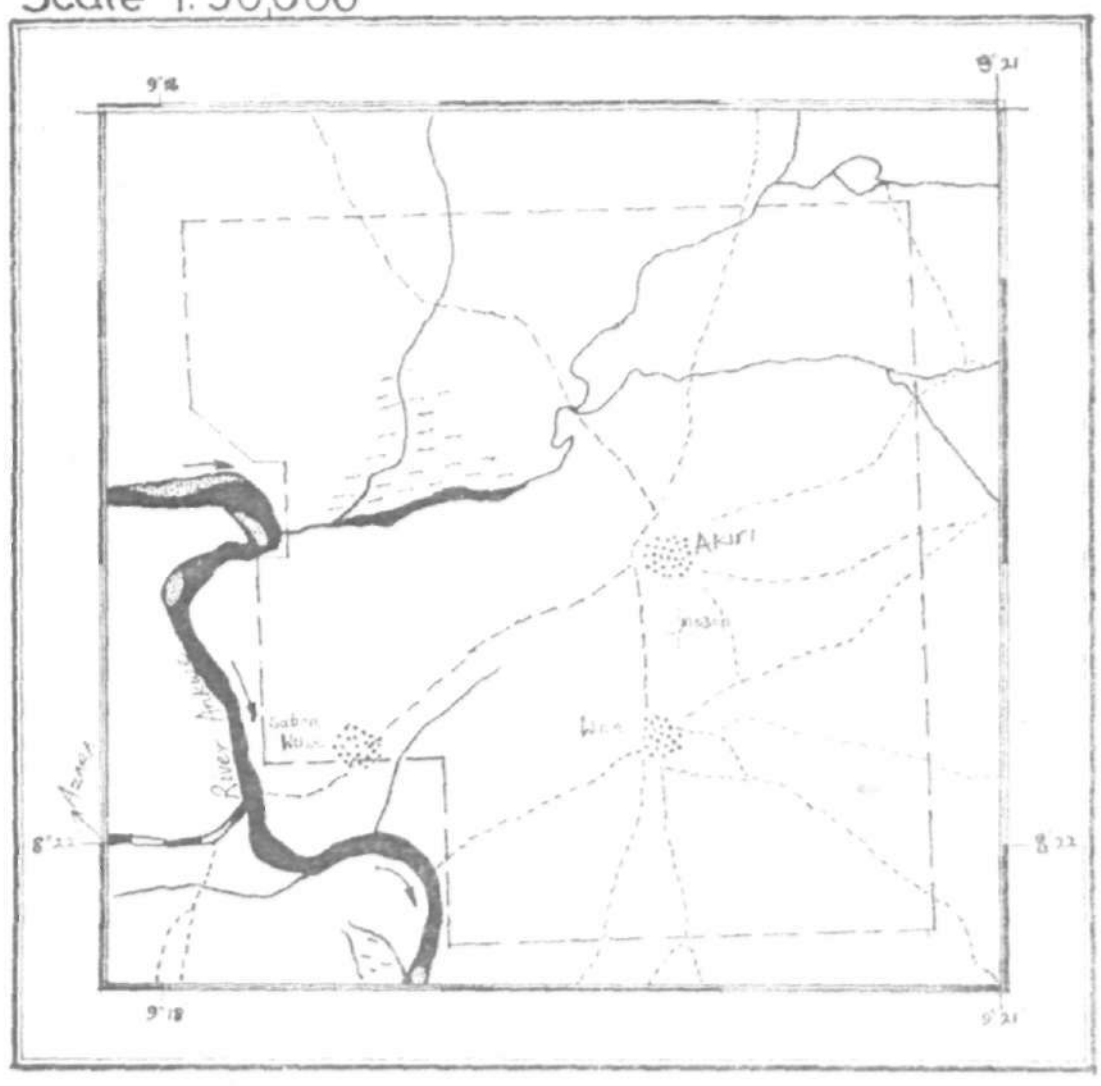
Corporation in consultation with the Ahmadu Bello University Physics Department. The gravity method was chosen for this investigation as it is the most appropriate tool for the detection of density variations within the earth, and salt deposit usually result from density differences between the salt and the overlying sediments.

This thesis is therefore a report of the detailed gravity investigation of the Akiri salt pit areas, which is about 4.8 km^2 and is bounded approximately by latitudes 8°21,5' and 8°24'N, and longitudes 9°18' and 9°21'E.(fig. 3)

1.4 LOCATION AND ACCESSIBILITY

The area covered by this survey is located within latitudes 8° 24.7'N, and longitudes 9° 17.8' and 9° 21'E on the Nigerian topographic map Akiri sheet 232 N.E., scale 1:50,000. The area indicated is approximately 5km^2, lies within the middle Benue valley, and is about 8.5km east-southeast of Azara (fig. 3). The area is accessible through Azara by only one unsurfaced motorable road which terminates at the Western bank of the River Ankwe. However, at certain periods during the dry season, from about the middle of January through March, when the river is dry, it is possible to get to the eastern end and through Sabo Wuse to Akiri and any four-wheel drive motor vehicle. There is also a fairly motorable road which approaches this area from Shendam through Jankar, but terminates at the northern bank of one of the tributaries of River Ankwe, at about 300m from Akiri village. These roads become almost unusable during the rainy seasons. Movement within the area is mainly along bush paths in the entire area. The area is generally flat particularly towards

Scale 1:50,000



Main footpaths .....

Minor footpaths .....

Stream .....

Village .....

Federal survey traverse point .....

Fig. 3 MAP OF PROJECT AREA

the eastern end of the central grid line through to Akiri hill, which is about 900 metres from the centre of the whole grid (NMC 34, 34). There is also a range of small hills along the southern end from the south-east corner of the survey area (fig. 12).

CHAPTER 2

GEOLOGY OF SURVEY AREA

2.1 REGIONAL GEOLOGY:

The evolution of the Benue trough has been closely related to magmatic activities which occured throughout Albian to late Cretaceous times. This began as a tensional depression and ended as a compressional belt. (Wright, 1976). (fig. 4).

The origin of the Benue trough has been a source of speculative discussion for at least the past three decades. A lot of work has been carried out to clarify these speculations and more studies are still being undertaken.

It is suggested that the Gulf of Guinea, the Benue trough and the South Atlantic developed between two R R R (Ridge-Ridge-Ridge) tripple junctions, one situated under the present Niger miogeosyncline and the other situated north of the Takutu rift structure of Guyana (McConnel, 1949). Later gravity and magnetic data provided by Hosper (1965, 1970); Cratchley and Jones (1965); Stonley (1966); and the Gulf Oil Company (Nig.) Limited, indicated that the R R R tripple junction hypothesis is essentially correct (Dessauvagie et al, 1970). Also Wright (1968) deduced from the works of Carter et al (1963); Reymont (1965); Cratchley and Jones (1965), that the Benue Valley is essentially a tensional fracture system which subsided intermittently, at first rapidly, from Middle Albian to early Senonian times, accumulating well over 6,000m of deltaic, estuarine and marine sediments with rare intercalated alkaline basic

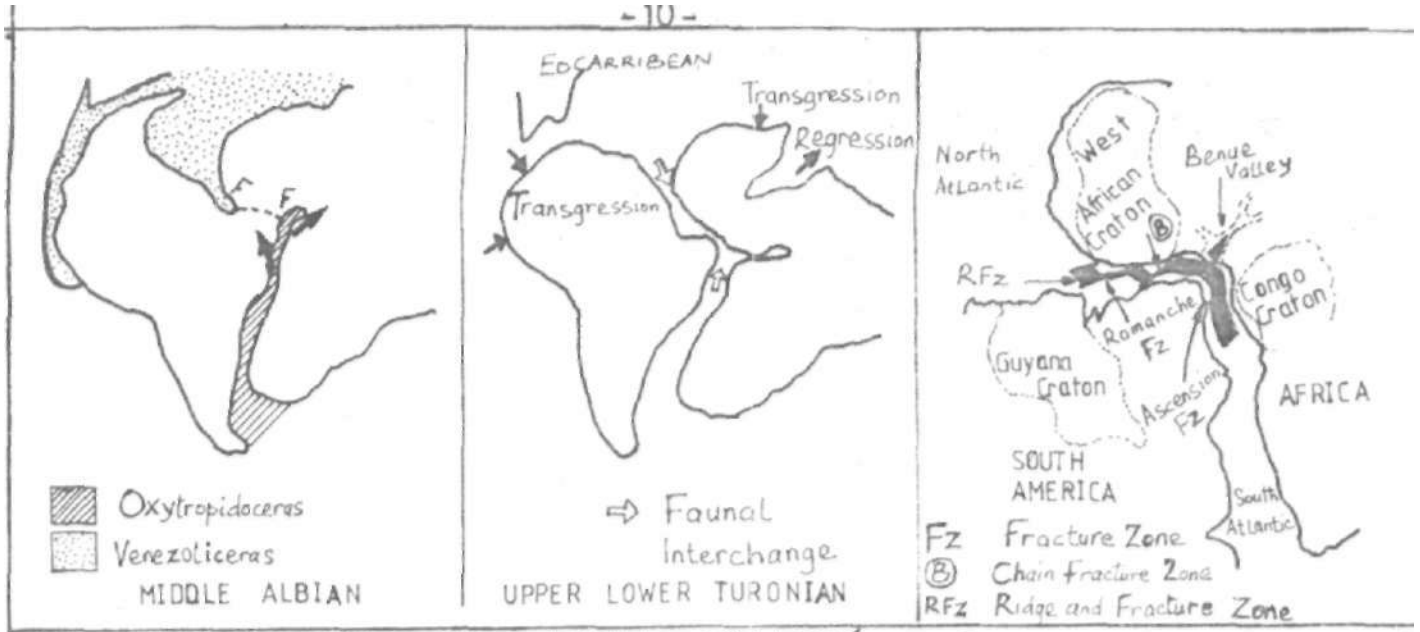
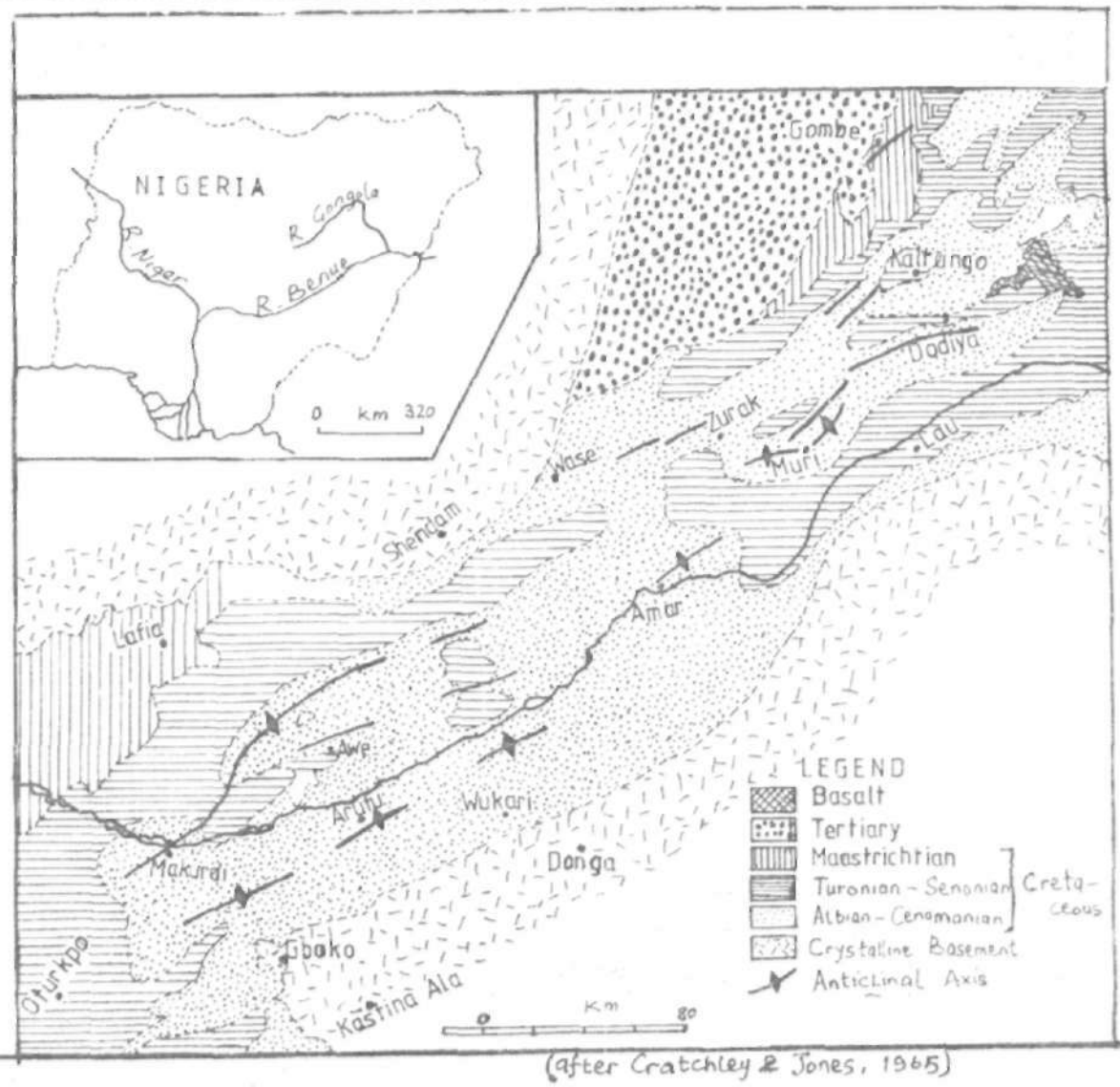


Fig. 4(a) DEVELOPMENT OF THE BENUE VALLEY (From Reyment & Tait, Black et al, 1972)



(after Cratchley & Jones, 1965)

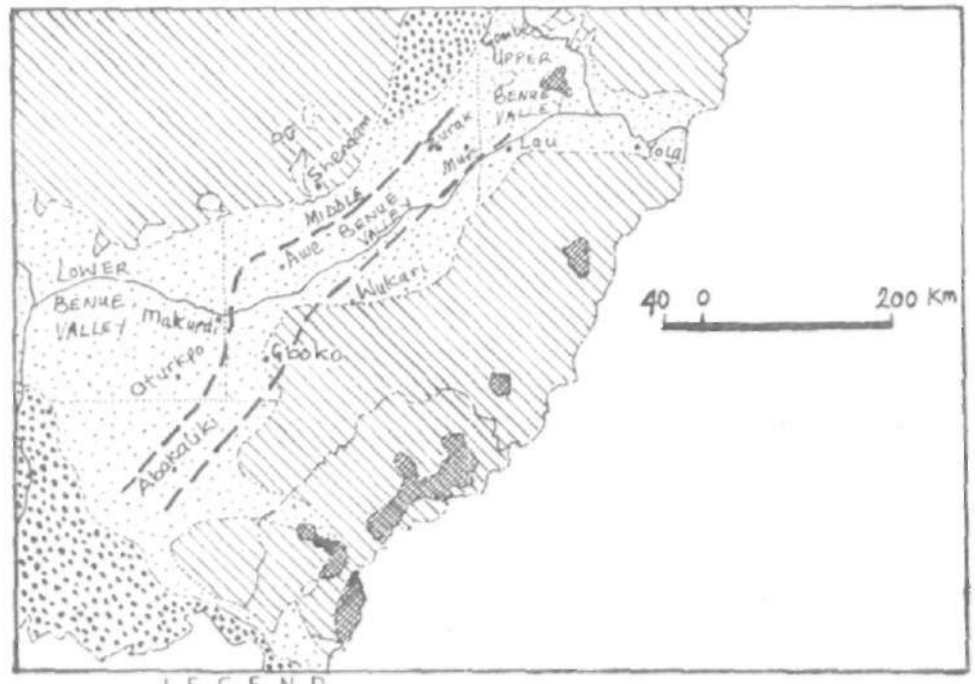
Fig. 4(b) GEOLOGY OF THE BENUE VALLEY

lavas. Compressional folding about dominantly NE-SW axes, occured during the later Senonian and Maestrichtian and was accompanied by faulting and mainly basic minor intrusive activity (both alkaline and calc-alkaline) with associated lead-zinc mineralisation.

However, as stated earlier, it is now accepted that the Benue trough was part of an R R R tripple junction, the arms of which developed at different rates and times. The southern arm was the first in the lowermost cretaceous, followed by the Benue trough in the Albian, and finally the north-western arm. Two folding episodes occured during the Santonian and post Maestrichtian times. Uplift, erosion and volcanin activities in the valley finally resulted in the stable structural feature considered to form part of the Nigeria-Cameroun dome (Halidu, 1968).

2.1.1 STRUCTURE OF THE BENUE TROUGH:

The Benue valley geologically consists of a linear stretch of sedimentary basin (Offodile, 1976) running from about the present confluence of the Niger and Benue rivers to the south-east, and bounded roughly by the basement complex areas in the north and south of the Benue river (fig.5). This elongated trough-like basin is continuous with the coastal basin. The trough is occupied by up to 6,000m of marine and fluvio-deltaic sediments ranging from Albian to Maestrichtian in age (fig. 5 . These have been folded about predomantly NE-SW axes, and there has also been some faulting, as well as, penecontemporaneous igneous activity and mineralisation (Wright, 1976). The main folds consist of series of parallel fold systems conforming roughly with the trend of the Benue Valley, ENE-WSW, with local bends in the



LEGEND

	Predomantly Sandstone	TERTIARY
	Sandstone- Shales	CRETACEOUS
	Crystalline Basement	PALAEOZOIC
	Basalt	TERTIARY - RECENT
	Intermediate Basic Intrusives	CRETACEOUS
	Approximate Limits of Lead-Zinc Field	
	Approximate Boundaries of the Divisions of the Benue Valley	

Fig5 Geology Of The Cretaceous Sediments Of The Benue Valley
(After Cratchley and Jones, 1965)

E-W direction. Major anticlinal folds enclose basins of turonian formations, with some important north-south trending faults (Offodile, 1976). Paleontologic studies reveal that the sediments are of late cenomanian to Turonian age. Some of the formations present are the Makurdi Sandstones, Eze-Aku, and Awgu Shales (Kogbe et al, 1978). The Albian deposits were probably folded before the deposition of the Muri-Keana-Makurdi sandstones (Offodile, 1976).

2.1.2 STRATIGRAPHY OF THE BENUE TROUGH:

The Benue Valley forms the most important part of a system of linear sedimentary basins which contain the Niger, Benue, and Gongola Rivers. All are filled with cretaceous rocks which are quite strongly folded in the Benue and Gongola valleys. For stratigraphic correlation the Benue Valley is subdivided into three regions: Upper, Middle, and lower Benue Valley. With the exception of the Middle-Benue Valley, where very little systematic and detailed geological mapping has been carried out, the other two subdivisions of the Benue valley have been fairly covered in detail, though some more work is still required. A fair detailed geology of the lower Benue valley has been published by McConnel (1949); Reyment (1965); Cratchley and Jones (1965); Nwachukwu (1972); Offodile and Reyment (1976); Kogbe et al (1978), and many other workers whose works are unpublished.

The Upper Benue Valley is separated from the Chad Basin by the Zambuk ridge which runs roughly north-east-wards from about Gombe town through Zambuk to Biu Plateau (fig. 5 & 6). Simmilarly, this region, has been covered in fair detail by Falconer (1911); McConnell (1949); Barber et al

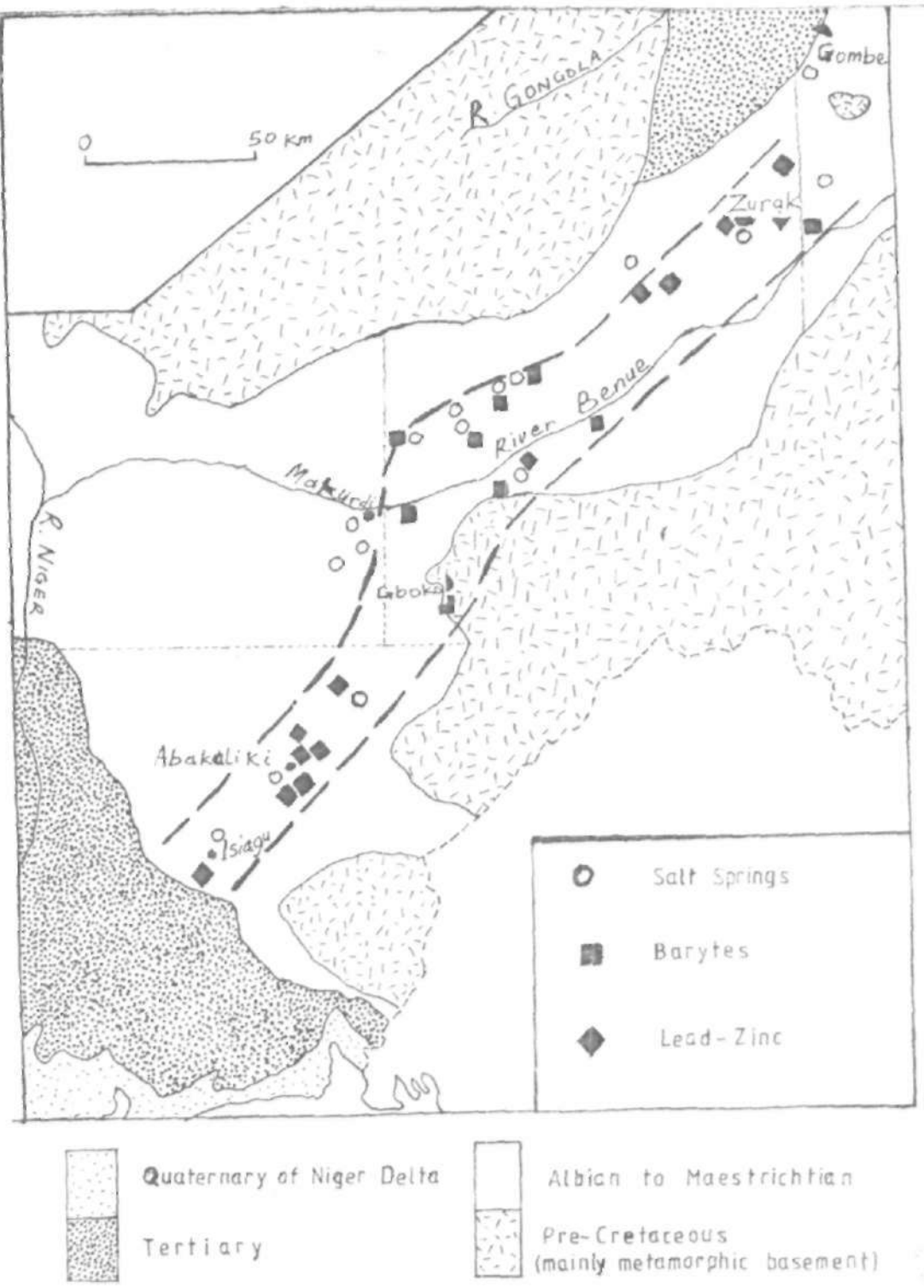


Fig 6 Map Of The Mineralisation Belt Of The Benue Valley
(From Wright, 1975)

TABLE I

STRATIGRAPHICAL SEQUENCE AND CORRELATION OF THE BENUE VALLEY

(After Cratchley and Jones, 1965)

GEOLOGICAL STAGES		SOUTH-WEST	MIDDLE BENUE		NORTH - EAST	
		OTUKPO-MAKURDI	KEANA-AWE -ARUFU	BASHAR-MURI-AMAR	GOMBE	LAU
MAESTRICHTIAN		Upper Coal Measures	?	Gombe	Gombe	Lamja
		False bedded Sandstone	'Lafia	Sandstone	Sandstone	Sandstone
		Lower Coal Measures	Sandstone'	?	?	Numarha Shale
CENONIAN	Campanian	Enugu-Nkporo Shales	?	Kumberi	Pindiga	Sekule Formation
	Santonian	? ?				
	Coniacian	Awgu-Ndeaboh Shales				
TURONIAN	Upper	Eze-Aku Shales	Marine Deposits	Formation	Formation	Jessu Formation
	Lower					Dukul Formation
CENOMINIAN		Makurdi Sandstone	Transition Deposits	'Passage beds'	Yolde Formation	Yolde Formation
		Eze Aku Shale ? ?	'Keana Sandstone'	'Muri Sandstone'	'Bima Sandstone'	'Bima Sandstone'

GEOLOGICAL STAGES	SOUTH-WEST	MIDDLE BENUE		NORTH - EAST	
	OTUKPO-MAKURDI	KEANA-AWE -ARUFU	BASHAR-MURI-AMAR	GOMBE	LAU
ALBIAN	Asu-River Group	Asu-River Group	Marine Deposits		Marine & Transition Deposits
Palaeozoic & Pre-Cambrian	Crystalline Basement				

GEOLOGICAL STAGES		SOUTHWESTERN NIGERIA	* MIDDLE BENUE	GOMBE AREA UPPER BENUE
CENOMANIAN	Early	hiatus	hiatus	hiatus ? ? ? ?
MIDDLE TO LATE ALBIAN		Asu-river formation	Awe formation	Bima formation ? ? ? ?
			Asu-river formation	

* MIDDLE BENUE = KEANA-AWE-ARUFU AREA

(1954); Reyment (1955); Carter et al (1963) and others. The stratigraphic sequence and correlation as given by Cratchley and Jones (1965) is shown in table 1. Correlation in the Middle-Benue area is tentative, particularly where lithologic sequences remain unnamed. Recent stratigraphic sequence and correlation by Offodile and Reyment, (1977) is given in Table 2.

2.1.3 MINERALISATION AND IGNEOUS ACTIVITIES

The Benue valley is marked by a lot of igneous activity, shown by the occurence of various intrusive and extrusive rocks. Intrusive activity is reported to have been from the late and post Albian times, to the end of Turonian (Offodile, 1976). The intrusive rocks are more common in the lower Benue area and occur as sills, dykes, etc., while the extrusive rocks occur separately. Extrusive rocks have been located in places both in the lower and the Middle-Benue valley (Wright, 1976). In few places they occur alongside the intrusive rocks. Igneous intrusions show marked association with both the anticlinal structures and the lead-zinc belt.

(a) A notable feature of the Benue Valley is a belt about 80 km wide and 560 km long extending from the SE of Abakiliki to Zurak in the NE. This is the lead-zinc mineralisation zone (fig. 6). The mineralisation is thought to be hydrothermal in origin, but the deposition is believed to have taken place under mesothermal conditions, before the end of the Turonian. The hydrothermal solutions are associated with Tertiary and recent volcanism (Farrington, (1952); McConnell, (1949). The Nigerian lead-zinc deposits are closely associated with saline springs and are impregnated in relatively narrow fracture zones in shales and mudstones, and to a lesser extent in sandstones. These sedimentary strata are of Albian and Cenomanion age.

The better defined lodes are located in steeply-dipping fracture-filling veins frequently striking NS and grouped in NE-SW zones generally associated with the axes of the major anticlines (Cratchley and Jones, 1965). Some of the solutions responsible for both igneous rock alteration and the lead-zinc mineralisation are thought to be brines already within the sedimentary pile (Gunthert and Richards, 1960).

(b) Limestone has a wide occurence in the Benue valley, starting from the lower areas around Makurdi to the upper parts. They occur principally in the Albian to Turonian formations in the area south of Makurdi east of Abinsi, at Arufu Giza and Keana areas. The most important outcrop is the Yandev limestone.

(c) There are also baryte occurences in several locations in the Benue valley, for example, at Aloshi, Wuse-Akiri, Keana, and Chiata (fig.8). They are mostly associated with the coarse sandstones and appear mostly within fractures.

(d) Coal occurs in Gombe area within the Gombe sandstone and in Marine formation (Awgu formation) of the middle - Benue. A good exposure of the coal can be seen by the River Ankwe about 48 km east of Lafia where several seams outcrop.

(e) Several brine springs have been observed within the whole length of the Benue valley. The salt springs occur along a linear zone which extends from southeast of Enugu to near Makurdi through Lafia division and as far as the northeast of Gombe (Phoenix and Kiser, 1966). The origin of these salt springs has still not been resolved and many hypothesis have

been advanced to explain the origin (see section 2.3.2).

2.2 LOCAL GEOLOGY

The area of the present survey lies in the sedimentary basin of the Middle Benue valley. The Akiri-Wuse area is fairly elevated, compared with most of the surrounding areas, with elevations ranging from 100m to about 200m above sea level. The area towards the southeastern area is most elevated and undulates towards the Akiri hill. The ground drops beyond this hill towards the north and to the west down to the Ankwe River (fig. 12).

The drainage system here is dominated by the Ankwe River which meanders in the north-south direction. It builds up substantial sand bars and banks as it meanders through the region. The river is perennial, almost dry and rather sluggish in the dry season, but full and fast during the rainy season. Few dendritic streams which provide the drainage within the survey area flow into the Ankwe River almost at right angles. A considerable amount of detrital materials are transported by the river during the rainy season. The River Ankwe empties into the Benue River in the south. The area is thickly covered with vegetation of the south Guinea Savanna type particularly in the rainy season. The soil within this area which is very good for farming varies from grey fine-grain sandy-clay in the north; to reddish-brown coarse-sandy-clay and lateritic-clays around the central to the southern parts; to dark-grey or blackish shaley sandy-clays around the east-southeast area.

Stratigraphically, the geological formations found to underlie the area are as follows:

Eze-aku formation:	Late Cenomanian - Turonian
Keana formation:	Cenomanian

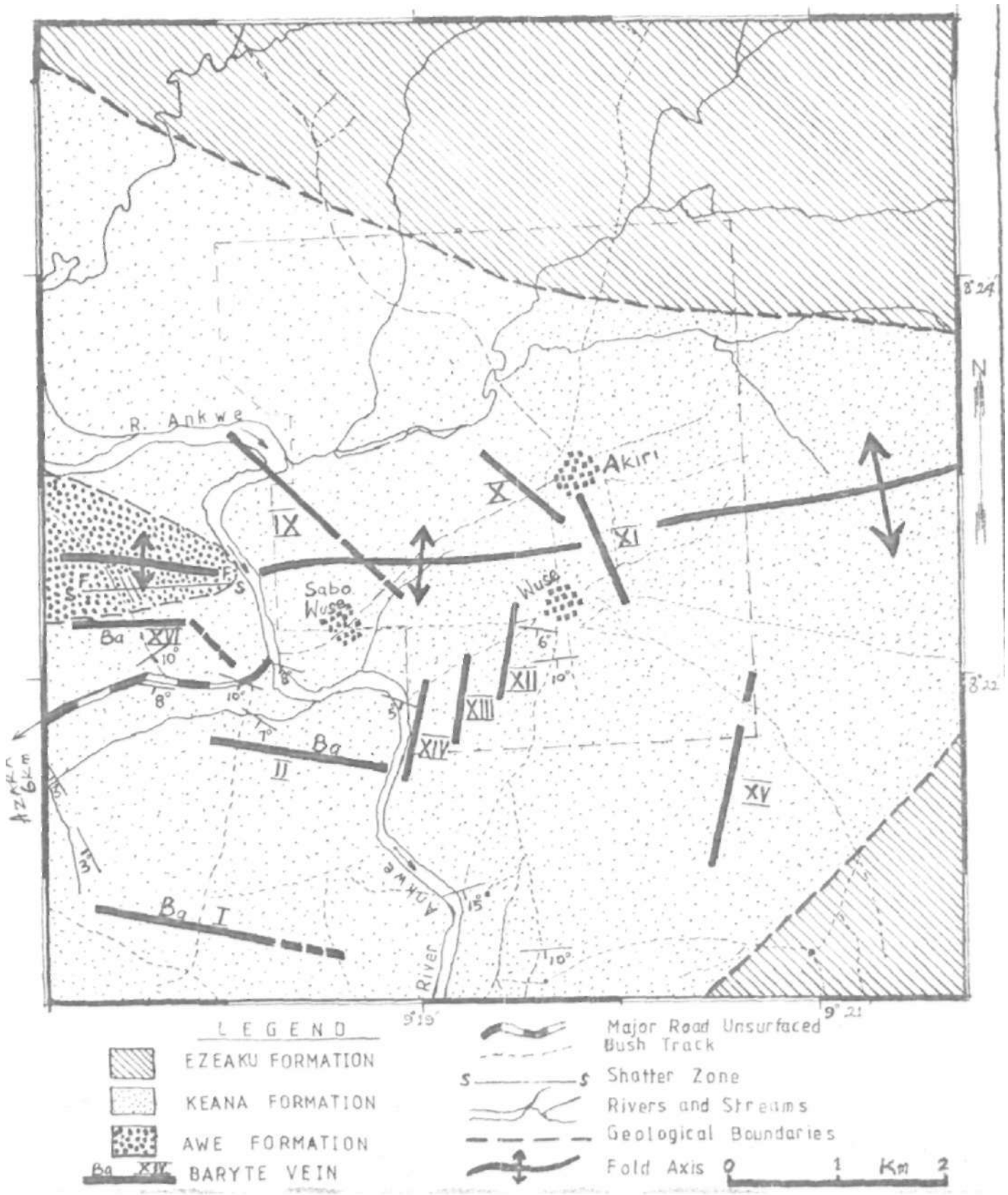
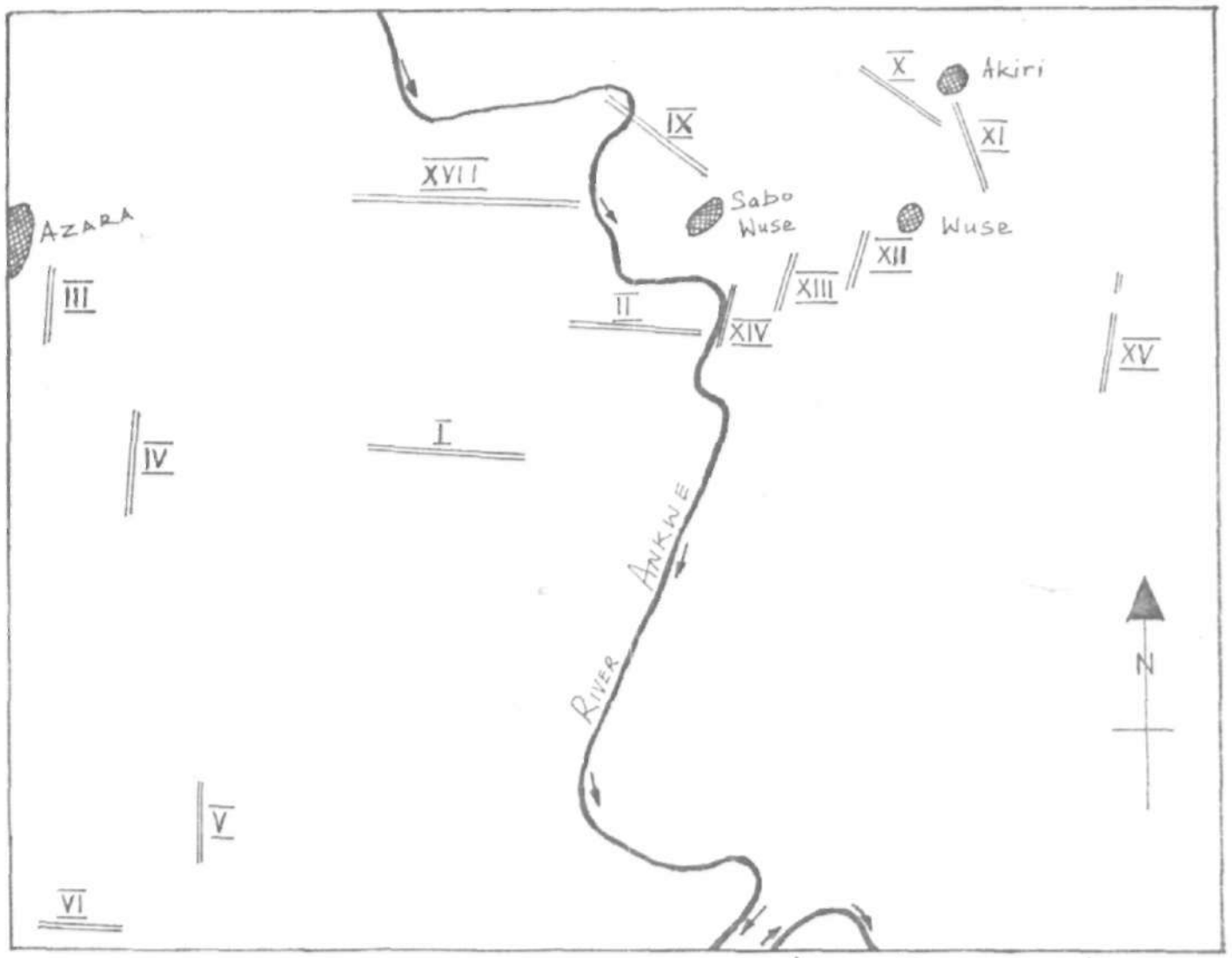


Fig. 7 Geological Map Of Project Area
(From Offodile et al, 1977)

Awe formation: Late Albian - Early Cenomanian (Offodile et al, 1977). (fig. 7)

The Awe formation, a saliferous formation, consisting predominantly of alternating sandstones and shales with subordinate limestones, occupies the core of the Keana anticline in this area. The Keana formation is of massive fine to coarse pebbly sandstones flanking the core of the anticline. Most of the barytes veins occur in this formation and the Akiri-Wuse brines appear to be related to fractures in this formation. The Azara-Akiri-Wuse area's brine springs issue from geological environment consistent with deposition during rapid oscillations of coastline resulting in short rhythmic transgression and regression processes (Offodile, 1975). This is typical of the transitional period between the Albian and Cenomanian. In this area the brines issue from the passage beds (Keana formation) between the continental Eze-aku formation and the marine Awe formation. The present survey area lies entirely within the Keana formation (fig. 7). The Eze-aku formation, which consists essentially of limestone, shale and some aandstones, flanking the plunging Keana anticline and overlying the Keana formation is not encountered within the area of survey.

In the survey area the formations are simply folded. The fold axis maintains a west-east trend in the Azara-Akiri area, and plunges to the north-east (Offodile et al, 1977). The Keana anticline is the major structural feature and it dominates the geology of the area (fig. 7). This structure which is more than 100 km long, extends southwards to Makurdi area where comparable features have also been mapped (Cratchley and Jones, 1965). The axis of the anticline appears to coincide with the Benue trough axis.



(From Turaki 1977)

Fig.8 Distribution Of Baryte Veins In Azara Area

The beds in the Keana formation within the area generally have low dips, ranging from 3° to 15°. Many of the fractures in the Keana formation outcroping in the survey area are mineralised with barytes, and the fractures appear to maintain a circular pattern around a possible buried structure (fig. 7 & 8). This circular arrangement of the barytes veins in the Akiri-Wuse area could be due to some kind of doming resulting from and intrusive rock, or a salt diapir, or a collapse structure typical of areas Underlain by salt beds (Offodile et al, 1977).

In the Akiri-Wuse barytes deposits, baryte is found only in accessory quantities with quartz and iron oxide predominant. On the whole, carbonates, siderite and ankerite occupy the largest volume in terms of materials deposited. The siderite and ankerite are very easily weathered, giving rise to the massive and pervasive limonitic surface cover to these deposits. Two distinct tectonic phases and cycles of mineralisation gave rise to the present mineral assemblage (Turaki, 1977). Subsequent chemical weathering of the carbonates gave rise to two types of barytes ores, (i) barytes with quartz, siderite and ankerite as gangue, which is on the surface to whallow depths; and (ii) barytes with quartz and limonite as gangue, found at deeper levels below the zone of oxidation by weathering processes (Turaki, 1977).

2.3.1 GEOLOGY OF SALT DEPOSITS: (SUMMARY)

To understand the genesis of salt deposits and other evaporites, certain physical factors are taken into consideration. These factors include; factors controlling the environments of deposition and initial composition, mineralogical changes produced by intrastratal solutions, reaction to stresses, and the ultimate structures formed (Borchert and Muir, 1964). These

factors can be considered from information accumulated in many branches of science such as: (i) Climatology which tells us about the tremendous control which climate exerts on conditions of deposition and the formation of rhythmic sequences. (ii) Mineralogy and petrology enables us to interpret textures, grain shape, secondary growth, and the suturing together of grains in terms of metamorphic changes. (iii) Tectonics permits us to assess correctly the importance of contemporaneous subsidence in controlling precipitation, and the significance of large - and small scale deformations, both in the evaporites themselves and in adjacent beds. (iv) Stratigraphy gives us information regarding the time and place of formation, while paleogeography indicates the relative position of land and sea, the morphology of the basins and the position of channels linking basins to the open sea, as well as the situation with regards to the climatic belts. (v) Current circulation, density layering in brines, temperature, and concentration gradient in polythermal system are obtained from oceanography, and (vi) bacteriology and a study of radioactive decays in basin environments can greatly help in our understanding of the geology of salt deposits.

Salt precipitation ordinarily takes place under dynamo-polythermal conditions in sea streams. Two phases can be distinguished during the stages of natural salt precipitation in the development of salt forming basins. (a) The phase of the normal basin with natural precipitation of salts, during which salt deposition proceeds in the normal sequence; and (b) the state of the playa (saline)- like dry basin with natural precipitation of salts. During this phase the formation of 'abnormal' sequences of precipitations takes place (Valyashko, 1962).

In dry salt lakes two factors determine the conditions of formation of saline precipitates. (i) The absence of a permanent layer of surface brine which preserves the already precipitated salt deposits from dissolution during the period of dilution. (ii) The accumulation of brine with the highest degree of concentration in the lower levels of bottom salt deposits and the slow mixing of their components (Valyashko, 1968). The order of succession of salt crystallization, determines also the normal order of their deposition. Saline deposits which very often form as diapirs have either tectonic or non-tectonic origins.

2.3.2 THE NIGERIAN BRINE FIELDS

The Nigerian brines issue in form of springs from cretaceous sediments (Offodile, 1975). This sedimentary sequence of upper cretaceous age outcrop within a broad belt of country extending from the vicinity of Enugu in the SE (or from the Cross River valley in the south) to Potiskum in the NE (or to the Gongola basin in the north) through the Benue valley (Phoenix and Kiser, 1966); Offodile, 1975) (fig. 9 in map holder at back cover).

The origin of the Nigerian brines has engaged the interest of a lot of workers for some time and many hypotheses have been put forward in this regard. However, no conclusive evidence or results have been obtained which could resolve the problem of the origin of the Nigerian brine deposits. Some of the hypotheses that have so far been suggested for the origin are summarized below:

(i) Falconer (1911) suggested an origin from evaporitic sequences and observed that saline deposits of connate origin commonly occur near the

apices of anticlines or domes.

(ii) Tattan (1942) and Simpson (1949) were of the opinion that the brines are derived from sea-water trapped as connate water in pore spaces of marine muds which later changed to shale. Intense folding and fracturing forced the salt out of the shale into sandstones associated with them.

(iii) McConnell (1949), however, suggested that the salt springs represented a late hypothermal phase of an expiring recent local volcanic activity. This he supported by the presence of comparatively recent igneous intrusions near all the brine springs and also the relatively high percentage of bicarbonate and carbonates in the spring waters.

(iv) Farrington (1952) proposed that the springs are seepages with the salt content derived by the leaching of disseminated alkaline salts. Also that the springs emanate from both coarse and fine sediments and show no direct association with igneous rocks though they are more common near areas of mineralization.

(v) Pargeter (1956) supported the connate water origin but without any volcanic source.

(vi) Phoenix and Kiser (1966) suggested the possible existence of evaporitic deposits which are equivalent to the sediments of the lower Cretaceous of Gabon and Congo (Hirtz (1965)· Belmonte et al, (1965)). They were also of the opinion that the differences in the concentration of iodide, fluorides, sodium chloride, magnesium, bicarbonate nitrate, and dissolved solids may be from the different origins of the springs, or due to the juxtaposition of the springs with mineralized rocks along the fault zones and volcanic rocks, and also the organic matter in the spring waters.

(vii) Okezie (1966) also supported the idea of an evaporitic source such as a saline dome while Beltaro and Bojarski (1971) supported the idea of evaporitic deposits, and also suggested that the tertiary intrusions were responsible for the galena, sphalerite, baryte, fluorite, subordinate pyrite and silver mineralisation. Orajaka (1973) proposed the possible existence of a rock salt deposit for the origin of the brines in the southern region of the Benue trough.

Offodile (1975) on the other hand disagrees with the proposal of a connate and the hydrothermal origin for the Nigerian brines. He however, supported (a) the possible existence of salt domes; (b) disseminated salt grains within pore spaces and or intercalations of thin salt beds of evaporitic origin within the cretaceous sediments.

The problem of the origin of the brine springs can only be resolved by more detailed geological surveys of the salt spring belt, drill-hole tests, chemical analysis of the spring waters, and detail geophysical survey of this belt for the accurate location of possible salt deposits.

TABLE 3

CHEMICAL ANALYSIS OF SOME NIGERIAN BRINES

(AFTER KISER AND AKINGBEHIN, 1974)

(PPM)	KANJE SPRING	KEANA SPRING	AZARA SPRING	AWE 3 SPRING	AWE 2 SPRING
Ca	1'1121	90	302	2.4	8.2
Mg	114	139	169	113	49
Na	3,500	3,460	7,260	3,070	2,950
K.	9.9	14	11	5.4	5.4
HCO_3	183	350	191	610	309
SO_4	6.6	4.1	7.5	5.4	14
CL	5,540	5,660	12,100	4,530	4,360

TABLE 4

ANALYSIS OF SOME SALT SPRING WATER

(AFTER BELTORO AND BOJARSKI, 1971)

LOCALITY	TEMP.	SALT%	NACL.	REMARKS
Awe Spring	92°F	0.74	Predominant	Traces of Mg and HCO_3
Awe	82°F	0.8	"	"
Azara	82°F	2.0	over 90	Traces of Boron & Iodine (I_2
Kanje	82°F	0.94	91	
Keana	95°F	Very dilute	Predominant	Seepage
Arufu	92°F	2.04	-	
Akwana Tanata	82°F	0.56	over	
Springs Azanka	82°F	1.95	90	Natural Evaporation occured
Singa	85°F	5.97		

CHAPTER 3

GRAVITY SURVEY

3.1 BASIS OF THE GRAVITY METHOD:

The gravity method is based on the measurements of small variations in the acceleration due to gravity. The difference between the observed variations and the theoretical values of gravity calculated from a knowledge of the gravitational field of the earth is called a gravity anomaly. The theoretical values of gravity used in the calculation of the Bonguer gravity anomaly, the type of anomaly commonly employed in geological interpretations, includes the effect of latitude, elevation, mass above and below a chosen datum plane, and local terrain departures. The anomaly values indicate any departures from the mass distribution assumed in calculating the anomaly. Horizontal variations in density causing these departures are the origin of the gravity anomaly, while vertical variations in density of horizontal layers affect all observations to the same degree and therefore will not affect the anomaly (Hinze, 1966). Thus, the density contrasts of particular interest in gravity prospecting for mineral deposits are the variations between the deposits and the country rock or the contrast between formations having or stratigraphic relationship to the occurence of the mineral deposits.

3.2 INSTRUMENTATION

In this survey, the LaCoste and Romberg gravity meter model G-446 of the department of Physics, Ahmadu Bello University, was used for the gravity measurements. The choice of the method and instrument was prompted by the nature of the survey, and the availability of equipment and time. Also salt

domes are generally always indicated by a relatively low Bouger anomaly on a Bouguer gravity map wherever they exist within sedimentary rocks of higher densities. The reliability of the instrument, its compactness, ease of transportation and operation, strongly recommends it for this type of survey. In Hamilton and Brule (1967), it was observed that under most conditions the instrument gives excellent results and that the drift of the instrument after earth tidal corrections have been removed is generally negligible except when vibration induced. If the instrument is stored and is kept on heat, the drift does not exceed +0.2 g.u. per day. Also under field conditions where there is no exposure to excessive vibration or too severe thermal or mechanical shock, the instrument maintains its quiescent drift character. Erratic performance due to vibration may result from transportation on carriers such as helicopter, motor toboggans, trains and some fixed-wings aircrafts. In which case certain precautions need to be taken, otherwise no problems from vibrations arise with many methods of transportation.

Prior to the actual field work, the instrument was kept under observation for three consecutive days. All the observations were made in room P208 of the Physics Department. An average amplitude of about 1.6 g.u. with an average hourly maximum variation of about 1.1 g.u. was recorded (fig. 10). A maximum tidal variation of about 2.6 g.u. was recorded in five hours. The gravity readings, after tidal corrections had been applied are also shown in fig. 10. The small variations in the tidal corrected readings could be attributed to the instrumental drift (quiescent drift) owing to the elastic creep in its spring members. The average daily drift of 1.4 g.u. which was recorded, though much higher than the value of 0.30 g.u. per day

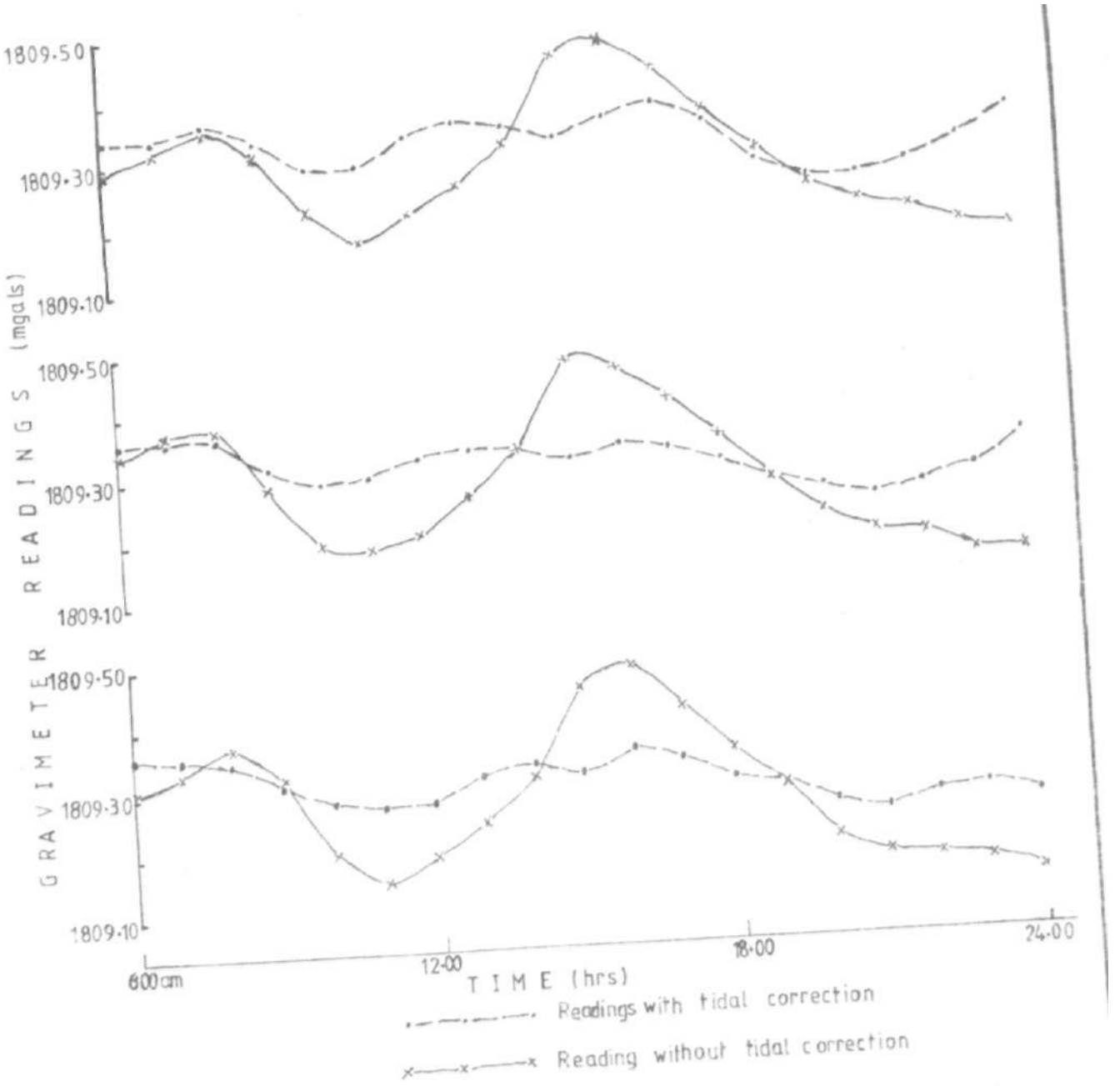


Fig. 10 GRAVIMETER DRIFT CURVES

stated by the manufacturers for the instruments was comparable with a drift of 1.7 g.u. per day for model G-42 of Zomorrodian (1972),(Umego, 1978). It is however, possible to have such large drift with frequent use of the instrument and with age. During this period of observation, the effect of temperature and the instrument's sensitivity to elevation were also tested. It was observed that when the instrument was maintained at 52°C for about 2 hours before readings were taken over a period of 6 hours, an average increase in drift of about 0.9 g.u. was recorded. The operating temperature for the instrument as quoted by the manufacturers is 50°C. However, it was observed that under normal conditions the instrument has always maintained a temperature of about 51°C. Finally it was observed that an average gravity variation of about ± 2.65 g.u. was obtained for an elevation variation of ± 1.0 m, when readings were taken at different floors of the Physics Department.

3.3 FIELD PROCEDURE

The actual field work was undertaken within a period of sixteen days from the 9th to the 20th of December, 1978, and from the 13th to the 16th of July, 1979. Before the start of the gravity field measurement, the mapping out of the grid lines, the location of the gravity stations and the elevations of the stations were determined by Mr. J.A. Knight (1978) Department of Lands Survey, Ahmadu Bello University, Zaria. The topographic contour map of the area was also made by him. This was a project undertaken by him on behalf of the Physics Department. The grid map and the topographic map are shown on figs. 11 and 12 respectively.

The grid lines run in the West-East direction, with a central line

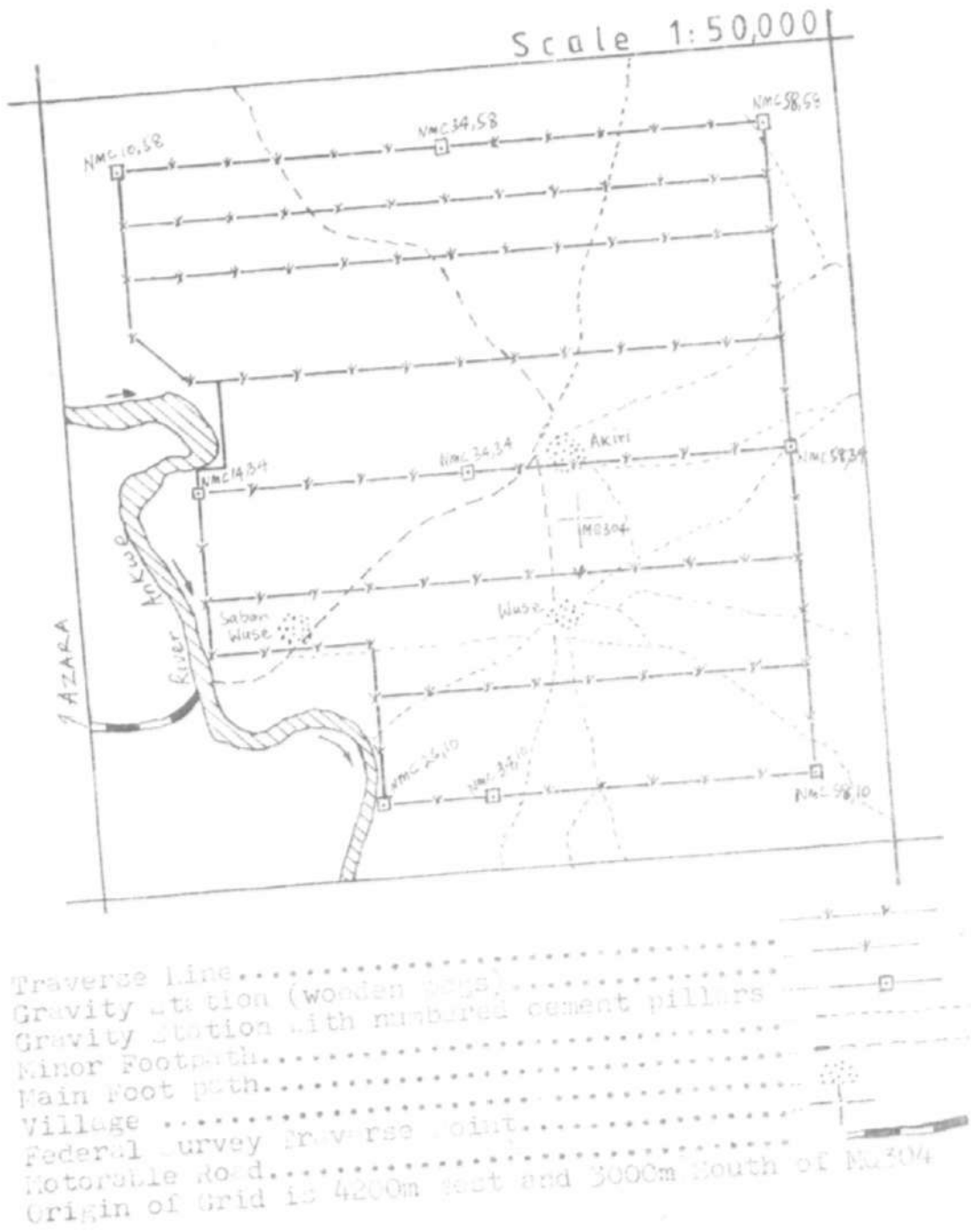
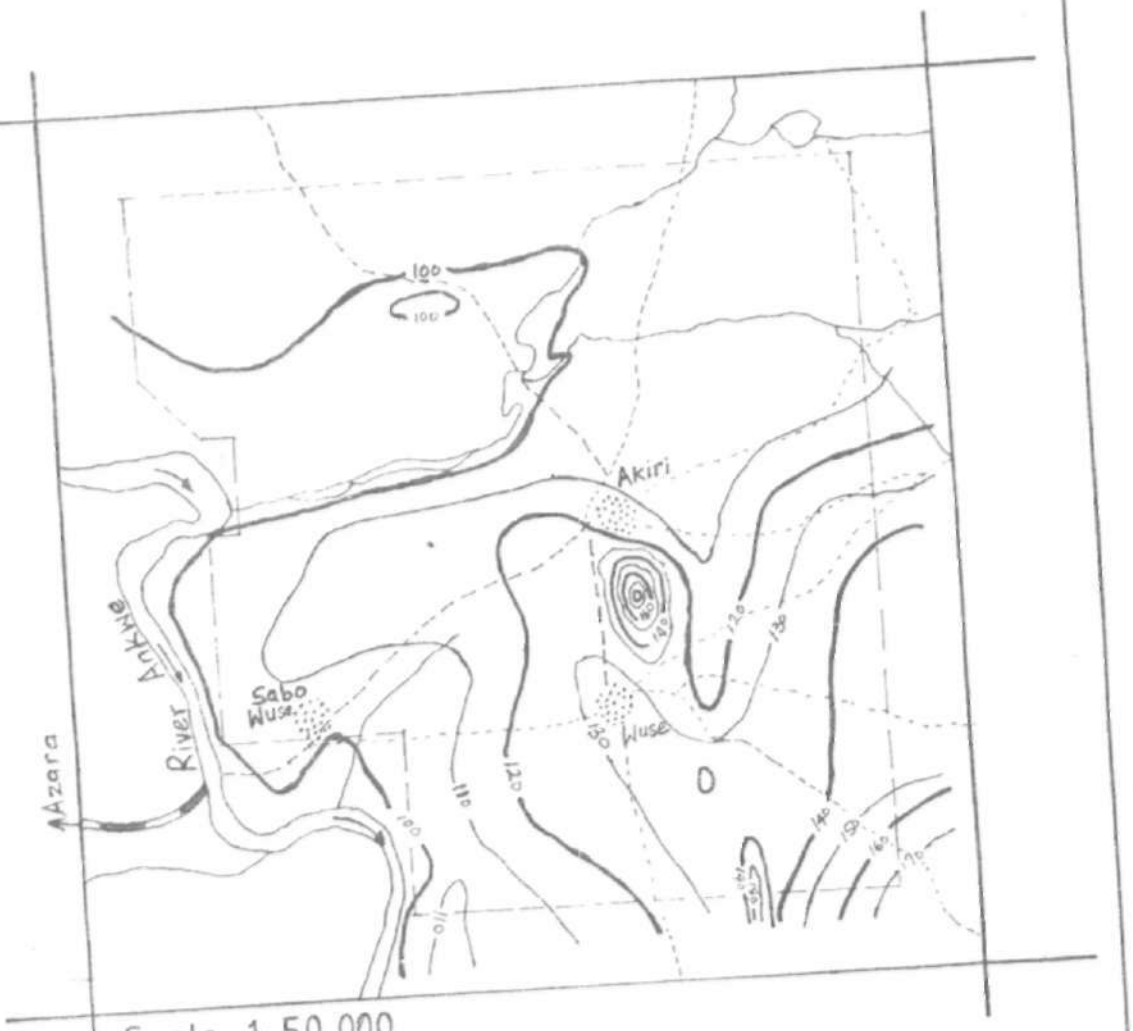


Fig. 11 Grid Map Of The Survey Area

passing through Akiri village and the salt pits. The four extreme corners of the grid are marked with numbered cement pillars. The grid lines running in the east-west and the north-south directions through the centre of the grid area, also have numbered cement pillars at their ends and at the cetral point. The grid is supposed to cover an area of 4.8 km^2, but owing to the currature of the River Ankwe into the area, the southern end is reduced to 3.2 km in width. There are seven west-east grid lines, 800 metres apart and on each grid line there are thirteen gravity stations at 400 metres intervals. At some stage of the field work, another grid line was added between the sixth and the seventh gridlines at the northern end. This brought to a total of eight grid lines traversed. This implies that a sixth of the survey area was covered by 400 m square grids while the remaining part was covered by 400 x 800 m square girds.

For easy reference and location, the grid lines were numbered from 10 to 58, starting from the south to the nortth with increments of 8. The gravity stations along the grid lines were also numbered from 10 to 58 with increments of 4 starting from the west to the east. Thus, each gravity station has two numbers indicating the row and the column of that station. In addition, the cement pillars have the prefix NMC on them. Hence, the central gravity station marked by a cement pillar has the number NMC 34, 34.

The first day of the field work was spent in tying the station NMC 34,34 to Umego's (1978) Standard base station (Number 9,000) at Ribi. This station has already been tied to the first order base of the Nigerian calibration line at Jos (Verheijen & Ajakaiye, 1978). Subsequent reduction of



Scale 1:50,000

Contour line

Footpath

Motorable road (unsurfaced)

Settlement

Stream

Contour interval = 10m

Fig 12 Topographic Map Of The Wuse – Akiri Area

all other gravity measurement were made with reference to this station (NMC 34,34) with the plane through it as the reference datum plane.

Owing to the geography of the area in terms of vegetation and the absence of lines interconnecting the mapped out grid lines it was not possible within the limited time to obtain a systematic closed base loops at the first instance. Instead, the available foot paths running across the grid lines were used to establish base stations at any convenient points. However, during the later part of the field work, a base network system was established as shown on fig. 13. In all fourteen base stations were established to cover the whole survey area. After the readjustment of the base network to eliminate the initial closure errors, the adjusted gravity differences as indicated on fig. 13 were used to calculate the absolute gravity values for the base stations. An average drift rate of about 1.0 g.u. per hour was obtained during the survey.

3.4 GRAVITY FIELD MEASUREMENTS AND REDUCTION

To minimise the effect of the instrumental drift, the time interval for the loops was maintained between two hours to two and half hours. This was as a result of the drift observations carried out prior to this field work, during which a mean maximum drift of about 2.6 g.u. was recorded in the period of five hours.

Gravity measurements were made systematically at the detailed stations within each loop. At each station repeated reading which differ by about one to three significant last figures were recorded. Readings were always started and ended at base stations that were interconnected. Also readings

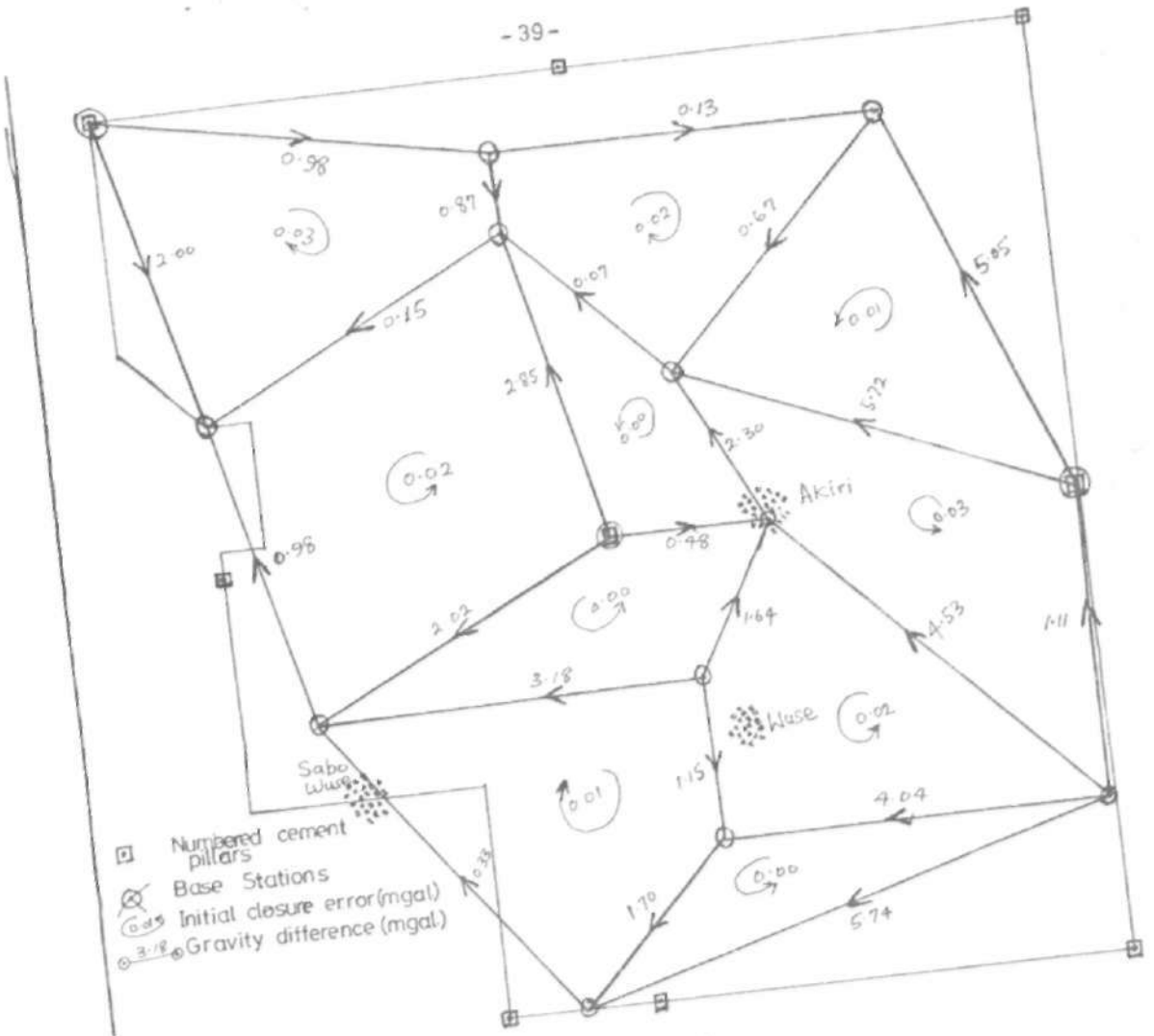


Fig.13 Base Loop Network

for any new day starts at the last base station of the previous day.

With the exception of terrain correlation all other forms of corrections applied to gravity data were affected. The terrain correction was not carried out due the size of the survey area and the gentle slope of the ground in most parts of the area. In the whole survey, only four stations were located on relatively high grounds. A maximum terrain correction value of about 0.01 g.u. was estimated for these stations. Drift, latitude, and elevation corrections were applied using conventional methods and formulae. These corrections were all computed manually. Also the Bouguer anomaly was computed using the expression:

$$g_{BA} = g_{ob} - g_{th}(\theta) + \frac{\delta g}{\delta z}(\pm h) - 2\pi\rho G(\pm h) \pm \Delta g_L \text{ ---- (1)}$$

while the free ir anomaly was obtained using the expression:

$$g_{FA} = g_{ob} - g_{th}(\theta) + \frac{\delta g}{\delta z}(\pm h) \pm \Delta g_L \text{ - - - - - - - (2)}$$

where,

Δg_L = Latitude correction

$\frac{\delta g}{\delta z}$ = 0.308596 mgals per metre

g_{ob} = observed gravity value.

$g_{th}(\theta)$ = theoretical gravity value at latitude θ

G = universal gravitational constant

h = Station elevation relative to the datum plane.

ρ = Assumed crustal density of 2.67×10^3 kg-m^{-3}

The assumed density value of 2.67×10^3 kg-m^{-3} as the mean crustal density for the data reduction was necessary for correlation with previous works

around the area (Cratchley and Jones, 1965; Ajakaiye and Burke, 1972; Ajakaiye and Ajayi, 1978· Umego, 1978). Dobrin (1976) and Parasnis (1975) have also given this value as the mean crustal density at depth. Also as the measured densities of rock samples collected may not be good representative of rock types at depth and as the near-surface density of 2.71×10^3 kg-m^{-3} obtained by the Parasnis (1962) method (see fig. 17) compares well with the above, it was deemed fit to use the above value for the present work.

The reference datum plane is the plane through the base station NMC 34, 34 which is at a height of 121.099 metres, above sea level and at the latitude of 8°23' north. The latitude correlation, was computed with the expression:

$$g_L = (3.017 \sin \theta - 0.00671 \sin^2 2\theta)\Delta\theta$$

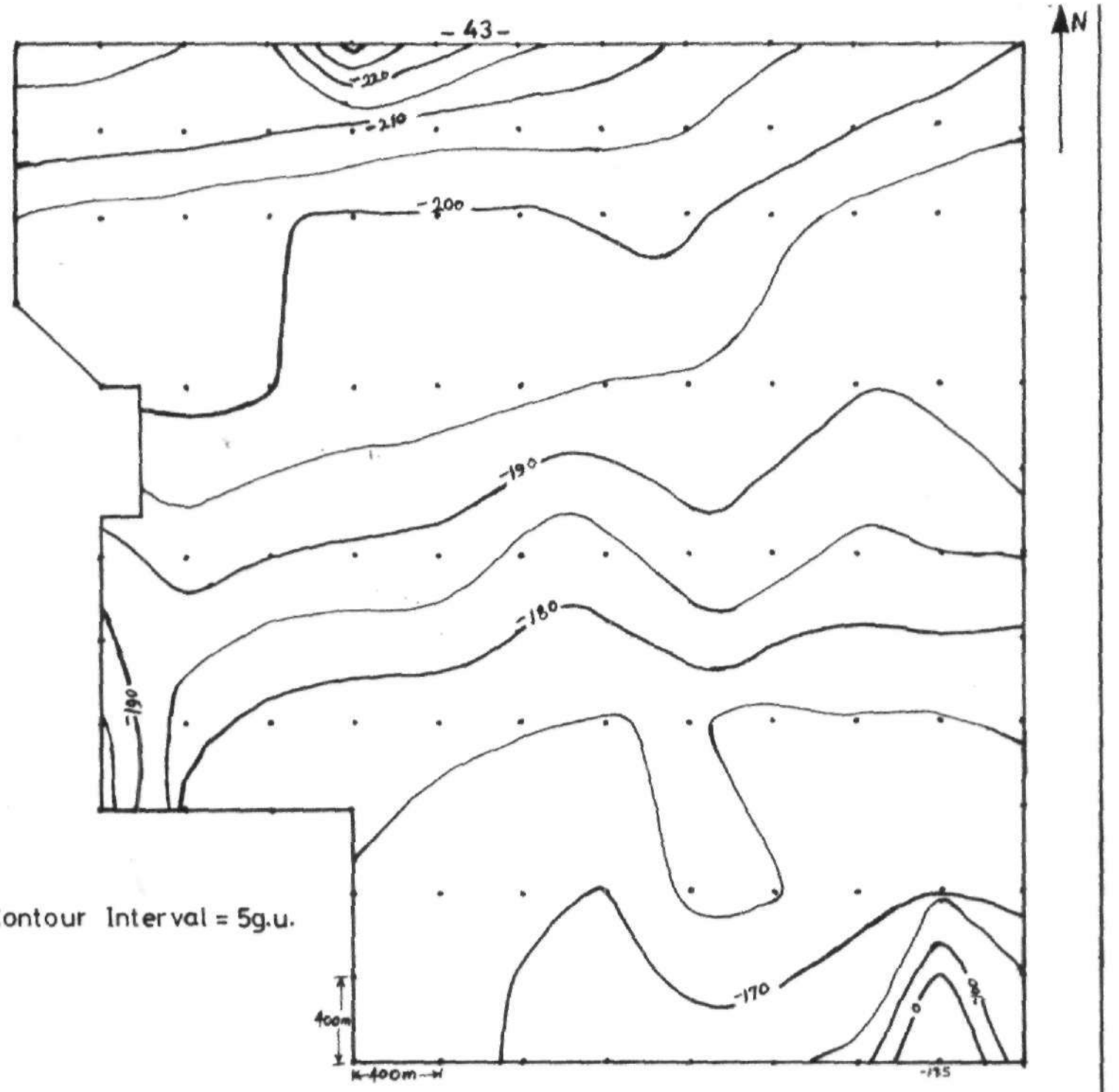
where $\Delta\theta$ is in minutes. This correction was subtracted from the gravity values north of the reference latitude and added to values south of this latitude. The theoretical gravity value at the latitude of 8°23' was computed with the 1967 International Gravity Formula (Jacobs 1974).

The resulting Bouguer and free air anomalies were contoured by hand at 5 g.u. intervals and shown on figs. 14 and 15 respectively.

Inaccuracies resulting in errors in the Bouguer anomaly are perhaps due to small errors in the latitude correlation and in determining the elevation of the gravity stations. An error of one minute in the latitude results in an error of about $\pm$ 0.009 g.u. in the latitude correlation. The stations elevations were determined with an accuracy of about $\pm$ 0.05 m, which could result in an elevation correlation error of $\pm$ 0.15 g.u. Also the Bouguer

density of 2.67 x 10^{-3} kg-m^{-3} used is higher than the mean density determined for the rocks of the cretaceous sediments in the area which is 2.45 x 10^{-3} kg-m^{-3}. These same rocks were ascribed a density value of 2.40 x 10^{-3} kg-m^{-3} by Cratchley and Jones (1965). With the elevation error of about ± 0.05 m, the Bouguer anomaly will be in error by about ± 0.28 g.u. for the maximum elevation difference of 60 metres encountered in the survey.

Apart from the above mentioned sources of errors, other sources of errors include calibration error of the gravimeter, precision with which the instrument was read, errors arising from the variation of free-air correlation factor with elevation and latitude, and finally error due to terrain effect. As stated earlier, the terrain correlation was necessary for few gravity stations within the south-eastern corner of the grid. This is possible to introduce an error of about 0.01 g.u. A cumulative error, arising from all the above sources will result in an estimated error of about ± 0.45 g.u. Thus, with the standard base (Umego's, 1978) accurate to within ± 0.23 g.u., the maximum error in the Bouguer anomaly will approximate to about ± 0.68 g.u.



Contour Interval = 5g.u.

Fig. 14 BOUGUER GRAVITY MAP OF THE SURVEY AREA

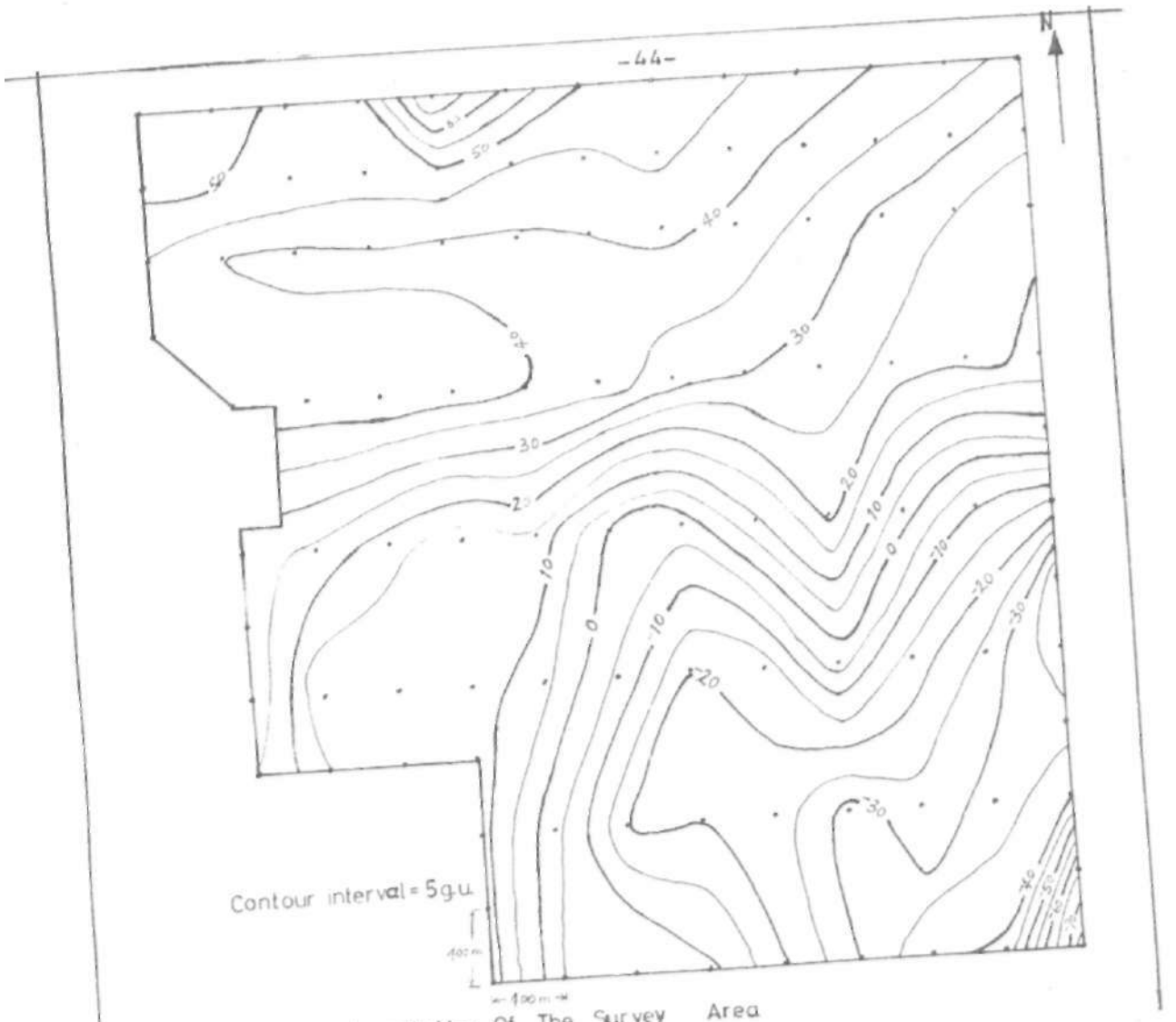


Fig. 15 Free - Air Anomaly Map Of The Survey Area

3.5 DENSITY DETERMINATION

3.5.1 INTRODUCTION

The accuracy of Bouguer anomalies and their interpretation depend greatly on the assumed densities of rocks or more accurately, the density differences between rocks. Density is of fundamental importance in gravity surveys and errors of about 0.1 $gm\text{-}cm^{-3}$ will cause a large error in the interpretation of gravity anomalies where two adjoining rock formations differ in density by this amount.

It should also be noted that relative rock densities are crucial for the solution of many questions relating to magnetic equilibra and differentiation, the emplacement of magmatic bodies, metamorphism, mountain building, the nature of the earth's interior, the facts of seismology, and the theory of isostasy.

3.5.2 SAMPLES COLLECTION AND IDENTIFICATION

In density measurements, it is not often possible to carry out field determinations, and so most of the measurements are done in the laboratory using samples collected in the field. For this purpose a total of 78 samples were collected from different places within the area. These samples include 45 samples of the most abundant rock outcrop, beach sands, and clay materials near the ground surface and from deep dugout trenches. Most of the outcrops have been very much weathered, so care was taken to collect fairly fresh samples and attempt was made to collect samples that were representative of the type outcrops within the whole area. The Keana formation which underlies the whole area of survey does not outcrop within this

area. The area is mostly covered by recent sediments which are mainly sand, clays, laterite and fine-grained micaceous sands around the beach.

From the samples collected four main types of rocks can be identified. These include, quartz and quartzites, massive fine to medium grain sandstones (some of them highly ferruginised), ironstones, and some fluvio-volcanics type of rocks which have fragments of quartz, barytes, coal, and chalcopyrite cemented together by ironstones and sometimes by iron-rich laterite. The above indicates that this area is within the area of active volcanism and intrusions and is perhaps highly mineralised. This might have been in the mid-Tertiary during the period when the beds within the Benue trough were being folded and uplifted (Wright, 1975).

3.5.3. DENSITY MEASUREMENT

It is often not easy to obtain accurate bulk density values from rock samples because of the difficulty of finding fresh unweathered samples, fragementation and or dehydration. Even then measured values depend markedly on the degree to which the pore spaces are filled with water. Also, as facilities for insitu measurements are not often available, both dry and saturated measurements are normally made. Though Nettleton (1940) and Parasnis (1952) have proposed analytical methods of determining densities, Nettleton's method can only give density information at relatively shallow depth and can only be used when the near-surface lithology is homogenous. However, the mean value of both the dry and saturated determinations approximates very closely to the insitu density of the rock (Parasnis, 1975).

The dry and saturated densities of the rock samples were determined

as usual with the electronic mettler balance No. PS15. After the dry density measurements had been completed, the samples were left completely immersed in water for over 36 hours before the saturated density measurements were made.

The density ρ of any material is given by the expression:

$$\rho = \frac{W_o}{W_o - W_1}$$

where W_o is the weight of the material in air and W_1 is the weight of the material when completely immersed in water of density 1,000 kg-m^{-3} or in any liquid of known density. The mettler balance can measure weights with an accuracy of 0.001 kg-- and the weights of the samples used range between 0.600 kg and 1.540 kg. The density values, thus obtained are accurate to about $\pm$ 0.02 x 10^3 kg-m^{-3}.

Out of the 45 samples of the rock types collected, 12 of them were identified as massive, fine to medium grained sandstones. These samples were collected at the south eastern end of the central part of the survey area beyond Akiri and towards the south western areas around Wuse (fig. 7). The sandstones do not outcrop much within this area and they are probably of the Keana formation which underlies all of the survey area. The calculated mean density for this rock type is (2.45 $\pm$ 0.09) x 10^3 kg-m^{-3}, and the estimated dry and saturated mean values are (2.46 $\pm$ 0.06) x 10^3 kg-m^{-3} and (2.44 $\pm$ 0.12) x 10^3 kg-m^{-3} respectively. Fig. 16 shows the density histogram for the 12 samples, which has a modal value of 2.48 x 10^3 kg-m^{-3} that is comparable to the mean density stated above. Also, this mean value compares well with the value of 2.45 -- 2.50 x 10^3 kg-m^{-3} obtained by

Cratchley and Jones (1965) for the Cenomanian - Bima sandstones. With the exception of only two of the samples that gave large deviations in their dry and saturated densities, probably due to weathering and or large pore spacings, the rest of the samples have maximum deviations of about 0.02×10^3 kg-m^{-3}. Using the relation for pore porosity

$$\phi = \frac{Ws - W_d}{Ws - W_L} \times 100,$$

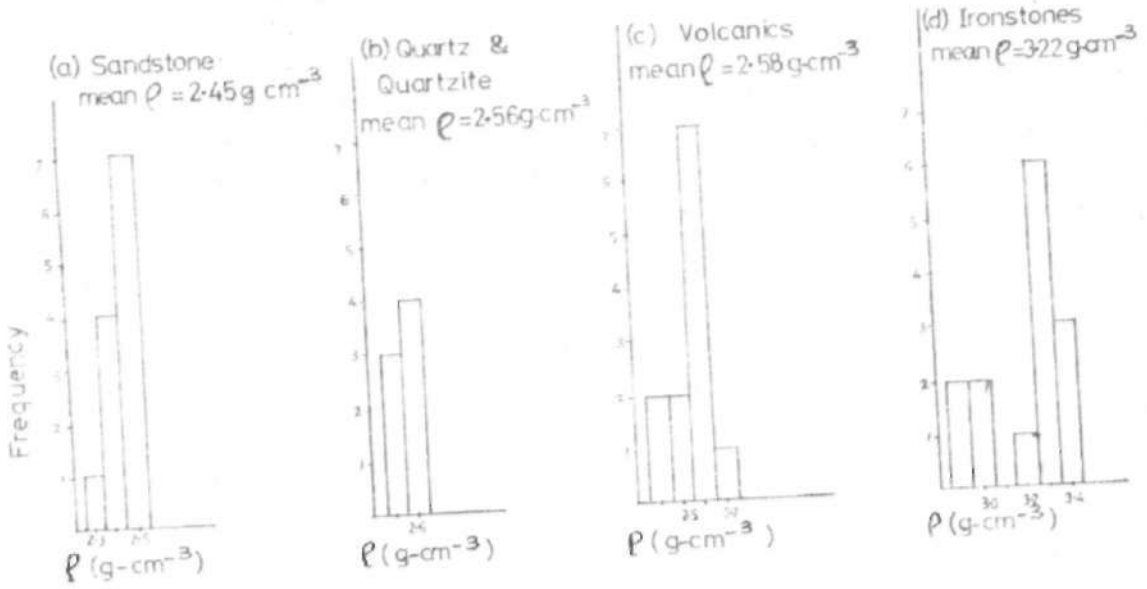
the pore porosity ϕ for the sandstones was calculated to be about 4.0 per cent. In the above relation;

Ws = weight of the saturated sample in air

W_d = weight of the dry sample in air

W_L = weight of the saturated sample in water

The remaining 33 samples of the type outcrop collected in the area is made up of ironstone (Limonite ?), quartz and quartzites, and some volcanic rock type. Two of the ironstone samples show some intercalations of very thin beds of light brown fine grain sandstones. All the ironstones were collected at about one kilometre east of the Akiri saltpits and about 300 m south east of Akiri village. The mean density obtained for the 14 samples is $(3.22 \pm 0.17) \times 10^3$ kg-m^{-3}. The large standard deviation obtained must have resulted from the sandstones impregnations and some angular fragments of laterite found in the samples located in the south east of Akiri. A histogram of the density values is shown in fig. 16. According to Mackay et al (1949), ironstones consist mainly of limonite and haematite, with undetermined amounts of alumina, and sometimes a little manganese; and they



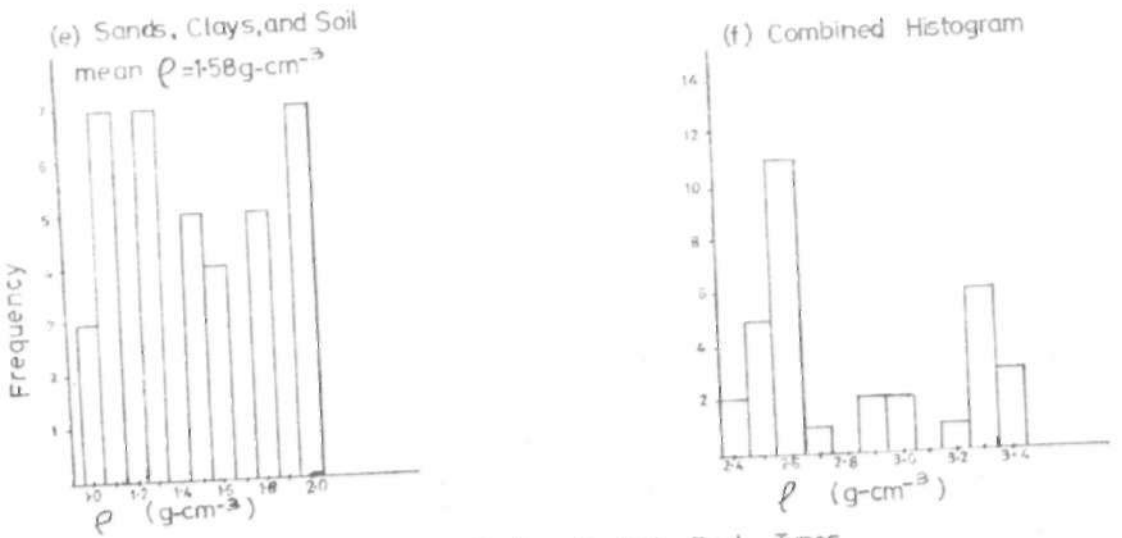


Fig. 16 Density Histogram Of Sediments and Rock Types

occur in three varieties. The type located in this area is the compact, homogeneous ironstone which is composed mainly of limonite and has a platy structure. Some iron-rich vesicular laterites and baryte veins were also found in the ironstones.

The volcanic or the fluvio-volcanic rock type found in this area is composed of fragments of quartz and barytes cemented together by laterite rich in iron. Fragments of chalcopyrite, coal, and fine grained sandstones were also identified in some of the samples. This rock type is associated with contact zones in areas of igneous intrusions. The samples were located mainly in the areas south to south-west of Wuse. The mean density of $(2.58 \pm 0.08) \times 10^3$ kg-m^{-3} was obtained from the 12 samples of this rock type. This value compares favourably with the value of 2.61×10^3 kg-m^{-3} obtained for acid igneous rocks by Telford et al (1976), and the value of $2.62 \pm 0.05 \times 10^3$ kg-m^{-3} obtained for the Tertiary to Recent volcanics of the Nigerian Younger Gravite Province by Ajakaiye (1975). The density histogram for this rock type is shown on fig. 16.

The quartz and quartzites were the other rock type located within the area. The quartz are the milky and vesicular type. The seven samples collected were located also in the south to the south west of Wuse. A mean density of $(2.56 \pm 0.02) \times 10^3$ kg-m^{-3} was obtained and this is in fair agreement with the value of $(2.594 \pm 0.029) \times 10^3$ kg-m^{-3} obtained for the upper Benue valley area by Osazuwa (1978) and the published value of 2.60×10^3 kg-m^{-3} by Telford et al (1976).

Fig. 16 shows the combined density histogram for the igneous, volcanic

and other rock types excluding the sandstones. The density data for all the rock types and sediments sampled are shown in table 5.

The densities ρ_s of the sediments were obtained using the specific gravity bottle method and the expression;

$$\rho_s = \frac{(W_2 - W_0)\,\rho_1}{(W_1 - W_0)\,(W_3 - W_2)}$$

Where ρ_1 = density of the liquid used, in this case water.

W_0 = weight of the empty gravity bottle.

W_1 = weight of the bottle filled with water.

W_2 = weight of the bottle, half filled with sediments.

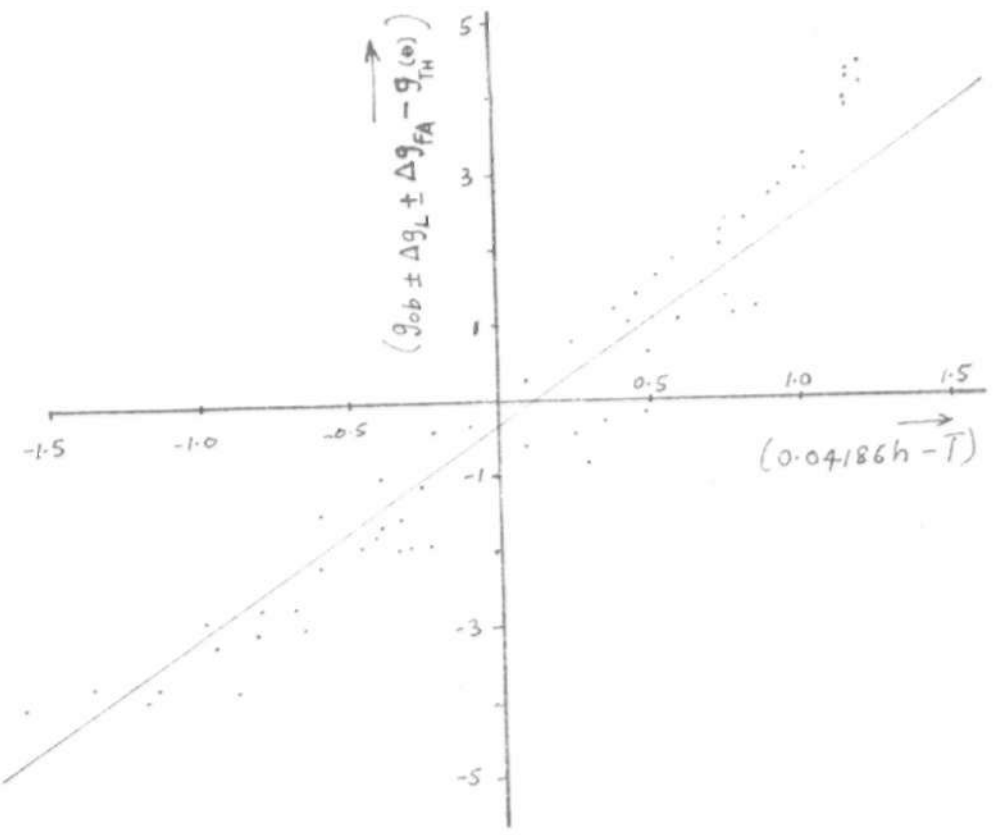
W_3 = weight of half sediments filled bottle, filled completely with water.

For the interpretation of gravity data, the density determination for surface sediments are not of great importance and thus are not often carried out, except when any near surface anomalous structure is contained within them. The density values obtained for the different rock types above may not be a perfect representation of the field situation owing to (i) the few number of samples collected; (ii) The variation in the compactness of the rocks at different horizons; and (iii) the probable alteration of the host rock by weathering, metamorphic and igneous activities. Thus, for more accurate and true representative density information of the area, it will be necessary to obtain reliable borehole information and also a more comprehensive surface density measurements that will involve a larger number of samples covering the whole area in more detail.

TABLE 5

DENSITIES OF ROCK TYPES SAMPLED IN THE SURVEY AREA

ROCK TYPI	NUMBER OF SAMPLES	DRY DENSITY		SATURATED DENSITY		OVERALL MEAN x 10^3 ($kg\text{-}m^{-3}$)	STANDARD DEVIATION
		RANGE x 10^3 ($kg\text{-}m^{-3}$)	MEAN x 10^3 ($kg\text{-}m^{-3}$)	RANGE x 10^3 ($kg\text{-}m^{-3}$)	MEAN x 10^3 ($kg\text{-}m^{-3}$)		
Sediments (Sands, Clay, Soil) (Recent)	33	1.12-2.01	1.58	-	-	1.58	0.09
Sandstones (Cretaceous)	12	2.38-2.54	2.46	2.09-2.56	2.44	2.45	0.09
Quartz & Quartzites	7	2.52-2.58	2.56	2.51-2.58	2.55	2.56	0.02
Volcanics (Tertiary)	12	2.44-2.68	2.56	2.45-2.73	2.60	2.58	0.08
Ironstone (Limonitic) (Tertiary)	14	2.86-3.40	3.22	2.89-3.42	3.22	3.22	0.17



mean surface density = slope of curve = 2.71 g-cm^{-3}

Fig.17 Determination of near surface density by Parasnis Method

CHAPTER 4

INTERPRETATION OF THE GRAVITY DATA

4.1 INTRODUCTION

A Bouguer gravity contour map is practically always a combination of (i) relatively sharp anomalies which must be of shallow origin; (ii) anomalies with intermediate dimensions which may be probably indicative of geologically interesting sources, and (iii) very broad anomalies of a regional nature which have their origin far below that of the section within which the geological interest lies (Nettleton, 1971). Gravity interpretation, therefore frequently begins with some procedure which separates the anomalies of interest from superficial disturbances on one hand and the smooth, presumably deep regional effects on the other hand. The anomaly separation procedure is perhaps the most critical step in the preparation of gravity data for interpretation. It is necessarily an empirical process and broadly may consist of either of two methods. Namely, an intuitive graphical method or an analytical method involving a numerical procedure applied to an array of values usually on a regular grid (Nettleton, 1971).

The analytical process is basically a filtering process intended to emphasize or enhance certain components of the gravity field and suppress others. The analytical method can take any of the following three forms.
(i) The use of vertical derivatives which are often very effective in accentuating local effects that may have small amplitudes relative to the gradients, but often produce strong curvature changes. Derivative maps are often very useful means of locating and identifying local anomalies in difficult cases

but it is however, difficult to interpret the results obtained from derivative computations. (ii) The method of least square smoothing which involves the fitting of a mathematical surface, such as a low order polynomial to the gravity data. This method has the advantage of the use of the computer and the methods of statistical analysis only. The errors involved may however, easily be of the magnitude of the local anomaly under investigation. (iii) Finally, there is the "Gridding" or the "Centre-point-and-one-ring" method. This consists of calculating the regional gravity at a point as the average of a number of values of the Bouguer gravity on the circumference of a circle of arbitrarily determined radius about the point. The method is very sensitive to the choice of the radius of the circle and is effective in outlinning the position of a local anomaly, but becomes inapplicable at the adges of the grid. This method is quite mechanical.

The intuitive graphical method or the visual smoothing is the most often employed method. Here the regional effect is obtained simply by visually smoothing the Bouguer gravity contours using the undisturbed parts of the contour map to provide the regional trend which is then continued smoothly through the disturbed areas. This method is very dependent on the skill and experience of the interpreter but it is flexible, and direct use may be made of any available geological information. Though this method is entirely empirical and depends on the operator's judgement, it is economical and when skillfully applied leads to effective isolation of local anomalies and the simple results obtained are directly amenable to quantitative analysis.

In the following report the visual smoothing method is employed to remove the regional background. This method is employed primarily because of its adaptability to geological interpretation. The analytical methods are mainly

convolution processes and residual anomalies obtained from them are not readily adaptable to quantitative interpretation of the possible geological cause of the anomaly (Skeels, (1966); Nettleton, (1971).

4.2. DESCRIPTION OF THE BOUGUER ANOMALY

The Bouguer anomaly map of the area indicates that the area is characterised by general negative anomalies (fig. 14). Generally, there is a strong WSW-ESE regional trend in most of the area which later trends almost in a W-E direction towards the extreme north. The Bouguer anomaly values range from - 165 to - 230 g.u. and there does not appear to be any apparent correlation between the Bouguer anomalies and the elevations (figs. 12 and 14). However, it is observed that the free-air anomalies and the elevation exhibit some direct correlation (figs. 12 and 15). This observation is consistent with the view expressed by Nettleton, (1971). It is also observed that apart from a few local disturbances superimposed on the strong regional trend at some places within the area, there is no typical salt dome anomaly evident from the gravity map. This effect might have resulted from the predominant regional trend over the gravity effect of shallow and relatively small structures.

4.3. THE RESIDUAL ANOMALIES

As was stated above, for quantitative interpretation of the possible geological cause of the prevailing anomalies, the visual smoothing method was employed in removing the regional backgroung. The residual anomalies obtained are shown on fig. 18. The anomalies have been contoured at 1.0 g.u. intervals. On the residual anomaly map, the follwing anomalies or features can be

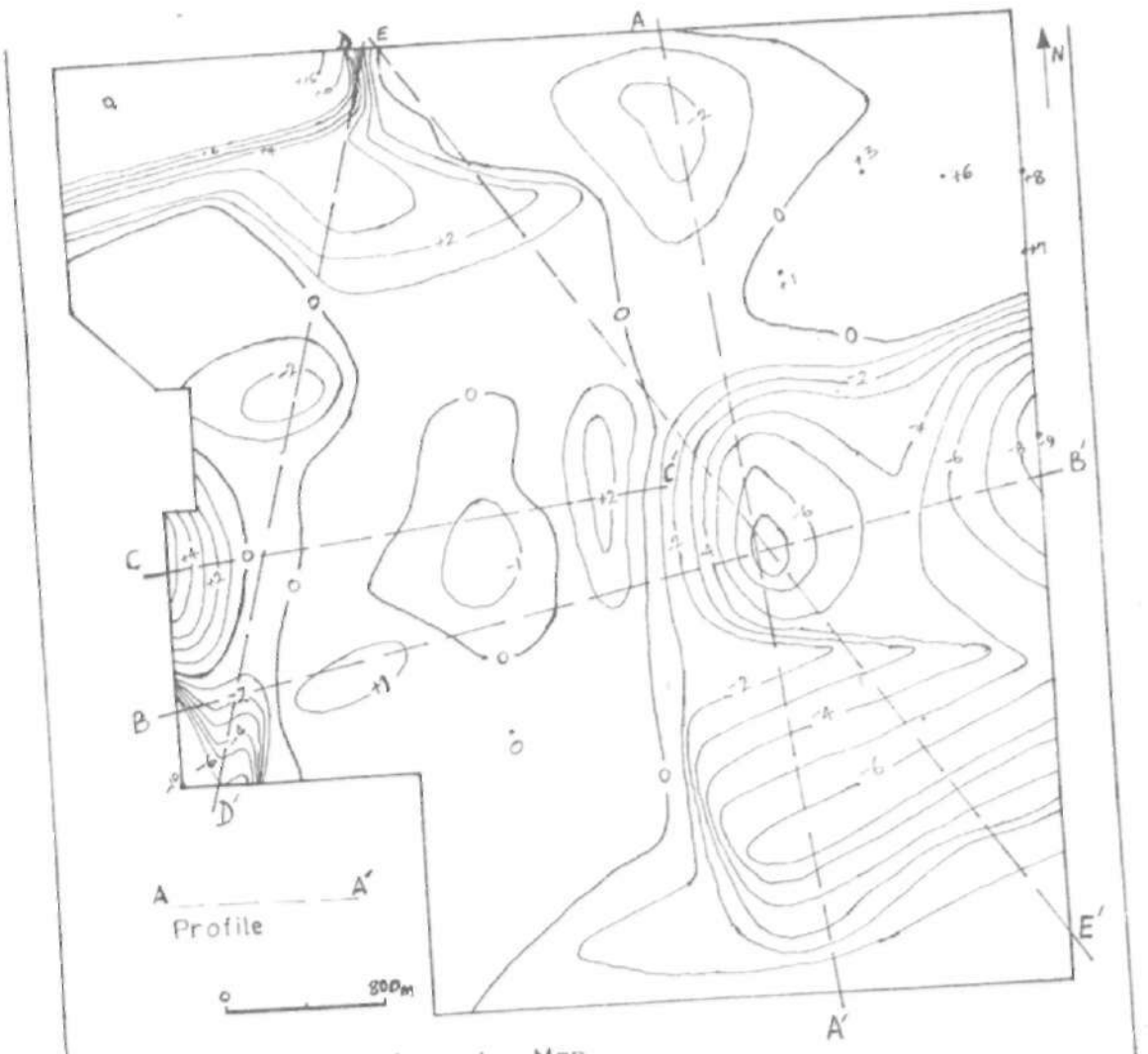


Fig. 18 Residual Anomaly Map

identified. (i) Two elliptical closures with values between + 1.0 and + 2.0 g.u. (ii) Four negative closures which are almost circular and having value that range between - 1.0 and - 7.0 g.u. The maximum negative closure of -7.0 g.u. is located south of Akiri saltpits. (iii) Two positive anomalies whose closures are not well defined appearing at the north-western corner and at the west-central extreme of the survey area. (iv) Three negative partial closures are located around the east-central extreme, the south-eastern area, and at the west-south-weat corner near Sabo-Wuse. As indicated on the residual anomaly map, these partial closures are of greater magnitude than the closure mentioned earlier. It will therefore be necessary to extend the survey area about one kilometer to the south-west, and also about one and half kilometer in the east to south-eastern directions. This will aid in defining adequately, the negative closures particularly.

Five profiles A-A', B-B', C-C', D-D' and E-E' have been taken as shown on fig. 18, for the quantitative interpretation of all anomalies indicated. The Bouguer anomaly, the free-air anomaly and the elevations along each of the profiles have also been plotted on figs. 19 to 23 for easy comparism. Along profile A-A', there appears to be a fairly direct correlation between the Bouguer anomaly and the elevation, while the free-air anomaly shows an inverse correlation with the elevation. Similarly, along profile B-B' there is a partial direct correlation between the free-air anomaly and elevation, while the Bouguer anomaly exhibits some inverse correlation with the elevations. In the case of profile C-C', the Bouguer anomaly and the elevation show both direct and inverse correlation, while the free-air anomaly has an inverse correlation with the elevation. Along profile D-D' the Bouguer anomaly and

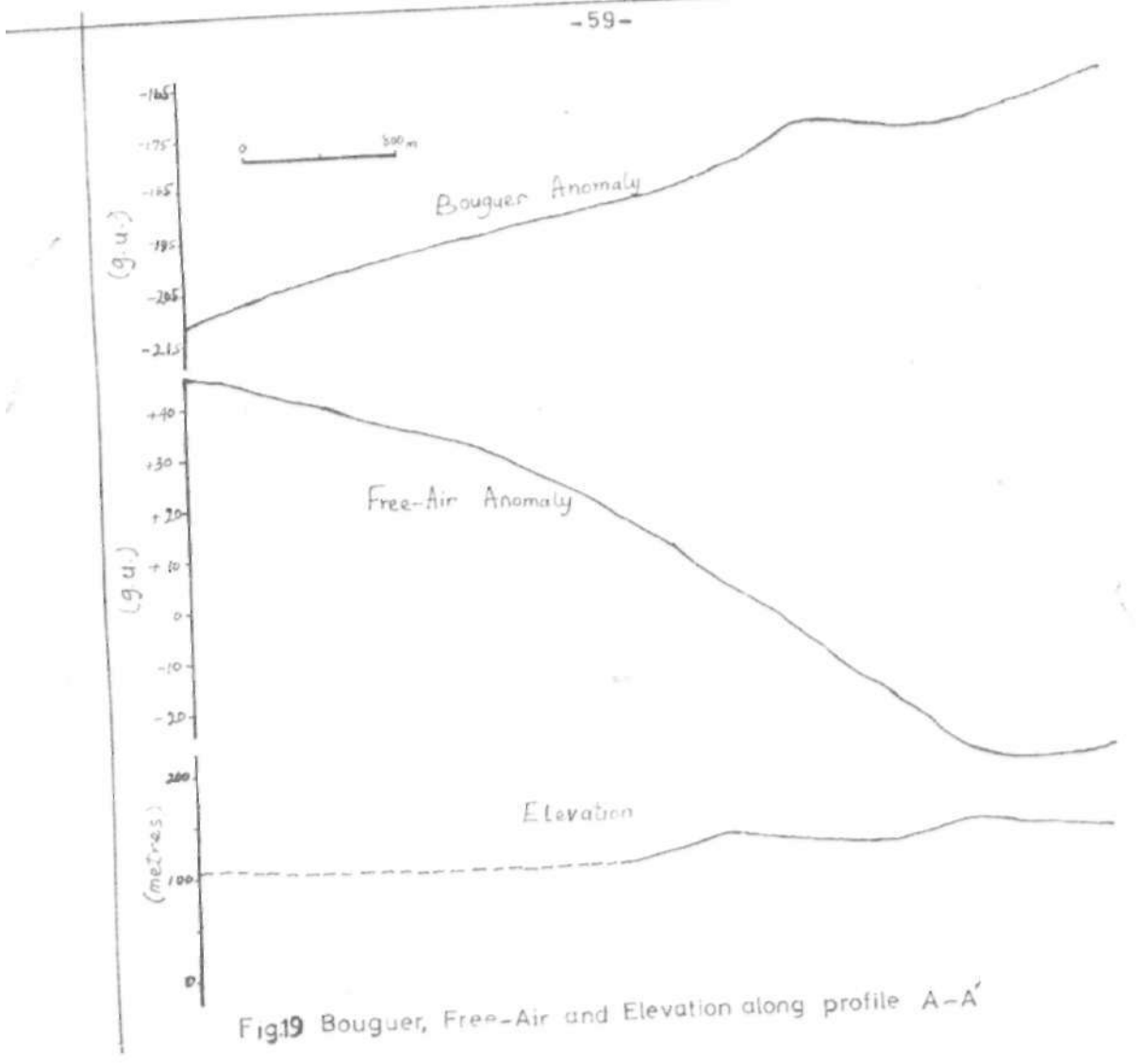


Fig.19 Bouguer, Free-Air and Elevation along profile A–A′

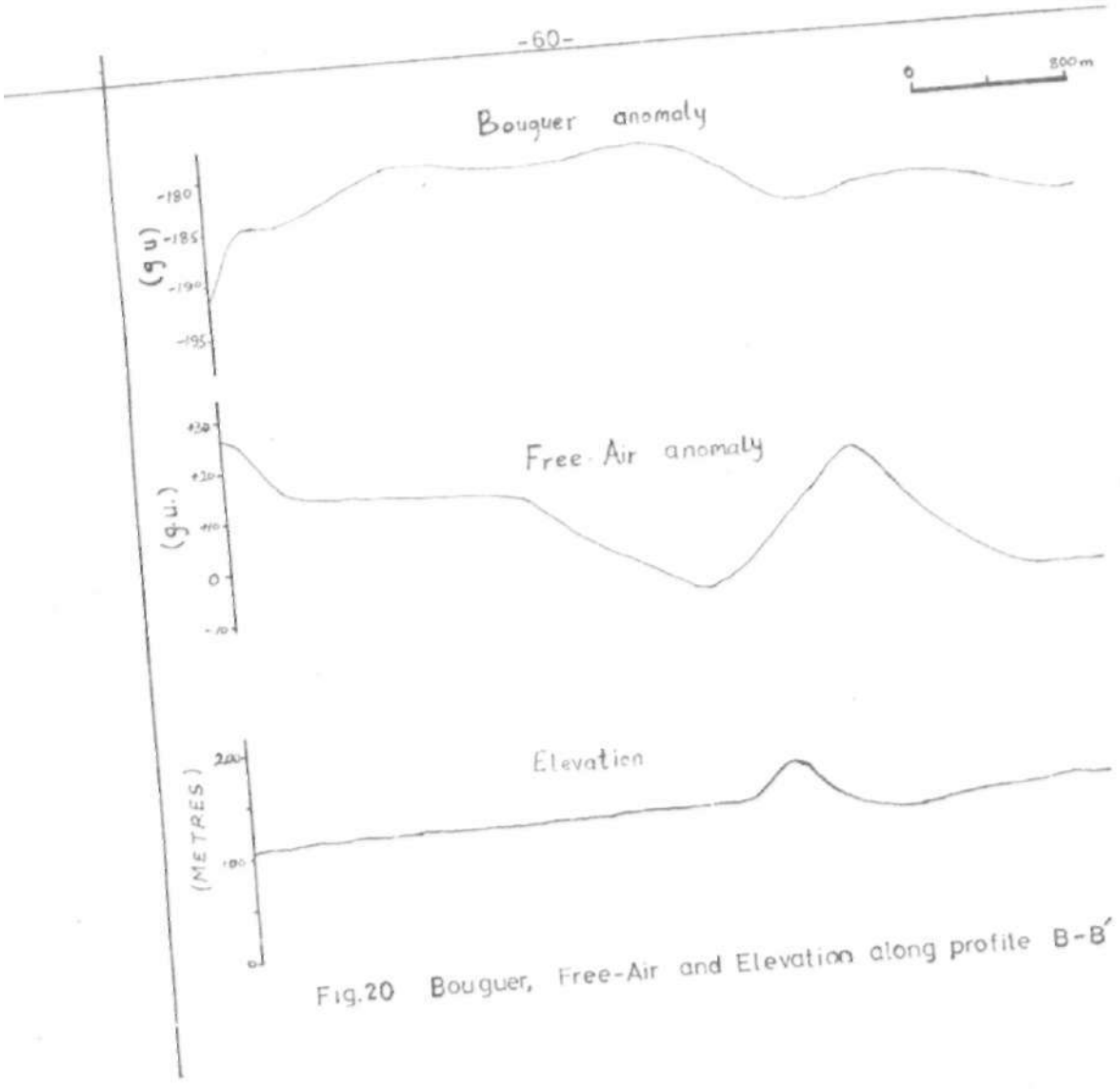


Fig.20 Bouguer, Free-Air and Elevation along profile B-B´

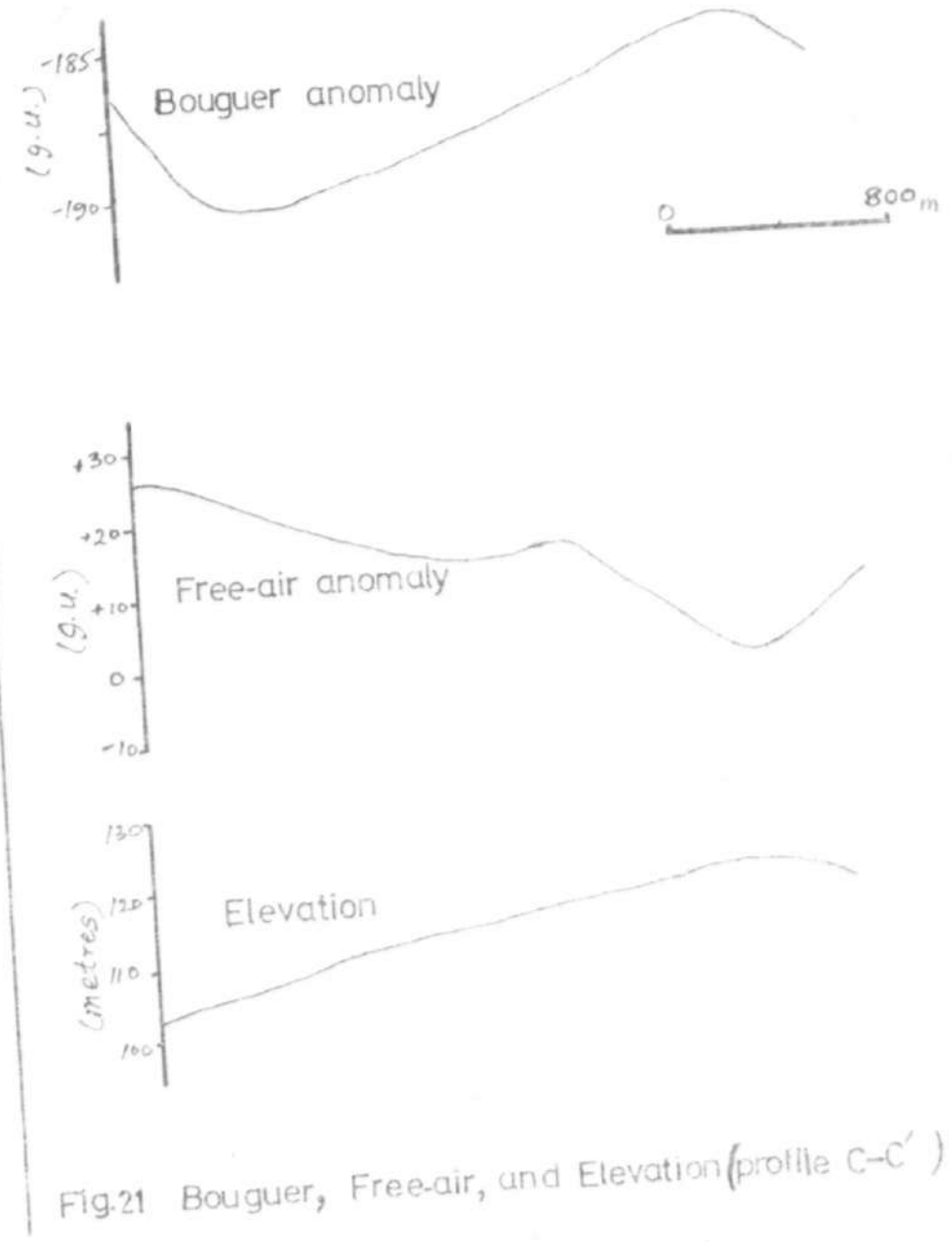


Fig.21 Bouguer, Free-air, and Elevation (profile C–C′)

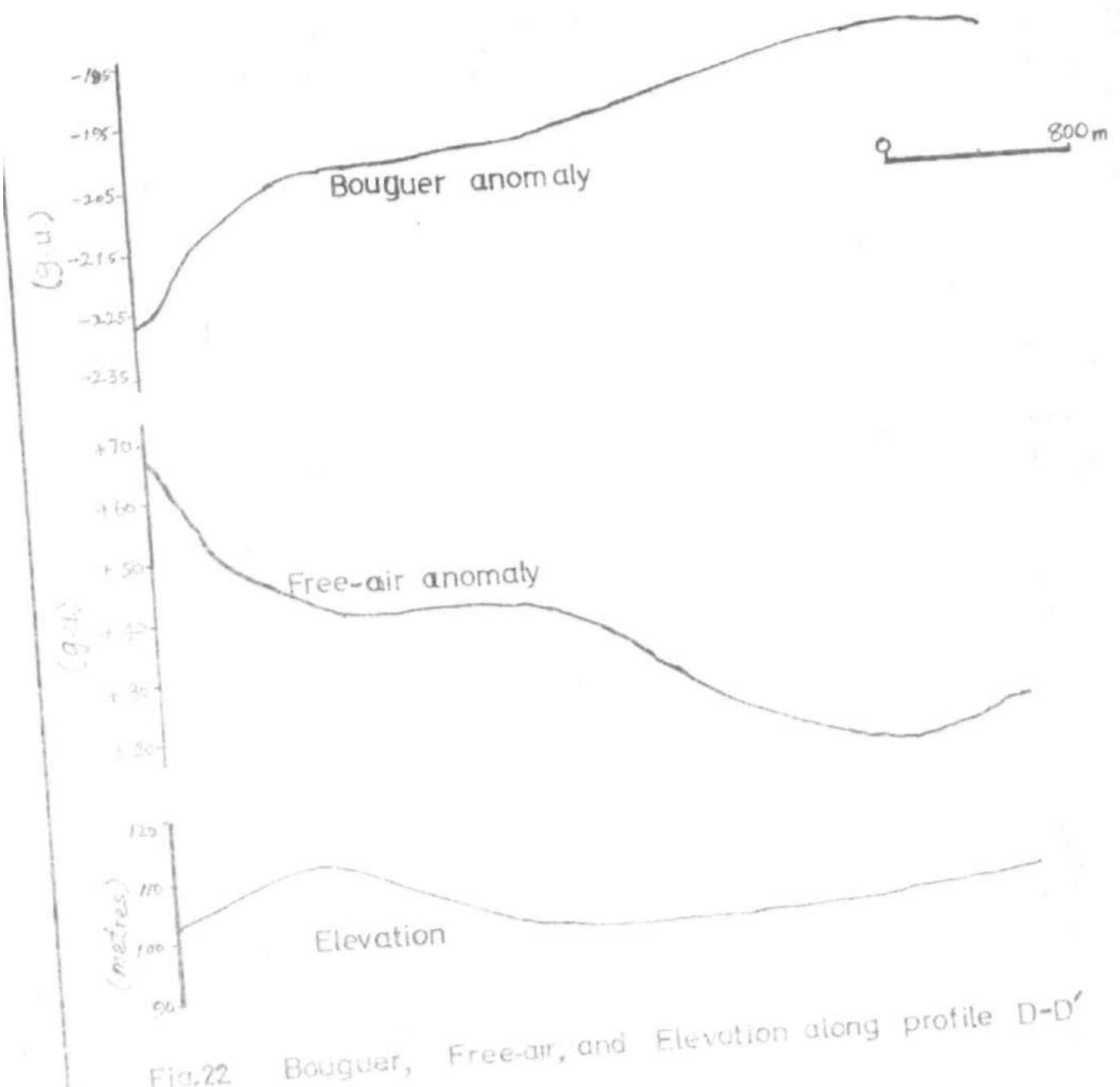


Fig.22 Bouguer, Free-air, and Elevation along profile D-D'

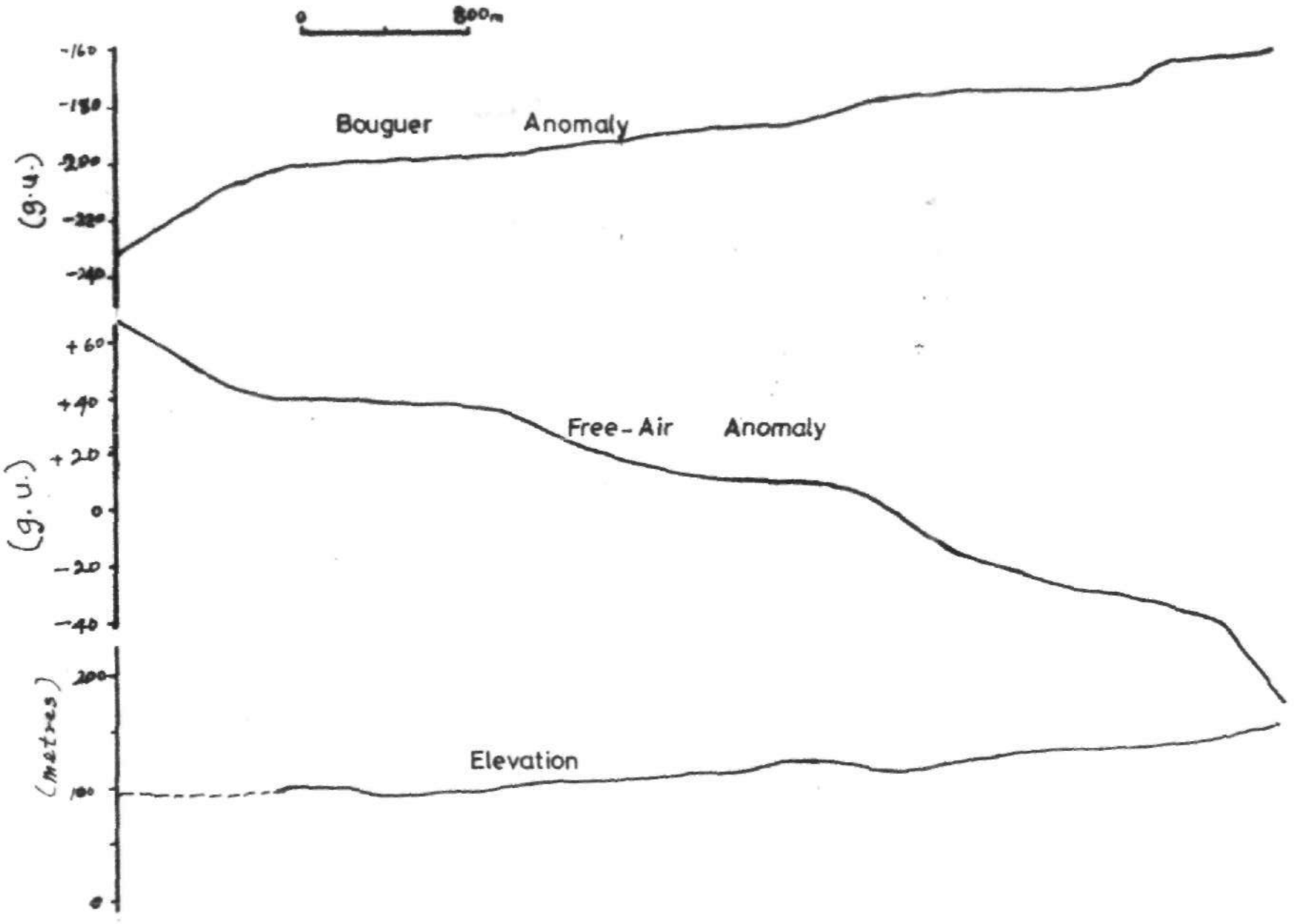


Fig.23 Bouguer, Free-air anomaly, and Elevation along profile E-E′

the elevation show a fair direct correlation, but however, the free-air anomaly and the elevation exhibit an apparent inverse correlation. Finally, along profile E-E', the Bouguer anomaly and the elevation show some form of direct correlation while an approximate inverse correlation may be adduced for the free-air anomaly and the elevation.

4.4. CORRELATION OF RESIDUAL ANOMALY WITH GEOLOGY

A comparision of the only available geological map of the area (Offodile et al, 1977) on fig. 7 and the residual anomaly map (fig. 18) shows very little or no direct correlation between them. Despite this lack of correlation a plausible geological interpretation has been attempted as follows:
Apart from the major negative anomaly located around Akiri (fig. 18) which can be directly adduced to be due to a low density material, possibly a buried evaporitic deposit, the other suspected major negative anomalies, at the western and eastern ends of profile B-B' (fig. 18), can be attributed to either of two possible origins. Firstly, these anomalies could be due to large variable thicknesses of sedimentary beds within an undulating bedrock. The elongated negative anomaly located around the southern ends of profile A-A' and E-E' has a similar origin and, or is due to low density recent sedimentary beds within the valley-like depression in that area (see fig. 12). Secondly, these suspected major negative anomalies could also be the result of low density material or evaporitic piercement salt bodies of intermediate size within the sedimentary host rock. The anomaly at the southern end of profile D-D' is more favoured by this second interpretation as a result of the geological observations (Offodile et al, 1977) of a possible domelike structure

due to a salt diapir. However, the anomaly at the eastern end of profile B-B' can also be of the same origin owing to its proximity to the Akiri salt springs. These springs are perhaps the result of leaching out of these salt deposits by transit underground waters (Offodile, 1975). Finally, it is possible that all the negative anomalies within the southwestern area, are due to a single low density material, perhaps, a salt dome overlain by some high density caprock possibly iron stone. It will however, be necessary to extend the survey area in order to properly define these anomalies.

The smaller negative anomalies located around the mid-points of profiles D-D' and C-C', and at the northern end of profile A-A', have gentle gradients and fairly broad lateral extent. These could be ascribed to depressions in the bedrock filled by cretaceous sediments. The anomalies are also observed to be located between positive anomalies in all cases, which lends some support to the above proposition for their origin. It could also be suggested that these anomalies result from shallow salt dome with some high density caprock. However, owing to the varying sizes, location and the assymimetry in the anomalies, the later proposition is not very likely.

The four positive anomalies identified on the residual anomaly map are possible due to raised portions of an undulating bedrock. This proposal is particularly fitting to the anomaly at the north-western corner, owing to its relative broad and elongated pattern even though the anomaly is not clearly defined. The other three positive anomalies are located around the vicinities of mapped baryte vein ridges. These barytes are found in association with quartz, lead, zinc, and iron minerals as gangue. The origin of these barytes

has also been ascribed to the result of the reaction between the salt brines and the ascending waters of hydrothermal origin (Offodile et al, 1977). Thus as these anomalies are all located near suspected salt deposits, a more probable source of the anomalies can be attributed to the thinning of the cretaceous sediments due to the intrusion of these mineralised ridges.

The geological map (fig. 7) shows that the survey area has a general simply geology, though it failed to show most of the igneous intrusions extending from the east-central area to the southwest that were observed on the field. Similarly, most of the barytes veins shown on the geological map have no anomalies associated with them on the residual anomaly map. This can possible be due to the poor degree of mineralisation of these veins, their small size, and their depth of burial such that their gravity effect may have been merged in the regional background and, or conpensated by the gravity effect of the low density overlying cretaceous sedimentary rocks.

4.5 QUANTITATIVE INTERPRETATION OF THE RESIDUAL ANOMALIES

The objective of gravity interpretation is to deduce the geological character of the subsurface from variations in the gravitational field. The inverse problem in gravimetry lies in determining the density variation of the earth from an observed gravity anomaly. The interpretation is inherently non-unique due to the fact that there is no single mathematical solution to the determination of the source of a gravity field no matter how precisely that field may be mapped (Nettleton, 1971). [illegible] Skeels (1947) proved convincingly, based on potential theory, that no computational procedure can extract a unique solution from gravity data. Nevertheless, it is often possible

to obtain particular solutions which satisfy the values of the observed anomaly and also fulfill additional constraints (Safon et al 1977). It is seldom, however, that any interpretation is based on gravity data alone. The procedure actually employed to interpret gravity data will depend on such factors as the purpose of the survey, its precision and the amount of geological information available. Quantitative interpretations are most fruitful where there is already substantial control on the geology of the area such as obtained from drilling logs or seismic data. These controls reduce greatly the ambiguity in the interpretation.

Several methods have been used in calculating the shape of a body of known density contrast responsible for an observed anomaly. In this work, simple geometric shapes have been used to simulate the causative body. Starting from an initial estimate using Skeels' (1963) method and with cylindical models an attempt has been made to obtain : an acceptable structure for the observed anomaly.

The choice of cylindical models was due to geological observations of possible salt deposits, the shape and size of the anomalies, and their general close fit for simulating small simple salt dome structures. Though the major negative anomalies are not definitely elliptical throughout, the availability of computational facility, and for the reasons above, right vertical cylindical models were adopted. The relatively constant density value of 2.20×10^{3} kg-m^{-3} (Billings 1972) was assumed for the rock salt. This value has been adopted with the assumption that the salt mass is located at a depth where the density variation within the salt mass, if any, is negligible.

However, there is no relevant subsurface geological information to support this. The average density of 2.40 x 10^3 kg-m^{-3} for the Cretaceous sediments (Cratchley and Jones, 1965) in the area gives a density contrast of - 0.20 x 10^3 kg-m^{-3} between the sedimentary host rock and the salt body. This density contrast and a computer program, of Nagy's (1965) version of Nabighian's expression (1962) for the gravitational attraction of a right circular cylinder, which has been adapted for use on the University computer were employed in the computations. The Keana formation which underlies the whole of the survey area, and the source of the salt mass is supposed to have a thickness of about 1500 m ESSO (1967), Offodile (1976). Hence all models were designed to have the maximum thickness of about 1500 m.

As was stated earlier (Section 4.3) five profiles have been intended for quantitative interpretation. However, owing to the short available time caused by lack of computer facility, and the small size of some of the anomalies, only the major negative anomalies, located at the Southern ends of profile A-A' and E-E' were interpreted. The anomaly at the end of profile B-B' could not be fully interpreted quantitatively owing to its poor closure, but has been however, correlated with the former two profiles.

A possible model for the anomaly on profile A-A' is shown on fig. 24 as a vertical cylinder 1850 m in diameter, and buried at a mean depth of 415 m. This cylindrical model is intruded by an iron oxide rich body with a density contrast of 0.82 x 10^3 kg-m^{-3}. The intrusive rock has a diameter of about 540 m and its top surface at its central point, is buried at a depth of about 411 m. The centres of the salt mass and that of the iron rock are located on the surface at points 1330 m and 1310 m, 38° South of Akiri.

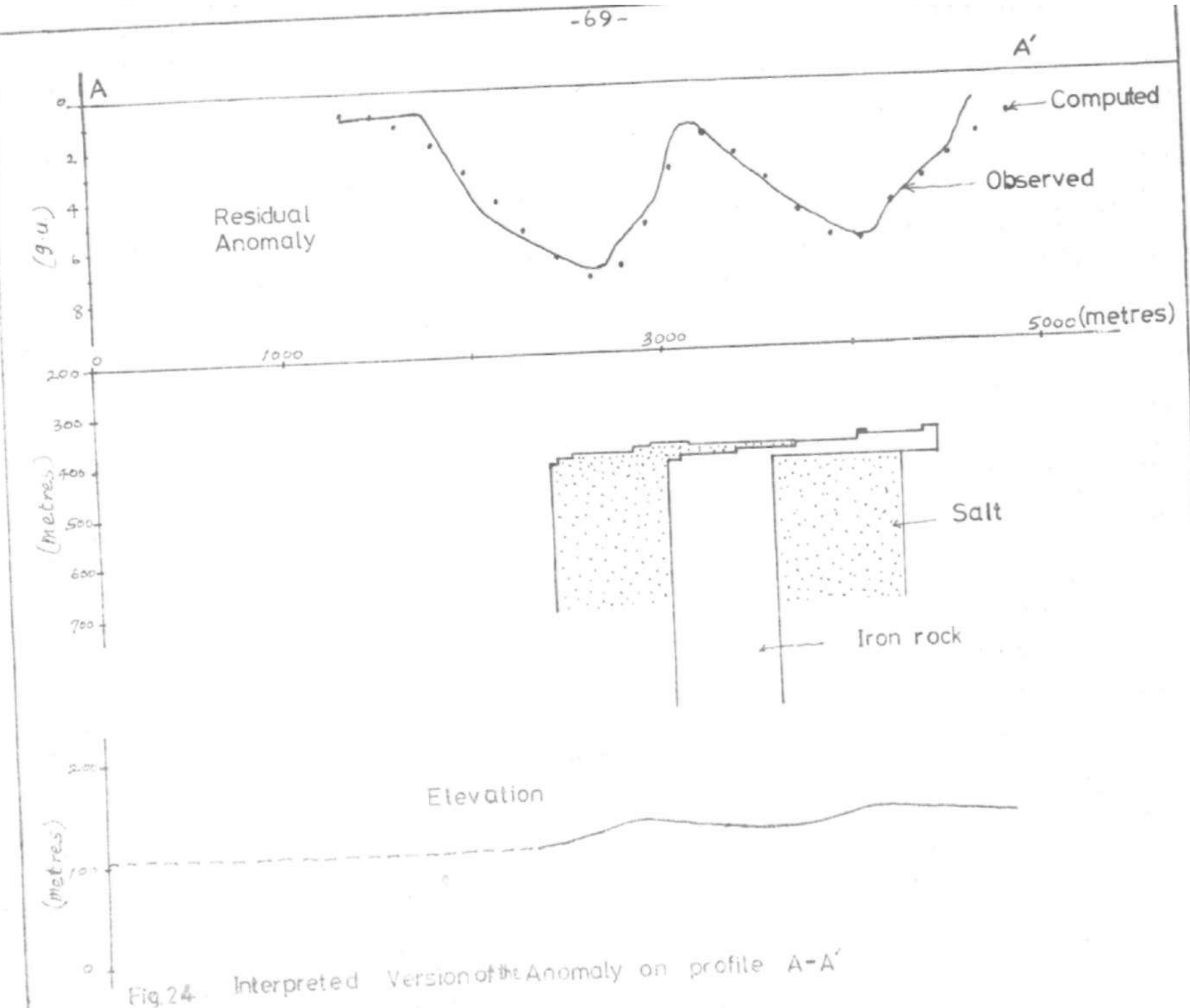


Fig. 24 Interpreted Version of the Anomaly on profile A-A'

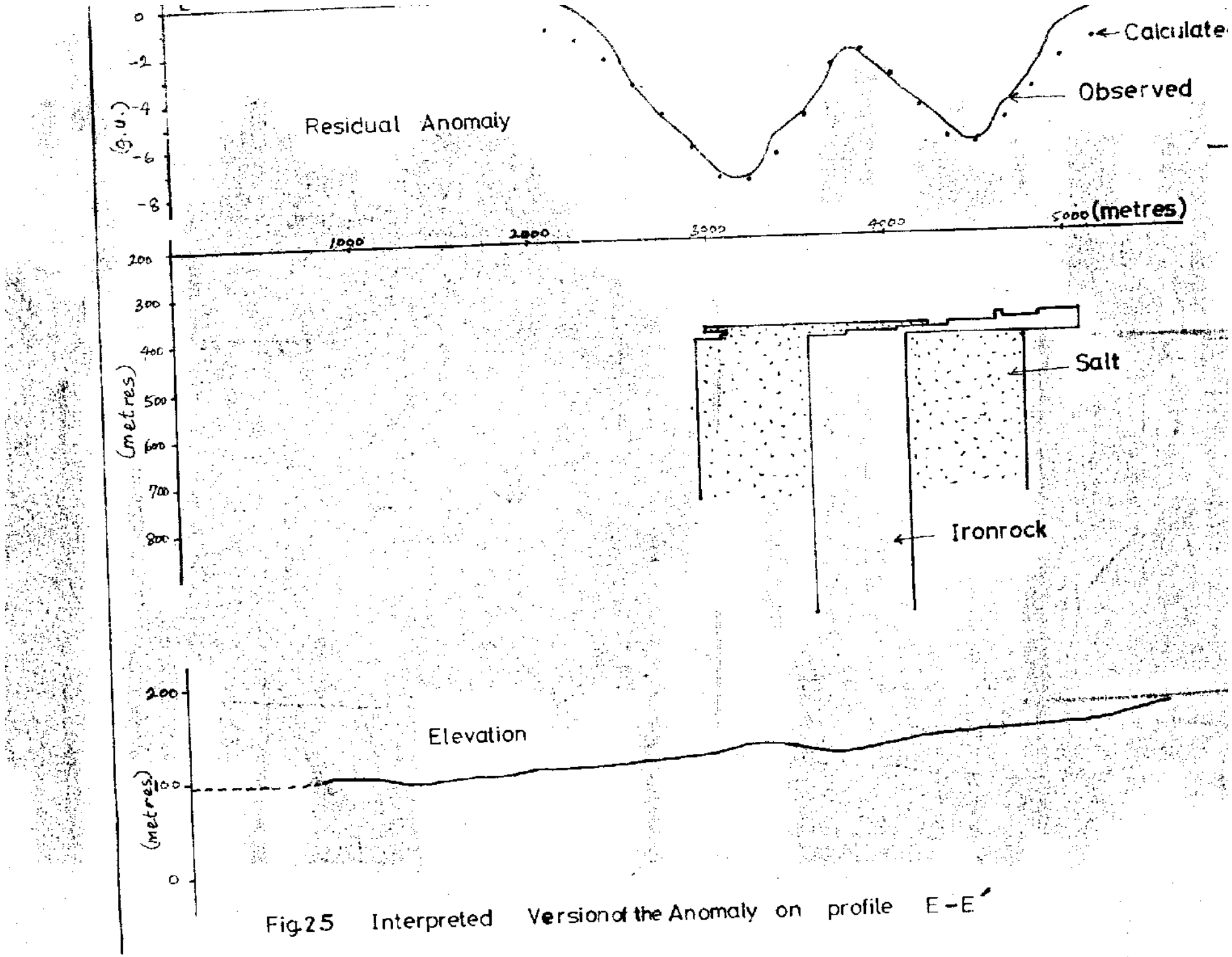


Fig.25 Interpreted Version of the Anomaly on profile E-E'

With the ironstone mass removed, an estimated rock salt mass of about 2.4×10^9 tonnes is Contained in this model.

Similarly the model for the anomaly on profile E-E' is shown on fig. 25. This is also a cylindrical model intruded by ironstone sill plug. The mass has a diameter of 1840 m and its top surface is buried at a depth of 412 m while the iron rock has a diameter of 540 m and is at a mean depth of 411 m at its central point. The locations of the centres of the salt mass and the iron rock on the surface are 1840 m and 1830 m 30° south-east of NMC 34,34. A salt mass of about 2.38×10^9 tonnes is estimated for this model.

Unique solutions are virtually impossible in gravity interpretation. The models presented are based mainly on the available data and simple assumptions. Discrepancies or deviations in the computad anomalies are perhaps due to overhangs common to salt domes, irregularities on the surface of the intruding iron rock, non-symmetry of the actual cylinder, and or the erosional effect of ground water at some depth within the salt mass.

Figs. 26 and 27 show some other models which were adopted for the anomalies but could not give any good fit to the observed anomalies. For these models, two dimensional polygonal models were adopted. The baryte caprock was adopted because of its occurrence within the anomalous area (see fig. 7), while the volcanic intrusion was adopted as the volcanic rock type is one of the rock types located within the survey area.

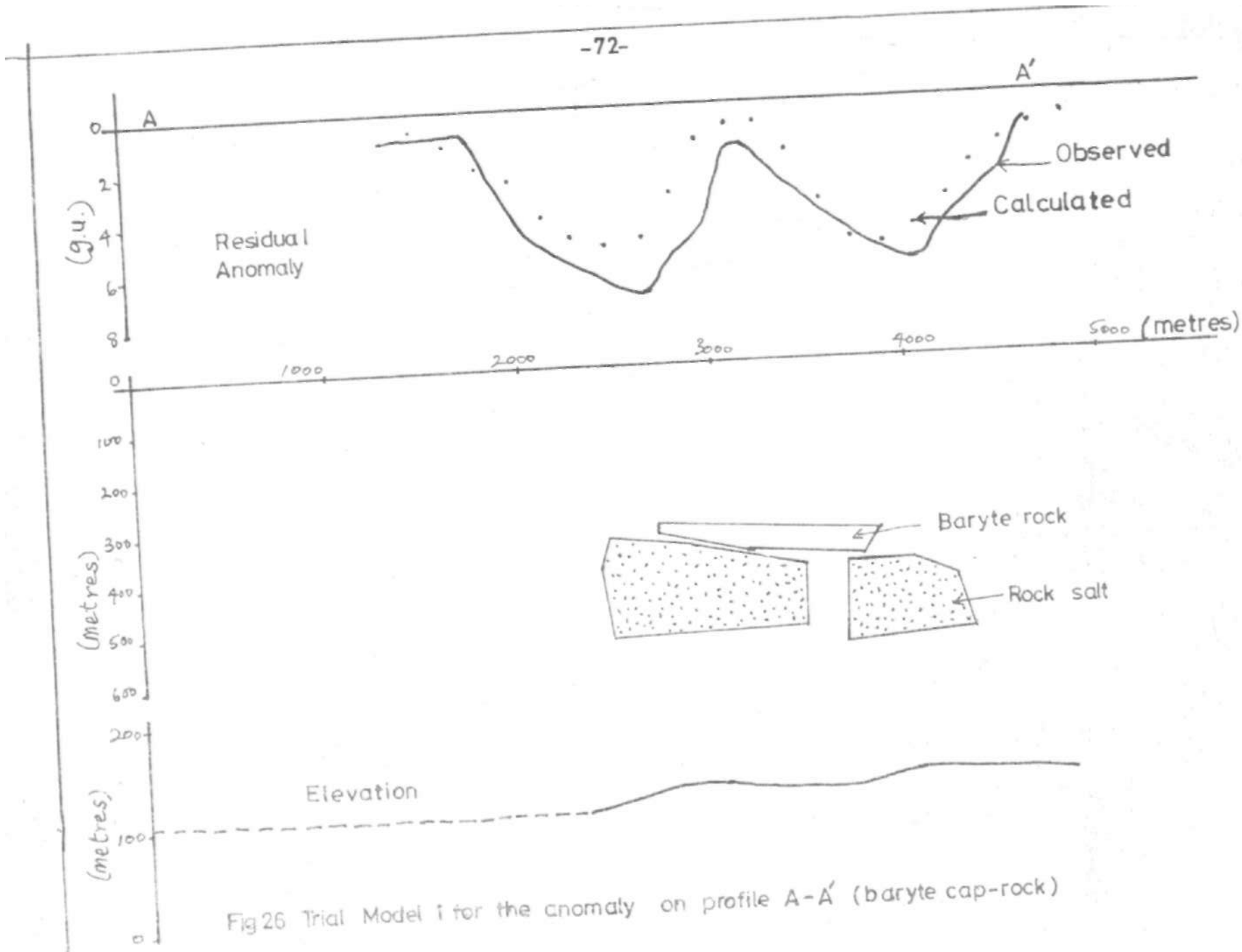


Fig 26 Trial Model I for the anomaly on profile A-A' (baryte cap-rock)

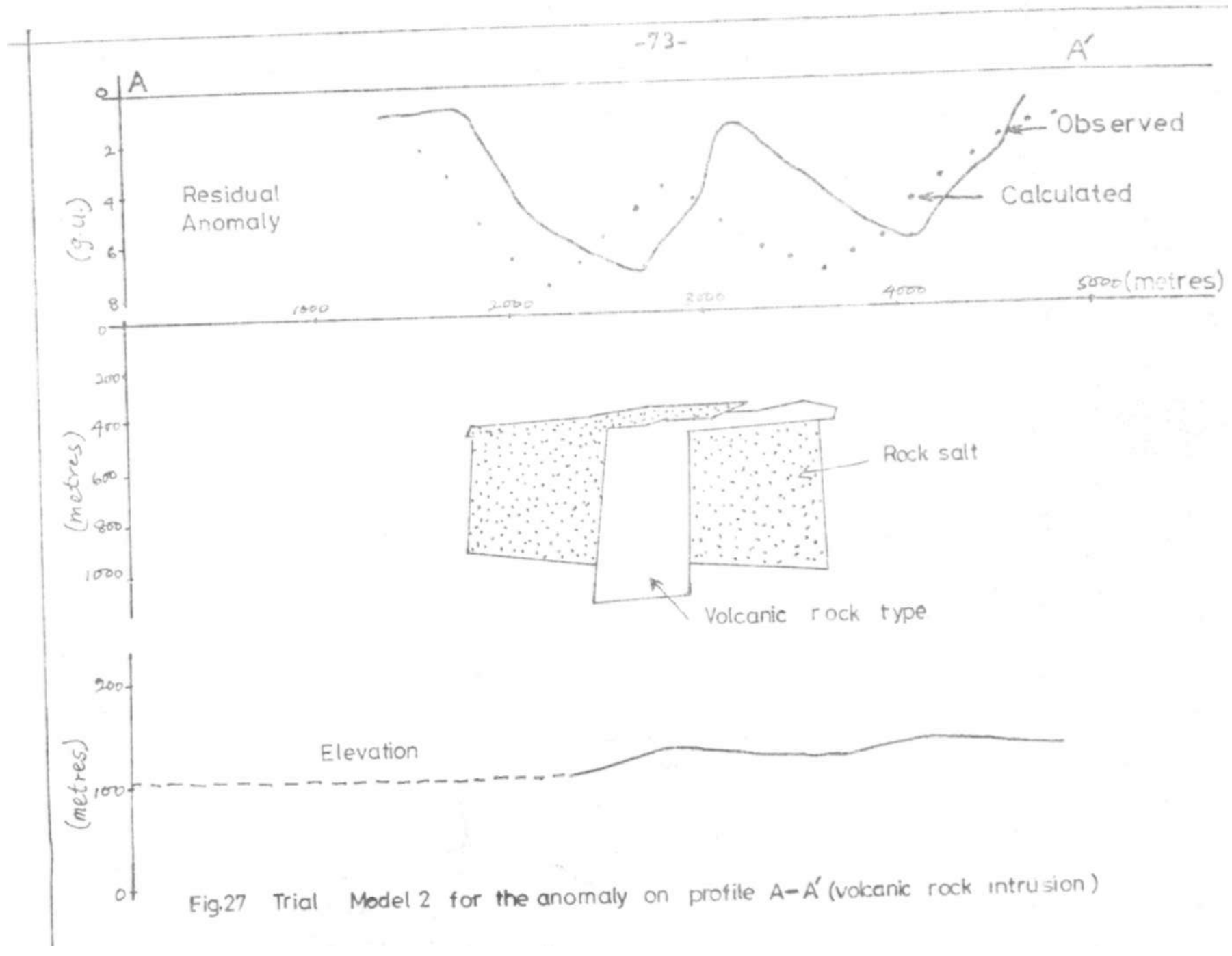


Fig.27 Trial Model 2 for the anomaly on profile A–A' (volcanic rock intrusion)

CHAPTER 5

5.1 SUMMARY OF RESULTS

The free-air anomaly map show some direct correlation with the topography of the area (fig. 12 and 15). The Bouguer anomaly map show a characteristic west-south-west to east-north-east trending negative anomalies (fig. 14). There are minor anomalies on the Bouguer anomaly map mainly within the southeastern areas, and at the extreme north. The anomaly values range between -165 to -230 g.u.

The residual anomalies were obtained by visually removing the regional anomalies from the Bouguer anomaly map. Only one composite major negative anomaly was obtained within the southeastern part of the survey area. Some other possible major negative closures are located at the ends of profiles B-B' while three other smaller negative anomalies are found dispersed within the area. Two small positive closures are interspered within the negative anomalies and two possible major positives are located at the eastern end of profile C-C' and at the northern end of profile D-D' (fig. 18).

A quantitative interpretation of the major negative anomaly gave a vertical cylindrical salt body that has been intruded by an iron oxide rock mass, as the causative structure. This view derives its validity from the available geological information on the area (Offodile et al, 1977) and field observations. The models on profiles A-A' and E-E' are located with their centres at 1330 m to 1310 m 38° southeast of the base station NMC 34,34. About 2.4×10^9 tonnes of salt mass has been estimated for this deposit. Other models that were attempted (figs. 26 and 27) suggest that

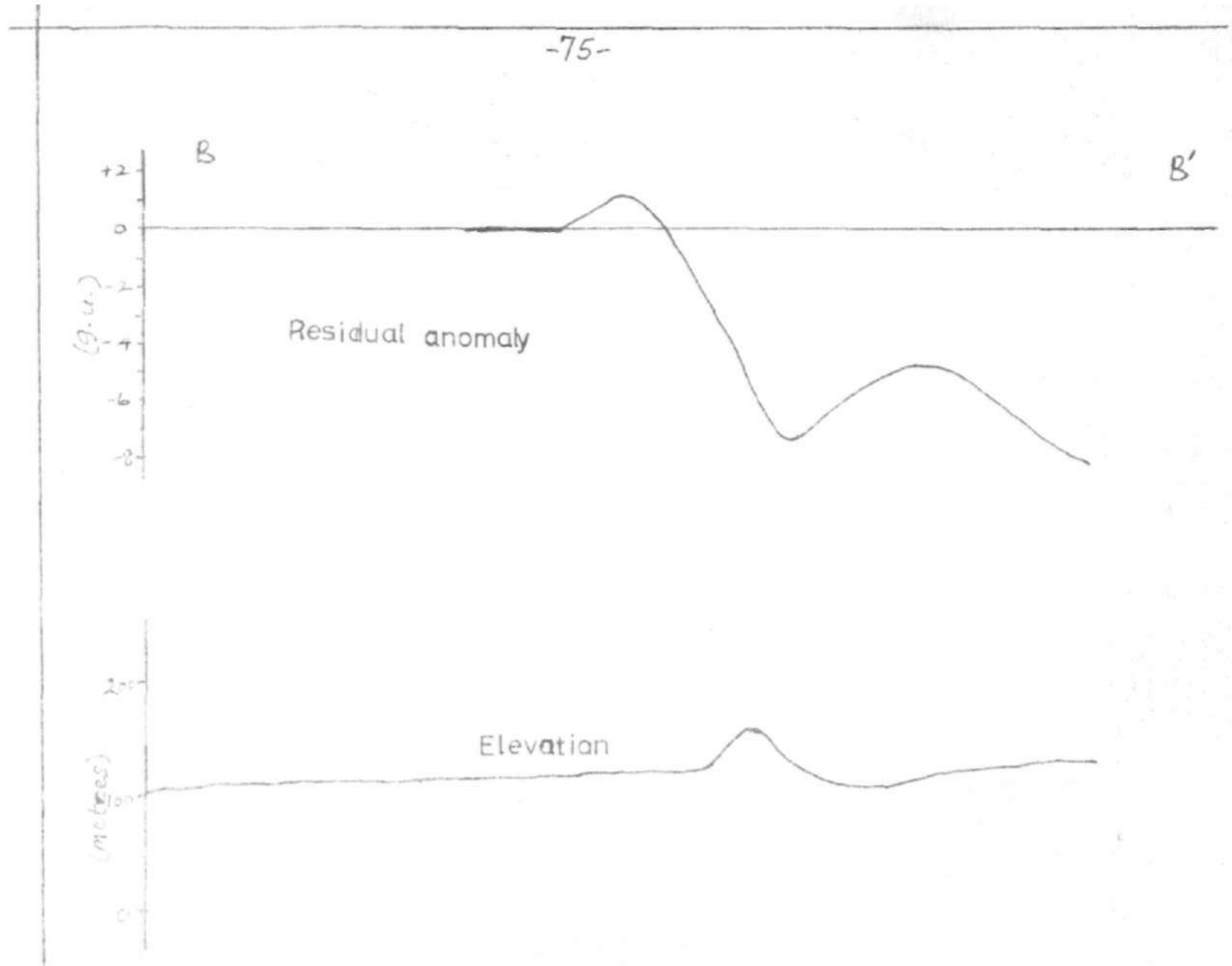


Fig. 28 Residual and Elevation along profile B-B'

the causative body of the observed anomalies is not a baryte-capped-salt dome nor a salt dome with a volcanic intrusion.

5.2 DISCUSSION OF RESULTS

The predominant negative Bouguer anomaly and its trend conforms with the observed trend of such anomalies within the Benue trough (Cratchley and Jones 1965), Ajakaiye and Ajayi (1977). As postulated by Cratchley and Jones, these negative anomalies are probably due to the thickness of the Cretaceous sediments in the trough. This is known to be about 6000 m thick at its deepest areas (Offodile 1976).

The minor anomalies on the Bouguer anomaly map do not show typical salt dome character neither do the anomalies correlate with the geology of the area. This could be due to the relatively small size, and the gravity effect could be masked by the strong regional background. The negative anomalies found on the resultant residual anomaly map can be attributed to the presence of shallow small salt deposits and recent sediments within the sedimentary host rock. The Keana formation which underlies the whole of the survey area is known to be impregnated with thin salt beds of evaporitic origin (Offodile, 1976). These thin salt beds have formed into shallow small salt masses by non-tectonic processes and the gravitational effect of such structures can be easily masked by a strong regional background. The absence of any typical salt dome characteristics on the Bouguer anomaly map can thus be attributed to the above cause.

The shapes of the modelled anomalies (profiles A-A' and E-E') initially suggest two spherical salt bodies. However, on correlating with the anomaly

along profile B-B' and considering the magnitudes of the crests within those anomalies, the intrusion or capping of a dome shaped salt mass by a denser rock type is then suggested. Cylindrical models approximating to a dome with a denser rock material intruding it and outflowing in a south-eastern direction were adopted (fig. 24 and 25). Cylindrical models have been used because of their close fit for simulating simple dome shapes and because of the shape and size of the anomalies. The ironstone rock type was chosen because it outcrops widely in this area. The ironstone intrusion was probably a later event as such volcanic activities in the area were of the Tertiary period (Wright, 1976).

From the results obtained it can be concluded that the Akiri salt springs owe their origin to the contact between transit groundwater and the proposed salt mass. The springs are located at the northern end of the salt mass with the beds dipping away from the anticlinal axis. Hence these springs result from the leaching of the salt body by groundwater movements which emerge from cracks, fracture and partings within the Keana formation.

Some of the positive anomalies are located at places where baryte veins have been mapped while the others lack correlation due to insufficient geological information of the area. However, the primary aim of the survey, which is to delineate and locate areas of possible salt deposits, has been relatively achieved, despite the lack of relevant information and many other inconveniences that were encountered.

5.3 RECOMMENDATIONS

From the results of this survey it can be concluded that salt deposit

large enough to sustain a modern mineral industry is not present within the survey area. However, larger salt masses have been indicated around the present area and with the incorporation of other located salt deposits, a salt industry may be feasible. For this purpose it is recommended that the survey area be extended towards the west across the river Ankwe and to the south by about one kilometer and by about one and half kilometers to the east beyond Akiri, so as to properly define the indicated negative anomalies. It will also be necessary to run some seismic spreads and possibly some resistivity soundings along the eastern end of profiles B-B' and the southern end of profile E-E' to conform the results of the present work. More detailed geophysical investigations particularly gravity surveys should be carried out in all areas of know salt springs.

As was stated earlier, since the basis of gravity surveys is the variation in the mass distribution within the earth, factual density information thus becomes a necessary requisite for geological interpretation of gravity data. It will therefore be necessary to obtain borehole density information of these areas. The Nigerian Mining Corporation and any such bodies interested in mineral prospecting should be approached to carry out borehole density logs in all the areas where salt springs are located. This will provide reliable and comprehensive density information of the areas of interest as well as that of the Cretaceous Sediments of the Benue Valley.

It is finally recommended that more detailed geological mapping be carried out within and around this area. This is necessary as there is very little published geological or geophysical information of this part of the Middle-Benue valley. The best field season in this area is the period

between the middle of January and the end of March, During this period the vegetation is sparse, the swamps and the river Ankwe are dry and all the roads leading to and within the area are usable.

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APPENDIX TABLE

ANALYSIS OF VARIANCE TABLE FOR:-
RATE OF GAIN IN EXPERIMENT I

Table 16

Sources of Variation	Degrees 2 Freedom	Sum of Squares	Mean Square	F.	F. Significance
Between Groups	6	6931.528	1155.255	5.059	0.002
Within Groups	21	4795.223			
Total	27	11726.751			
Table 17 FEED INTAKE IN EXPT. 1					
Between Groups	6	81807.322	13634.554	3.029	0.027
Within Groups	21	94525.501	4501.214		
Total	27	176332.823			
Table 18 FEED EFFI- CIENCY IN EXPT 1					
Between Groups	6	96.87	16.2	17.6	0.001
Within Groups	21	19.32	0.92		
Total	27	116.19			
Table 19 SERUM CALCIUM LEVELS					
Between Groups	6	2.5610	0.4268	0.556	0.762
Within Groups	35	26.8799	0.7680		
Total	41	29.4410			

Table 20 Serum phosphorus levels - Experiment 1

Sources of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F.	F. Prob.
Between Groups	3	0.4714	0.1571	0.072	0.974
Within Groups	20	43.8091	2.1905		
Total	23	44.2804			

Table 21 Analysis of Variance Table for Faecal output of calcium in Expt. 1

Between Groups	6	21.6	3.6	257.14	0.001
Within Groups	14	0.2	0.014		
Total	20	21.8			

Table 22 Analysis of Variance for Faecal output of phosphorus in Expt. 1

Betweem Groups	6	0.03	0.005	1.72	n.s.
Within Groups	14	0.04	0.003		
Total	20	0.07			

Table 23 Analysis of Variance for calcium retention in Expt. 1

Between Groups	6	15.109	2.5	277.8	0.001
Within Groups	14	0.121	0.009		
Total	20	15.23			

Table 24 Phosphorus retention in Experiment 1

Between Groups	6	45.07	-	-	n.s
Within Groups	14	-	-	-	
Total	20	45.07	-	-	

Table 25
SPECIFIC GRAVITY OF HUMERUS IN EXPT. 1

Sources of Variation	Degrees 2 Freedom	Sum of Squares	Mean Square	F.	F. Prob,
Betwwen Groups	6	0.1470	0.0245	49.676	.000
Within Groups	21	0.0104	0.0005		
Total	27	0.1574			
Table 26 % ASH IN DRY FAT FREE BONE IN EXPT. 1					
Between Groups	6	63.379	10.563	1.215	0.337
Within Groups	21	182.519	8.691		
Total	27	245.989			
Table 27 % CALCIUM IN DRY FAT FREE BONE IN EXPT. 1					
Between Groups	6	53.1054	8.8509	2.405	0.063
Within Groups	21	77.2836	3.6802		
Total	27	130.3889			
Table 28 % PHOSPHORUS IN DRY FAT FREE BONE IN EXPT. 1					
Between Groups	6	3.0809	0.5135	1.436	0.248
Within Groups	21	7.5097	0.3576		
Total	27	10.5907			

Table 29
ANALYSIS OF VARIANCE
FOR DRY MATTER
DIGESTIBILITY (%)

Sources of Variation	Degrees Freedom	Sum of Squares	Mean Square	F.	F. Signi.
Between Groups	6	551	91.8	91.8	0.001
Within Groups	14	14	1		
Total	20	565			
Table 30 ANALYSIS OF VARIANCE FOR URINARY OUTPUT OF CALCIUM IN EXPT. 1					
Between Groups	6	0.014	0.0023	32.86	0.001
Within Groups	14	0.001	0.00007		
Total	20	0.015			
Table 31 ANALYSIS OF VARIANCE FOR CALCIUM AVAILA-BILITY IN EXPT. 1					
Between Groups	6	237.0	39.5	1.41	n.s.
Within Groups	14	393.0	28.1		
Total	20	630.0			
Table 32 ANALYSIS OF VARIANCE FOR PHOSPHORUS AVAILABILITY IN EXPT. 1					
Between Groups	6	36.3	6.05	11.2	0.001
Within Groups	14	7.52	0.54		
Total	20	43.82			

Table 33: Analysis of variance table for rate of gain in experiment 2.

Sources of Variation	Degree of Freedom	Sum of Square	Mean Square	F	F. Significance
Main effects	4	3067.62	766.91	4.10	0.01
Ca	2	2642.91	1321.45	7.06	0.004
Ph	2	541.14	270.57	1.45	0.255
2-Way Interact	4	551.46	137.86	0.74	-
Ca Ph	4	551.46	137.86	0.74	-
Explained	8	3619.08	452.39	2.42	0.05
Residual	24	4491.80	187.16		
Total	32	8110.874	253.47		

Table 34. Analysis of variance table for dry matter feed intake in experient 2.

Main effects	4	42472.88	10618.2	.775	.552
Ca	2	8076.94	4038.5	.295	.747
Ph	2	32643.18	16321.6	1.191	.321
2-Way Int.	4	60334.89	15083.7	1.101	.379
Ca Ph	4	60334.89	15083.7	1.101	.379
Explained	8	102807.77	12850.97	0.938	.504
Residual	24	328785.96	13699.42		
Total	32	431593.72	13487.30		

Table 35: Analysis of variance table for feed efficiency in experiment 2.

Main effects	4	253.53	63.13	3.999	0.01
Ca	2	208.68	104.34	6.61	0.005
Ph	2	53.60	26.80	1.70	0.204
2-way Int.	4	82.468	20.62	1.31	0.296
Ca Ph	4	82.468	20.62	1.31	0.296
Explained	8	335.000	41.88	2.65	0.031
Residual	24	378.86	15.786		
Total	32	713.86			

Table 36 ANALYSIS OF VARIANCE FOR SERUM CALCIUM LEVELS IN EXPERIMENT 2.

Sources of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F.	F. Signi.
Mean Effects	4	1.136	1.784	1.505	0.217
Ca	2	5.669	2.834	2.392	0.103
Ph	2	1.467	0.734	0.619	0.543
2-Way Interact.	4	1.066	0.266	0.255	0.923
Ca Ph	4	1.066	0.266	0.255	0.923
Explained		8.202	1.025	0.865	0.552
Residual	45	53.333	1.185		
Total	53	61.535			

Table 37: ANALYSIS OF VARIANCE FOR SERUM PHOSPHORUS LEVELS

Sources of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F.	F. Signi.
Main Effects	4	8.107	2.027	1.839	0.138
Ca	2	0.768	0.384	0.349	0.708
Ph	2	7.339	3.670	3.330	0.045
2-Way Interact.	4	0.990	0.247	0.225	0.923
Ca Ph	4	0.990	0.247	0.225	0.923
Explained	8	9.097	1.137	1.032	0.427
Residual	45	45.590	1.102		
Total	53	58.688			

Table 38. ANALYSIS OF VARIANCE FOR % ASH IN DRY FAT FREE BONE

Main Effects	4	85.793	21.448	15.648	0.001
Ca	2	39.559	19.780	14.430	0.001
Ph	2	46.234	23.117	16.865	0.001
Explained	8	89.022	11.128	8.118	0.001
2-Way Interact.	4	3.228	0.807	0.589	0.674
Ca Ph	4	3.228	0.807	0.589	0.674
Residual	27	37.009	1.371		
Total	35	126.03	3.601		

Table 39 % DRY MATTER DIGESTIBILITY IN EXPT. 2

Replicate	1	0.243	0.243	0.349	
Treatment	8	280.33	35.04	50.27	
Ca	2	211.44	105.72	151.68	
Ph.	2	64.34	32.17	46.16	
2-Way Interact.	4	4.55	1.14	1.636	
Residual	9	6.277	0.697		
Total	17	286.85	16.874		

Table 40: ANALYSIS OF VARIANCE FOR CALCIUM IN DRY FAT FREE BONE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F.	F. Prob.
Replicate	3	10.806	3.602		
Treatment	8	67.817	8.477	5.663	.01
Calcium	2	16.08	8.04	5.556	.01
Phosphorus	2	46.078	23.039	15.922	.001
Interaction	4	5.659	1.4148	0.945	
Error	27	40.429	1.497		
Total.	35	119.052			

Table 41 ANALYSIS OF VARIANCE FOR PHOSPHORUS IN DRY FAT FREE BONE

Replicate	3	2.8722	0.9574	1.745	
Treatment	8	33.752	4.219	7.692	.001
Calcium	2	15.0087	7.504	13.681	.001
Phosphorus	2	10.593	5.297	9.657	.001
Interaction	4	8.1503	2.0376	3.7149	.05
Error	27	14.8091	0.5485		
Total	35	51.4333			

Table 42 ANALYSIS OF VARIANCE FOR FAECAL CALCIUM IN EXPT. 2

Sources of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F.	F. Signi.
Replicate	1	0.01	0.01		
Treatment	8	9.6	1.2	80	.001
Calcium	2	9.48	4.47	298	.001
Phosphorus	2	0.073	0.04	2.7	n.s
Cax P Interact.	4	0.047	0.012	0.8	n.s
Error	9	0.132	0.015		
Total	17	9.622			

Table 43: ANALYSIS OF VARIANCE FOR URINARY OUTPUT OF CALCIUM IN EXPT. 2

Replicate	1	0.0012			
Treatment	8	0.007	0.0009	3.0	n.s
Calcium	2	0.0063	0.0032	1.0	n.s
Phosphorus	2	0.001	0.0005	1.7	
Ca x P Interact.	4	-	-	-	-
Error	9	0.0028	0.0003		
Total	17	0.011	0.00065		

Table 44. ANALYSIS OF VARIANCE FOR CALCIUM RETENTION IN EXPT. 2

Replicate	1	0.0204	0.0204	
Treatment	8	17.13	2.14	13.38
Calcium	2	16.95	8.48	53.0
Phosphorus	2	0.116	0.058	0.363
Ca x P Interact.	4	0.064	0.016	0.1
Error	9	1.40	0.16	
Total	17	18.55	1.09	

Table 45. ANALYSIS OF VARIANCE FOR FAECAL OUTPUT OF PHOSPHORUS IN EXPT. 2

Sources of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F	F. Signi.
Replicate	1	0.804	.804	12.6	.001
Treatment	8	3.56	.445	6.95	.001
Calcium	2	0.287	.144	2.25	
Phosphorus	2	3.21	1.61	25.16	.001
Ca x P Interact.	4	0.063	0.016	0.25	
Error	9	0.576	0.064	-	
Totals	17	4.94	.291	-	

Table 46. URINARY OUTPUT OF PHOSPHORUS IN EXPERIMENT 2

Replicate	1	0.00025	.00025		
Treatment	8	0.00067	.000084	.84	n.s
Calcium	2	0.00067	.000034	.34	
Phosphorus	2	0.00052	.00026	2.6	
Ca x P Interact.	4	0.00083	.000021	.21	
Error	9	0.0009	.0001		
Total	17	0.0018			

Table 47 PHOSPHORUS RETENTION IN EXPERIMENT 2

Replicate	1	0.07	0.07	2.3	
Treatment	8	9.19	1.15	38.3	.001
Calcium	2	0.29	0.15	5.0	.001
Phosphorus	2	8.87	4.44	148.0	.001
Ca xP Interact.	4	0.03	0.008	0.27	
Error	9	0.23	0.03		
Total	17	9.49	0.56		

Table 48. ANALYSIS OF VARIANCE FOR AVAILABILITY OF DIETARY CALCIUM IN EXPERIMENT 2.

Sources of variation	Degree of Freedom	Sum of Squares	Mean Square	F	F	Significance
Replicate	1	0.491	0.491			
Treatment	8	178.44	22.31	3.24	P	0.05
Calcium	2	114.77	57.39	8.24	P	0.01
Phosphorus	2	33.44	16.72	2.43	n.	s.
Interaction	4	30.23	7.56	1.10	n.	s.
Error	9	62.01	6.89			
Totals	17	240.94				